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Forest Research Association

BOREAL FORESTS AND GLOBAL CHANGE

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CONFERENCE PAPERS ADVANCE ABSTRACTS

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Forward

We, the IBFRA '94 Conference Committee, would like to welcome you to Saskatoon, Saskatchewan and the Fourth Annual Meeting of the International Boreal Forest Research Association (IBFRA). This year, the IBFRA-hosted conference **"Boreal Forests and Global Change"** is an exciting new venture in the evolution of the Association's activities. We hope it will help to move IBFRA forward as an organization fulfilling an essential role in international boreal research, and lead to further new developments in the future.

We wish to express our sincere thanks to our sponsors: The Canadian Global Change Program of the Royal Society of Canada, Prince Albert Model Forest Association, Weyerhaeuser Canada and Weyerhaeuser International, The Province of Saskatchewan, International Science Foundation, and Natural Resources Canada (Canadian Forest Service).

In the following pages you will find abstracts for close to 100 papers which will be presented during the coming three days, either as posters or verbally. The abstracts are ordered alphabetically by first author surname. Where there is more than one author, the name of the presenter is underlined. For a few papers, we were unable to obtain copies of the abstract early enough to include here, due to our need to get this booklet printed in advance of the conference. Please check the latest conference schedule for a complete list of titles.

We made a conscious and deliberate decision to not hold concurrent sessions of verbal presentations, and to give increased opportunity for face-to-face dialogues with presenters, by highlighting the poster portion of the conference program. We urge you to visit all the posters which will be on display throughout the conference, and to meet at least some of the presenters in person during the formal poster session on Monday, or at the informal session on Tuesday evening.

We are sure you will find the IBFRA '94 conference program both interesting and enjoyable (if not a little demanding!). We look forward to meeting you personally during the coming days.

Mike Apps
Conference Chair

David Price
Program Chair

Ron Bronstein
Facilities and Logistics

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Treasurer

Guy Brassard
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John Doornbos
Field Tours

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Carbon in Russian forests: geographical distribution and tendencies of dynamics

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The forests of Russia amount to 22% of the world's forests. The total area of the forest sector is 1,183 Mha comprising: 771 Mha covered by forests; 113 Mha temporarily unstocked forest land (clearcuts, burnt areas, open woodlands); and 299 Mha nonforested areas (peatlands, water, etc.). The growing stock of mature and overmature stands is 44.6 billion m^3 (61.6% of the total growing stock). Detailed data for the carbon budget of the forests are absent. This presentation includes information about the ecogeographical distribution of carbon storage of forest vegetation and carbon dynamics in the next 30-50 years. To estimate the carbon pool contained in natural ecoregions (biomes and their subdivisions), we used: (1) the 1988 National Forest Inventory database for 71 administrative territories of Russia; (2) 2,290 experimental sample plots from many authorities on biomass of various forests (used only for calculation of conversion factors) and (3) a new, original map of the 63 forest ecoregions.

The total carbon pool of the forest vegetation amounts to 31.4 Pg C (Alexeyev and Birdsey, 1994). The distribution of carbon across the territory is very uneven. In the subarctic open forests and woodlands (146.9 Mha) there are 2.3 Pg C; in the vegetation of the northern taiga and mountain taiga (182.5 Mha) - 4.9 Pg C; in the middle taiga (283.8 Mha) - 10.7 Pg C; in the southern taiga (209.2 Mha) - 10.4 Pg C; in the mixed broadleaved-conifer forests (28.9 Mha) - 1.6 Pg C; in the broadleaved deciduous forests (forest-steppe) and mountain sub-boreal forests (28.4 Mha) - 1.3 Pg C; and in the steppe forests (3.9 Mha) there are 0.2 Pg C. There are many young stands in the forests of the southern taiga, and in the mixed forests and forest-steppe, in the European part of Russia which have been greatly depleted through clearcutting. This territory may be considered as a sink for carbon in the next 50 years. The main areas of forests and woodlands of the northern taiga and forest-tundra consist of overmature conifer stands, characterized by very low growth and accumulated fuel for wildfires. These ecoregions seem to be sources, rather than sinks, of carbon. There are also old conifer stands in the major part of the middle taiga areas of Siberia and the Russian Far East. This territory is susceptible to harvesting, wildfires, and pest invasions, and is therefore another potential carbon source.

Long-term experiments in selection forest of Norway spruce (*Picea abies*)

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The selection system (selective cutting of single trees) is one of many possible harvesting methods to reduce the acidification of forest areas compared to that resulting from clear-cutting. This cutting method also maintains most of the biomass and reduces nutrient leaching of the forest compared with the leaching which follows clear-cutting. The influence of a selection system on different ecosystems is comprehensive, and the effects on growth and production of the trees is considered very important. This investigation studied the effect of the selection system on forest production. Volume, increment, diameter distribution, and some stand characteristics were measured in 16 experimental plots located in a selection forest over periods of up to 69 years. The volume production was on average 15-20% lower than the estimated yield capacity in even-aged forests. There was much variation in increment. Losses were lower in vegetation types where regeneration possibilities were good, and in fields with medium and low site indexes. Annual increment was on average 3.7% of standing volume. It is important to harvest in such a way that promotes the development of an "inverse J-shaped" diameter distribution. The selection system is most successful on sites favouring good natural regeneration.

Biodiversity and sustainable forestry in boreal forests: how West and East can learn from each other

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In Europe, the conifer-dominated boreal and hemi-boreal forests form a belt between 55°N and 65°N from Scotland in the west to the Ural mountains in the east, as well as within an altitudinal belt in the central European mountains. The history of these forests varies considerably among different regions. Smaller natural or semi-natural areas are found in remote parts of Finland, Sweden, and Norway as well as in the Alps and the Pyrenees. Areas sufficiently large to encompass naturally dynamic systems however, are found only in parts of boreal Russia.

We started a long-term co-operation with Russian scientists in 1991. Using the distinct differences between east and west, caused by different political and management systems, we studied how structures at different geographical scales, including assemblages of plants, animals and fungi, as well as natural processes, change with an increasing degree of human impact. The following studies are being carried out:

1. *Fine-scale forest structure.* Using stratified sampling in different site types, detailed forest structure is being described in 314 m^2 plots. This method is used also by the Swedish and Finnish National Forest Surveys.
2. *Medium-scale forest structure.* We describe the structure of one particular landscape (100 km^2) by making two 10 km transects (south to north and east to west) which cross at the centre of the chosen landscape. Forest structure is described using relascope at 50 m intervals. Landscapes are chosen in gradients from natural forest to landscapes with a long forest history, in Sweden, Russia, and Lithuania.
3. *Large-scale forest structure.* Remote sensing data and Russian forestry maps and stand descriptions are the basis for analysis using GIS.
4. *Habitat requirements of indicator species.* To quantify the need for different structures for long-term survival, it is necessary to study the presence, population density, and preferably, fitness, of species that are adapting to different habitat properties. Such species should not be threatened by extinction or endangered, but neither should they be too common, since this will seriously hamper the possibility of obtaining sufficient sample sizes. Suitable species are found among those listed as "care-demanding" in the Red-Lists. To cover the variation in habitat properties, we are studying resident birds, lichens, fungi, insects, and vascular plants.

Current state of global forests in the context of the global carbon cycle

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International agreements made during and since the 1992 UN Conference on Environment and Development (the UNCED Earth Summit) in Rio de Janeiro have helped to focus increased atterntion on the role of global forests and their management in the global carbon cycle. In particular, the influence of global forests on the levels of carbon-based greenhouse gasses in the earth's atmosphere is more than an interesting scientific quest: It has immediate consequences for global decision-making. A recent international workshop on global forests and the carbon cycle, involving 45 scientists representing a wide range of viewpoints and expertise on the subject, provides a contemporary review of the science of the global carbon cycle. Drawing on the workshop discussions, I will first highlight the connections between the dynamics of the carbon cycle, the climate system, and terrestrial ecosystems, while giving specific emphasis to global boreal forests. In this connection, I will explain why the problem of the 'missing sink of atmospheric carbon' continues to be an issue of both scientific and policy interest.

I will then deal directly with the linking of these science issues to resource management policy: Can changes in resource management influence atmospheric carbon levels? If so, over what time frames and at what spatial scales (regional, national or global) are the policies required? What part can forest management play: e.g., is it possible to use forest plantations and forest reserves to offset fossil fuel emissions and, if so, for how long? How much can storage of carbon in forest products, and the use of bioenergy to offset fossil fuel use, contribute to reductions of atmospheric carbon? The answers to such questions rely on a conceptual model that balances removal of carbon from the atmosphere through photosynthesis (as CO_2) and its return (primarily as CO_2, CO, and CH_4) through a variety of combustion, respiration and decomposition process. Positive balances imply reduced atmospheric C and a planetary 'sink' of atmospheric carbon; negative balances represent a planetary 'source'. The accounting framework that is used to calculate the balance - a carbon budget model - must account for all the carbon flows and changes in the main storage pools; the model must conserve carbon. Such models permit the systematic evaluation of past, present and potential future atmospheric carbon exchanges (under different scenarios of future environment and policy). I will present a generic structure of such a model and illustrate with several existing examples. Used in the 'what-if' mode these models can show clearly where, in principle, the most significant policy 'gains in carbon storage' can be made. The 'optimum' path for carbon management, however, cannot be selected by such models. This selection remains a societal challenge whose resolution depends on balancing perceptions of the future with environmental degradation (or enhancement) on the one hand and socio-economic problems (or prosperity) on the other.

A biometric survey of the central Canadian boreal forest

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As a contribution to the BOReal Ecosystem Atmosphere Study (BOREAS), a total of 93 sites have been surveyed in the boreal forest regions of Manitoba and Saskatchewan. Sites were selected using satellite, air photograph, and forest cover map data. Each site represents a minimum 100m by 100m homogeneous stand, suitable for satellite imaging. Measurements at each site include overstory (species composition, DBH, pathogens, age, etc.), understory (percent cover by species), debris, and soil characteristics. These data provide a background database for the diverse measurements of land surface climatology, tropospheric chemistry, and remote sensing that constitute the BOREAS project. The sites will be used to spatially and conceptually extend flux measurements from a small number of tower sites.

Sites are concentrated in two regions: north of Prince Albert, Saskatchewan, and west of Thompson, Manitoba. Additional sites are located on the Boreal Forest Transect Case Study (BFTCS) between Batoche, Saskatchewan and Gillam, Manitoba. The surveyed sites were classified according to three criteria: dominant species (*Picea mariana*, *Populus tremuloides*, *Pinus banksiana*, or "mixed"), age (mature, immature, or young/recently disturbed), and productivity (low, medium, or high). Overstory, understory, and debris measurements were usually taken at three plots at each site. This study focuses on 51 sites surveyed in 1993. Overstory, understory, and debris measurements were taken at three points at each site. In 1993, sampling was carried out at 123 plots. In 1994, sampling was completed at the 93 sites, providing data from an additional 125 plots.) The sites are predominantly in medium and high productivity stands.

Overstory data, primarily from point-sampling, have been used to estimate basal area per hectare, trees per hectare, and biomass. Stand basal areas ranged from 5 $m^2 ha^{-1}$ (in disturbed *Pinus banksiana* stands) to over 60 $m^2 ha^{-1}$ (in a mixed-wood stand). The number of trees per hectare ranged from a few hundred (in either lower productivity *Pinus banksiana* or older mixedwood stands) to over 20 thousand (in an immature, high productivity *Picea mariana* stand). Preliminary estimates of total live biomass range from 9 t ha^{-1}(in a recently disturbed *Picea mariana* stand in Manitoba) to 214 t ha^{-1} at a mixed-wood site in Saskatchewan. The Prince Albert sites tend to have greater values than Thompson for basal area and biomass, but the number of trees per hectare is highly variable.

Understory data, based on fixed-area plots of 2 x 2m or 5 x 5m, provide cover estimates by species for each sampling point. Over 100 species were recorded, with an average of 15 entries per plot. Soils were analyzed for texture, density, organic content, and nutrients. Debris measurements include woody debris in several size classes, plus samples of litter and duff layers. Combining overstory, debris, and soils data will allow estimates of total carbon storage in these components of the forest ecosystem.

Predicting the effects of climate change on fire frequency in the southeastern Canadian boreal forest

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Although an increasing frequency of forest fires has been suggested as a consequence of global warming, there are no empirical data that have shown a climatically driven change in fire frequency since the warming that has followed the end of the "Little Ice Age". We present here evidence from fire and tree-ring chronologies, that post-"Little Ice Age" climate change has profoundly decreased the frequency of fires in the boreal forest of northwestern Québec. A 300-year fire history (AD 1688-1988) from the Lake Duparquet area (48°28'N, 79°17'W) shows a significant decrease, starting 100 years ago, both in the number and extent of fires. This decrease in fire frequency is also associated with a long-term increase in the mean ring width of northern white cedar (*Thuja occidentalis* L.) in the same area. Agreement between the standardized tree-ring chronology and fire years, together with a negative correlation with a drought index reconstructed for the AD 1913-1987 period, shows that the decrease in fire frequency may be related to a reduced frequency of drought periods since the end of the "Little Ice Age". Using daily data from the Canadian Atmospheric Environment Service's General Circulation Model, the components of the Canadian Forest Fire Weather Index (FWI) System were calculated for the $1xCO_2$ and $2xCO_2$ scenarios. The average FWI over much of eastern Canada, including the Lake Duparquet region, decreased under the $2xCO_2$ simulation, whereas FWI increased dramatically over western Canada. According to these results, fire frequency would decrease and increase in the eastern and western parts of Canada respectively. Our results stress the importance of large regional variability and call into question previous generalizations suggesting increased disturbance with climate warming.

Development of frost-hardiness during mild winters in 60 year old conifer provenance experiments in Finland

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A possible effect of climatic change on conifers in boreal regions is that they will deharden during mild mid-winter periods, which increases the risk from frost damage if the temperature subsequently drops again. To test this hypothesis, twig samples were taken regularly during four successive winters from northern and southern Scandinavian origins in a Scots pine (*Pinus sylvestris*) and a Norway spruce (*Picea abies*) provenance experiment, both established in 1931 in Punkaharju, south-eastern Finland. These samples were subjected to freezing tests in order to measure the frost hardiness of buds and needles. The northern origins hardened earlier and deeper than the southern ones. The first three winters were all relatively mild with several periods of thaw. During these periods, the spruce provenances dehardened, but rehardened rapidly after the temperature dropped again. This dehardening-rehardening process occurred several times during one winter, even during late-winter. For pine, this process was not observed. All provenances maintained a high level of frost hardiness, even during mild spells. During the last, normal, winter no dehardening was observed in either species. These results do not confirm the hypothesis that global warming will result in an increased risk of frost damage.

Parallel to the frost-hardiness tests, concentrations of polyamines, which are known to be correlated with adaptation to many kinds of stress conditions, were measured in the spruce experiment, using the same provenances. Polyamine concentrations were highest in the northern provenances. Strong fluctuations in polyamine concentration during winter seem to be correlated with outdoor temperatures, and hence also with frost-hardiness.

Managing the boreal forest by maintaining its inherent pattern

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The forest industry has become sensitive to its image through pressure from environmentalists and the European markets, and in cooperation with natural resource departments across the country, is working hard to change this image by developing environmentally sound management. The dilemma is how to continue resource extraction from the forest, while ensuring that wildlife populations do not become endangered. An important ecosystem process in the boreal forest is forest fire, and the forest industry has traditionally argued that clear-cutting simulates forest fire by creating large areas devoid of vegetation that can then grow back either through natural regeneration or by planting. What is neglected in present forestry is the landscape pattern created through harvesting, which often consists of large continuous expanses of recently clear-cut land. In ecology we often talk about process and pattern. I will argue that we should emulate the pattern across the landscape. Wildlife (including all life-forms) has evolved in landscapes with inherent patterns. If we can maintain the inherent pattern in a landscape, then we can maintain the wildlife. Here I outline a method for describing landscape patterns and maintaining these patterns through forest management.

