SILVICULTURAL SYSTEMS FOR BOREAL AND TEMPERATE FORESTS

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Contents

Summary

Wood is an environmentally friendly material. The future will see a greater reliance on second growth forests to supply demand. Silvicultural practices focus more today on what should be left after harvesting to maintain forest composition, structure, diversity

and values. A forest analysis is required in the field to examine stand history, present stand conditions, natural patterns of succession and feasible silvicultural treatment options. In many areas, the number of people familiar with local forest conditions who are conducting the above tasks is greatly inadequate. Many future problems concerning sustainable development could be addressed by increasing the number of qualified field people working in forestry.

New technologies, such as geographical information systems (GIS), are providing spatially explicit information for landscape and stand-level planning, and feedback mechanisms (adaptive management). While the impacts of treatments are often understood at the stand level, there is typically a great deal of uncertainty at the landscape or regional scale. Some countries are in a better position than others to take advantage of existing and newly developing technologies.

Controversies in forestry will probably continue because of the long time periods involved in managing forests, and the dichotomy between the demands for high timber yields and management systems for the protection of natural forest features. Third party certification programs may play a major role in resolving these difficulties.

The long-term implications of the silvicultural treatments applied today will not be known for many decades. Natural disturbances and global changes need to be integrated into predictive forest development models to address future uncertainties and risks. Important research areas that need greater attention include developing new methods to increase forest productivity, defining the indicators of forest sustainability, improving methods of forest soil and water conservation, species habitat protection, prevention of forest fragmentation and in some instances, methods of ecological restoration.

1. Introduction

1.1. The Forest Resource

The boreal forest is a large nearly continuous area situated between 50^{o} and 60^{o} N latitude in the northern hemisphere and includes part of the Russian Federation, Canada, the Nordic countries and Alaska (USA). Also known as the northern coniferous forest or taiga, it encompasses a vast area found between the northern tundra and the temperate forest to the south. Its composition is relatively homogeneous, consisting predominately of conifers including spruce (*Picea*), larch (*Larix*), pine (*Pinus*) and fir (*Abies*). Broadleaf deciduous species such as alder (*Alnus*), birch (*Betula*), and aspen (*Populus*) are also common in early stages of forest succession.

Temperate forests are found in the more southern mid-latitudes, but no internationally accepted definitions exist to separate the temperate from the boreal forest zone. Generally, the milder temperate forests are dominated by deciduous species including maple (*Acer*), oak (*Quercus*), beech (*Fagus*), and basswood (*Tilia*), but conifers can predominate in colder or drier areas. Some temperate areas, on the western coast of continents, support highly productive temperate rain forests where abrupt changes in elevation enhance seasonal rainfall. The temperate forests of the Southern Hemisphere are distinctive with their humid subtropical climates supporting various conifer species such as *Araucaria* and *Podocarpus* or southern beech (*Nothofagus*).

The temperate/boreal forest resources assessment (TBFRA) report of Europe, Commonwealth of Independent States (CIS), North America, Australia, Japan, and New Zealand contains recent summaries prepared by the UN-ECE/FAO on the forest resources of 55 industralized temperate/boreal countries. For this area collectively, the species distribution by area was 47% coniferous, 26% hardwood and 27% mixed coniferous/broadleaved species. The total area of forest and other wooded land was 2 478 million ha. Of this, 1 682 million ha (68%) were classified as forest or about half the world total, which was estimated by FAO as 3 454 million ha in its State of World Forestry 1999 report.

Forest land within the TBFRA report requires a minimum tree crown cover of 10%, although in some cases the classification of forest land was based on productivity, for example, in the United States, timberland is defined as forest land capable of producing 1.4 m^3 $ha^{-1} year^{-1}$. Forested areas of lower productivity are considered unproductive or classified as other wooded land. The CIS countries contain over half the forestland in the TBFRA area with 856 million ha. North America has over a quarter with 462 million ha. The other wooded land is distributed differently with more than half of it in the “Other TBFRA” countries, which included Australia. Australia has 422 million ha of area classified as other wooded land, while North America had nearly one-third of the other wooded land (254 million ha). Within the TBFRA area, Europe has 10% of the forest and 5% of the other wooded land.

