Working Paper

Biodiversity of Siberian Forests: Concepts, Preliminary Analyses, and Proposed Research Directions

Peter N. Duinker, Editor
Contributors: Mattias Carlsson, Peter Duinker, Michael Gluck, Ronald Plinte, Irina Venevskaia

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Foreword

This is the time Siberia's forest sector has recently gained considerable international interest. IIASA, the Russian Academy of Sciences, and the Russian Federal Forest Service, in agreement with the Russian Ministry of the Environment and Natural Resources, signed agreements in 1992 and 1994 to carry out a large-scale study on the Siberian forest sector. The overall objective of the study is to focus on policy options that would encourage sustainable development of the sector. The goals are to assess Siberia's forest resources, forest industries, and infrastructure; to examine the forests' economic, social, and biospheric functions; with these functions in mind, to identify possible pathways for their sustainable development; and to translate these pathways into policy options for Russian and international agencies.

The first phase of the study concentrated on the generation of extensive and consistent databases for the total forest sector of Siberia and Russia. The study has now moved into its second phase, which encompasses assessment studies of the greenhouse gas balances, forest resources and forest utilization, biodiversity and landscapes, non-wood products and functions, environmental status, transportation infrastructure, forest industry and markets, and socioeconomic problems. This report was produced during a Biodiversity Summer Workshop in 1995 carried out at IIASA under the leadership of Dr. Peter Duinker, Lakehead University, Ontario, Canada.

About the Authors

Peter Duinker, PhD, is Associate Professor and Chair in Forest Management and Policy at the Faculty of Forestry, Lakehead University, in Thunder Bay. During 1986–1988, he worked at IIASA as a research scholar in the Environment Program, where, with Sten Nilsson, then leader of the Forest Study of the Biosphere Project, he studied the potential effects of continued air pollution on forest decline in Europe. Dr. Duinker is coordinator for the Biodiversity and Landscapes cornerstone of the Siberian Forest Study, and spent two months at IIASA during summer 1995 to lead the Study's Biodiversity Summer Workshop.

Mattias Carlsson, Michael Gluck, Ron Plinte and Irina Venevskaia all participated in IIASA's Young Scientists Summer Program in 1995, and comprised the participants in the Biodiversity Summer Workshop. Mattias Carlsson is pursuing a PhD in forest ecology and management at the Swedish University of Agricultural Sciences. Michael Gluck (MScF) is a landscape biologist at the Centre for Northern Forest Ecosystem Research of the Ontario Ministry of Natural Resources in Thunder Bay. Ron Plinte (MScF) is a research assistant with the Chair in Forest Management and Policy at the Faculty of Forestry, Lakehead University. Irina Venevskaia is from Russia and is currently carrying out her M.Sc. in the field of Environmental Sciences and Policies at the Central European University in Budapest, Hungary.

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by Peter Duinker

1.1. Introduction and Background

1.1.1. Worldwide Concern for Forests and Biodiversity

Long-term sustainability of the global ecosystem is today of great concern to many world leaders, scientists and citizens. Humankind's impacts on how the earth functions are stronger and more widespread than ever before. Recognition of these impacts brought the environment squarely onto political agendas in the 1970s, where it has remained ever since. People are genuinely worried about earth's capacity to continue to support a growing population with a comfortable standard of living (World Commission on Environment and Development, 1987).

Forests

Of all the kinds of ecosystems people are concerned about, those at center stage are forests. Several factors underlie forests' importance to people as they ponder earth's ecosystems. One is that people are romantic about forests – trees are associated with pleasant places to be. Another is that people know that forests provide them with copious goods and services, and that there are far fewer forests in the world today than there would be naturally, and many forests are in poor condition. Finally, while people demand many products made of wood, they associate much of timber harvesting with big industry, and they are quite ready to criticize large corporations for ruining their favorite ecosystems.

There is ample evidence of people's strong feelings about forests and of the attention they are being given in a wide range of forums and venues. Let us take North America as an example. Popular Canadian singers/songwriters Bruce Cockburn and Raffi have turned out songs specifically about forest destruction. David Suzuki has covered forests a number of times on the highly rated TV series "The Nature of Things". US-made movies such as "Medicine Man" and "Fern Gully" portray overt messages about destruction of tropical rainforests. Popular books and magazines on the topic of forest conservation have appeared frequently (e.g., Swift, 1982; Mackay, 1985; Baxter, 1986; Gillis and Roach, 1986; Shands, 1988; Black, 1993; Lansky, 1993; M'Gonigle and Parfitt, 1994). Public interest groups not primarily concerned about forests frequently focus on forests early in their programs. Examples from Canada are the Taskforce on the Churches and Corporate Responsibility (1991), and the Social Investment Organization. Some of the highest-profile environmental controversies are about forests – the spotted owl in the US Pacific Northwest forests, and timber harvests in the forests of Clayoquot Sound on Vancouver Island (Clayoquot Sound Scientific Panel, 1995), to name but two of many. Massive environmental impact assessments have recently been undertaken for regional forest management – Minnesota and Ontario are the best examples (Duinker and Hay, 1994). Numerous roundtables on sustainable development, particularly those of Canada and its provinces, have directly addressed forests and their sustainability (e.g., Forestry Sectoral Task Force, 1992; Thompson and Webb, 1994). The Government of Canada has even gone so far as to produce, now for the fifth year in a row, an annual report to Parliament on the state of Canada's forests (Canadian Forest Service, 1995). As far as I know, this is the only ecosystem type, or natural resource system, about which the Canadian parliamentarians and public are annually apprised.

Moving on to the global scale, forests also command considerable attention in international discussions. Most notable so far is the UNCED Statement of Forest Principles (Anonymous, 1992), which, while less than a global convention, embodies a worldwide consensus on how forests should be conserved during their use and management. And just during the past year, two new global consensus-seeking forums have been established: (a) the World Commission on Forests and Sustainable Development, under the auspices of the InterAction Council, and (b) the UN Intergovernmental Panel on Forests.

Biodiversity

Concomitant with worldwide attention to forests, there is a growing concern also for the variety of lifeforms on earth. In the past decade, the emerging label for this concern has become biodiversity, or biotic diversity (or biological diversity) (Probst and Crow, 1991; Duinker, 1993; 1996; Salwasser, 1994). Biodiversity represents a collecting place for a wide range of issues regarding the variety of life. Not only does it capture the issue of species extinctions, but it also includes the conservation and use of genetic resources, species migrations and introductions into ecosystems beyond historical limits, and others.

While few people understand the concept of biodiversity to any depth, most literate citizens of the world, at least in the so-called developed countries, hold the view that biodiversity conservation is important. Indeed, the world community has formalized this concern into an international agreement called the Convention on Biological Diversity. The overwhelming participation of countries in placing their initial signatures on the agreement at Rio in June 1992, and their subsequent signatures indicating full participation, stunned observers – this is clearly no ordinary agreement, and is seen as a landmark achievement (Glowka *et al.*, 1994).

Biodiversity strategies are becoming commonplace. They are being prepared at all levels, but most commonly at the scale of states/provinces (e.g, Biodiversity Task Force, 1992) and nations (e.g., Anonymous, 1995). Under the auspices of the United Nations Environment Programme, the global community has just recently realized the first global assessment of the state of earth's biodiversity (Heywood, 1995).

Forests and Biodiversity

Worldwide concern for both forests and biodiversity – an obvious and natural mutualism. Much of the biodiversity debate (although certainly not all) focuses on forests, and much of the forest sustainability debate (again, certainly not all) focuses on biodiversity conservation. Thus, conservation of forest biodiversity firmly links two broad spheres of concern about the global environment. And it does so throughout the world. Major attention to forest biodiversity is not reserved only for the threatened, species-rich tropical rainforests, nor for the spectacular temperate rainforests of North America's west coast. It extends to all types of forest ecosystems around the globe, not the least of which are the boreal forests. It should be no surprise, therefore, that a study of the future of the forests of Siberia, i.e., the IIASA Siberian Forest Study, would investigate the conservation of forest biodiversity.

1.1.2. The Siberian Forest Study at IIASA

Siberia's forests comprise a vast ecosystem complex of global importance, both economically and ecologically. They already serve Russia and the world as a source of wood, a symbol of wilderness, and a critical stabilizer of the global climate. With care, they could serve as a sustainable foundation for development of the Russian economy.

The Siberian Forest Study of the International Institute for Applied Systems Analysis (IIASA) is the most extensive international study ever undertaken of this vast ecosystem. The goals of the study are to:

(a) assess Siberia's forest resources, forest industries, and infrastructure;

(b) examine the forest's economic, social, and biospheric functions;

(c) with these functions in mind, identify possible pathways for their sustainable development; and

(d) translate these pathways into policy options for Russian and international agencies.

The study was formally launched in 1992 with an agreement between IIASA, the Russian Academy of Sciences, and the Russian Ministry of Ecology and Natural Resources. The study comprises three phases. Phase I included the establishment of the study and the creation of a unique Russian network of some 25 institutes. When the study began it was difficult to know what information would be available, and thus what detailed questions might be usefully addressed. Therefore, the first task after the study was set up was to assemble the best possible data on the widest possible front. During Phase I, using the Russian network, the study has been able to develop a unique and comprehensive database on the following five themes: Forest Resources, Ecology and Global Change, Markets, Industry and Infrastructure, and Socio-Economics. The data are stored in a spatially referenced format for analysis and display using a geographic information system (GIS).

The databases serve as the foundation for assessments and analyses to be carried out during Phase II. Nine areas called "cornerstones" define the scope of the study, and eight of these are theme areas which will be analyzed in the overall policy framework of the study:

Siberian Study Databases
Biodiversity and Landscapes
Environmental Status
Forest Industry and Markets
Forest Resources and Forest Utilization
Greenhouse Gas Balances
Non-Wood Products and Functions
Transportation Infrastructure
Socio-Economics

The cornerstones are not ranked in any way – it is considered imperative that all cornerstones be fulfilled in support of development of policy recommendations concerning the sustainable development of Siberian forests.

The assessment studies are being carried out as a joint effort by the IIASA core team, the Russian network, and a Western network. Phase III of the study will include integrated analyses and identification of the policy implications.

1.1.3. The Biodiversity/Landscapes Cornerstone of the Siberian Forest Study

Objectives of the biodiversity and landscapes cornerstone (Anonymous, 1994) are to:

(a) determine the current biodiversity of the Siberian ecoregions;

(b) identify management regimes of the Siberian ecosystems and landscapes that will promote sustainable biodiversity; and

(c) determine the types of reserve strategies that must be combined with management strategies to secure sustainable biodiversity.

A first approximation of what might be accomplished in the biodiversity and landscapes cornerstone was developed by IIASA personnel associated with the Siberian Forest Study in autumn of 1994 (Anonymous, 1994). During a planning meeting at IIASA in March 1995, participants discussed in great detail how to accomplish the goals of the cornerstone. According to the results of that meeting, under ideal conditions, the study would:

- make a comprehensive description of the current and recent historical biodiversity conditions in Siberian forests;
- develop detailed forest-management regimes and prescriptions to conserve forest biodiversity;
- predict forest-biodiversity responses, in terms of a wide range of indicators, to an array of forest-management strategies (including normal, timber-production-oriented, and biodiversity-conservation-oriented strategies) for all Siberian forests; and

- develop management and policy recommendations for conserving forest biodiversity during the future development and exploitation of Siberian Forests.

However, the study does not have ideal conditions. It has severe limitations on funds (and therefore limited personnel), time, and data. Given these restrictions, and the skills, ideas and interests of the members of the first analytical team assembled to work toward the cornerstone's objectives (i.e., all the contributors to this report), we devised and implemented the following study elements in an IIASA Biodiversity Summer Workshop during the summer of 1995. Our work must be considered exploratory at best for several reasons, not the least of which is that we were the first analytical users of the Siberian Forest Study databases.

Overview of the Preliminary Analyses

Participants in the Biodiversity Summer Workshop mounted four projects during the summer of 1995. Three of the projects addressed the same fundamental question at different spatial scales: what can we understand about forest biodiversity from the Siberian forest databases assembled at IIASA? The fourth project aimed to augment those databases with species-oriented information for subsequent biodiversity analyses. Here I discuss some of the principles and philosophy we took to the work, and describe the structure of the analyses.

Shaping Factors

The nature of the work was shaped in a major way by the following factors:

1. *The available databases* – The Siberian Forest Study has worked with its network of Russian collaborators to secure three databases: (a) an ecoregional "green" database containing so-called anthropospheric (e.g., land use), atmospheric (e.g., climate), biospheric (e.g., forest composition), pedospheric (e.g., permafrost), and hydrospheric (e.g., water bodies) data, covering all Siberia; (b) an enterprise-based forest inventory database for 1988, covering all Siberia; and (c) a standwise forest inventory database for the enterprise Katinsky CLPKh. As stated above, the Workshop participants comprised the first analytical group to make use of the databases, and many database problems were encountered during the analytical work.

2. *The members of the team* – In my view, it is important to give analysts plenty of latitude to take research projects in their own directions. Thus, some of the approaches taken in the analyses reflect the personal style and preferences of the individual analysts, and the resulting diversity is refreshing.

3. *The time available* – we had three months during which to complete the first round of analyses. This is a tight time frame for project conceptualization, database exploration, trouble-shooting of database problems, data manipulation and analysis, and report preparation. The accomplishments, while significant, are thus modest.

Ecodiversity as the Principal Level of Interest

Given the data provided for analysis, and propositions in the literature about starting forest biodiversity analysis at the ecosystem level (e.g., Duinker, 1996), we have focussed our analytical efforts at understanding diversity among ecosystems. A general definition of ecosystem – i.e., assemblages of organisms interacting with each other within a specified abiotic environment – indicates that the concept is independent of spatial scale. Thus, a rotting log on the forest floor is an ecosystem, as is the entire Siberian forest, as is the whole planet.

Given that understanding of ecosystems is facilitated using an hierarchical approach (e.g. Noss, 1990), we are viewing them in a hierarchy. Thus, ecoregions are ecosystems that together comprise the Siberian sub-continental ecosystem, enterprises are ecosystems that together form an ecoregion, and stands are ecosystems that together make up a forest enterprise. The boundary definitions at each of these levels are not entirely ecological (i.e., there is some degree of administrative and timber-oriented influences), but these are limitations we must accept because of the nature of the databases to be used in our analyses. Analysis at each of the three levels in our hierarchy can refer, as appropriate, to the results achieved in the other levels, helping us form an integrated perspective on biodiversity conservation for Siberian forests.

Despite our ecosystem focus, individual species of forest plants and animals are also of interest in our work. However, the databases contain little or no information about species other than overstorey tree species. That is why we decided to augment the databases with species-oriented habitat and range information. Once such a database is sufficiently assembled, we intend to analyze the special habitat-conservation requirements of specific species and how forest management can play a role in assuring such conservation.

Human Activities as a Central Theme

The conservation of forest biodiversity is a concern for society because human activities, mainly forest management for timber, are often seen to be agents of unwanted change in biodiversity patterns. Given this, all three ecodiversity analyses (ecoregions, enterprises, stands) have tried to discern, each in its own way, how specific human actions may have influenced ecosystem patterns. Our analyses could only look into the past and present, because the available databases contain no forecasts for future activities or future forest patterns, nor were we, given the time constraints, able to generate our own forecasts. Analysis of future forest ecosystem patterns, especially as influenced by future human actions, will be carried out later if time and resources permit.

The Projects of the Biodiversity Summer Workshop

Pan-Siberian Analysis using the Ecoregion Database

As part of the Databases cornerstone, the Study has assembled a database of economic, physical and ecological variables for each of 63 ecoregions covering all Siberia. The objective of our pan-Siberian analysis was to evaluate whether major ecological influences on biodiversity could be detected using the ecoregion database. Mike Gluck (Chapter 2) approximated current ecosystem diversity, or ecodiversity, by describing interactions among variables related to climate, soils, vegetation, and human activity.

Regional Analysis using the Forest Enterprise Database

The databases of the Study also contain basic forest and forest-management data for each forest enterprise in Siberia. Ron Plinte (Chapter 3) used the relevant data for ca. 30 enterprises in the Angara-Lena ecoregion (south-central Siberia) to describe and analyze biodiversity and search for patterns that could illuminate broad influences of human activity on biodiversity.

Enterprise Analysis using the Ust-Ilimnsk Stand-level Database

At our finest scale of data resolution, Mattias Carlsson (Chapter 4) used a set of stand-level forest and forest-management data to describe how forest structure and composition and landscape patterns change when natural landscapes are exploited for timber purposes. He also examined relationships between abiotic and biotic variables in natural landscapes to build preliminary guidelines for forest-management decision-making.

Species of Interest in Siberian Forest Biodiversity Conservation

Comprehensive biodiversity analyses must balance ecosystem-oriented approaches with examination of the threats of continued human activities on populations of specific species (Duinker, 1996). Unfortunately, species-population data and knowledge of species-habitat relationships for Siberian species are not widely available outside Russia in a format usable for analysis. Therefore, Irina Venevskaia (Chapter 5) set about to identify forest species which can be adversely affected by continued timber management and by direct exploitation, and to describe their range, ecology, and susceptibility to anthropogenic stress in sufficient detail for future conservation-oriented analysis.

1.2. Concepts of Forest Biodiversity Conservation: A Review of Selected Literature

1.2.1. Conceptions and Definitions

Forest Biodiversity

There are many definitions of biodiversity, and such a plurality is to be welcomed. A useful entry point into defining biodiversity is to dissect the term. "Bio" refers to life, and "versitas" in Latin means variety (Canadian Forest Service, 1994). Thus, biodiversity means variety of life. A definition of biodiversity commonly used in North American forest literature 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". We shall use as our starting point in this study the definition contained in Article 2 of the Convention on Biological Diversity (CBD) (Glowka *et al.*, 1994):

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

Most people agree that biodiversity has many facets. Kimmins (1992) spoke of: (a) genetic diversity; (b) within-ecosystem species diversity (so-called alpha species diversity); (c) among-ecosystem species diversity (beta species diversity); (d) within-ecosystem structural diversity; (e) among-ecosystem structural diversity; and (f) temporal diversity. Noss (1990) presented a hierarchical characterization of biodiversity, with two axes forming a matrix. One axis is composed of composition, structure, and function, and each of these sets of ecological attributes can apply at each of the following four scales: (a) regional landscape (or forest, for our purposes); (b) community/ecosystem (stand); (c) population/species; and (d) gene pools.

Thus, forest biodiversity includes all the ways we have of realizing and characterizing the variety of life in forests. We include not only composition and structure of biota, but also the processes in which organisms are engaged and which affect them, and, most significantly, the ecosystems that form the habitat for organisms and are defined in terms of both biotic and abiotic elements. We find such a wide scope for the concept to be attractive – while it complicates matters by including the ecological processes that give rise to patterns of variation in biota, this is useful because it raises the fundamental question of why biotic variations occur as they do.

(Note: if there is meaning to biodiversity, perhaps there is also meaning to "abiodiversity", or the variety and variability of abiotic components of the earth. Then, perhaps a more appropriate appellation for ecosystem diversity is ecodiversity, which includes all the combinations of biotic communities and abiotic environments (see Noss (1995) for a recount of his personal communication with Stan Rowe).

To make biodiversity an operational concept in forest science and management, it is necessary to be explicit about what is considered to be part of it, and how the parts or elements are to be measured. Let us begin with the last part of the CBD definition: "this includes diversity within species, between species, and of ecosystems":

- *diversity within species* – this deals mainly with genetic variability within species; this aspect of biodiversity is beyond the scope of the Siberian Forest Study:
- *diversity between species* – this deals with various measures related to comparisons of species with each other, including uniqueness, abundance, richness, range, etc.; this aspect of biodiversity

is within the scope of the Siberian Forest Study as we examine the conservation of habitats for important species such as rare/threatened/endangered species of plants and animals, hunted/trapped animals, and medicinal plants;

- *diversity of ecosystems* – this deals with variation of ecosystems and ecosystem complexes at various scales, depending on the area under investigation; this is the main element of biodiversity being addressed in the Siberian Forest Study, at scales of (a) forest stands to forest enterprises (101 to 105 ha), (b) forest enterprises to forest ecoregions (105 to 107 ha), and (c) forest ecoregions to all Siberia (107 ha to 108 ha)

Forest Landscapes

The Siberian Forest Study originally combined the concepts of biodiversity and landscapes into one cornerstone. Given that we are using a comprehensive interpretation of the concept of biodiversity, for our purposes we see the conservation of forest biodiversity as including the conservation of forest landscapes. We base this decision on the following kinds of definitions we have found in the literature:

- "... a landscape is defined as the physical and biological space within which a species exists" (Young, 1995).
- "A terrestrial landscape is a mosaic of heterogeneous land forms, vegetation types, and land uses" (Urban *et al.*, 1987).
- "We define a landscape as a continuous piece of our forest holdings corresponding to 5,000–25,000 hectares" (Stora Skog, undated).

Thus, such definitions of a landscape suggest that it is nothing more than a large (broad-scale) ecosystem, and ecosystems are already included in the definition of biodiversity. Indeed, Noss (1990) has the forest landscape as the highest element in his hierarchy of ecological levels for the selection of biodiversity indicators.

To avoid confusion we also need to consider the Russian concept of landscape. To Russian ecologists, landscape is used for a broader scale, in the range of 100,000 to 1,000,000 ha (A. Shvidenko, personal communication, 1995). The Russian equivalent for the western "landscape" is the range of scale from "terrain" up to "stow" (or sub-landscape).

1.2.2. Objectives in Forest Biodiversity Conservation

In biodiversity conservation strategies for countries or states/provinces, it is impossible to set precise, quantified targets. Rather, general statements that describe broad directions to be pursued are most appropriate. Most such statements are variations on the following theme: "to conserve biodiversity". The Ontario Ministry of Natural Resources (1994) followed the recommendation of the Ontario Forest Policy Panel (1993):

> "to ensure that current natural biological diversity of forests is not significantly changed and where necessary and practical, is restored".

This kind of goal statement could be used by Russia for forest biodiversity conservation in Siberia. It speaks to the benchmark against which future biodiversity conditions will be assessed (i.e., current natural), but it leaves open the question of how to measure natural forest biodiversity.

At the level of the forest enterprise, where operational decisions that influence future forest structures are made, there is a need to become more precise so managers can design the appropriate action sets. An example, still without quantified targets, is the biodiversity goal of Weldwood of Canada (Hinton Division), which manages ca. one million hectares of public forest in west-central Alberta (Weldwood of Canada, 1993):

> The biological diversity of forest lands will be provided for by ensuring that representative stages of forest succession, along with the varieties of plants, animals, and microorganisms, are present throughout each forest biogeoclimatic zone.

A strong set of forest-level objectives for biodiversity conservation comes from the ecosystem-management guidelines for the White River Forest near Wawa, Ontario. In the forest-management plan, the forest managers are, for example, calling for a specific percentage of the area of each so-called working group (defined by the dominant tree species) in stands older than the official rotation age, and a specific smaller percentage of the area in stands older than 1.5 times rotation age (Anonymous, 1993). These are the kinds of targets that are needed for foresters to design action sets specifically dedicated to achieving biodiversity conservation as specified.

1.2.3. Approaches to Forest Biodiversity Conservation

We believe there are two fundamental ways in which to conserve forest biodiversity, particularly in connection with habitats of particular species and ecosystem diversity: (a) protected areas; and (b) biodiversity-sensitive forest management where timber is harvested.

Protected Areas

In this report, "protected area" refers to forest areas in which timber harvesting is not permitted (other forms of human intervention may also be forbidden, but here we are concerned only with timber harvest). Protected areas are not free of effects of human intervention, since all of earth's ecosystems are affected by air pollution of one sort or another, and any climatic changes (e.g., CO_2 increases, ozone depletions) that have occurred as a result of human activity. Moreover, wildfire is actively suppressed in most forests in the northern hemisphere, even in protected areas. Thus, protected areas and otherwise unexploited forests are subject to unintentional atmosphere-mediated effects, and the intentional effects of fire suppression, whereas forests where timber is harvested are subject to these same unintentional and intentional effects as well as the effects of timber harvests and associated treatments.

Protected areas in forests are a vital component of any strategy for biodiversity conservation (e.g., Noss, 1990; 1995) or forest sustainability (e.g., Ontario Forest Policy Panel, 1993). Indeed, to quote Noss (1990):

> "For native biodiversity at the landscape level of organization, which consists of gradients and mosaics of many community types, big wilderness is the only option. Wilderness and biodiversity need each other".

According to Klever *et al.* (1994), Russia has an outstanding network of so-called zapovedniks, or strictly protected areas. These areas are, relatively speaking, large and numerous (76 in total), and are often surrounded by territory that is effectively wilderness. They conserve populations of more than two thirds of the rare and endangered species listed in the Russian Red Data Book (Klever *et al.*, 1994). Russia's conservation of forest biodiversity using protected areas seems, relative to what other countries have done and can do, rather advanced (Klever *et al.*, 1994).

Biodiversity-sensitive Forest Management

Protected areas in most forests of the world, in the sense of large set-asides from timber harvest, can only cover a small fraction of the total forest area (say, from a few percent to 10-20 percent). This is because governments are usually choosing to keep most of their forest areas in actual or potential timber production. The biodiversity-conserving effects of protected areas are fundamentally important (Noss, 1990; 1995), but a full program of forest biodiversity conservation must also deal in a substantive way with all forests subjected to timber harvest and other manipulations. A most forceful argument is made for this in the programs of Wildlife Habitat Canada (undated), a non-profit foundation dedicated to conserving wildlife habitat. Wildlife Habitat Canada advocates a so-called "100% solution" to biodiversity conservation. This means that biodiversity is a key management objective in both protected forests and timber-managed forests.

What does it mean, in practical terms, to set biodiversity as a key objective in forest management? Let us distinguish between a local-scale prescription-based approach and a region-scale outcome-based approach. This distinction arises from the simple management system model where actions (e.g., timber harvests and regeneration treatments) are designed for and applied in a system (forest ecosystem) to produce desired conditions in (e.g., biodiversity) and outputs from (e.g., timber) the system. In a prescription-based approach, one assumes that one knows what biodiversity-conserving treatments to implement at the local scale, and one simply replaces normal treatments with the biodiversity-conserving ones. Examples would include: (a) leaving mature green trees behind in a final-felling operation; (b) regenerating cut areas with mixed-species plantations; (c) refraining from use of herbicides to promote the growth of planted trees; and (d) refraining from clearcutting in all-aged stands of shade-tolerant tree species (e.g., Swedish Society for Nature Conservation and World Wide Fund for Nature Sweden, 1995). To repeat, the assumption is that biodiversity will be conserved if such treatments are generally applied.

In an outcome-based approach, one first forecasts the region-scale biodiversity implications (using specially designed quantitative indicators) of a range of suites of biodiversity-conserving treatments. Following evaluation, one chooses and implements the action strategy (i.e., treatment definitions and location- and time-specific schedules) that seems from the forecasts to conserve biodiversity adequately, given other objectives and various constraints on management. Monitoring of strategy implementation and system performance (i.e., the biodiversity indicators) then permits learning and error correction to occur (for more detail on adaptive management of forests and other ecosystem types, see: Holling, 1978; Baskerville, 1985; Walters, 1986; Lee, 1993; Ontario Forest Policy Panel, 1993; Maser, 1994; Gunderson *et al.*, 1995).

The outcome-based approach has the clear advantage of forcing explicit attention on the long-term, broad-scale biodiversity implications of alternative-forest management strategies, and it recognizes an explicit adaptive-management framework for biodiversity conservation. The prescription-based approach has the advantage of simplicity of application and verification. A full strategy for forest biodiversity conservation requires combining the two approaches into the management framework. Attention to biodiversity issues is needed at both local (i.e., stand) and regional (i.e., forest) scales. Judicious evaluation of alternative local treatment prescriptions, with spatially and temporally explicit implementation schedules, in terms of regional biodiversity indicators is the right way to go. A local prescription-based approach alone is dangerous, because it easily misses the important biodiversity implications of landscape-scale patterns. Likewise, a regional outcome-based approach alone is dangerous, because it easily misses the implications of changes made in local stand compositions and structures (see Hunter (1990) for valuable discussions of biodiversity conservation at landscape and stand scales).

1.2.4. Indicators of Forest Biodiversity

Given the broad definitions of biodiversity we introduced above, it is no surprise that the biodiversity literature offers a wide variety of indicator proposals. Indicators are measurable components of biodiversity. Below, we explore how people suggest that indicators be chosen and classified. We favor the forest-related literature in our review, even though there are entire volumes devoted the measurement of biodiversity (e.g., Magurran, 1988).

Criteria for Indicator Selection

In a widely-quoted paper, Noss (1990) suggested that indicators should be:

1. sufficiently sensitive to provide early warning;

2. widely applicable;

3. capable of providing a continuous data over wide ranges of stress;

4. relatively independent of sample size;

5. easy and cost-effective to measure;

6. able to distinguish between natural variation and anthropogenic stress; and

7. relevant to ecological significant phenomena.

Noting that indicator selection is as much art as science, McKenny *et al.* (1994) offered guidelines whereby indicators should:

- be easy to measure;
- be amenable to monitoring using sound statistical design;
- be measurable with little disturbance to ecosystems and organisms;
- have long-lasting relevance (therefore, avoid fads);
- include processes and flows, alongside states and stocks;
- provide early warnings;
- include some ecosystem components of high public profile;
- include some integrative ecosystem components;
- span the full gamet of relevant spatial scales and levels of ecological organization;
- be selected as part of an overall ecosystem management process; and
- be firmly connected to clear management objectives.

To these lists of criteria, we would add that, in our view, indicators are preferably those directly associated with attributes of ecosystems or their components, as distinct from those directly associated with human actions that threaten or conserve biodiversity. In other words, the response is more important than the dose.

Indicator Proposals

Several recent reports offer advice on and long lists of potential indicators of biodiversity. For example, Noss (1990) presented a comprehensive table of prospective compositional, structural and functional indicators at four levels of organization – regional landscape, community-ecosystem, population-species, and genetic. To give an idea of the range of possibilities, reproduced below are Noss' (1990) indicators at the regional landscape level:

- *Composition* – identity, distribution, richness and proportions of patch (habitat) types and multi-patch landscape types; collective patterns of species distributions (richness, endemism)

- *Structure* – heterogeneity; connectivity; spatial linkages; patchiness; porosity; contrast; grain size; fragmentation; configuration; juxtaposition; patch size frequency distribution; perimeter-area ratio; pattern of habitat layer distribution

- *Function* – disturbance processes (areal extent, frequency or return interval, rotation period, predictability, intensity, severity, seasonality); nutrient cycling rates; energy flow rates; patch persistence and turnover rates; rates of erosion and geomorphic and hydrologic processes; human land-use trends

McKenny *et al.* (1994) differentiated between species-based and system-based indicators of forest biodiversity. For each, they provided lists of potential indicators, of which I reproduce below only the species-based indicators as examples of their work:

Species-based Indicators (McKenny *et al.*, 1994, Table 1):

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

What is clear from the Noss (1990) and McKenny *et al.* (1994) lists is that biodiversity has become an integrative concept for just about all environmental concerns related to life forms. This, of course, leaves the forest analyst with much discretion as to which indicators to choose as the most useful in a particular situation. To finish these examples, I list below the biodiversity indicators recently published as part of Canada's exercise in developing criteria and indicators of sustainable forest management. The Canadian Council of Forest Ministers (1995) recently adopted the following biodiversity indicators:

Ecosystem Diversity – percentage and extent, in area, of forest types relative to historical condition and to total forest area; percentage and extent of area by forest type and age class; area, percentage and representativeness of forest types in protected areas; levels of fragmentation and connectedness of forest ecosystem components.

Species Diversity – number of known forest-dependent species classified as extinct, threatened, endangered, rare, or vulnerable relative to the total number of known forest-dependent species; population levels and changes over time of selected species and species guilds; number of known forest-dependent species that occupy only a small portion of their former range.

Genetic Diversity – implementation of an in situ/ex situ genetic conservation strategy for commercial and endangered forest vegetation species.

1.2.5. Analytical Tools for Assessing Forest-Management Strategies in Biodiversity Conservation Terms

To assist decision-makers in choosing effective and efficient biodiversity-conserving forest-management strategies, quantitative models are needed to project future biodiversity conditions under alterative strategies. We find it useful to distinguish between two kinds of models for this type of analysis:

1. models designed to project forest-ecosystem conditions into the future under alternative management scenarios; and

2. models designed to interpret or assess future forest-ecosystem conditions in terms of biodiversity indicators.

Assessment models are needed when the forest-ecosystem conditions projected by a chosen forecasting model are not directly interpretable in biodiversity terms. For example, a forecasting model may be able to project future forest inventories, but these may need to be interpreted or assessed in terms of the habitat requirements for particular species of fauna.

Many quantitative (and computer-based) models are available for predicting potential future states of forest ecosystems. A well-known family of such models is based on the JABOWA model (see Shugart *et al.*, 1992). These models are essentially plot models that track detailed forest composition and structure through future time. Other detailed forest simulation models include the FORCYTE series (Kimmins, 1993). To track the future of large, spatially heterogeneous forests, forest-inventory forecasting models have been developed. Some of these are optimization models, while others are basically simulators. Some are lumped models in that similar stands are aggregated together for computational efficiency (e.g., FORMAN (Wang *et al.*, 1987), whereas others are designed to track the future of each individual stand (e.g., Moore and Lockwood, 1990). For biodiversity indicators where the spatial patterns of forest-ecosystem conditions are important, it is necessary to use disaggregated, spatially explicit forest simulators.

As alluded above, many biodiversity indicators are not directly interpretable or assessable from the outputs of forest forecasting models. In such cases, additional calculations, using the forecast outputs as input data, are required. Early models focussed mainly on species diversity based on information theory. These have remained popular (e.g. Magurran, 1988) and subject to further developments. Later efforts have been dominated by species-habitat models (e.g, Verner *et al.*, 1986; Bonar *et al.*, 1990; Duinker *et al.*, 1991; 1993; Greig *et al.*, 1991) from the discipline of wildlife ecology and habitat fragmentation models (e.g., McGarigal and Marks, 1994 – FRAGSTATS) from the discipline of landscape ecology (e.g, Forman, 1995).

1.3. Directions for Further Research

The projects completed during the 1995 Biodiversity Summer Workshop constitute a useful start to the research necessary to meet the objectives set for the cornerstone. Further analyses are required before a fully grounded policy assessment for the conservation of Siberian forest biodiversity can be made. The following projects complement the Summer Workshop accomplishments in providing such a grounding.

1.3.1. Biodiversity Data for the Siberian Forest Databases

Objective

To complete the augmentation of the Siberian forest databases with species-oriented data regarding habitat requirements and ranges.

Rationale

A key concern in biodiversity conservation, whether for forests or other ecosystems, remains the preservation of indigenous species in their native habitats. This is especially of concern for rare/ threatened/ endangered species, but also for species that are of direct social and economic value.

Outcomes

This project will yield numerical, descriptive and geographic databases for Siberian species of the following types: (a) rare/threatened/endangered species, both animal and plant; (b) medicinal plants; and (c) hunted/trapped animals.

1.3.2. Local-forest Simulation Analysis of Biodiversity Conservation: East Siberia

Objective

To examine the biodiversity-conservation implications of alterative forest-management strategies for the Katinsky (Ust-Ilimnsk) forest.

Rationale

Forest management is a potentially strong influence on forest biodiversity, in both positive and negative directions (Duinker, 1996). Forest management plans can only be adjusted to conserve biodiversity more effectively if alternative strategies are formulated and their effects on biodiversity simulated over future time. This project will use the Katinsky (Ust-Ilimnsk) Forest Enterprise database already assembled at IIASA and analyzed in a preliminary way by Carlsson (Chapter 4) during the Biodiversity Summer Workshop.

Outcomes

The study will yield an assessment of how forest management plans for the Katinsky forest should be formulated to have the most beneficial positive impacts (and the smallest negative ones) on forest biodiversity over the long-term future. The results will generate insights into required management strategies which may be applicable elsewhere where forest managers are ready to plan forest management with biodiversity conservation in mind.

1.3.3. Local-forest Simulation Analysis of Biodiversity Conservation: West Siberia and the Far East

Objective

To examine the biodiversity-conservation implications of alterative forest-management strategies for local forests in West Siberia and the Far East.

Rationale

Results of analysis of biodiversity conservation opportunities for the Katinsky forest can not necessarily be transferred directly to other regions of the vast territory of Siberia. This project seeks to undertake parallel investigations to the Katinsky study for quite different forests in the east and west of Siberia (i.e., the Far East, and West Siberia).

Outcomes

The study will yield an assessment similar to that for the Katinsky forest. It will also generate a comparative analysis of biodiversity-conservation strategies for the three forests analyzed (i.e., Katinsky, one in Far East, one in West Siberia).

1.3.4. Pan-Siberian Forest Biodiversity Analysis

Objective

To describe and analyze Siberian forest biodiversity using pan-Siberian forest databases, at both landscape and enterprise resolutions, according to protocols established by Gluck and Plinte.

Rationale

Researchers Gluck (Chapter 2) and Plinte (Chapter 3) have each worked out methods for describing and analyzing the biodiversity of Siberian forests. Gluck used an ecoregional database with 63 polygons across Siberia, and Plinte used the 1988 State Forest Account (SFA) data for the 30+ enterprises of just one ecoregion. The Siberian Forest Study has arranged to take delivery of two new pan-Siberian databases in 1996: (a) a landscape polygon database, onto which the "green" ecoregional data will be distributed; and (b) a 1993 SFA database. The first database is a stronger platform for the types of analyses made in summer 1995 by Gluck and Plinte.

Outcomes

The project will generate descriptions of the forest biodiversity of Siberia according to the assembled data and two spatial resolutions, as well as analyses and assessments of the major abiotic and anthropogenic factors accounting for the described biodiversity patterns.

1.3.5. Definition of Biodiversity-sensitive Forest-management Strategies

Objective

To develop and describe forest-management strategies for Siberian forests that are designed specifically to conserving biodiversity.

Rationale

As stated above, forest management can be a strong influence on the conservation of biodiversity. Both the types of treatments made locally and the arrangement of the treatments in time and space across a whole forest have strong implications for biodiversity. Such strategies provide essential data inputs into simulation analysis for biodiversity conservation studies, and into development of forest-management guidelines.

Outcomes

The study will yield a set of quantitative descriptions for all major approaches to adjusting forest-management strategies for the conservation of Siberian forest biodiversity. Specifications are to be made for types and amounts of timber harvest, regeneration, protection, access, and other actions.

1.3.6. Policy Assessments for Biodiversity Conservation

All the research projects described above, once implemented, would form a firm foundation of knowledge and data upon which to undertake an assessment of the policies required for Russia to move forward decisively in conserving Siberia's forest biodiversity. The policy assessment should be completed in two phases. First, there should be an initial policy workshop during late 1996, during which Russian and western experts would examine all the analytical results so far and assess their policy implications. Through 1997, project scholars should organize and run a series of detailed policy workshops, again for Russian and western experts, during which alternative scenarios for the future development of Siberia's forests, and the biodiversity consequences of these scenarios, are analyzed.

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2. Describing Siberian Ecodiversity: A Database Approach

by Michael Gluck

Abstract

The objective of this paper is to evaluate whether major ecological influences on biodiversity patterns can be detected using the Siberian Ecoregion Database of the Siberian Forest Study at IIASA. An approximation of the current levels of ecosystem diversity, or ecodiversity, is gained by describing the current interactions between climate, soils, vegetation and humans. The aim of this paper is not to prove or disprove the existence of ecological relationships, which would be a redundant exercise, but rather to evaluate the effectiveness of a large, synoptic and generalized database in articulating the basic ecological relationships responsible for and expressing ecodiversity. Relationships between human-caused disturbance and vegetation diversity were examined spatially and statistically to evaluate the effectiveness of the database. Ecosystems across Siberia were described using ecoregions, ranging in size from 145 thousand to 16 million ha, as the smallest units of resolution. Temperature and precipitation information contained in the database combined with soil taxonomy information were used to measure abiotic ecosystem factors. Vegetation diversity was used for describing the biodiversity of the forest landscapes. Phytomass production served as a measure of vegetation function and the distribution and abundance of dominant tree species was used to describe vegetation composition. Structure of the forest vegetation was measured using the age-class structure of the dominant tree species. The results of these analyses show that the Siberian Ecoregion Database is useful in providing very broad ideas of how vegetation diversity varies across the landscape. In particular, the diversity of vegetation can be modeled as a response to air and soil temperature, growing degree days and the intensity of human disturbance using information from the database. Enhancements to the database can be made to increase its ability to describe ecodiversity.

2.1. Introduction

Describing current levels of forest biodiversity is a starting point for asking questions about forest sustainability. Biodiversity can be thought of as the variety of the structure, composition and function of organisms across time and space. Ecosystems are communities of organisms interacting with their environments as integrated units. A meaningful description of ecosystem biodiversity should include descriptions of abiotic and biotic processes. Perhaps this is why Noss (1995) suggested that the term eco-diversity as a more suitable term to what is commonly referred to as biodiversity. Describing Siberian ecodiversity treats biodiversity as an expression of ecosystem processes. Ecodiversity not only elucidates the variation of, among and between organisms, but also why this variation may occur. For example, ecodiversity can address the distribution of a tree species as a result of climatic conditions or resulting from human-caused changes in the environment or both. In this paper I will use the term ecodiversity to describe the variety of ecosystems whereas I will reserve biodiversity to describe the variety of organisms.

The objective of this paper is to evaluate whether influences of the major ecological driving forces on biodiversity patterns can be detected using the Siberian Ecoregion Database (SERD) of The Siberian Forest Study at the International Institute of Applied Systems Analysis (IIASA). An approximation of current natural levels of ecodiversity will be gained by describing the current interactions between climate, soils and vegetation. I will describe ecosystems across Siberia using ecoregions, ranging in size from 145 thousand to 16 million ha, as the smallest units of resolution. I will use vegetation diversity to describe the biodiversity of the forest landscapes. Phytomass production will serve as a measure of vegetation function, and the distribution and abundance of dominant tree species will indicate vegetation composition. I will examine the relationships between disturbance and vegetation structure measured through the intensity of human impact on forest age-class structure. The aim of this paper is not to prove or disprove the existence of the above relationships, which would be a redundant exercise, but rather to evaluate the effectiveness of a large, synoptic and generalized database in articulating the basic ecological relationships responsible for and expressing ecodiversity.

2.2. Approach to Describing Siberian Ecodiversity

I have structured my approach to describing Siberian ecodiversity around a hierarchy of three hypotheses. The first two I will support using ecological literature, and the third I will test using the SERD.

Hypothesis 1: Ecosystems are organized hierarchically such that higher level processes constrain lower level processes.

Ecosystem diversity is determined by a hierarchy of abiotic and biotic processes that occur at different spatial and temporal scales (Urban *et al.*, 1987). A hierarchical system is one that can be divided into discrete functional systems operating at different scales (Simon, 1962). The dynamics of ecological processes at one scale of these systems are constrained by those operating at higher levels (O'Neill *et al.*, 1982). The responses of landscapes to these processes are three basic attributes of ecosystems: function, composition and structure (Franklin *et al.*, 1981). Noss (1990) proposed that these attributes could be used to describe the biodiversity of landscapes. The key to understanding landscape diversity lies in the explanation of the mechanisms operating at different spatial and temporal scales and relating these processes to ecosystem function, composition and structure.

Many conceptual hierarchical models of ecosystems have been proposed in which abiotic processes such as meso-climate, parent material, groundwater flow, surface water flow and soil formation constrain vegetation and fauna diversity (e.g. Klijn and Udo de Haes, 1994, Delcourt *et al.*, 1983) (Figure 1). In these models, landscape attributes at lower levels are responses to constraining factors or driving forces at upper levels. For example, diversity in climatic conditions results in varying rates of weathering of parent material. Similarly, differences in parent materials cause differences in groundwater flow, which in turn affect soil composition, and so on. This is not to say, however, that lower levels of the hierarchy cannot affect processes operating at higher levels, as may be the case when removal of the forest canopy causes changes in soil temperatures.

Hypothesis 2: Biodiversity (function, composition and structure of vegetation) is a response to both "top-down" and "bottom-up" processes operating at broader and finer scales of space and time.

Romme (1982) proposed that plant community diversity results from two vegetation patterns: first, patterns related to the distribution of species along limiting gradients; and second, patterns related to portions of a landscape being in different stages of recovery following disturbance. However, both species distribution and landscape disturbance patterns are expressions of diversity that result from very different processes operating at multiple hierarchical levels. Species distribution is partially an expression of climate and soil patterns that develop over long periods of time and space, whereas disturbances occur over smaller areas in shorter time periods. Landscape structure, composition and function represents a balance between processes operating at different levels (Levin, 1992). To understand processes operating at both higher and lower levels, we must examine ecodiversity using both "top-down" and "bottom-up" approaches that examine landscape composition, structure and function as a responses to higher and lower hierarchical levels.

It is useful to present a model of the expected relationships between climate, soil, vegetation and human activity with vegetation diversity, although this approach describes only part of the ecosystem and is not intended to be holistic (Figure 2). Climate and soil processes operate on larger time and space scales than vegetation and directly influence biodiversity in a top-down manner. Air and soil temperature, length of growing season, fluctuations in air temperature, the presence of permafrost and precipitation are all thought to interact to produce a wide range in forest productivity in boreal forests (Bonan and Shugart, 1989). For example, permafrost conditions reduce soil drainage and nutrient availability, thus reducing plant metabolism (Bonan, 1992). The distribution of tree species is limited by tolerances to climatic extremes. For example, the range of cedar (*Pinus siberica*) is limited to a minimum 630 growing degree days above 5°C (Korzukhin *et al.*, 1989). Together, climate and soil are top-down influences on the function and composition of forest vegetation.

The age-class structure of vegetation is partly a result of differences in the intensity and timing of disturbances. However, the intensity and distribution of human-caused disturbances can be thought of as an indirect result of favorable climate and soil conditions. Transportation infrastructure to access resources is created to areas where climate and soils provide high productivity. In other words, people exploit the forest where its productivity is high and it is accessible. Noss (1995) stated that the density of roads can be considered as one of the best single indicators of human disturbance in wildlands. I will consider transportation density as a description of the intensity of disturbance by humans as a bottom-up influence on vegetation structure.

Hypothesis 3: Relationships exist between climate, soil, and vegetation diversity that are measurable using the SERD.

I tested the ability of the SERD to articulate the expected relationships between climate, soil, vegetation diversity and human-caused disturbance presented in hypothesis three using the null hypothesis:

Hypothesis 4: There is no relationship, measurable using the SERD, between abiotic processes and the function, composition and structure of vegetation.

Measurements of vegetation diversity, climatic conditions, soil conditions, and human-caused disturbance will be derived from the SERD. I will use linear regression and cross-tabulation to investigate relationships between these components.

2.3. Methods

2.3.1. Study Area

Siberia extends east from the Ural mountains to the Pacific Ocean and north from the arctic islands to the borders of Mongolia and China (Figure 3). Siberia covers over 1280 million hectares of which 650 million are classified as forested. About 450 million hectares of the forest are covered with coniferous species, with nearly 55 percent of the growing stock classified as mature and overmature (Figure 4). Most of the latter group occurs beyond roads and railways. Siberia's forests constitute 20 percent of the world's forests and nearly 50 percent of total coniferous area of the world (Shvidenko and Nilsson, 1994).

2.3.2. The Siberian Ecoregion Database

The SERD is the most comprehensive database ever assembled outside of Russia on Siberia's environment, forest resources and related factors (Anonymous, 1995). It contains about 390 environmental attributes for 63 ecoregions. Information for the SERD has been acquired through the participation of a Russian network collaborating with the IIASA Siberian Forest Study. The Oracle database system is used for its management. Arc/Info Geographic Information System (GIS) software provides a linkage to the ecoregion boundaries, thus allowing for spatial representation of the SERD attributes.

2.3.3. Measurements of Ecodiversity

Creating descriptions of ecodiversity represents a translation of data into information. Each description is mappable using the database GIS linkage.

Measurements of Vegetation Diversity

Differences in the structure, composition and function of vegetation across Siberia were used as descriptions of vegetation diversity. With the exception of phytomass data, all information for forest vegetation was derived from the 1988 Forest State Account (Table 1). A summary of the information in each SERD table used is presented in Appendix 1.

Measurements of vegetation function were derived from total phytomass information presented in SERD table 3110. Phytomass information was taken from the map created by Bazilevich (1993). High and low estimates for detritus, phytomass pools and production rates were determined from the highest and lowest values that occurred in each ecoregion polygon. I took the average of the high and low estimates to determine mean values for each ecoregion. These mean values were divided by ecoregion area to express phytomass and detritus values in tonnes per hectare and primary production in tonnes per hectare per year (Figures 5, 6 and 7 respectively).