Management perspective on the Prince Albert Model Forest

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The Canadian government launched the model forest program to contribute to the development of sustainable forestry at the working scale. In 1992, an area of about 315,000 ha boreal forest north of the city of Prince Albert, Saskatchewan, was chosen as one of ten model forest sites across Canada. The Prince Albert Model Forest has pure and mixed stands of aspen, white spruce, jack pine, black spruce, and balsam fir growing on glacial tills in a very dry boreal climate. A non-profit association of seven equally represented partners including First Nations, government, and industry, was formed to implement a research project and to develop a long-term integrated management plan. The project will revolutionize forestry because it replaces the exclusive planning and management privileges of traditional forestry agencies with a broader decision-making body that allows for direct participation of scientists and representatives of communities directly affected by forest management. The management plan will reallocate the forest landbase to various degrees of use intensity in order to perpetuate ecological processes of forest renewal. It will also reallocate the economic benefits derived from forest resource use. Clear-cuts up to 100 ha have been the main harvesting method since industrial forestry began in Prince Albert in 1965. A number of different ecosystem research projects have been launched to investigate the effects of current forestry practices by comparing mature forests with forests regenerated on naturally burned and clear-cut areas. Sites were also established for long-term ecological monitoring of forest practices. Strong First Nations involvement in forestry is paramount to sustainable development of all of Canada's boreal forest. Therefore, socio-economic research aims at the identification of socio-economic sustainability criteria that will more adequately assess forest management options in regions with significant indigenous population. An historic approach has been used to understand the local management environment. Forest resource use by, and race relationships between indigenous people and caucasians can be divided into four phases: (1) colonial trade and predominant use of fur-bearing animals prior to caucasian settlement; (2) marginalization of indigenous people and increasing timber extraction following Confederation; (3) First Nation empowerment and sustained timber yield management occurring at present; and (4) cross-cultural co-operation along with ecosystem management as a desired option for future forest development. The legacy of non-co-operation among various participants and current funding policies are major challenges to making the transition from visionary concepts to practical implementation of sustainable forestry.

Modeling a mountainous forest site in Russia

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The BORFOR forest gap model was selected to estimate carbon pools of forest ecosystems in Russia. BORFOR simulates the growth of a forest ecosystem (i.e., live trees, mosses and forest floor organic layer) and incorporates soil moisture, the presence/absence of permafrost, and the depth of the active layer. The latter factors are particularly important to boreal forest simulations. Before applying BORFOR across the Russian landscape, a modeling effort was undertaken for a mountainous site in the Russian Far East to gain insight into the input parameters required to run BORFOR and the availability of input data.

The vegetation and land-cover input to BORFOR were identified using an unsupervised classification of temporal Global Vegetation Index (GVI). The image class description at the continental scale required a supplemental description of the species specific to the mountainous ecosystems before they could be used as input data. The GVI image classes represent vegetation and land-cover at a higher level of spatial detail than that available from thematic maps. The carbon values estimated with BORFOR on the mountainous site were compared to estimates based on measured biomass densities. BORFOR correctly simulated living tree biomass in all forest types (except mixed forests) and forest floor carbon in all cases (except spruce-fir forest). BORFOR should be modified to include decomposition rates and coarse woody debris accumulation for individual tree species. In the future, BORFOR will be used to estimate the change in carbon pools and fluxes resulting from a changing global climate, forest management practices, and fire suppression.

Regeneration responses of near-boreal species to an array of silvicultural options

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The effects of a number of silvicultural systems and regeneration methods on the composition, distribution and abundance of tree regeneration are being studied in a long-term experiment on the Penobscot Experimental Forest in east-central Maine ($44^0$52'N, $68^0$38'W). The area is in the Acadian Forest Region which shares its northern ecotone with the boreal forest. The elevation is low (less than 75 m above sea level), the soils are of glacial origin and tend to be moderately poorly to poorly drained, and the climate is cool and moist. The Penobscot Experimental Forest is predominately coniferous with a mixture of spruces, mostly red and white with a few black; balsam fir, eastern hemlock, northern white cedar, eastern white pine, and the occasional tamarack and red pine. Associated hardwoods are primarily paper birch and red maple.

One of the original objectives of the experiment was to determine the best silvicultural system or regeneration method for increasing the spruce component in northern conifer forests. Spruce is favoured over its common associate, balsam fir, for both pulpwood and lumber products. Spruce is also less susceptible than balsam fir to the spruce budworm, a native defoliating insect that reaches epidemic levels about every 40 years.

In the experiment, even-age treatments include two and three stage shelterwood systems, and clear-cut harvesting. Uneven-age treatments include fixed and flexible diameter limit methods, and selection with 5, 10 and 20 year harvest intervals. The experiment was established between 1952 and 1957 in stands with a history of logging but, no recent activity. There is also an unmanaged control. Each treatment and the control are replicated twice in compartments averaging 10.1 ha in area.

Exploring implications of climatic change to the composition of western Canadian forests, based on phenological enhancements to a patch model of forest succession

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We enhanced the forest patch model, ZELIG, to explore the implications of $2xCO_2$ climate change scenarios on several forest regions in British Columbia and Alberta. In addition to the processes and phenomena commonly represented in individual-based models of forest stand dynamics, we added some species-specific phenology and site-specific frost events. This consideration of bud-break heat sum requirements, growing season limits, chilling requirements for the induction of dormancy and cold hardiness, and frost tolerance, improved the ability of ZELIG to predict the present composition of B.C. forests. Simulations based on future climatic regimes predicted by the GFDL general circulation model (GCM) predict some major shifts in equilibrial forest composition. Lowland temperate coastal forests are predicted to be severely stressed because indigenous species will no longer have their winter chilling requirements met. High-elevation coastal forests may either remain stable or decrease in productivity, while interior subalpine forests are expected to become more similar to those of the coastal mountains. Interior low-elevation forests in southern B.C. are likely to persist relatively unchanged, while northern interior sub-boreal and boreal forests could support Douglas-fir and western larch (if planted), which would have a competitive advantage over the present spruce and pine species. While we believe these model enhancements to be a significant improvement over existing formulations, the resulting predictions must still be viewed with caution. Model limitations include: (1) the current inability of GCMs to specify future variation in monthly temperature and precipitation; (2) sparse information on the phenological behaviour of several important tree species, and (3) a poor understanding of the degree to which growth is constrained by different suboptimal climatic events.

DENDROSCAN: tree-ring width and density measurement system

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Tree-rings contain a record of diameter growth and carbon storage in the tree trunk. The width of the rings can be measured by a variety of systems, but the density (carbon storage) is most easily measured using X-ray densitometry. We demonstrate a system for tree-ring width and density measurement which allows the measurement of both, or of ring widths alone. It can use prepared wood samples (for ring widths only) or X-ray positives; it is inexpensive, composed of readily available parts, and has a high degree of precision and accuracy. The resolution of the system is limited mainly by the scanner; a 600 dots per inch scanner will yield up to 0.005 mm resolution. Unlike other X-ray densitometry systems which can cost upwards of $250,000 (Canadian), the capital cost of this system is under $25,000. The operating cost is also small, with a single operator capable of taking as many as 300 short increment cores from straw to data disk in one week.

The biological productivity of spruce forests in north-European Russia

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This paper investigates the biological productivity of forest plant communities in northern Europe. It is based on research carried out in the central zone of the European taiga, and begins by discussing previous literature on the subject.

Most studies of biological productivity in forests have been done on foliage; very few have involved the biological productivity of areas which have been cleared, which is the main topic of this paper*.

*Abstract presented here is translated from a brief summary of the Russian manusript.

Effects of simulated winter-thaw duration on die-back of eastern hardwoods

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Current evidence suggests an increase in mean global surface temperature of 0.5 °C has occurred since 1860, with a greater increase recorded during winter than summer. It has also been suggested that greenhouse gas-induced climate warming will be greater at higher latitudes, approaching 3-4 °C in parts of Canada. Hence, under a greenhouse climate, it is likely that the frequency of mid-winter thaw events across Canada would increase significantly. Work by Braath (1987) on the birch decline of the 1930's, has prompted experimental examination of the potential role of extreme climatic events, such as the duration of winter thaws, on die-back of birch species. Many winter thaw anomalies have occurred in New Brunswick, including the 1936 thaw which Braath suspected of causing the 1930's birch decline.

A simulated winter thaw study was carried out to parameterize a model of dieback responses of paper birch to winter thaw conditions similar to those suspected of causing the 1930's birch decline. Twenty double polyethylene-walled, climate-controlled chambers delivered heated air to the aerial portions of potted two year old plants allowing their roots to remain frozen in the ground. In addition entire potted trees were placed within each chamber as a root thawed treatment. Trees were removed from the randomized block design after treatment periods and frozen (-10 °C).

Observations were made of (1) xylem conductivity, both prior to and following a period of growth in a greenhouse; and (2) dieback. Results indicate certain effect thresholds of accumulated growing degree days during the thaw. Root thawing during the simulated thaw reduces the capability of the plants to recover from xylem cavitation and decreases the growing degree threshold of effect on the amount of dieback. The interrelationships between the various effect and treatments will be examined with regression models to help explain and predict responses to climate change. The results will also be discussed in relation to the 1930's birch dieback.

Effects of stand age and structure on diversity of nonvascular plants in aspen mixedwood forests

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Diversity of nonvascular plants (i.e., mosses, lichens, liverwort and fungi) was determined by point-sampling on surfaces of downed woody material (>11 cm diameter) and standing trees in young (23-63 years), mature (51-63 years), and old (122-146 years) aspen/mixedwood stands. The diversity and relative abundance of nonvascular plants on logs were greatly affected by factors such as decay class, light and pH. Old aspen/mixedwood stands had the greatest variety of woody substrates available in different decay classes, and therefore supported the greatest number of species. Under current operating rules, woody material must be manipulated to reduce fire hazard. Our results strongly suggest that this would severely alter the profile of downed woody material, and lead to a decrease of nonvascular diversity in managed stands.

Sustaining biodiversity: global change and the importance of old-growth forest

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Birds are a major component of biodiversity in forests. They are particularly suitable as flagships for less obvious organisms because they are conspicuous, tolerably well-known, amenable to monitoring by volunteers, and occupy a variety of niches in the forest food-web. Several different components of global change are likely to put increasing pressure on the oldest age-classes forest stands, especially those beyond rotation age, which are naturally rare in boreal forest and likely to become rarer as exploitation intensifies. We present a case study from the Prince Albert region of Saskatchewan, in which we investigate whether any bird species are particularly dependent on stands of post-rotation age in the mixedwood forest, and describe their use of the major components of the forest. We suggest that such studies are needed urgently for other stand types, if ecosystem-based approaches to sustainable forestry are to succeed in anticipating and mitigating the impacts of global change on biodiversity in the Canadian boreal forest.

Fire history models revisited: implications for the Alberta boreal mixedwood

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Simple population-level models of fire effects have assumed that risk of fire is constant in time and space (stationarity) and that fire hazard is history-independent. Both assumptions are known to be false for many systems, and models of greater mathematical sophistication have recently been developed; these are generally based upon at least several centuriesof reconstructed fire history data. No such data sets presently exist for my study area in northeastern Alberta. This study is an attempt to see what can be learned from the available data, which includes forest inventory data sets and 60 years of fire history records.

I developed a simple population level simulation model of disturbance and succession for a major component of the boreal mixedwood, consisting of aspen, mixed aspen and white spruce and pure white spruce stands. Other stand types (pine and black spruce) are spatially segregated by site preference, are not successionally related to the "aspen-white spruce complex" and have different fire regimes; they comprise distinctive populations which should not be aggregated in a study of this kind.

The forest is treated as a spatially aggregated population of stands characterised by age and species composition. Succession is represented by a constant rate of increase in white spruce content. Fire is assumed to be the only stand-level mortality factor; relative fire risk is a function of white spruce content. Background hazard rates were estimated from recent and historical fire records to explore the possible impacts of fire suppression. Changing fire regimes and Poisson distributed "fire years" can be simulated, to partially remove the assumption of stationarity.

The apparent composition of the study area is inconsistent with a constant fire regime, and is difficult to reconcile with historic fire data. The effect of fire supression appears to be generally overestimated. Possible explanations for the existing forest structure include spatial non- stationarity in fire effect (for which some evidence exists), and the existence of significant areas of self-replacing stands whose ages have been underestimated in the inventory data.

Structure and productivity of larch stands naturally regenerated in a clear-cut in south Siberia

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Peculiarities in the post-clear-cutting succession of a *Larix sibirica* Ledeb. phytocoenosis of th eherbaceous (mesophytic) forest type, located in Eastern Hentey, are considered. Using morphometric methods, th edimensional hierarchy of cenopopulation individuals was determined and the structure and bioproductivity of the aboveground phytomass components were studied including: standing wood, herbaceous cover and litter. Aboveground stand phytomass was measured as 33.8 t ha^{-1} (oven dry weight). Productivity values for the phytocoenosis were 2.1 t ha^{-1} yr^{-1} for living stand vegetation mass and 0.7 t ha^{-1} yr^{-1} for the dead organic mass in litter. In the case of undisturbed natural succession, relatively stable climax ecosystems can be expected to develop in 100 years. If the natural succession is influenced by destructive external factors, however, such as forest fires or insect outbreaks, then the native tree species can be replaced by secondary birch stands and meadow or steppe vegetation communities. The successional dynamics and stability of the phytocoenosis can be artificially supported by cutting decaying trees in pole-stage stands (30-40 years of age). It is desirable that the forest cover in harvesting areas should recover through regeneration of native indicator species, accompanied by the development of the original larch cenopopulation.

Role of environmental impact assessment science in ecologically sustainable boreal forest management: the Saskatchewan example

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A major objective of environmental impact assessment (EIA) is prediction. If a development will have an impact or an effect on its environment, the process of assessing the effects is, therefore, prediction. Two major goals in science are: (1) explanation of observed phenomena and(2) prediction. The EIA process makes use of academic science to provide the explanatory framework for the required data gathering, which is needed for the scientifically valid prediction of effects. Following this, the EIA process leaves science *per se* and enters the decision-making process. Follow-up monitoring after a development proceeds is required to test the predictions for their accuracy, important in both the scientific and decision-making aspects of EIA. This testing, a return to science, is needed not only for future EIAs in any project area but, also for ongoing project management. In boreal forest management, where EIA prediction is ecosystem-oriented rather than site-specific only, the EIA process needs to be tied to long-term forest management plans. This must be done via ongoing tests of predictions, and then by feeding the test-derived information back into a dynamic decision-making process. In Saskatchewan, this unique and holistic application of the EIA process to long-term forest ecosystem management, has been initiated in the Meadow Lake forest Management Licence Agreement (FMLA) area. This is an example of harnessing the scientific predictive and testing capacity of the EIA process to set the stage for ecologically sustainable, integrated forest resource management. This also is an example of local action to address a global problem by ensuring the continued integrity of ecological processes in a portion of Canada's boreal forest.