The ownership status was determined for all TBFRA countries, but the pattern of ownership is changing rapidly, especially in the CIS countries that are in transition to market economies. For the TBFRA countries together, about 80% of the total forest and other wooded land are in public ownership. Present ownership patterns vary greatly among countries. In Europe, for example, there are about 77 000 holdings in public ownership and 10.7 million in private ownership. Of these, the average size of public holdings is 1 200 ha, as compared to 10.6 ha for private holdings. In contrast, there are 64 public holdings with an average size of 1.99 million ha and 9.94 million private holdings with an average size of 17.2 ha in the USA.

The volume of growing stock in the TBFRA area is just over 200 billion m^3. The Russian Federation, USA and Canada account for nearly 80% of this volume. About two thirds of the total volume or 134 billion m^3 in forests is available for harvesting. The amount of growing stock per unit area varies widely ranging from 50 m^3/ha to more than 250 m^3 ha^{-1}. Generally, the amount of growing stock increased during the 1990s, increasing by about 640 million m^3 annually. In the Commonwealth of Independent States (CIS), growing stock on forestland decreased by an average of 23 million m^3 $year^{-1}$, declining as much as 113 million m^3 $year^{-1}$ in the Russian Federation alone because forestland was transferred to other land categories.

While the figures within the TBFRA report are probably the best available, further analysis would be needed to determine whether or not the data is reliable. There may be some problems, for example, with standardizing the definitions of categories, sampling and survey methodologies and in making any adjustments in national data. In addition, much of the data is too general in nature to assess sustainability in terms of forest structure, productivity and health. The extensive nature of the resources, the remoteness and the related difficulties of surveying a large part of the area made even the task of compiling the data needed for the TBFRA enquiry a difficult challenge. Four countries, the Russian Federation, Canada, the United States and Australia, account for over 85% of the forest and nearly 94% of other wooded land. Consequently, the reliability of the estimates from these four countries has a large influence on the overall results. Further, a significant area of temperate forest was not included in the TBFRA study, notably areas in China and the two Koreas within the Northern Hemisphere, and Argentina and Chile in the Southern Hemisphere.

1.2. Natural Disturbances and Anthropogenic Factors

Forests are dynamic and continually changing due to various natural and anthropogenic disturbances. The TBFRA survey reported that the most important causes of forest damage in the boreal and temperate forest zones were insects and fire. The incidence and scale of forest damage changed from year to year and those areas that were affected overlapped complicating their impact assessment. Nevertheless, the areas affected were large with, for example, up to 205 million ha damaged by insects and disease in Canada alone during the period 1986-1995. Further, almost 29 million ha of forests were damaged by fire in Canada in the same period. Browsing damage was also widely reported and in some parts of Europe it was greater than any other identified cause of forest damage.

There are a number of difficulties in examining forest damage at an international scale. Inventory methods vary among countries and until recently, they concentrated mainly on an assessment of wood resources. Such issues as forest diversity, water quality and carbon sequestration were not included. Anthropogenic factors also affect the total amount of forested land and add greater complexity to forested areas by changing the intensity and rate of timber harvesting, the conversion of forest lands to other uses and the severity of environmental damage. The total annual fellings in the TBFRA region were estimated to be about 1 632 million m^3. Removals (fellings minus harvesting losses) amounted to almost 1 220 million m^3.. Of this, 695 million (57%) was from North America and 360 million (30%) from Europe. For the whole TBFRA region, felling of growing stock was 52.6% of net annual increment. Coniferous species were used more intensively than broadleaved species with fellings of growing stock/net annual increment (NAI) ratios of 62.5% for conifers and 42.2% for hardwoods.