I described vegetation composition using dominant species information in SERD table 3108 and forest resources information in SERD table 3103. Table 3108 contains the composition of each dominant species class occupying more than ten percent of the forest area available for exploitation (AFE immature, mature and overmature stands available for final harvest). I manipulated table 3103 to provide the AFE for each dominant species class for each ecoregion. By multiplying dominant species AFE by the composition for each genus, I determined how much area it occupies as dominant and sub-dominant roles in dominant species groups. These areas were summed and converted into percent area by dividing by total AFE to produce what can be considered the effective area that a genus occupies in the forested area of an ecoregion. The effective area of a genus provides a better indication of its ecological amplitude than the dominant species distribution. I calculated dominant species richness for each ecoregion by counting the number of dominant species that were present in SERD table 3103 as an additional measure of vegetation composition (Figure 8). Examples of effective area calculation are presented in Appendix 2.

Age-class information used to describe vegetation structure was taken from SERD table 3103. Age classes vary by dominant species and administrative region. They are based upon approved ages of cutting according to the Instructions in the State Forest Cadaster (Shvidenko, 1995). Area values for all species for age classes young I and II, middle age, immature, mature and overmature were converted into percent areas of the forest area (Figure 9).

Measurements of Human Impact

Noss (1995) stated that the single best indicator of human disturbance in wildlands is the density of roads. I have extended this idea to include railways and roads as indicators of the density of human impact. SERD table 14 provides the total distances of roads and railways for each ecoregion. Transportation density was calculated by dividing the total distance of roads and railways by the area of the ecoregion (Figure 10).

Measurements of Climate Process

Climate variables in SERD table 21 were calculated using data collected from meteorological stations. Mean annual air temperature (herein called air temperature) and annual sum of degree days above 5°C values (herein called heat sum) were calculated using data from 1200 stations collected from 1881 to 1960 (Figures 11 and 12 respectively). Annual sum of precipitation above 5°C (herein called precipitation sum) values were calculated using data from 1340 stations collected from 1891 to 1964 (Figure 13). Estimates of mean annual precipitation should be considered as provisional because the majority of standard deviations exceed five percent of the mean annual values.

Measurements of Soil Process

Main soil group information was taken from the Soil Map of Russia Using 1989 FAO Legend (Stolbovoy and Sheremet, 1995) (Figure 14). The main soil group which comprised the greatest area of an ecoregion was assigned to that ecoregion by visual estimation. Mean annual soil temperature (herein called soil temperature) values were calculated using data from 1150 stations data from 1947 to 1963 and extrapolated to the 1881 to 1960 time period using air temperature data (Figure 15). 3.4 Statistical Analysis I divided the investigation into three sections. The first used regression analysis to explore the direct relationships between measurements of climate process and vegetation function and composition. The second used cross tabulation and linear regression to look for the expression of relationships between measurements of soil process and vegetation function and composition. The final section used linear regression to examine the indirect relationships between measurements of climate and soil process and vegetation structure via transportation density.

For cross-tabulation in the second section, I assigned vegetation measurements into equal interval classes. Detritus pool data were classified into nine classes of 40 tonnes per hectare per class. Phytomass pool data were assigned to 10 classes of 20 tonnes per hectare per class. Primary production data were translated into 5 classes of 4 tonnes per hectare per year per class. Dominant species richness data were divided into 10 classes of two dominant species per class.

Regression coefficients and significance levels are presented for linear regression results. Chi-squares and Lambda values are presented for cross-tabulation. Lambda is a proportional-reduction-in-error measure of association which reflects the reduction in error when values of the independent variable are used to predict values of the dependent. A value of one means the independent variable perfectly predicts the dependent. A value of zero means the independent variable is no help in predicting the dependent (SPSS, 1995).

2.4. Results and Discussion

2.4.1. Direct Influence of Climate on Vegetation Function and Composition

Linear regression results suggest that the relationships between climate and vegetation function and composition are detectable using the SERD, but to a limited degree (Table 4). Positive significant ($P = 0.01$) relationships are evident between phytomass pools and heat and precipitation sum measurements and mean air temperature ($R^2 = 0.19$, 0.33 and 0.29, respectively). Phytomass production shows a significant ($P = 0.01$) positive relationship between heat sum and air temperature ($R^2 = 0.46$ and 0.35, respectively). This shows that the SERD is able to express relationships between climate and optimum growing conditions for above-ground phytomass. There are no significant ($P = 0.05$) relationships between detritus pools and climate that are measurable using the SERD. The relationship between phytomass and heat sum is similar to that found by Van Cleve and Yaire (1986) which expresses an increase in annual production with growing degree days above 10°C. However, I also expected the amount of detritus to increase with lower soil temperatures as an increase in forest floor layers over permafrost insulates the soil layer and decreases average soil temperature (Bonan, 1992).

Effective area of genuses shows some statistically significant relationships ($P = 0.01$) between climate and dominant species. Birch (*Betula pendula* and *Betula pebescens*) and aspen (*Populus tremula*) exhibit positive relationships ($R^2 = 0.17$ and 0.15 respectively) with heat sum, whereas larch (*Larix siberica* and *Larix dahurica*) displays a negative relationship ($R^2 = 0.29$). Aspen, birch and fir (*Abies siberica*) all show positive relationships ($R^2 = 0.19$, 0.16 and 0.26, respectively) with air temperature, while larch displays a negative relationship ($R^2 = 0.50$). Relationships with temperature variables may reflect a genus' role in the ecosystem across a gradient of temperatures. For example, we know that larch is able to withstand cold temperatures better than any other Siberian dominant species, whereas aspen, birch and fir demand warmer growing seasons (Korzukhin *et al.*, 1989). Larch's negative relationship with heat sum and air temperature pronounce this by showing that larch occupies a greater proportion of the ecoregion area as temperatures decrease (Figure 16). On the other hand, the effective areas of aspen, fir and birch increase with air temperature and heat sum (e.g. aspen in Figure 17). The only significant ($P = 0.01$) relationship with precipitation sum is expressed by fir and spruce (*Picea siberica*) which have the lowest tolerance to drought among the main trees species in Siberia (Korzukhin *et al.*, 1989). Spruce and fir both show positive relationships ($R^2 = 0.18$ and 0.28 respectively) with precipitation sum, thus reflecting this characteristic.

Significant relationships do not extend to pine (*Pinus silvestris*) and cedar and there is no single climatic predictor of effective area for all genuses. Multiple regression using all three climatic variables does not improve the ability to predict genus effective area. This is due to the high intercorrelation of the climatic measurements.

Dominant species richness shows significant ($P = 0.01$) positive relationships with all measures of climate. Richness has the strongest positive relationships of all the vegetation composition variables with heat and precipitation sums and also a positive relationship with mean air temperature ($R^2 = 0.51$, 0.63 and 0.32 respectively). The occurrence of what can be termed minor dominant species such as willow, oak and alder cause an increase in the dominant species richness. It makes sense that dominant species richness expresses strong relationships with climate because minor dominant species occupy areas of favorable meso-climates.

2.4.2. Direct Influence of Soil on Vegetation Function and Composition

Cross-tabulation of main soil types with detritus and phytomass pools, primary production and dominant species richness showed poor relationships between the databases (Table 5). Intuitively, some patterns between main soil groups and vegetation can be detected, although the statistical correlations do not support any strong associations. The chernozems described by the FAO (1993) as having favorable production potential do occur in the steppe ecoregions where phytomass production is greatest (Figure 7). The majority of the low-phytomass-producing ecoregions in the north of Siberia have podzoluvisols and podzols which are characterized as having low nutrient levels and poor drainage (FAO, 1993). The areas of highest detritus pools occur in histosols, both of which have developed in very cold and/or wet conditions (FAO, 1993; Van Cleve and Yaire, 1986) (Figure 5). These results suggest that main soil groups do not contribute significantly to the measured values of vegetation function and composition. However, I feel that the FAO main soil groups are appropriate for describing broad-scale interactions of soils and vegetation and that further investigation into integrating the FAO soils database (especially at larger scales) with the SERD is warranted.

Linear regression of soil temperature on vegetation measurements showed the ability of the SERD to express the ecological relationships between soil heat regime and vegetation. I expected the SERD to show that low soil temperatures reduce soil productivity by restricting nutrient availability, root elongation and water uptake, based on the review of the subject by Bonan (1992). Phytomass pools, primary production and dominant species richness all expressed significant ($P = 0.01$) positive relationships with soil temperature (R^2 of 0.21, 0.39 and 0.41 respectively) (Table 6). These relationships are similar in nature to those shown with air temperature and heat sum, again demonstrating the ability of the SERD to express basic relationships between soil temperature and some vegetation descriptions.

2.4.3. Indirect Influence of Climate and Soil on Vegetation Structure

Linear regression of heat sum, precipitation sum, air temperature and soil temperature on transportation density (Table 7) show that favorable growing conditions (warm air and soil temperature and higher precipitation) express significant ($P = 0.01$) positive relationships with transportation density ($R^2 = 0.27$, 0.17, 0.32 and 0.36 respectively). This is not surprising, as people tend to live in areas with the best growing conditions and most favorable climate. In 1914, the Trans-Siberian Railway opened up Siberia to a flood of migration into the areas that make up the southern, and some of the most productive, ecoregions. Populations climbed from ten million in 1914 to over 21 million by 1959 (French, 1989). Regression of vegetation measurements on transportation density (Table 8) shows significant ($P = 0.01$) positive relationships with age class II and middle-aged forests ($R^2 = 0.10$ and 0.26 respectively) and negative relationships with mature and overmature forest ($R^2 = 0.27$) (Figure 4). These results may be a reflection of the large amount of forest exploitation that occurred in the southern ecoregions during the latter half of this period of development. Middle-age-class forests are generally in the range of 40 to 60 years old (Figure 18). Shvidenko and Nilsson (1994) indicated that the area along the Trans-Siberian Railway has been under continuous exploitation since World War II.

2.5. Conclusions and Recommendations

The objective of this working paper was to evaluate whether top-down and bottom-up ecological influences on vegetation diversity can be measured using SERD. This boils down to an question of scale – is the ecoregion scale, and the aggregation of data within it, effective in articulating basic relationships between vegetation function, composition and structure and abiotic processes? Evaluating the ability of the SERD to express these relationships is a necessary precursor to describing biodiversity across Siberia. My response to this question is not simple.

The ecoregion units are useful in providing very broad ideas of how vegetation diversity varies across the landscape. For example, relationships between dominant species richness and climatic variables are well expressed by the SERD. Although some of ecological relationships are detectable, information is lost through the process of aggregation. For example, relationships of climate with the effective area of genuses are only articulated by those species especially intolerant to climatic extremes. The aggregation of climatic data into ecoregional values does not capture the spatial and seasonal/annual temporal variance that comprises the climatic characteristics of the ecoregion. In particular, measures of precipitation, a major environmental factor affecting available moisture in non-permafrost areas, is aggregated to a point where reported standard deviations ranges from 3 to 75 percent of the mean. The original climatic records contain valuable information that is lost within ecoregion-sized, 75-year averages. This information in its original form is necessary to allow modeling of climatic influences on biodiversity and as baseline information for forecast modeling.

If the ecoregions are not an appropriate scale to describe Siberian ecodiversity, then what scale would be more suitable? Landscape units should be created that are smaller and more homogeneous in terms of climate, soils and vegetation diversity. I suggest a top-down approach for delineating these units that considers the processes responsible for biodiversity. For example, landscape units could be delineated by considering environmental processes operating in an ecological hierarchy as discussed in Section 2.2.2. If this approach were to be adopted, then administrative boundaries should be used only at the lowest level of detail. In other words, one should maintain enterprise boundaries only to permit the transfer of Forest State Account information into the landscape units, but use no other administrative boundaries.

There are several components missing from the SERD that limit one's ability to describe ecodiversity. Information on disturbance by fires, insects and diseases are required to include non-human agents of forest change. Detailed information on soils, such as moisture, nutrient availability and permafrost, is required at a scale that is ecologically meaningful. Any additional data should be evaluated as to their level of aggregation prior to incorporation into the SERD. Data that have become ambiguous through spatial and temporal aggregation provide little information for describing ecodiversity.

The SERD is a starting point for asking questions about Siberian ecodiversity – it should be thought of as a model that shows both strengths and shortcomings in representing ecosystems. Like any model, it points us in the direction to improve understanding of a system and thus an ability to express this knowledge. The issue of scale is central to the improvement of the Siberian biodiversity analysis. An improved database should articulate clearly the expected relationships between climate, soils, vegetation diversity and disturbance regimes. With effective tools we can begin to ask competent questions about ecodiversity. The SERD provides a framework in which to develop these tools.

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Table 1. Measurements of vegetation diversity using ecoregion database variables.

Ecosystem Feature	Description	Measurement
vegetation function	phytomass	-phytomass in dertritis (tn/ha) -phytomass above ground (tn/ha) -production of phytomass (tn/ha/yr)
vegetation composition	distribution and abundance of forest types	- effective genus area - dominant species richness
vegetation structure	forest age-class structure	- percent area by age class

Table 2. Measurements of climatic process using ecoregion database variables.

Ecosystem feature	Description	Measurement
climate	temperature	-mean annual air temperature (C) -growing degree days above 5° C (C)
	precipitation	-total precipitation during growing season greater than 5° C (mm)

Table 3. Measurements of soil process using ecoregion database and other variables.

Ecosystem feature	Description	Measurement
taxonomy	main soil group	-FAO soil classification
heat regime	temperature permafrost	-mean soil temperature (C) -permafrost classes

Table 4. Summary of linear regression coefficients (R^2), Y intercepts (b0) and slopes (b1) for vegetation function and composition on annual climatic measurements. All regressions have 61 degrees of freedom.

Vegetation Function and Composition	Total Degrees > 5°C			Total Precipitation>5°C			Mean Air Temperature (°C)		
	R^2	b0	b1	R^2	b0	b1	R^2	b0	b1
detritus (tn/ha)	.01	-1.20	-1.64	.00	69.83	.02	.02	83.59	1.87
phytomass (tn/ha)	.19**	35.01	.04	.33**	32.09	.24	.29**	126.90	5.84
production (tn/ha/yr)	.46**	94.00	-.01	.07*	4.56	.01	.35**	9.26	.58
aspen (%area)	.17**	-.12	.00	.03	.02	.00	.19**	.11	.12
birch (%area)	.15**	-.12	.00	.00	.25	-.00	.16**	.29	.02
cedar (%area)	.05	-.03	.00	.01	.05	.00	.02	.10	.00
fir (%area)	.16	-.10	.00	.18**	-.05	.00	.26**	.11	.01
larch (%area)	.29**	1.05	.00	.09	.60	-.00	.50**	.15	-.06
pine (%area)	.01	.16	.00	.08	.21	-.00	.01	.10	-.00
spruce (%area)	.01	.03	.00	.28**	-.09	-.00	.13**	.12	.01
dominant species richness	.51**	.84	.01	.63**	3.10	.03	.32**	13.43	.57

where : * = significant at P = 0.05

** = significant at P= 0.01

Table 5. Summary of Pearson chi-square scores with associated degrees of freedom and Lambda values for cross-tabulation of main soil groups and vegetation function and composition codes.

Vegetation Function and Composition	Pearson chi-sq	df	Lambda
detritis code	100.96**	64	.16
phytomass code	80.26	64	.21
production code	51.14	32	.11
genus richness code	109.70	64	.23

where : ** = significant at P = 0.01

Table 6. Summary of linear regression coefficients (R^2), Y intercepts (b0) and slopes (b1) for vegetation function and composition on mean soil temperature. All tests have 61 degrees of freedom.

Vegetation Function and Composition	R^2	b0	b1
detritis (tn/ha)	.01	80.97	1.28
phytomass (tn/ha)	.21**	122.28	5.16
production (tn/ha/yr)	.39**	8.96	.56
genus richness	.47**	13.12	.70

where : ** = significant at P = 0.01

Table 7. Summary of linear regression coefficients (R^2), Y intercepts (b0) and slopes (b1) for annual climatic and soil temperature measurements on transportation density (km/100km^2) measurements. All regressions have 61 degrees of freedom.

	Total Degrees > 5°C			Total Precipitation>5°C			Mean Air Temperature (°C)			Mean Soil Temperature (°C)		
human impact	R^2	b0	b1	R^2	b0	b1	R^2	b0	b1	R^2	b0	b1
transportation density (km/100km^2)	.27**	-.04	00	.17**	-.00	.00	.32**	.10	.01	.36**	.79	.10

where : ** = significant at P= 0.01

Table 8. Summary of linear regression coefficients (R^2), Y intercepts (b0) and slopes (b1) of vegetation structure on transportation density (km/km^2) measurements. All tests have 57 degrees of freedom.

Vegetation Structure	R^2	b0	b1
age-class I (%area)	.10	6.10	35.50
age-class II (%area)	.10*	5.96	26.20
middle age (%area)	.26	17.50	81.25
immature (%area)	.06**	10.90	19.77
mature and overmature (%area)	.27**	59.39	-161.57

where : ** = significant at P = 0.01
* = significant at P = 0.05

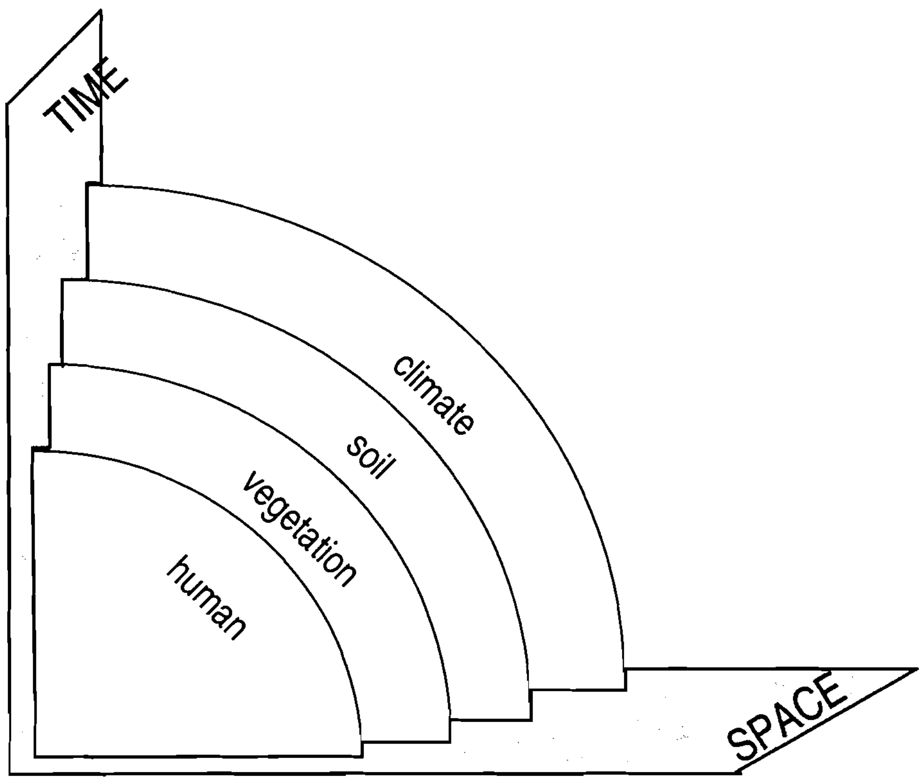

Figure 1. Ecosystem model showing climate, soil, vegetation and humans as overlapping processes along scales of space and time. Adapted from Klijn and Udo de Haes (1994).

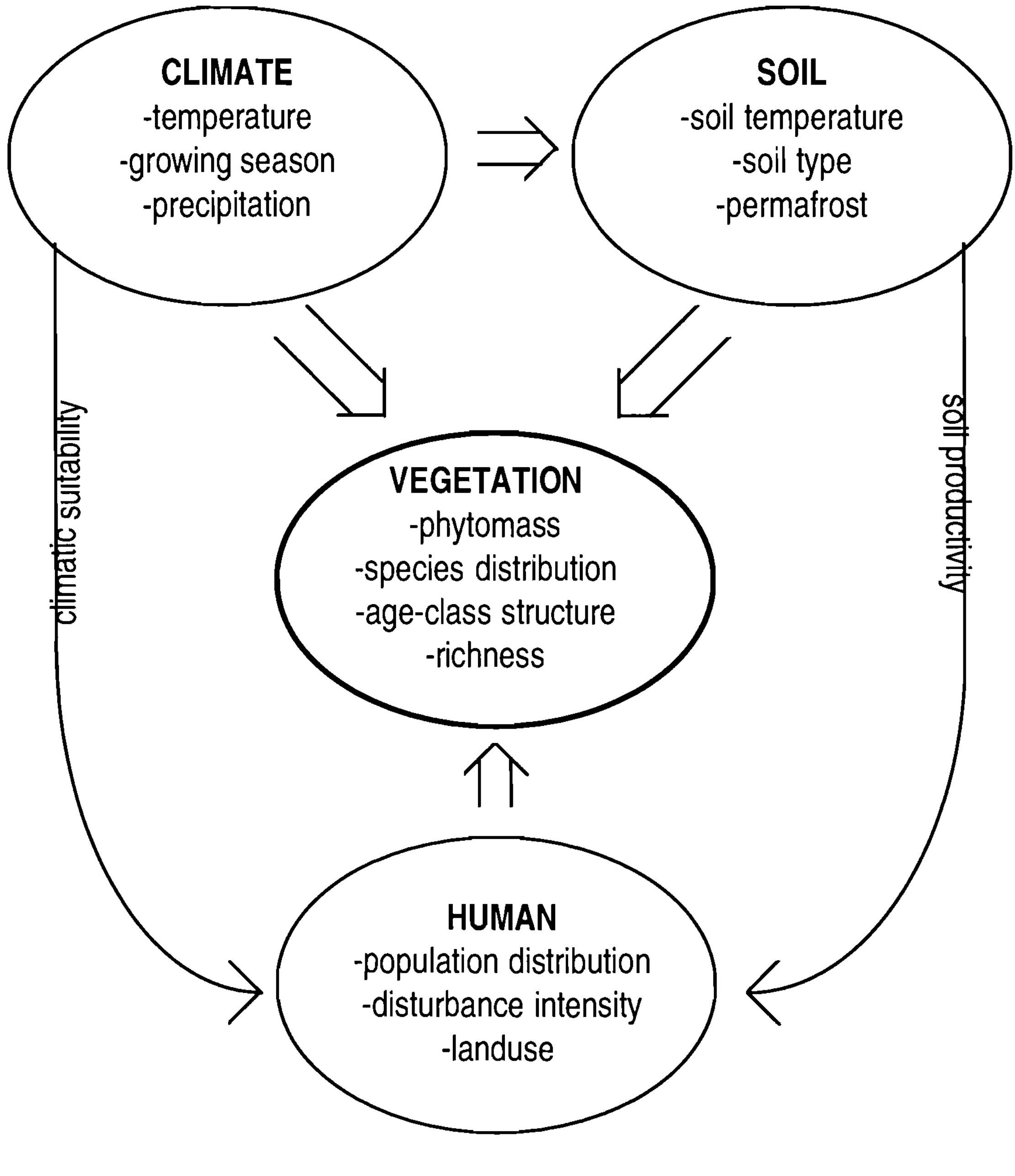

Figure 2. Model of expected relationships between climate, soil, vegetation and human activity with vegetation diversity. Double lines represent direct relationships and single lines indirect relationships.

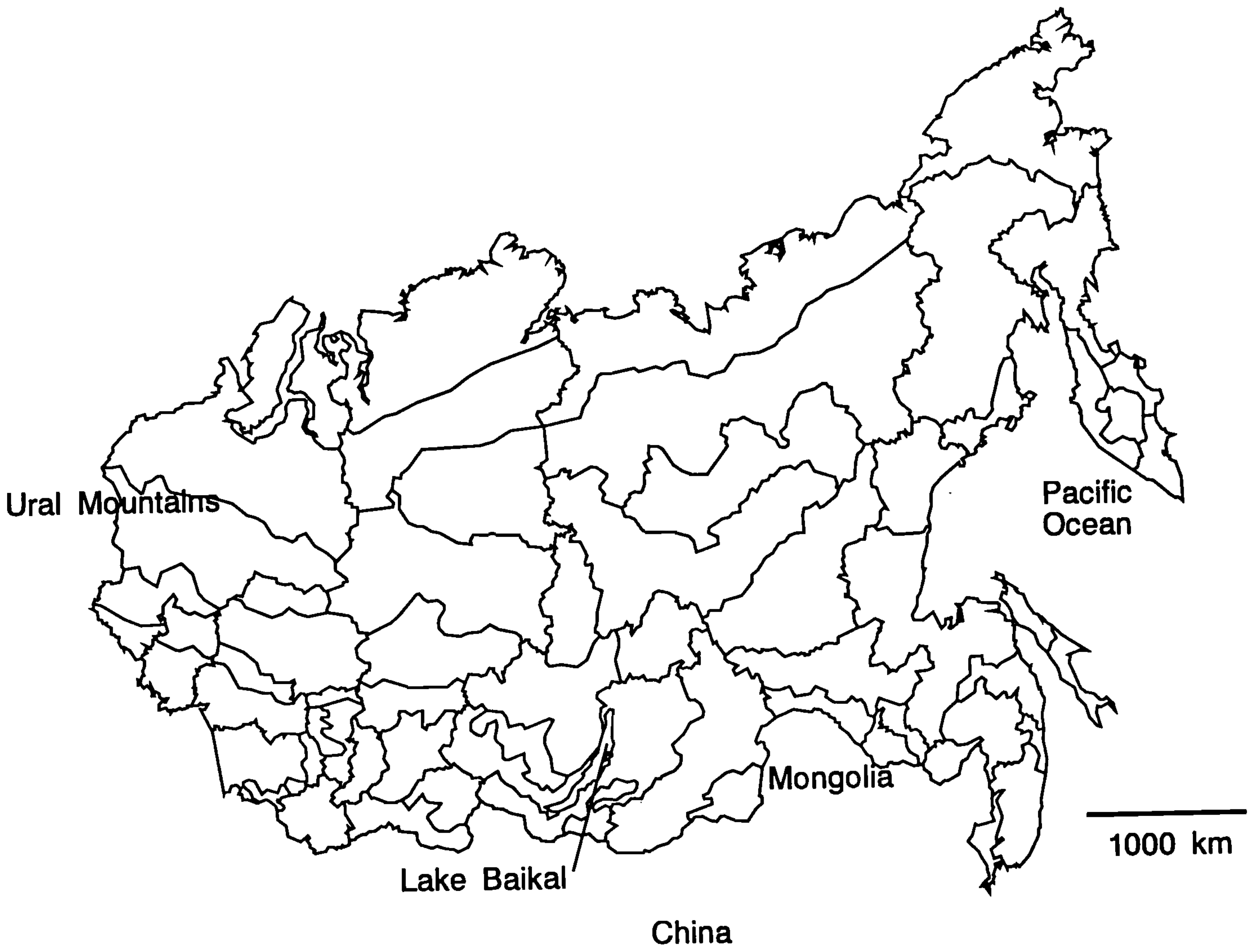

Figure 3. Map of Siberia showing ecoregions.

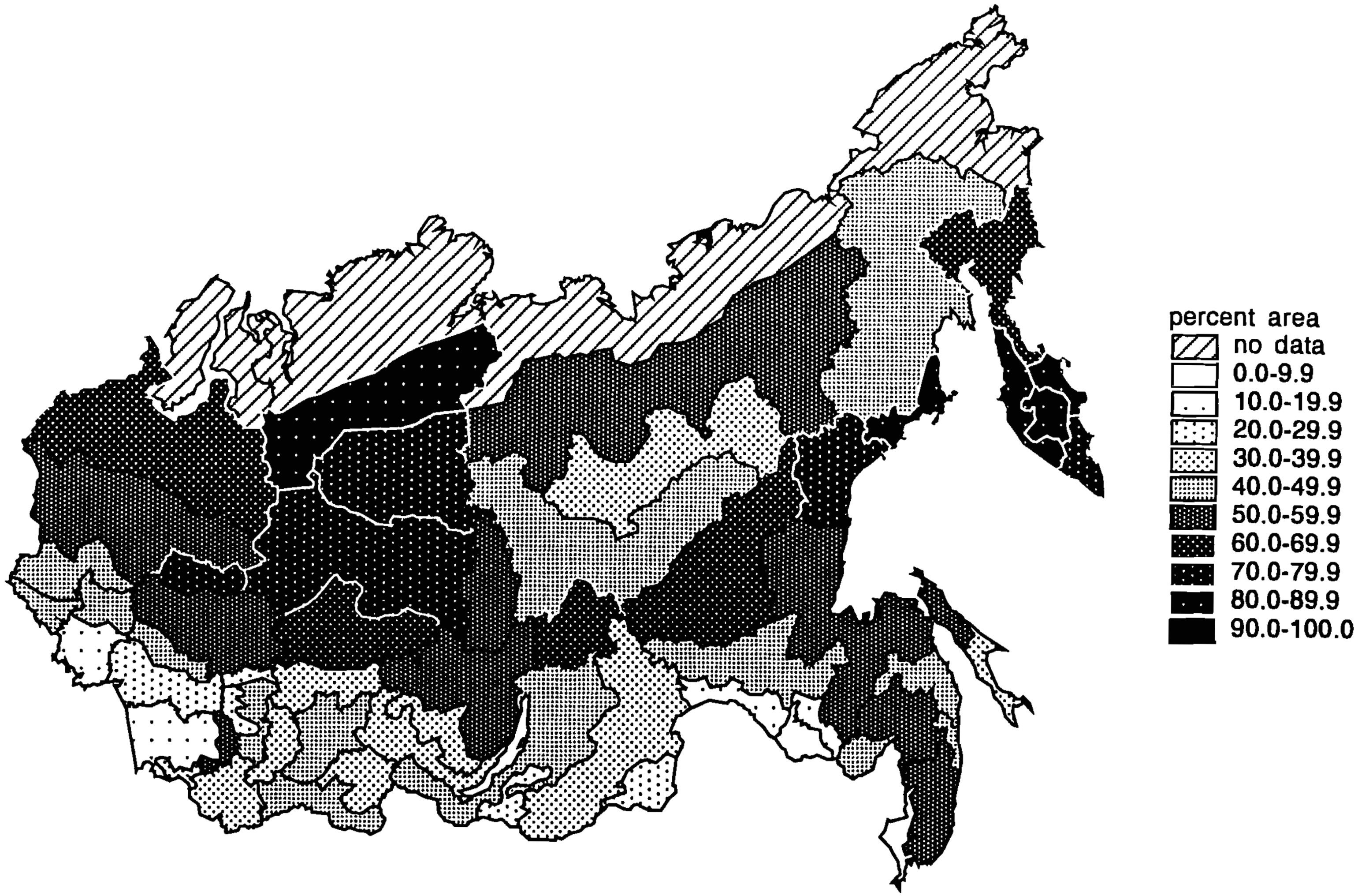

Figure 4. Percent area of ecoregion covered by forest of mature and overmature age classes (Source: SERD Table 3103).

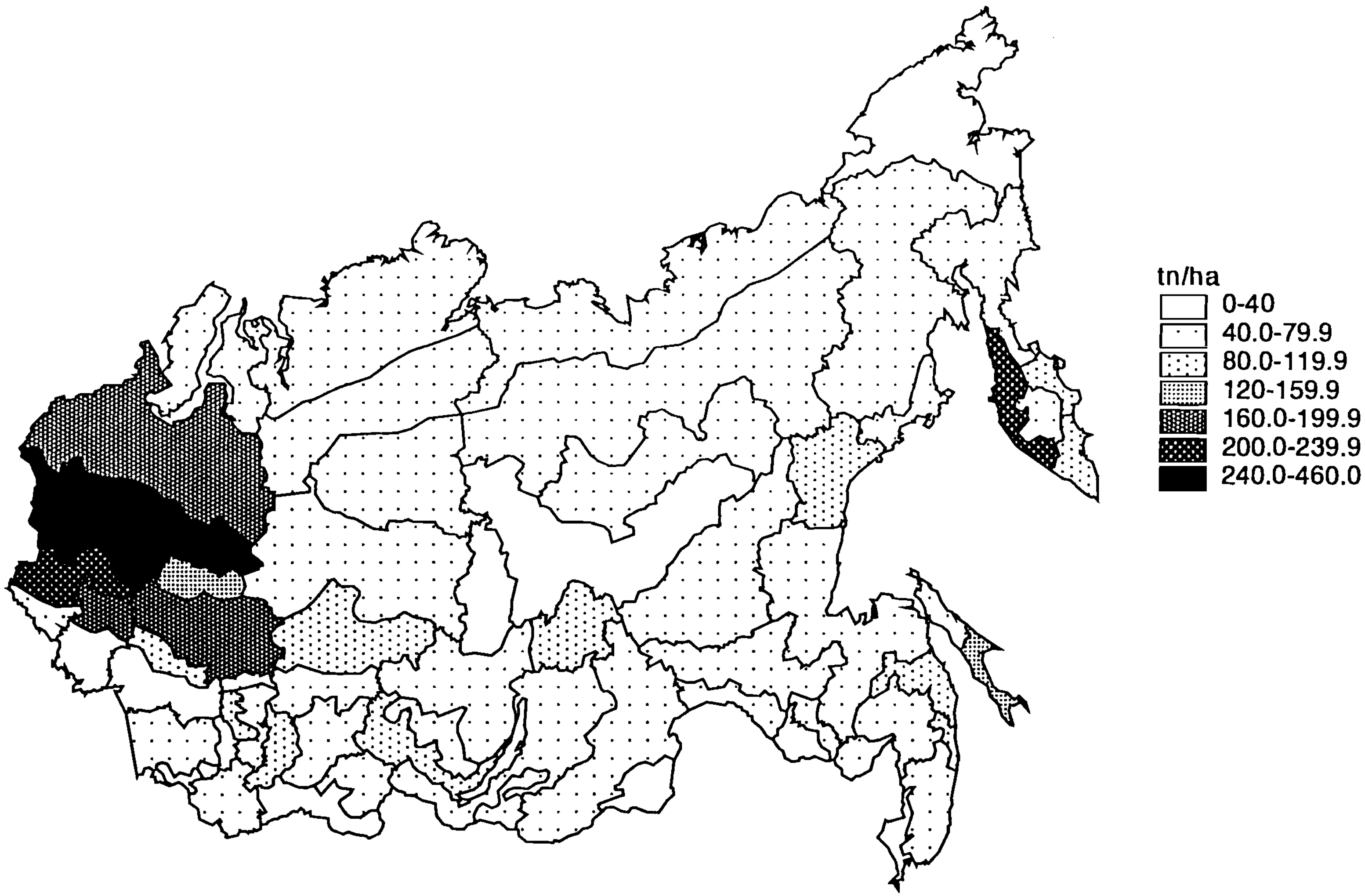

Figure 5. Average amount of detritis (tn/ha) (Source: SERD Table 3110).

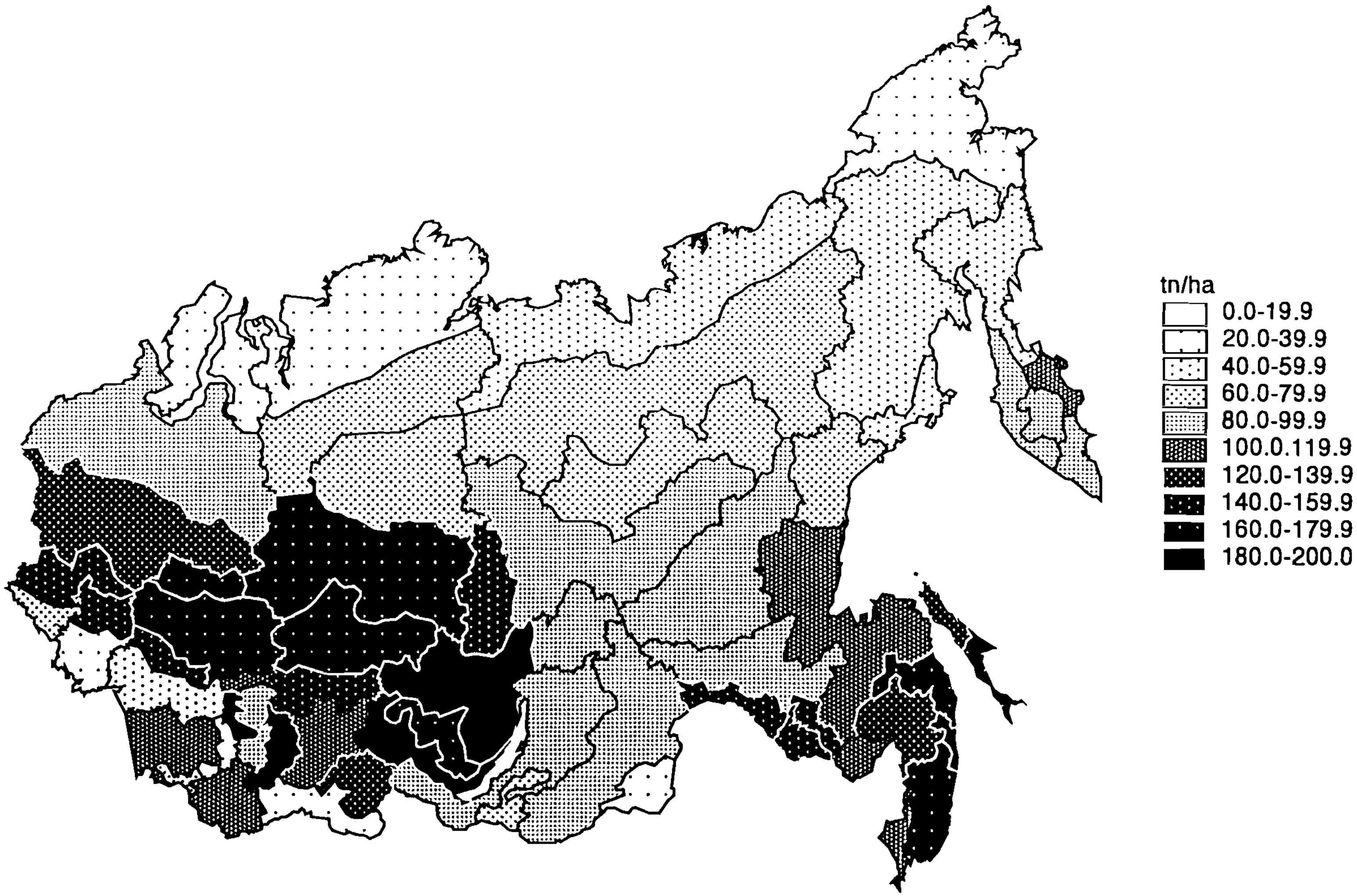

Figure 6. Average amount of phytomass (tn/ha) (Source: SERD Table 3110).

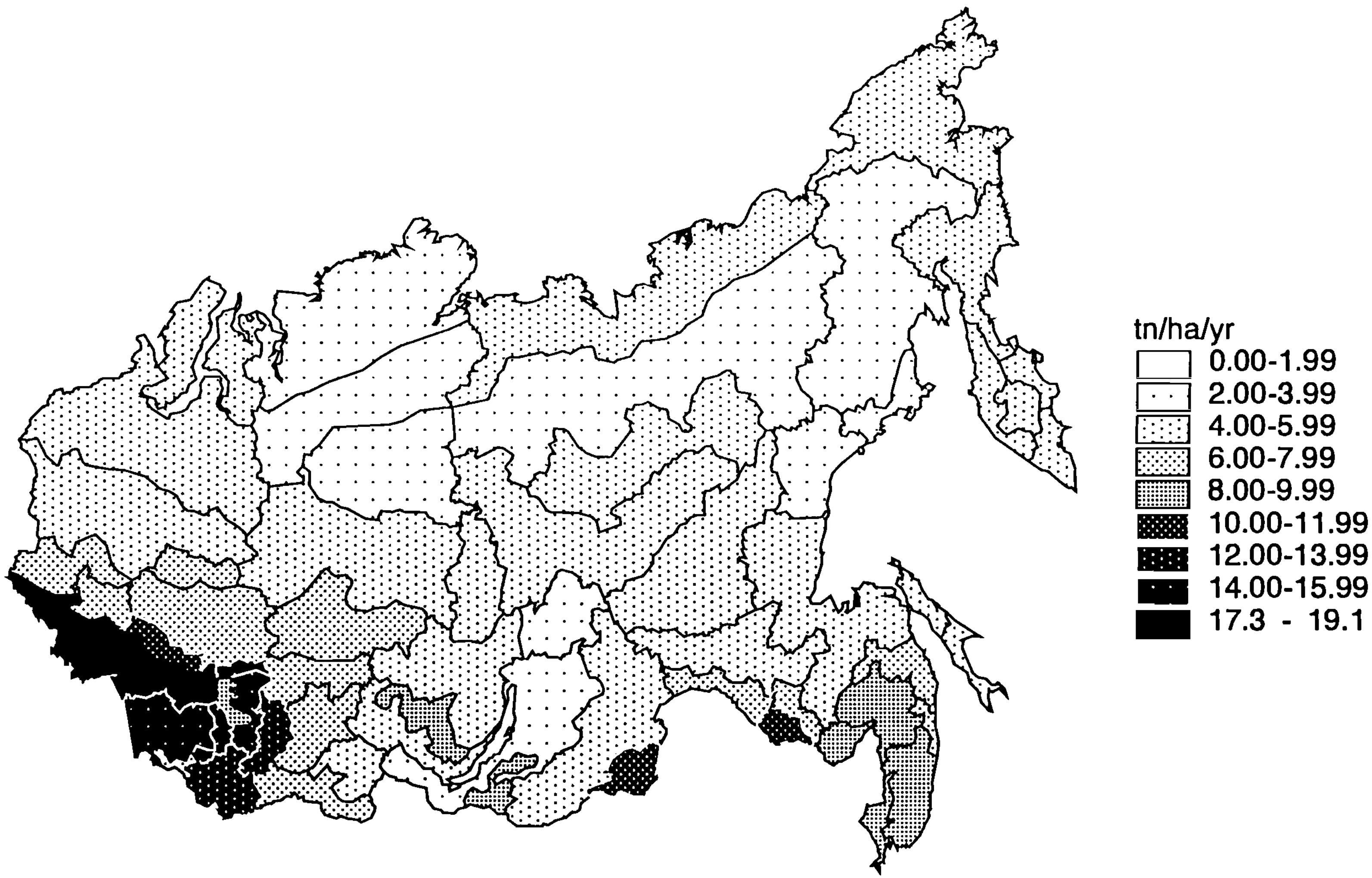

Figure 7. Primary production of phytomass (tn/ha/yr) (Source: SERD Table 3110).

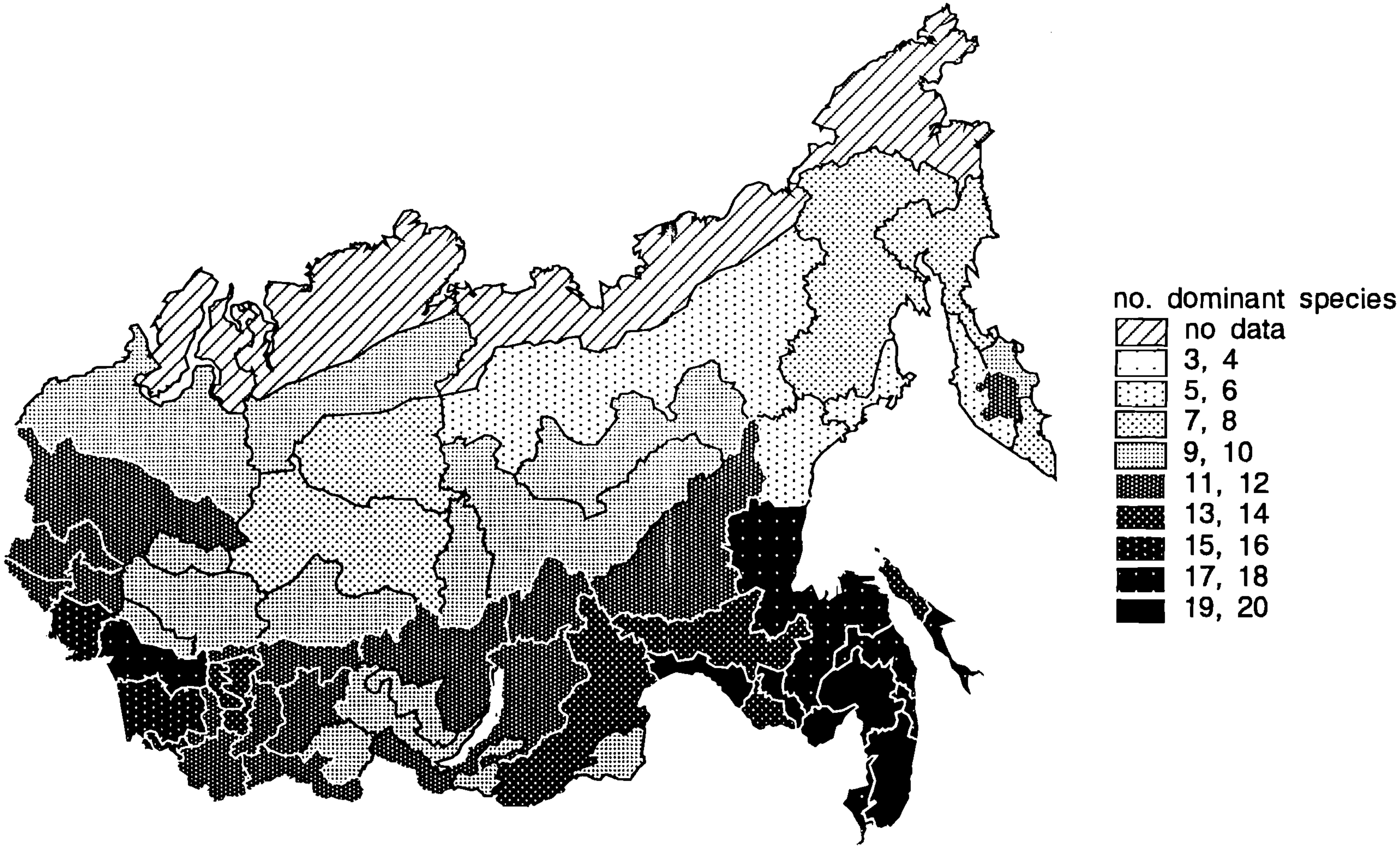

Figure 8. Dominant species richness measured as the number of dominant species per ecoregion (Source: SERD Table 3103).

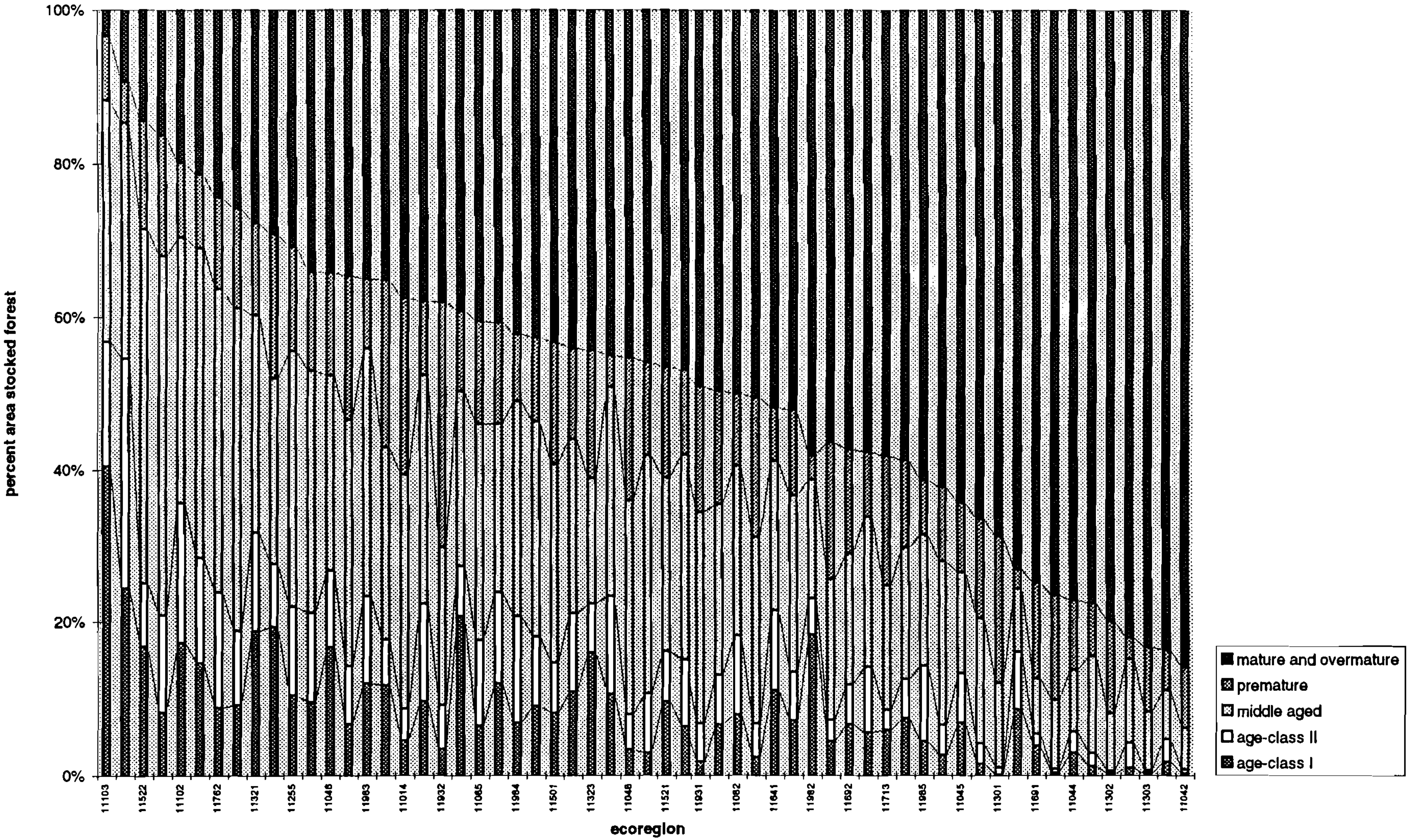

Figure 9. Vegetation structure expressed as forest age-class structure (Source: SERD Table 3103).