Gazing skyward: methodologies for conserving the boreal forest by changing the focus of management action from the vegetation to the atmosphere

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Historically, the management of air quality and forests have occurred in isolation. Modelling, however, suggests that boreal forests will be highly sensitive to changes in atmospheric composition, so much so that the persistence of the boreal forest in areas like central Saskatchewan will depend more upon the management of the atmosphere than upon the management of the vegetation. Forest management institutions must be both advocates of major emission reductions and models of energy efficiency and conservation. Case studies indicate that currently this is not a management priority. Simple methodologies do exist for setting targets and evaluating progress towards reducing institutional contributions to global warming.

Effects of climate change on insect defoliator populations in Canada's boreal forest: plausible scenarios and research approaches

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Annual forest losses from tree mortality due to insect attack in Canada are estimated at 51.0 million m^3 per year. These losses are 1.5 times those due to wildfire and amount to one third of the annual harvest volume.

If predicted climate changes take effect, the damage patterns caused by insects may be drastically altered, especially for the many insects whose occurrence in time and space is severely limited by climatic factors. This possibility substantially increases the uncertainties associated with the long-term planning of pest control requirements, with hazard rating models, with depletion forecasts, and with projections for the sustainability of future timber supplies. Moreover, because insect damage affects the rates of various processes in nutrient and biogeochemical cycling, potential changes in damage patterns can affect considerations of ecosystem integrity and resilience.

Based on our ongoing research and current knowledge, we develop plausible scenarios for the effects of climate change on the damage patterns caused by three of the boreal forest's more important pest species. These are the jack pine budworm, the spruce budworm, and the large aspen tortrix. Various research approaches being used to explore the key processes underlying the response of insect populations to climate change are also discussed in terms of these scenarios.

Strategies for maintaining biodiversity in boreal Sweden

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A model for managing Swedish boreal forests, which combines the concept of mimicking natural disturbance regimes with the core area-corridor concept, is presented and discussed. The model meets the demands of the recently adopted new Swedish forest policy in which both timber production and preservation of biological diversity are the main objectives with equal levels of importance. The strategy adopted to realize these goals on a national level, is to double the current reserved area (2.5% of the productive forest land), and to raise the frequency of natural structures and processes in the remaining managed forests. The model is developed for, and applied to, a representative North-Swedish forest landscape of 10 000 ha. We suggest that five areas (total area < 100 ha) within the landscape which are habitats for several Red-Listed species should be preserved, strengthened with buffer zones and/or connected by corridors. New vegetation successions on fire-influenced sites are initiated by reintroducing prescribed burning. At the landscape level (which is the operational scale for forest companies), management should aim at simulating natural landscape elements which are of more varied size and complex shapes than those generated by man. At the stand level, silvicultural methods that mimic processes of three types of fire- or storm- induced natural successions should be used. Structural components characteristic of those successions should be built into the stands.

Reasons for the choice of strategy in Sweden, as well as difficulties caused by e.g., forest state, ownership, legislation, economics, and knowledge in fulfilling the new Swedish forest policy, are discussed.

Forest operations and environmental protection

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Increased mechanization in forestry usually means increased traffic over the ground, which also is a substrate for growth. Soil compaction, rut formation, and damage to stems and roots will all result in growth reduction. To reduce soil disturbance and tree damage, smaller machines or machines with less ground pressure must be considered.

Today the traffic may cover 10-30% of the site area. This is mainly due to yarding during clear-felling and thinning. If present trends of heavy mechanization continue, in the future there could be as many as six machine entries on to the site by the time a stand has reached an age of 50 years.

Skidding is often recognized as the major cause of soil disturbance with 50-75% of skid trails considered as apparently compacted. Rut formation from forwarders is also a problem although harvesters seem to give minor problems. The engine torque powering the driving wheels adds considerably to the influence of the total weight of the vehicle on the ground. High tractive forces and slipping may contribute twice as much to soil disturbance as the vehicle ground pressure.

The paper presents a brief literature survey of research reports from several countries; on work dealing with the causes and extent of damage to trees and forest floor due to forest operations. Recent results from the Norwegian Forest Research Institute will be presented.

Prince Albert Model Forest: a history of changing human use from pre-contact to 1950

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This paper presents the findings of a multi-disciplinary study of the Prince Albert Model Forest and the people of the Montreal Lake Cree Nation who inhabit the area. Information gathered through an extensive review of historical records and from oral histories of residents of the Model Forest are synthesized to provide an overview of cultural, land and resource use change from precontact times to the middle of the 20th century.

Although the Prince Albert Model Forest area was used, travelled through, and possibly inhabited for undetermined periods in precontact times, permanent settlement in large numbers was not recorded until the middle of the 1800's. Reasons for this relatively late date may be related to the region's geographic position relative to major rivers and the activities of the fur trade. As fur became depleted in other parts of Western Canada, the Cree moved into the region. Changes were rapid between 1850 and 1950, with furs, forests, and the expanding urban, agricultural, and recreational land uses influencing the human geography of the area.

Impacts of forest harvesting on the foraging ecology of bats near Nelson, B.C.

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Forest harvesting results in different habitat types that may affect wildlife. To assess the potential effects on insectivorous bats, commuting and foraging activity patterns were monitored using ultrasonic detectors placed in three habitats resulting from forest harvesting (clear-cuts, edge of clear-cuts, and forest). Samples were taken in various forest stand age classes (80-250 years) for 90 minutes after sunset. Bat activity was significantly greater along the edge of clear-cuts than in clear-cut or forest habitat. In the forest, no foraging activity was observed and commuting activity peaked briefly 30 minutes after sunset, suggesting that forest habitat is not a primary foraging area but, is important habitat for roosting. Activity was greatest along the edge of clear-cuts associated with older forest. The preference for edge habitat suggests that forest harvesting may create habitat beneficial to bats from a foraging perspective. However, it is essential to note that other aspects of bat ecology must also be considered before comprehensive conclusions about the impacts of forest harvesting can be made.

Forest health monitoring in Canada: how healthy is the boreal forest?

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The Canadian boreal forest covers 299.2 Mha along a continuous belt from Newfoundland north and west to the Yukon. Major tree species are white spruce, black spruce, jack pine, lodgepole pine, balsam fir, white birch and trembling aspen, occurring singly and in mixtures. Wildfire is the driving successional force in the boreal forest and various insects and diseases damage trees in extensive and periodic outbreaks. These stresses although having dramatic effects, do not seriously impinge on the health of the forest. Anthropogenic activities include those associated with habitation, and extensive logging for the pulp and paper industry.

In order to ensure the sustainability of forests, it is necessary for the forest manager to know the condition of the health of these forests. Since 1984, the Canadian Forest Service has been monitoring the health of the forest using the Acid Rain National Early Warning System (ARNEWS). The system was established to detect early signs of damage from air pollution so that appropriate action can be taken.

Results to date show that tree mortality has been at normal levels and was caused by identifiable and known stresses; insects, diseases, drought, and frost, etc. No signs of pollution damage have yet been observed in boreal forests. An early warning system to detect and monitor conditions remains essential to the monitoring of the health of forests and ensuring their sustainability.

The arthropod biodiversity of *Populus* spp. coarse woody material in north-central Alberta

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The biodiversity of arthropods in *Populus* coarse woody material (snags, stumps, logs) of different decay classes is currently being studied in aspen-mixedwood stands of rotation age (60 years) and post-rotation age (85+ years), near Lac la Biche and Eureka River, Alberta. Three collecting methods were used in the first year of sampling (1993): arthropod rearings from wood samples, modified window traps, and collection by hand. Over 8000 arthropods from over 230 species were collected. Research focused on beetles (Coleoptera), of which there are over 130 species, representing approximately 30% of all arthropods collected. Preliminary data from reared Coleoptera shows that 42% were collected only from Lac la Biche and 26% collected only from Eureka River. Of the total number of beetles, 25% of the fauna was collected only in post-rotation stands, and 10% collected only in rotation age stands. In addition, moderately decayed wood had the highest species diversity, and extremely decayed wood the least. The significant spatial variation in the structure of snag arthropod communities argues for management decisions based on the regional and stand level, and not the forest management agreement (FMA) level. Also, the differences in fauna among stands of differing age-classes and in woody material in varying states of decay, suggests that conservation of biodiversity in managed areas could be maximized by leaving a mosaic of different age-class stands across the landscape, and to maximize dead woody material of all decay types.

The energy balance of the winter boreal landscape

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The boreal forest is a complex mosaic of land surfaces varying from closed coniferous canopies, through sparsely vegetated cleared areas to open lakes. The structure of these cover types interacts in very different ways with the incoming radiation and overlying atmosphere. The consequence is a substantial variation in microclimate, and in the surface fluxes of radiation, heat, and water vapour. This is particularly marked in the winter period when the vegetation interacts strongly with snow. Climate models predict large changes of temperature in northern latitudes in response to increased atmospheric carbon dioxide. These changes are large because of the strong positive feedback between energy flux and snowcover. However, there will be further modification of climate arising from changes in landscape cover type. Forest cover will change both as a direct result of land clearing and as a result of the response of the vegetation community to climate warming.

During the winter of 1993/94 a study took place to quantify the energy balance from the main cover types of the boreal landscape. The study was based on the southern edge of the boreal forest in Canada. Measurements were made over a mature jack pine stand, a recent clear-cut and a frozen lake. Short wave albedos of 20% over the jack pine, 20-50% over the clear-cut, and 20-85% on the frozen lake (depending on snow cover) were measured. There were correspondingly large contrasts in the total radiation inputs and turbulent heat fluxes. The results of these experiments will be used to design much improved descriptions of boreal forest in the next generation of climate models.

Artificial regeneration of spruce on cold, wet soils

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Regeneration concerns were expressed in the late 1970s when beetle salvage logging commenced in the Bowron drainages of British Columbia. At that time, the primary concerns were of cold, wet soils and vegetation competition at higher elevations (>1100m) on north and east aspects. A series of research trials were established in the early 1980s on several sites along the Coalmine Road in the Bowron Valley by the British Columbia Forest Service. The ten-year results of two trials planted with the same seedlot and stock-type at the same time are presented. One trial used different sizes of inverted mineral mound (ecophysiology project, Ecophys) to address establishment and growth issues. The other used mounding coupled with herbicide site preparation or brushing treatments (mounding and herbicide project, M&H) to monitor the questions of biological importance.

On both sites, survival with the control treatment (the "do nothing but plant" option) was poor: 34% at Ecophys and 66% at M&H. Seedling/sapling growth was also the poorest for the controls at both sites. Ten-year survival on mounded treatments was greater than 90% at both sites, even reaching 100% at M&H. At Ecophys, inverting the organic mat and creating mineral cap mounds increased ten-year stem volume by at least 311% over the controls. Mounding approximately doubled the stem volume over the control at M&H. Herbicide site preparation increased stem volume by 238% over the control, while mounding and herbicide site preparation resulted in a stem volume increase of 310%. The control at M&H was 151% that of the control at Ecophys, while the common mound treatment was 78% of that observed at Ecophys. Using herbicide as a brushing treatment resulted in similar stem volumes to the mounding treatment at M&H. These data indicate an interaction between treatment and site: one size does not fit all.

A cost analysis was performed for the mounding and herbicide project and for the control and common mound treatments at Ecophys. The most costly treatment to establish at M&H, mounding and herbicide site preparation, was the most cost-effective at year 10, $220 per cubic metre produced. The controls at M&H and Ecophys cost $737 and $2,100 m^{-3} respectively. The common mounding treatments cost $303 and $255 m^{-3} at M&H and Ecophys respectively. These data indicate that under certain conditions, spending more during establishment does result in greater growth and survival.

Jack pine seedling emergence: effect of water regime, cover, organic horizon thickness and ashes

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The impacts of water regime, cover, organic horizon thickness and ashes on jack pine seedling emergence were investigated. For this, 220 monoliths were taken to the laboratory and received prescribed burning leading to fire severities of 100%, 75%, 50%, 25% and 0%. One half of each monolith contained ashes whereas the other half was kept ash-free. Each half of all the monoliths was then sown with jack pine seeds. The monoliths were incubated under different shading regimes [100%, 75%, 50%, and photosynthetically active radiation], and watered under four different moisture regimes. Seedling emergence was greatest under high moisture regimes, high fire severity with intermediate shading, and without ashes. Ashes had an inhibitory effect on seedling emergence.

Fire hazard reduction using less flammable vegetation: species selection and testing

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There are many areas in the boreal forest where fire frequency is increased by anthropogenic ignitions. In these areas, the combination of highly flammable vegetation and large number of ignition events creates a high fire hazard. The resultant fires cause considerable ecological, economic and social damage. Fire frequency in the boreal forest is expected to increase during climate change. Fires caused by people might be expected to increase as humans continue to move into less-populated areas of the boreal forest. The objective of the Fire Hazard Reduction Project is to reduce anthropogenic fire frequency by the strategic replacement of highly flammable vegetation with less-flammable vegetation.

Tissue moisture content is probably the most important plant characteristic affecting flammability. It is not known, however, how moisture and other fuel characteristics interact to determine overall flammability of herbaceous species. We tested the hypothesis that ignitability, one component of flammability, can be predicted from physical and chemical fuel characteristics. Live and dead tissue samples of abundant native, and commercially available herbaceous species were collected in June 1994. Stems were sorted into 1 mm diameter size classes. Tissue density and surface area to volume ratio were determined for each stem class. Caloric value, total ash and silica-free ash were measured for all tissue types and species. Time to ignition of 15 stems per stem class per species is currently being measured in a muffle furnace. Ignition tests are being conducted on oven-dry samples and there are provisions to test at higher moisture content. Time to ignition will be regressed against physical and chemical fuel characteristics.

Information about the quantity and distribution of fuel is just as important as knowledge of fuel quality. The amount of letter and standing dead crop is continuing to be measured for selected species through field sampling and by experiments on decomposition. The ability of several species to grow quickly in the spring to shade the litter has been investigated with experiments on temperature-dependent growth rates. Future experiments will test the ability of selected plant species to reduce the probability of ignition and rate of fire spread under field conditions.

The establishment of less-flammable vegetation in fire-prone areas or around property and sensitive natural areas may help prevent ignition or retard fire spread. This technique could be a long term, cost effective and environmentally friendly method of fire prevention and control in selected areas of the boreal forest.

The aspen parkland in western Canada: a dry-climate analogue for the future boreal forest?

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General Circulation Models predict that the future climate of the southern boreal forest in western Canada will be similar to that presently experienced by the aspen parkland transition zone. Analysis of regional climate gradients and vegetation zonation have indicated that moisture rather than temperature is the controlling factor. In the parkland, aspen has a stunted growth form, low productivity and is subject to severe dieback during periods of drought. Measurements on a transect in the aspen parkland north of Saskatoon suggest that the degree of exposure amplifies the effects of water stress. If predicted warming and drying occurs, continued commercial harvesting of aspen in the low boreal forest may be greatly reduced.

Estimation of the carbon pool and its annual deposition in phytomass of forest ecosystems in Russia

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On the basis of the results of evaluating the forest fund of Russia (i.e., distribution of areas and stand-stocking, according to dominant species and age classes) and from calculations of the coefficients relating the stock of stem-wood to other phytomass fractions in terrestrial ecosystems, estimates of the carbon pool for all land categories in the forest fund (1,183 Mha) have been obtained. Annual deposition of carbon was also calculated, taking into account the changes in the stock of stem wood and phytomass. The carbon pool in the phytomass (live plant tissues) was estimated as 41.2 Gt, including 38.6 Gt for the afforested areas (771.1 Mha). Annual carbon deposition was 211.6 and 184.4 Mt yr^{-1} for the total and afforested areas respectively.