Under global change, extremes in climate may be greater in future. The impacts of the various natural and anthropogenic factors, such as greater extremes in climate, may have increased influence on forest productivity, structure and health. Existing natural disturbance and ecological models will need refinement or further development to incorporate these possible changes, thus enhancing their use in silvicultural planning and in making predictions about future outcomes from applying various combinations of forest management alternatives.

1.3. The Goal of Sustainable Development

Global forests have declined throughout history as human populations expanded. Numerous problems were created by deforestation including shortages of firewood, losses of species diversity and habitat, soil erosion and fertility losses, stream sedimentation, flooding and forest fragmentation. These problems are not new, but their impacts today are far greater and more widespread.

Silviculture is an applied science requiring knowledge in such fields of natural science as forest ecology, plant physiology and soil science. Silviculture is also an art form creating landscapes through treatments selected using judgement without full knowledge of future treatment effects on forest structure and function. If practiced well, silviculture can be applied in various ways to achieve ecosystem management. Once the management objectives for a stand or landscape have been developed, silvicultural techniques can be applied to reach them. These techniques can be used to maintain or enhance forest regeneration, species composition and diversity, stand structure and forest productivity. Through the application of silviculture, natural processes can be guided to develop forests with desirable characteristics in a shortened period of time.

The expanding world population is placing increasing demands on the world's forests. Such large demands together with the competing uses for forest resources have highlighted the decline of forests generally, and scarcity of some forest types and species living within them. In some areas, controversy has developed concerning how intensively and for what purposes forests should be managed. The outcome in terms of management objectives will affect the selection and use of silvicultural systems (Figure 1).

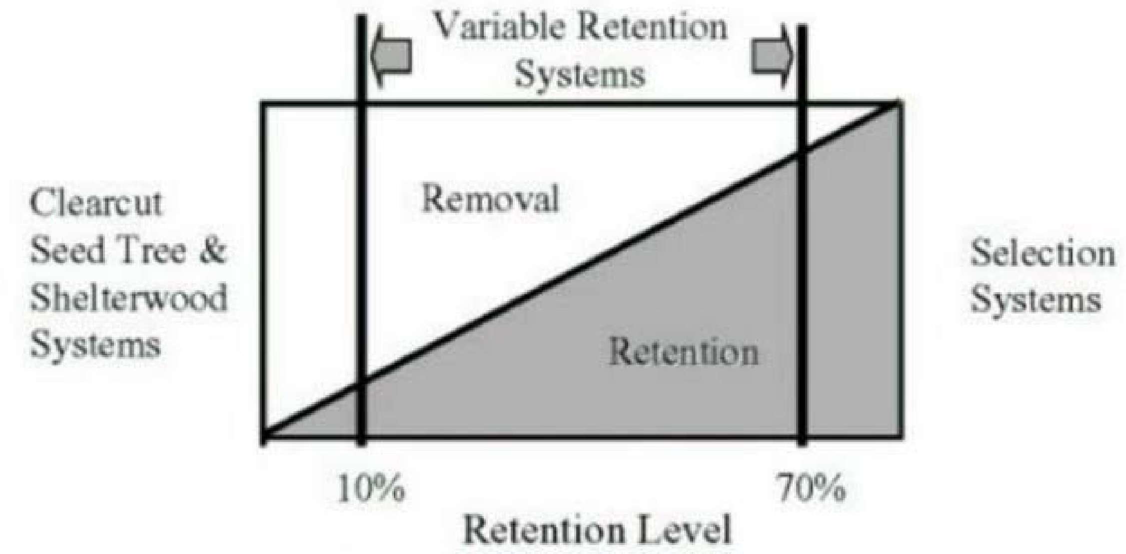

Figure 1. Silvicultural systems as defined by retention level. Variable retention systems retain more than 10% and less than 70% of the pre-harvest volume representative of the pre-harvest species, age and size distribution (after Franklin *et al.*, 1997).