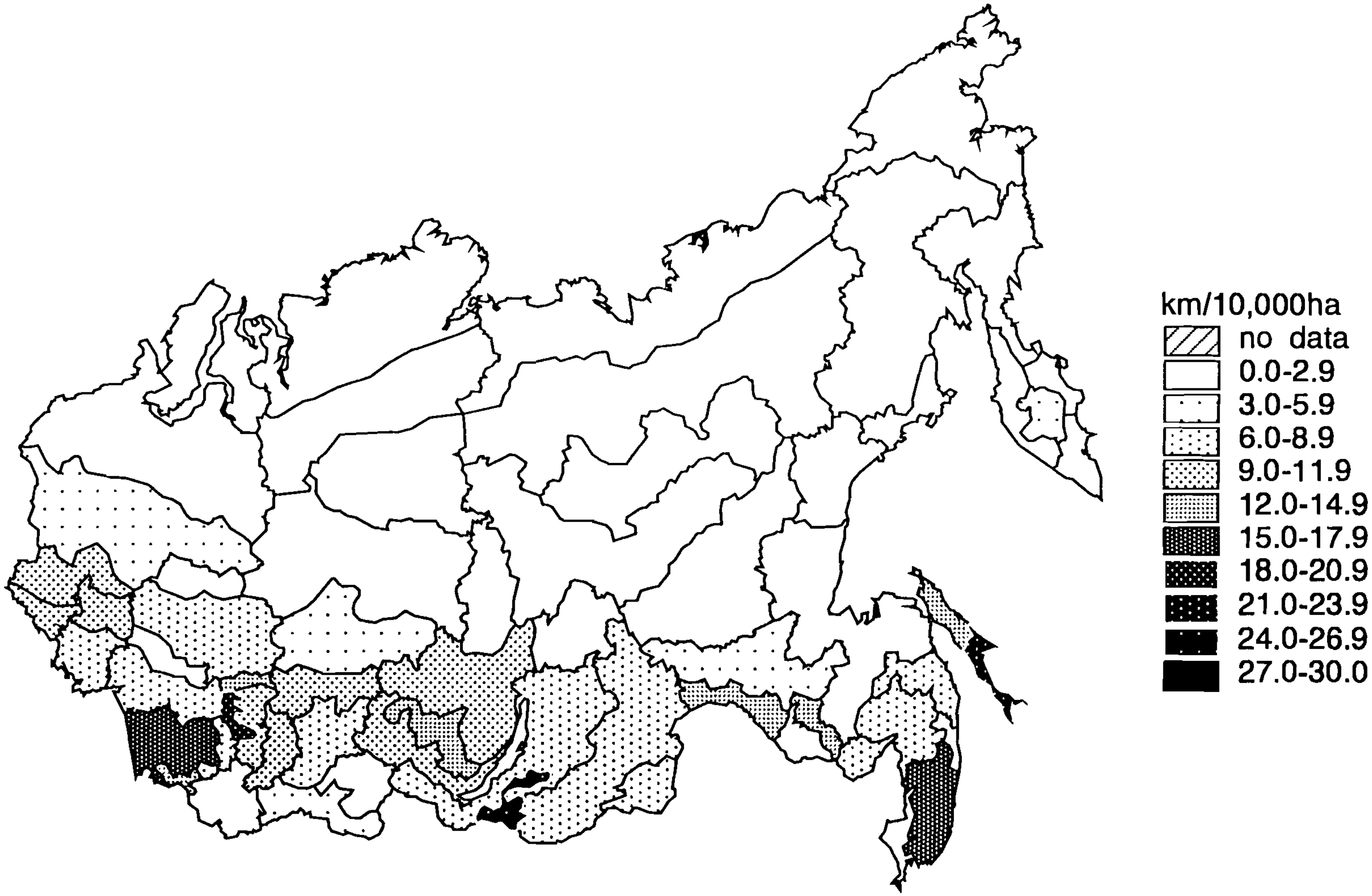

Figure 10. Density of roads and railways by ecoregion (km/10,000ha) (Source: SERD table 15).

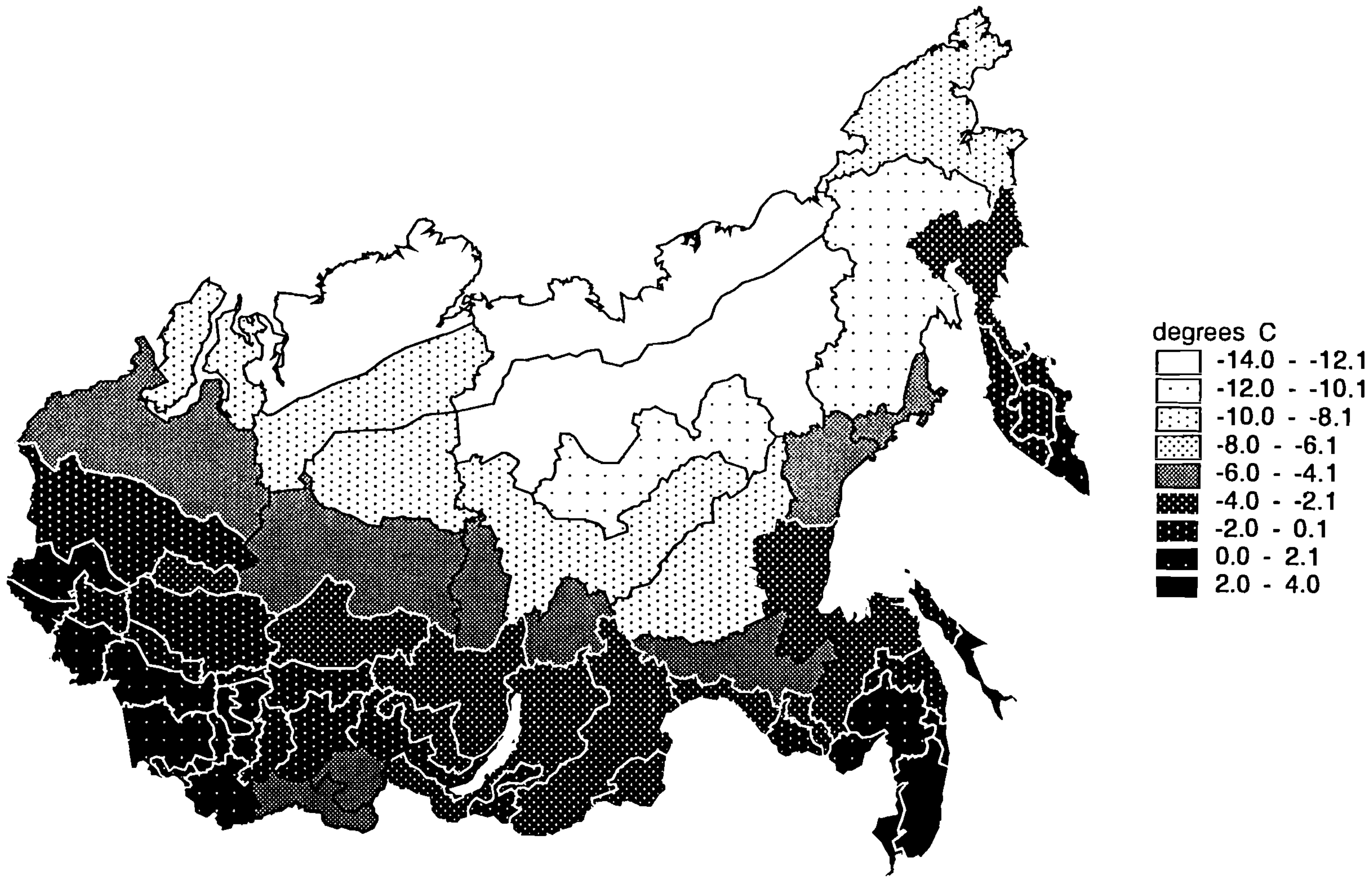

Figure 11. Mean annual air temperature (Source: SERD table 21).

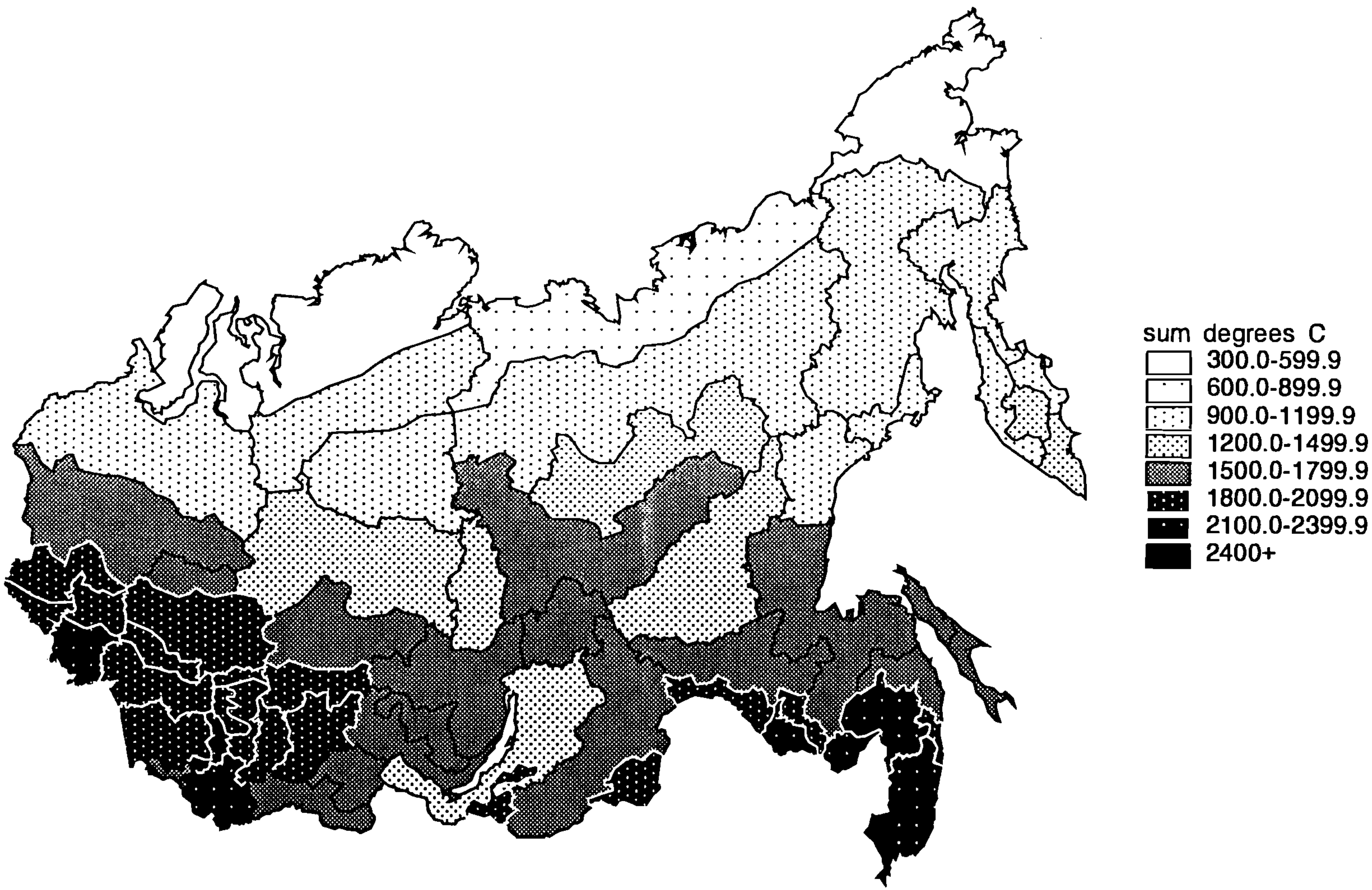

Figure 12. Growing degree days greater than 5 degrees C (Source: SERD Table 21).

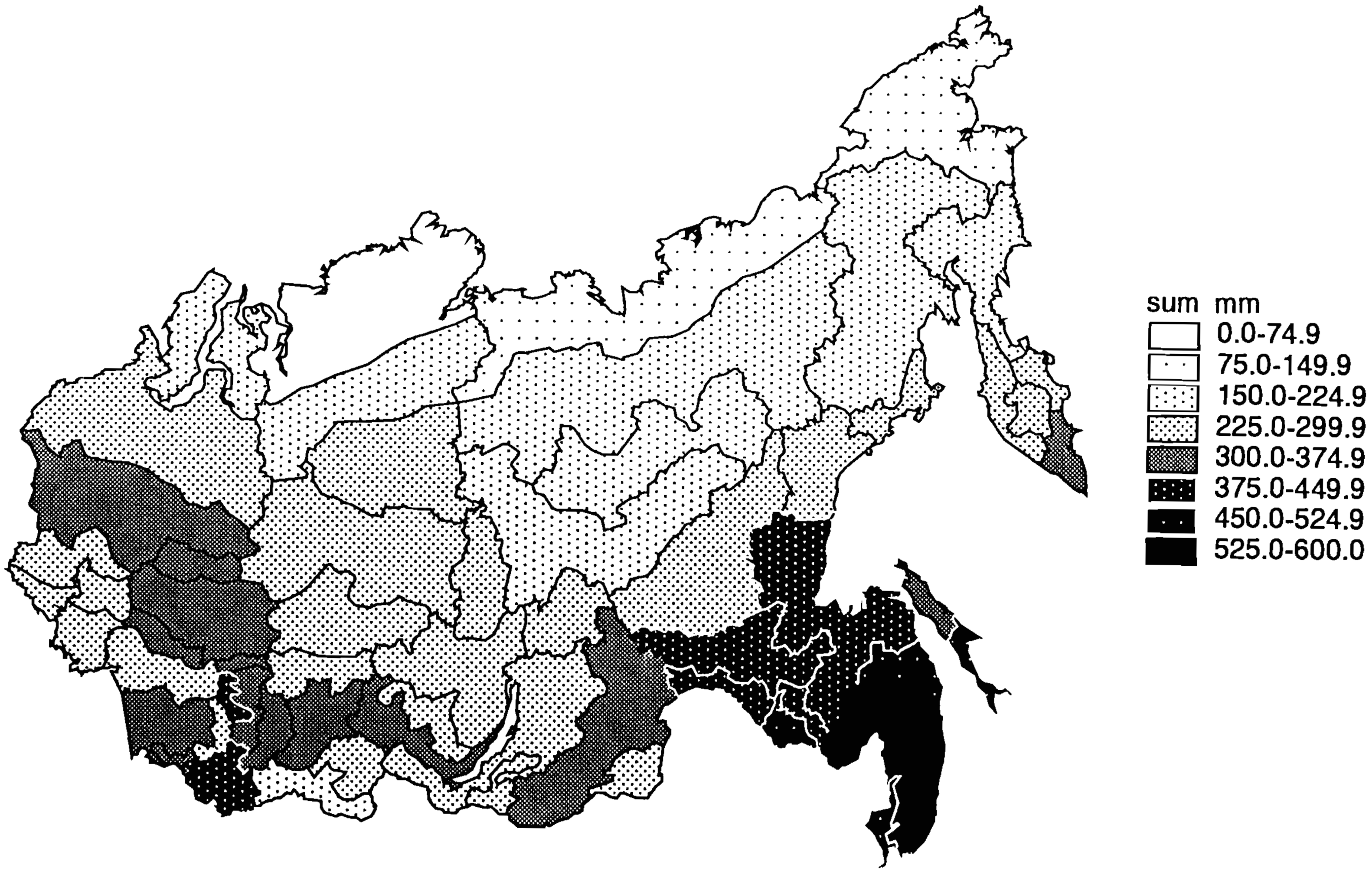

Figure 13. Average annual precipitation when daily mean air temperature is greater than 5 degrees C (Source: SERD Table 21).

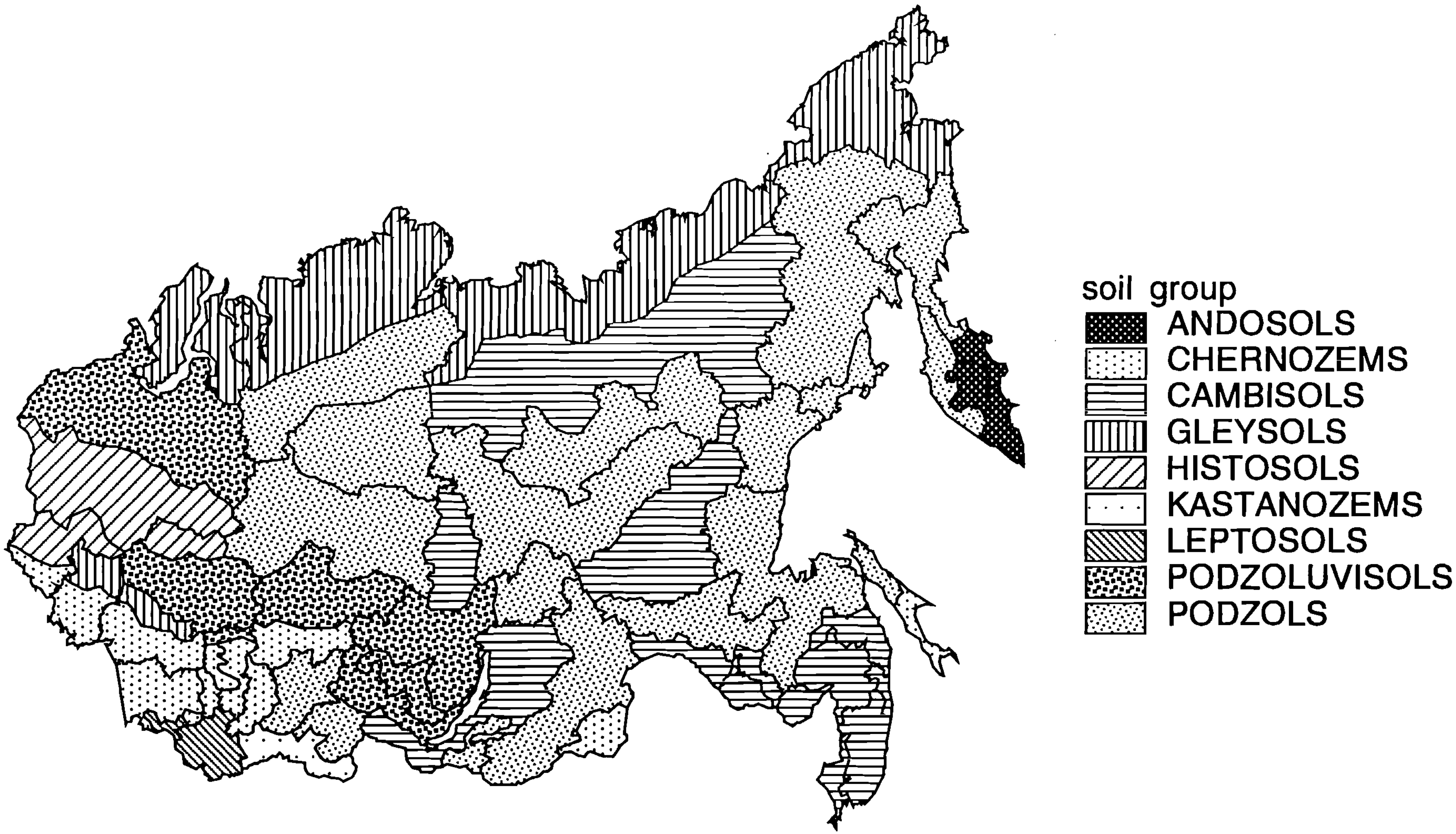

Figure 14. Main soil groups of Siberia (Source: Stobovoy and Sheremet 1995).

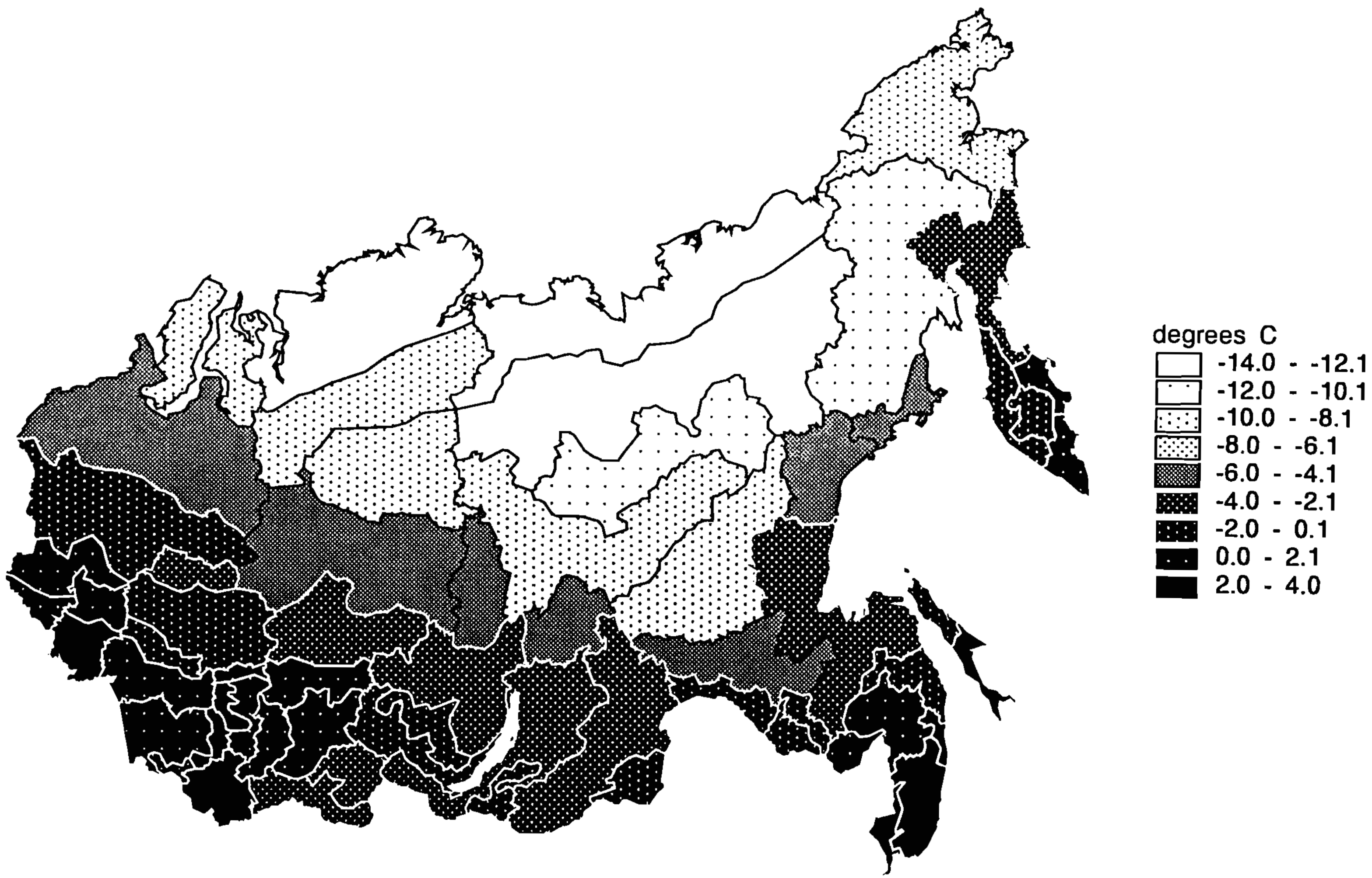

Figure 15. Mean annual soil temperature (Source: SERD table 21).

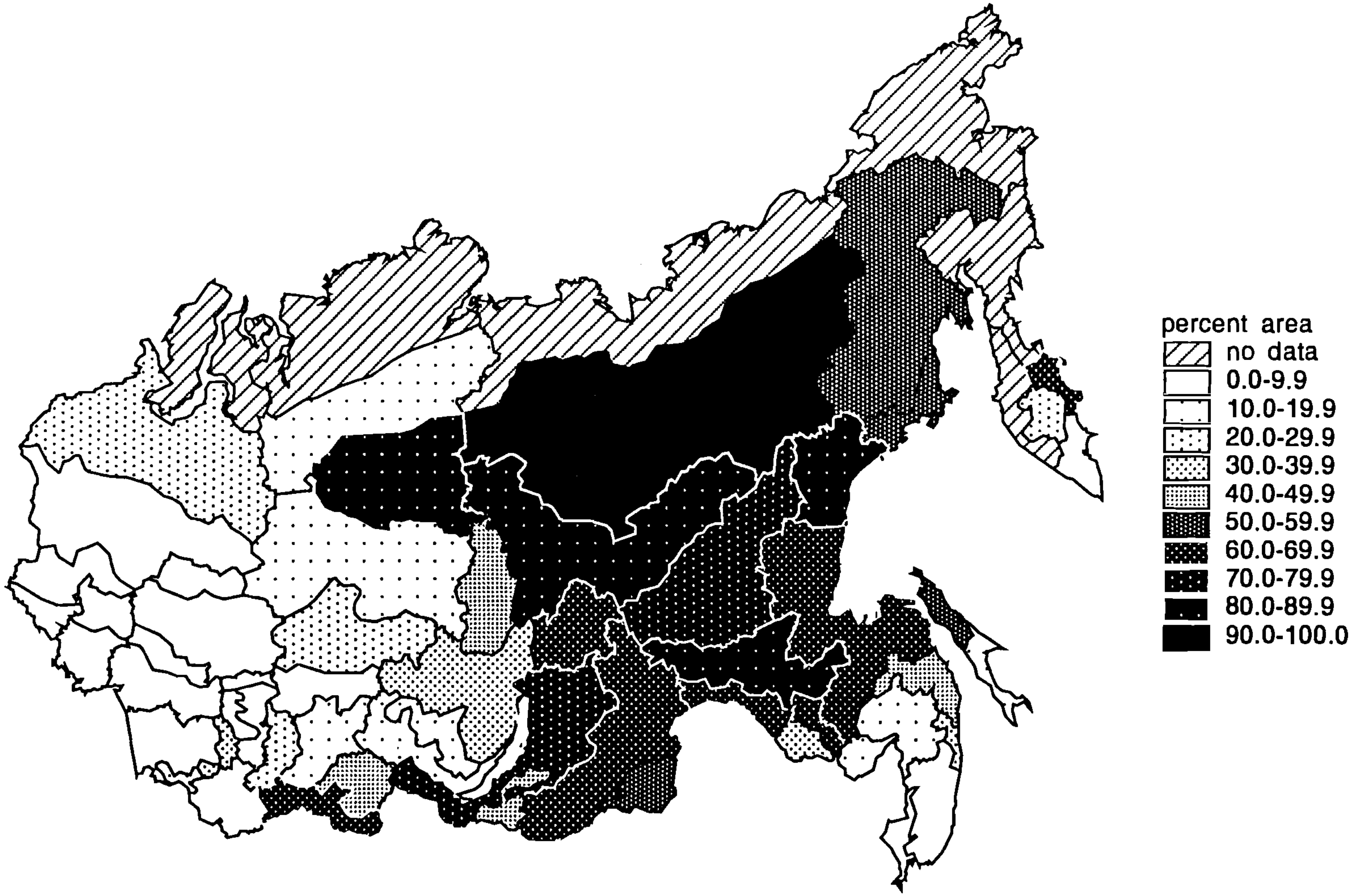

Figure 16. Percent effective area of ecoregion covered by larch (Source: SERD Tables 3103 and 3108).

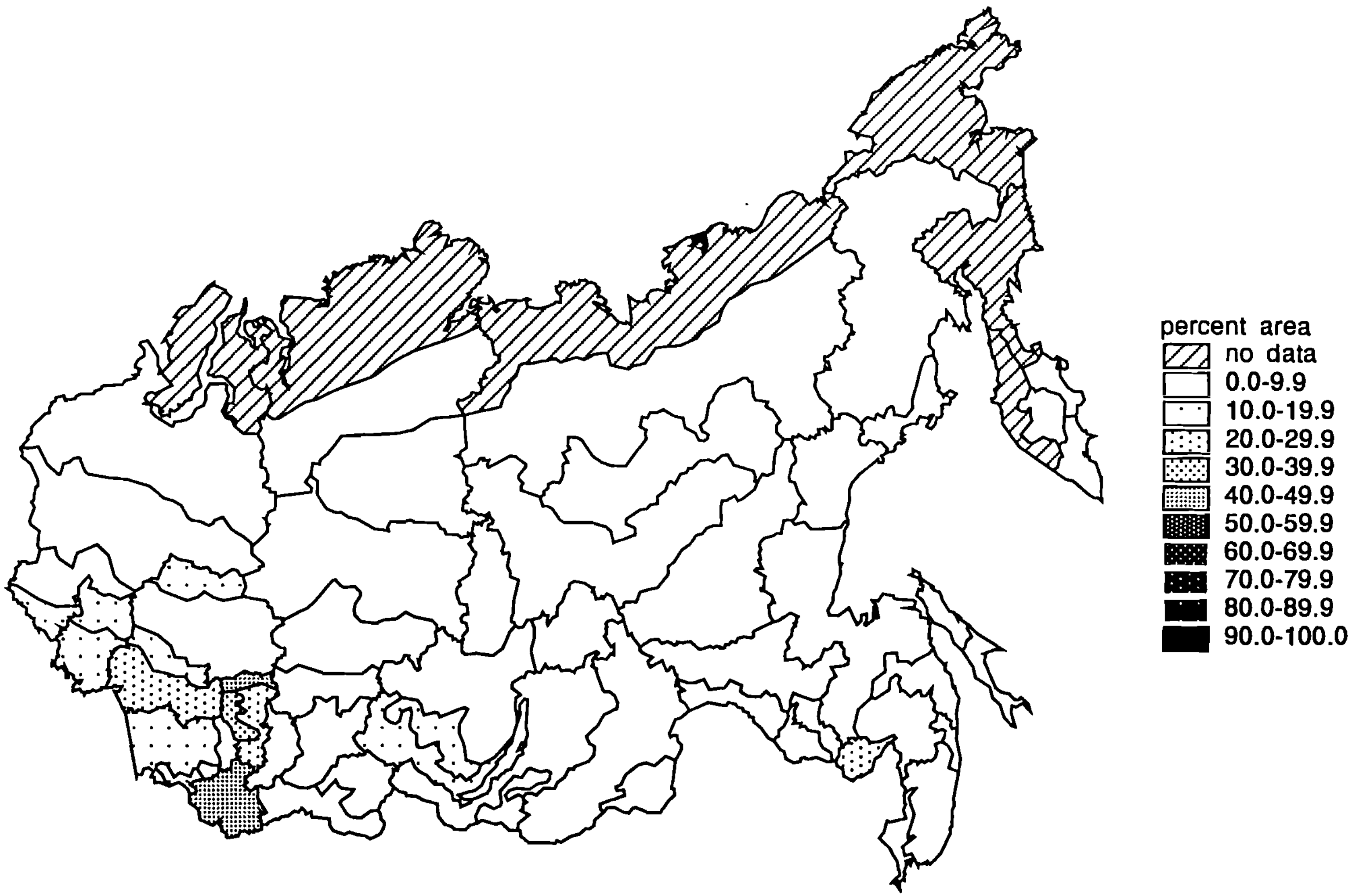

Figure 17. Percent effective area of ecoregion covered by aspen (Source: SERD Tables 3103 and 3108).

APPENDICES

APPENDIX 1: Summary of cross tabulation of main soil group and climate and soil temperature measurements.

Table A.2.1. Cross tabulation of FAO main soil groups and detritus pools for 63 ecoregions.

	Detritus Pool Class (tn/ha)								
main soil group	0 to 30	30 to 60	60 to 90	90 to 120	120 to 150	150 to 180	180 to 210	210 to 240	240 to 270
andosols		1	1	1					
chernozems	3	5	2		1				
kastazozems	1								
gleysols		3	1	1		1			
histosols					1			1	1
leptosols		2							
podzoluvisols		1	4			1	1		
podzols		9	8					1	
cambisols	1	5	6						

Table A.2.2. Cross tabulation of FAO main soil groups and phytomass pools for 63 ecoregions.

	Phytomass Pool Class (tn/ha)								
main soil group	20 to 40	40 to 60	60 to 80	80 to 100	100 to 120	120 to 140	140 to 160	160 to 180	180 to 200
andosols				2	1				
chernozems	3	1	1	1	1		1	1	2
kastazozems	1								
gleysols	3	1					2		
histosols					1	1	1		
leptosols			1		1				
podzoluvisols				1	1			3	2
podzols		3	5	5	2	2		1	
cambisols			1	2	2	1	3	2	1

Table A.2.3. Cross tabulation of FAO main soil groups and primary production classes.

	primary production code				
Main Soil Group	0 to 4	4 to 8	8 to 12	12 to 16	16 to 20
andosols		3			
chernozems		2	2	5	2
kastazozems		1			
gleysols	1	4	1		
histosols		3			
leptosols		1		1	
podzoluvisols	6	5	2	1	
podzols	6	11	1		
cambisols	2	5	5		

Table A.2.4. Cross tabulation of FAO main soil groups and dominant species richness for 63 ecoregions.

	Richness Class (number of dominant species)								
main soil group	0	5 to 6	7 to 8	9 to 10	11 to 12	13 to 14	15 to 16	17 to 18	19 to 20
andosols			1	1	1				
chernozems				1	4	2	2	2	
kastazozems					1				
gleysols	4			1	1				
histosols				1	2				
leptosols					1	1			
podzoluvisols				5	2			1	
podzols		3		5	2	3			
cambisols		1	5	1	2	1		3	4

APPENDIX 2: Examples of effective area calculation.

The Angara-Lena Ecoregion (ID number 11253) will be used to show calculation of effective area.

1. Area Available For Exploitation (AFE) for each dominant is obtained from SERD Table 3103.

dominant species	area AFE (ha)
pine	4,029,031
spruce	986,330
fir	469,508
larch	3,119,007
cedar	976,567
birch	1,132,017
aspen	556,952
TOTAL	11,269,412

2. Species composition for each dominant species is obtained from SERD Table 3108.

dominant species	share in composition	intermediate species 1	share in composition	intermediate species 2	share in composition	intermediate species 3	share in composition	intermediate species 4	share in composition
pine	60	larch	20	birch	10	aspen	10		
spruce	40	larch	30	cedar	20	birch	10		
fir	100								
larch	70	pine	20	birch	10				
cedar	30	larch	30	pine	20	spruce	10	birch	10
birch	50	pine	20	larch	10	cedar	10	spruce	10
aspen	100								

3. Calculate the effective area each genus occupies by multiplying the share in composition by dominant species AFE.

example: pine

As a dominant species:	60% of pine	(4,029,031 x 0.6)	2,417,418.6
As intermediate species 1:	20% of larch	(3,119,007 x 0.2)	
	20% of birch	(1,132,017 x 0.2)	850,204.8
As intermediate species 2:	20% of cedar	(976,657 x 0.2)	195,313.4
Total effective area of pine:			3,462,936.8

example: birch

As a dominant species	50% of birch	(1,132,017 x 0.5)	566,008.5
As intermediate species 2:	10% of pine	(4,029,031 x 0.1)	
	10% of larch	(3,119,007 x 0.1)	714,803.8
As intermediate species 3:	10% of spruce	(986,330 x 0.1)	98,633.0
As intermediate species 4:	10% of cedar	((976,567 x 0.1)	98,633.0
Total effective area of birch:			1,477,102

Table 4. Summary of linear regression coefficients (R^2), Y intercepts (b0) and slopes (b1) for vegetation function and composition on annual climatic measurements. All regressions have 61 degrees of freedom.

vegetation function and composition	total degrees > 5°C			total precipitation>5°C			mean air temperature (°C)		
	R^2	b0	b1	R^2	b0	b1	R^2	b0	b1
detritus (tn/ha)	.01	-1.20	-1.64	.00	69.83	.02	.02	83.59	1.87
phytomass (tn/ha)	.19**	35.01	.04	.33**	32.09	.24	.29**	126.90	5.84
production (tn/ha/yr)	.46**	94.00	-.01	.07*	4.56	.01	.35**	9.26	.58
aspen (%area)	.17**	-.12	.00	.03	.02	.00	.19**	.11	.12
birch (%area)	.15**	-.12	.00	.00	.25	-.00	.16**	.29	.02
cedar (%area)	.05	-.03	.00	.01	.05	.00	.02	.10	.00
fir (%area)	.16	-.10	.00	.18**	-.05	.00	.26**	.11	.01
larch (%area)	.29**	1.05	.00	.09	.60	-.00	.50**	.15	-.06
pine (%area)	.01	.16	.00	.08	.21	-.00	.01	.10	-.00
spruce (%area)	.01	.03	.00	.28**	-.09	-.00	.13**	.12	.01
dominant species richness	.51**	.84	.01	.63**	3.10	.03	.32**	13.43	.57

where : * = significant at P = 0.05
** = significant at P= 0.01

3. Indicators of Biodiversity and Landscapes at the Enterprise Scale in Siberia: The Case of Angara-Lena

by Ron Plinte

Abstract

The aim of this study is to describe and analyze the biodiversity of Siberian forests at the enterprise scale. A suite of descriptive indicators was developed to represent critical ecosystem components. Using these indicators, it is possible to determine the variation of ecosystem parameters from natural levels, or more generally, to gauge human impacts upon regional forest biodiversity and landscapes. The case study ecoregion is Angara-Lena Southern Taiga in the south of the East Siberia economic region, immediately northwest of Lake Baikal.

Ecosystems and biodiversity are complex and usually cannot be measured directly nor comprehensively. Descriptive indicators are more useful for evaluating biodiversity than one or several measures which combine and summarize data into one index which hides information from the forest manager. Since managing Siberian forest biodiversity involves human intervention in complex ecosystems, a broad suite of indicators is required to explore its multiple facets.

Challenges to describing biodiversity using the available database were: data quality; data validation and consistency; incomplete basic data; and spatial units that are administratively, not ecologically, based. Other challenges were: existing models of biodiversity conservation are incomplete and uncertain; all the important components of biodiversity are not measured in the inventories; integration with other scales of biodiversity assessment in Siberia is difficult; and the lack of descriptive information on Siberian biodiversity and forest ecology in the English language.

From the six indicators and supplemental information reported here for the Angara-Lena ecoregion, the status of biodiversity and landscapes can be viewed in two zones: the west side where threats to biodiversity are potentially high, and the east side where biodiversity can be considered, from a timber management point of view, to be secure. Potential threats to biodiversity in the western sector arise from: low levels of protected areas; and elevated levels of area affected by logging and the extent of fragmentation in some enterprises. Positive signals for the conservation of biodiversity in the vast enterprises of the eastern sector of Angara-Lena are the small extent of timber management activity, and the relatively high levels of protected areas.

The study has been only a rudimentary demonstration of the approach due to limitations in data, Siberian forest ecology information, and project resources. For determination of better indicators of biodiversity and landscapes, improved database information should be integrated with extensive information on the landscape and conservation biology of sensitive and generalist species of the ecoregion under study. An expansion of this approach is recommended for the evaluation of biodiversity and landscapes in ecoregions across Siberia.

3.1. Introduction

Planning for the conservation of forest biodiversity of regional landscapes in Siberia requires a two-pronged strategy (as described in Section 3.2.3: Conservation of Biodiversity): ecologically-sensitive management of the general landscape, and incorporation of a network of reserves. A network of reserves may be planned through a gap analysis which would test the correspondence between the habitat needs of rare species, and the existing network of protective reserves for the ecoregion.

To accomplish ecologically-sensitive management of regional landscapes, we require an evaluation of the status of regional biodiversity. Once past and current patterns of biodiversity for managed and unmanaged zones are understood, then management actions can be taken for biodiversity maintenance and restoration. To get a complete picture of Siberian forest biodiversity, the enterprise scale must also be considered, which consists of land units, or forest enterprises, on the order of a few hundred thousand to a few million hectares. A biodiversity evaluation method was tested on the Angara-Lena ecoregion. This ecoregion lies in the south-central area of the vast Siberian forest, and encompasses an immense forest of 29 million hectares in size.

A preliminary picture of the biodiversity of the Angara-Lena was produced by evaluating ecological parameters, or indicators of biodiversity, for each of its 33 enterprises, and examining distributions of the parameters across the ecoregion. The data source for this study was the Forestry Enterprise database from 1988. The goal of managing for biodiversity of regional landscapes could be to maintain natural levels of all ecosystem parameters. Descriptions of current and past levels of biodiversity across ecoregions are required as a baseline. It is then possible to measure human impacts upon natural landscapes by remeasuring levels of relevant biodiversity indicators at a future time.

Ecosystems and biodiversity are complex assemblages so that often cannot be measured directly nor comprehensively. Therefore we require indicators that can reveal the status of a range of critical ecosystem or biodiversity features. These features are chosen for the significant role they play within ecosystem functioning, and are constrained by the limited number of database parameters available. Critical features of forest ecosystems can be identified through ecological information on wildlife species with a wide range of habitat requirements. To incorporate the management of rare species in biodiversity conservation for regional landscapes, information on selected rare species that have a broad range of habitat requirements is needed (both types of information are provided in the chapter by Venevskaya, but were not utilized here). The objective of this study is to describe the biodiversity of Siberian forests at the enterprise scale, and the effects of forest management activities on that biodiversity.

3.2. Biodiversity and its Measurement from a Regional Landscape Perspective in Siberia (Theory and Concepts)

3.2.1. Indicators

To make the broad definition of biodiversity, as stated in Section 1.2.1 (of biodiversity project), operational at the enterprise scale, we need to "identify measurable attributes or indicators of biodiversity for use in environmental inventory, monitoring, and assessment programs" (Noss, 1990). Indicators must be relevant to the goals of forest management. Managing ecosystems with the goal of maintaining natural levels of all ecosystem parameters has been recommended by some researchers (Noss, 1983; Hunter, 1990; Booth *et al.*, 1993; Schlaepfer, 1993). A systems approach to biodiversity conservation of regional forests dictates the identification and analysis of ecosystem components and their interaction. Both "species-based" indicators and "system-based" indicators are needed for an adequate characterization of forest biodiversity (McKenney, *et al.*, 1994).

System-based measures can provide valuable information about ecosystem, or landscape, diversity. These measures will contribute to the management of biodiversity at the enterprise scale, which should emphasize landscape and ecosystem features that affect the population size and distribution of wildlife, due to the difficulty of determining minimum viable wildlife populations (Probst and Crow, 1991). Gauging species diversity alone is inadequate for measuring biodiversity (May, 1995), as is sole consideration of populations of endangered species (Schuck *et al.*, 1994).

Descriptive indicators are far more useful for evaluating biodiversity than one or several measures which combine and summarize data into one index; in the latter, information is hidden from the forest manager (Kouki, 1994; Plinte, 1995). Biodiversity indicators, within a larger set of forest sustainability indicators, must not be overly complex 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). Since managing forest biodiversity involves uncertain effects of human intervention in complex ecosystems, a broad suite of indicators is required to explore its multiple facets (Plinte, 1995).

3.2.2. Boreal Forest Ecology and Landscape Classification

Boreal forests operate "as a complex interrelation between solar radiation, soil moisture, the forest floor organic layer, nutrient availability, forest fires, insect outbreaks and vegetation patterns" (Bonan and Shugart, 1989). The patterns of variation in the current vegetation of a landscape reflect the variation in environmental conditions, geology, soil development, and topography, all interacting with current climate (Malcolm, 1994). For a systems analysis approach to understanding the complex nature of regional biodiversity, we need to keep in mind a systems model of these components and processes of boreal ecosystems, in the analysis of our indicators of biodiversity.

A model has been developed for the landscape classification across all scales of the Siberian forest (Figure 1) (Shvidenko, 1995). Since natural systems are organized in hierarchies, we also need to describe biodiversity in a hierarchical structure. Spatial scale is one of the most important considerations when mapping biodiversity (Miller, 1994). Within hierarchy theory, higher levels of organization incorporate and constraint the behavior of lower levels (Allen *et al.*, 1987; Klijn and Udo de Haes, 1994).

The hierarchy of natural systems are more accurately envisioned as continuums across fine to broad scales, instead of existing at distinct levels. Ecological processes span across scales, as in the disturbance process of fire which can range in extent from a few hectares to hundreds of thousands of hectares.

The bounds of this study are, strictly speaking, the ecosystem scales of landscape and sub-landscape. In practice, it will include the effects of ecosystem processes operating at lower levels of terrain and stand as well. Some indicators are simply aggregations of data from these lower levels. The measurement of biodiversity at the enterprise level is measurement of inter-landscape diversity.

3.2.3. Forestry Enterprise Database and Description of Regional Biodiversity

In contrast to the above model of the organization of Siberian forest ecosystems, the data available in the Siberian database for measurement of biodiversity at the enterprise scale exist in an artificial hierarchy which separates the continuum of landscape scales into distinct levels (Figure 1). The configuration of ecoregions within the database was established based on climatic and relief factors, as well as enterprise boundaries (Shvidenko, 1995). The enterprise mapping units are not based on ecological boundaries, but rather are administrative units. This artifact of data collection and organization is another barrier to describing biodiversity accurately (Reid *et al.*, 1993). The classification will be improved in the near future as a new layer of data for landscapes is currently being developed (Shvidenko, 1995).

Ecosystem attributes are of three main types: composition, structure, and function (Franklin, 1981). Noss (1990) went further to state that these attributes determine, and constitute, the biodiversity of an area. Unfortunately it is not possible to describe directly the ecological function attribute with the Siberian forest database. Therefore only the composition and structure attributes are being analyzed. They can be considered to be surrogates, or reflections, of the functions or processes operating within Siberian forest ecosystems.

Having noted previously the limitations of the database with regard to scale, it is nonetheless integrational to some degree as its parameters are not strictly limited to the landscape scale. The enterprise database is composed of: (a) parameters derived from the stand or operational level, and (b) parameters which represent processes at the sub-landscape and landscape levels. Aggregations of data from lower hierarchical levels can act as indicators of processes operating at the sub-landscape and landscape scales. The enterprise database contains parameters related to forest composition, forest management operations, and other anthropogenic uses and impacts. Their spatial pattern across the ecoregion will reflect the variability among enterprises in selected forest composition, and natural and anthropogenic disturbance parameters, including fragmentation intensity.

Therefore, the indicators of biodiversity extracted from the database can provide a reflection of both natural ecosystem processes and anthropogenic disturbance processes. Many other ecosystem processes are also characterized through elements of forest diversity, the processes that underlie that diversity. The description of human-caused disturbance patterns provides a characterization of the disturbance processes, and determines human impact on regional biodiversity and landscapes. The indirect impacts of humans, such as climate change and acid precipitation, are more difficult to determine and are unlikely to be discernible in the results of this study. However, long-term monitoring of the indicators utilized here is expected to provide information to detect some patterns of indirect impact.

Diversity measures can be analyzed and displayed in a variety of ways. Histograms of area and number of stands in each class for each stand trait are convenient for the display of richness and evenness.

Maps are best for displaying spatial distribution. Richness refers to the number of classes in which there are stands (Hunter, 1990; Burton *et al.*, 1992). For example, a forest with eight 20-year age classes (i.e., stands of all ages up to 160 years) is richer than a forest with four age classes (e.g., a forest with stands only up to age 80 years, or a forest with stands of only 0-40 years and 80-120 years of age). Evenness refers to the balance of representation of stands 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.

3.3. Methodology

3.3.1. Study Area

The case study ecoregion for this study is the Angara-Lena Southern Taiga which is situated in the south of the East Siberian economic region, immediately to the northwest of Lake Baikal, within the Irkutsk Oblast. The entire southern taiga vegetation zone covers 18.5% of Siberian Forest Fund land (Shvidenko and Nilsson, 1994). The Angara-Lena ecoregion has a total area of 29.2 million ha (Table 1 and Figure 2a). Its 33 forest industry enterprises range in size from 320,000 ha to 3.14 million ha, with an average size of 880,000 ha (Figure 2b). A small majority of the ecoregion occurs in enterprise size classes greater than one million ha, with the greatest amount of area (8.2 million ha) in the 0.5 to 1.0 million ha class. As for the climate of Angara-Lena, annual average air temperature is -4 C, annual average soil temperature is -3 C, total average annual precipitation is 425 mm, and snow cover is an average 181 days of the year (database Table ER21).