Stores of carbon were calculated for different forested zones and regions of Russia. A model of the optimal structure for the forest fund is under review, which provides no losses for forest management yet allows maximal carbon deposition. The assessment of potential carbon stock is derived, taking into account the effects of forest fires, felling, and other natural and anthropogenic factors.

Rooting distributions of white spruce/aspen trees in mature and recently cutover stands in Saskatchewan

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Questions have been asked concerning the role of Canadian forests in acting as a sink for carbon. Although one tends to observe the above-ground portion of the tree, considerable carbon can be stored below-ground in root systems. In the boreal mixedwood forest, however, little is known about the distribution of carbon in the form of root systems for aspen and spruce trees when growing in mixedwood stands. The objective of this study was to determine the rooting distributions (length and weight) for spruce and aspen in a mature stand and two recently cutover sites. In the mature stand, roots were found to a 1.2 m depth with aspen root length densities being 10 times those for spruce even though the number of aspen stems was twice that for spruce. Greater than 50% of the root length of both species was found in the LFH layer in mature stands and this trend was also found in the cutover stands. More information is necessary to accurately quantify carbon from root systems in forest soils and how root growth and turnover may affect these sinks.

Investigation of damaged forests in Siberia on an eco-geographical basis (landscape ecological approach)

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Investigations of damaged Siberian forests were completed on an eco-geographical basis using aerial- and satellite images. During the investigation process, maps were made at medium and large scales. These maps are of: physical-geographical division of forests into districts; forest disturbances; ecological situations in the forests in connection with their condition and evolution. For key sites, landscape, forest type and soil maps were made at large and medium scales.

Simulation of long term forest sector carbon budget: stand level assessment under a changing climate in Finland

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Forests and wood-based products have been proposed for use as carbon (C) sinks in mitigating the greenhouse effect. Forest management and use of wood products are presented with a challenge in meeting the requirements to store C in forests and wood products, while at the same time fulfilling the needs of consumers. In this context, the study presented here aims to evaluate the effects of forest management and the use of wood products on the forest sector C budget at the stand level, both under the current climate and a changing climate in southern and northern Finland.

Flows of C in the forest ecosystem were simulated with a gap-phase dynamics type model, while flows of C in wood products were simulated using a model that processes raw material into final products, following them until C is returned to the atmosphere. The average forest sector C storages in southern Finland over the 500 year simulation period were 174-181 Mg C ha^{-1} under the current climate, and 206-217 Mg C ha^{-1} under the changing climate scenario. In northern Finland, average forest sector C storages were 101 Mg C ha^{-1} under the current climate, and 191-198 Mg C ha^{-1} under the changing climate. The respective average C storages in unmanaged forest ecosystems were 200 and 191 Mg C ha^{-1} in southern Finland, and 142 and 193 Mg C ha^{-1} in northern Finland. Approximately 27-43 % of forest sector C was stored in wood products over a 500 year period. Wood products contributed 15-22 % of forest sector emissions to the atmosphere. Over short periods, forest sector C sequestration potentials are much greater than over longer periods.

Productivity of boreal forest ecosystem under changing climate

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The paper summarizes a forest ecosystem model developed for assessing the effects of climate change on the functioning and structure of boreal coniferous forests assuming that temperature and precipitation are the basic dimensions of the niche occupied by any tree species. Special attention was paid to specifying weather patterns at a level representing the time constants of different physiological and ecological processes relevant to the survival, growth and death of trees. In this way, the long-term dynamics of the forest ecosystem were coupled to climate through physiological mechanisms such as photosynthesis and respiration in terms of energy flows through the ecosystem. Furthermore, hydrological and nutrient cycles couple the dynamics of the forest ecosystem with climate change through soil processes, which represent the thermal and hydraulic properties of the soil and the decomposition of litter and humus with mineralization of nutrients.

The simulations for southern Finland (62°N) indicated that a transient increase in temperature of 5 °C over 100 years could reduce the soil moisture content in Scots pine dominated forest ecosystems. At the same time, this temperature increase could enhance photosynthesis up to 6-8% under the current atmospheric CO_2 concentration and up to 8-10% under an elevated CO_2 concentration (from 330 ppm to 660 ppm). Enhanced respiration (12-14% greater than under the current climate) resulted in total stem production increasing only up to 4% when only the temperature increase was assumed. Simultaneous elevation of CO_2 concentration increased total stem wood production up to 6%. Since transpiration increased only up to 5%, water use efficiency of Scots pine-dominated forest ecosystems increased up to 3%, particularly during late rotation.

"Evergreen" aspen in the boreal forest

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Quaking aspen is one of the most aggressive species in the boreal zone. Its highly competitive ability is based partly on the photosynthesis of its bark.

Studies were made in the boreal zone (Krasnoyarsk region, Siberia and Saskatchewan, Canada). Chlorophyll concentration in aspen bark (twigs and stems) was found comparable to that of the leaves. The bark is estimated to contain up to 20% of total tree chlorophyll content when fully leafed. Chlorophyll was also found in the pith of twigs (up to age 5-8 years). The photosynthetically active radiation (PAR) incident on the bark chloroplasts is sufficient to support significant photosynthesis, since the level of PAR on the bark surface may reach 1000 $\mu mol\ m^{-2}\ s^{-1}$ or more, and the transmittance of the aspen bark periderm in the red absorption band of chlorophyll is 50-60%. The fluorescence response of aspen bark (fluorescence spectra, Kautsky effect. and delayed light emission) was similar to that of leaves. In all measurements on the bark of twigs and stems, photosynthesis was detected (using a LI-COR infra-red gas analyzer). In general however, net photosynthesis was negative since the bark consists mainly of respiring tissues and the chloroplasts are concentrated mainly in a thin cortical layer just beneath the periderm (which is comparable to the leaf in thickness). It should be noted that there are two sources of CO_2 for bark photosynthesis: external (which passes from the atmosphere through the lenticels, and from the soil with water flux), and internal, or respired CO_2. The internal ("recycled") CO_2 could significantly affect the net carbon balance. This conclusion is supported by a relatively high potential maximum rate of photosynthesis, determined from net O_2 evolution chamber measurements, which in aspen bark reached one third that of the leaves (under similar conditions of light, temperature and humidity). Chlorophyll was also found in the twig/stem bark in other woody and shrub species (more than 60 species), but in general, its density was less than in aspen bark. In measurements with several selected species, bark photosynthetic activity has also been detected.

The reflectance spectra of aspen bark were similar to those of other chlorophyll-containing tissues. Deviations may exist due to pigments in the periderm; and the white bloom often found on the bark surface. Under high levels of solar radiation (e.g., at the southern edges of stands), the bloom on the bark surface presumably acts as a "sun shield", protecting bark tissue from ultra-violet radiation and heat damage. Understanding the spectral properties of bark is necessary for the improvement of light-tree/stand interaction models.

The role of bark photosynthesis is most significant during leafless periods (fall and spring), and also for trees affected by foliar pests, fungi, and pollution. Results indicate that bark input into the carbon balance is significant, a factor which may be important for understanding the "carbon deficit" in global carbon balance modelling.

Global carbon dynamics of higher latitude forests during an anticipated global climate change

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The responses of vegetation and soils of higher latitude forests to anticipated climate change are investigated. The study is performed with a high resolution process model (the Frankfurt Biosphere Model) in which photosynthesis is driven by the variables surface temperature, precipitation, radiation (including cloud cover) and atmospheric CO_2 concentration. Typical output data include monthly gross and net primary production and monthly heterotrophic respiration, as well as seasonal dynamics of leaf area index (LAI). The model can be run in a transient as well as in a steady state mode. Annual intercomparisons allow changes in living biomass and soil carbon to be determined. As a first order approximation, the areal extent of eight distinct vegetation forms of northern forests and tundra are retained, and the response to climate is entirely due to changed physiological responses of the vegetation. The results will be compared with those obtained by a shift in the borders of the biomes under prescribed fixed relations between climate and biome, with typical values applied to standing biomass, net primary production and soil carbon.

The role of coarse woody debris in the carbon budget of Russian forests

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To understand the role that Russian boreal forests play in global climate change, it is necessary to identify and accurately quantify all stores and fluxes of carbon in forest ecosystems. The carbon stores and fluxes related to coarse woody debris (CWD) of boreal forest ecosystems are not well understood. Recognizing this problem, a model was created to estimate the accumulation and decomposition of CWD as a function of forest type, age, and site quality. The model was based on 113 growth curves, for five classes of site quality, for coniferous and deciduous species found in Russian forests. Data on the dynamics of growing stock and the formation of CWD were incorporated in the model. Applying 2, 4, and 6% decomposition rates to the declining (with age) pool of CWD, the pool of the residual CWD (after decomposition) was estimated and expressed as a ratio to the age-dependent growing stock. Relating the ratios to the present growing stock of Russian forests, considering their age and distribution by species, site quality, and stocking, it was estimated that at the end of the 1980s, Russian forests were accumulating 118 Tg C yr^{-1} in CWD or 23 % of the net carbon accumulation in phytomass. The accumulation of residual CWD continued beyond 130-140 years.

The problems of forest management in Russia

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Analysis of existing systems of forest management in the Russian Federation, discussion of forest ownership, division of functions in forest management and exploitation of forest resources, density of forest yield, mechanisms of forest funding etc. There has been specified the need for increasing legal and economic protection of forests under conditions of transition to a market economy. Directions for development and improvement have been worked out for Russian Federation forest legislation and implementation of forest management.

Dynamics of the dead wood carbon pool in Russian boreal forests

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Dead wood and the ecological processes controlling its accumulation are aspects of the carbon cycle in forest ecosystems which have not been studied adequately. Woody detritus is potentially a large carbon pool very sensitive to disturbance and forest management practices. Expansion of intensive forest management for timber production has significantly reduced the dead wood carbon pool. On the other hand, projected forest dieback associated with global climate change may dramatically increase dead wood mass and its role in the global carbon cycle. Understanding dead wood dynamics is necessary for balancing past, current and future global carbon budgets and for developing strategies to conserve and sequester carbon in forest ecosystems.

Our study examines dead wood dynamics in a series of permanent plots established in closed, productive forest stands of north-west Russia. These plots represent different species, successional stages and types of disturbance (thinning, clear-cut harvest and windthrow). Long-term plot records provide data on mortality inputs over succession and a chronosequence of dead trees to measure decomposition rates. A total of 110 logs, snags and stumps was sampled for decay rates and to develop a system of decay classes. Dead wood stores were measured on 63 plots 0.2-1.0 ha in size.

Average mortality input on the plots was 53 Mg C ha^{-1} over 60 years of observation or 10-35% of the total wood increment. Annual decomposition rates are low in Russia due to severe climate: 2.5% for pine, 2.7% for spruce, and 3.0% for birch. These data suggest a steady-state dead wood mass of 29-35 Mg C ha^{-1} would be expected in these forests. Measured dead wood storages ranged from 1-4 Mg C ha^{-1} in young to mature intensively managed stands, 15-36 Mg C ha^{-1} in old-growth forest, 21 Mg C ha^{-1} on a clear-cut and 53-87 Mg C ha^{-1} following a windthrow event.

The size of the dead wood carbon pool and its role in the carbon balance depend upon the successional stage, management and disturbance regimes. Intensive forest management, including short harvest rotations, thinning and wood salvage, reduces dead wood carbon storage to 5-15% of the potential level found in undisturbed old-growth forest. In contrast, natural disturbance increases the dead wood carbon pool by a factor of 2-4. In old-growth forests, dead wood comprised 14-18% of the total wood mass, a proportion quite similar to the larger, more productive forests of the Pacific Northwest (USA). If this proportioning is characteristic of cool conifer forests, it would be useful to estimate the potential dead wood mass for old-growth forests without inventories. The use of a single live/dead wood ratio across the range of successional stages, a common practice in carbon budget calculations, may however, substantially over- or under-estimate the dead wood carbon pool depending upon the type of disturbance regime.

Desiccation to coniferous stock planted in the southern boreal forest of B.C.

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Many white spruce seedlings planted in the northeastern part of BC are injured or killed between the first post-planting fall and the next spring. These injuries are characteristic to the planted seedlings and do not affect older plantations and naturally regenerated seedlings. Typically observed symptoms vary from injury to foliage, mostly on the southwestern side of a seedling, through death of the upper part of the shoot, to death of the whole tree (Krasowski *et al.* 1993). In accordance with BC ecosystem classification (Meidinger and Pojar 1991), the injury occurs throughout the Boreal subzone approximately from the latitude of 55°N to 57°N. No similar symptoms have been reported north of the Prophet River--approximately the northern boundary of the BWBSmw1. The severity of injuries and losses vary from year to year depending on climatic patterns.

An ongoing study has identified the major cause of the injury as early spring desiccation. Thorough monitoring of environmental variables on research sites has shown frozen soil persisting until mid- to late April at the 5 and 10 cm depths and until early May at 50 cm. During this time, daytime temperatures are often above 10 °C imposing high evaporative demand on the plants. The temperature usually declines to below freezing at night which delays thawing of the ground. The deep freezing of the soil results from a typically low snow pack and very cold winter air temperatures in this geographic area. Soil temperatures however, although below 0 °C, are not sufficiently low to damage the root system which usually stays uninjured even in trees severely injured above the ground. Planted trees, especially those grown in container-nursery culture, have their water-absorbing roots deep in the frozen soil. Therefore, they cannot take advantage of superficial soil thawing that makes water available to naturally regenerated seedlings which possess extensive shallow roots and to established spruces that have developed adventitious roots.

The study reported here compared a number of nursery stock characteristics, planting dates, and microsite manipulations in relation to observed injury levels. It also examined other possible injury causes such as direct low temperature, photo-injury, and dehardening of seedlings by warm temperatures in winter (Chinooks). The above were addressed by studies performed directly on sites located in the affected area, and by experiments with artificially induced environmental conditions performed at the research station.

The use of shallow rooting stocks with chemically- or mechanically- pruned root systems has been recommended as a potential remedy to the problem as well as site preparation treatments promoting faster soil warming. Sheltering spruce plantations with a young aspen overstory reduces the injury by prolonging snow cover and reducing seedling exposure, but effective densities of aspen are impractical and detrimental to the growth of spruce seedlings past the first season.

The role of logging residues in site productivity after first thinning of Scots pine and Norway spruce stands

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The intensity of biomass harvesting influences the carbon and nutrient cycles and the productivity of a forest site. The effects of whole-tree harvesting (WTH) on the quantity of organic matter and nutrients, and on wood production, were studied in 15 field experiments representing four different site types.

The material consists of two 5-year periods from 8 experiments and the first 5-year period from 7 experiments. The treatments were: 1) WTH, 2) merchantable stemwood harvesting (MSH), 3) WTH and compensating fertilization equivalent to the amount of N, P, and K removed in logging residues, 4) WTH and normal NPK fertilization, and 5) MSH and normal NPK fertilization. In eight experiments, there is an additional treatment of MSH and double logging residues.

WTH increased the removal of biomass and nutrients in relation to the MSH as follows:

	Biomass	N	P	K	Ca	Mg
Pine stands	1.7	3.6	3.5	3.0	2.4	2.4
Spruce stands	1.5	3.3	2.2	2.5	2.1	1.9

When the nutrient amounts removed were compared with the total amounts in the humus layer, the following percentages were found:

		N	P	K	Ca	Mg
Pine stands	MSH	5	9	39	25	35
	WTH	19	31	115	61	85
Spruce stands	MSH	6	42	61	40	33
	WTH	20	103	152	87	66

In spite of the considerable nutrient removal due to WTH, especially in the spruce stands, after ten years there were no significant effect on the nutrient content of the humus layer. However, there was some indication of soil acidification.