Each silvicultural system consists of a range of activities by which a forested area is harvested, regenerated and tended through time. Historically, as forests were exploited and wood supply shortages occurred, early methods were developed to reforest harvested areas. Forestry gradually evolved and silvicultural systems developed to regenerate, tend and harvest forests throughout their lifetime that could provide a sustained yield of wood products. Silvicultural systems are not preset inflexible treatments that can be applied without analysis. They can and should be modified to account for stand histories, local site conditions and forest management objectives.

The forester has three options for regeneration: (1) advance regeneration; trees that were present in the understory of stands before harvesting, (2) natural regeneration: trees grown from seed that falls on the site after harvesting, and (3) artificial regeneration; trees grown in nurseries and planted on the site. A number of considerations will affect what regeneration method or methods are used (Figure 2).

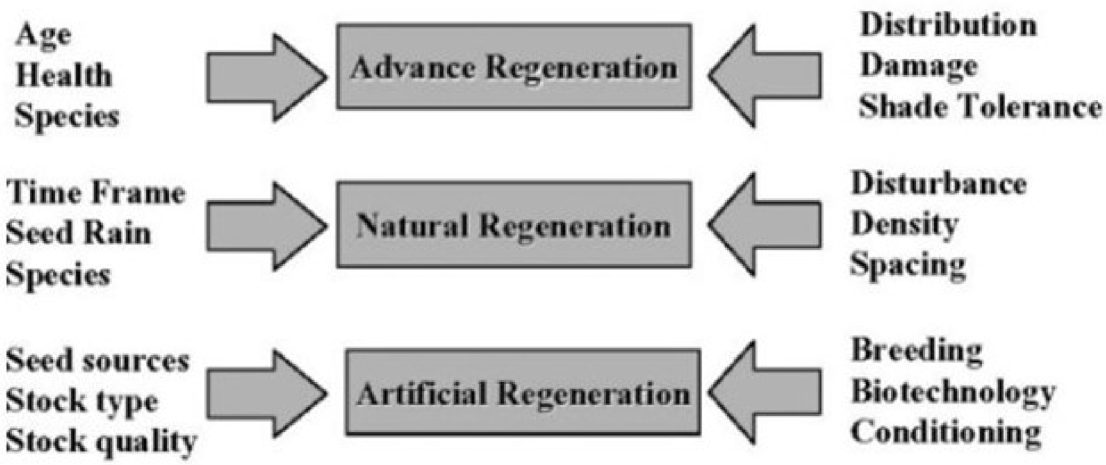

Figure 2. Some considerations in the choice of regeneration type.

By the early 1990s, people's attitudes were shifting away from the historical commodity-based view of forestry. This conceptual change to what became known as sustainable development, or later also described as ecosystem management, meant environmentally sound development that met the needs of the present generation without compromising the ability of future generations to meet their needs. As applied to forestry, this would encompass the management and use of all forest values without compromising their preservation and use by future generations. This new approach aimed for a balance between protecting forest ecological structure and function, while maintaining the production of forest values for social and economic benefits. This has resulted in a shift in focus from sustaining yields of outputs and balancing competing uses, to sustaining ecosystem health, diversity and productivity.

These emerging concepts do not necessarily change the practice of silviculture, but they change the way resource managers evaluate the impacts of forestry operations. Attention must now focus beyond the traditional forest stand in time and space and examine all the major components of an ecosystem at various scales. In this context, foresters continue to manage forests to meet people's needs, but the primary goal is to accomplish this while sustaining healthy forests in perpetuity for future generations. This has proven to be a major challenge with the emphasis now on conserving various forest resources and values, and meeting the different concerns held among interest groups about how sustainable forestry can be achieved. With heightened environmental concerns and the broader scope of meeting sustainable development in forestry, efforts are underway by forest industries to comply with various certification standards. These standards exist to satisfy the concerns of customers about the source of forest products. Certification is attempting to provide some degree of assurance that certified products were harvested from forests managed in a sustainable way.