3.3.2. Data

The entire Siberian Forestry Enterprise database contains 200 parameters for 2,500 forestry enterprises and 35 parameters for forest industry enterprises (Anonymous, 1994). The most recent data available for this study are from 1988. The data in the Enterprise database are arranged in 14 tables, with multiple variables of forest composition, structure, and management. The growing stock table was not available for my use. These tabular data were linked to spatial data for enterprises on Arc/Info GIS. An accurate 1988 GIS coverage was created for the Angara-Lena ecoregion by importing some of the polygon boundaries from the 1993 coverage into the 1988 coverage.

3.3.3. Analytical Methods

The challenge of describing biodiversity, landscapes, and forest management impacts across an ecoregion was framed as two null hypotheses:

(1) Regional Siberian biodiversity cannot be described and evaluated effectively utilizing indicators of biodiversity extracted from the Siberian Enterprise database.

(2) Forest mangement operations do not have a measurable impact upon regional Siberian biodiversity.

The testing of the above hypotheses was approached from two angles:

(1) What ecosystem information is desirable to manage Siberian forest biodiversity and landscapes, at the enterprise scale in particular, taking into account habitat and landscape requirements for a broad range of forest-dwelling wildlife species, with a broad range of habitat requirements? Emphasis is given to sensitive, specialist and rare species. This process was intended to be informed by conservation biology literature, and by a companion project on species of interest in forest biodiversity conservation (see chapter by Venevskaya). However, as this information was not available from this parallel study, background information was drawn from North American and European boreal forest research. A major challenge to describing the biodiversity of Siberian forests is the poor availability of English language information on Siberian forest ecology and species habitat requirements.

In summary, the criteria for selection of biodiversity indicators are:

- forest characteristics pertaining to the composition or structure of forest ecosystems; and
- forest characteristics related to habitat requirements and conservation of a broad range of forest-dwelling wildlife species.

(2) Secondly, which data parameters available in the Siberian forest enterprise database can provide useful information on: composition, pattern, and process attributes of biodiversity, landscapes, and human impacts on biodiversity through forest management?

The convergence of the two strategies, where the data requirements for the evaluation of biodiversity were met by data availability, led to the development of the indicators reported here. The forest management philosophy of an ecosystem approach was incorporated in the choice, development, and evaluation of the biodiversity indicators. A preliminary picture of the biodiversity of the Angara-Lena was produced by evaluating ecological parameters, or indicators of biodiversity, for each of its 33 enterprises, and examining distributions of parameters across the ecoregion. Indicators are displayed with basic tables and histograms. Data parameters were mapped by enterprise to reveal spatial characteristics. Arc/Info software was utilized. Both spatial and non-spatial attributes of indicators were evaluated quantitatively and descriptively to reveal patterns associated with biodiversity and principles of conservation biology.

It was not possible to analyze and display all parameters within the database relevant to biodiversity and landscapes, within the resource constraints of this study. Therefore, I set priorities on parameters to be processed based on the time and resources available, and database adequacy. Indicators are ranked on criteria of data availability, data quality, and effectiveness in revealing patterns of biodiversity (Table 2). Recommendations were made regarding further required analysis as well. For analysis purposes, the triangular-shaped ecoregion was partitioned into three geographic zones: northwestern, northeastern, and southeastern. Variations in enterprise parameters related to geographic zone were investigated.

3.4. Results and Discussion

The indicators refer only to SFL within the Angara-Lena ecoregion and not the entire enterprise landbase. SFL amounts to 90% of ecoregion area (Figure 2). In managing the biodiversity of forest landscapes, data for entire landscapes are required so that integrated planning for whole landscapes is feasible. This may not be a problem here if other land users are concentrated in discrete areas and not dispersed throughout landscapes. The SFL total reported here does not include "land for long-term lease", however this totals only 6,188 ha for the ecoregion.

3.4.1. Indicators of Biodiversity

Forest Cover Diversity

Specific Canadian boreal 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, 1992), and the barred owl (Van Ael, 1993). 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 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. Conversions of type classes can also be tracked.

The richness and evenness of cover type diversity for this forest would be gauged based on comparison to historic values for this region of the boreal forest. Depending upon the number of years that the forest has had a logging presence, 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.

Structure and Analysis of Indicator. The "forest land area" for all "main forest species" and " other tree species" were extracted from FSA88-F200. Enterprises were ranked by percent of pine (*Pinus spp.*, mainly *silvestris*) working group, and all working groups were graphed by area and % area of forest land area. Pine was chosen because it is the most common tree species and is commercially the most significant. The percent area of pine forest was mapped by enterprise for Angara-Lena.

Results and Discussion. The two main cover types by area in the Angara-Lena ecoregion are pine and larch (*Larix spp.*, mainly *sibirica* and *dahurica*), which represent 34% and 24% respectively of the 23.5 million ha total forest land area (Appendix 1.1, Figure 3 and 4). Other major types that each cover about 10% of forest land area are birch (*Betula spp.*, mostly *pendula* and *pubescens*) (13%), cedar (actually *Pinus sibirica korayensis*) (13%) and spruce (*Picea spp.*, mainly *abies* and *sibirica*) (8%). Minor forest types accounting for between one and five percent are aspen (mostly *Populus tremula*) (5%) and fir (*Abies spp.*, mainly *sibirica*) (4%). Working groups that account for very limited area are willow (Salix spp.), poplar (*Populus spp.*, not *tremula*) and grey alder (*Alnus incana*). These uncommon species should be monitored closely, and regeneration encouraged to maintain their presence in the ecoregion. The percent area for coniferous species in the small enterprises in the west side should be monitored for reductions, because they and especially pine are heavily exploited there (Shvidenko, 1995). In 1990, 81% of pine annual allowable cut (AAC) was logged in Angara-Lena as a whole, and over 200% of AAC for coniferous species in some enterprises in the late 1960s and 1970s (Shvidenko, 1995). The proportional representation for all species should be compared to historic values to determine if they are within their natural range of variation.

The species composition values agree fairly well with those reported for the Irkutsk Oblast (Nilsson *et al.*, 1994) of which Angara-Lena forms a significant proportion. Exceptions are that pine and poplar proportions are significantly lower in Angara-Lena, and larch is double the Irkutsk percent area. These species proportions should be compared to historic values to determine if they are within their natural ranges.

Almost half of the enterprises have > 40% forest land area in pine, and represent 37% (8.7 million ha) of the ecoregion forest land area. About 69% of these enterprises are smaller than 0.5 million ha in forest land area, i.e. smaller enterprises tend to have a higher proportion of pine. The seven enterprises with the least forest land area of pine (< 25%) all have forest land area > 600,000 ha, and represent 35% (8.2 million ha) of forest land area for the ecoregion. The smaller industrial enterprises were likely established to exploit the pine forests.

The following general trends with percent pine forest land area can be noted in significant working groups. Cedar has a strong inverse relationship in occurrence, and there is generally minimal area of cedar in enterprises with % pine > 44%. This may indicate a strong difference in site preference between cedar and pine, as pine is better adapted to drier, less fertile sites and fire (Korzukhin, 1989). The most consistent significant occurrence of fir of 7-13% for six enterprises is coincident with a % pine of 35-45%. The following species are not strongly correlated with % pine forest land area within enterprises: birch, spruce and aspen. Larch has a slight opposite occurrence to pine. Larch is less tolerant to less fertile and dry sites than pine, but more so than cedar (Korzukhin, 1989).

The highest proportions of pine forest area (> 30% of forest land area) occur primarily in the north of Angara-Lena, with the exception of a small enterprise in the south (Figure 5). It is assumed that the smaller zones of pine > 40% in the northwest and northeast are predominantly fire disturbed and/or low fertility due to the high proportion of pine and low level of cedar.

3.4.2. Forest Age Diversity

The distribution of forest area among stand age classes, given that age is a reasonable proxy for many stand characteristics, can be an important integrative indicator of overall forest condition. An example of the importance of age-class distribution is some wildlife species strongly prefer specific age classes (or rather, stand conditions as represented by age class. Examples from North America are marten (Martes americana) and woodland caribou (*Rangifer tarandus*) for older coniferous stands.

It may be important, as one considers biodiversity and 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. Knowledge of the historic and current disturbance regimes affecting age distribution in Angara-Lena would help to interpret this indicator. The average area of fire disturbance in Angara-Lena over the last decade was 0.18% of forest land area annually (43,000 ha/year), and the average area of logging disturbance for 1970-1990 was 0.24% annually (57,000 ha/year) (Shvidenko, 1995). Forest clearcutting can, if deliberately designed for this purpose, create a fire-like pattern of successional patches across the landscape. A landscape consisting of a large range of forest patch sizes is maintained where a fire-origin disturbance regime dominates in the boreal forest. Large disturbance patches cover the majority of the landscape, and generally all the ecosystems within a disturbance patch are the same age (Welsh, 1992).

Structure and Analysis of Indicator. The richness and evenness of forest-stand age-class distributions give a picture of the diversity of stand ages within the forest. The distribution of forest area by age group was plotted for Angara-Lena. 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 distribution could also provide a guide for this forest.

Enterprises were ranked on their proportions of young and over-mature age groups, and graphed by area and percent forest land area. These age groups were chosen because they perhaps would reveal patterns related to timber management and fire suppression. Patterns and relationships of age across enterprises and by size of forest land area were noted. The percent area of over-mature forest was mapped for the ecoregion.

Results and Discussion. The broad pattern of Angara-Lena's forest age distribution is that of unevenness (Appendix 1.2a and Figure 6). There is a relatively small proportion of forest land area in young forest of 3.1 million ha (13% of forest land area). A significant amount of forest land area occurs in the next oldest middle-age group of 5.4 million ha (23%). The maturing forest covers the smallest proportion of forest land area of 2.6 million ha (11%), and mature and over-mature forest in combination comprise over half of forest land area (12.3 million ha). If this ecoregion was dominated by a fire disturbance regime, the young age group would be presently under-represented and the oldest age groups over-represented. Wildlife habitats in these age groups would be under- and over-represented respectively. However, for individual small enterprises in the west there has been over-exploitation for coniferous species, especially for pine. In these cases under-representation of the young age classes may not be a problem.

The 17 enterprises across the center of the % forest land area distribution, ranked young age group, vary by only 13% (9-22%) (Appendix 1.2a and Figure 7). There is no obvious trend between % area young and enterprise size across the full range of the distribution (Figure 8). The four enterprises with the highest % young forest average 263,000 ha in size, while the four enterprises with the lowest % young forest average 1.075 million ha.

There is a general inverse relationship between the percent over-mature forest land area and percent young forests (Appendix 1.2b and Figure 9). The eight enterprises with the greatest percent over-mature have an average percent young area of 8%, whereas the eight enterprises with the lowest % over-mature have 22% young forest area on average (Figure 10). There is a similar trend in the percent middle-age distribution. Enterprises with the lowest % over-mature forest tend to be larger, and vice versa. Six of the eight enterprises with < 20.1% over-mature forest are > 0.5 million ha, whereas only half as many enterprises with > 39.9% over-mature forest are > 0.5 million ha. Therefore logging in the smaller enterprises may be both reducing over-mature forest area and increasing young forest area to some degree. Knowledge of the year of logging initiation in Angara-Lena would be of benefit to interpret these data. Zones of forest land with > 30% over-mature forest land area occur in the northwest, northeast and south corners of the ecoregion (Figure 11). These zones of higher % area over-mature forest within the smaller industrial enterprises generally correspond to enterprises with low transportation corridor density (Figure 19) and low % area logged (Figure 23).

Critical Habitats

The protection of critical habitats of large-bodied, area- and human-sensitive vertebrate species is imperative to biodiversity conservation plans (Noss, 1991). The size of wilderness areas may be a critical habitat attribute for area-sensitive, large-bodied species (Diamond, 1975; Whitcomb *et al.*, 1976; Newmark, 1987) such as caribou or wolves (*Canis lupus*). Large wilderness areas are important for the protection of many different associations of wildlife species (Noss, 1990b). The area and distribution of protected areas, of different levels of protection status, can be an indicator of the habitat availability for sensitive species. The lower size threshold for both viable roadless wilderness areas in the USA (Wilderness Act, 1964), and for wilderness zones in parks in Canada (OMNR, 1992) has been established to be 2,000 ha. In combination with species distributions, a "gap analysis" can be performed which identifies additional critical habitats for protected area status (Iacobelli, 1995). A network of protected areas is also important for the representation of natural forest regions (Hummel and Hackman, 1995).

Structure and Analysis of Indicator. Group I forest is not a good indicator of critical habitats since, although this is the highest protection category in Russian forest classification, in most enterprises there is a significant proportion of "allowable forest exploitation" (AFE) in the Group I forest. Therefore the sub-category within Group I which represents truly protected forest (non-AFE) was selected for this indicator. Group II forests are special zones and belts where there are some restrictions on forest utilization, but they are basically open to exploitation (Shvidenko, 1995). Group III forests are open to unrestricted exploitation.

Results and Discussion. For the Angara-Lena ecoregion, only one large protected area (Nature Reserves + National and Nature Parks + Scientific and Historic Forests) exists (although not reported in FSA88-F100). A majority of enterprises contain greater than 10% Group I forest (Appendix 1.3 and Figure 12). However, these enterprises are relatively small as only 28% (five of 18) are larger than 800,000 ha, while 47% (seven of 15) of enterprises possessing less than 10% Group I forest are larger than 800,000 ha (Figure 13).

For Angara-Lena, Group I non-AFE (protected) forest ranges from 0.5% to 44% of State Forest Land (SFL) area per enterprise, with the addition of the 100% protected status of the Baikalo-Lensky Nature Reserve (Figure 14). The total protected area of SFL is 2.71 million ha (10.3%) which is 9.3% of total ecoregion area. This includes 2.05 million ha Group I non-AFE forest which is 7.8% of SFL area (7% of total ecoregion area), and the 660,900 ha of the nature reserve. The protection of large viable habitats and representation of natural regions are actually the critical criteria here, and not the precise percentages of area protected (Hummel and Hackman, 1995).

However, only 27% of all enterprises (nine of the 33), with total areas representing 31% of ecoregion SFL area (8.24 mill. ha), have more than 4% protected forest. The five enterprises with the greatest proportions of protected forest contain 81.5% (1.67 million ha) of total protected ecoregion SFL area. Furthermore, six of the 11 enterprises larger than 800,000 ha in SFL area possess only 2% or less protected area (Figure 15). There is therefore an uneven distribution of protected area across Angara-Lena.

Critical habitats for large-bodied area- and human-sensitive vertebrate species are not well protected within protection reserves across the ecoregion. Exceptions are the Baikalo-Lensky Nature Reserve, and possibly the five enterprises with > 11% protected area, depending upon whether their protected areas are concentrated in large viable areas. The highest concentrations of protected area occur in a zone of larger enterprises that span north to south just east of the ecoregion center (Figure 16). This zone corresponds well with the zone of low proportion of pine area (Figure 5) and low percent area logged (Figure 23). This suggests the criteria for selection of protected areas may be influenced by low timber values, and are not necessarily solely determined by the protection of critical habitats and representation of natural regions.

Forest Fragmentation

According to Harris and Silva-Lopez (1992), fragmentation is the unnatural detaching or separation of expansive forest 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 roads, management treatments (e.g., clearcutting) and 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).

Roads may well create the greatest impact on the forest landscape of any forest-management-related activity (Plinte, 1995). 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 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 in North America because 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 and Analysis of Indicator. Road access is measured here as kilometers of road, by road class, per 10,000 ha, for total SFL area of each enterprise. Enterprises were classified into 10 km/10,000 ha road density classes (Figure 17), and their distribution across the forest mapped. Road density in the ecoregion is correlated geographically with level of timber management activity per unit area since most roads are constructed for this purpose. 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 unusable.

The transportation corridor category includes all road classes and railways. Even the classes of least developed roads were included since they are cleared corridors through the otherwise continuous forest, and contribute to fragmentation for the duration of their existence.

Results and Discussion. The distribution of SFL area by corridor density class for Angara-Lena is greatly skewed to the low density classes (Table 3, Figure 17). There is 57% (14.93 mill. ha) of the SFL area that has density less than five km/10,000 ha, 16% (4.12 mill. ha) between five and 10 km/10,000 ha, and 92% (24.23 mill. ha) is below 30 km/10,000 ha (Appendix 1.3). A mere 880,000 ha (3% of SFL area) has corridor density above 50 km/10,000 ha. A standard for road densities for grizzly bears of below 30 km/10,000 ha has been set by the U.S. Forest Service (Nikiforuk, 1995).

There is a negative relationship between corridor density and enterprise area (Figure 18). Most of the largest enterprises have the lowest corridor densities, while the opposite also holds true. There are three obvious anomolies to this pattern: the large enterprises 11252238 and -2240, and the small enterprise -9104. Since the values reported here are averages for entire enterprises, there will be regions within enterprises that have much higher corridor densities, where timber management operations are concentrated, and other remote regions with very low to zero corridor density. This highlights a disadvantage of aggregating and reporting data for large enterprises millions of hectares in size.

When compared to a forest management unit in boreal Ontario, Canada, of comparable average size (770,000 ha), the average corridor densities in Angara-Lena are low. An average road density was calculated for the Spruce River forest in Ontario to be 81 km/10,000 ha, from data of a recent study (Plinte, 1995), compared to an average corridor density of 10 km/10,000 ha for Angara-Lena. This points to the conclusion that the vastness of Siberia provides the strongest protection for its biodiversity. There is a concentration of enterprises with relatively high transportation corridor densities in the southwest of the ecoregion (Figure 19). A considerable amount of the west and almost all of the eastern side of the ecoregion have a low corridor density of < 10 km/10,000 ha. Zones of high fragmentation tend to correspond with zones of high percent area logged (Figure 23). This supports the hypothesis that corridor density is a good indicator of intensity of logging activity (also refer to Carlsson, this volume). Broad-scale wildlife habitats are likely to be considerably fragmented by roads in these enterprises on the west side with elevated corridor densities.

Forest Cover Extent

One of the two basic requirements of forest sustainability is the maintenance of forest land areas as forest land. The proportion of land area that remains as forests can be used as an indicator of biodiversity. Reduction in forest cover extent will affect forest ecosystem function and wildlife habitat, and will compromise biodiversity.

Structure and Analysis of Indicator. Forest cover area as reported in FSA88-F301 is SFL area minus the area of roads and other non-forest and unforested types. Forest enterprises were ranked by forest cover % and graphed along with total SFL area per enterprise.

Results and Discussion. The average forest cover extent for Angara-Lena is 86%. There is no apparent relationship between % forest cover and enterprise size across the full % forest cover distribution. The forest cover extent for the seven largest enterprises > 1.2 million ha is in the range of 80-93% forest cover. However, the five enterprises with the lowest % forest cover (< 71%) are among the smallest enterprises, and have < 360,000 ha in SFL area. These enterprises have some of the highest transportation corridor density levels of 24-102 km/10,000 ha (Appendix 1.4). Three of these five enterprises have the largest % logged areas of 8-12% (Figure 21), and the other two have a relatively high 6%. Enterprise 2255 has an exceptionally low % forest cover of 47%, and it has 6% logged area. The low level of forest cover extent in these five enterprises is therefore likely related to human development.

Decreased values for this indicator become a concern for biodiversity conservation when they are related to human development activities. Therefore the discovery of more complete explanations for low forest extent values is important for further research.

Forest Disturbance Extent

Forest landscapes and biodiversity can be adversely affected by human disturbances. It is assumed that disruption to forest landscapes in a given enterprise is proportional to the percent of SFL area disturbed anthropogenically.

Broad-scale natural disturbance in the Siberian boreal forest is a major process that determines forest composition and pattern. It thereby determines the availability and suitability of wildlife habitat and the level of forest biodiversity. Agricultural land is normally considered to be forest land conversion, but in the long term it can be considered to be disturbance because it can revert back to forest.

In some boreal forests, fire is the predominant factor producing natural landscape patterns (Heinselman, 1981; Ward and Tithecott, 1993) dependent upon soils, forest cover species, and climate. Where the disturbance regime is predominantly of fire-origin, a landscape consisting of a large range of forest patch sizes is maintained. Other natural disturbance types such as wind, insects and disease, can predispose forests to fire by reduction of tree vigor and death.

The decline in incidence of fire due to fire suppression in Canadian boreal forests has meant the "alteration and reduction of the major vector of natural development of boreal succession patterns" (Thompson, 1992). 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 can create a new and artificial pattern across the forest landscape.

Timber management can affect the boreal landscape mosaic in a number of ways (Middleton, 1991). Conventional clearcutting in the Canadian boreal forest has reduced the average patch size and distribution (Thompson, 1992; Ward and Tithecott, 1993). 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.

Alternatively, multi-age stands resulting from the predominance of other finer-scale disturbance types may be replaced with single-age and single-species stands by logging. The patterns of clearcut timber harvesting and fire suppression in Angara-Lena over the period of timber management may have changed forest biodiversity away from natural patterns. There are other potential effects at the stand level of alteration of: soil structure and moisture regime (Karpachevsky, 1995); stand structure; dead and down woody debris; genetic diversity; and wildlife habitat. Tracking the cumulative percent area logged thus provides information on the degree of these types of timber-mangement impacts as well as impacts on biodiversity and landscapes.

Structure and Analysis of Indicator. All types of forest disturbance available in the FSA-88 database are included in the indicator. Disturbance types not in the database at the time for the analyses include disturbance due to insect, disease and wind damage. Fire data are limited to % unstocked burns. SFL area data by enterprise for plantations and unstocked logged area were combined to give the total forest area directly disturbed by timber management. Enterprises were ranked by this "total area logged" and graphed for area and % area of SFL (Appendix 1.5, Figures 11 and 12). Enterprises were then classified by percent SFL area logged and mapped to reveal spatial patterns. The percent "unstocked burn" is assumed to include recent burns and older ones that have not regenerated to a "stocked" status.

Results and Discussion. More than half of all enterprises have had > 3% of their SFL area logged, and the area logged for all of Angara-Lena ecoregion is 2.5% (Appendix 1.6 and Figure 21). The % area logged and enterprise size are, to a large degree, inversely related within the ecoregion (Figure 21 and 22). The smaller enterprises tend to be logged more intensely because they are the more accessible enterprises where infrastructure (road network) has been developed.

Agricultural land is rather insignificant across Angara-Lena as only 6 enterprises have > 0.2% SFL area in agriculture, and the amount of agricultural land is 0.15% for the entire ecoregion. The % SFL area of unstocked burns is in general inversely related to % SFL area logged, and related to size of enterprise. The large enterprises with a higher percent of recent burns (% unstocked burns) tend to occur in the low logging intensity and more isolated east side of the ecoregion.

Most of the logging in Angara-Lena has occurred in the west side, with especially high levels in three enterprises in the southwest, and one in the extreme south (Figure 23). The three enterprises in the southwest also have below-average percent areas of over-mature forest of 10-24% (Figure 11 and Appendix 1.2b). Much of the east side of the ecoregion, where the largest enterprises as well as the vast majority of protected areas (Figure 16) occur, has had only < 1% of its area logged. Most enterprises with high % area logged correspond to zones of higher fragmentation by transportation corridors (Figure 19). Exceptions are enterprises 11252206, -2238, and -9103, on the west side, which have unexpectedly low corridor densities considering their high % area logged. Road or railway length may be under-reported in the database for these three enterprises.

The indicator confirms that the greatest threat to biodiversity and landscapes is in the west and especially in the southwest zone of Angara-Lena. The accuracy of the indicator depends to a large extent on whether % logged area is indeed equivalent to % plantations + % unstocked cuts, and the accuracy of these data.

3.5. Conclusions and Recommendations

3.5.1. Challenges to Describing Biodiversity and Landscapes

Describing biological diversity in this project was a challenging task for a number of reasons.

Database Challenges

1. First of all, the relevance of the data for biodiversity analysis could be questioned. Inventory and record keeping may not have been of the best accuracy due to bureaucratic pressures. For example, total areas burned were being vastly under-reported before 1988 (Shvidenko, 1995). However, it is assumed that major inaccuracies have been discovered and corrected.

2. Massive amounts of various types of data from institutions and forest enterprises from across the vast territory of Siberia have been integrated to create the database.

3. The basic data are incomplete. Some variables have missing values and some data tables are missing altogether. This difficulty will hopefully be resolved with further development of the database.

4. The spatial units (forest enterprises) are administratively, and not ecologically, based. To effectively gauge patterns and processes contributing to forest biodiversity, the spatial units of measure must be ecologically based. Otherwise the patterns detected may be to some degree artifacts of the administrative boundaries, and not the true landscape. The successful use of the FSA database for portraying biodiversity and landscapes at the enterprise level varies depending upon enterprise size. An adequate picture may be portrayed for an enterprise on the order of 500,000 ha if it is part of a single landscape, but data reported for an enterprise that is millions of hectares in size are likely too highly aggregated, if the enterprise represents several landscapes. There is a difficulty if the ecoregion boundary does not coincide with an ecological boundary because indicators then cannot be interpreted within the framework of an entire natural region.

Other Challenges

5. Existing models of biodiversity conservation are incomplete and uncertain (El-Ashry, 1995; Noss, 1992; Soule and Mills, 1992). Conservation biology is a relatively new and evolving field of research. It deals with theories of complex interactions of many forms of fauna, across many hierarchical scales in space and time, within large and diverse landscape units. Many theories are still being tested, and numerous interactions within ecosystems are still unknown.

6. All the important components of biodiversity are not measured in the inventories, which are oriented toward the logging of timber. Required data for better understanding of biodiversity and landscapes include: size and distribution of fire and other disturbance regimes; climate data; soils information; and logging history and date of origin. These additional data would be useful for understanding the natural range of variation of patterns of flora and associated fauna.

7. Integration with other scales of biodiversity assessment (see other papers in this volume). How well integrated is our knowledge of patterns of biodiversity at scales above and below that of the enterprise level? Analysis of biodiversity within each scale of Siberian forests should lead to the identification of processes operating across scales.

8. The lack of descriptive information on Siberian biodiversity and forest ecology in the English language is a major barrier for North Americans and Europeans in applying western concepts to unravel the biodiversity question in Siberia. Limited English-language research literature by Russians on Siberian forests was available to us during this project. Some reports are available from Swedish and Finnish research studies on Russian forests.

   Critical features of forest ecosystems were to be identified through translated information on species with a wide range of habitat requirements, provided by another facet of the overall project. It was also the intention to incorporate the management of rare species through information on selected species that have a broad range of habitat requirements. It is strongly recommended that this be undertaken in later phases of an ongoing Siberian biodiversity research program.

   A two-pronged strategy is recommended for the conservation of biodiversity (Recchia and Broadhead, 1995): management of the general landscape; and the incorporation of a network of reserves. A plan for a network of reserves, created through a gap analysis of representation of natural areas and critical habitats for sensitive species, should be included in future work.

3.5.2. Conclusions

This descriptive study on defining and measuring indicators of biodiversity and landscapes at the enterprise scale for Siberia, including graphical analysis, has been exploratory. It admits to a general ignorance of forest ecosystems and timber management impacts on them. It is an adaptive approach that seeks to learn about forest biodiversity and means for its measurement in the process of delving into relationships within and among forest attributes. The approach is recommended for the evaluation of biodiversity and landscapes in ecoregions across Siberia.

The study has been only a rudimentary demonstration of the approach due to limitations of data, Siberian forest ecology information, and project resources. It should be expanded to include a deeper examination of relationships between ecosystem attributes, and between human disturbances and these attributes across landscapes. Additional indicators are required to illuminate more of the important ecosystem attributes related to biodiversity and landscapes, some of which were identified in this research.

From the six indicators and supplemental information reported here for the Angara-Lena ecoregion, the status of biodiversity and landscapes can be considered in two zones: the west side where threats to biodiversity are potentially high, and the east side where biodiversity can be considered, from a timber management point of view, to be secure. Potential threats to biodiversity in the western sector arise from low levels of protected areas, and elevated levels of area affected by logging and the extent of fragmentation in some enterprises. Positive signals for the conservation of biodiversity in the vast enterprises of the eastern sector of Angara-Lena are the small extent of timber management activity, and relatively high levels of protected areas. This is a reflection of the vastness of Siberia which provides the strongest protection for its biodiversity.

A balanced biodiversity-conservation strategy is required for the ecoregion. The western sector consisting of some 11.8 million ha requires a higher level of protected areas to ensure sufficient critical habitats for sensitive species, and adequate representation of its natural regions.

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TABLE 1: A priorized selection of biodiversity categories for indicators, for the analysis of Siberian forest biodiversity and landscapes at the enterprise scale, within an ecologically hierarchical framework.

ECOLOGICALLY HIERARCHICAL LEVEL	BIODIVERSITY CATEGORY FOR INDICATORS	ENTERPRISE DATABASE TABLE REFERENCE OR OTHER DATA SOURCE
Broad /Landscape Scale Processes or Patches	(3) Critical Habitats	"Functional Land Use" (F100) - Protected area classes - Exploitable protected areas Rare and specialist species distribution (Gap Analysis)
	(4) Forest Fragmentation	"Transport Facility" (F309) (road and rail density)
	Forest Conversion	"Transport Facility" (F309) - by road, rail, and landings
	Watershed Disruption due to drainage	"Drainage" (F308) (drainage density or % area drained)
	(6) Disturbance Extent	"Functional Land-Use" (F100) - burned, logged, unregenerated, agriculture (% of forest lands)
	(5) Forest Cover Extent (% forest cover)	"Forestry Land Use" (F301) "Area and Stock Change" (F302)
Fine/Stand Scale Processes or Patches	(2) Age Diversity	"Species Distribution" (F200)
	(1) Forest Cover Diversity	"Growing Stock" (not currently available)(F500) "Species Distribution" (F200)
	Productivity	"Growing Stock" (not currently available)(F500) "Density and Site Index" (F307)
	Naturalness -Regeneration	"Area and Stock Change" (F302) "Forest Restoration" (F304) "Restocking Change" (F305) "Functional Land Use" (F100)

Note: Numbers in brackets show priority given to indicator.

Table 2: Total enterprise area and percent State Forest Land within enterprise size classes (source: FSA88-F301 and FSA88-F100).

ENTERPRISE SIZE CLASS	SFL AREA	TOTAL ENTERPRISE AREA	SFL AREA AS PROPORTION OF TOTAL ENTERPRISE AREA	NUMBER OF ENTERPRISES
	SFL_TOT	AREA_ADM_UNIT		
(ha x 000.000)	(ha x 000.000)	(ha x 000.000)	(%)	
0,1 - 0,5	4.21	4.91	85.7	13
0,5 - 1,0	8.20	8.82	93.0	12
1,0 - 1,5	3.60	3.71	97.1	3
1,5 - 2,0	3.48	3.85	90.5	2
2,0 - 2,5	4.60	4.74	96.9	2
2,5 - 3,0	0.00	0.00	0.0	0
3,0 - 3,5	2.23	3.14	71.1	1
ECOREGION TOTAL	26.32	29.17	90.2	33

Table 3: State Forest Land area within transport corridor density classes (source: FSA88–F309).

CORRIDOR DENSITY CLASS (km/10.000 ha)	SFL AREA (ha)	PERCENT SFL AREA (%)
0	0	0.00
1-10	19,053,706	72.39
10.1-20	3,198,001	12.15
20.1-30	1,982,380	7.53
30.1-40	843,707	3.21
40.1-50	357,718	1.36
50.1-60	335,163	1.27
60.1-70	308,373	1.17
70.1-80	0	0.00
80.1-90	0	0.00
90.1-100	0	0.00
100.1-110	240,278	0.91
TOTAL	26,319,326	100.00

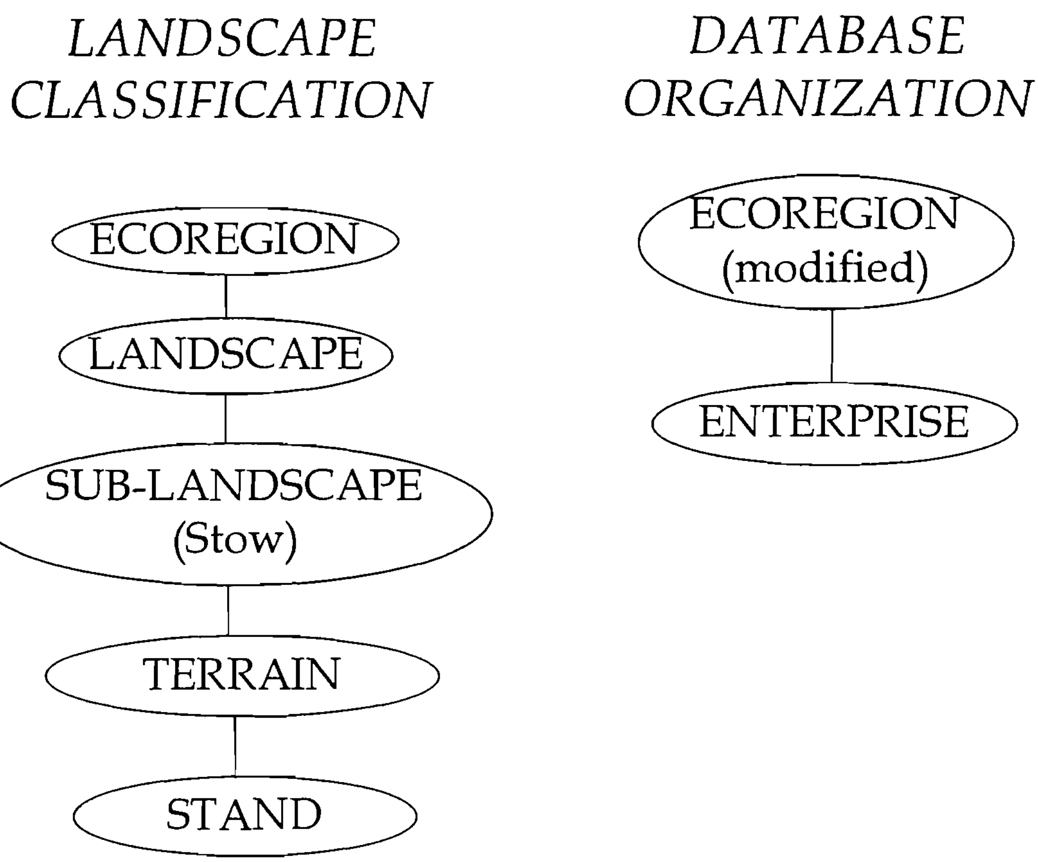


Figure 1: Landscape classification of Siberian forests and structure of the Siberian forest database.

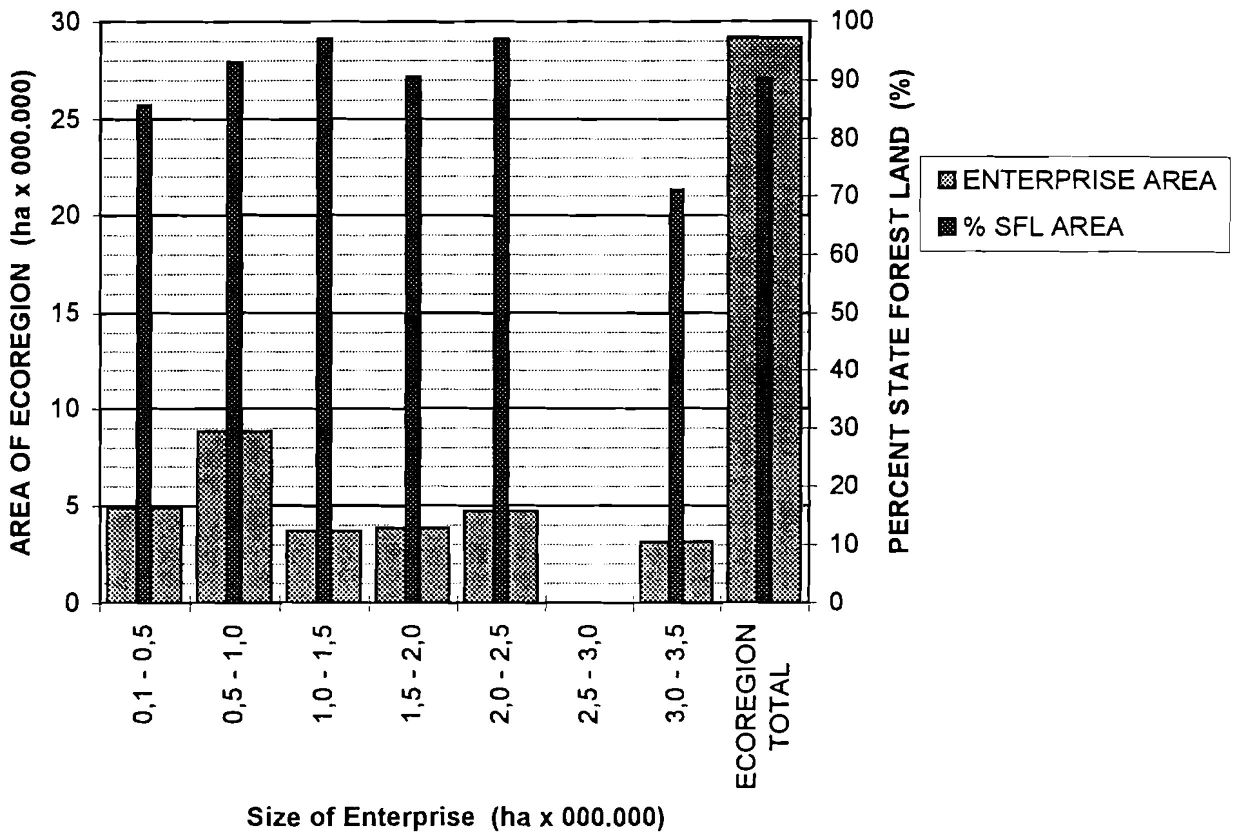
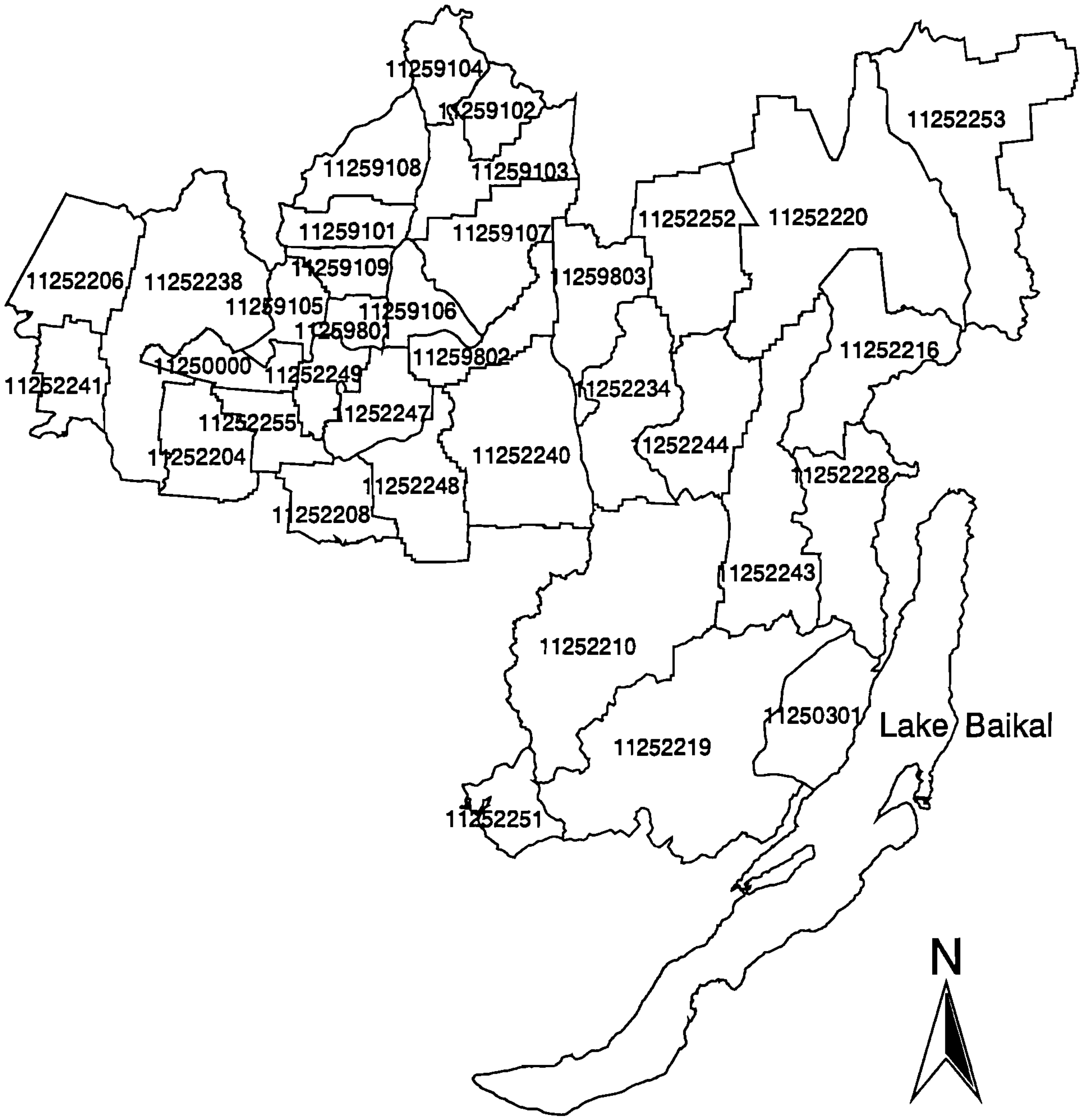


Figure 2a: Total enterprise area and percent State Forest within enterprise size classes (source: FSA88-F301 and FSA88~F100).



Scale: approx 1: 4 000 000

Figure 2b. Forest enterprises in the Angara-Lena ecoregion (Source: Shvidenko 1995)

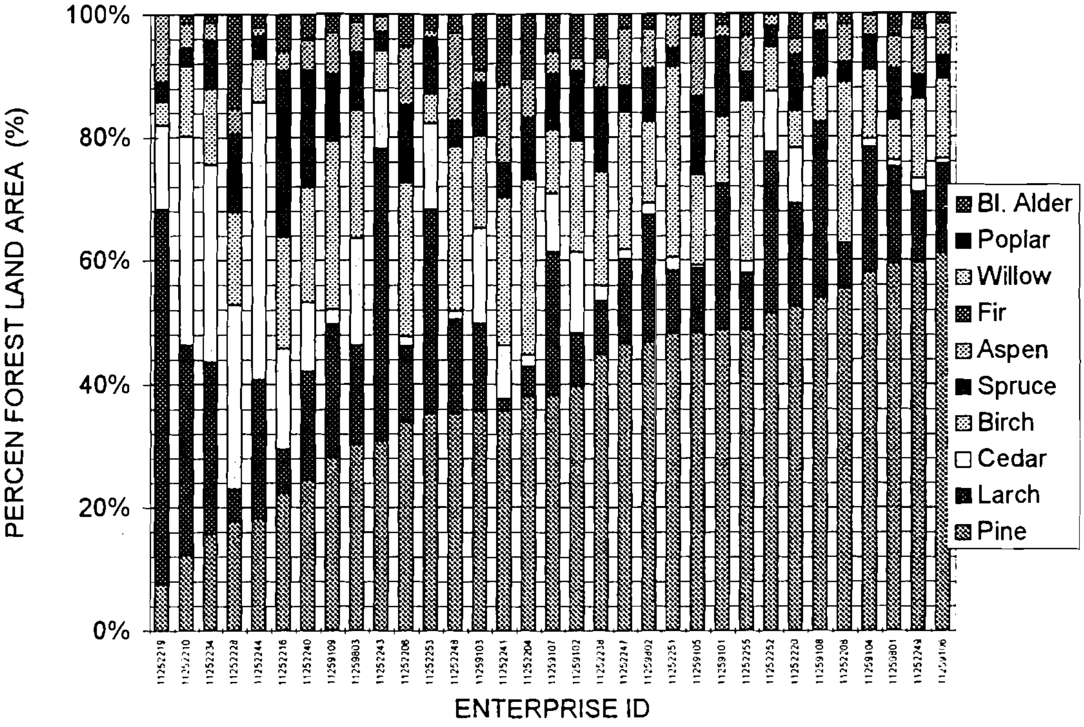


Figure 3. Percent area of dominant forest species by enterprise in Angara-Lena (Source: FSA88-F200).

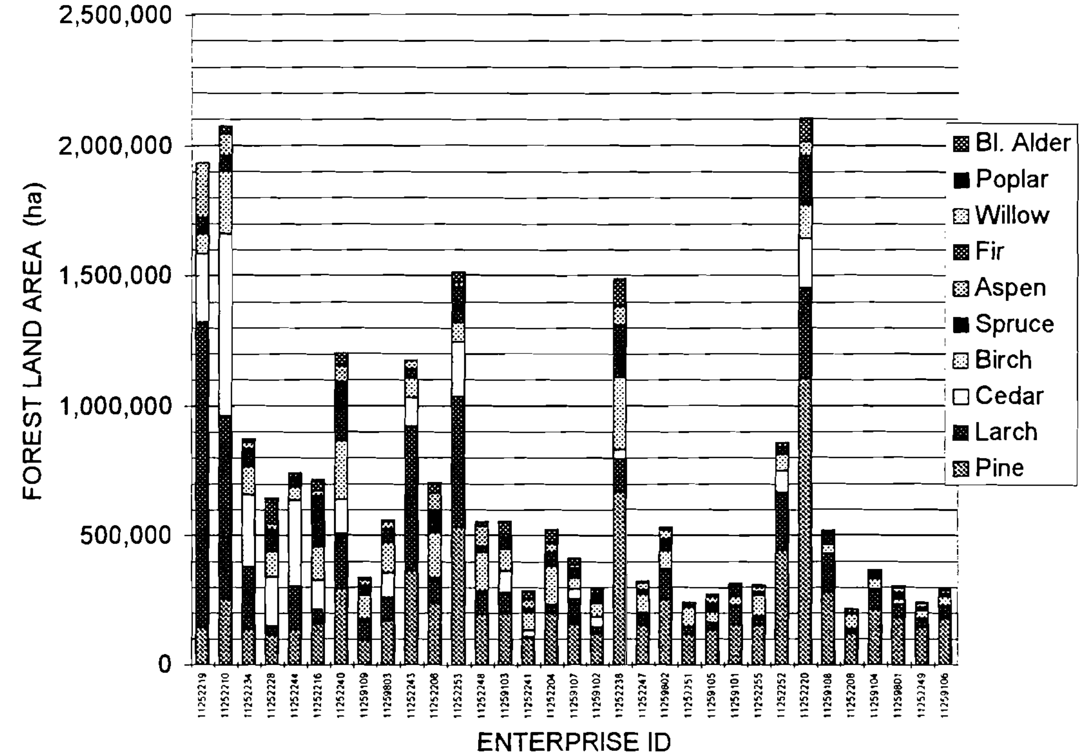


Figure 4. Area of dominant forest species by enterprise in Angara-Lena (Source: FSA88-F200).

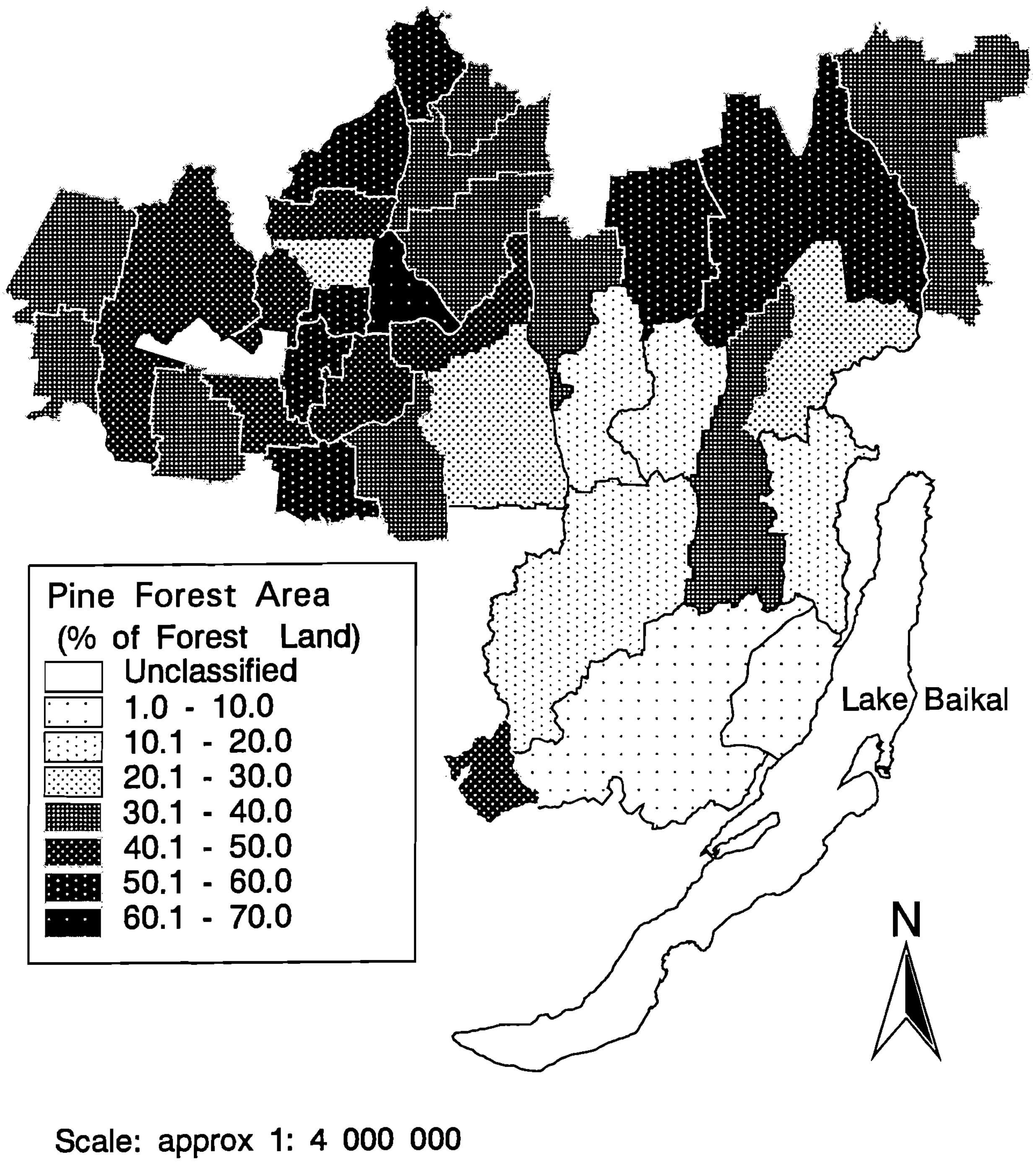


Figure 5. Area of pine forest in the Angara-Lena ecoregion (Source: FSA88-F200).

