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Silviculture's Role in Managing Boreal Forests

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ABSTRACT

Boreal forests, which are often undeveloped, are a major source of raw materials for many countries. They are circumpolar in extent and occupy a belt to a width of 1000 km in certain regions. Various conifer and hardwood species ranging from true firs to poplars grow in boreal forests. These species exhibit a wide range of shade tolerance and growth characteristics, and occupy different successional positions. The climate is subarctic, with short growing seasons, and the soils are shallow. Both wildfires and timber harvesting play an important role in shaping the structure and composition of boreal forests. Both uneven-aged and even-aged silvicultural systems can be used to produce commercial harvests, but systems can also be designed to meet a variety of other forest management objectives. Wildlife habitat maintenance, water production or conservation, and fire hazard reduction are only some of the objectives for which silvicultural systems can be designed. Coarse wood debris, snags, shrubs, canopy layers, and species composition are examples of forest attributes that can be managed using silvicultural systems. Systems can be designed to sustain predator habitat, yet provide a continual production of

wood products. Uneven-aged systems tend to favor the regeneration and development of shade-tolerant species, whereas even-aged systems tend to favor shade-intolerant species. These systems and all of their permutations can create and maintain a suite of different stand compositions and structures that can be used to meet a wide variety of management objectives.

KEY WORDS: boreal forest, even-aged stands, forest composition, forest management, forest structure, global timber markets, silvicultural systems, subarctic, uneven-aged stands.

INTRODUCTION

The use and management of natural resources is an issue facing many societies throughout the world. This issue is particularly important for boreal forests world wide, and it is the primary issue being addressed for most North American forests. Because timber markets, carbon sequestration, migratory bird and fish habitat, and other similar issues are of regional to global importance, the decisions of how boreal forests are managed are no longer exclusively local. The timber market in New Zealand affects the price of lumber in Portland, Maine as it does the price in Vancouver, British Columbia. As human populations grow, the demand for wood and other forest resources will continue to expand. Boreal forests are excellent sources of wood for emerging countries to use for economic development, similar to the use of forests during the westward expansion in the United States. Moreover, developed countries are able to reserve their forests while importing forest products from developing countries. This exportation of environmental problems and the globalization of timber markets makes the management of boreal forests not only a local issue, but also one of regional, national, and global significance.

BOREAL FORESTS

Boreal forests, or taiga, are circumpolar in extent and occupy a belt up to 1000 km wide in certain regions (Larsen 1980). Conifers occupying boreal forests include members of the genera *Picea, Abies, Pinus,* and *Larix*. In North America, white spruce (*Picea glauca*), black spruce (*Picea mariana*), jack pine (*Pinus banksiana*), balsam fir (*Abies balsamea*), and tamarack (*Larix laricina*) are the primary conifers. Hardwood tree species include members of the genera *Populus, Betula, Alnus,* and *Salix*. These species have different life histories with varying levels of fire, insect, and disease resistance. More importantly, these species exhibit a wide range of shade tolerance and growth characteristics, and occupy different successional positions. In general, the poplars tend to be short-lived (typically 75 yr) species, whereas the firs and the spruces tend to be long-lived (typically 200 yr) species (Larsen 1980, Burns and Honkala 1990).

The continental climate in which these forests grow is subarctic and is characterized by mean monthly temperatures ranging from the -30º s C in January to the 10º s C in July. Annual rainfall is typically 1000 mm. Summers are humid, with peak precipitation usually occurring in August. The soils of the subarctic are mostly spodosols, with peat accumulations common and permafrost occurring in the northern portions (Larsen 1980). Because of these conditions and the species' life histories, forest productivity is low (1 - 4 m^3 ha^{-1} yr^{-1}) and organic decomposition is slow (Aber and Melillo 1991).