In pine stands, the effect of logging residues on stem wood increment was slightly positive but not significant. In spruce stands, the nutrient content of residues was about three times that of the pine stands, while growth reduction due to WTH was 10 % (1.4 m^3 ha^{-1} yr^{-1}) during the 10-year period.

Economic impact estimation for forest-dependent communities: a case study of the NorSask Forest Management License Agreement Area in Saskatchewan

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Regional development impacts of economic projects are among the top of the list of concerns for planners, the public, and policy makers. In the remote areas of northern Saskatchewan, where employment opportunities are relatively fewer, and unemployment rates relatively higher, than those elsewhere in the province, it is only natural to search for ways to improve the economic well-being of the northern residents. Forest resources, by virtue of their location, are the natural target for generating employment and income opportunities for local people. This requires estimation of the local economic impacts of various forest development projects. Similarly, various public and private agencies may construct different options for managing forest resources. Each of these options, at least in theory, could have a different impact on the local economy. A tool for estimating such impacts is therefore warranted.

This study is based on a local area input-output model. Using secondary data sources, a model has been constructed for the NorSask FMLA region. Model construction begins with the creation of a transactions matrix for the region. This matrix portrays the regional composition of the economic activities, and the interdependencies that exist among various economic sectors. This matrix becomes the basis for creation of multipliers for various economic activities in the region.

Local impacts of a forest management option are determined by two factors: (1) the nature of the production sectors that exist in the region, and their interdependencies; and (2) the pattern of expenditures by the receiving agents of the outlay for the project. More importantly is the question of location where the money is spent. If workers receive income from a given project, but if that money is not spent on local goods and services, then most of the development effect of that expenditure would be leaked out to other regions. Using primary data on the NorSask region, different types of activities, such as harvesting, silviculture, and outfitting, among others, would be evaluated in terms of their local impact.

Integration of socio-economic indicators and assessment methods in an overall project appraisal framework: a case study of the Prince Albert Model Forest

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Forests are multiple use resources. They provide not only economic benefits, but also social and environmental benefits. Even among the economic benefits, forests generate timber benefits, and non-timber benefits. In an attempt to develop integrated forest management programs, all these aspects of forest values must be considered.

Development of the evaluation framework for various forest management options requires a comprehensive conceptual framework, encompassing all three aspects of benefits -- social, environmental, and economic. From an economic viewpoint, two questions are relevant: (1) what aspects of economic well-being should be included in the framework?; and (2) how should one integrate economic and non-economic values in a single decision-making framework?

The purpose of this paper is two-fold: (1) to suggest socio-economic indicators that are appropriate in light of the goals and objectives of the Prince Albert Model Forest in order to compare future management options; and (2) to provide a state-of-the-art review of various techniques that have been used in the forest management literature. Included among these techniques are: integrative frameworks, such as multiple criteria decision-making tools, multiple objective optimization tools, natural resource accounting, and multiple accounts analysis, among others. Each of these tools would be evaluated in terms of its appropriateness for forest management in the Prince Albert Model Forest region.

The effect of policy decisions on the carbon budget of the Canadian forest sector

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The Carbon Budget Model of the Canadian Forest Sector (CBM-CFS2) was used to explore the effects of several policy options on the net exchange of carbon over the next 50 years. The study demonstrates the effects of changes in rotation length, regeneration strategies, and the management of disturbances such as fire and insects on the forest sector C budget. The implications of decisions that affect the forest product sector, such as changes in product life-spans and recycling options, are addressed. The paper concludes that although forest policy options can have significant impact on the C budget, there are many potential impediments to their implementation.

Post-fire vegetation recovery and tree establishment at the Arctic treeline: a climate change hypothesis

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A fire of unusual severity burned across the forest-tundra ecotone near Inuvik, Northwest Territories in the summer of 1986. It was thought that this event represented a partial analogue of the impact of climate change in subarctic environments on vegetation. Burned:unburned paired study sites around the fire perimeter, established in 1973 and relocated in 1990, showed that total vascular plant cover had reached pre-fire levels after 22 years. Tall shrubs have become dominant in the tundra. Cryptogams showed minimum recovery. Biomass was sufficient to support another fire. Post-fire *Picea mariana* and *Picea glauca* densities showed little recovery in previously treed areas, whereas *Betula papyrifera* and *Populus balsamifera* showed an increase in densities and had extended their range into previously treeless areas.

It was concluded that severe fires increased the probability of *B. papyrifera* and *P. balsamifera* establishment on mineral soils and that these species were able to invade pre-fire treeless areas enhanced through their long distance seed dispersal mechanisms. These results could have implications for vegetation changes in the subarctic regions related to global warming scenarios. It is predicted that deciduous tree species will increase in abundance and could invade tundra areas in a stepwise fashion after each fire.

The Canadian Regional Climate Model

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The spatial resolution of General Circulation Models (GCM) will always remain relatively coarse owing to the heavy computational load of such models, due, in turn, to their global nature. Nested limited-area models offer the possibility of increasing the linear resolution of climate models by nearly an order of magnitude compared to GCMs. A Canadian Regional Climate Model (RCM) is currently being assembled, based on the dynamical framework of MC2 (a non-hydrostatic model developed by the late André Robert at UQAM, used as a Mesoscale Compressible Community model by scientists of the Cooperative Centre for Research in Mesometeorology), and the subgrid-scale physical processes parameterisation of the second-generation Canadian GCM developed at the CCC.

Preliminary results of the RCM at 45 km resolution, nested within the 450 km GCM, will be presented for one simulated month of January. These results demonstrate the feasibility, from both the scientific and the computational viewpoints, of the nested RCM approach.

Fire-climate dynamics in northern Alberta since 1850

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The reconstruction of fire-climate dynamics at the decadal scale has typically been limited to the period of historical records, or to areas with long fire scar records. In this study we use historical fire records and forest stand-age data analysed using life-table methods, to reconstruct annual (1950-1989) and semi-decadal (1850-1989) variations in area burned in the 44,870 km^2 area of boreal forest in Wood Buffalo National Park (WBNP).

Annual area burned between 1950 and 1989 was negatively correlated with mean fire-season precipitation and annual tree ring-width indices from five stands in WBNP, and positively correlated with the fire-season means of temperature and fire weather. Life-table estimates of semi-decadal variations in mean annual percentage area burned were positively correlated with historical records of annual area burned in WBNP between 1950 and 1989, and significantly negatively correlated with tree ring-width indices from five stands in WBNP between 1850 and 1989. Peaks in annual area burned and semi-decadal estimates of mean annual percent area burned appear to be episodic, with an average interval of 30 to 40 years. Potential causes of these decadal scale variations in fire and climate are discussed.

Genetic control of stem growth and respiration among jack pine provenances from a north-south transect

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The bole respiration of eight provenances of jack pine (*Pinus banksiana* Lamb.) were compared to assess whether there were genetic differences in the rates of respiration that would affect responses to changing climate. Trees were growing in a provenance trial established near Fredericton, N.B., Canada during 1966. Trees were chosen so that breast-height diameter and 1993 annual stem growth were similar for the selected trees of all provenances. The CO_2 efflux near breast-height of two trees per provenance was measured continuously for 3-4 day periods at six times during 1993.

Respiration rates at a reference temperature were highest early in the growing season and declined thereafter for each tree. There were substantial differences between northern and southern provenances in the seasonal course of bole respiration. It appeared that maximal respiration rates occurred earlier for southern provenances than for northern provenances, and that southern provenances continued to exhibit growth respiration in September, at which time northern provenances exhibited only maintenance respiration. During July and August, the respiration rates of northern provenances were slightly higher than those of southern provenances. There were no differences between northern and southern provenances in respiration rates observed in October, after the onset of dormancy in the cambia of all provenances. The within-growing season differences in respiration between northern and southern provenances could give rise to differences in the efficiency of converting photosynthate into stem biomass that would affect responses to changing climate. The similarity of respiration rates in October suggests that there were not genetic differences in the maintenance respiration done between growing seasons.

Impact of 1980-1989 large fires on forests near the boreal-subarctic interface: a population and landscape level interpretation.

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Large fires burned in excess of 30,000 km^2 of forest between 1980 and 1989 in James Bay territory, 200 km from the southern limit of the forest tundra of northern Québec. These fires provide an opportunity to assess forest stability in relation to recent fire regime and post-fire climate near the boreal-subarctic interface in this area. Tree population density before and after fire were estimated at 83 sites burned in 1981, 1983, 1988 and 1989. Since post-fire seedling establishment lasts only a few years in these tree species, prognostics concerning tree population density in regenerated forests could be based on density measurements after 3 or more years following fire.

The results indicated that jack pine regenerated adequately on sites burned in 1981 and 1983. A low black spruce regeneration potential favoured a regional expansion of jack pine, which attained higher cone production when fires occurred. In the 1988 fire, a minimal 95% decrease in tree population density was noticed in 67% of the sites, while more than half of the sites burned in 1989 exhibited a tree regeneration which was only 25% of the pre-fire density. Post-fire climate seems to have been more suitable for seedling establishment following the 1981 and 1983 fires, which could explain the better regeneration success than that following those of 1988 and 1989.

These results suggest that forests in the study area were not in equilibrium with recent fire regime and post-fire climate. This instability can be seen by an expansion of jack pine at the expense of black spruce, and by a sharp decrease in total tree population density after the 1988 and 1989 fires. The opening of forest cover after those fires can be seen as a step leading toward a southward expansion of forest tundra into the northern boreal forest, in the context of a global warming.

Dynamics of snags and downed woody material in aspen-dominated mixedwood forests of northeastern Alberta

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This study examines the density, structure, and succession of snags and downed woody material (DWM) in early (23-26 years), mature (51-63 years) and old (122-146 years) stands in fire-origin aspen-dominated mixedwood forests of northeastern Alberta. Nearest neighbour, line intersect and increment growth techniques were used to sample trees, snags and DWM in four stands of each stand age-class. Overall snag densities (≥10 cm DBH) were ordered: mature = old > early. Overall volumes of DWM were ordered: old > early = mature. Comparisons of size distribution and decay patterns indicated that early stands retained a significant amount of snags and coarse DWM from the pre-fire stand. In mature stands, most of the pre-fire snags had fallen and were replaced by smaller post-fire snags. There was no significant decrease in the volume of pre-fire DWM. However, most of the coarse DWM was in advanced decay classes. In old stands, all snags and coarse DWM originated from the post-fire cohort of trees. Characteristics of snags and DWM within each age-class reflected the mix of pre- and post-fire materials. Overall, old stands exhibited a wider range of variation in sizes and stages of decay for snags and coarse DWM. A classification system for trembling aspen and balsam poplar snags was derived through analysis of their characteristics and decay rates. This study suggests that old stands offer a wider range of snag and DWM associated habitats and that some of the early stands retain "biological legacies" from pre-fire stands. Changes in global climate are likely to increase fire intensity and frequency. In turn, this would reduce the "biological legacies" left by the pre-fire stand as well as the frequency of older stands throughout the landscape.

Disturbance impacts on forest temporal dynamics

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A spatial simulation model is developed for investigating the possible impacts of disturbances on boreal forest temporal dynamics. Two types of disturbances are identified: type I (without contagion) and type II (with contagion). We examine two mechanisms of disturbance initiation and two kinds of forest renewal process for their effects on the average biomass of the forest. The results show that if disturbances are randomly initiated, then there are no significant differences between the temporal forest dynamics generated by the two kinds of disturbances. Significant differences appear however, when disturbance initiation is related to forest age. For a given disturbance frequency, type I disturbances result in younger forests than do type II. Such results, we conclude, are caused by changes in the probability of disturbance for a given stand due to the contagious processes. The results suggest that more attention should be paid to spatial dynamics affected by contagious disturbance processes when simulating biomass dynamics of forests.

Reforestation trials in the Russian Far East

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Cooperative forest planting trials were initiated in the Russian Far East (RFE) during 1989. Seeds collected from the RFE were used to produce high quality containerized seedlings at Weyerhaeuser greenhouses in Washington state. These seedlings were used to establish research planting trials in 1991 and 1992 in the Khabarovsk territory near Vanino and Khabarovsk. Large-scale operational planting projects were carried out in 1993 and 1994 using an additional 1.2 million seedlings.

Seedling survival and growth has been excellent in the research plantings and over a wide range of deforested sites. The results demonstrate that high quality seedlings can be used to successfully reforest a variety of site conditions resulting from burning and harvesting operations in the RFE. Planting project management, planter training, and plant compensation based on planting quality and quantity criteria also were successfully introduced and used. Crucial to the operational planting success was good logistical support and a well trained, organized and positively motivated work force.

Activities are now focusing on assisting with improvements in reforestation processes in the Khabarovsk Territory. The initial emphases are on fire control, seedling production, and resource assessment.

The structural character and biodiversity of virgin-secondary forest in Changbai Mountain

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Natural forests are generally divided into virgin and secondary forests, although there is much forest that is of neither type. The broadleaved-Korean pine forest region characterized by that in the Changbai Mountain area is referred to as virgin-secondary forest. This kind of forest is formed from virgin forest by repeated extensive selection cutting and natural disturbances. Thus, some plant elements and soil conditions characteristic of the virgin forest remain, while many elements of a secondary forest community are established. Because the structure of this forest community is unique, some special management measures need to be taken in virgin-secondary forests.

Research has shown that the structure of virgin-secondary forest presents an obvious, uneven aged character. The difference in ages among standing trees of the same diameter is also clearly evident. The stand structure of the community is complex. Generally, there are a main forest layer, a succession layer, and regeneration layer, all composed of woody species, with indicators found in every layer. The composition of virgin-secondary forests is complex, although the stem count for broadleaved species is considerably lower than that seen in virgin forests, and some species disappear completely. The Simpson Diversity Index of species in virgin-secondary forests is about 0.6-0.88, while the Shannon Wineer diversity index is 1.0-3.5. This demonstrates that the composition of virgin-secondary forests is not fixed.

The Nashwaak Experimental Watershed Project: snowmelt and streamflow before and after clear-cutting

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Snowpack depth, snowpack water equivalents, and stream discharge rates were determined as part of the work associated with the Nashwaak Experimental Watershed Project. Maximum snow depth was found to be lower within the cut watershed throughout the winter season. Also, clear-cutting advanced the snowmelt season by about two weeks.

Snowmelt was addressed as a special function of the forest hydrology model (ForHym) in relation to: (1) the radiative energy balance before and after clear-cutting; (2) monthly mean air temperature; (3) total precipitation volume and its monthly snow fraction. Snowpack depth, soil moisture, and stream discharge rates, among other hydrological variables, were also calculated using the model. Model calculations generally agreed with actual observations.

BOREAS Interactive Multimedia Interpretation: communicating messages to the general public so that they can understand and appreciate the science and ecology of the boreal forest

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The scientific and ecological integrity management communities associated with the **Bo**real **E**cosystem-**A**tmosphere **S**tudy (**BOREAS**), realized the value and importance of communicating their research approach, elementary boreal forest ecology and the relevance of these, to the general public. To achieve this result, computer-based interactive multimedia software was developed.

The project utilizes interactive multimedia on the Macintosh as an educational tool to provide an opportunity for the lay public to explore, at their own pace and according to their interests, material on the relationship between the boreal forest and the atmosphere as it is being examined by **BOREAS**.

The program is housed in a portable kiosk with a graphical, touch-screen interface, incorporating narration, music, images in thousands of colours, video and computer animations. Main sections include: details on the objectives and experiments of **BOREAS**, an introduction to the atmosphere and climate and a primer on the boreal forest ecosystem.