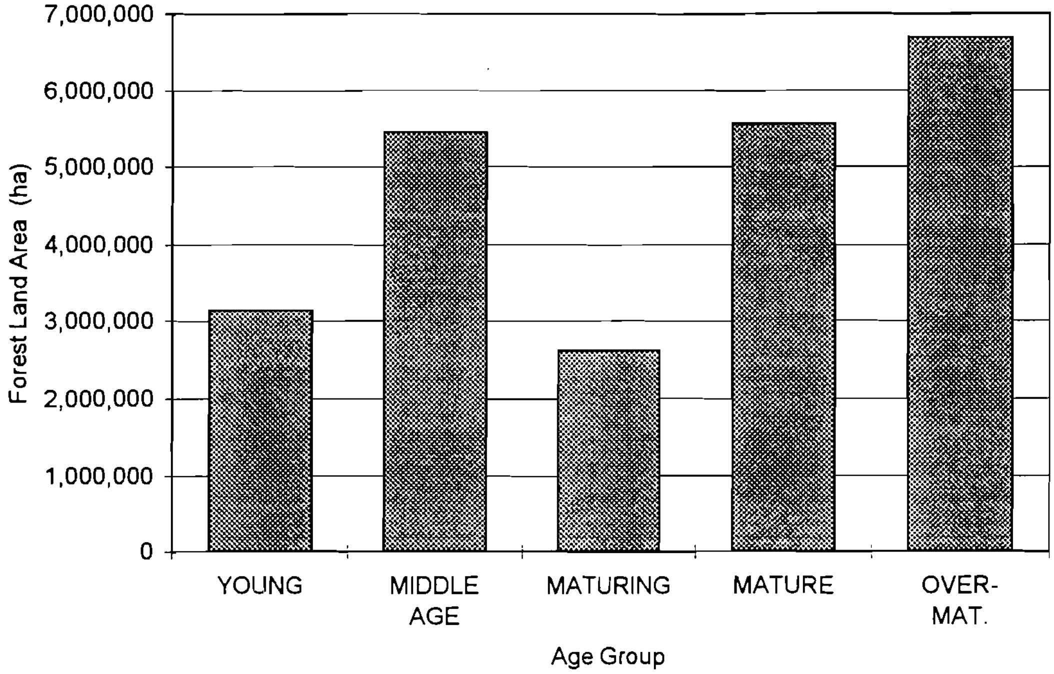


Figure 6. Forest age distribution for Angara-Lena.

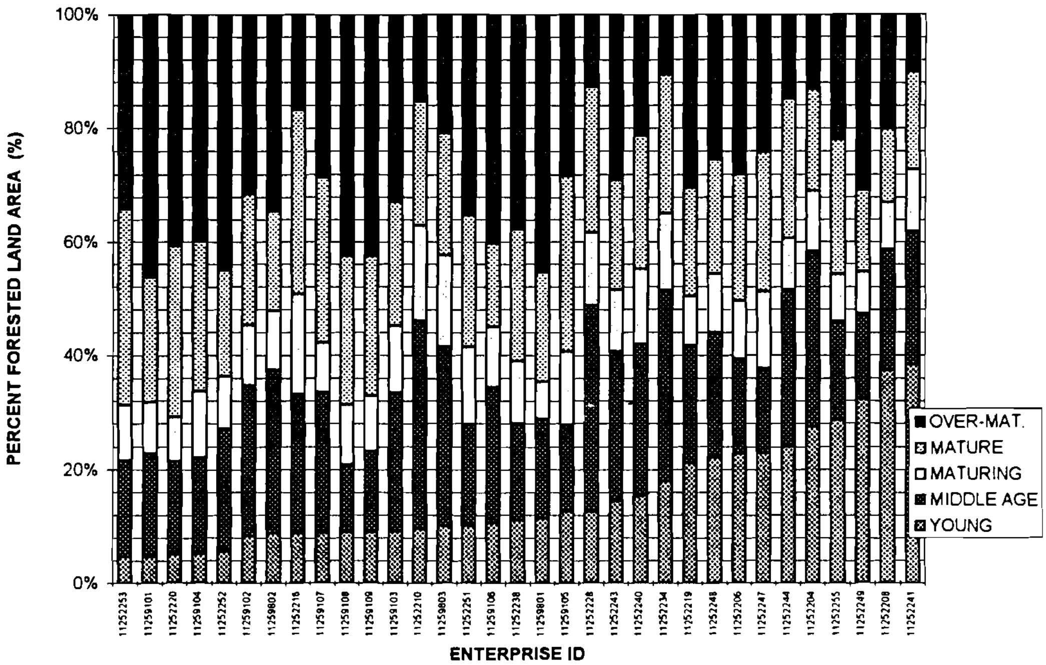


Figure 7. Percent forested land area by age group and enterprise ranked by % young, for Anagara Lena (Source: FSA88-F200).

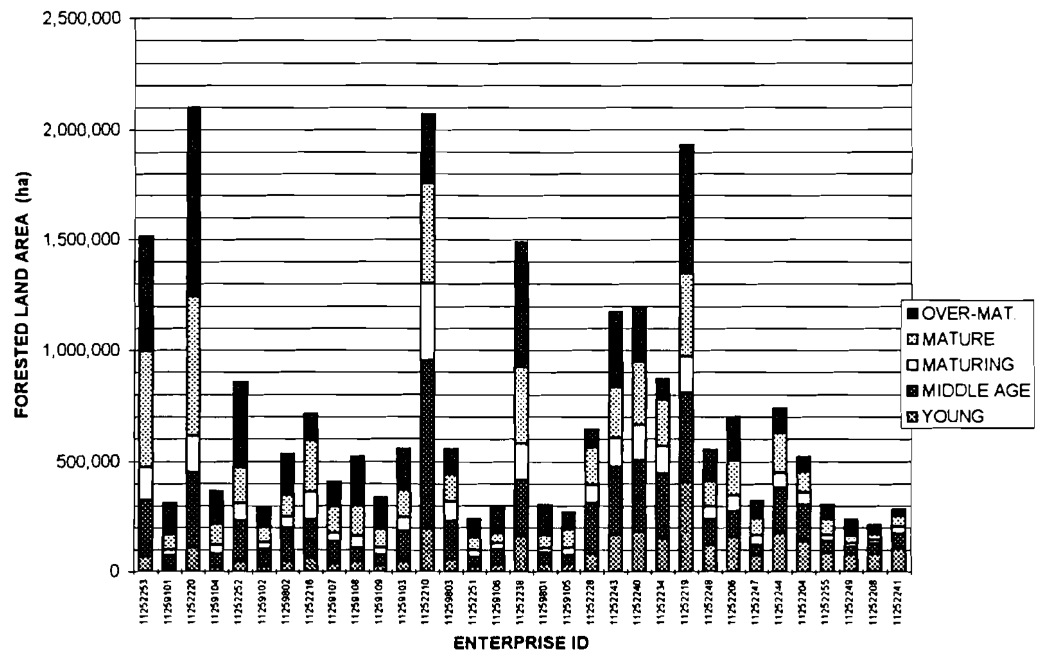


Figure 8. Forested land area by age group and enterprise ranked by % young, for Anagara Lena (Source: FSA88-F200).

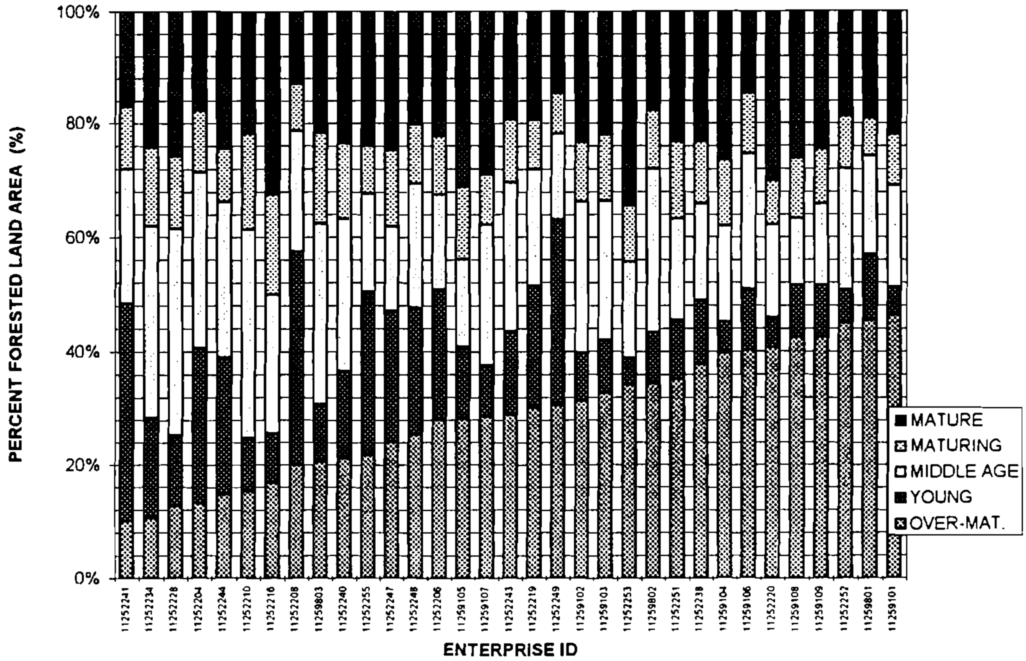


Figure 9. Percent forested land area by age group and enterprise ranked by % over-mature, in Anagara Lena (source: FSA88-F200).

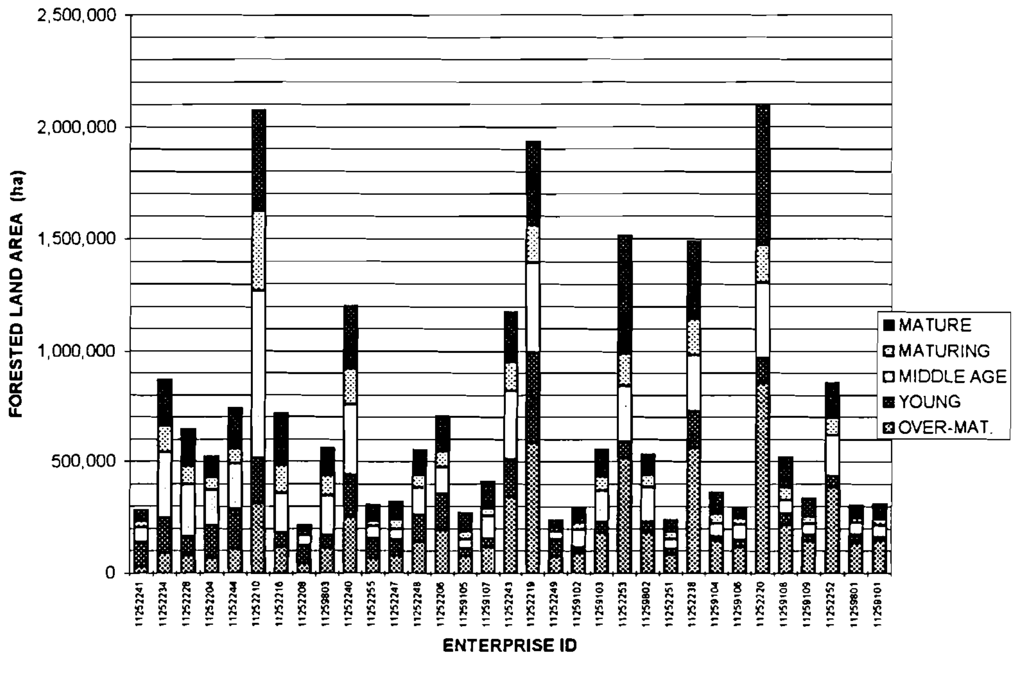


Figure 10. Forested land area by age group and enterprise ranked by %over-mature, in Anagara Lena (source: FSA88-F200).

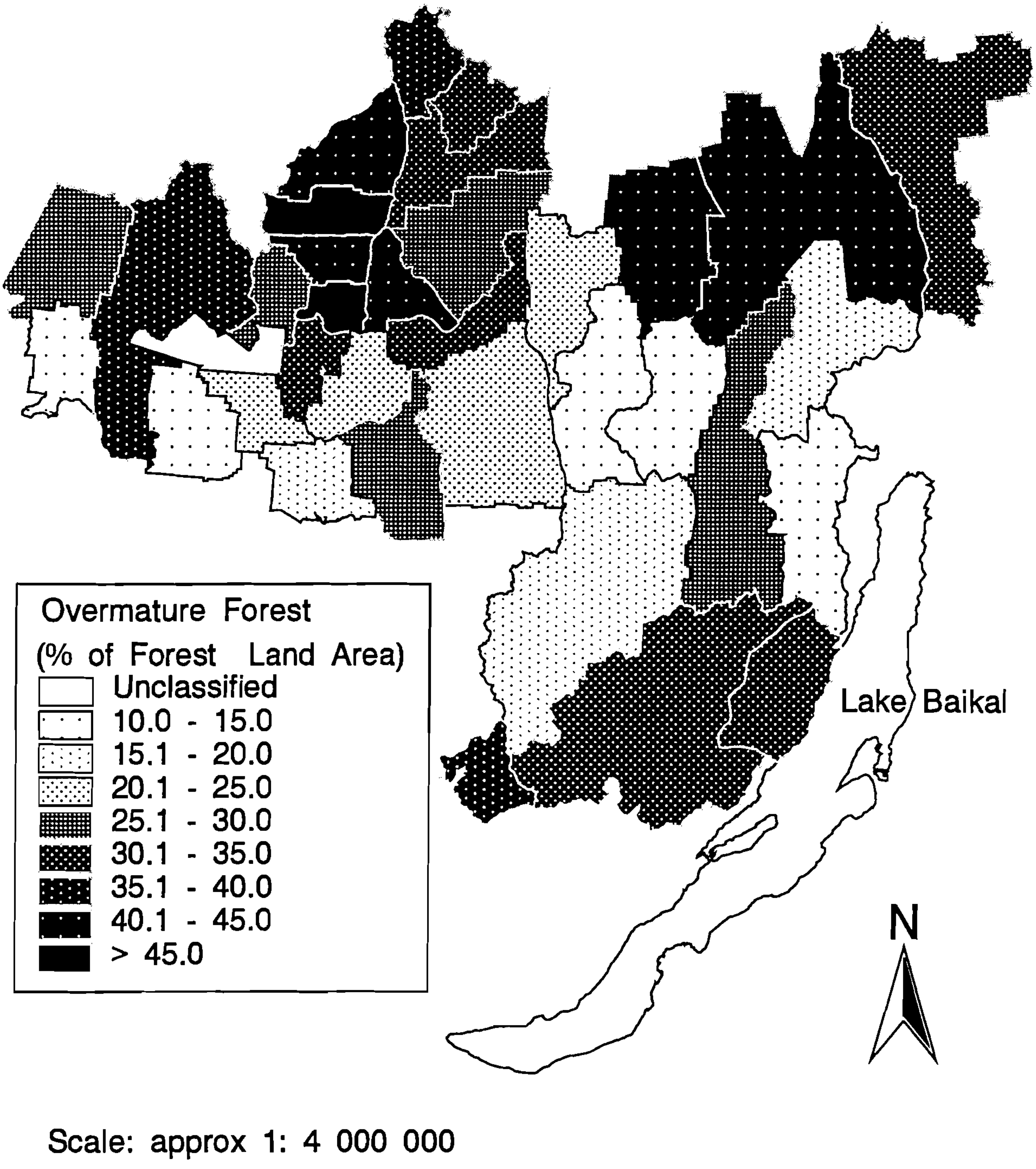


Figure 11. Area of overmature forest in the Angara-Lena ecoregion (Source: FSA88–F200).

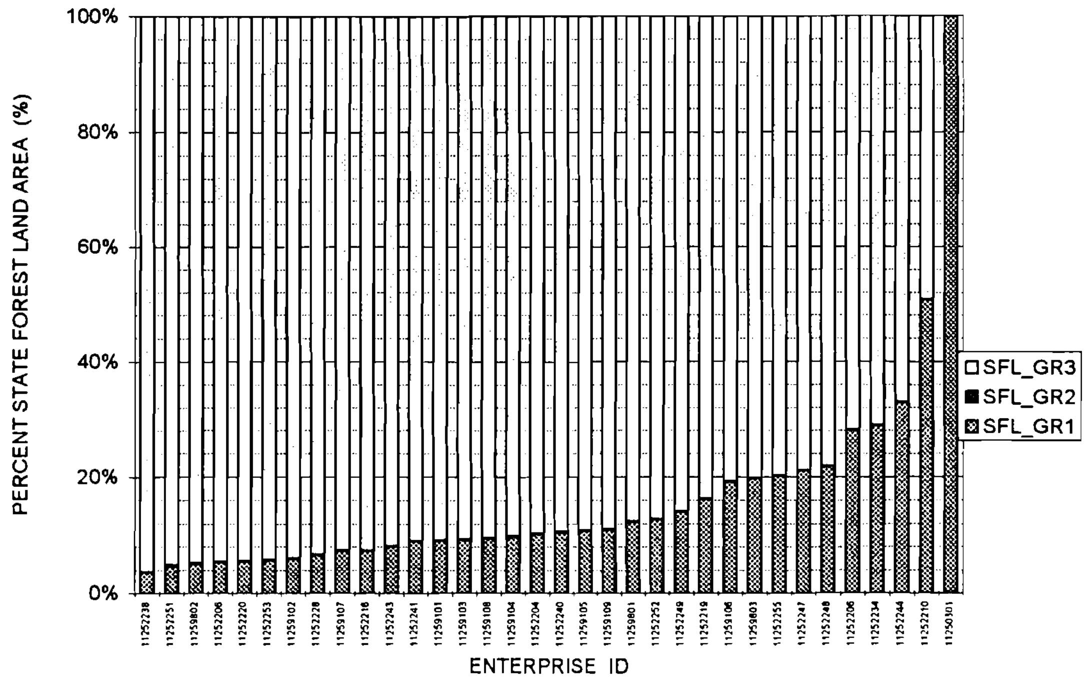


Figure 12. Percent State Forest Land area by protection category for Angara Lena
(Source FSA88-F100).

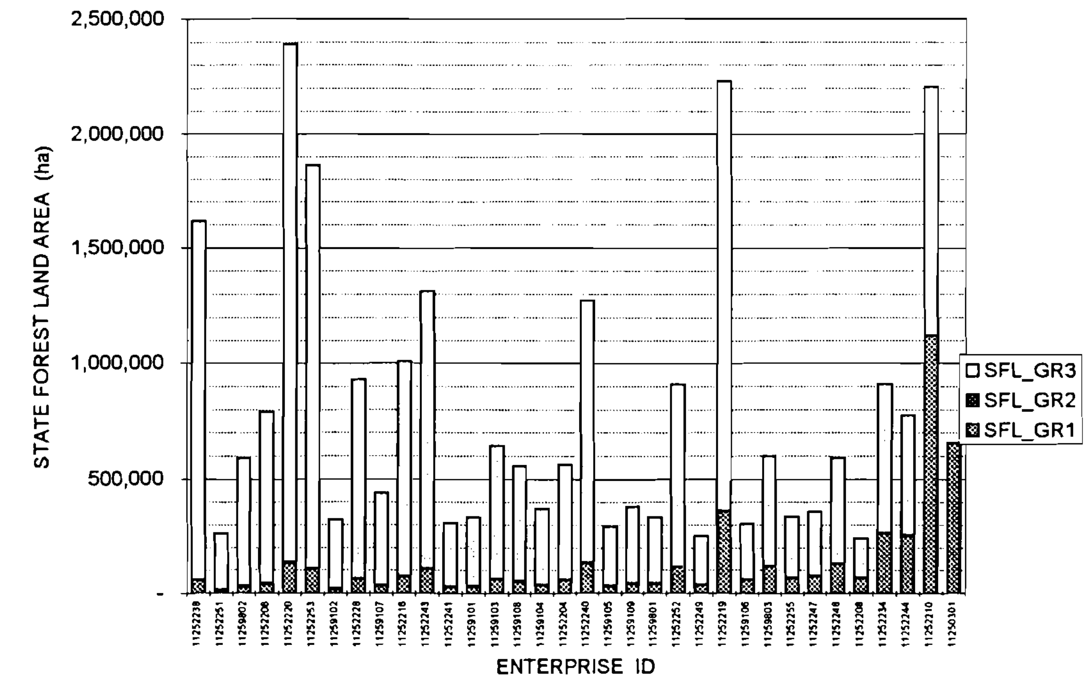


Figure 13. State Forest Land area by protection category for Angara Lena
(Source: FSA88-F100).

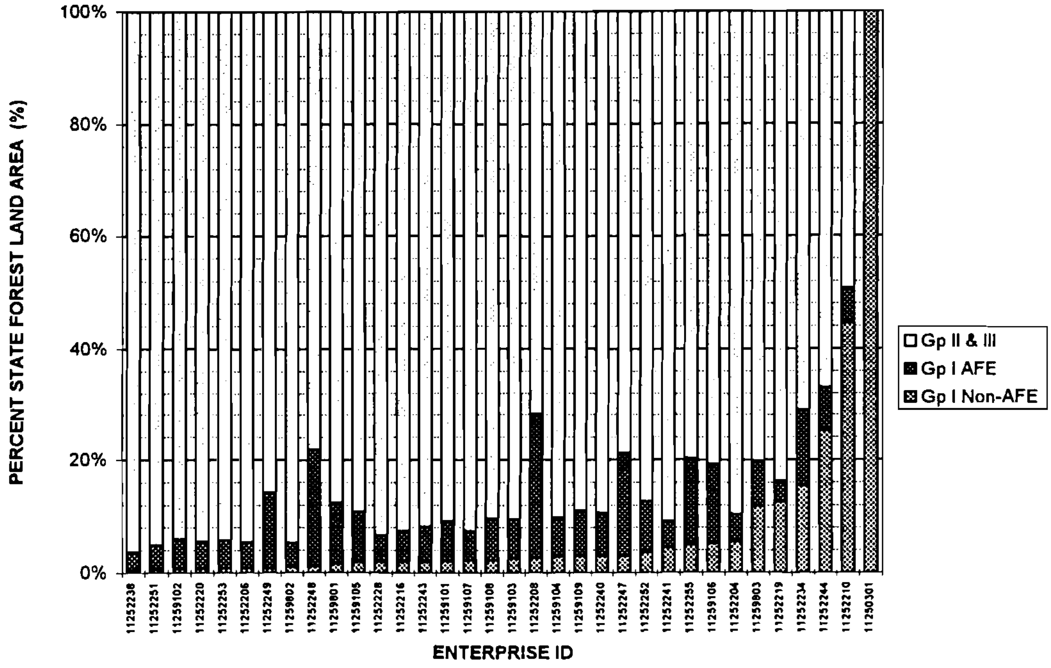


Figure 14. Percent State Forest Land area by Group I non-AFE and protection category in Angara-Lena (source: FSA88–F100).

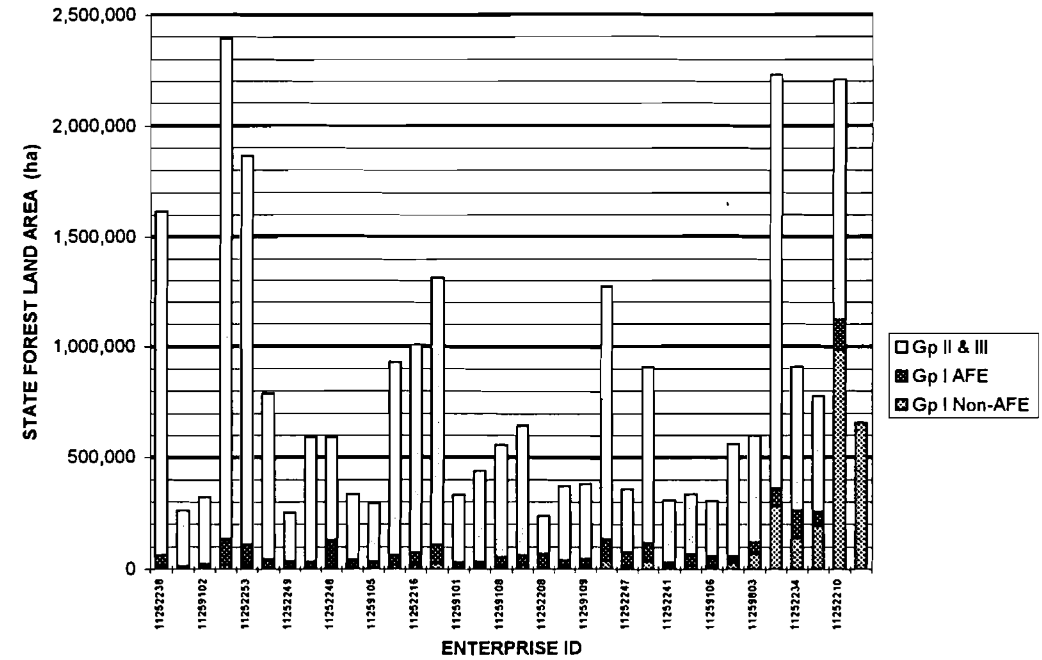


Figure 15. State Forest Land area by Group I non-AFE and protection category in Angara-Lena (source: FSA88–F100).

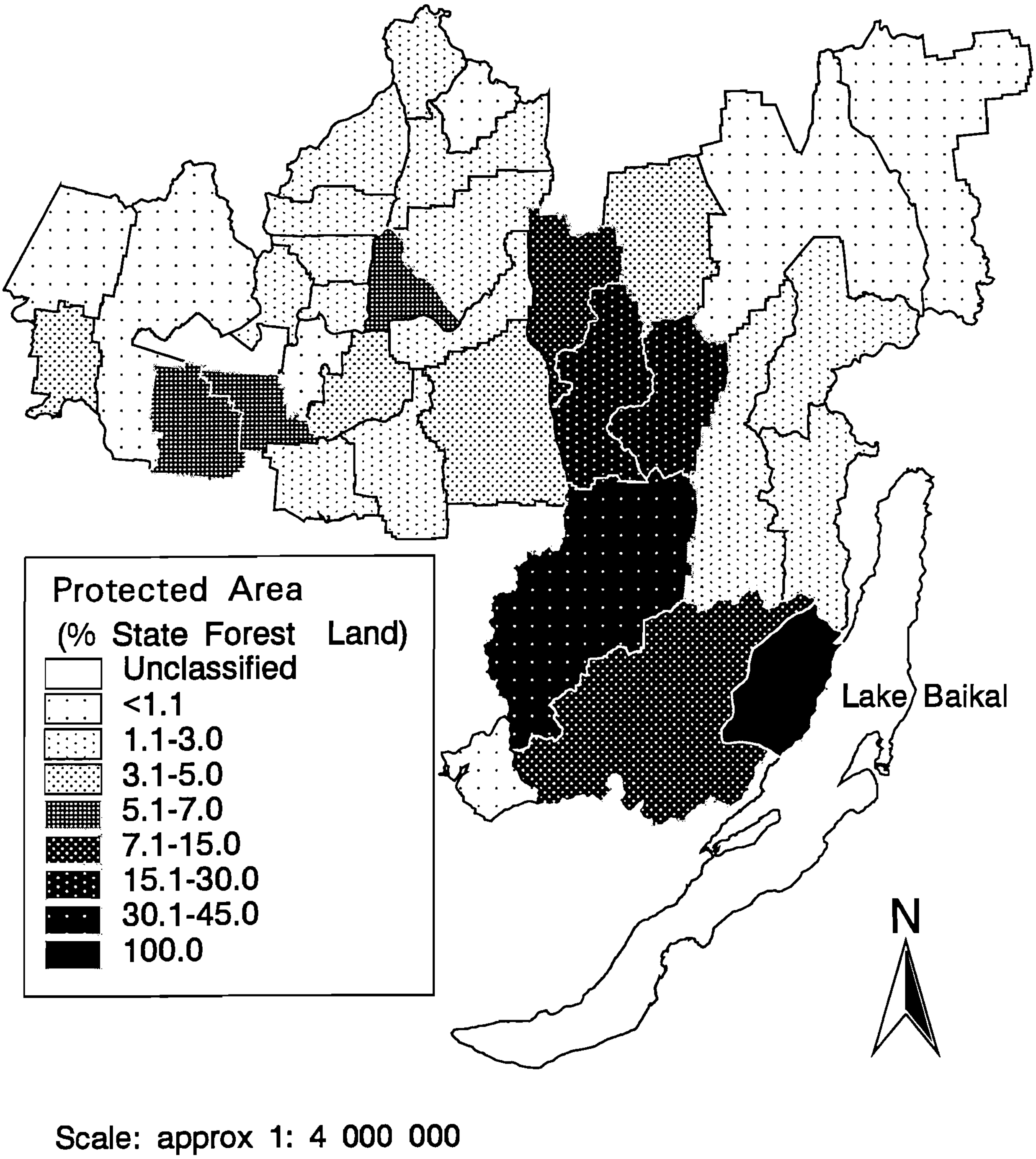


Figure 16. Protected area in the Angara-Lena ecoregion (Source: FSA88–F100).

FCorDens

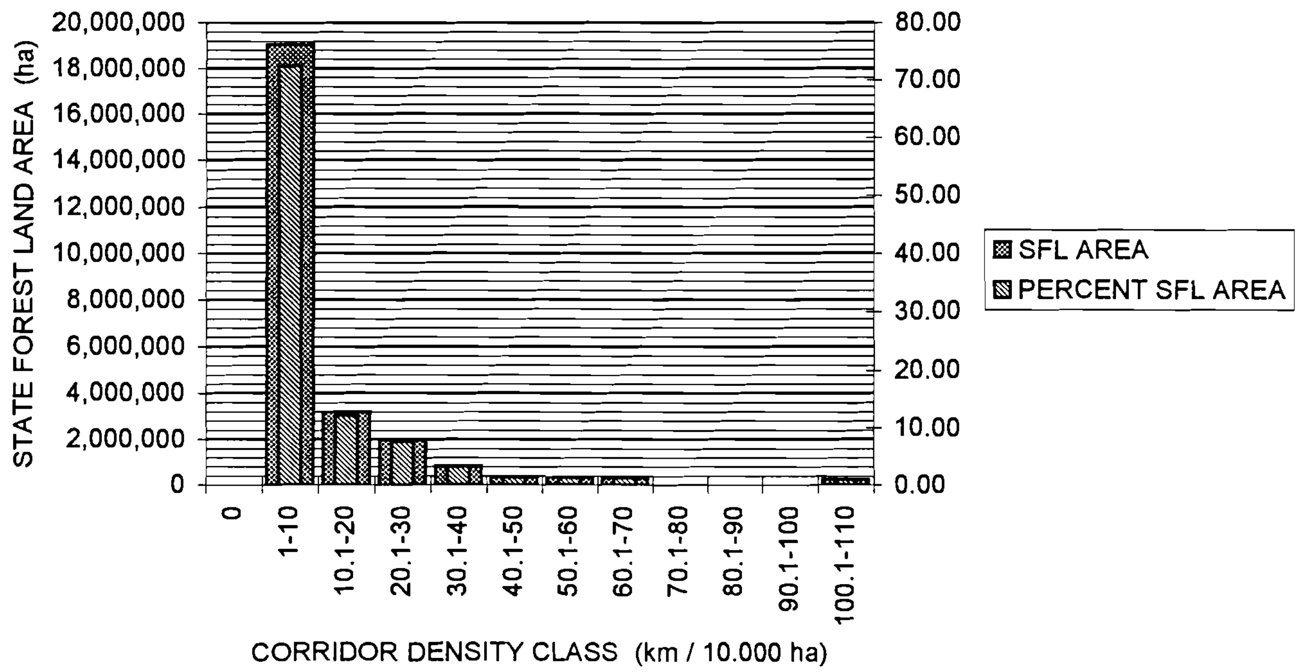


Figure 17. State Forest Land area within transport corridor density classes (Source: FSA88–F309).

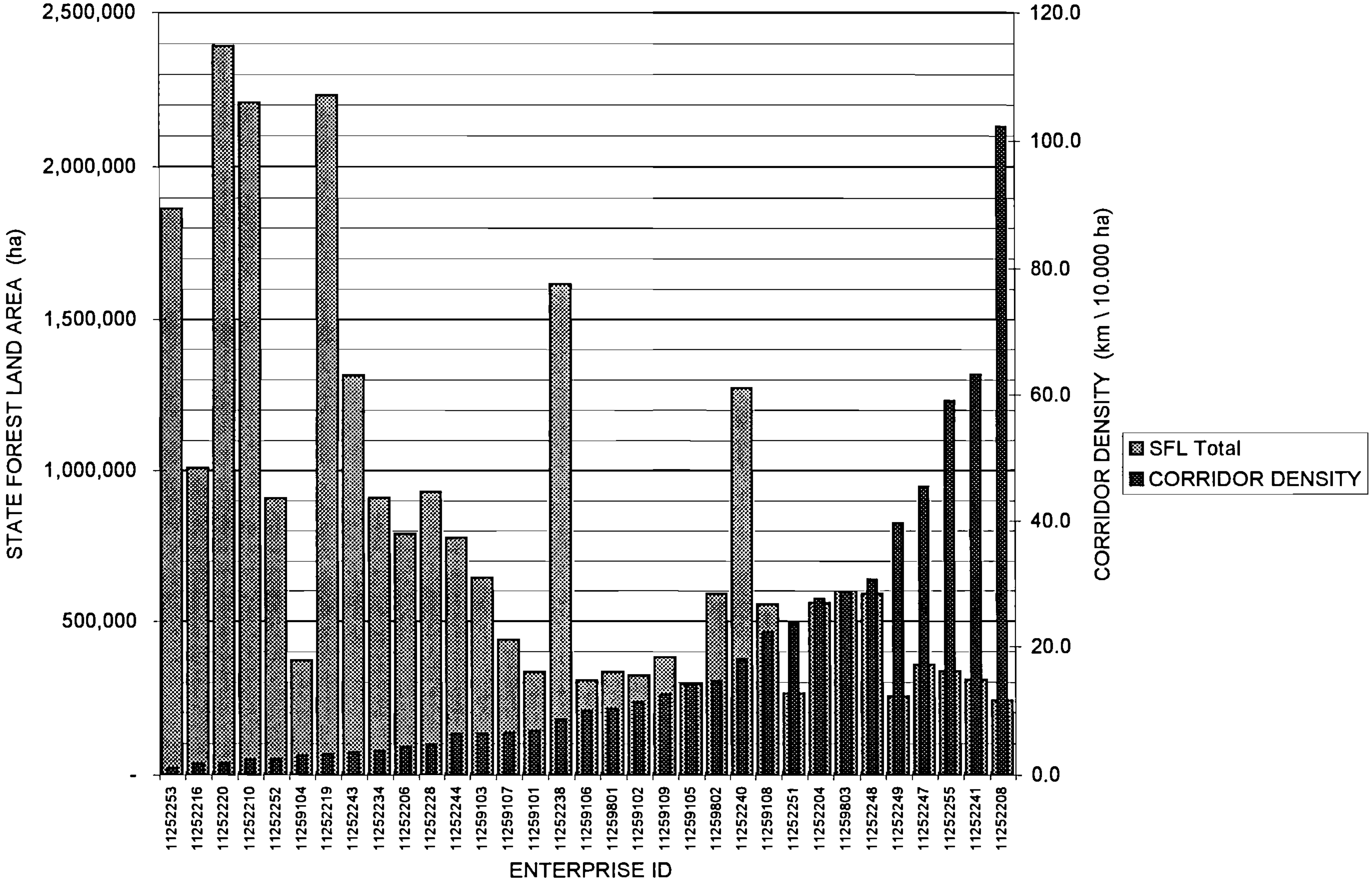


Figure 18. Transport corridor density and State Forest Land area by enterprise in Angara-Lena (source: FSA88–F309).

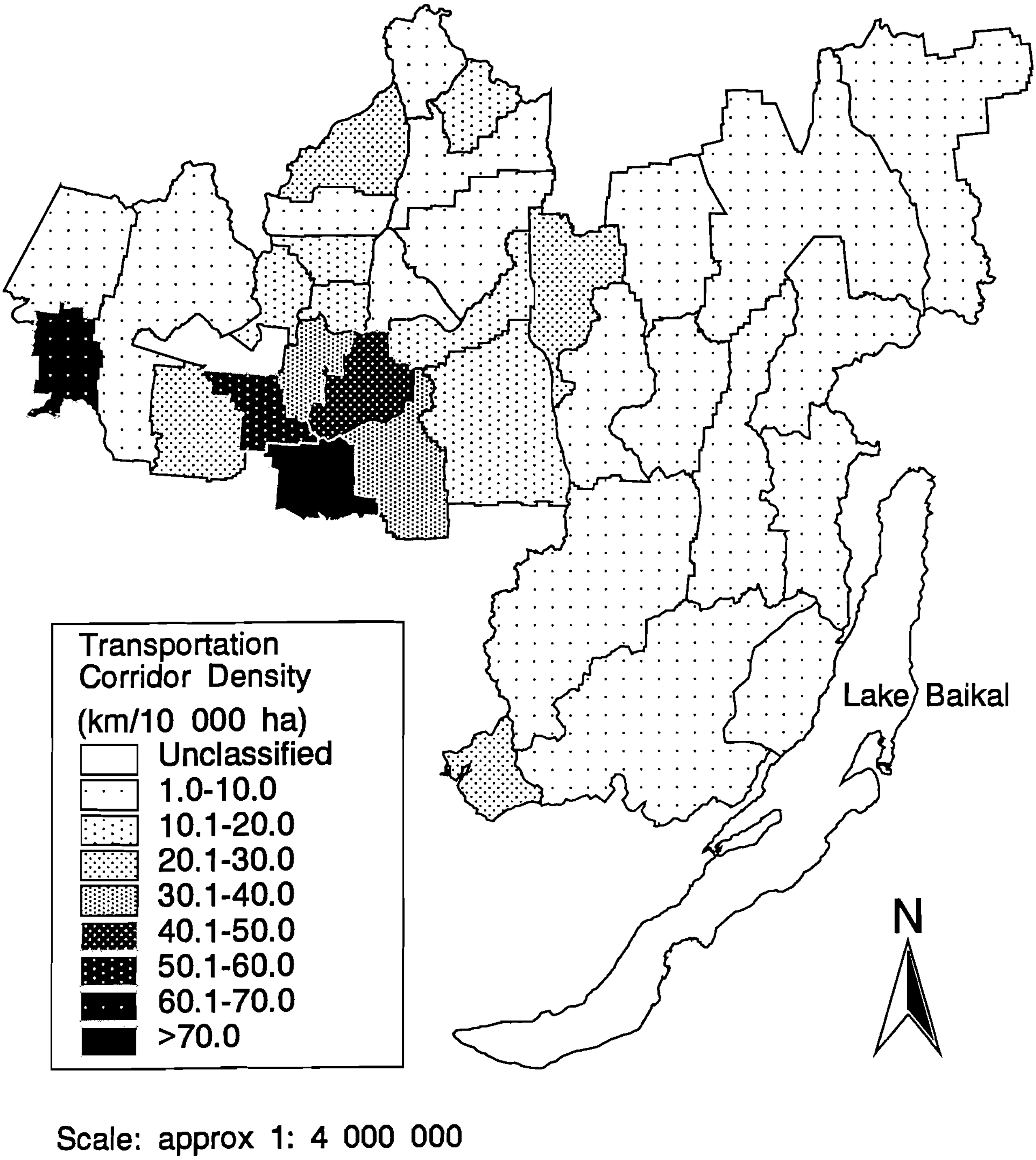


Figure 19. Fragmentation by transportation corridors in the Angara-Lena ecoregion (Source: FSA88-F309).

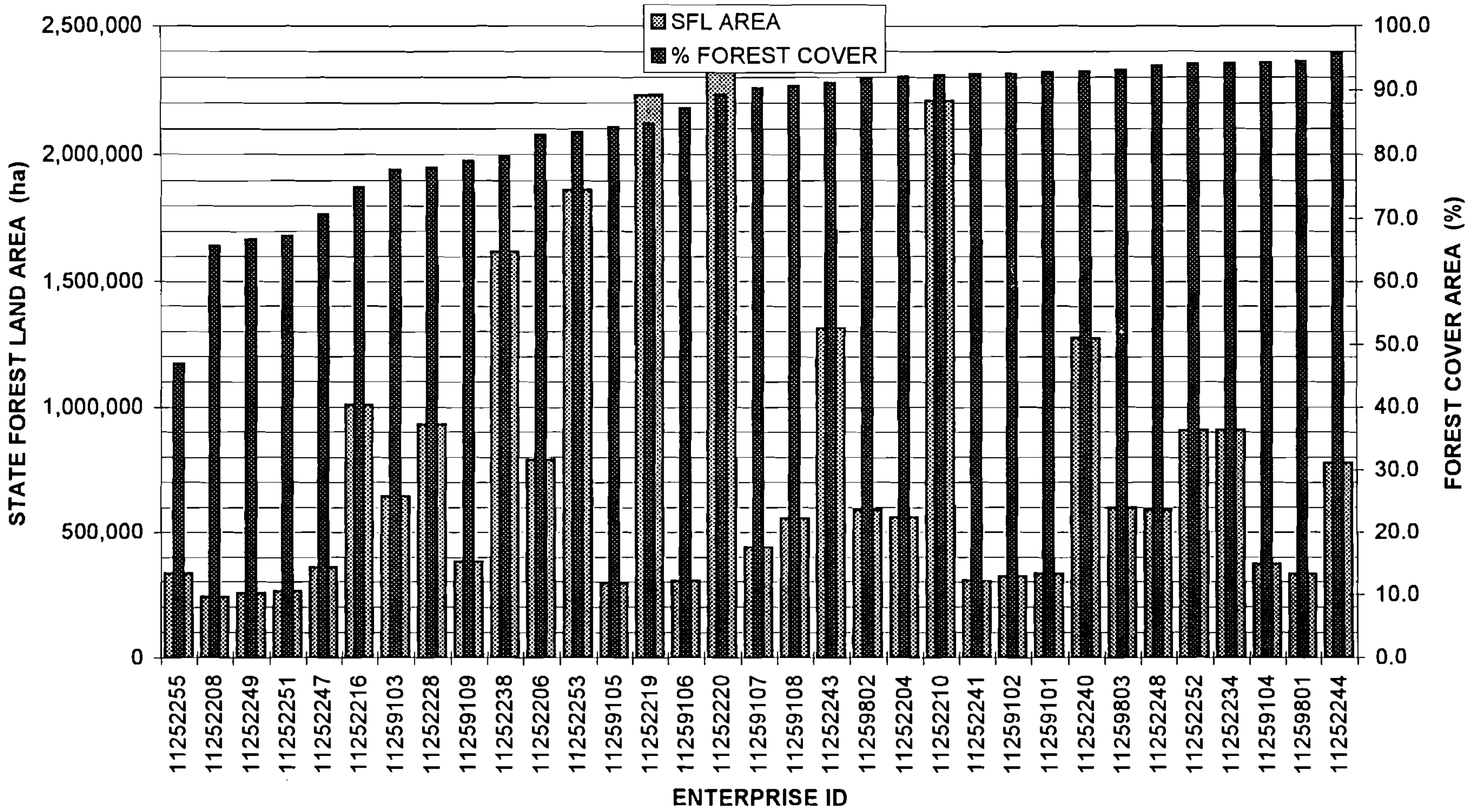


Figure 20. Percent forest cover area and State Forest Land area in Angara Lena (Source: FSA88–F301).

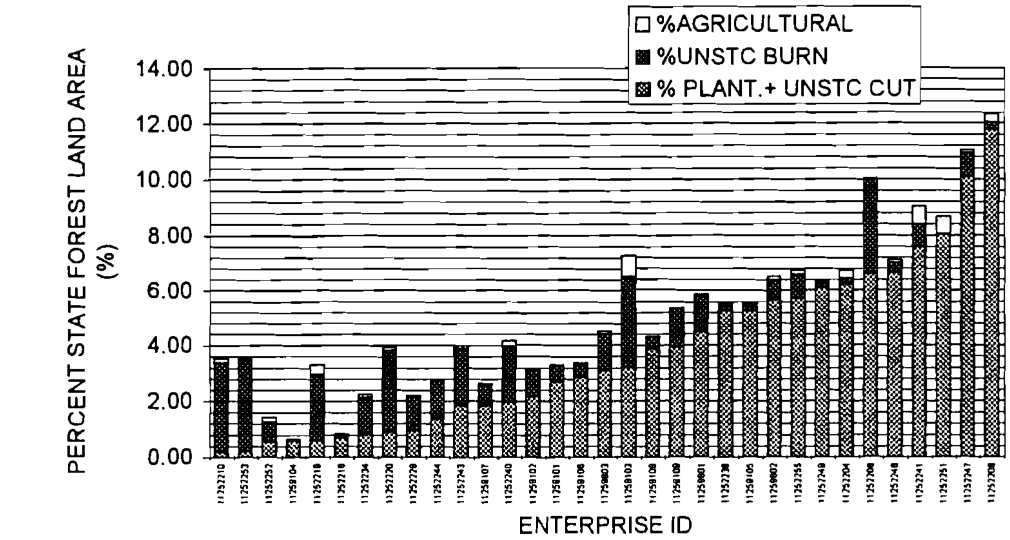


Figure 21. Percent State Forest Land area by disturbance type in Angara-Lena (Source: FSA88–F100).