Wildfires play an important role in shaping the structure and composition of boreal forests. Stand replacing and mixed fire regimes are possible (Larsen 1980, Aber and Melillo 1991). Stand-replacing fires can burn large areas, initiating new stands containing seral species such as jack pine and aspen (*Pinus tremuloides*), whereas the mixed fire regimes include both stand-replacing fires and low-intensity surface fires. These fire regimes create a mosaic of conditions that allow a mixture of early-, mid-, and late-seral species to thrive. Such stands may contain mixtures of jack pine, aspen, balsam fir, and spruce. These fire regimes operate on frequencies (cycles) ranging from 40 to 65 yr for the low-intensity surface fires to > 200 yr for stand-replacing fires (Larsen 1980, Dryness et al. 1986, Chandler et al. 1991). These cycles, in turn, may influence the life cycles of mammals and birds, such as the snowshoe hare (*Lepus americanus*) and Northern Goshawk (*Accipiter gentilis*) (Doyle and Smith 1994). The aforementioned fire regimes also influence decomposition, nutrition, and other processes important for maintaining boreal forests (Larsen 1980). Because of different growth rates, species mixes, vegetation longevity, shade tolerance, insect disease relationships, species interactions (all possible combinations of plant and animal interactions), and disturbance regimes (fire and weather), multitudes of different successional pathways naturally occur in boreal forests, creating a multitude of different forest structures and compositions.

Similar to the variety of stand structures and compositions that occur in boreal forests, human activities also create a variety of forest conditions. Management actions range from intentionally burning the forest, which was often done by native peoples, to present-day suppression of wildfires (Agee 1993). Because boreal forests are an important source of raw materials, they currently and potentially supply considerable amounts of the wood resources consumed throughout the northern hemisphere (Larsen 1980). The methods used to harvest trees range from removing individual stems to large-scale clear-cutting. Although the practice of silviculture has always supplied techniques for producing timber, silvicultural systems can be designed to produce a suite of forest compositions and structures that can meet a wide variety of management objectives.

SILVICULTURE

Silviculture is the art and science of managing forests for specific objectives outlined by a landowner (Baker 1934, Smith 1962, Smith et al. 1997). Silvicultural practices manipulate forest vegetation through prescriptions to fulfill various objectives such as sustaining wildlife habitat, maintaining hydrological processes, restoring ecosystems, conserving biodiversity, and producing wood products. Depending on the objective, silviculture is the specialty that incorporates the concepts and principles from many scientific disciplines (soils, ecology, wildlife, modeling, economics) (Toumey 1928, Baker 1934, Hawley 1937, Smith 1962, Nyland 1996). This synthesis produces stand-level treatments that can sustain the integrity, diversity, and resiliency of ecosystem conditions over a variety of temporal and spatial scales (Burton et al. 1992, Kaufmann et al. 1994, Nyland 1996). The field of silviculture can display to landowners how different forest uses and products can be realized, and yet maintain ecologically sound ecosystems. It also integrates biophysical factors and ecosystem processes and structures to show how they influence forest community establishment and development (Broun 1912, Toumey 1928, Baker 1934, Smith 1962, Oliver and Larson 1990, Nyland 1996). These relations include, but are not limited to, the interactions among soils, climate, topography, native and exotic vegetation, and wildlife. Furthermore, the practice, through the development of silvicultural systems, can display probable biophysical responses caused by indigenous and human disturbances (wildfire, wind, insects, diseases, hydrologic disturbances, and timber harvest), illustrating the consequences that these disturbances have over the short and long term. Other disciplines and the lay public often assume that all tree harvesting is the application of silviculture systems, but this is an incorrect assumption. Only when foresters follow the preceding silvicultural principles while managing forests is silviculture being practiced.

SILVICULTURAL SYSTEMS AND FOREST STRUCTURE

A silvicultural system outlines a plan of treatments over the life of a stand to fulfill a set of values or interests for a particular landowner. This plan should ensure that future yields of goods and other values are conserved, while harvesting or utilizing currently available goods (Smith 1962, Smith et al. 1997). Therefore, silvicultural systems need to be placed within the context of the ecological and environmental characteristics of the ecosystem being managed.

Silvicultural systems can be developed for the boreal forests to create an assortment of forest structures, compositions, and conditions. Both even-aged and uneven-aged silvicultural systems can be used to manage these forests. Even-aged systems produce stands with trees relatively close in age, but this does not necessarily mean a single forest canopy is created or maintained. Uneven-aged systems produce stands containing trees with different age classes. However, silviculture systems can also use a combination of these two types to develop stand structures that have both even-aged and uneven-aged characteristics. Each silvicultural system, in combination with the tree species present and the multitude of other ecosystem components, can provide an array of forest structures and compositions.