1.4. Objectives

The challenge today of reaching sustainable development is a complex problem. Environmentally sound methods of ecosystem management are needed to meet present demands for forest products, while meeting other demands on the forest and sustaining forest ecosystem health, diversity and productivity for future generations. The objectives of this paper are to describe the silvicultural systems used in the boreal and temperate forests today, to discuss the changing role of silviculture emphasizing the benefits and limitations to its application, and to discuss the implications for human use, now and in future.

2. Silvicultural Systems and Their Applications

2.1. The Development of Silvicultural Systems

A silvicultural system defines the timing, sequence and kind of treatments that will produce the desired outcomes from forests. Such treatments include harvesting, regeneration and stand-tending methods and cover all activities for the entire length of a rotation cycle (life of the forest stand). The silvicultural system describes a long-term, planned program of treatments extending throughout the life of the stand. Stand tending activities are not intended to lead regeneration but these practices focus on shifting the growing space from certain trees or other plants by weeding, brushing or thinning, or ameliorating the site or tree characteristics by such practices as fertilization, drainage or pruning.

Forests are, and probably will remain, the source of raw material for a major industrial sector. About 80% of the world’s wood raw materials are harvested from old or native forests. In many boreal and temperate forest areas, native or old forests are considered to represent valuable ecological systems and human values. Intensive harvesting of these stands can threaten natural forests and their diversity.

In the near future, there will be a much greater reliance on second growth forests as the source of multiple commodities and services. Second growth forests or stands have grown up after the removal of a previous stand by harvesting, fire, insect attack or other causes. In many cases, second growth forests are plantation forests that have been established by planting or/and seeding for the purpose of reforestation. Reforestation is the renewal of a tree crop either by natural means (seeded on-site from adjacent stands) or by planted seedlings or direct seeding. Higher growth rates in second growth stands can reduce the pressure to harvest natural forests.

Silviculture applies to forest stands and the trees in those stands. Traditionally, the discipline of forest management has worked with a collection of stands and integrated silvicultural plans for the entire forest lot or administrative unit. The need to consider ecological, economic, and social aspects in the sustainable use of forests requires that the stand-level impacts of silvicultural practices be addressed at a larger scale. For example, in the maintenance of biodiversity, stand level practices can maintain or even increase suitable habitats. Leaving corridors, that are linear strips of natural or semi-natural vegetation, can provide connectivity for many species. Also, forest fragmentation is affected by the way that stand level practices are implemented, for example, by such factors as form and size of harvest blocks.

	CC	**ST**	**SW**	**DIS**	**AGG**	**D+A**	**SEL**
Advance Regeneration	--	-	++	0	+	++	+
Natural Regeneration	-	+	+++	++	+	+++	-
Planted Regeneration	++	++	+	+	++	+++	-
Forest Structure	--	-	+	+	++	+++	+++
Habitat (microclimate)	--	-	+	+	+	++	+++
Woody Debris	++	++	+++	+++	+++	+++	++

Potential gains are indicated by +, losses by - and neutral impacts by 0. ST, seed tree; SW, shelterwood; DIS, dispersed retention; AGG, aggregated retention; D+A, combined dispersed and aggregated retention.

Table 1. Examples of possible impacts on ecological characteristics through a continuum of overstory retention from 0% (CC, clearcut) to greater than 70% (SEL, selection).

Ecological impacts of silvicultural practices are relatively well known at the stand level and they vary with the level of tree retention (Table 1), but at a regional scale a great deal of uncertainty prevails about the combined effects of various stand treatments. Larger scale forest level planning and actual management are now making greater use of information technology, such as Geographic Information Systems (GIS), to guide stand level decision-making and to link potential impacts of silvicultural activities to watershed or landscape level.