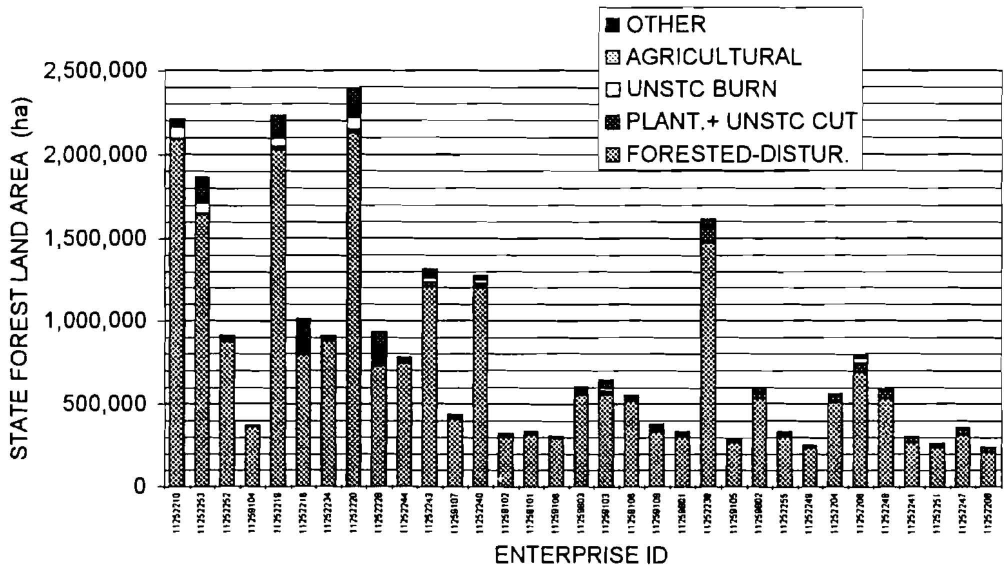
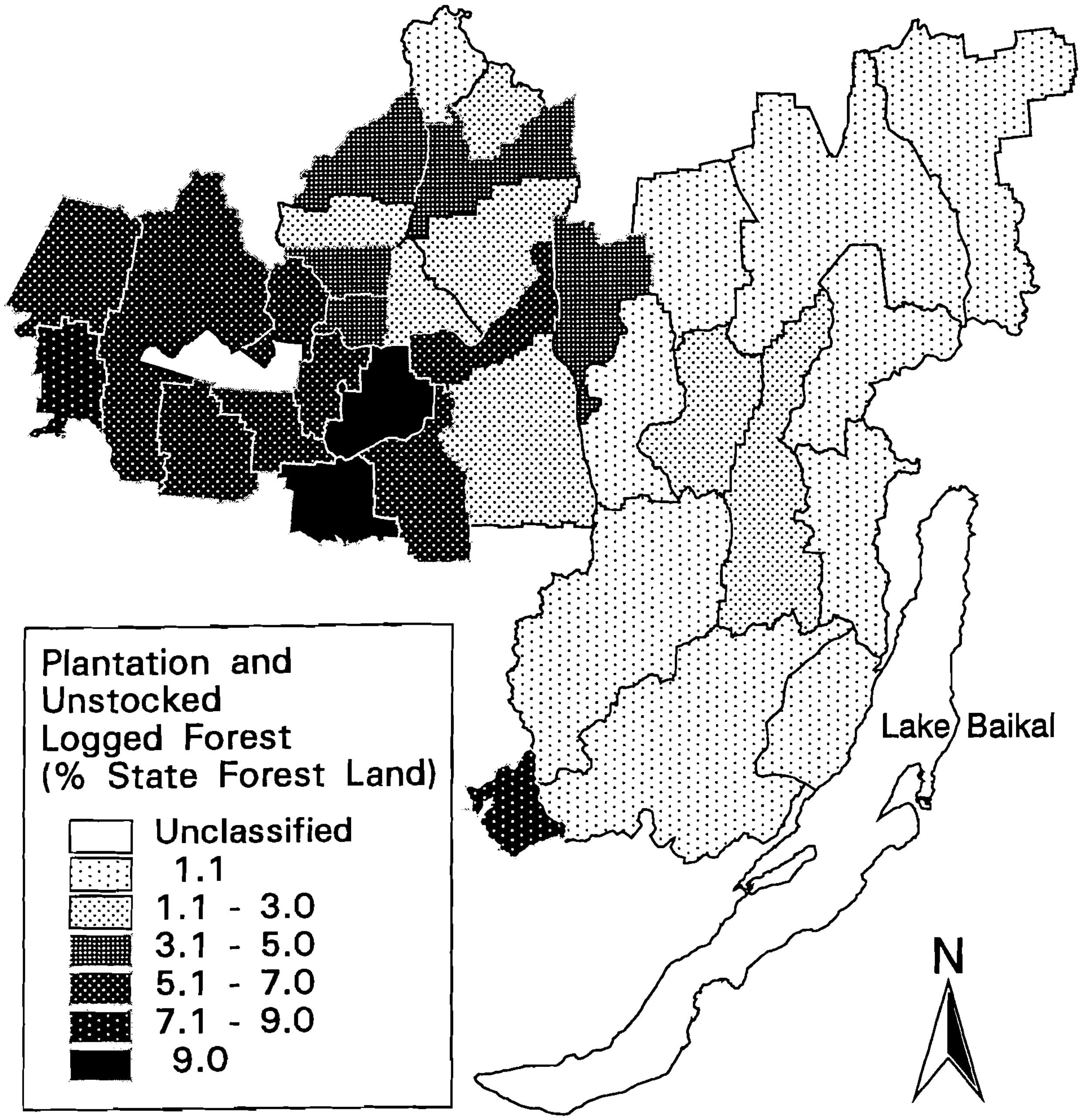


Figure 22. State Forest Land area including disturbance types in Angara-Lena (Source: FSA88–F100).



Scale: approx 1: 4 000 000

Figure 23. Area of plantations and unstocked logged forest in the Angara-Lena ecoregion (Source: FSA88–F100).

APPENDICES

Appendix 1.1. Area of dominant forest species by enterprise in Angara Lena (Source: FSA88–F200).

ENTERPRISE	FOREST LAND AREA BY DOMINANT FOREST SPECIES											FOREST LAND
	Pine	Pine	Larch	Cedar	Birch	Spruce	Aspen	Fir	Willow	Poplar	Black Alder	
FE–ID	*Pinus silv.*	*Pinus silv.*	*Larix sp.*	*Pinus sib.*	*Betula sp.*	*Picea sp.*	*Populus trem (mostly)*	*Abies sp.*	*Salix sp.*	*Populus sp.* (not tremula)	*Alnus incana*	FL–TOT
	(ha)	(% of Forest Land)	(ha)	(ha)	(ha)	(ha)	(ha)	(ha)	(ha)	(ha)	(ha)	(ha)
11252219	144,260	7.46	1,174,578	264,434	74,724	62,074	213,434	152	30	0	0	1,933,686
11252210	256,023	12.35	703,442	700,439	238,919	60,204	83,408	29,874	977	137	0	2,073,423
11252234	136,767	15.68	243,721	277,645	107,936	68,089	26,361	10,924	631	0	0	872,074
11252228	113,840	17.63	34,579	191,970	97,125	82,219	26,667	98,454	331	381	0	645,566
11252244	135,303	18.24	166,964	333,223	52,436	27,437	9,690	16,548	56	0	0	741,657
11252216	159,755	22.32	50,981	117,386	128,765	192,809	22,721	41,639	554	1241	0	715,851
11252240	294,989	24.52	210,967	133,251	225,726	227,498	60,311	50,255	65	0	0	1,203,062
11259109	95,076	28.15	72,761	8,155	92,257	36,352	23,008	10,185	0	0	0	337,794
11259803	168,613	30.22	90,031	96,112	116,473	51,303	27,948	7,452	6	0	0	557,938
11252243	363,118	30.86	555,995	109,895	76,786	36,119	30,500	4,408	0	0	0	1,176,821
11252206	238,087	33.85	86,358	10,908	175,634	87,765	67,060	37,571	0		0	703,383
11252253	533,206	35.22	500,350	211,612	73,075	137,152	18,308	40,153	0	167	90	1,514,113
11252248	195,284	35.32	83,465	7,678	148,018	22,749	78,839	16,933	0	0	0	552,966
11259103	198,677	35.69	78,299	85,472	83,945	47,862	11,377	50,989	0	0	0	556,621
11252241	101,676	35.73	5,358	24,901	67,826	15,783	36,185	32,651	225	0	0	284,605
11252204	199,579	38.12	24,596	10,024	148,655	51,973	33,143	55,570	0	0	0	523,540
11259107	157,512	38.16	95,415	39,468	42,626	37,090	15,246	25,360	0	0	0	412,717
11259102	118,226	39.66	25,492	39,040	53,794	33,596	6,273	21,642	0	0	0	298,063
11252238	668,300	44.89	126,768	36,950	275,599	202,130	71,128	107,891	0	0	0	1,488,766
11252247	151,087	46.53	44,113	5,008	72,485	14,219	29,951	7,840	0	0	0	324,703
11259802	250,177	46.87	109,527	10,097	70,461	45,600	34,188	13,608	57	0	0	533,715
11252251	116,280	48.22	24,481	4,944	74,741	6,962	13,268	490	0	0	0	241,166
11259105	132,341	48.36	28,011	1,551	40,339	34,226	27,509	9,691	8	0	0	273,676
11259101	153,900	48.74	73,590	752	34,797	40,478	6,121	6,110	0	0	0	315,748
11252255	151,253	48.78	28,100	6,023	80,563	14,408	18,666	10,959	83	0	0	310,055
11252252	441,618	51.42	223,844	84,149	62,095	29,044	15,867	2,178	0	0	0	858,795
11252220	1,104,664	52.53	349,859	186,974	128,493	188,585	55,311	88,835	8	127	0	2,102,856
11259108	280,852	53.89	147,168	1,054	38,330	38,540	10,517	4,739	0	0	0	521,200
11252208	119,931	55.34	15,695	189	56,801	6,802	13,517	3,775	0	0	0	216,710
11259104	212,307	57.97	74,258	5,016	41,252	20,053	11,843	1,504	0	0	0	366,233
11259801	182,166	59.48	47,733	3,466	20,080	24,978	16,460	11,377	0	0	0	306,260
11252249	144,033	59.58	27,693	5,354	30,940	9,186	18,168	6,358	0	0	0	241,732
11259106	179,194	61.03	42,775	2,518	38,032	10,708	15,489	4,910	0	0	0	293,626
TOTAL	7,898,094	NA	5,566,967	3,015,658	3,069,728	1,963,993	1,148,482	831,025	3031	2053	90	23,499,121
% TOTAL	33.6102	-	23.6901	12.8331	13.0632	8.3577	4.8873	3.5364	0.0129	0.0087	0.0004	100

Appendix 1.2a. Forested land area by age group and enterprise ranked by % young, for Anagara Lena (Source: FSA88-F200). (agediv.xls)

ENTERPRISE ID	YOUNG	% YOUNG	MIDDLE AGE	MATURING	MATURE	OVER-MAT.	FOREST LAND TOTAL
FE-ID	1CL + 2CL		FL-MDL-TOT	FL-MATRG	FL-OMAT-TOT - FL-OMAT-INCOMAT	FL-OMAT-INCOMAT	FL-TOT
	(ha)	(%)	(ha)	(ha)	(ha)	(ha)	(ha)
11252253	71,253	4.71	254,795	149,068	522,033	516,964	1,514,113
11259101	15,276	4.84	56,706	28,314	69,106	146,346	315,748
11252220	110,170	5.24	341,080	162,820	632,462	856,324	2,102,856
11259104	19,265	5.26	61,766	42,411	96,754	146,037	366,233
11252252	48,994	5.70	184,017	78,972	160,482	386,330	858,795
11259102	24,871	8.34	78,868	31,083	69,540	93,701	298,063
11259802	46,900	8.79	153,244	54,641	94,756	184,174	533,715
11252216	63,467	8.87	174,304	125,677	232,348	120,055	715,851
11259107	37,080	8.98	101,418	36,114	119,841	118,264	412,717
11259108	47,020	9.02	61,764	54,529	136,391	221,496	521,200
11259109	30,498	9.03	47,980	32,690	82,923	143,703	337,794
11259103	50,519	9.08	136,355	64,422	122,679	182,646	556,621
11252210	198,333	9.57	756,504	350,090	451,655	316,841	2,073,423
11259803	56,644	10.15	175,620	88,833	121,141	115,700	557,938
11252251	24,833	10.30	42,651	32,685	56,026	84,971	241,166
11259106	30,984	10.55	70,007	31,089	43,293	118,253	293,626
11252238	164,832	11.07	253,586	162,490	345,279	562,579	1,488,766
11259801	34,921	11.40	53,437	20,133	58,471	139,298	306,260
11259105	34,622	12.65	41,613	35,095	85,076	77,270	273,676
11252228	81,761	12.67	233,096	83,042	165,697	81,970	645,566
11252243	169,908	14.44	309,029	127,934	227,954	341,996	1,176,821
11252240	184,543	15.34	319,595	159,958	283,301	255,665	1,203,062
11252234	155,659	17.85	291,899	119,976	211,780	92,760	872,074
11252219	407,472	21.07	399,709	165,703	374,750	586,052	1,933,686
11252248	122,604	22.17	120,577	57,229	111,782	140,774	552,966
11252206	160,039	22.75	116,992	72,067	156,627	197,658	703,383
11252247	74,563	22.96	47,976	43,689	80,056	78,419	324,703
11252244	178,690	24.09	202,867	68,745	181,183	110,172	741,657
11252204	143,785	27.46	161,245	56,635	92,578	69,297	523,540
11252255	88,662	28.60	53,849	25,272	74,546	67,726	310,055
11252249	78,408	32.44	36,086	17,420	35,397	74,421	241,732
11252208	81,150	37.45	45,823	18,248	28,103	43,386	216,710
11252241	109,325	38.41	66,938	31,177	48,622	28,543	284,605
TOTAL	3,147,051	NA	5,451,396	2,628,251	5,572,632	6,699,791	23,499,121
% TOTAL	13.4	-	23.2	11.2	23.7	28.5	100.0

Appendix 1.2b. Forested land area by age group and enterprise ranked by % over-mature, for Anagara Lena (Source: FSA-F200).

ENTERPRISE ID	YOUNG	% YOUNG	MIDDLE AGE	MATURING	MATURE	OVER-MAT.	% OVER-MAT.	FOREST LAND TOTAL
FE-ID	1CL + 2CL		FL-MDL-TOT	FL-MATRG	FL-OMAT-TOT - FL-OMAT-INCOMAT	FL-OMAT-INCOMAT		FL-TOT
	(ha)	(%)	(ha)	(ha)	(ha)	(ha)	(%)	(ha)
11252241	109,325	38.4	66,938	31,177	48,622	28,543	10.0	284,605
11252234	155,659	17.8	291,899	119,976	211,780	92,760	10.6	872,074
11252228	81,761	12.7	233,096	83,042	165,697	81,970	12.7	645,566
11252204	143,785	27.5	161,245	56,635	92,578	69,297	13.2	523,540
11252244	178,690	24.1	202,867	68,745	181,183	110,172	14.9	741,657
11252210	198,333	9.6	756,504	350,090	451,655	316,841	15.3	2,073,423
11252216	63,467	8.9	174,304	125,677	232,348	120,055	16.8	715,851
11252208	81,150	37.4	45,823	18,248	28,103	43,386	20.0	216,710
11259803	56,644	10.2	175,620	88,833	121,141	115,700	20.7	557,938
11252240	184,543	15.3	319,595	159,958	283,301	255,665	21.3	1,203,062
11252255	88,662	28.6	53,849	25,272	74,546	67,726	21.8	310,055
11252247	74,563	23.0	47,976	43,689	80,056	78,419	24.2	324,703
11252248	122,604	22.2	120,577	57,229	111,782	140,774	25.5	552,966
11252206	160,039	22.8	116,992	72,067	156,627	197,658	28.1	703,383
11259105	34,622	12.7	41,613	35,095	85,076	77,270	28.2	273,676
11259107	37,080	9.0	101,418	36,114	119,841	118,264	28.7	412,717
11252243	169,908	14.4	309,029	127,934	227,954	341,996	29.1	1,176,821
11252219	407,472	21.1	399,709	165,703	374,750	586,052	30.3	1,933,686
11252249	78,408	32.4	36,086	17,420	35,397	74,421	30.8	241,732
11259102	24,871	8.3	78,868	31,083	69,540	93,701	31.4	298,063
11259103	50,519	9.1	136,355	64,422	122,679	182,646	32.8	556,621
11252253	71,253	4.7	254,795	149,068	522,033	516,964	34.1	1,514,113
11259802	46,900	8.8	153,244	54,641	94,756	184,174	34.5	533,715
11252251	24,833	10.3	42,651	32,685	56,026	84,971	35.2	241,166
11252238	164,832	11.1	253,586	162,490	345,279	562,579	37.8	1,488,766
11259104	19,265	5.3	61,766	42,411	96,754	146,037	39.9	366,233
11259106	30,984	10.6	70,007	31,089	43,293	118,253	40.3	293,626
11252220	110,170	5.2	341,080	162,820	632,462	856,324	40.7	2,102,856
11259108	47,020	9.0	61,764	54,529	136,391	221,496	42.5	521,200
11259109	30,498	9.0	47,980	32,690	82,923	143,703	42.5	337,794
11252252	48,994	5.7	184,017	78,972	160,482	386,330	45.0	858,795
11259801	34,921	11.4	53,437	20,133	58,471	139,298	45.5	306,260
11259101	15,276	4.8	56,706	28,314	69,106	146,346	46.3	315,748
TOTAL	3,147,051	NA	5,451,396	2,628,251	5,572,632	6,699,791	NA	23,499,121
% TOTAL	13.4	-	23.2	11.2	23.7	28.5	-	100.0

Appendix 1.3. State Forest Land area by protection category in Angara-Lena
(source: FSA88-F100).

ENTERPRISE ID	GROUP I NON-AFE	% GROUP I NON-AFE	GROUP I AFE	GROUP I TOTAL	% GROUP FOREST	GROUP II & III	SFL TOTAL
FE-ID				SFL-GR1	SFL-GR1	SFL-GR2 + SFL-GR3	SFL-TOT
	(ha)	(%)	(ha)	(ha)	(%)	(ha)	(ha)
11252238	8,272	0.5	51,694	59,966	3.7	1,558,338	1,618,304
11252251	1,510	0.6	11,555	13,065	5.0	250,233	263,298
11259102	2,092	0.6	17,215	19,307	6.0	302,841	322,148
11252220	17,444	0.7	115,849	133,293	5.6	2,258,050	2,391,343
11252253	14,467	0.8	93,221	107,688	5.8	1,756,844	1,864,532
11252206	6,293	0.8	36,563	42,856	5.4	746,523	789,379
11252249	2,047	0.8	33,713	35,760	14.1	217,459	253,219
11259802	5,992	1.0	25,061	31,053	5.3	559,343	590,396
11252248	6,947	1.2	122,294	129,241	21.9	461,247	590,488
11259801	5,221	1.6	36,212	41,433	12.4	292,362	333,795
11259105	5,746	1.9	26,176	31,922	10.8	263,252	295,174
11252228	18,165	2.0	44,151	62,316	6.7	867,880	930,196
11252216	19,807	2.0	54,383	74,190	7.4	934,846	1,009,036
11252243	26,167	2.0	80,833	107,000	8.1	1,207,743	1,314,743
11259101	6,843	2.1	23,539	30,382	9.1	303,175	333,557
11259107	9,389	2.1	22,904	32,293	7.3	408,547	440,840
11259108	11,968	2.2	40,829	52,797	9.5	503,567	556,364
11259103	16,375	2.5	44,207	60,582	9.4	584,978	645,560
11252208	6,333	2.6	61,294	67,627	28.1	172,651	240,278
11259104	10,554	2.8	25,911	36,465	9.8	336,130	372,595
11259109	11,218	2.9	31,048	42,266	11.1	339,776	382,042
11252240	38,492	3.0	96,995	135,487	10.6	1,138,959	1,274,446
11252247	10,829	3.0	64,769	75,598	21.1	282,120	357,718
11252252	33,917	3.7	81,672	115,589	12.7	794,652	910,241
11252241	13,787	4.5	14,162	27,949	9.1	280,424	308,373
11252255	17,084	5.1	50,687	67,771	20.2	267,392	335,163
11259106	15,948	5.2	42,889	58,837	19.2	247,438	306,275
11252204	30,960	5.5	27,046	58,006	10.3	503,995	562,001
11259803	70,831	11.8	48,021	118,852	19.8	481,865	600,717
11252219	283,207	12.7	79,238	362,445	16.2	1,869,357	2,231,802
11252234	140,651	15.5	122,322	262,973	28.9	646,843	909,816
11252244	196,635	25.3	59,613	256,248	33.0	521,000	777,248
11252210	983,672	44.5	136,876	1,120,548	50.7	1,087,691	2,208,239
11250301	* (659,900)	100.0	-	-	-	-	* (659,900)
TOTAL	2,048,863	NA	1,822,942	3,871,805	14.7	22,447,521	26,319,326
% TOTAL	7.8	-	6.9	14.7	NA	85.3	100.0

* Nature reserve area included within enterprise 11252219

Appendix 1.4: Transportation corridor density (Source: FSA88-F309).

ENTERPRISE I	CORRIDOR LENGTH	SFL Total	CORRIDOR DENSITY
FE-ID	LGTH-TOT CLASS 1	SFL-TOT	
	(km)	(ha)	(km/10,000ha)
11252253	190	1,864,532	1.0
11252216	164	1,009,036	1.6
11252220	430	2,391,343	1.8
11252210	523	2,208,239	2.4
11252252	225	910,241	2.5
11259104	110	372,595	3.0
11252219	701	2,231,802	3.1
11252243	459	1,314,743	3.5
11252234	337	909,816	3.7
11252206	341	789,379	4.3
11252228	430	930,196	4.6
11252244	492	777,248	6.3
11259103	409	645,560	6.3
11259107	287	440,840	6.5
11259101	226	333,557	6.8
11252238	1,383	1,618,304	8.5
11259106	304	306,275	9.9
11259801	341	333,795	10.2
11259102	364	322,148	11.3
11259109	477	382,042	12.5
11259105	418	295,174	14.2
11259802	859	590,396	14.5
11252240	2,293	1,274,446	18.0
11259108	1,241	556,364	22.3
11252251	621	263,298	23.6
11252204	1,548	562,001	27.5
11259803	1,727	600,717	28.7
11252248	1,808	590,488	30.6
11252249	1,005	253,219	39.7
11252247	1,627	357,718	45.5
11252255	1,980	335,163	59.1
11252241	1,951	308,373	63.3
11252208	2,456	240,278	102.2
TOTAL	27,727	26,319,326	10.5

Appendix 1.5. Forest cover extent of State Forest Land area in Angara Lena (Source: FSA88-F301 and FSA88-F100).

ENTERPRISE ID FE-ID	SFL AREA SFL-TOT (ha)	% FOREST COVER FOR-COVER (%)
11252255	335,163	46.9
11252208	240,278	65.7
11252249	253,219	66.7
11252251	263,298	67.2
11252247	357,718	70.7
11252216	1,009,036	75.0
11259103	645,560	77.7
11252228	930,196	78.0
11259109	382,042	79.0
11252238	1,618,304	79.8
11252206	789,379	83.1
11252253	1,864,532	83.5
11259105	295,174	84.3
11252219	2,231,802	84.8
11259106	306,275	87.2
11252220	2,391,343	89.2
11259107	440,840	90.3
11259108	556,364	90.6
11252243	1,314,743	91.1
11259802	590,396	91.8
11252204	562,001	92.1
11252210	2,208,239	92.3
11252241	308,373	92.4
11259102	322,148	92.5
11259101	333,557	92.7
11252240	1,274,446	92.8
11259803	600,717	93.1
11252248	590,488	93.8
11252252	910,241	94.0
11252234	909,816	94.1
11259104	372,595	94.2
11259801	333,795	94.5
11252244	777,248	95.7
TOTAL	26,319,326	85.3

Appendix 1.6: State Forest Land area by disturbance type in Angara Lena (Source: FSA88–F100).

ENTERPRISE ID	SFL TOTAL	FORESTED -DISTURB.	PLANTATION + UNSTC CUT	% PLANTATION + UNSTC CUT	UNSTC BURN	%UNSTC BURN	AGRICULTURAL	%AGRICULTURAL	OTHER LANDS
FE–ID	SFL–TOT	FL–NOLSE TOT - DISTURB.	PLANTATION +FL–UNSTC–CUT		FL–UNSTC BURN				
	(ha)	(ha)	(ha)		(ha)		(ha)		(ha)
11252210	2,208,239	2,088,175	4,276	0.19	70,480	3.19	3,328	0.15	44,297
11252253	1,864,532	1,643,976	3,925	0.21	60,950	3.27	1,113	0.06	154,568
11252252	910,241	869,171	5,108	0.56	6,440	0.71	1,519	0.17	28,003
11259104	372,595	366,166	2,204	0.59	65	0.02	144	0.04	4,016
11252219	2,231,802	2,030,352	13,656	0.61	52,529	2.35	7,695	0.34	128,915
11252216	1,009,036	791,638	6,972	0.69	1,233	0.12	263	0.03	208,930
11252234	909,816	876,758	7,344	0.81	11,901	1.31	1,045	0.11	12,791
11252220	2,391,343	2,126,144	21,776	0.91	69,530	2.91	2,664	0.11	171,229
11252228	930,196	727,630	8,831	0.95	11,668	1.25	147	0.02	181,920
11252244	777,248	743,023	10,698	1.38	10,451	1.34	423	0.05	12,653
11252243	1,314,743	1,204,317	24,176	1.84	27,064	2.06	1,518	0.12	57,916
11259107	440,840	411,205	8,146	1.85	3,275	0.74	203	0.05	18,011
11252240	1,274,446	1,199,247	25,351	1.99	25,168	1.97	2,505	0.20	22,753
11259102	322,148	297,895	7,064	2.19	2,967	0.92	1	0.00	14,221
11259101	333,557	314,577	8,948	2.68	2,056	0.62	50	0.01	7,926
11259106	306,275	292,240	8,774	2.86	1,409	0.46	147	0.05	3,705
11259803	600,717	557,584	18,679	3.11	7,696	1.28	629	0.10	16,150
11259103	645,560	554,162	20,810	3.22	21,147	3.28	5,004	0.78	45,226
11259108	556,364	519,277	21,650	3.89	2,326	0.42	16	0.00	13,180
11259109	382,042	334,560	15,130	3.96	5,231	1.37	132	0.03	26,989
11259801	333,795	303,631	14,925	4.47	4,595	1.38	85	0.03	10,782
11252238	1,618,304	1,471,796	84,804	5.24	3,242	0.20	1,724	0.11	56,738
11259105	295,174	270,898	15,548	5.27	620	0.21	142	0.05	7,966
11259802	590,396	532,788	33,352	5.65	4,307	0.73	814	0.14	19,145
11252255	335,163	298,904	19,120	5.70	2,884	0.86	539	0.16	13,951
11252249	253,219	233,087	15,379	6.07	631	0.25	173	0.07	3,963
11252204	562,001	510,865	34,892	6.21	1,263	0.22	1,744	0.31	13,237
11252206	789,379	689,940	52,200	6.61	26,585	3.37	467	0.06	20,187
11252248	590,488	534,892	39,160	6.63	2,061	0.35	699	0.12	13,710
11252241	308,373	272,037	23,351	7.57	2,500	0.81	2,002	0.65	8,483
11252251	263,298	238,914	21,146	8.03	0	0.00	1,656	0.63	1,582
11252247	357,718	309,857	36,118	10.10	3,000	0.84	417	0.12	8,326
11252208	240,278	206,437	28,251	11.76	605	0.25	741	0.31	4,510
TOTAL	26,319,326	23,822,143	661,764	2.51	445,879	1.69	39,749	0.15	1,355,979

4. Biodiversity Implications of Timber Management in a South-Central Siberian Forest Enterprise: The Ust-Ilimsk Case Study

by Mattias Carlsson

Abstract

The objective of this paper is to try to understand natural and human-induced disturbances that operate across landscapes (10^4 to 10^5 ha) in Siberia. However, the main interest has concentrated on how human activities affect the natural forest conditions. The impacts have been elaborated by comparing landscapes with different degrees of human influences. The study area is the Katinsky forest enterprise covering an area of 372,400 ha in Irkutsk Oblast some 100 km north of Ust-Ilimsk. For this area a digitalized map of each forest stand and a connected database have been developed by the IIASA Siberian Forest Study. Within the total forest area, five landscapes were defined along two gradients – land density and forest-floor vegetation. The forest of each landscape was then classified into nine classes according to the dominant five species and their age.

The transformation of old forest to young by logging is the major change in the structure of the forests. The lack of very old forest (over 200 years) in managed areas might have important effects on fauna and flora species dependent on late successions. Forest type patterns are significantly changed in managed landscapes, showing a higher degree of fragmentation. However, changes in diversity are ambiguous when landscapes of different degrees of exploitation for timber purposes are evaluated. Diversity can both increase and decrease when logging is carried out.

4.1. Introduction

Biodiversity, as defined by Noss and Cooperrider (1994) and Boyle (1991), covers all levels of biological organization. To be credible, conservation of biodiversity (Noss, 1995) must therefore include all these levels. Views broader than single patches or habitats for understanding biodiversity are vital (Liljelund *et al.*, 1992; Franklin, 1993). This study is focused on the landscape level (10^4 to 10^5 ha) and seeks to understand natural and human-induced disturbances that operate across landscapes rather than within single stands.

Time is also of great importance when understanding ecosystem behavior. Vegetation composition, structure and pattern all change over time due to abiotic and biotic processes (Bonan and Shugart, 1989). Time-series analysis of vegetation changes along with analysis of the driving factors would contribute greatly to an understanding of biodiversity and ecological processes. This includes examination of vegetation variability and also relations between driving factors and vegetation (Zachrisson, 1977; Swanson *et al.*, 1993). Variability and also abiotic and biotic relations could to some extent be evaluated with nontemporal data by comparing different landscapes with similar abiotic characteristics. This approach has been used in this study since temporal data were not available.

It has been stressed that abiotic variables (e.g., hydrology and soil) control vegetation type and distribution (Granlund and Wennerholm, 1935; Bonan and Shugart, 1989; Angelstam *et al.*, 1993). For example, tree-species distribution is meant to be related to soil moisture content and fertility (Lundmark, 1986; Fries *et al.*, 1995). Seldom, however, are the strengths of these relationships presented. Indeed they are sometimes taken as general rules by foresters without reflection on the combination of factors that control vegetation. The risk with such a conceptual view of the forest is that management that tries to mimic naturalness instead creates strong relationships that are not significant in nature. Managers are then bringing order to a system that lacks order through creating less diverse forests.

Forest sustainability can be defined as conditions where a forest retains its essential ecological composition, functions, and patterns, and supports a full range of societal values, in both the present and the future (Plinte, 1995). There is no inherent superiority of naturalness that makes it the only or even the best reference for a definition of forest sustainability. Nevertheless, mimicking naturalness has been stressed to be the most objective reference for sustainability (Liljelund *et al.*, 1992; Mladenoff *et al.*, 1992; Swanson and Franklin, 1992; Andersson, 1994; Fries *et al.*, 1995). The problems with such an approach, such as understanding the natural variability of ecosystems, distinguishing natural ecosystems from unnatural, or determining if human influence is natural or not, have been discussed (Nilsson, 1992; Swansson *et al.*, 1993; Noss, 1995). After pointing out some of the problems with naturalness, Noss (1995) concluded that even if naturalness as a state is not a very good reference for forest management, it would be sensible to restore natural disturbances. Forest sustainability, however, also includes components related to culture, beauty and other social needs. Thus, natural is not the only one reference but rather one among several references that are based on what humans want from the forests. Even though I am stressing that naturalness is not the only reference for forest sustainability, in this study it is used as a reference for determining the impact of forest management.

The main objective of the study is to describe how forest structure and composition and landscape pattern change when natural landscapes are exploited for timber purposes. Another objective is to test hypotheses about relations between abiotic and biotic variables in natural landscapes in order to come up with potential guidelines for future forest-management decisions.

4.2. Materials and Methods

4.2.1. A Conceptual Model

The dynamic conditions of boreal forests are determined by several driving factors such as natural disturbances, biotic processes and human influence (Engelmark *et al.*, 1993; Mladenoff *et al.*, 1993) (Figure 1). At a landscape level, these are more or less affected by the landscape characteristics (e.g., topography and soil characteristics) in driving the forest conditions (Zachrisson, 1977; Swanson *et al.*, 1988). This is shown in Figure 1 as a filter between the driving factors and the forest conditions. Added to this are climatic variations that control the driving factors (from annual to long-term variations) and through them the forest conditions.

In this study the main interest is how human activities affect natural forest conditions. This is evaluated by comparing landscapes with different degrees of human influence. There is, unfortunately, a major drawback in this approach. I would suggest that all forested ecosystems of the world are more or less affected by humans so that no really natural ecosystems exist. Human impacts can be divided into unintentional (e.g., air pollution) and intentional (e.g., exploitation, fire suppression). The former produce landscapes which are the most natural we can describe. Such landscapes would be the ultimate reference for this study. However, fire suppression, which significantly affects forest structure and composition and landscape pattern (Suffling, 1993; Ward, 1993) is carried out in the studied area. Thus, the reference landscapes in this study are changed even more than landscapes unintentionally affected by humans. The conclusion is that no purely natural state exists in the study area. However, the pseudo-natural state described would be expected to change even more due to exploitation for timber purposes, so it is used in place of the ultimate reference here.

4.2.2. The Study Area

In this study I have used data from the Katinsky forest enterprise covering an area of 372,400 ha in Irkutsk Oblast some 100 km north of Ust-Ilimsk (59°00'N, 103°00'E). This is a rolling landscape in the southern taiga which rises to between 150 to 450 m above sea level. Several rivers have cut down into the parent material to create numerous valleys. The biggest one is the Angara River which stretches along the western border. The forests in this area are dominated by pine (*Pinus silvestris*), birch (*Betula pubescens* and *Betula pendula*) and larch (*Larix sibirica*) but other tree species are also found such as spruce (*Picea sibirica*), fir (*Abies sibirica*), cedar (*Pinus sibirica*) and aspen (*Populus tremula*). Exploitation of forests has been going on around Ust-Ilimsk for several decades at least. This is now affecting the southern and western part of the Katinsky forest enterprise where the road density is high while the northern and eastern parts have low road density (Figure 2).

4.2.3. The Sampled Landscapes

Within the total forest area, five landscapes were defined along two gradients – road density and forest-floor vegetation. Road density was classified into three classes (low, medium and high road density) and forest-floor vegetation into two classes (mosses-herbs and lingonberry) (Table 1).

The forest of each landscape was then classified into nine classes according to the dominant tree species and their age. Tree species were aggregated according to their fire regime into three classes. One class includes species that are not tolerant to fire but are fast to colonize burned sites (birch and aspen). Another includes species that are not tolerant to fire and dependent on continuous forest cover for a long time (spruce and fir). The third includes species that are moderately tolerant to fire which means that they can survive and regenerate even if fire occurs (pine, larch and cedar) (Korzukhin *et al.*, 1989). These classes were then each divided into three classes by age representing different successional stages. Young successions range from 0 to 50 years, intermediate from 50 to 100 years, and late successions older than 100 years.

Increasing road density from low to medium, and medium to high, presumably to exploit timber, is clearly exposed in the landscapes through the increasing presence of straight-edged clearcuts (Figures 3 and 4). The five sampled landscapes range from 17,000 ha to 19,500 ha in size and from 1 km of road per 10,000 ha to 106 (Table 2).

4.2.4. Abiotic Variables

To examine the impact of abiotic variables on vegetation, three abiotic variables were chosen of which only one existed in the database from the beginning, i.e., site index. The other two, fertility and soil moisture content (moisture), were generated from the forest-floor vegetation. This was done by classifying the forest-floor vegetation across two dimensions (Figure 5) containing fertility on one axis and soil moisture content on the other (A. Shvidenko, personal communication, July 1995). Site index generated from tree height over tree age, and fertility and moisture generated from vegetation type, make all abiotic variables derivatives of biotic phenomena. Nevertheless, both site index and forest-floor vegetation are correlated to abiotic variables (Hägglund and Lundmark, 1977) such that they are expressing the abiotic characteristics of the ground such as water availability and soil fertility.

4.2.5. Analysis

Maps were created and analyzed using ARC/INFO (Geographic Information System), and FRAGSTATS a software package for analyzing spatial patterns such as patch size, patch shape, diversity, edge density and contagion.

To determine statistical correlations, linear multiple regression was carried out on random samples from the population of stands in each of the defined landscapes. The most complex model in terms of independent variables was calculated first. Step by step, nonsignificant independent variables were removed until the independent variables were significant at the 5% level. To determine if correlations or adjusted R were different from each other, levels were set according to my own judgment. The levels are presented with the tables where such judgments have been made.

I calculated a landscape diversity index based on Shannon-Weaver information theory index (Shannon and Weaver, 1962), which describes overall landscape structure (Turner and Rusher, 1988). Landscape diversity is calculated by:

$$H = -\sum_{k=1}^{m}(p_k)\mathrm{LOG}(p_k)$$

where p_k is the proportion of the landscape in ecosystem type k, and m is the total number of types on the landscape. The value of H increases with greater landscape diversity.

4.3. Results and Discussion

The results are presented in three parts: (a) a general description of the composition and structure of the forest; (b) regression models of relations between abiotic and biotic variables; and (c) a spatial description of the forest. The focus throughout is on how the system state and the relations respond to changes in intensity of human impact and how a system with low human impact is structured.

4.3.1. Composition and Structure of the Forests

In this study, composition and structure refer to how the components (e.g., trees and tree species) in the sampled landscapes are arranged and distributed. The descriptions are based on stand-level information.

Age-Class Distribution

The distributions of age classes are significantly different, based on personal judgment, in the landscapes where the density of road is high (Figure 6). The amount of young forest is 10% to 25% higher while the very old forest (>160 years) is dramatically reduced compared to forest where road densities are low. There is a greater portion of forest between 80 and 160 years old in the landscape where road density is high (HM). This could relate to selective cutting of the most valuable trees which would lower the stand age, or it could signal a major disturbance 100 to 150 years ago. Also there is a greater proportion of 40-year-old forest in the landscape with medium road density and forest-floor vegetation dominated by mosses and herbs (MM) which could be due to one or several big former disturbances (e.g., fire, wind throw or insects) 40 years ago. This is supported by the fact that there is a large homogeneous area of young broadleaf stands with irregular edges stretching along the eastern border (Syrjänen *et al.*, 1994).

Both the landscapes with low road density (LM, LW) have a high frequency of forest in old successional stages. A comparison of the two shows that the moss- and herb-dominated landscape (LM) has developed a shift in the maximum age class from 120-159 to 200-239 year-old forests. This could indicate that the external dynamic (e.g., fire) is less frequent in moss- and herb-dominated landscapes (LM). Additionally, average stand age seldom exceeds 200 years for the lingonberry-dominated landscapes and 240 years for the landscapes dominated by mosses and herbs, suggesting that stands that reach that age are likely to have either external disturbances (e.g., fire) or internal disturbances (e.g., wind throw, insects or diseases) which would in both cases lower the average stand age. The age-class structure of both landscapes remind one of boreal landscapes in North America influenced by fire suppression (Ward and Tithecott, 1993), showing a normal distribution rather than a negative exponential age-class distribution which is an accepted model of natural fire regimes (Van Wagner, 1978). This seems consistent with the fact that fire suppression is carried out in the area.

Tree Species Composition

Pine is the stand-dominating tree species (percent stand composition > 70%) in all landscapes (Figure 7). The amount of pine-dominated stands ranges from 10% to 45% of the total landscape area overall and from 25% to 40% in landscapes with low road density. While high and medium road density do not exclude pine-dominated stands, where road density is high or medium the proportion of larch as a dominating tree species is low in both the lingonberry and moss- and herb-dominated landscapes. This could be due to exploitation of larch-dominated stands or the opposite that roads are built where the proportion of other tree species (e.g., pine or spruce) are high. It could also be related to some other random reasons (e.g., site characteristics) that were not discernible from the data. Stands over 100 years of age show a smaller proportion of larch-dominated stands but roughly the same proportion of lower densities of larch. This may indicate that larch-dominated stands are cut (Figure 8).

Birch is the other tree species that is consistent as a dominant species throughout all the landscapes. The amount of birch-dominated stands ranges from 5% to 15% of the total landscape area overall and is 10% in landscapes with low road density. Aspen has earlier colonized some of the disturbed patches in the moss- and herb-dominated landscapes with high road density which has made it a significant dominating species in 100 to 150 year old successions. This is more likely due to suitable abiotic conditions for aspen than to human impact. These successions may be overtaken by larch since larch is mixed in with the broad-leaves in these stands. If that is the case, old successions of broadleaf tree species (150 years) can be present also in natural landscapes to a relatively high percentage (Fries *et al.*, 1995).

In the landscapes with low road density, birch seems to be the stronger competitor in early successions, although this could also be due to more favorable abiotic conditions for birch rather than related to human impact (Figure 8). However, the amount of pine as a stand-dominating species increases when road density becomes high, indicating reforestation with pine and suggesting that a change in early-succession dominating-species composition is related to human activities.

Tree species occurring only at low densities change with forest-floor vegetation so that all moss- and herb-dominated landscapes contain fir at low densities and both lingonberry-dominated landscapes contain spruce (Figure 7). Korzukhin *et al.* (1989) suggested that fir is the more demanding species of the two in terms of soil nutrient availability which could explain why fir is missing in the lingonberry-dominated landscape. Spruce could be restricted for the same reason in that landscape type. These tree species are hardly ever dominant in stands, which is a consistent pattern throughout all landscapes. Also, cedar is found at low densities in landscapes with low road densities but is reduced close to zero when road density is increased. Cedar is found almost exclusively in older stands (>100 years) so the difference between cedar representation between high and low road density is related to a much smaller proportion of old stands containing cedar. This might be due either to illegal harvest (Shvidenko and Nilsson, 1994) or to some other restricting factor (e.g., flooding) (Korzukhin *et al.*, 1989).

More of the seven tree species are significantly represented at low dominance levels (i.e., 0-30%) than at high levels (i.e., 70-100%) for all five landscapes. The road density nevertheless decreases the species richness of dominating species somewhat from three to one in lingonberry-dominated landscapes and three to two or three in moss- and herb-dominated landscapes. For tree species found at low densities, both the total percentage of stands containing tree species represented at densities below 35% and the species richness decrease with increased road density. Taken together, this means that stands get more homogeneous in terms of tree-species composition when road density is increasing. This is especially pronounced in young stands (<50 years) (Figure 8), where fewer tree species are represented. Shannon's diversity index for young forest (Shannon and Weaver, 1962) is twice as high for the low-road-density landscape as the high-road-density one. However, the same index only differs 10% between the two landscapes for old forests (>100 years). This leads to the conclusion that the diversity decrease is induced by the human transformation of forest from old to young stages. This is supported by Syrjänen *et al.* (1994) who came to the same conclusion when they studied exploited landscapes in the European part of Russia.

Stand Structure

Arranging the sampled landscapes along road density and forest-floor vegetation did not explain the variation in stand structure represented by the presence of a super-canopy layer (scattered large trees above the main canopy) (Figure 9). A super-canopy layer could be created either by natural disturbance (e.g., fire or wind throw) or by human disturbance (e.g., regeneration under seed trees or high-grading). For four out of the five landscapes, the amount of super-canopy layer varies from three to eight percent. The outlier is the landscape with medium road density dominated by mosses and herbs, which has super-canopy layers of pine, spruce and larch covering 21% of the total area. As suggested above, there could have been a major disturbance event 40 years ago in this landscape. The data show that these super-canopy layers are almost all related to a 40-year-old birch succession shown as high frequencies of 40-year-old forest and birch-dominated stands (Figure 8).

In all landscapes, larch is one of the main super-canopy tree species. The number of tree species presented in super-canopies is increasing when the road density is increasing in the moss- and herb-dominated landscapes from two to three to five and in the lingonberry-dominated landscapes from two to three. In landscapes with low road densities, pine and larch are the only super-canopy layer tree species. In medium-road-density landscapes, spruce is added, and in high-road-density both cedar and birch are added. Whether this is caused by nature or by logging is hard to tell. Possibly the increased number of tree species making up the super-canopy layers can relate to the fact that trees are left on sites after logging (e.g., as shelterwood trees or because they are not desired). Nevertheless, Fries *et al.* (1994) suggested that not only conifers but also broadleaf tree species can be left after logging to enhance biodiversity and mimic naturalness; this study has been unable to discern whether this was the case in the study forest.

Altogether, it seems that forest management in the area keeps super-canopy layers to the same extent as unaffected forest. However, this has not been the case in some other countries (e.g., Finland and Sweden) where very little remains of super-canopy layers (Nilsson, 1992; Fries *et al.*, 1995). A greater concern about this has developed during recent years among forest companies and forest-owner associations in Scandinavia.

4.3.2. Relations between Abiotic and Biotic Variables

To describe how relations change along the road-density gradient and forest-floor vegetation gradient, and also how variables are related to each other, regression analysis was carried out. The main idea was to see if and how abiotic variables affect biotic variables (e.g., vegetation characteristics). Such effects could be related either to natural processes or to human behavior (when carrying out forest operations), or both if human influence is related to natural processes. All detailed results are found in Appendices I–V.

It has been suggested (Bonan and Shugart, 1989) that abiotic factors control vegetation. This control should be readily detectable when the range of the abiotic factors is wide. However, if the resolution of abiotic data is fine, as in landscapes of the size 10^4 to 10^5 ha where forest inventory data are available, external disturbances might destroy the patterns otherwise created by abiotic factors mapped at a broader scale. In Scandinavia, silvicultural methods are to a large extent chosen based on the soil characteristics including soil moisture content and fertility (Lundmark, 1986; Angelstam *et al.*, 1993). The choices are often made on a stand level and sometimes on a landscape level, the same resolution as in the Ust-Ilimsk data set. Such choices constitute a strategy where there is a desire to mimic natural patterns. Does this hold true in areas with low road density in Siberian forests? To test this, regression analysis was carried out. Biotic dependent variables included stand age, super canopy, density, tree species and forest type (as presented above). Abiotic independent variables were fertility, soil-moisture content and site index.

Structure: distribution of age-classes, super-canopy layer and density. The distribution of the dependent biotic variables age class, super-canopy layer and density is not explained by the available independent variables at low road densities (Table 3). This is not changed when road density becomes higher, suggesting that forest operations are carried out without considering any relations between the dependent and independent variables but are controlled by other factors like accessibility. The abiotic variables alone do not determine stand management in a way that affects age class, super-canopy layer or density.

Composition: distribution of tree species. The distribution of percentage of broadleaf pioneers is somewhat better predicted in lingonberry-dominated landscapes than moss- and herb-dominated landscapes by the chosen independent variables (Table 3). Average adjusted R decreases from 0,20 in the former landscapes to 0,13 in the latter. The prediction for conifers moderately tolerant to fire shows the same pattern, with average adjusted R decreasing from 0,28 to 0,13. However, species not tolerant to fire do not show the same pattern. Instead, the adjusted R is high for all landscapes. Only the moss- and herb-dominated landscapes with medium road density show low adjusted R. I suggest that a larger proportion of post-fire succession in this landscape than in the others explains the weaker relations between the representation of spruce and fir and the independent variables. The large disturbance that occurred some 40 years ago then destroyed the relations that were found in the other landscapes between the biotic and the abiotic variables. If this assumption is true, the relations that show up in the four out of the five landscapes is not stable in fire-driven landscapes. Swanson *et al.* (1988) argued, in accordance with this, that major landforms (e.g., major ridges and valley bottoms) provide shelter from disturbances (e.g., fire or wind) so that the landscape relief is in such situations more important in determining stand boundaries than other topographic positions.

Road density does not change the adjusted R for either representation of broadleaf or representation of conifers not tolerant to fire, indicating that logging is not affecting these relations the way it is carried out (Table 3). The regression models for pine, larch and cedar, however, get worse in predicting the representation of these tree species when road density is increasing in the landscapes dominated by mosses and herbs. Logging might therefore have an impact on these tree species so that the relation that was found between the representation of pine, larch and cedar and moist and site index is either lost or weakened.

Moisture is the overall best predictor for the lingonberry-dominated landscapes (Table 4). Both broadleaf and spruce-fir are positively correlated with moisture which means that the percentage of these tree species at the stand level is higher when the ground is more moist. The tree species moderately tolerant to fire show the opposite correlation. Moisture might therefore be an abiotic variable which could help one make silvicultural decisions regarding composition in lingonberry-dominated landscapes, even though it explains far from all the variation as mentioned above. Moisture also is highly significant in predicting spruce-fir and pine-larch-cedar representation in moss- and herb-dominated landscapes.

The negative correlation between fertility and the representation of spruce and fir indicates that higher proportions are to be found on less fertile sites. This result does not agree with other findings where spruce and fir are considered nutrient demanding (Korzukhin *et al.*, 1989). The explanation for this could, for example, be that the independent variable for describing fertility used in this study does not truly express nutrient availability, or that some other factor, such as fire, destroyed the expected representation of spruce and fir.

Forest-type and age-class distribution and representation. Relations between age-class distribution of the three forest types and fertility, moisture and site index change when logging is done (Table 3). The results also indicate that the natural variation is bigger than that created by human impact by not arranging the landscapes with different road densities in clear trends (e.g., the adjusted R and the coefficients for independent variables do not line up in a trend).

The age-class distribution of conifers moderately tolerant to fire is to a certain extent affected by fertility, moisture content and site index in landscapes with low road density (adjusted R ranges from 0,11 to 0,37) as is that of broadleaf pioneers (adjusted R 0,22) and conifers not tolerant to fire (adjusted R 0,47) (Table 3).

The overall best predictor for age-class distribution is site index (Table 4). For conifers moderately tolerant to fire, fertility and moisture are also significant predictors. While the coefficients are consistently negative for site index as a predictor of the age-class distribution of broadleaf pioneers, the sign changes between landscapes in both conifers moderately tolerant to fire and conifers not tolerant to fire. For the moss- and herb-dominated landscapes with low road density, the sign is always negative, showing that the higher productivity sites are occupied by the older forest. When road density is increased to high, however, this relation is changed to the opposite. This could be due to logging of old stands on high productivity sites, creating a greater proportion of young forest on these sites.

Conclusion. The main impression is that other independent variables (e.g., landforms, broad-scale soil characteristics) are also needed to predict the dependent biotic variables. This means that the soil characteristics available for this study do not always give support in deciding silvicultural methods if the goal is to mimic natural relations.

4.3.3. Spatial Description of the Forests

Humans can affect forest structure, composition and relations as shown above. It is also possible that landscape patterns change due to human influences. In this study a number of spatial descriptors were calculated for each of the five landscapes based on the classification of forest according to age and fire regime.