Uneven-aged systems

Uneven-aged silvicultural systems usually create and maintain forests with a minimum of three age classes by harvesting and tending portions of stands at frequent (20 - 40 yr) intervals (Nyland 1996). There are two uneven-aged systems: single-tree selection and group selection. Both of these systems, when combined, can form hybrids such as patch selections, or patch and strip systems (Nyland 1996, Smith et al. 1997). Single-tree selection usually maintains a mature age class, one to two intermediate age classes, a young age class, and a regeneration class. Individual trees are removed during each entry from all of the age classes, ensuring that a multi-aged, multicanopied, and multispecies stand is maintained. Use of this system in the boreal forests would regenerate and favor shade-tolerant and late-successional species such as balsam fir and spruce, and would exclude seral jack pine and aspen.

Along with encouraging shade-tolerant tree species, individual-tree selection systems would support the diseases and insects that accompany these species. Bole diseases (*Phellinius,* etc.), root diseases (*Armillaria,* etc.), and defoliators (spruce budworm (*Choristoneura fumiferana*) are only some of the diseases and insects encouraged by uneven-aged systems. The frequent entries utilized with selection systems would facilitate stem damage (entry points for disease) on residual trees, and harvesting equipment would potentially compact, displace, or destroy the forest floor and soil. Because individual-tree selection favors shade-tolerant species and dense growing conditions, optimum individual tree growth would not likely be realized.

Group selection can be used to increase the proportion of shade-intolerant species such as aspen or jack pine. This uneven-aged system also creates stands with three or more age-classes, but the different cohorts are regenerated and maintained in small groups. The openings created using group selection usually vary from one to two tree lengths in diameter. With this system, clusters of the different age classes are dispersed throughout the stand. These single-aged clusters give the overall stand an uneven-aged structure (Nyland 1996). Aspect, slope, size of opening, and forest floor disturbance all determine the amount and species of trees and other vegetation regenerated. The conditions produced by this system tend to favor a mix of shade-tolerant to shade-intolerant tree, shrub, and forb species. Similar to stands managed with single-tree selection, group selection systems also invite many insects, diseases, and soil disturbance. These small openings may create conditions of local frost that could injure vegetation, especially in the subarctic, thereby impeding forest regeneration and development.

When neither group selection or individual-tree selection systems produce conditions that fulfill the management objectives, a combination of both systems might be appropriate. These hybrid systems use a combination of single-tree selection in a portion of the stand and small patches scattered throughout the stand. These systems create a stand with a mixture of shade-tolerant species and multiple canopies within the single-tree selection area, and provide areas that encourage the regeneration of shade-intolerant trees, forbs, and shrubs in the small openings. This species richness and habitat diversity is not achieved by using only one uneven-aged system.

Even-aged systems

Even-aged silviculture systems usually create and maintain stands with trees representing one age class, or a narrow range of age classes. Historically, lethal fires created forests containing even-aged stands. Similarly, clear-cutting, shelterwood, and seed-tree systems create and maintain even-aged stands. The composition of these forests is usually dominated by shade- intolerant trees (jack pine, red pine, aspen) and shrubs (willow and cherry, *Prunus* spp.).

With the exception of clear-cutting, the other even-aged systems (seed-tree and shelterwood) include some high forest cover. Overstory density and species prescribed in seed-tree and shelterwood systems depend on the site, species, and desired forest structure and composition. For example, 10 - 20 seed trees/ha might be prescribed for a poor seed-producing species, whereas 5 - 10 seed trees/ha might be utilized with a prolific seed-producing species. Also, various numbers of seed trees might be prescribed for maintaining mammal or bird habitat. The numbers of overstory trees prescribed in shelterwoods depend on how much shelter is required to successfully regenerate desired tree species, or how many trees are required to provide wildlife habitat, scenic values, or to meet other site objectives. As canopy cover increases, the amount of shade-tolerant (i.e., balsam fir, spruce) regeneration will also increase.

Trees in shelterwood and seed tree systems can be grouped, spaced, defined by species, or other designated criteria. The seed tree and shelter component used in these systems can be short- (removed early in the life of the regenerated stand, 30 yr or less) or long-lived (left on the site through the life of the regenerated stand). If the overstory is removed early, the regenerated stand will consist primarily of shade-intolerant species. In contrast, by maintaining reserve trees, two-storied, two-aged stands will develop. This reserve component will establish conditions favorable to the development of both shade-intolerant and shade-tolerant vegetation. This overstory component will ensure that large trees will always be on the site, and that these trees will provide future snags and downed logs, both important structures for many wildlife species.