All applications of silvicultural systems require knowledge of site factors (e.g., fertility, moisture, elevation), all associated species, characteristics of crop trees, and successional pathways after disturbance at the site. Forest ecosystem classifications form the ecological basis for forest management, and are an important tool in the use of all silvicultural systems. Forest ecosystem classifications are available for all boreal forest in Northern-Europe, North America, and for parts of Northern Asia and much of the temperate forest area. Principles of silviculture are common, as defined in the silvicultural systems, but applications of any of the systems always require local knowledge of the ecosystems combined with practical experience.

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Bibliography

Franklin J.F., Berg D.R., Thornburgh D.A. and Tappeiner J.C. (1997). Alternative silvicultural approaches to timber harvesting: variable retention harvest systems. Chapter 7 In: K.A. Kohm and. Franklin J.F (Eds.) *Creating a forestry for the 21st century: the science of ecosystem management*. pp. 111-138. [New approaches to timber harvesting are described emphasizing their impacts on forest structure, species composition and diversity].

Kelty M.J., Larson B.C., and Oliver C.D. (Eds.). (1992). *The ecology and silviculture of mixed-species forests.* Kluwer Academic Publishers, the Netherlands. 287 pp. [Uses case studies from around the globe to present ideas and research on the ecology and management of mixed-species forests].

Kuusla K. (1990). *The dynamics of boreal coniferous forests.* Finnish National Fund for Research and Development, Helsinki, Finland. 172 pp. [Describes the Boreal coniferous forests of North America and Eurasia].

Larson J.A. (1980). *The boreal ecosystem*. Academic Press, Inc. London, U.K. 500 pp. [Summarizes information on Boreal forest ecosystems].

Matthews J.D. (1989). *Silvicultural systems*. Clarendon University Press, Oxford, U.K. 284 pp. [Explains silvicultural systems, especially those applied in the United Kingdom].

Nylund R.D. (1996). *Silviculture concepts and applications*. McGraw-Hill Companies Inc., N.Y. 633 pp. [Provides context and descriptions of silvicultural systems and their application].

Oliver C.D. and Larson B.C. (1996). *Forest stand dynamics*. Wiley, New York. [Presents a biological basis for silviculture and describes patterns of stand development].

Powers R.F. (2000). The role of planted forests in a "Green Certified" Century. In Proc.. Reforestation for the Millennium: Back to our Roots. 21st Annual Forest Vegetation Management Conference held Jan. 18-20, 2000 in Redding, CA. USDA For. Serv. Pub. pp. 1-17. [Presents the argument that plantation forests are our best hope for meeting the demand for wood while preserving the condition of natural forests].

Savil P., Evans J., Auclair D. and Falck J. (1997). *Plantation silviculture in Europe*. Oxford University Press. 297 pp. [Presents an overview of silvicultural practices, especially those used in western Europe].

Sedjo R.A., Goetzl A. and Moffat S.O. (1998). *Sustainability of temperate forests*. Resources for the Future, Washington, D.C. 102 pp. [Discusses the developments and limitations to reaching sustainability in Temperate forests].

Schütz J.P. (1999). Close-to-nature silviculture: is this concept compatible with species diversity? *Forestry* **72**, 359-366. [Explains the selection system and more multifunctional ways of practicing silviculture].

Smith D.M., Larson B.C., Kelty M.J. and. Ashton P.M.S (1997). *The practice of silviculture: applied forest ecology.* John Wiley and Sons Inc., New York. 537 pp. [Using examples primarily from North America, it presents concepts and provides an analytical approach for the practice of silviculture].

UN-ECE/FAO. 2000. Forest resources of Europe, CIS, North America, Australia, Japan and New Zealand. *Geneva Timber and Forest Study Papers* **17**, United Nations, N.Y. 445 pp. [Characterizes the extent and condition of Boreal and Temperate forests].

Walker L.C. and Oswald B.P. (2000). *The southern forest geography, ecology and silviculture*. CRC Press, Boca Roton, U.S.A. 332 pp. [Explains the past and present forests and silvicultural practices used in the southern United States].

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