Changes of Representation of Forest Type

The most significant change of forest types between different road densities is the transformation of old succession pine, larch and cedar forest (Figures 6, 7, and 9) to younger successions of pine and broad-leaves. The amount of young pine-dominated stands increases dramatically which could lead to a lack of broadleaf-dominated stands in the future (even if no such lack could be observed today in the landscape with high road density). Approximately 15% of the landscape with low road density consists of pioneer broadleaf-dominated stands. Decreasing that more could be critical in terms of habitat isolation (Andrén, 1995). The differences between the lingonberry-dominated landscapes are much smaller.

In the landscape with high road density, a relatively large percentage of old broadleaf stands is found (Figure 10). These are still not overtaken by other later successional species like spruce, and fir or possibly by larch, pine or cedar. This seems to be happening, however, in the other landscapes where the percentage of old broadleaf stands is low. This might be due to abiotic factors such as high water table which could delay or even hinder the succession with conifers. For example, Korzukhin *et al.* (1989) described birch and aspen as more tolerant to low soil oxygen availability. In the other landscapes, succession of broad-leaves to conifers seems to be finished when the stands become more than 100 years.

Spatial Changes at the Landscape Level

Road density. The main spatial descriptors that change on a landscape level when road density becomes high are the size of the largest patch index, patch size standard deviation, Shannon's diversity index and the contagion (Table 5). Changes are here referred to as more than 10% change between low and high road density. All the others are stable when road density changes. Scattered logging in the moss- and herb-dominated landscapes with high road density has affected the size of the largest patch so that it is 50 to 60% of the size in landscapes with medium and low road density. There is a correlation between largest patch index and contagion since contagion measures the aggregation of raster/pixels with the same forest type. Thus a high value of contagion may result from landscapes with a few large, contiguous patches. On the other hand, lower values generally characterize landscapes with many small and dispersed patches so the fragmentation after logging is reflected in both. Nevertheless, contagion seems to be the more sensitive descriptor since the increase in road density from low to medium is not at all reflected by largest patch index but is to some extent by contagion.

The diversity increase with road density means an increased probability of two randomly chosen patches having a different forest type. The rise in diversity could be related to the dominance of old pine, larch and cedar forest in the landscape with low road density, making the unexploited landscape homogeneous. The patch size standard deviation is decreased when road density is increased. This could be explained by the fact that the largest patch is much bigger in the landscape with low road density. At the same time the data show an unexpected result, namely that the amount of very small patches (<20 ha) is equal in the moss- and herb-dominated landscapes with high and low road density (Figure 11). Results from Canada show that fire suppression creates a skewed distribution of fire-size distribution (Ward and Tithecott, 1993). From an almost normal distribution when the fires can develop freely, the distribution becomes negative exponential, with a high proportion of small fires creating many small patches. Possibly this can explain the unexpected high proportion of small patches in the moss- and herb-dominated landscapes with low road density.

Forest-floor vegetation. The type of forest-floor vegetation seems to correlate with some of the spatial characteristics. Those which are different between moss-herb and lingonberry-dominated landscapes are largest patch index, patch density, mean patch size, patch size standard deviation, edge density, Shannon's diversity index and interspersion and juxtaposition index (interspersion and juxtaposition index measures the extent to which patches are interspersed; higher values result from landscapes in which patch types are well interspersed i.e equally adjacent to each other). This suggests that the lingonberry-dominated landscapes are more homogeneous (i.e., fewer differences in forest type over the landscape). This could be related to higher frequency of broad-scale disturbances (e.g., fire) (Zachrisson, 1977) and less representation of tree species due to limitations in nutrient availability (Korzukhin *et al.*, 1989).

Spatial Changes at the Forest-type Level

Road density. Dissolving landscape patterns into patterns for each forest type demonstrates that the main changes are related to young and old pine, larch and cedar stands (Table 6). These patches show changes in largest patch index, patch density, mean patch size, patch size standard deviation, edge density and area-weighted mean shape index when road density is increasing. I suggest that they are all related to logging. Not so astonishing is that the largest patch index, patch density and mean patch size increase for young pine, larch and cedar forests when road density becomes high. More surprising is the area-weighted mean shape index increase, describing a more irregular shape of these patches in the moss- and herb-dominated landscape with high road density. My suggestion is that this is related to a checker-boarder like pattern, produced by logging activities, with long edges.

The change in patterns for old pine-larch-cedar forests is opposite to the changes in young pine-larch-cedar forests. As average patch size and largest patch index become smaller with increased road density in old pine-larch-cedar forest, the contrary is happening for young pine-larch-cedar forest. The patch density, however, increases in both cases which means that the number of patches increases. This is happening when logging starts to fragment the old forest by the scattered clearcuts occupying the landscape. However, there has to be a certain density of clearcuts before the isolation of old forest patches starts to occur. In this study no isolation of old forest was found when road density is medium (30 km/10,000 ha). This indicates that increasing road density from medium to high (100 km/10,000 ha) might result in fragmentation beginning to occur (compare with Plinte, this volume).

Forest-floor vegetation. For the forest types spruce-fir and birch-aspen, no significant changes could be found in spatial patterns that are consistent among both types of landscapes (different forest-floor vegetation). The exception is young birch-aspen patch density and edge density which both decrease when road density becomes high. However, between the two types of landscapes, differences in patch density and interspersion and juxtaposition index show up for tree species not tolerant to fire and broadleaf pioneer species. Also, for the matrix of tree species moderately tolerant to fire, the interspersion and juxtaposition index is smaller in the lingonberry-dominated landscapes which furthermore demonstrates the lower interspersion in these landscapes. I suggest that these differences are related to the different abiotic conditions and refer to the more homogeneous patterns in the lingonberry-dominated landscapes, as discussed above.

Patch-size Distribution in Moss- and Herb-dominated Landscapes

The U-shaped distribution of old pine, larch and cedar patches in the landscape with low road density changes toward an inverse-J shape as road density increases (Figure 12). The matrix of old forest is obviously fragmented into a finer-grained landscape of various forest types, indicating that forest operations have been carried out in this forest type.

Young successions of pioneer broad-leaves show a higher amount of small patches in the landscapes with low and medium road density, suggesting that the natural disturbances generally are small and that logging may sometimes destroy small patches in between larger patches of desired timber (Figure 12). The same explanation could be used for the lower representation of small patches of old spruce and fir (Figure 12). Also, in young pine, larch and cedar stands, the representation is higher in the low-road-density landscape. There is an unexpected result in that the representation of large patches of spruce and fir is higher in the high-road-density landscape. This could be explained either by natural variation occurring in landscapes over time, or by some other factor not examined in this study. Higher distribution of young pine, larch and cedar above 60 ha shows up in the landscape with high road density. These patches are suggested to relate to the size of the clearcuts created, which has been found to range between 50 to 500 ha.

4.4. Conclusions

I have drawn the following main conclusions from the study:

The transformation of old forest to young by logging is the major change of the structure of the forests. The lack of very old forest (over 200 years) in managed areas might have important effects on fauna and flora species dependent on late successions. Also, forest-type patterns are significantly changed in managed landscapes, showing a higher degree of fragmentation. The matrix of old pine, larch and cedar forest that dominates the unmanaged landscapes gets fragmented when road density becomes high (100 km per 10,000 ha).

Soil characteristics, such as fertility, site index and soil moisture content, can to a certain extent be related to the composition of the forest. However, these relations are not necessarily stable over time when external disturbances (e.g., fire) are driving the system conditions and therefore the relations do not show up as strongly as expected. These relations are, it seams, somewhat destroyed by natural external disturbances.

Change in diversity is ambiguous when landscapes of different degrees of exploitation for timber purposes are evaluated. Diversity can both increase and decrease when logging is carried out. This conclusion is supported indirectly by others who claim that, for example, fire control can either decrease or increase diversity depending on the initial fire frequency (Suffling, 1991). Suffling (1991) found that forest-type diversity reached an optimum when fire frequency was intermediate, leading to a greater mixture of early and old successions. I suggest that the same is happening when timber management is carried out in uniform forest landscapes like the ones in this study. Forest landscapes subject to uniform disturbance (i.e., disturbance regime, frequency and intensity) would be uniformly structured (e.g., with a high amount of mature mosaic), and would if the disturbance intensity or type (e.g., timber management is introduced to a pristine area) are changed, produce new habitats and in turn increase the diversity. Uniform disturbances can occur as a result of for example fire suppression (Suffling, 1991) or flat topography (Swanson *et al.*, 1988). In this study it seems like low landscape diversity in pristine forests has been registered as a result of these two factors.

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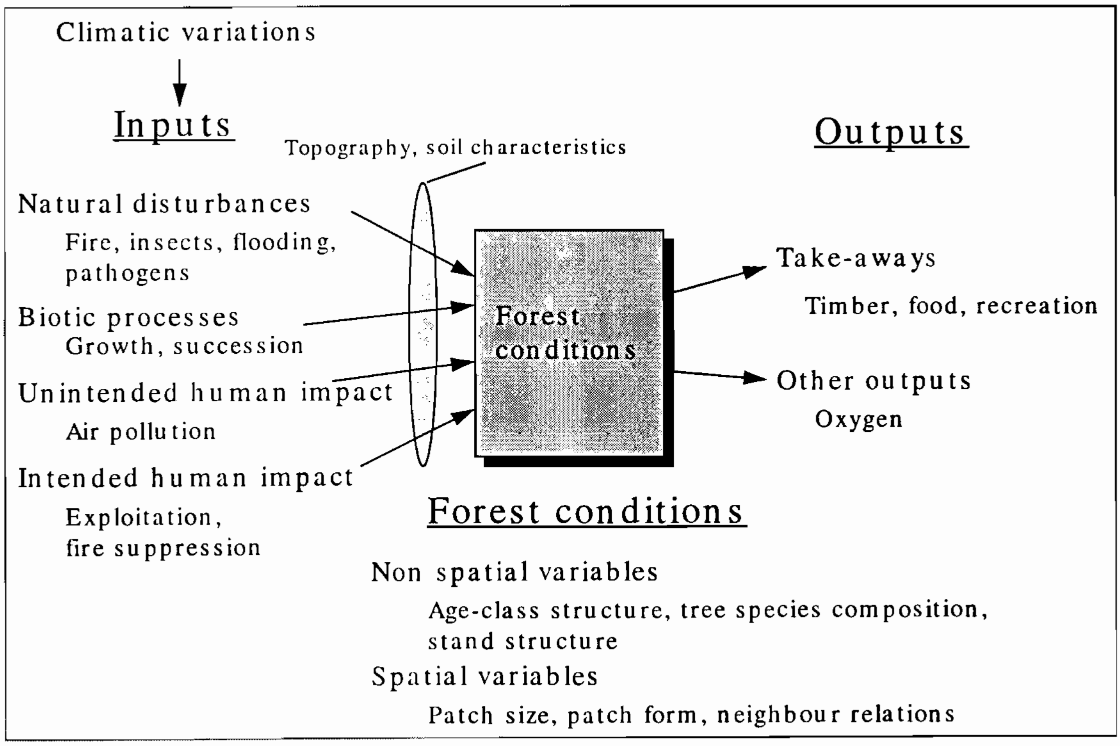


Figure 1. A conceptual model of the system studied.

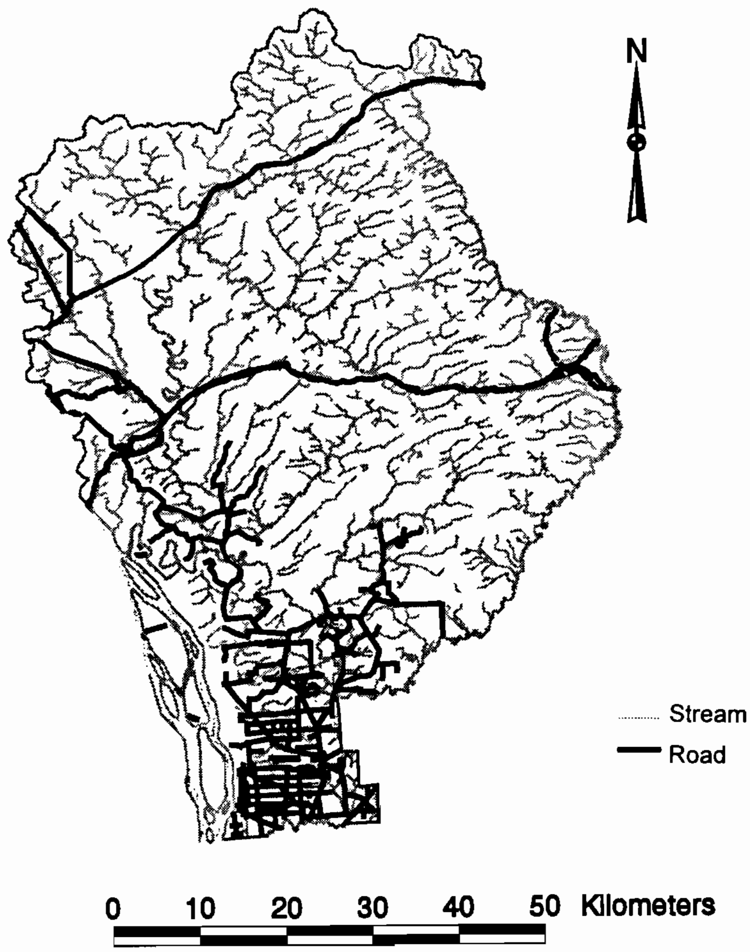


Figure 2. The roads in Katinsky forestry enterprise. Road density is much higher in the south where exploitation of the forests has been going on for decades.

Soil fertility

Soil fertility	Very dry	Dry	Mesic	Moisture	Very moisture	Marsh
Rich	-	-	-	Herbs and herbs-green moss	Large grass	Alder and riparian zones
Fairly rich	-	-	Lingonberry-herbs	Blue berry and green moss	Herbs-sedge	Sedge
Fairly poor	-	Lingonberry	Lingonberry-green moss	-	Ledum	-
Poor	Very thin humus layer	-	-	-	-	Bog moss

Soil moisture content

Figure 5. The classification of forest-floor vegetation along dimensions of fertility and soil moisture content (Shvidenko, 1995, personal communication).

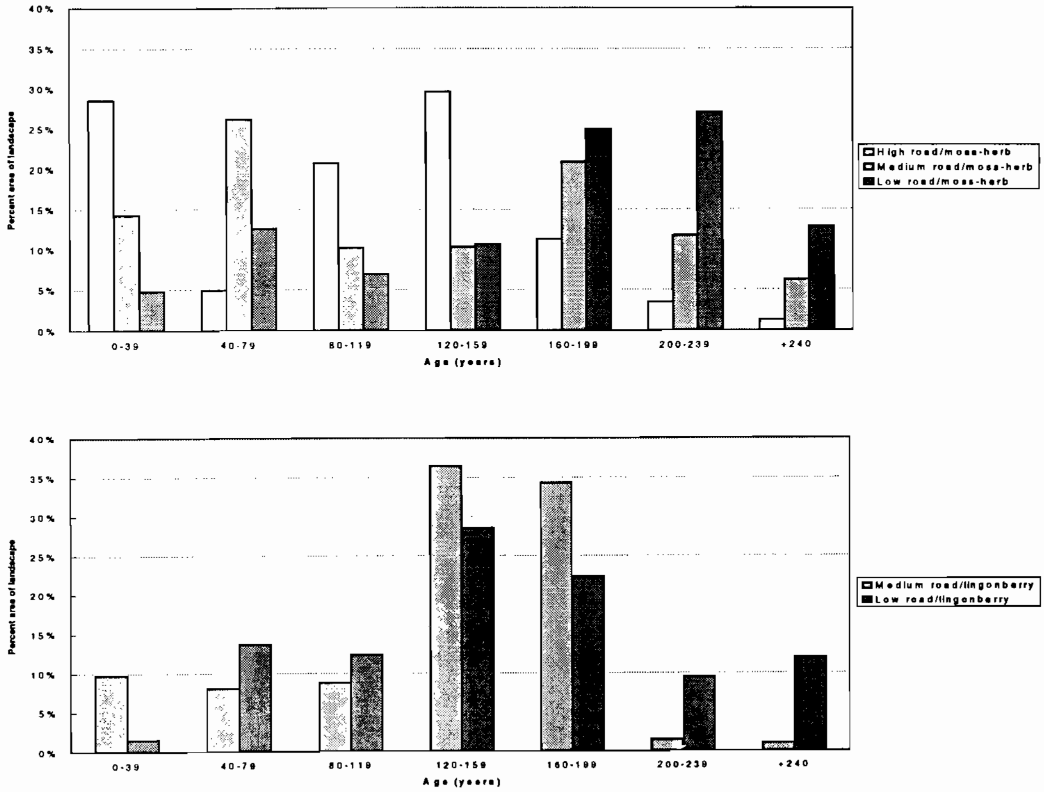


Figure 6. Age-class distribution in the landscapes where the forest-floor vegetation is dominated by mosses and herbs (above) and lingonberry (below).

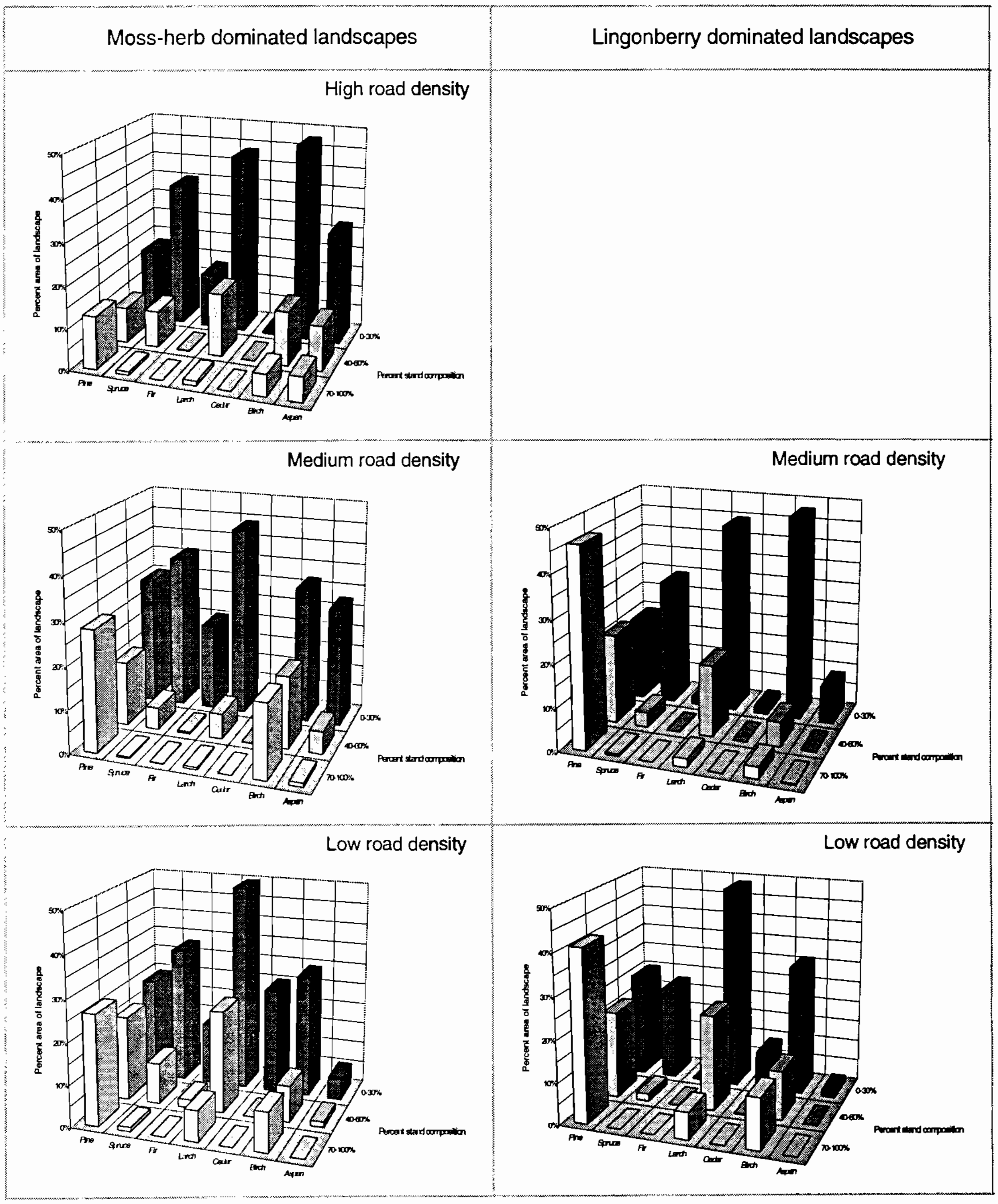


Figure 7. Tree-species composition in the defined landscapes.

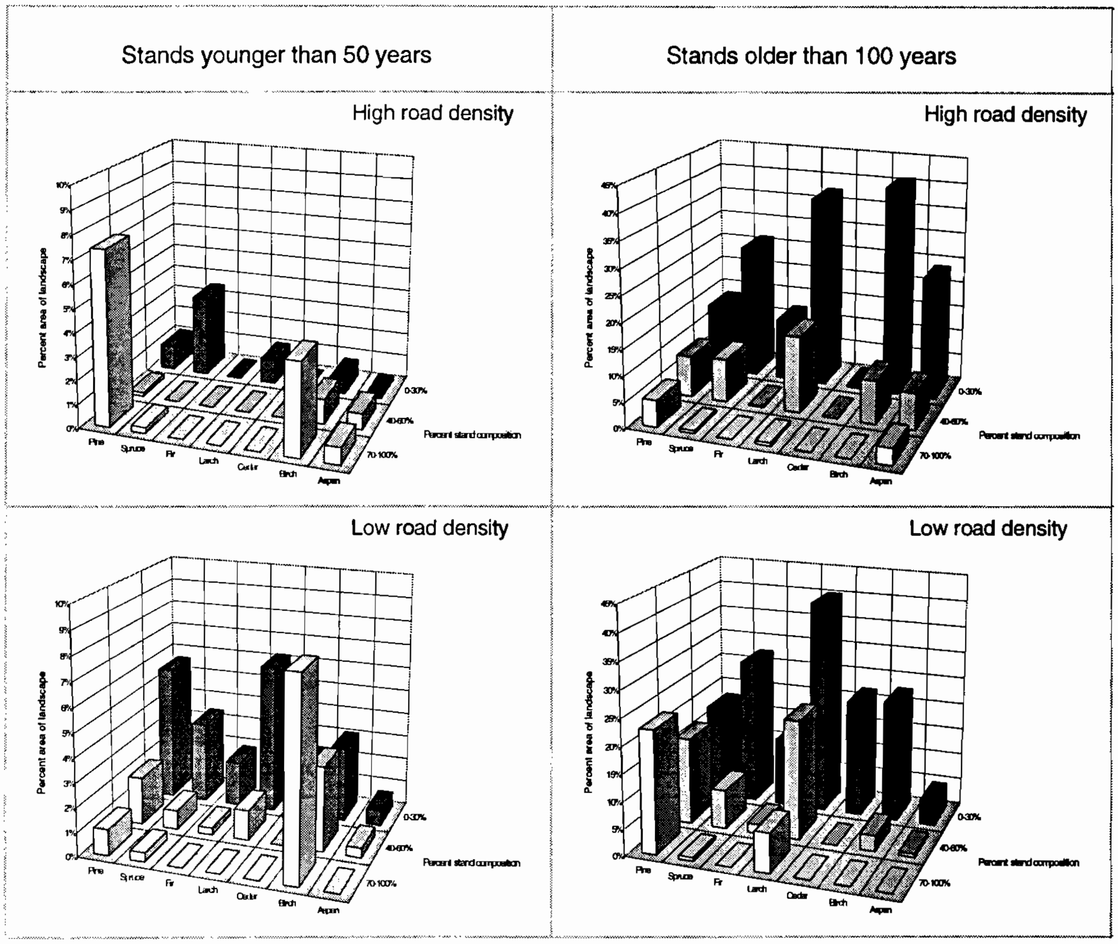


Figure 8. Tree-species composition for stands younger than 50 years and older than 100 years in the moss- and herb-dominated landscapes.

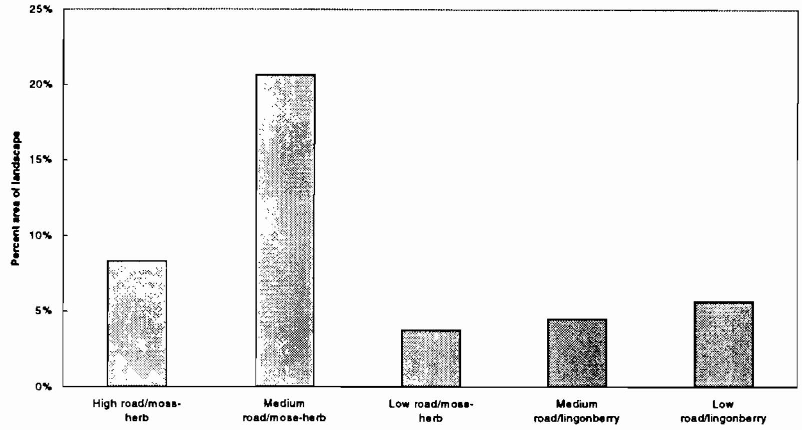


Figure 9. The amount of super-canopy layers in the studied landscapes. Super-canopy layers involve the presence of scattered large trees above the main canopy.

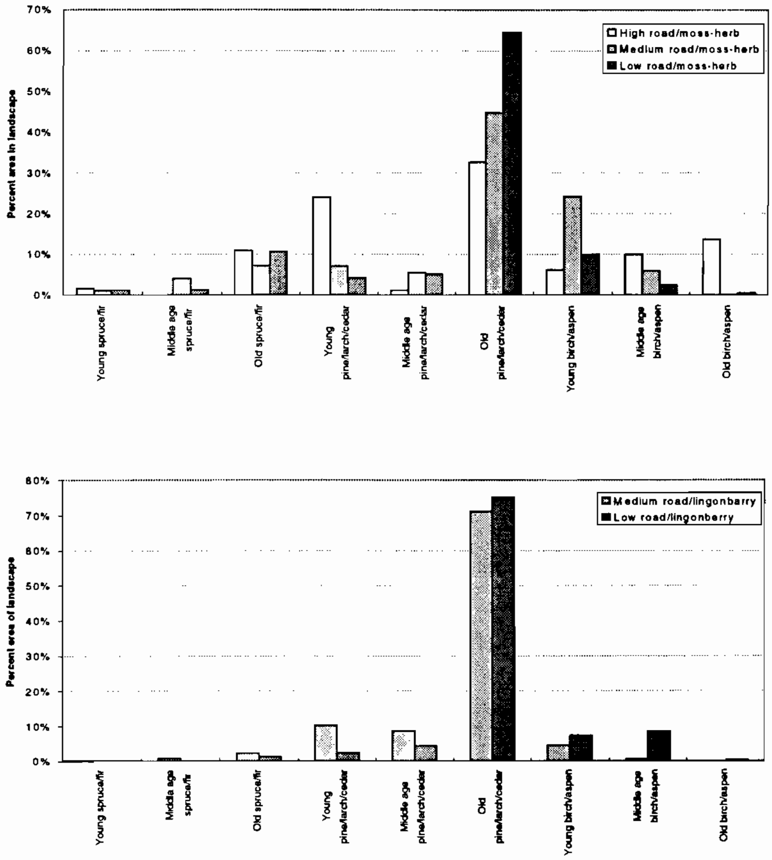


Figure 10. Forest-type distribution in the defined landscapes.

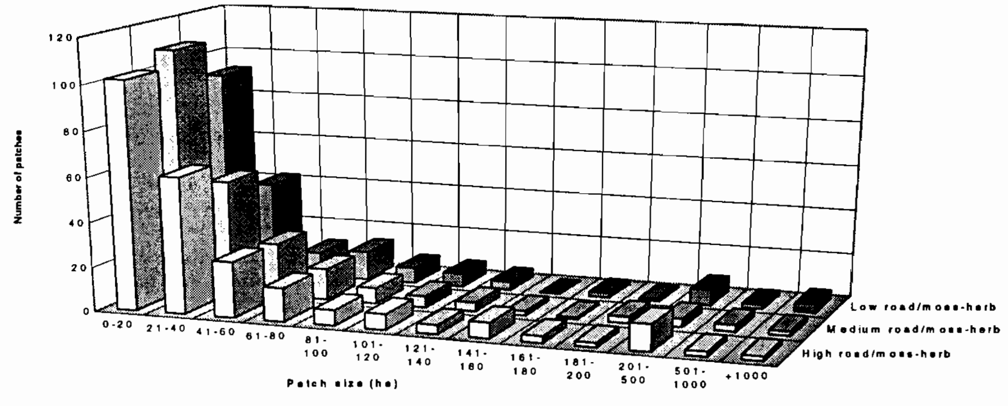


Figure 11. Patch-size distribution for the moss- and herb-dominated landscapes.

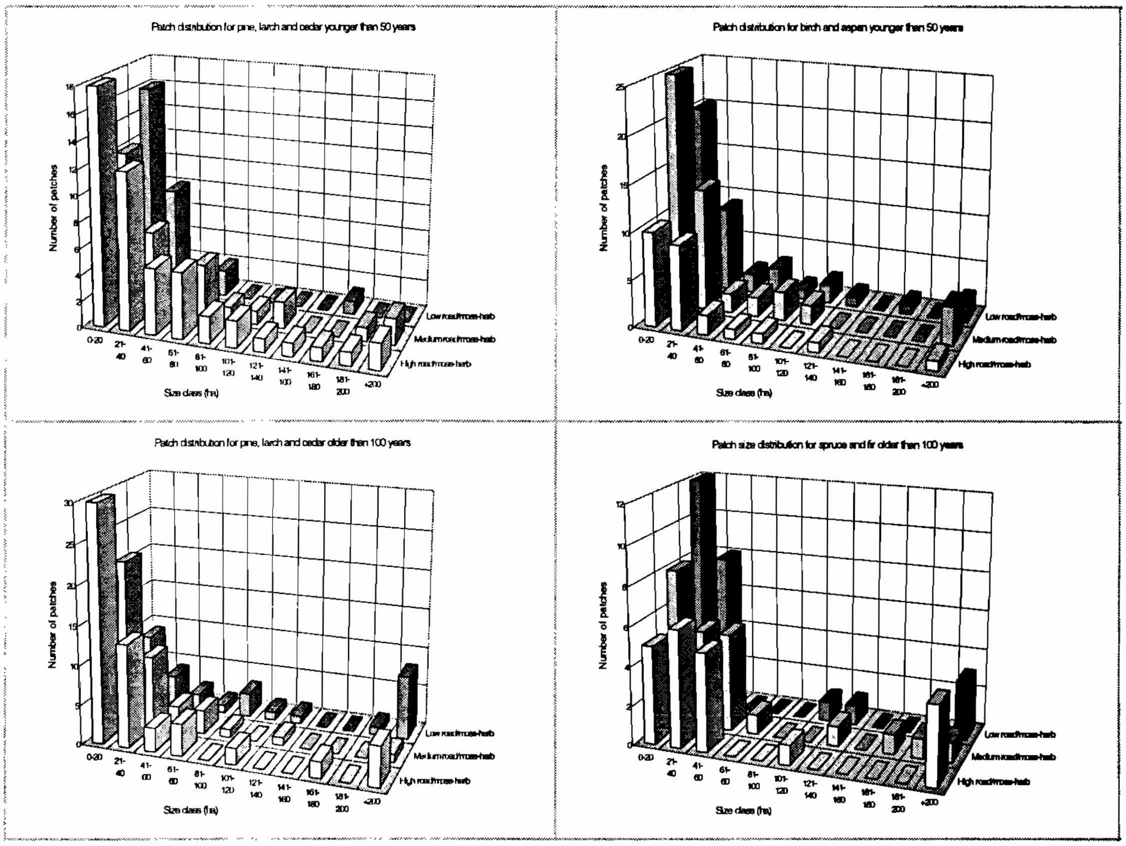


Figure 12. Patch-size distribution for some forest types presumed to be affected by logging.

Table 1. The five sampled landscapes along the gradients road density and forest-floor vegetation.

	Forest-floor vegetation	
Road density	Lingonberry	Mosses-herbs
Low	LW	LM
Medium	MW	MM
High	-*	HM

*No landscape was found with lingonberry-dominated forest-floor vegetation and high road density

Table 2. Road density and area of the five defined landscapes.

	Area (ha)	Road density (km/10.000 ha)
HM	18.621	106
MM	17.629	28
LM	19.329	1
MW	17.376	17
LW	17.724	6

Table 3. Increasing adjusted R for the best linear regression model found.

Dependent variables	Moss and herb dominated landscapes	Lingonberry-dominated landscapes
Age	MM = 0,036	MW = -0,0049
	HM = 0,065	LW = 0,064
	LM = 0,16	
Super-canopy	MM = -0,0023	MW = 0,031
	HM = 0,020	LW = 0,044
	LM = 0,072	
Density	MM = 0,023	MW = 0,0025
	HM = 0,064	LW = -0,017
	LM = 0,089	
Broadleaf pioneers (age)	LM = 0,16	LW = 0,050
	MM = 0,22	MW = 0,21
	HM = 0,27	
Conifers moderately tolerant to fire (age)	MM = 0,033	MW = -0,0040
	HM = 0,11	LW = 0,37
	LM = 0,28	
Conifers not tolerant to fire (age)	MM = 0,014	LW = *
	HM = 0,18	MW = *
	LM = 0,47	
Broadleaf pioneers (density)	HM = 0,091	LW = 0,20
	LM = 0,14	MW = 0,21
	MM = 0,17	
Conifers moderately tolerant to fire (density)	HM = 0,038	MW = 0,26
	MM = 0,14	LW = 0,30
	LM = 0,20	
Conifers not tolerant to fire (density)	MM = 0,11	LW = 0,21
	LM = 0,33	MW = 0,41
	HM=0,40	

* Too few observations to make regression analysis

Table 4. P-values of the independent variables fertility, moisture and site index arranged in increasing order from top to bottom. Only significant independent variables at the 5% level or better are presented.

	Fertility		Moisture		Site index	
Dependent variables						
Age	LM*** HM*** MM**				LM*** HM** MM*	
Super-canopy		LW**	LM**	MW** LW*	LM*** HM*	
Density	LM*** HM** MM*				HM***	
Broadleaf pioneers (age)		-	MM*** -		HM*** LM*** MM**	-
Conifers moderately tolerant to fire (age)	HM*** LM*	LW***	HM** LM**	LW**	LM*** HM** LM**	LW***
Conifers not tolerant to fire (age)		- -		- -	LM*** HM**	- -
Broadleaf pioneers (percentage)	LM*** MM***	MW***	HM*	LW*** MW**	MM*** HM*** LM***	MW***
Conifers moderately tolerant to fire (percentage)		LW*	LM*** MM*** HM**	MW*** LW***	MM** LM*	
Conifers not tolerant to fire (percentage)	LM*** HM*** MM***	MW*** LW**	LM*** HM*** MM***	MW*** LW***		MW*

- Too few observations to be able to do regression analysis.
* Significant at 5% level, ** significant at 1% level, *** significant at 0,1% level.

Table 5. Spatial descriptors of the defined landscapes at landscape level.

Land-scape	TA (ha)	LPI (%)	PD (#/100ha)	MPS (ha)	PSSD (ha)	ED (m/ha)	AWMSI	AWMPFD	SHDI	PRD (#/100 ha)	SHEI	IJI (%)	CONTAG (%)
HM	18.621	18	1,25	80	266	40,2	4,28	1,15	1,75	0,05	0,79	72	59
MM	17.629	34	1,30	77	410	42,7	5,69	1,18	1,59	0,05	0,72	75	62
LM	19.329	29	0,99	101	447	36,5	4,16	1,17	1,27	0,05	0,58	71	70
MW	17.376	65	0,78	128	958	27,8	6,75	1,19	1,06	0,05	0,48	62	75
LW	17.724	58	0,64	155	957	26,6	4,96	1,17	0,96	0,06	0,42	57	78

(HM = high road density and moss- and herb-dominated, MM = medium road density and moss- and herb-dominated, LM low road density and moss- and herb-dominated, MW = medium road density and lingonberry-dominated, LW = low road density and lingonberry-dominated)

(TA = total landscape area, LPI = largest patch index, PD = patch density, MPS = mean patch size, PSSD = patch size standard deviation, ED = edge density, AWMSI = area weighted mean shape index, AWMPFD = area weighted mean patch fractal dimension, SHDI = Shannons diversity index, PRD = patch richness density, SHEI = Shannons evenness index, IJI = interspersion and juxtaposition index)

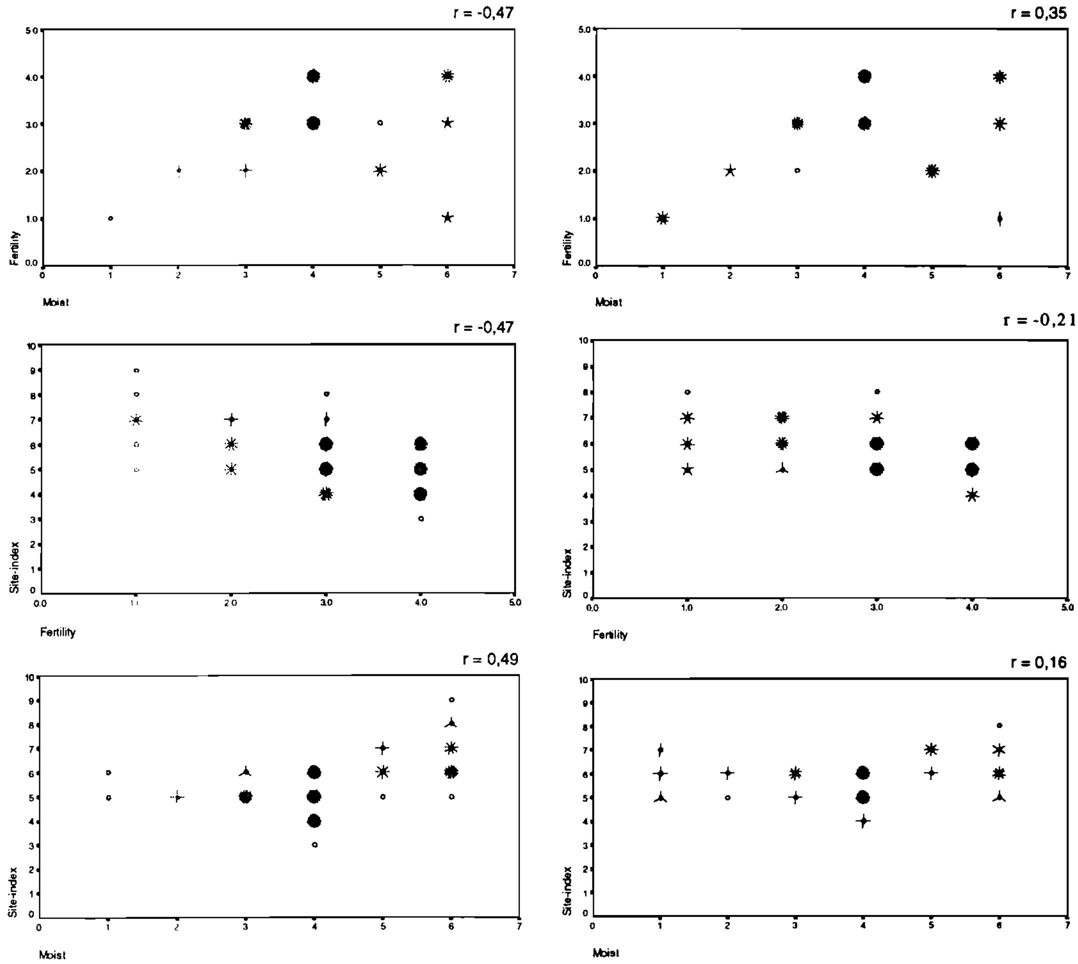
Table 6. Spatial descriptors of the defined landscapes at forest type level.

Landscape	TYPE	LPI (%)	PD (#/100 ha)	MPS (HA)	PSSD (HA)	ED (m/ha)	AWMSI	AWMPFD	IJI (%)
Medium road/lingonberry	0	2	0	74	131	6	4,8	1,2	62
Low road/lingonberry	0	0	0	41	16	2	1,6	1,1	45
High road/moss-herb	1	1	0	38	46	2	2,6	1,1	57
Medium road/moss-herb	1	0	0,1	17	13	2	2,0	1,1	64
Low road/moss-herb	1	0	0,1	26	18	2	2,3	1,1	64
Medium road/lingonberry	1	0	0	9	2	0	1,7	1,1	47
Low road/lingonberry	1	0	0	22	0	0	2,5	1,2	11
High road/moss-herb	2	0	0	20	0	0	1,7	1,1	48
Medium road/moss-herb	2	1	0,1	36	31	5	2,5	1,1	66
Low road/moss-herb	2	0	0	36	29	2	3,5	1,2	55
Medium road/lingonberry	2	1	0	42	36	1	2,6	1,1	37
Low road/lingonberry	2	0	0	6	0	0	2,8	1,2	6
High road/moss-herb	3	3	0,1	97	138	11	3,8	1,2	70
Medium road/moss-herb	3	1	0,1	55	64	9	2,9	1,2	67
Low road/moss-herb	3	4	0,1	83	166	13	4,7	1,2	61
Medium road/lingonberry	3	0	0,1	30	21	3	2,3	1,1	61
Low road/lingonberry	3	0	0,1	19	13	3	3,2	1,2	15
High road/moss-herb	4	11	0,3	89	290	13	3,2	1,1	54
Medium road/moss-herb	4	1	0,2	32	42	9	2,4	1,1	65
Low road/moss-herb	4	1	0,2	28	34	5	2,0	1,1	64
Medium road/lingonberry	4	3	0,2	54	80	10	2,8	1,1	47
Low road/lingonberry	4	0	0,1	28	26	3	1,8	1,1	56
High road/moss-herb	5	1	0	34	31	1	2,0	1,1	82
Medium road/moss-herb	5	1	0,2	30	34	6	1,8	1,1	69
Low road/moss-herb	5	1	0,2	33	30	6	2,1	1,1	70
Medium road/lingonberry	5	1	0,3	33	39	9	2,0	1,1	48
Low road/lingonberry	5	1	0,1	35	25	6	2,5	1,1	46
High road/moss-herb	6	18	0,3	103	426	27	7,1	1,2	80
Medium road/moss-herb	6	34	0,2	255	1055	28	9,2	1,2	85
Low road/moss-herb	6	29	0,2	416	1061	27	4,7	1,2	84
Medium road/lingonberry	6	65	0,1	772	2704	23	8,5	1,2	77
Low road/lingonberry	6	58	0,1	606	2115	23	5,5	1,2	76
High road/moss-herb	7	2	0,1	46	89	6	2,5	1,1	66
Medium road/moss-herb	7	8	0,3	83	219	18	3,2	1,2	69
Low road/moss-herb	7	1	0,2	47	59	13	2,9	1,2	57
Medium road/lingonberry	7	1	0,1	51	27	5	2,3	1,1	44
Low road/lingonberry	7	1	0,1	61	64	8	2,8	1,1	32
High road/moss-herb	8	2	0,2	53	60	9	2,0	1,1	74
Medium road/moss-herb	8	1	0,1	53	58	8	3,2	1,2	75
Low road/moss-herb	8	1	0,1	31	34	4	3,5	1,2	59
Medium road/lingonberry	8	0	0	22	10	1	1,6	1,1	64
Low road/lingonberry	8	4	0,1	99	167	9	4,7	1,2	42
High road/moss-herb	9	4	0,2	91	149	10	2,7	1,1	72
Medium road/moss-herb	9	0	0	16	0	0	1,6	1,1	0
Low road/moss-herb	9	0	0	24	25	1	1,9	1,1	23
Medium road/lingonberry	9	0	0	0	0	0	0,0	0,0	0
Low road/lingonberry	9	0	0	17	3	0	2,7	1,2	38

(HM = high road density and moss- and herb-dominated, MM = medium road density and moss- and herb-dominated, LM low road density and moss- and herb-dominated, MW = medium road density and lingonberry-dominated, LW = low road density and lingonberry-dominated)

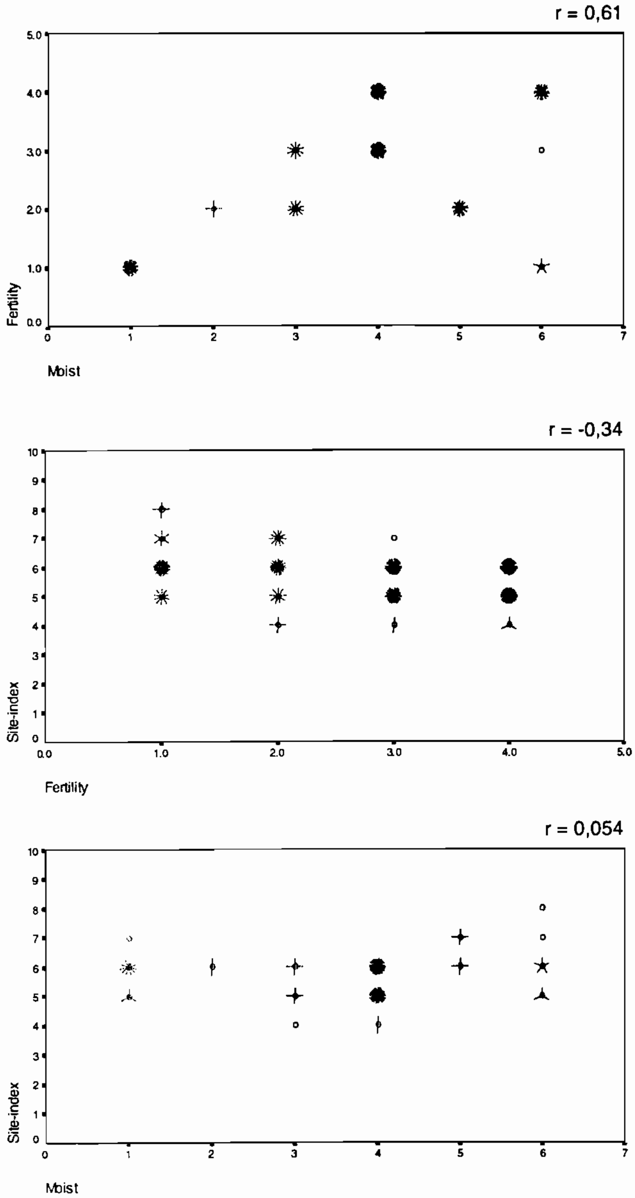
(TYPE = forest type; 0 = non forest land, 1-3 tree species not tolerant to fire 1) 0-50 years, 2) 51-100 years and 3) +100 years, 4-6 tree species moderately tolerant to fire divided in the same age-classes, 7-9 pioneer broadleaf species divided in the same age-classes, TA = total landscape area, LPI = largest patch index, PD = patch density, MPS = mean patch size, PSSD = patch size standard deviation, ED = edge density, AWMSI = area weighted mean shape index, AWMPFD = area weighted mean patch fractal dimension, IJI = interspersion and juxtaposition index)

High road density/moss-herb | Medium road density/moss-heb

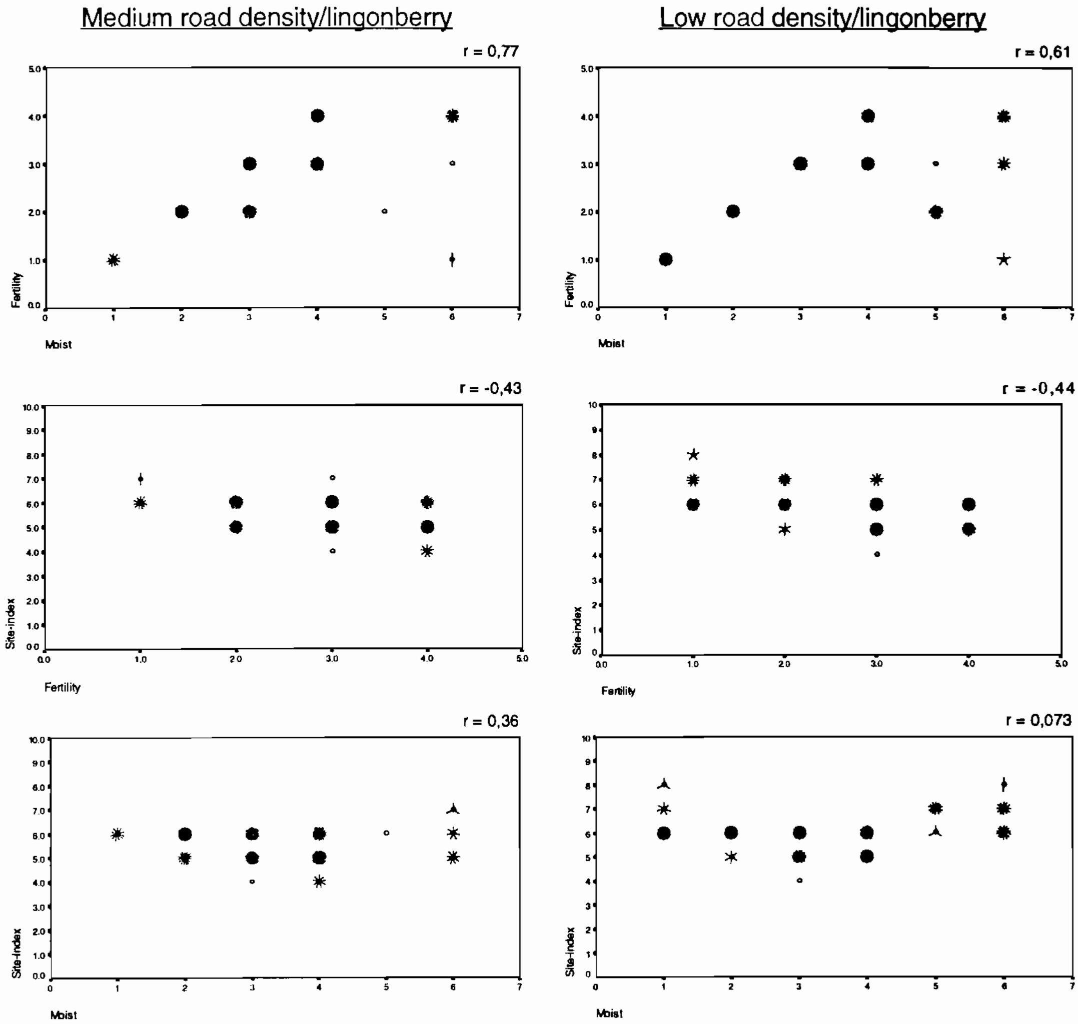


Distribution of the independent variables fertility, site index, and moisture.