The clearcut system favors the regeneration and development of shade-intolerant species (aspen and jack pine). Openings of > 2 ha are usually considered clearcuts. Under these conditions, early seral species thrive and grow at their optimum rates. Clearcut silvicultural systems are usually favored for the production of commercial forest crops, but occasionally can address forage production issues for wildlife and domestic livestock.

Forest floor

Crown canopy closure (opening size), species composition, and the spatial and vertical distribution of the reserve trees are the primary tree attributes controlled by the silvicultural system. Another component that influences the amount and kind of forest regeneration is the intensity and kind of forest floor disturbance. Mechanical disturbance, prescribed fire, and chemical application are techniques used to prepare sites for natural and artificial regeneration. In general, burned-over surfaces and mineral soil are excellent sites for seed germination (Haig et al. 1941). In contrast, unburned organic layers on the forest floor, depending on their moisture content, provide less favorable sites for seed germination, and, depending on their composition, they can impede the planting and development of artificial regeneration. Undisturbed organic materials often favor the establishment of heavy-seeded plants (with seeds that can penetrate the heavy organic layers) and advance regeneration. Conifers and deciduous tree species have differential responses to forest floor disturbance, as do shrub and forb species. Some species become established primarily from seed (jack pine), whereas others regenerate from sprouts (aspen). Therefore, the amount and kind of canopy cover (opening size) and the amount and kind of forest floor disturbance influence the composition and quantity of plants that regenerate.

The forest floor not only influences vegetation regeneration, but also is an important source of nutrients and habitat for microorganisms. In some forest ecosystems, the forest floor contains > 50% of the nitrogen reserves of a site, and > 50% of its nitrogen fixation capacity. In addition to nutrients, organic materials and especially humic substances are critical habitat for ectomycorrhizae. Similar to the nitrogen relations, > 50% of the ectomycorrhizal activity of a site can occur in forest floor organic materials (Harvey et al. 1987). In boreal forests, these materials are often shallow and make up the majority of the soil (Larsen 1980). Because of their importance and their scarcity, organic materials are sensitive to disturbance from timber harvesting and site preparation, and are easily consumed by both prescribed and wildfires. Therefore, forest floor disturbance should be planned carefully in boreal forests to ensure that critical soil organic layers are maintained when creating conditions for vegetation regeneration and development.

Coarse woody debris is another forest component often overlooked in silvicultural systems. Coarse woody debris (material > 7.5 cm in diameter) is an important source of nutrients, forest floor organic matter, and wildlife habitat (Harmon et al. 1986). Depending on the forest type, 7 -74 Mg/ha (metric tons) of coarse wood debris are recommended for maintaining forest productivity (Graham et al. 1994). In boreal forests, it would appear that at least a minimum of 20 Mg/ha should be left after harvesting and site preparation. This material can decompose and become an important part of the forest soil. It is very likely that coarse woody debris may be more important in boreal forests, because of shallow soils, than in other mixed-conifer forests. In addition to maintaining forest productivity, this material provides habitat for many mammals, invertebrates, birds, and fish (Harmon et al. 1986).

Forest tending

The silvicultural system does not end with the regeneration treatment (i.e., clearcut, seed tree, etc.). After a stand is regenerated or entered using an uneven-aged system, some tending of the stand ,using intermediate treatments, is usually required. It is critical in uneven-aged systems that, during each entry (20- 40 yr intervals), the stand is tended. In both even-aged and uneven- aged systems, these thinning, cleaning, weeding, liberation, or sanitation treatments can occur in all canopy levels. During these treatments, stands are cultured to ensure that the desired stand composition and structure are maintained. In addition, these intermediate treatments can provide forest products.

The opening size, canopy composition and structure, forest floor disturbance, and coarse woody debris specified in a silvicultural system, in combination with the biophysical template (slope angles, aspects, climate, soils, elevations, etc.) present in the boreal forests, enable the practice of silviculture to create and maintain a suite of forest conditions. This plethora of conditions can be used to address the variety of management issues facing the boreal forests.