The poster session will provide a background on development of the hardware and software and the interactive approach to the content. Information on hardware requirements and how to receive a copy of the software will be provided.

Simulating carbon dynamics of the boreal forest in Pukaskwa National Park

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The development of forests in Pukaskwa National Park was simulated over 150 years to investigate carbon dynamics and to test the feasibility of simulating large tracts of heterogeneous boreal forest. Pukaskwa National Park, located on the north shore of Lake Superior, encompasses 1,835 km^2 of the Superior Section. We developed a patch model called BOPAS (BOreal PAtch Simulator) to simulate the development of carbon pools as a function of environmental parameters. Using GIS techniques, we divided the park into patches defined by a unique combination of forest type, age, climatic variables, soil type, and topography, and then used a gap-dynamics model to develop biomass-over-time relationships for each patch type. BOPAS uses these relationships to simulate the development of carbon pools for each tree species, and for moss and litter/humus. We report results for constant climate, but the model can be easily adapted to changing climate scenarios. BOPAS gave good results for above-ground carbon storage. With no disturbance, tree carbon increased to a maximum of 4.2 kg C m^{-2} at 30 years, then slowly declined. Carbon storage was stabilized by introducing disturbance in the form of fire with a return interval of 100 years. The stable value was around 3.6 kg C m^{-2} which agrees closely with published values. In contrast, forest floor carbon was much lower than expected, being only 40 percent of tree carbon. Forest floor carbon was anticipated to be substantially higher than tree carbon based on a preliminary survey in the park and values reported in the literature. Published data, however, were very limited in coverage and gave such a wide range of values that it was impossible to draw any firm conclusions about the validity of the model. BOPAS also showed that the forest floor carbon pool was relatively constant over time, but no published data were available to test this prediction. In summary, this work has demonstrated the feasibility of the BOPAS approach, but has highlighted the necessity for more extensive data on forest floor carbon storage and dynamics.

Climatic data for harvested and mature trembling aspen stands in the boreal mixedwood section of Saskatchewan

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The commercial clear-cut harvesting of overstory trees exposes the forest floor and understory species to increased solar radiation. Some researchers have suggested that increased forest soil temperature after clear-cutting may inhibit the regeneration (suckering) of trembling aspen. The objective of this study was to evaluate clear-cut harvesting on various climatic parameters in a mature trembling aspen stand and adjacent trembling aspen clear-cut. Automated weather stations recorded soil temperature (LFH and 2, 10, 50, and 100 cm mineral soil depth), air temperature, relative humidity, photosynthetically active radiation, precipitation, wind speed and wind direction. Results indicate that minor differences exist between forest and clear-cut soil and air temperatures. The difference in wind speed between clear-cut and forest increased as wind velocity increased. The largest soil temperature difference occurred in the LFH horizon. The role of the LFH horizon as an insulating layer able to moderate soil temperature is demonstrated. The slight soil temperature increases observed in the clear-cut are not expected to impede trembling aspen regeneration at this site. The commercial clear-cut harvesting of trembling aspen with adequate checks and controls (e.g. harvest season, soil disturbance/degradation) is thus not expected to impact negatively boreal forest dynamics within the mixedwood section of Saskatchewan.

Temporal and spatial variations of terrestrial biomes, net ecosystem exchange of CO_2 and terrestrial carbon storage since 13,000 yr BP in Europe: reconstruction from pollen data and statistical models

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Statistical models obtained from field measurement data are used to reconstruct the past terrestrial carbon storage from pollen data since 13,000 yr BP in Europe. The pollen-based climatic and biome reconstructions provide the input data for these statistical models, e.g., annual mean temperature, total annual precipitation, annual actual/potential evapotranspiration and biome type with a spatial resolution of 0.5° longitude and 0.5° latitude. Our reconstructions indicate that the last 13,000 yr BP were characterized in Europe by variations of terrestrial biome, net ecosystem exchange of CO_2 (including net primary productivity (NPP), and soil respiration (SR)) at various temporal and spatial scales. For the region under consideration, our results also suggest that changes in climate have significantly altered the distribution of terrestrial biomes, and affected the uptake of CO_2 in NPP and release of CO_2 from SR. These changes however, did not translate into significant changes in carbon storage in the potential terrestrial biosphere during the Holocene. The largest decrease in terrestrial carbon storage (compared to the present) was found during the late-Glacial period, due mainly to the presence of the ice sheet and weak extension of forest. In conclusion, the potential terrestrial biomes in Europe, over the long-term (centuries to millenia), act as a small sink for atmospheric CO_2. The paper will present the methodology using European data and focus on results concerning the boreal forest of northern Europe.

Canada's biomass inventory: deriving biomass from volume

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The importance of Canada's forest in the global carbon cycle needs to be better understood. The distribution of biomass as well as the changes associated with different management scenarios have implications for the long term sustainability of the forest resource. The purpose of the National Biomass Inventory initiative is to provide efficient and timely estimates of the above ground biomass components on forest land in Canada. This study builds on existing data and knowledge to generate spatially referenced biomass estimates for use in carbon budget modelling and resource assessment.

The results of the first phase of the national biomass inventory are presented here and focus on generating above ground biomass estimates for productive forest land. Volume:biomass conversion factors are given for unique combinations of site class and age (or maturity) class by species within province. The non-merchantable above ground biomass components are estimated as fractions of the merchantable biomass. These conversion factors and fractions were computed by constructing hypothetical stands for each site/age/species/province combination and estimating the merchantable volume and all of the above ground biomass components from published equations.

The conversion factors are relatively insensitive to changes in stand age, density, site quality, and size distribution. This may be a function of the published biomass and volume prediction equations which use only DBH and height as independent variables. Consequently, the resulting estimates are relatively stable and should provide good regional estimates of above ground biomass components. The conversion factors and fractions will be used, in conjunction with the current national forest inventory, to produce spatially referenced biomass estimates for the productive forest land in Canada. Future work will focus on biomass estimates for the submerchantable and unproductive forest.

Large-scale spatial variability of soil properties in the mixedwood forest of Saskatchewan, Canada

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The magnitude of and controls on spatial variability of soil properties in typical landscapes of the mixedwood (*Picea glauca* and *Populus tremuloides*) forest in Saskatchewan is largely unknown; yet information on spatial variability is critical for designing proper experimental and sampling designs on soil-forest interactions in this area. Our presentation summarizes research conducted in typical landscapes of the Prince Albert Model Forest on the spatial variability of major soil properties and its relationship to soil and land form distribution.

A chaotic suite of superficial glacial sediments occurred at all of the study sites and resulted in a complex distribution of soil morphological properties and textural characteristics in the landscape. These soil units were not, however, associated with distinctive slope morphological units at the sites. The spatial pattern of soil chemical (pH, phosphorus, sulphur) and biochemical (soil organic carbon, soil nitrogen) properties were not clearly related to the soil or slope characteristics at the sites. This argues that the basic hydrological controls on soil formation and processes in the dry, cool boreal forest landscapes differ greatly from their grassland counterparts in southern Saskatchewan.

Monitoring of forest site conditions and phytomass by remote sensing methods

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Problems in methodology are discussed for the combined use of remote sensing data and ground observations in forest ecological investigations. It has been established that space and aerial imagery data on geomorphological conditions, soil characteristics, and forest type and phytomass, supported by traditional methods of forest morphology research, are vital for ecological forest monitoring, with regard to stand phytomass parameter determination.

The role of snow accumulation and snow melt in nitrogen cycling in the boreal forest

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Nitrogen (N) availability limits the primary productivity of boreal forests over much of their geographical range. Because boreal forests are snow-covered up to eight months of the year and receive a substantial amount of N during this time, winter cycling of N and its sensitivity to climate change may be an important control on the evolution of boreal forests and related carbon storage. This paper examines N dynamics during winter in the boreal forest and evaluates potential changes in N dynamics with changing climate. Through dry deposition and episodic wet deposition, N is incorporated in intercepted snow and surface snow as nitrate and ammonium. However, N is not well conserved by snow over the winter. Evidence from western Canada indicates substantial nitrate loss from snow that has been physically transformed through sublimation (intercepted snow) and "kinetic" metamorphism (surface snow). As the snowpack ripens during melt, rapid within-snowpack N transformations occur due to concomitant biological, chemical and physical processes. Biological consumption (by micro-organisms) can dramatically reduce the presence and availability of N in melting snow. Most remaining nitrate is eluted with the first components of meltwater and flushes from the snowpack along preferential flowpaths. Upon reaching the soil, nitrate may be incorporated in refreezing ice layers at the soil surface, infiltrate to the soil or runoff to streams. The transport mechanism is determined primarily by the soil texture, snowmelt rate, soil-ice content and soil temperature.

Climate strongly affects most of the factors important to winter cycling of N. Hence, several scenarios of nitrate transport and storage under possible future climates were examined. For instance, in warmer winters intercepted snow sublimation will increase slightly whilst kinetic metamorphism will decrease substantially, reducing the net exclusion of N from snow crystals. However, an increased frequency of mid-winter melts may promote enhanced within-snowpack biological activity, resulting in increased N consumption and transformation from nitrate to ammonium. Warmer soils will increase forest uptake of the remaining N.

The Boreal Forest Transect Case Study: an integrative study of ecosystem processes and carbon dynamics across three three biomes of central Canada

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The Boreal Forest Transect Case Study (BFTCS) is a multi-disciplinary ecological study organized around a 1,000 km transect located in central Canada. The transect is oriented along an ecoclimatic gradient in a region likely to undergo significant environmental change within the next few decades, and crosses the climate-sensitive boreal forest biome, including northward and southward transitions into the neighbouring tundra and grassland biomes. Motivated by the need to extend the Boreal Ecosystem-Atmosphere Study (BOREAS) to larger spatial and temporal scales, the planned 10-year BFTCS project will build on the intensive measurements and small-scale modelling advances obtained from BOREAS, and enable these results to be applied to a wider range of sites over a longer period. In addition to consideration of microscale processes with time-frames of the order of one year or shorter, BFTCS will allow investigation of the effects of larger scale, longer term processes including forest succession and ecosystem disturbances. Parallel development of a hierarchy of models, including a comprehensive forest sector carbon budget model, and transect-scale ecosystem models, will facilitate expansion of the smaller-scale experimental results to the area of the transect and other larger regions. The study will ultimately provide a knowledge-base of key processes and their environmental sensitivities, and assessments of possible climate feedbacks, which will be used to assess the possible consequences of global change both regionally and globally.

Monitoring primary production from space

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Satellite remotely sensed observations provide a unique capacity to monitor terrestrial biospheric activity at regional and global scales. Spectral vegetation index images from these observations capture the heterogenity of vegetation growth patterns across the Earth's surface including the significant decline in vegetation activity above 50°N latitude. Conversion of these observations to meaningful assessments of vegetation growth, particularly changes within and between years, requires more than a simple linear transform between the spectral vegetation index and the desired variable. A conceptual and methodological framework for monitoring primary production from remotely sensed observations alone is proposed. Results from the BOREAS vegetation gradient will be presented as an example of the outcome of the approach. Other sites, where similar quality ground measurements are being collected, are actively being sought to continue development and validation of this satellite remote sensing approach to biospheric monitoring.

Impacts of silvicultural practices on maintaining genetic diversity in white spruce forest in Saskatchewan.

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Genetic implications of silvicultural systems in regenerating white spruce stands in Saskatchewan were examined. Adjacent stands of natural old growth, and of naturally and artificially regenerating white spruce, were sampled at five different sites. Genetic diversity in these stands was determined by random amplified polymorphic DNA analysis. Preliminary results indicated that the natural old growth and naturally regenerating young stands have marginally higher genetic diversity than the artificially regenerated white spruce.

Methane fluxes from boreal forest wetlands in Saskatchewan

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Methane flux measurements from static chambers covering 0.23 m^2 ground area, indicate boreal forest wetlands in Saskatchewan are important contributors to global CH_4 emission and, suggest differing peat areas vary in their CH_4 flux. The Boundary fen in the Prince Albert National Park emitted an average of 0.148 g CH_4 m^{-2} d^{-1} during peak production from the end of June until the end of July, with fluxes reaching 0.531 g CH_4 m^{-2} d^{-1}. A fen in the Canwood Forest Reserve showed emissions reaching a peak of 0.293 g CH_4 m^{-2} d^{-1} and averaging 0.098 g CH_4 m^{-2} d^{-1} during peak production from the end of June until 1 August. These CH_4 fluxes are similar to those reported in freshwater wetlands around the world. A small upland catchment basin in Prince Albert National Park which is only saturated part of the year, emitted only 0.0087 g CH_4 m^{-2} during 1992 and all of the CH_4 flux occurred during spring ice thaw. Methane flux may have been inhibited by sulphate-reduction activity in this site as stimulated by higher sulphate levels which appear to be mineralized during aerobic periods. Methane fluxes were found to vary within a wetland according to different peat conformations. Areas with floating peat mats and shallow peat under forest had lower CH_4 fluxes relative to open water or deep solid peat locations. Therefore, as a peatland grows with time, the magnitude of the CH_4 flux will change according to the dominant peat conformation type.

Quebrachitol, a new compound related to freezing stress and maple dieback

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The winter preceding the recent widespread maple dieback in southern Quebec was characterized by a thaw-freeze event that let the cold penetrate the soil and possibly caused a perturbation of the root system. We tested the hypothesis that the induced frost-damage to the roots was responsible for the symptoms decline observed in the trees. We freeze-stressed mature maple trees by limiting precipitation (snow) reaching the forest floor under selected trees. Reduced snow cover (30 cm) caused a decrease in soil temperature to -2 °C and a decrease in unfrozen soil water content to 25% (v/v) compared to 0 °C and 35% (v/v) for the control trees. In response to this treatment, we isolated by HPLC an o-methyl-inositol that has not previously been associated with stressed trees. The NMR (^{13}C) and GC/MS (EI and CI) techniques permitted the identification of quebrachitol 2L-O-methyl-chiro-inositol) that was further quantified in leaf and sap samples by GC (capillary column). The quebrachitol concentration increased four-fold in the spring sap in response to superficial frost. Complete absence of snow cover induced a deep frost ($T < -6$ °C) at root level concomitant with significant dieback of the trees. In these treated trees, the leaf quebrachitol concentration increased up to 4% of dry weight, which is an elevated concentration when compared to the content of the most abundant sugar (sucrose) that never reached values higher than 1%. Since a frost stress at root-level induces a physiological drought, our results support the suggestion of a role in plant osmoregulation for quebrachitol. It is noteworthy that abscisic acid (ABA) concentration in the spring sap also increased in response to deep frost. ABA is another compound generally associated with cold- and drought-stress.

Carbon interactions in forest-soil systems

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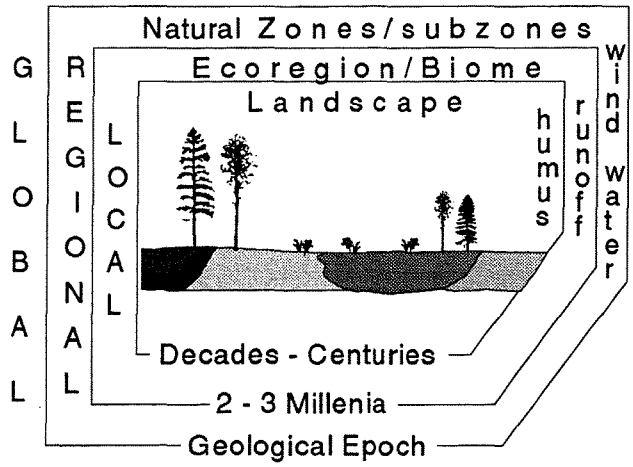
Verification of the role played by forest-soil systems (FSS) in the carbon budget needs a comprehensive analysis of phenomena and processes at global, regional and local levels. Global zonality of biomes affects spatial cycles of biogenic reserves of organic and mineral carbon. The role of meridionally-oriented winds (in different seasons) may exceed the smaller scale processes of global carbon redistribution. Carbon reserves in soils within natural zones are determined by humus amounts, the reserves of phytomass and mortmass and annual production, as shown on digital maps compiled by N.I. Bazilevich. Specific time (relaxation) of global dynamics is measured at a scale of geological epochs.