Low road density/moss-herb



Distribution of the independent variables fertility, site index, and moisture.



Distribution of the independent variables fertility, site index, and moisture.

Regression models for age versus fertility, moist and site index.

Random sample 25% of the population

	Adj R	n	Significance F	Intercept		Fertility		Moist		Site index	
				Coefficient	P-value	Coefficient	P-value	Coefficient	P-value	Coefficient	P-value
HM	0,065	184	0,0009	298,43	0,0000	**-26,53**	**0,0003**	-	-	**-18,97**	**0,0058**
MM	0,036	210	0,0085	285,74	0,0000	**-21,83**	**0,0048**	-	-	**-17,15**	**0,0453**
LM	0,161	252	0,0000	438,74	0,0000	**-16,38**	**0,0001**	-	-	**-43,22**	**0,0000**
MW	-0,005	191	0,5568	171,18	0,0012	-8,09	0,2524	-0,03	0,9949	-4,44	0,5641
LW	0,064	148	0,0058	250,91	0,0028	11,48	0,2217	-8,30	0,1388	-18,24	0,1473

Bold marked means significant at the 5% level

Regression models for super-canopy versus fertility, moist and site index.

Random sample 25% of the population

	Adj R	n	Significance F	Intercept		Fertility		Moist		Site index	
				Coefficient	P-value	Coefficient	P-value	Coefficient	P-value	Coefficient	P-value
HM	0,020	184	0,0300	-0,18	0,0846	-	-	-	-	**0,04**	**0,0300**
MM	-0,002	210	0,4746	0,29	0,4089	0,04	0,4146	-0,07	0,1277	0,01	0,8049
LM	0,072	252	0,0000	-0,50	0,0002	-	-	**0,04**	**0,0089**	**0,08**	**0,0008**
MW	0,031	191	0,0084	-0,07	0,0904	-	-	**0,03**	**0,0084**	-	-
LW	0,044	148	0,0143	0,17	0,0456	**-0,09**	**0,0071**	**0,05**	**0,0211**	-	-

Bold marked means significant at the 5% level

Regression models for density versus fertility, moist and site index.

Random sample 25% of the population

	Adj R	n	Significance F	Intercept		Fertility		Moist		Site index	
				Coefficient	P-value	Coefficient	P-value	Coefficient	P-value	Coefficient	P-value
HM	0,064	183	0,0009	1,48	0,0000	**-0,09**	**0,0049**	-	-	**-0,11**	**0,0004**
MM	0,023	210	0,0156	0,52	0,0000	**0,04**	**0,0156**	-	-	-	-
LM	0,089	252	0,0000	0,48	0,0000	**0,05**	**0,0000**	-	-	-	-
MW	0,003	191	0,3257	0,58	0,0006	0,01	0,7283	-0,02	0,1244	0,01	0,6687
LW	-0,017	148	0,9246	0,78	0,0000	0,00	0,9721	0,00	0,9252	-0,01	0,6289

Bold marked means significant at the 5% level

Regression models for the percentage of broad leaf pioneer species versus fertility, moist and site index.

Random sample 25% of the population

	Adj R	n	Significance F	Intercept		Fertility		Moist		Site index	
				Coefficient	P-value	Coefficient	P-value	Coefficient	P-value	Coefficient	P-value
HM	0,091	184	0,0001	7,56	0,0000	-	-	**0,82**	**0,0445**	**-1,48**	**0,0000**
MM	0,166	210	0,0000	-12,21	0,0000	**1,46**	**0,0000**	-	-	**1,89**	**0,0000**
LM	0,142	252	0,0000	-6,99	0,0001	**1,13**	**0,0000**	-	-	**1,00**	**0,0003**
MW	0,211	191	0,0000	-6,38	0,0001	**0,76**	**0,0005**	**0,43**	**0,0032**	**0,80**	**0,0008**
LW	0,195	148	0,0000	-0,81	0,1620	-	-	**0,97**	**0,0000**	-	-

Bold marked means significant at the 5% level

Regression models for the percentage of conifer species moderately tolerant to fire versus fertility, moist and site index.

[illegible] of the population

	Adj R	n	Significance F	Intercept		Fertility		Moist		Site index	
				Coefficient	P-value	Coefficient	P-value	Coefficient	P-value	Coefficient	P-value
HM	0,038	184	0,0046	8,52	0,0000	-	-	**-1,06**	**0,0046**	-	-
MM	0,142	210	0,0000	17,71	0,0000	-	-	**-1,29**	**0,0000**	**-1,31**	**0,0011**
LM	0,199	252	0,0000	14,92	0,0000	-	-	**-1,25**	**0,0000**	**-0,67**	**0,0236**
MW	0,264	191	0,0000	11,54	0,0000	-	-	**-1,36**	**0,0000**	-	-
LW	0,300	148	0,0000	10,00	0,0000	**0,80**	**0,0115**	**-1,56**	**0,0000**	-	-

[illegible] significant at the 5% level

Regression models for the percentage of conifer species not tolerant to fire versus fertility, moist and site index.

[illegible] of the population

	Adj R	n	Significance F	Intercept		Fertility		Moist		Site index	
				Coefficient	P-value	Coefficient	P-value	Coefficient	P-value	Coefficient	P-value
HM	0,403	184	0,0000	-0,25	0,7821	**-0,94**	**0,0000**	**1,18**	**0,0000**	-	-
MM	0,108	210	0,0000	0,40	0,5077	**-0,55**	**0,0003**	**0,62**	**0,0000**	-	-
LM	0,332	252	0,0000	-0,37	0,3227	**-0,84**	**0,0000**	**1,15**	**0,0000**	-	-
MW	0,407	191	0,0000	1,32	0,2069	**-0,76**	**0,0000**	**1,06**	**0,0000**	**-0,31**	**0,0469**
LW	0,213	148	0,0000	-0,13	0,6641	**-0,33**	**0,0050**	**0,47**	**0,0000**	-	-

5. Species of Interest in Forest Biodiversity Conservation

by Irina Venevskaia

Abstract

The objective of this paper was to map a number of Siberian keystone species from a biodiversity point of view. The work has been carried out in the form of analyses of Russian literature and data sources on biodiversity. The data have been incorporated in the Siberian Study Database and the ranges for the selected species are described in the GIS-system of the Siberian Forest Study. Currently, there are 45 rare animal species and 18 hunted and trapped animals in the species density database. The work with including rare plant species and medicinal plants in the species density database continues.

From the analyses it can be concluded that rare and endangered animal species are decreasing much faster than rare and threatened plant species. The changed economic conditions in Russia have during the past seven years resulted in an uncontrolled harvest and rapid extinction of rare animals in Siberia.

5.1. Introduction

The legendary Russian scientist M.V. Lomonosov, founder of the Russian Empire Academy of Sciences and the Moscow University, wrote at the beginning of the 18th century: "The power of Russia will increase by Siberian resources". This prediction has become a reality. Today Siberia is the most important Russian region, rich in minerals and other natural resources.

However, the strong invasion of industry and intensive agriculture, as well as direct exploitation of the minerals and biota of Siberia in the 20th century, has led to decreased biological productivity within natural ecosystems. Such negative trends, typical for all Russia, can be seen clearly in the last thirty years, especially in the industrialized regions of Siberia (Sokolov *et al.*, 1994). Such losses of biological productivity affect both species composition and species numbers in all landscapes across Siberia, and especially forests, which form the biggest part of this subcontinent.

Therefore, when dealing with biodiversity in Siberia, we can not avoid the concept of "diversity among species" or *species diversity*, mainly for two reasons: first, species, as the living part of landscapes and connected in complex trophic relationships, are the most sensitive ecological elements to anthropogenic stresses; and second, the species level of biodiversity has a bigger meaning to the general public than other ones, which are well defined only for experts.

The term species diversity is used commonly in mass media as a synonym of biodiversity. For example, N.S. Cooper wrote in 1995:

> "When you walk into a typical English churchyard, you are greeted by a sense of the great diversity of life there . . . Typically, there is a wide range of trees. The subtle texture of the 'grass' is created by the variety of leaf forms that make up the sward. The stonework is decorated by a pastel pattern of lichens and mosses. This sensation of *biodiversity* (italics are mine) is confirmed by studies, largely unpublished, of the importance of churchyard sites for rare and uncommon species".

In particular, *species diversity* is described often as the number of species in a site or habitat. However, in terms of species number alone, life on the Earth appears to consist essentially of insects and microorganisms. Therefore, such an interpretation seems weak from an anthropocentric point of view.

Species are the primary subject of evolutionary mechanisms, and the origination and extinction of species are the principal agents governing biodiversity. On the other hand, species cannot be systematically enumerated with total precision, and the concept of what species are differs for different groups of organisms.

Then, the number of species provides only a partial indication of biodiversity, because we should consider also the extent of variation within and among different species. So, the more different a species is from others, the greater its contribution to any measure of biodiversity. Such measures of "taxonomic distinctiveness" are under development (May, 1994).

The ranking of areas by species diversity is also a problem because it depends on the scale used. So, *species diversity* for an area can differ according to scale and make a different contribution to local, regional or national biodiversity.

Generally, the reasons for spatial variations in species diversity are not fully understood and involve two interconnected questions: the origin of diversity through evolution, and the maintenance of diversity. Therefore, we can only make imprecise propositions when looking into the future (Wilson, 1988).

The most fundamental and irreversible form of biodiversity loss is extinction of species (Pearce and Moran, 1994). However, the loss of biodiversity in the form of critical changes in species abundance is also important as it can lead to genetic erosion and has implications for food supply and sustainability of locally-adapted agriculture and industry.

Siberia is estimated to house close to 4,000 indigenous vascular plant and tree species (Malyshev *et al.*, 1993) and nearly 700 vertebrate animal species (Evsikov, 1990). So, we are forced to concentrate only on some aspects of species diversity, taking into account the general objective and time frame of the Siberian Forest Study and data availability.

There are three main objectives for the species diversity assessment in the frame of the Siberian Forest Study:

- To identify species which can be affected by timber exploitation and by direct consumption;
- To describe their range, ecology and anthropogenic stresses; and
- To analyze their current status and possibly make projections and identify protection measures.

5.2. Principles of Species Enumeration for the Study

"All animals are equal, but some animals are more equal than others" wrote George Orwell in his famous tale "Animal Farm" in 1946. This "pig principle" seems not to be acceptable in species diversity conservation from an *ethical* point of view. Ethics provides a powerful argument against destruction of species diversity, especially from an ecocentric point of view (Holland, 1995). However, there are ethical arguments for species diversity conservation also from an anthropocentric point of view. Only a small proportion of species is actively exploited by humankind. Other species nevertheless may be important for the following reasons:

- They have unused or unknown values at present, but they could raise human well-being if the values were exploited.
- They may become vital in future technologies (Leitzell, 1986).

Arguments for the conservation of species biodiversity for its *aesthetic* appeal have limited force, as they must depend on relative judgment. These arguments also can not counteract the human desire to destroy harmful organisms. However, one can not skip aesthetic non-resource values when speaking about the maintenance of biodiversity (Kellert, 1986).

Many species have *resource* value for humans. These are mainly agricultural species (Randall, 1986). However, local sustainability of some regions can not be maintained only by cultivated plants and livestock; they have also a strong dependency on consumption of wild animals and fishes. The Siberian North, being a homeland of northern indigenous peoples, exemplifies such regions (Stonehouse, 1989). Here, the maintenance of species diversity means saving the cultural heritage of these peoples.

Fur, bones and leather of animals, as well as fiber from some plants, also provide important materials for human use. These species resource values are not as important as food supply, but considerable amounts of species are harvested for these values (Randall, 1986). In addition, such natural products are usually the most expensive goods in national and international trade. Consumption for these purposes may pose a real danger for the existence of the harvested species.

Medicaments derived from natural sources can be ranked second after the food resource value of species. Nearly 120 chemicals extracted in pure form from around 90 species are used in world medicine

(World Conservation Monitoring Center, 1992). Some 80% of the people in less-developed countries rely on traditional medicines for primary health care, despite the availability of modern synthetic medicine (World Conservation Monitoring Center, 1992). There is hope that technological advances within pharmaceutical science will soon allow the design and manufacturing of more synthetic drugs, but nowadays many of the medicinal drugs cannot be manufactured synthetically.

One can see that a pragmatic approach dictates that a variety of equally valid arguments (resource values, ethics and aesthetics) provides a powerful basis for species conservation. I used the following criteria for identification of species for an initial assessment of Siberian species diversity:

1. Ethics (all species have to exist);
2. Socio-economic value (exploited species should be conserved for future generations); and
3. Aesthetics (beautiful species are of great public appeal).

I identified the following types of species of primary interest for the first stage of the Study:

Wild animals:

1. Rare, threatened and endangered species; and
2. Hunted/trapped species.

Higher plants:

1. Rare, threatened, endangered species; and
2. Medicinal species.

Later stages of the study can assume determination of other species, such as those important for the stability of Siberian ecosystems.

Some species have crucial roles in ecosystem dynamics, such as prey, predator, symbiont, or competitor roles. Such species, not dominant but holding crucial roles in ecosystems, are called keystone species (Mills *et al.*, 1993). Most examples of keystone species come from marine ecosystems and application of this concept to forest ecosystems is still being discussed (Lawton and Jones, 1995). However, one can try to find keystone species in Siberian ecosystems. The minimal requirements for such research activity are accurate description of the major forest ecosystems including all the trophic chains and temporal dynamics of species involved.

The more well-known concept for foresters is that of indicator species, which could also be applied in biodiversity assessments for Siberia. This term refers to species that have such a narrow ecological tolerance that their presence or absence is an indicator of environmental conditions (Noss, 1990). Foresters often use the term "indicator" to refer to certain understory plants as an index of site conditions. Nowadays the term "indicator" is used to describe species that are sensitive to environmental degradation. Certain types of widely distributed mosses and lichens so abundant in Siberia can be good indicators for industrial pollution impacts (Treshow and Anderson, 1991). So, application of this concept can be fruitful for estimation of the environmental status of Siberian ecosystems. A search for indicator species is also of interest in ecosystem diversity estimation, i.e., for the next higher level of biodiversity assessment (see chapters by Gluck, Plinte, and Carlsson).

5.3. Methods for Analysis of Species Diversity in Siberia

The following steps have been taken to describe species diversity in Siberian forests:

1. A preliminary analysis of Russian literature and data sources.
2. Collection of data, translation into English, and creation of a biodiversity database at species level.

3. Incorporation of the data into the Siberian Forest Databases (ecoregional and enterprise databases).

4. Description of the ranges of the chosen species by using GIS.

5. Analyzing the dynamics of species.

5.4. Analysis of Russian Literature and Data Sources

Generally, Russian literature contains much information on species ecology, species characteristics, and relations with other species. Data on ranges and numbers of species is relatively scarce. As a rule, all the literature and other sources of information are in Russian. I used the following main sources of information (and some additional sources):

1. For rare, threatened and endangered wild animals, the Red Book of Russia (USSR Academy of Sciences, 1985).

2. For hunted/trapped animals, the proceedings of the Siberian Biological Institute (Evsikov, 1990) and the proceedings of the Central Russian Laboratory on Hunting and Nature Reserves (Nazarov, 1988).

3. For rare, threatened and endangered plants, the Red Book of Russia (USSR Academy of Sciences, 1984).

4. For medicinal plants, the atlas of areas and resources of medicinal plants of USSR (Institute of Medicinal Plants of USSR, 1980).

Further steps assume a concentration on some of the species identified and, therefore, a search for deeper descriptions of the chosen species to demonstrate their potential responses to different forest-management strategies.

5.5. Collection of Data and Preparation of a Database on Species Biodiversity

The translated and filtered data on particular species were incorporated into the Siberian Forest Study Databases. The data were entered into computer spreadsheets. All the chosen species were described in a similar way to facilitate access to the database.

The tables contain mainly verbal information, where possible, quantitative information. The table headings are the following:

1. Species

2. Order

3. Family

4. Taxon

5. Size

6. Weight

7. Category

8. Ecology

9. Limiting factors

   9.1 Biotic

      9.1.1 Predators

        9.1.2 Competitors
        9.1.3 Diseases
        9.1.4 Food
    9.2 Abiotic
    9.3 Anthropogenic

10. Status

11. Purpose of harvest

12. Type of harvest

13. Protection measures

14. Ecoregion

15. Numbers

16. Harvest mortality

17. Reserves

The category item (7) in the table divides the species into two types: H – harvested species (hunted/trapped animals and medicinal plants); and R – rare, threatened and endangered species. Depending on this subdivision, some of the items will be empty. So, for H tables, columns 10 (Status), 13 (Protection measures) and in some cases 17 (Reserves) will be empty, while columns 11 (Purpose of harvest), 12 (Type of harvest) and 16 (Harvest mortality) will be empty for rare species. Some of the tables for rare and endangered species are presented in Appendix 1 as illustrations.

5.6. Incorporation of the Species Database into the Siberian Forest Databases

The species database is connected with Siberian Forest databases through ecoregions (with Ecoregional Database) and reserves (with Enterprise Database). The latter ones can be either zapovedniks (nature reserves) or zakazniks (hunting reserves).

A huge problem is the estimation of species numbers and the harvest mortality for ecoregions. There are 63 Siberian ecoregions determined mainly by ecological integrity criteria (Shvidenko, 1995). The data for hunted/trapped animals, in contrast, are presented by administrative units, as registered by Russian hunting state authorities. Fortunately, the borders of nearly 15 administrative units (oblast' or krai) coincide with ecoregional borders. It allows us to distribute species numbers according to forested areas in the ecoregions, assuming proportionality to these areas. The same problem exists for medicinal plants. However, there are additional data on the geographical distribution of medicinal plants, allowing one to prepare more-accurate estimates.

5.7. GIS application for the Species Range Descriptions

The final species inventory presentation includes spatial representation of species ranges and distributions. Many nature conservation managers and researchers are using GIS tools for species diversity representation (Miller, 1994). GIS capabilities provide many advantages here. These benefits include the ability to edit and update species maps, and to carry out simple (overlay) and complicated (kriging) spatial analysis.

Maps of the species distributions in this study are mainly provisional, especially for rare species. Nevertheless, they are vitally useful both for scientific and management purposes. Our maps were prepared as ARC-INFO coverages and ARC-VIEW shapefiles and included in the whole Siberian GIS (see Figure 1).

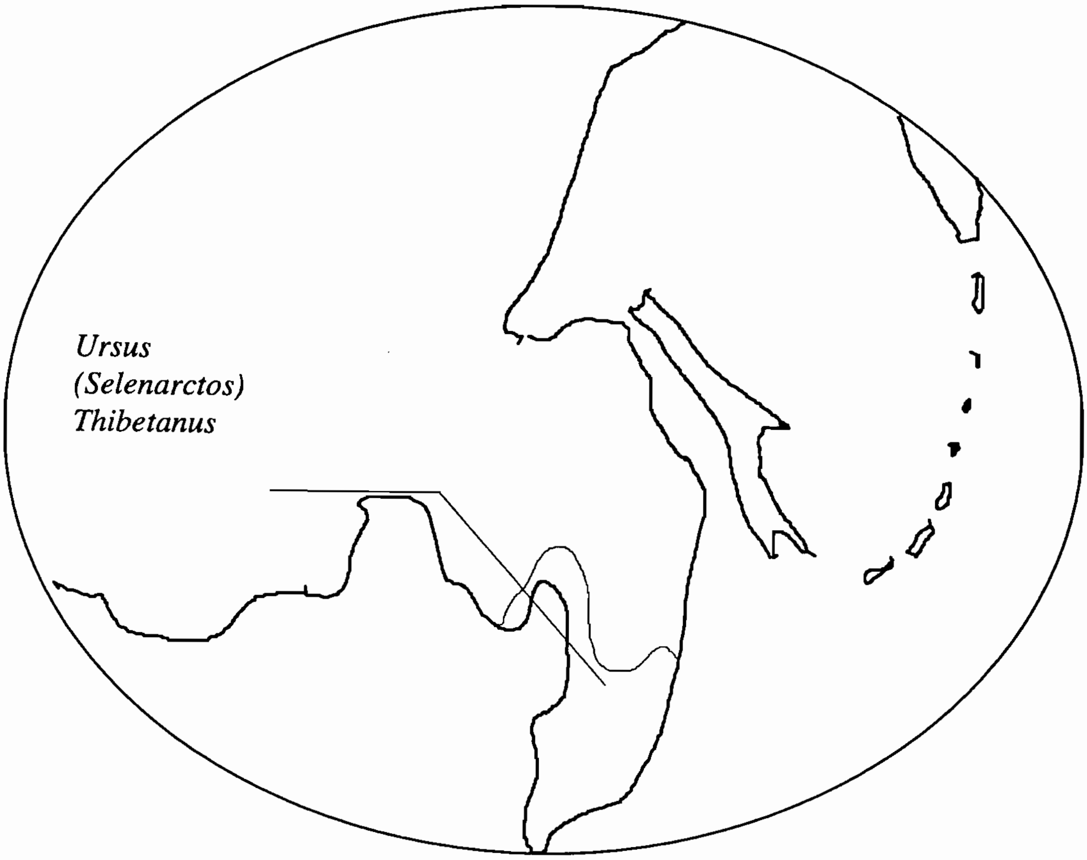


Figure 1. Example of the GIS presentation: The area of Himalayan bear in Russian Far East.

5.8. Analysis of Species Dynamics

There are many methods for mathematical descriptions of species dynamics (Norton and Possingham, 1993). These approaches can be classified in the following taxonomy of models:

- Pure versus applied models;
- Spatial versus nonspatial models; and
- Static versus dynamic models.

Pure models address mainly questions of theoretical interest, while a rational combination of different kinds of applied models fits the general purposes of the study. Many models, operating with species numbers, have no spatial component. This assumes that all properties of the environment are spatially uniform and the population is well-mixed. Such assumptions are rarely valid in nature and are determined mainly by visible complexity of spatial population models. However, the spatial structure of the Siberian Forest databases dictates that our models must be spatially distributed. The modeling procedure should, of course, be undertaken within a GIS application.

Static spatial models are based on different variations and types of regression or correlation analysis (Dobson, 1983). These models, when generating spatial predictions, are assuming that, within the range of conditions under which the original data were collected, the quantified relationship between the entity under study and the environmental conditions will hold true. For example, abundant harvested species can be related somehow in a simple way mathematically with climatic and edaphic parameters as well as with human harvesting activity. While these static relations are important for a description of Siberian species diversity, they often leave questions.

Construction of dynamic spatial models represents a great challenge to wildlife modelers. They could be applied for estimation of both harvested and protected species in both time and space. Generally, such models concentrate on forest simulation under different management scenarios and estimation of some habitat suitability indices (for example, the HSG forest modeling system of Moore and Lockwood (1990)). Design or modification of such models for Siberian regions may require considerable efforts and time resources due to the complex character of data availability and complex stand structures (roughly half of the Siberian forest stands are mixed unevenaged ones). Therefore, concentrating on one interesting species in a definite region would probably be more feasible.

Thus, the most reasonable first step of species numbers predictions in the frame of the study are: (1) regression analysis of harvested species over different climate or nutrient parameters; and (2) estimation of minimum viable population size for one species as an example (probably ungulate) and for one zapovednik (nature reserve).

5.9. Sketch of Preliminary Analysis of Species Diversity in Siberia

Presently, the questions about saving, restoring and increasing the zoological and floristic resources of Siberia acquire special considerations, due to rapid economic changes in the region. I will give a brief sketch of the species biodiversity in Siberia, according to our classification.

5.9.1. Rare, Threatened, and Endangered Plants

Six hundred and eight vascular plants of the former Soviet Union are considered as rare, threatened and endangered species. From this amount, approximately one third belongs to the Siberian region (USSR Academy of Sciences, 1984). Most of them are concentrated in the Far East, in Primorskii Krai, Sachalin Island and South Kurily Islands.

Only twenty-nine rare, threatened, and endangered plant species in Siberia are trees and bushes (see Table 1), the others are grass species.

Table 1. Russian transliterations of trees and bushes (including lianas) from the Red Book with their Latin names and geographical areas.

1. CONIFEROUS TREES AND BUSHES	
Cupressaceae	
1. Microbiota perekrestnoparnaia (*Microbiota decussata*)	Sichote-Alin mountains
2. Mozhzhevel'nik tviordyi (*Juniperus rigida*)	South of Primorskii Krai
Pinaceae	
3. Yel' Glena (*Picea glehni*)	South Sachalin, South Kurily
4. Listvenniza ol'ginskaia (*Larix olgenis*)	The sea coast of Primorskii Krai
5. Pichta Maira (*Abies mairiana*)	South Sachalin, Kurily
6. Pichta sachalinskaia stroinaia (*Abies sachalinesis*)	Kamchatka, the Kronozky coast
7. Sosna gustozvetnaia (*Pinus densiflora*)	Primorskii Krai
Taxceae	
8. Tis ostrokonechnyi (*Taxus cuspidata*)	South of Chabarovskii Krai

2. SOFT AND HARD DECIDUOUS TREES, BUSHES, AND LIANES

Actinidae	
9. Aktinidia Djiral'da (*Actinidia giraldi*)	South of Primorskii Krai
Araliaceae	
10. Zamanicha vysokaia (*Olopanax elatus*)	South of Primorskii Krai
11. Kalaponaks semilopastnyi (*Kalaponax septemlobus*)	South of Primorskii Krai, Kurily
Betulacae	
12. Beresa Maksimovicha (*Betula maximowicziana*)	Kurily, Kunashir Island
13. Beresa Shmidta (*Betula schmidtii*)	South of Primorskii Krai
Fabaceae	
14. Lespedeza plotnokistevaia (*Lespedeza cyrtobotrya*)	South West of Primorskii Krai
15. Pueraria dol'chataia (*Pueraria lobata*)	South of Primorskii Krai
Verbenaceae	
16. Orechokryl'nik mongol'skii (*Cariopterix mongolica*)	Zabaikal'ie
Ericaceae	
17. Rododendron Shlippenbacha (*Rhododendron schlippenbachii*)	Primorskii Krai
Vitaceae	
18. Vinogradovic iaponskii (*Ampelopsis japonica*)	South of Primorskii Krai
19. Devichii vingrad triostrennyi (*Parthenocissus tricuspidata*)	South of Primorskii Krai
Hydrangeaceae	
20. Hortensia chereshkovaia (*Hydrangea petiolaris*)	South Sachalin, South Kurily
21. Deizia gladkaia (*Deutzia glabrata*)	Chabarovskii and Primorskii Krai
22. Shizofragma hortenzievaia (*Schizophragma hydrangeoides*)	Kurily (Kunashir Island)
Caprifoliceae	
23. Kalina s'edobnaia (*Vibrurnum edule*)	Chukotsk Peninsula
Salicaceae	
24. Topol bal'zamicheskii (*Populus balsamifera*)	South of Chukotsk Peninsula

Cornaceae	
25. Botrokarium spornyi (*Bothrocaryum controversum*)	Kurily (Kunashir Island)
Aristolochiaceae	
26. Aristolochia manschurskaia (*Aristolochia manshuriensis*)	South West of Primorskii Krai
Magnoliaceaea	
27. Magnolia obratnoiaitsevidnaia (*Magnolia obovata*)	Kurily (Kunashir Island)
Rosaceae	
28. Kizil'nik blestiaschii (*Cotoneaster lusidus*)	South of East Siberia
29. Ploskosemiannik kitaiskii (*Prinsepia simensis*)	South of Primorskii Krai

Some of the tree and bush species have unique features. *Betula schmidtii*, for instance, has no close relatives in the genera *Betula*. It has different morphological features (gray, or even black stem, black-cherry branches) and can live 200 and sometimes up to 400 years. The wood density of *Betula schmidtii* is 1.048 g/cm^3. The rigidity of *Betula schmidtii* wood is 3.5 times higher than that of oak. The tree was named "iron birch" by the local people for its unique physical and mechanical features (Artamonov, 1989; Hill, 1990). Pinus densiflora has long been used by Russian conquerors of Primorie for building their houses. This species is very valuable for Primorskii Krai as it protects the mountain soils of the monsoon region from water erosion. Nowadays, the Pinus densiflora area decreased critically mainly due to human-induced forest fires. Special silvicultural measures are required to regulate populations of Pinus densiflora, including special thinning regimes and fire protection (Artamonov, 1989).

Some species are constantly overconsumed by local people due to their exceptional food and especially medical values. Fruits of *Actinidia giraldi* (the local name is "Japan grape") are actively gathered by local people for wine and jam production. Leaves of *Rheum altaicum* have always been used as food and medicaments by the Altaian people. In spite of full or partial prohibition of harvest, the populations of those two species are diminishing rapidly.

The most well-known Siberian rare grass species is Panax ginseng. This species is also presented in the IUCN Plant Red Book. *Panax ginseng* has exceptional value for its wonderful medicinal features. Even in 1809, one *Panax ginseng* root had an average price of 5000 German marks (Artamonov, 1989). The Chinese and Siberian legends about the "King of plants" or the "Man-root" show that this old representative of the Tertiary flora has always been a rare and valuable plant. Now it is grown at special plantations in China, Russia, Japan and USA for commercial and conservation purposes.

Generally, different threats to plants of Siberia can not be quantified and subdivided easily, but most of them can be traced to human needs for food, medicaments or timber. A lot of work has already been done to promote the survival of Siberian plant species. This includes legal protection measures, continuing publication of floristic surveys of Siberia (Malyshev and Peshkova, 1993-1995) (ten volumes have been already published and four more volumes are planned), establishment of nature reserves in which local flora and fauna are protected by law (for example, the world-famous nature reserve "Kedrovaia pad"), and the establishment of special botanical gardens, which have facilities for propagating and growing rare species (the biggest dendrarium named after Siberian flora explorer V.N. Komarov is situated in St. Petersburg). However, considerable reductions of funding for science in Russia can limit or even dissipate the potential for conservation of the Siberian flora.

5.9.2. Medicinal Plants

Plants, used either in ready form or as a raw material for the pharmaceutical industry, are a considerable source for Russian medicine. Approximately 40% of all medicaments used in Russia are of plant origin. Half of these medicaments are prepared from cultivated plant species, while the rest can be found only in natural conditions.

The annual harvest of medicinal plants in Russia is of the order of ten thousand tonnes (unfortunately, basic data for the past five years of consumption are practically absent). However, the amounts harvested generally, and especially for some plants, can not satisfy the demands of the raw material for the pharmaceutical industry.

Of the 141 natural plant species officially used in Russia for medicinal purposes, 101 can be found in Siberia. Thirty-two species exist mainly in the Asian part of Russia; the others can be found both in Siberia and in the European part (Institute of Medicinal Plants of the USSR, 1980).

Seven plant species gathered in the biggest amounts for medicinal purposes in Russia are the following:

1. *Helichrysum arenarium*
2. *Adonis vernalis*
3. *Schisandra chinesis*
4. *Hippopae rhamnoides*
5. *Thermopsis lanceolata*
6. *Arcostaphylos uva-ursi* ("bear berry")
7. *Rosa majalis*

All of these species are abundant in different parts of Siberia.

Helichrysum arenarium and Adonis vernalis are steppe (grassland) species, concentrated in the southern parts of West Siberia. Both of them are harvested practically only in the European part. However, while resources of *Helichrysum arenarium* are quite scarce in Siberia, resources of *Adonis vernalis* are considerable there. The best quality raw material of *Adonis vernalis* can be gathered in Stavropol Krai (Northern Caucasus) and in Kemerovo region (Siberia). In the Stavropol region, there are 1,500 ha with *Adonis vernalis* and with the possible annual harvest equal to 36 tonnes, while in the Kemerovo part the annual harvest is about 200 tonnes from 4,380 ha (Poshkurlat, 1970).

Arcostaphylos uva-ursi, known as a "bear berry", covers a huge area, associated with the whole Eurasian boreal zone. Also, there are big stocks of the species in Siberia (15-30 kg/ha for different types of pine forests), but it is practically not used in the region. A weak infrastructure and comparatively bad quality of raw material of *Arcostaphylos uva-ursi* in Siberia are the two main reasons for limiting the potential usage of this species in the region.

The annual need of Rosa majalis fruits for Russia was estimated to 6–8 thousand tons (Chrzhanovsky *et al.*, 1972). This need is satisfied by approximately half, mainly due to weak mechanization of labor forces. Siberia could produce half of the annual yield of *Rosa majalis*, but it suffers the same problems as for *Arcostaphylos uva-ursi*.

Thermopsis lanceolata is a typical Central Asian and Siberian species. It is a ruderal grass species associated with river banks and meadows in the south of West and East Siberia. Grass and seeds of the species have been harvested in Siberia for the pharmaceutical industry since the 1930s (Elova, 1940). The reproduction and consumption of *Thermopsis lanceolata* is stable now.

The *Schisandra chinesis* area in Russia is situated in Primorskii Krai (62.5% of the area), Chabarovskii Krai (25%), Sachalin (9.4%) and Amur region (3.1%) (Gutnikov, 1951). The chemicals extracted from seeds and fruits of this liana are well-known cardiological medicaments, so the need for this plant is always high. However, 6400 ha occupied by *Schisandra chinesis* in the Russian Far East can satisfy the needs of the Russian pharmaceutical industry only in favorable years. Special preliminary preparation of raw material in favorable years for long-term storage and cultivation in special enterprises could be the only solution of this problem.

Another medicinal plant species typical of West Siberia is *Helichrysum arenarium*. The need for the oils extracted from the species is estimated as a thousand tonnes for Russia. The resources of the plant in Siberia are considerable and a deficit in this product is connected only with absence of labor forces in the regions where *Helichrysum arenarium* grows.

5.9.3. Rare, Threatened, and Endangered Animals

The causes of animal species extinction can be roughly subdivided into five factors (Fisher *et al.*, 1969).

Natural causes. Extinction is part of evolution. So, the mean life of a bird species was 2,000,000 years and for a mammal species 600,000 years before the human epoch, based on paleontological data (Fisher *et al.*, 1969).

Hunting. Pressure on species can result from human hunting for food, clothing, sport, status symbol, and quasi-scientific collection.

Introduced predators. These include mammal predators like in Australia and New Zealand, introduced in an attempt to regulate explosive populations of rats or rabbits, but which turned their predator interests toward native fauna.

Other introduced animals. These are species that have become strong competitors in the native habitats of the indigenous animals.

Habitat disturbance and destruction. These are cases of total or partial destruction of habitats, through the felling of forests, the drainage of boggy soils, and many other human activities.

In total, human-induced cases of bird-species extinction have been estimated as 77% percent of the total number, and for mammal species 75%, according to the IUCN Red Book data (Fisher *et al.*, 1969).

It is not easy to separate the causes of extinction for Siberian animals, due to limited information. However, preliminary analysis of data on Siberian rare, threatened and endangered animal species allow us to conclude that the proportion of human-induced cases of extinction is approximately the same as in the rest of the world (75-80%) and the majority of these were caused by hunting.

There are 45 rare, threatened and endangered animal species in Siberia counted in the Red Book of Russia. Fifteen of them belong to the mammals taxon (202 species of mammals totally for Siberia), two belong to reptiles, and the other twenty eight species are birds (470 bird species in total have been found in Siberia) (USSR Academy of Sciences, 1985).

The most famous rare animal in Siberian is *Panthera tigris altaica Temminck* (Amurian tiger). The last dwelling individuals of this beautiful species occupy the Sichote-Alin mountains in Primorie. The Siberian population of Amurian tiger here is estimated as 240-250 individuals. The Chinese population includes not more than 20 individuals (Pikunov, 1994).

The Amurian tiger was probably the first species seriously touched by the current "wild" capitalism in the Russian Far East. Annual tiger harvest by hunting (with or without official permission), registered by Far East nature conservation authorities, oscillated around 20-35 cases during the period 1985-1990. The breakup of the USSR and the consequent diminishing of control measures resulted in a threefold increase of this number. For the 1991-1994 period, the number of tiger kills is estimated as 60-70 individuals annually (Pikunov, 1994).

Tiger bones are one of the most valuable products in Tibetan medical science. A twenty kilogram tiger skeleton costs $35,000 on Asian markets. This factor, along with fast modernization of transport and hunting tools used by bandits, make the survival of the species more than problematic. Only an international program with strict measures against predator elimination of the species can stop this war against the tiger.

Uncontrolled hunting is also the main reason of rarity for some ungulate species in Siberia. For Altai mountain ram (argali), *Ovis amon amon Linneaeus*, the area and the number of its population are diminishing to critical levels (the number of argali individuals is estimated to 200–300). Dzeren (*Gazella (Procapra) gutturosa Palas*), so abundant in the beginning of our century in South Tuva and Zabaikal'ie, now is considered rare on Russian territory due to unfavorable conditions caused by unregulated hunting and pasture allocation. The population of another rare ungulate species, Putoranski snow ram *Ovis nivicola borealis Severtzov* is in much better position than the last two. It has approximately 1500 individuals, living in high mountains at the northern border of the boreal zone in Siberia.

5.9.4. Hunted/Trapped Animals

Rapid utilization of natural resources and the inevitable technological invasion of wild ecosystems led to severe decreases in numbers of many types of animals in Siberia, especially those that are traditionally hunted, trapped and fished. Siberia has about 90% of the valuable pelts taken from wild nature in Russia. The main country stocks of sable, kolinsky, squirrel, ermine and muskrat are concentrated in Siberia. At the same time, though, population numbers of most of the main fur species in taiga, mountain forests, forest-steppe and steppe are steadily decreasing. During the last 10-15 years, the stock of sable in Altai region and in East and West Sainy declined by one third, of squirrel, kolinsky and ermine by several times, and of muskrat in West Siberia by ten times (Saphonov *et al.*, 1990).

Taking into account the almost complete utilization of productive hunting land in the taiga zone, the subsequent development of the hunting industry in Siberia can be based only on special land uses with wide implementation of biotechnical and breeding measures.

Ungulate animals in Siberia have considerable significance. They are providers of delicacy meat and tanning and medicinal raw materials, and are of particular importance as key elements of forest-based recreation. The main ungulate species dwelling in Siberia are moose (*Alces alces*), roe (*Capreolus capreolus*), north deer (*Rangifer tarandus*), and maral (*Cervus elaphus sibiricus*). These are the major harvested animal species in Siberia. The populations of these ungulates, which account to 500,000 and more individuals, are ecological stable now. The north deer lives in Taimyr and Yakutian tundra, moose and maral in the southern taiga.

Hunted ungulate species with moderate numbers, from tens of thousands to hundred thousand individuals include deer, snow ram (*Oris nivicola eschscholtz*) (except putoranski), and Siberian he-goat (*Ibex Alpium Sibiricarum*). These species demand strict regulation of harvests (Ditzevich, 1990). The current state of hunted game-bird species could be considered as satisfactory in taiga sub-zones and as non-satisfactory in southern taiga forests (Ravkin *et al.*, 1990). If additional measures for the protection of zootic communities in Western Siberia and, especially in the Ob' floodplain (South-West of Siberia) will not be implemented, then one can expect further diminishment of waterfowl birds during the next decade in this region (Ravkin *et al.*, 1990). For this group of birds, it will be a catastrophe because their numbers decreased by 8-10 times during the last 10-15 years, especially in the forest-steppe zone of West Siberia. Indeed, the state of hunted bird resources in Western Siberia gives rise to anxiety. According to field observations during the last 30 years, the stock of waterfowl birds diminished by 10-20 times (Ravkin *et al.*, 1990). Indeed, West Siberia is the main region of waterfowl bird reproduction for all Russia, where about 20 million geese and ducks dwell.

The populations of willow ptarmigan, hazel grouse, and wood grouse have a satisfactory population. However, in the settled regions of Siberia, their numbers have become stable at a low level while in oil and gas industry regions and in coniferous cutover area, their numbers continue to decrease. For example, the harvest of black grouse has diminished by 20–25 times since the 1960s in Western Siberia (Ravkin *et al.*, 1990).

On the whole, in the forest and forest-steppe zones of the West Siberian plain, the yearly stock of hunted birds before hunting consists of 80 million individuals with a biomass about 55,000 tonnes and with a value of about $1,3 billion (estimate by Siberian Biological Institute of Russian Academy of

Science; Evsikov, 1990). To calculate the total stock of game birds for all Siberia is impossible due to absence of information about the population in some regions.

5.10. Conclusions

The recent state of harvested animal species in Siberia is much worse than that of harvested plants. Rare, threatened and endangered animal species are decreasing significantly faster than rare, threatened and endangered plant species. The changed economic and political situation in Russia, and particularly in Siberia, can be associated with uncontrolled harvesting and rapid extinction of Siberian rare animals during the past seven years. Habitat disturbance and destruction seems to be a secondary cause compared with the explosion of uncontrolled hunting. However, accurate spatial analysis of the species numbers should be done to estimate possible habitat disturbance of rare, threatened and endangered species induced by forest practice. The use of a forest simulation model under different management scenarios and estimation of habitat suitability indices for one or a few animal species in a definite region (provisional region could be Far East) would probably be of great help for the purposes of the Siberian Forest Study.

There are currently 45 rare, threatened, and endangered animal species and 18 hunted/trapped animals in the species diversity database. Data on Siberian plant species have been collected and are under preparation for inclusion in the database. The ranges of some rare species have already been prepared as ARC-INFO coverages.

Further steps of this investigation will include:

1. Collection of new data for the Siberian species diversity database and incorporation of the data into the general databases of the Siberian Forest Study;
2. Representation of spatial data on the rare Siberian species in a GIS format; and
3. Spatially oriented analysis of species dynamics.

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Appendix

Illustration of the database on
rare and endangered animal species

The codes for the protection status (see "Status"in the following tables) is a modified version used by IUCN (Groombridge, 1987; and Luxmoore, 1992). The original IUCN codes and the modified codes used in the Russian literature are presented in the following:

Modified code	Original code
1	**1. EXTINCT** - *Species not definitely located in the wild during the past 50 years* (criterion as used by CITES). **2. ENDANGERED** - *Taxa in danger of extinction and whose survival is unlikely if the causal factors continue operating.* Included are taxa whose numbers have been reduced to a critical level or whose habitats have been so drastically reduced that they are deemed to be in immediate danger of extinction. Also included are taxa that are possibly already extinct, but have definitely been seen in the wild in the past 50 years.
2	**3. VULNERABLE** - *Taxa believed likely to move into the ENDANGERED category in the near future if the causal factors continue operating.* Included are taxa of which most or all the populations are decreasing because of over-exploitation, extensive destruction of habitat or other environmental disturbances; taxa with populations that have been seriously depleted and whose ultimate security has not yet been assured; and, taxa with populations that are still abundant but are under threat from severe adverse factors throughout their range.
3	**4. RARE** - *Taxa with small world populations that are at present not ENDANGERED or VULNERABLE, but are at risk.* These taxa are usually localised within restricted geographical areas or habitats or are thinly scattered over a more extensive range.
4	**5. INDETERMINATE** - *Taxa known to be ENDANGERED, VULNERABLE or RARE but where there is not enough information to say which of the three categories is appropriate.*
5	**6. OUT OF DANGER** - *Taxa formerly included in one of the above categories, but which are now considered relatively secure because effective conservation measures have been taken or the previous threat to their survival has been removed.*

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I

Species			*Nemorhaedus caudatus* (Amurski goral)
Order			*Artiodactyla* (Even-toed ungulates)
Family			*Bovidae*
Taxon			Mammals
Size			
Weight			Average 60 kg
Category			Rare
Ecology			Precipitous rocky plots, slopes of knoll on the sea coast, rocky exposure of rocks along forest slopes on the inner part of Sihote-Alin. Two types of feeding places: 1. Gentle slopes of ridge turned to the sea and river beds of streams on slopes and in forest cover of oak forest with spot of larches, cedars, maples. Type of grass is long-stem herbs. 2. Open rocky parts with plots of grass and bushes.
Limiting factors	Biotic	Predators	Wolf (dependig on winter character, wolves can kill 3–18% of population), lynx (rare)
		Competitors	
		Diseases	Parafit (in capture), gelmint (in nature and it takes places rare)
		Food	
	Abiotic		Deep snow (30–40 cm). Deep-snow winters reiterate over 6–15 years
	Anthropog.		Poaching
Status			1
Protection measures			Open-air cage keeping, reacclimatize in habitat places
Numbers			There are 600–750 rams in the Far East: Mali (Small) Hingan: 10–15, Black Mountains: 15, Sihote-Alinskii zapovednik: 50–60, Lazovski zapovednik: 120–130, other parts of Sihote-Alin: 400–500 individuals. (Fertility: individuals current year count 25–26%, mortality of animals in age 0.5–1.5 is 36% (on average), 25% of this number are killed within 1 year)
Reserves			1. Lazovski zapovednic 2. Sihote-Alin zapovednik

II

Species			*Felis euptilura* (Amurski forest cat)
Order			*Carnivora* (Carnivores)
Family			*Felidae* (Cats)
Taxon			Mammals
Size			
Weight			Up to 4 kg
Category			Rare
Ecology			Sparse deciduous forest, cedar broad-leafed forest (rare), cat prefers dense narrow vallies, reed brushwood near lake shores. Cat inhabits old burned forest, cutover forest area, forests bordering agricultural fields. The animal avoids dark coniferous taiga and does not ascend to mountain taiga.
Limiting factors	Biotic	Predators	
		Competitors	
		Diseases	
		Food	
	Abiotic		Deep snow (inability to prey mice rodent)
	Anthropog.		Bush cutting, plough up parts of virgin soil with high grass, burning out separated forest stand, economic activity
Status			2
Protection measures			Trapping and hunting are prohibited. Explanatory work among hunters about the significance of the cat should be carried out
Numbers Reserves			

III

Species			*Sphenurus sieboldii* (Green pigeon)
Order			*Columbiformes*
Family			*Columbidae*
Taxon			Bird
Size			
Weight			
Category			Rare
Ecology			Deciduous and mixed forests with cherry (*Cerasus*) and cherry (*Padus*), lianas of *Actinidiaceae* and grape, *Sambucus* bushes which the bird uses in food
Limiting factors	Biotic	Predators	
		Competitors	
		Diseases	
		Food	
	Abiotic		
	Anthropog.		
Status			3
Protection measures			Creation of protective area in Kunashir Island and Kril'on peninsula
Numbers			
Reserves			

IV

Species			*Emberiza goldewskii* (Ovsjanka Godlevskogo)
Order			*Passeriformes*
Family			*Emberizidae*
Taxon			Bird
Size			
Weight			
Category			Rare
Ecology			Nest biotopes connected with open places in birch and larch forest stands. In Altai it dwells on stone-warm slopes which are covered with steppe herbs and with xerofit bushes
Limiting factors	Biotic	Predators	
		Competitors	
		Diseases	
		Food	
	Abiotic		
	Anthropog.		
Status			4
Protection measures			
Numbers			
Reserves			

V

Species			*Panthera pardus orientalis* (East-Siberian leopard)
Order			*Carnivora* (Carnivores)
Family			*Felidae* (Cats)
Taxon			Mammals
Size			270 cm, tail 75 cm
Weight			Over 100 kg
Category			Rare
Ecology			Smooth mountains, covered with deciduous and mixed forests (oak and lime verdure) and with steep cleft, caves
Limiting factors	Biotic	Predators	
		Competitors	Tiger
		Diseases	
		Food	Wild ungulate animals (ram, spotted deer)
	Abiotic		Poaching, forest harvesting and conversion of habitats
	Anthropog.		Poaching
Status			1
Protection measures			Trapping and hunting are prohibited, possibility of reacclimatization of the Caucasus protection zone
Numbers			
Reserves			