SILVICULTURAL SYSTEM FOR SUSTAINING PREDATOR HABITAT

The Northern Goshawk is a high-level predator living in boreal forests throughout the world (Brown and Amadon 1968). In general, goshawks nest in mature to old forests with relatively large trees, high canopy closure (relative to surrounding areas), sparse ground cover, and open understories (Squires and Reynolds 1997). Snags, multiple canopies, and down woody debris are also common in nest stands. The goshawk is a large bird, weighing up to 1.4 kg, that preys on a wide variety of small mammals (squirrels, rabbits), woodpeckers, and other medium-to-small birds (robins, jays). A major food source in boreal forests is the snowshoe hare. Snags, herbaceous understories, shrubs, and small openings are only some of the forest structures required by prey. During the nesting season, a goshawk pair selects prey from a variety of forest conditions over large areas (2500 ha), depending on the prey species and their availability (Reynolds et al. 1992). Therefore, goshawks and their prey require a variety of forest structures dispersed over large areas.

In boreal forests, goshawks nest in stands containing large old fir and spruce. In addition, lush understories covered by forbs and shrubs, snags, and openings are used by prey and by goshawks for hunting. Group selection could be used to sustain these conditions over a goshawk home range (nest stand plus foraging area). A silvicultural system could be designed to maintain 10% of the area in seedlings, shrubs, and forbs arranged in small openings dispersed throughout the home range. The reminder of the area would contain 10% sapling sized trees, 20% young (20 - 80 yr-old) forest, 20% mid-aged (80 - 160 yy) forest, 20% mature (160 - 200 yr-old) forest, and 20% old (> 200-yr-old) forest. To convert a forest to this matrix of different structures would take > 200 yr to complete.

Small openings created in the forest using group selection would quickly be occupied by mixtures of shrubs, along with aspen, pine, fir, and spruce. These conditions provide prey habitat, especially for the snowshoe hare, and provide hunting opportunities for goshawks. As trees in openings become young and mid-aged, thinnings to maintain forest growth would provide aspen and pine timber products. Similarly, by growing trees for > 200 yr before harvesting, the system produces high-quality spruce and fir lumber. Large, dominant reserve trees left in openings add structural diversity, provide snags when dead, and create coarse woody debris as they fall. Multiple goshawk home ranges managed using group selection would contain old-growth characteristics throughout, and > 40% of the landscape would contain trees > 160 yr old. In addition to providing goshawk habitat and timber products, a boreal forest managed in this manner would provide habitat for other wildlife, would be resilient, and would offer many recreational opportunities.

SILVICULTURE IN A LARGER CONTEXT

Silviculture is applied at the stand level, but treatments need to be placed in context by assessing or evaluating larger areas. Viewing landscapes and larger areas provides information about processes or structures that are not recognizable at the stand level. For example, climate, smoke dispersal, ungulate migration, and fish migration are processes that are not easily viewed at the stand level. By understanding how stand treatments might be affected by processes operating at larger scales, and how stand treatments might affect these large-scale processes, more informed decisions can be made on when, where, and how silvicultural treatments should be applied.

The boreal forests are a major world resource. Carbon sequestration, wildlife habitat, timber resources, water, recreation, minerals, oil, gas, and numerous other resources that humans value are present in these forests. Silviculture can provide the systems, tools, and techniques for managing the vegetation component of these forests. However, humans, through the political and public processes of governments and societies throughout the world, need to decide how they want to use boreal forests. More often than not, resource exploitation is their primary use, and clear-cutting is the preferred method of harvesting trees. Clearcutting boreal forests, in itself, does not make a silvicultural system.

For the most part, the differing opinions of how boreal forests should be managed are not silvicultural; they are political and legal. It was recognized in the United States early in the 1900s, with the establishment of the National Forest System, that forests were unique resources requiring conscientious management. Various laws and policies were written to guide how forests were used, but forest management is as contentious now as when the National Forest System was established (Kohm and Franklin 1997). By the 1930s, it was recognized that the amount of harvesting occurring on some forests could not be sustained, but managers, politicians, and society in general failed to act on these warnings (Hutchison and Winters 1942).

The same situation is occurring in boreal forests throughout the world. It is recognized that functioning forests (all of the parts together and operating) cannot be maintained while sustaining their continued level of use. Often, the debate centers around the type of silvicultural system being used, instead of the amount, location, and intensity of human use, or exploitation, or both. Silvicultural systems could be designed for the boreal forests to fulfill a wide range of management objectives, ranging from minimal intervention in natural processes (designing and implementing natural prescribed fire prescriptions or preserves) to producing a high volume of high-quality forest products. Silviculture has the tools and expertise to provide society with a variety of boreal forest conditions, once short- and long-term management objectives have been politically and legally defined.

RESPONSES TO THIS ARTICLE

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