The regional carbon balance of FSS is calculated within each biome (ecoregion) taking into account anthropogenic effects. Landscapes are differentiated through parameters of this balance as well as in the biogeochemical carbon cycle; hence it is especially important to estimate more precisely and correctly every contribution to the carbon balance. Ecoregions and the system of soil-geographical provinces serve as regional models. Expert soil data bases and Basilevich's maps (1:2,500,000) are considered as a factographic basis. Specific time is 1.5-3 thousand years.

The local level of FSS is determined by a landscape. At this level, mechanisms responsible for the interactions between forest and soil and the carbon exchange are manifested. Specific time is close to the age of forest stands, varying from decades to several centuries.

Higher order processes appear to be background and/or relict features of modern processes. Objective parameters for the carbon balance may be determined only at three levels of the geographic basis for analyzing factorial data.

The effect of stand age on mammal biodiversity in aspen-dominated boreal mixedwoods

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Most of the usable fibre in Alberta's boreal forest has been allocated to logging companies. Since maximum resource exploitation is becoming prevalent throughout the boreal forest, short-rotation logging may have global implications to our biota. Consequently we examined the effects of truncation of age-class distribution of aspen-dominated mixedwoods on mammal biodiversity. We estimated relative abundance and species-richness of mammals during 1992 and 1993 in four young, four mature, and four old aspen-dominated mixedwood stands in northeast Alberta. Methods included winter track counts, spring and fall scat counts, small mammal trapping, and nocturnal bat surveys. Although numbers of small mammals differed dramatically between years, the relative proportions of small mammals of different ages were similar. Relative abundance was greater for a larger number of mammal species in old, followed by young, followed by mature stands. Old stands supported high numbers of southern red-backed vole, meadow vole, masked shrew, meadow jumping mouse, red squirrel, northern flying squirrel, *Myotis* species, weasels, and deer. Early stands supported high numbers of southern red-backed vole, snowshoe hare and moose. Mature stands supported high numbers of black bear, deer mouse and meadow jumping mouse. Species-richness did not differ among stand age classes but generally followed the same trend as relative abundance. Mammalian biodiversity appeared to reflect the structural complexity of the stands. Old stands that were structurally complex supported a greater variety of mammals at high relative abundance, mature stands that were structurally simple supported few species at high relative abundance, and fire-generated young stands that were intermediate in complexity due to remnants of the forest that preceded the fire (snags and downed woody material) were intermediate in species-richness at high relative abundance. Consequently we recommend logging practices that result in structured young stands and deferment of some stands to escape rotation.

Changes in bird species richness and abundance during succession of aspen-dominated boreal forests

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Short rotation logging practices will change the boreal forest landscape greatly by removing much of the older aged forests and simplifying the landscape mosaic. This may have negative impacts on native birds that breed within the area. To evaluate changes expected from decreasing the amount of old forests and possibly simplifying the structure of young forests, we surveyed birds and vegetation in young (23-26 years), mature (51-63 years), and old (greater than 120 years) aspen-dominated boreal forests in Alberta and compared the abundance of birds with the vegetational characteristics of the forests.

The vertical and horizontal complexity of live and dead vegetation in old forests was greater than that found in young and mature forests. The abundance of snags and downed logs was greatest in old forests, moderate in young forests and lowest in mature forests. Many of the bird species, for which we have adequate data, were present in all three forest age classes. Three species, however, had strong selection for young forests and 14 species had strong selection for old forests. Old forests had greater bird species-richness than young forests, which in turn had greater bird species richness than mature forests. Selection for old forests by birds was not related to the general feeding habitats of the birds, nor to the general nesting location of the birds. Approximately half of the bird species that had strong selection for old forests preferred to live in coniferous forests during the breeding season and may have been selecting old forests because those forests contained coniferous trees. Reduced complexity of vegetation within young forests and the reduced area of old forests that may occur when aspen-dominated boreal forests are harvested, may have negative effects on birds within the area.

This study was conducted in forests that regenerated after fires and results may not be applicable to landscapes where fires have less influence on the spatial and temporal patterns of the vegetation. Results from this study should be interpreted cautiously because the viabilities of the bird populations were not determined.

Unmixing the mixedwood: potential problems in managing Alberta's boreal forest

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The boreal mixed wood forest is a complex mosaic of stands of varying age and composition. The dominant coniferous tree species are white and black spruce (*Picea glauca* and *Picea mariana*, respectively), with balsam fir (*Abies balsamea*) and jack pine (*Pinus banksiana*) also present. Dominant deciduous species are trembling aspen (*Populus tremuloides*) and balsam poplar (*Populus balsamifera*), and lesser amounts of white birch (*Betula papyrifera*). Although relatively pure stands of all these tree species exist, the most common later seral stand types are those comprised of a mix of species, most often trembling aspen, balsam poplar and white spruce. Recent development of industrial forestry in Alberta has resulted in division of the boreal mixed wood landbase for coniferous saw log production and deciduous pulpwood production. Under the current landbase classification system, any forest stands containing 40 percent or greater coniferous content in the canopy are allocated as coniferous landbase. The remaining forest is generally managed as deciduous. As a result of the uncertainty associated with the current forest inventory, clear-cut harvesting strategies, intensive management for conifer regeneration in single-species stands, and the short rotation period proposed by pulpwood producers, the mixed stands characteristic of the boreal mixed wood ecoregion may be a disappearing resource. We have explored the implications of this for local wildlife, using the forest bird communities as indicators of habitat diversity. During the summers of 1993 and 1994, and the winter of 1993/94, we sampled over 150 older (> 100 years) forest sites, ranging from pure deciduous to pure coniferous stands (based on forest inventory data). Birds were sampled using fixed-radius point counts in the summer, and line transects in the winter. Intensive sampling of forest structure and composition was also conducted at each site, using a circular plot method. Although certain bird species exhibited a strong preference for either deciduous or coniferous stand types, bird community diversity, both in terms of richness and evenness, was significantly higher in the mixed stands. Both composition and structure of the forest habitat were important in explaining variation in the presence or absence of individual species and overall community diversity. We discuss our findings in the context of current management of the boreal mixed wood forest, and recommend policies which might reduce adverse affects of local wildlife, and better balance multiple objectives.

System for evaluation of growth and mortality in Russian forests

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Growth (current increment) and natural mortality of forest stands are of essential importance for global carbon cycle investigations, as well as for many aspects dealing with forest management. The current Russian inventory system does not detect these indicators in individually inventoried stands, and different regional and federal aggregated estimates vary greatly in Russia (growth estimates vary from 700 to 1,400 million m^3 yr^{-1}. Official data on average growth is 736 million m^3 yr^{-1}; natural mortality is estimated in different publications to vary from 380 to 1,200 million m^3 yr^{-1}.

There are numerous yield tables of different types (normal and modal, overall (general) and regional, for pure and mixed stands, etc.) for the basic forest-forming species in Russia, as well as a number of different stand models designated for estimating increment. The basic objective with our work was to generate a computer system capable of estimating gross and net growth and natural mortality, from the models and yield tables mentioned above, supplemented with data from the forest inventory and direct measurements on test plots. The system can use both data for aggregations of separate stands and for data of the forest state account.

The system under development includes a hierarchical and spatially distributed set of models for:

1. fully stocked stands: general and aggregated for ecoregions
2. productivity under a different stocking and,
3. regional models/correction coefficients for real (modal) stands

The modelling has been oriented to available information on species composition, age, site indices and density. Basic models were developed for even-aged stands. A set of auxiliary models modify stand growth for a different types of age structure (for relatively uneven-aged stands, uneven-aged stands and gradually uneven-aged stands).

Mitcherlich growth functions were chosen as the basic mathematical functions for fitting experimental data/tables/model outputs in order to construct a simple, but adequate unified modelling system. To summarise, the computer software uses a set of multidimensional matrices with coefficients determining the Mitcherlich functions as elements of an interactive system, allowing the evaluation of current increment and natural mortality by a large number of ecoregions with input data from the Russian forest inventory.

Investigations completed so far show that the proposed modelling system could give quite satisfactory results allowing the design of a numerical basis for evaluating current increment and mortality for Russia.

Boreal forest catchments: research anticipating global change at high latitudes

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Circumpolar subarctic boreal forest ecosystems are subject to change from a variety of agents and processes. Climate warming predicted by many GCMs indicates that regions north of 60°N may be subjected to major warming in the near future, producing increased permafrost thaw, altered vegetation distribution and biological productivity, and perhaps release of large quantities of stored organic carbon into the global carbon cycle. Evaluating change in ecosystems can entail use of ecosystem "samples" i.e., sectors of the landscape representative of the larger ecoregion, and available for repeated long term measurement and analysis. Boreal forest research and monitoring programs based on hydrologically defined landscape units (catchments) have been established in discontinuous permafrost regions at 65°N, 148°W in the Yukon-Tanana Uplands of central Alaska, and at 62°N, 158°W in the Kolyma River headwaters of Magadan Oblast, northeastern Russia.

The Alaska site comprises Caribou-Poker Creeds Research Watershed (CPCRW) and Bonanza Creak Experimental Forest (BCEF). This composite CPCRW/BCEF biosphere observatory covers 150 km^2, with environmental settings varying from highly productive floodplain forests and permafrost-free coniferous and hardwood forest stands on south-facing slopes, to low productivity permafrost-underlain coniferous woodland on north-facing slopes and in cold valleys. Ecosystem monitoring supports research into basic ecosystem processes, forest succession, hydrologic regime and stream ecology. Hydrometeorologic monitoring is carried out at 22 sites ranging from flood-plain (BCEF) to treeline (CPCRW). Long term ecological monitoring is complemented by intensive process studies conducted under the Long Term Ecological Research (LTER) program. A National Atmospheric Deposition Program (NADP) station is operated in CPCRW to monitor precipitation constituents, complementing ongoing research into water quality of streams in CPCRW.

The Kolyma Water Balance Station (KWBS), is located on Kontaktovy Creek, a tributary to the Kulu River 200 km from Susuman in the boreal forest headwaters of the Kolyma River. The 21 km^2 KWBS was established in 1948 specifically to evaluate hydrologic processes and water supply in this region. Discrete catchments within KWBS range from 0.7 to 15 km^2, and comprehensive climatic and hydrologic measurements are conducted year-round by resident staff. KWBS offers more than 40 years of hydrologic and climatic data, and has the potential to support interdisciplinary research into global change consequences on boreal forests in this remote region of northeast Russia.

These sites offer exemplary opportunities for comparative research and monitoring in subarctic boreal forest ecosystems of northwestern North America and northeastern Eurasia. Results already available from these sites provide a quantitative baseline for assessment of physical and biological change in response to regional pollution and global warming in coming decades.

Modelling forest regeneration in clear-cuts and burned areas in the Angara region

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A method is discussed to select measures aimed at enhancing natural forest regeneration in areas under extensive management. Indices are determined on the basis of available information on geomorphological site characteristics and stand parameters, using a specific criterion, that describe the forest regeneration process. Using these indices as model inputs, clear-cuts and burned sites can be incorporated into a stratified system, such that within each stratum, the natural forest regeneration process is uniform. Analyzing these strata, one can choose a regime of forest treatments appropriate for a given stratum and, hence, for the clear-cut and burned sites included therein.

Effects of site preparation on soil temperature

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Limitations to the successful establishment of conifer seedlings are often the result of low soil temperatures. Site preparation prior to forest renewal can markedly affect the soil thermal regime, providing warmer and cooler microsites in which seedlings can be planted. This study investigates the effects of five types of mechanical site preparation on soil temperatures in a boreal mixedwood stand in Saskatchewan. The five types of site preparation under investigation include three high-speed mixing types (Feric Rototillller, A-2 Forester, and the Grizz), and two inversion techniques (Savannah Disc, and Delta Power Disc Trencher). Dataloggers were used to monitor soil temperatures in each of the five treatments and a control treatment (shear-bladed only). Soil temperature probes were placed at 2, 10, and 20 cm depths in each treatment, and readings taken hourly. Daily temperature fluctuations along with daily maximum temperatures were greatest in the Savannah treatment at all depths during the growing season. The Delta treatment resulted in the lowest daily temperature fluctuations. Average daily soil temperatures were highest in the Savannah treatment at all depths throughout the growing season, followed by the three high-speed mixers which showed higher soil temperatures than the control treatment at both the 2 and 10 cm depths. The Delta treatment recorded average daily soil temperatures lower than that of the control treatment at all depths throughout most of the growing season.

Short rotation logging of Alberta's boreal mixedwood forests: is there reason to be concerned about loss of forest age and structure?

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Alberta has witnessed an almost complete allocation of its publicly owned boreal mixedwood forests to commercial wood harvest. Much of this allocation is characterized by intensive short rotation clear-cut harvest and will arguably result in the loss or reduction of older seral stages in forest succession. To address the possible consequences of short-rotation clear-cut logging on aspen mixedwood communities, a large interdisciplinary study was initiated in 1991 on the Alberta-Pacific Forest Industries Forest Management Agreement Area. Following two years of research on young (25 years), mature (40-60 years), and old (100+ years) stands, structural and compositional differences along a successional pathway have been identified. This presentation will outline the rationale and experimental design of this cooperative project involving government, industry, and universities, and will set the stage for detailed presentations on plant community structure, floristics and composition of birds and mammals. Results of this study emphasize the importance of maintaining age-class diversity within the boreal mixedwood community and the critical need to examine the provincial forest harvest regulations in light of forest ecosystem management.

The application of a fully integrated bioeconomic optimization model to the boreal forest of west-central Saskatchewan.

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An integrated forest resource optimization model was developed and tested for a 1.7 million ha commercial forest (NorSask FMLA) to assist in the development of a forest management plan and assessment of environmental impacts associated with that plan. The model is driven by full economic and biological accounting of the key variables which are necessary to allocate, conserve and manage a commercial forest. The objective of the model is to maximize the net present value (NPV) of the forest with full consideration of the benefits and costs for managing both timber and non-timber resources as part of a simultaneous management process over a 220 year time-frame.

Major emphasis has been placed on management for biodiversity based on the hypothetical distribution of ecosystem types and age-classes as determined by ecosystem-specific fire cycles, the protection of caribou populations at 90% of the theoretical carrying capacity and the distribution of economic benefits to communities located within the FMLA area. Non-timber resources included in the valuation include moose, white-tailed deer and fishers. Additional yield data is generated from the model on blueberries and water. Full accounting ledgers on the private and public value from the forest clearly demonstrate the economic benefits from managing the forest for the resource features listed.

Extensive biological information was required for model operation. Successional curves, natural and managed stand yield curves, treatment response yield curves and non-timber resource yield curves were developed, described mathematically, peer received and incorporated into the model for analysis.

Eight alternative forest management plans were developed by varying the level of constraints imposed on the forest. The alternatives included: (1) do nothing (no harvest); (2) unconstrained timber management, (3) constrained by provincial Long Run Sustained Yield and Annual Allowable Cuts, (4) highly constrained for biodiversity, benefit distribution and caribou; (5) single pass harvesting; (6) relaxed distribution of economic benefits; (7) relaxed caribou population maintenance and (8) relaxed biodiversity. A comprehensive framework to evaluate the economic and ecological risks, community benefits and water yield associated with each alternative, was developed for the selection of a preferred forest management plan.

This paper describes the development of the optimization model and its application to operational management of the boreal forest.

The IBFRA Stand Replacement Fire Working Group: progress to date and future plans

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Members of the IBFRA Stand Replacement Fire Working Group met for the first time in Krasnoyarsk, Siberia in 1992 to develop a number of hypotheses that would guide future cooperative fire research activities between Russian and western fire scientists. These hypotheses were related to quantitatively understanding the role of fire in boreal ecosystems, and to the prediction and modelling of forest fire occurrence, behavior and impact in the boreal zone. During 1993, a conference on Fire in Ecosystems of Boreal Eurasia was held in Krasnoyarsk to compile and publish the state of knowledge on fire in boreal ecosystems, bringing together forest fire scientists from Russia, China, Europe and North America. A subsequent Fire Research Campaign Asia-North (FIRESCAN) was organized following the conference, in which an experimental fire was conducted in the Krasnoyarsk Region of Central Siberia, allowing western and Russian fire scientists to compare research methodologies.

This new spirit of cooperation continued in 1994 with postburn fire ecology measurements being made at the 1993 fire site, and the ground-truthing of numerous large fires in Central Siberia. A second experimental fire, which again will be documented by Russian and western fire scientists, is planned for 1995 in northern Canada. Extensive collaboration is also underway on remote sensing of large Siberian forest fires, the suitability of the Canadian Forest Fire Danger Rating System for use in Russia, the translation of numerous Russian scientific papers, and the physical modelling of high-intensity fires.

A comparison of satellite-based and Russian map-based estimates of the forest cover of Krasnoyarsk Territory, Siberia.

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The status of the 8 million km^2 of Russian forests is poorly known both in and outside Russia. Understanding the types of forests and the area and rates of change in this region is particularly important for understanding the global carbon cycle. Knowing whether the forests are changing and how fast they might be changing, could prove or disprove current hypotheses about the assumed mid-latitude carbon sink as described by Tans *et al.* (1990). Generally available statistical data on the extent and composition of the forests (Anon. 1990) is of questionable reliability (Alexeyev, pers. comm.).

One of the largest regions in central Siberia is Krasnoyarsk Kray (territory) which covers some 2.4 million km^2 or about 25% of the area of the USA. We have chosen to examine this region with NOAA AVHRR satellite data and to compare classifications of that data with existing Russian land cover, forestry, and potential vegetation maps digitized here, and with Russian statistical data. Krasnoyarsk Kray is considered to be about 50% forested (Anon. 1990).

Maps to be compared with the satellite data include a 1:2,500,000 scale forest cover map dated 1990, and a 1:4,000,000 scale vegetation map dated 1990. Other maps at smaller scales may also be evaluated including 1:8,000,000 scale vegetation and soils maps dated 1986, and 1:16,000,000 scale vegetation zone map originally from 1976.

Effect of climate change on C:N pools in a boreal watershed ecosystem

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In the Lake Superior Basin, a decade of small watershed study shows declining ($p<0.05$) inputs of atmospheric NO_3^-, increases ($p<0.05$) in winter NH_4^+ input, snowpack transformation of NH_4^+ to NO_3^-, and strong ecosystem retention (>90%) of mineral nitrogen (N), yet increases ($p<0.05$) in winter and annual streamwater N discharge. These trends suggest factors other than precipitation input are responsible for the changes in surface water N. The objective of the ongoing study reported here is to assess if possible changes in the nitrogen cycle, as might occur from global climate scenarios for temperature and moisture, could complement inorganic precipitation N inputs to the boreal forests of Isle Royale. Total annual atmospheric N input (6-10 kg ha^{-1} yr^{-1}) is more than 20% of annual uptake by canopy and sub-canopy species. There are significant differences in mineral soil N pools for dominant canopy species (492, 564, and 1153 kg ha^{-1} for birch, spruce, and alder, respectively). Annual soil NO_3^- N concentrations vary by vegetation type ($p<0.05$) being higher beneath alder (11.6 mg N kg^{-1}) than spruce and birch (1.1 and 0.9 mg N kg^{-1} respectively). Soil NH_4^+ concentrations do not differ among vegetation types. Field net N mineralization is inversely related ($p<0.001$) to soil temperature, but laboratory incubations show a gain ($p<0.03$) in mineralization over temperatures from 10 to 20 °C. Field net N-mineralization varies with incubation period ($p<0.01$) and species ($p=0.05$). Annual net mineralization is 35, 38, and 84 kg N ha^{-1} yr^{-1} for birch, spruce, and alder respectively. There are no apparent relationships among field net mineralization, net nitrification, and initial mineral N concentrations and soil moisture. A 2 to 5 °C increase in summer soil temperature could increase available N in an amount exceeding processes such as herbivory, atmospheric inputs, and windthrow.

Boreal forest futures: modelling the controls on tree species range limits and transient responses to climate change.

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We examine the range limits of European boreal and northern deciduous tree species with a bioclimatic model (STASH) using specific mechanisms that explain in some detail the geographic distribution and gross patterns in productivity for these species. The results differ considerably from (and are frequently more realistic than) predictions from conventional gap models where growth rates are assumed to decline to zero at minimum and maximum growing degree day limits. For example, towards the southern limit of *Picea abies*, the model correctly shows no decline in productivity but rather an abrupt cut-off corresponding to a chilling requirement acting on regeneration. In transient climate scenarios this cut-off can prevent further natural regeneration even as *Picea* yield is increasing in response to increased summer warmth and longer growing season. STASH is therefore used to examine changes in potential range limits and forest species composition under a gradient of greenhouse gas-induced climate change, while possible effects on transient forest dynamics at a number of sites throughout Sweden are examined using the gap model FORSKA 2 with environmental drivers and response functions taken from STASH.

STASH predicts drastic changes in species distributions in response to the large climate changes (especially winter warming) expected for northern Europe. The degree of sensitivity of a particular site to such changes in species composition is dependent both on the climate change prediction and on the transient dynamics of the forest community in question. FORSKA 2 is also used to illustrate the possible constraints on species reaching new equilibrium distributional limits. Such constraints include changes in disturbance rates and delayed migration of "new" species.

Pattern of deforestation and recovery of a boreal forest landscape in northeast China

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We studied the pattern and change of a boreal forest landscape in northeast China using aerial photographs from the 1950's to 1980's. We compared the aerial photographs with the corresponding ground features. Six tree species, three age classes for each tree species as well as eighteen patch types were identified. The differences between 1955 and 1980 show changes in landscape pattern during the period. The results indicate that fragmentation is the most obvious change to the boreal forest landscape after deforestation. This is revealed by the increased number of patches and the decrease in patch size. Forest cutting not only creates many smaller logged areas, but also changes other patches into several smaller patches. Questions have arisen for a long time, concerning the optimal size, shape and distribution of clear-cuts. In traditional forestry, the only consideration for the size, shape and distribution of clear-cuts relates to the expected benefit for regeneration of tree species. Hence most logged areas are small in size, averaging 10.92 ha per patch. On the other hand, the regeneration strategies of tree species in large areas also play an important role in the spatial partition of patches, which results in decreasing patch size and increasing patch number. The areal composition of different patch types has changed greatly since 1955. In particular, hardwood forest areas have increased significantly; among conifers, *Larix gmelini* has decreased significantly, while *Pinus sylvestris* var. *mongolica* has remained about same. Except for old mature *L. gmelini*, the area of old age classes of other species has increased to some extent. In addition, except for old mature *L. gmelini*, young and middle age classes of all tree species in 1980 occupy a larger proportion of the area than in 1955.

These observations indicate that many ecosystems are in the early successional stages due to deforestation. These ecosystems are more productive than mature ecosystems. Pioneer tree species, such as *Betula playphylla*, grow very quickly. Hence, plants in the early successional stage can absorb a lot of CO_2 and become an important sink for CO_2. We tentatively name this the "early succession effect". Plants in the early successional stages increase the absorption capacity for CO_2 and primary production not only because of the beta effect, but also because of the mechanism of plant community succession processes. This implies that through conservation of the lumber from logged forests, it is possible to manage forests in a way to increase their role as a sink for atmospheric carbon.

A simulation model of the change of landscape pattern and its application to a boreal forest landscape in northeast China

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We developed a spatially explicit model to simulate the change of landscape pattern under human impact and to calculate total amounts and spatial distributions of the carbon content and carbon dioxide fluxes resulting from deforestation and recovery in the boreal forest. The major assumptions used in our model are based in a general way on the "maximum power principle". The assumption means that land to be cleared is chosen by farmers and other developers such that initially land near roads and rivers is developed and then development (e.g., deforestation) moves progressively upstream and up-slope to regions with less favorable energy returns on human investment. Our model simulates both land use conversion rates, i.e., the quantity of land conversion from one type to another over time, and the spatial pattern of that land use change. We used both digitized and remotely sensed data from northeast China to test this model. We found that: (1) variation in the accuracy of the model predictions depends on the rate drivers and land-use transfer matrix; (2) the drivers of land use change are scale-dependent, which shows that topographic features are more important than climate variables for a large scale simulation, and that climate variables are more important than topographic features at a smaller scale; (3) the amount of land-use change is greatly influenced by population growth and land-use policy, but topographic features greatly determine the pattern of land-use change; (4) the results of our spatial modeling approach provides more insight for understanding the boreal forest carbon budget and for making extrapolations to very different time scales than otherwise possible.

Litter quality and potential rates of decomposition in forested ecosystems.

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The breakdown and decay of plant materials represents the major pathway by which carbon is returned to the atmosphere in most forested ecosystems, especially the boreal forest, and has the potential to be greatly impacted by climate change. Decomposition is influenced by a wide array of factors including macroclimate, microclimate, soil biota, soil nutrients, substrate piece size and substrate quality. To separate the influence of some of these factors, a 10-year study, the Canadian Intersite Decomposition Experiment, was established in 1992 to measure the decay of 11 standard litter types on a range of forest types at 21 sites across Canada. As part of the study we analyzed the nutrient contents (N, P, S, K, Ca, Mg) and C fractions (sugars, cellulose, hemicellulose, lignin, tannin by ^{13}C NMR and wet chemical proximate analysis) in a total of 42 primarily foliar litter types. The litter types varied greatly in their qualities. Simple models of litter decay based on summed exponential curves suggest that variation in substrate quality could account for a 5-10 fold difference in the rate of total mass loss. The application of such a model to the litter types analyzed, especially those in the long term decay study, will be discussed.

Case study of a carbon emission response option in Saratov, Russia

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Under the terms of the Framework Convention on Climate Change (FCCC), drafted at the June 1992 United Nations Conference on Environment and Development, developed countries will strive to reduce their greenhouse gas (GHG) emissions to 1990 levels. The terms of the FCCC allow participating countries to jointly implement projects to offset GHG emissions.

The first Joint Implementation (JI) project in Russia is presently being conducted pursuant to recently negotiated Agreements between Oregon State University (working under the U.S. Environmental Protection Agency) and the Russian Federal Forest Service. The objective of the project is to evaluate the biological, operational and institutional opportunities to manage a Russian boreal forest plantation as a carbon sink. The project is in the Saratov oblast (700 km southeast of Moscow), which is primarily an agricultural region. Two 210 ha sites, which were formerly marginal agricultural land, were planted in the fall of 1993 and spring of 1994. The terms of the JI Agreement (which is intended as a model for similar projects) include provisions for: seedling protection; plantation maintenance; field evaluation of biomass; plantation preservation; restrictions on timber harvest; restrictions on the use of slash debris; replanting and reestablishing the plantation in the event of loss; the transfer of the right to the carbon offset "credits"; an equal share of carbon offset "credits" produced to the JI partners. The experience gained to date suggests that JI forestry projects in Russia are viable and represent a cost-effective alternative for many countries to meet their obligations under the FCCC.

Roosting ecology of bats in the West Arm Demonstration Forest near Nelson, B.C. and the potential effects of forest harvesting practices

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During the summer of 1993, I set out to characterize the trees bats use as roosts in the West Arm Demonstration Forest, an area of approximately 14,500 ha in the southern interior of British Columbia. Tree roosting sites were located either by watching trees at dusk for emerging bats or by attaching radio-transmitters to bats and tracking them to their roosts. Once tree roosting sites had been located, I measured a wide range of characteristics relating to the tree and its location. Preliminary results indicate that bats use loose bark, and natural and old woodpecker cavities, as roosting sites, and change roost sites on a regular basis. Bats show a distinct preference for certain tree species, and trees with large diameters and heights. The information collected will be used to develop a set of recommendations regarding the kinds and numbers of trees that should be left untouched during forest harvesting to maintain a healthy population of roost trees.

Landscape-scale variability of nitrogen mineralization and nitrification in undisturbed and disturbed forest soils in Saskatchewan, Canada

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The spatial distribution of NH_4^+ and NO_3^- in forest soils, as affected by management, was studied at the landscape-scale. A sampling grid, consisting of 169 points, was established at an undisturbed site located in Prince Albert National Park, Saskatchewan, Canada. Additional grids, consisting of 36 and 49 sampling points, were established at a burned site and a clear-cut site, respectively. Similar levels of inorganic N at the undisturbed and disturbed sites suggests that management practices had little effect on the availability of inorganic N. Similarly, the spatial distribution of inorganic N was not related to the land-form element complexes, which indicates that hydrological processes were not the dominant factor controlling the distribution of inorganic N at the scale studied. The occurrence of NH_4^+ as the dominant inorganic N form suggests that nitrification was strictly limited at these sites. Potential net N mineralization and nitrification in the forest floor and surface mineral soil horizons, collected from footslope and shoulder complexes at each of the three study sites, were studied in a controlled aerobic 8-week incubation experiment. Under controlled conditions, accumulation of the KCl extractable NH_4^+ and NH_3^- was affected by both land-form element complex and site disturbance. Thus, under optimal conditions, both landscape and management may play important roles in defining the potential for nitrification in forest soils.

Simulation of mixedwood management of aspen and white spruce in northern British Columbia

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The boreal mixedwood is a productive, important component of the forestry scene in B.C. There is growing interest in managing northern the mixedwood component of the boreal white and black spruce (BWBS) zone. After clear-cutting or fire, aspen normally regenerates prolifically from root suckers. In contrast, plantations of white spruce are not easily established because of frost damage and grass competition. But if there is an adequate seed source, white spruce can regenerate naturally under an aspen canopy as long as the aspen stand is not too dense. In order to predict the probable outcomes of different strategies for managing the northern mixedwood, it is necessary to use stand level simulation modelling. FORECAST, an ecosystem simulation model, was calibrated using available data and simulations were undertaken to examine: (1) effects of initial density of aspen root suckers on yield of white spruce; (2) effects on stand yield of underplanting aspen stands with spruce at age 40 years.

Results of the simulations suggest that mixed wood management regimes on the same site have higher stand yield and improve site quality. Simulations provide results consistent with published information and observations on the performance of pure and mixed stands of aspen and white spruce. This model shows potential for comparing the relative effects of different management strategies. It can also be used to explore effects of climatic change on boreal forest. A calibrated version of the model should be useful as both a management simulator and a research tool.