Developing a silvicultural framework and definitions for use in forest management planning and practice

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ABSTRACT

Lack of a management framework on which to base silviculture options has plagued the forest management planning process in Ontario. The Forest Management Planning Manual for Ontario's Crown Forests directs that strategic silvicultural options be developed and identified in terms of the (i) applicable forest unit, (ii) associated assumptions, and (iii) extent to which they can be used on a forest management unit. In this paper, we describe a framework for classifying management (or silviculture) intensity and propose definitions for extensive, basic, intensive, and elite intensities of silviculture to support the framework's use in planning and application. We outline how the Canadian Ecology Centre – Forestry Research Partnership, a research partnership between Tembec Inc., the Ontario Ministry of Natural Resources, and Natural Resources Canada, is considering applying these in the forest management planning process. The framework and definitions can be used to develop strategic silviculture options within an active adaptive management approach. This framework should help to reduce uncertainties associated with forest development, treatment costs, response to treatments, and success rates provided appropriate monitoring. The framework and definitions described were specifically developed for silviculture related to reforestation of even-aged boreal forests.

Key words: intensive silviculture, adaptive management, forest management

RÉSUMÉ

L'absence d'un cadre de référence en aménagement à partir duquel il serait possible d'établir les options sylvicoles a constitué une lacune du processus de planification de l'aménagement forestier en Ontario. Le Manuel de planification de la gestion forestière des forêts publiques de l'Ontario exige que des options stratégiques de sylviculture soient élaborées et identifiées en fonction (i) de l'unité forestière visée, (ii) des prémisses utilisées et (iii) de l'étendue de leur utilisation dans une unité de gestion forestière. Dans cet article, nous discutons d'un cadre de référence permettant de classifier l'intensité de la gestion (ou de la sylviculture) et proposons une définition de l'intensité extensive, primaire, intensive et élite de sylviculture afin d'aider à l'utilisation du cadre de référence au niveau de la planification et de son application. Nous soulignons comment le Centre écologique du Canada – Partenariat pour la recherche forestière, un partenariat de recherche regroupant Tembec Inc., le Ministère des Richesses naturelles de l'Ontario et Ressources naturelles Canada, compte utiliser ces dernières au sein du processus de planification de l'aménagement forestier. Le cadre de référence et les définitions peuvent être utilisés pour élaborer des options stratégiques de sylviculture lors d'une approche d'aménagement adaptatif déjà amorcée. Ce cadre de référence devrait permettre de minimiser les incertitudes associées au développement forestier, aux coûts des traitements et aux taux de succès à condition d'assurer un suivi adéquat. Le cadre de référence et les définitions qui ont été décrits, ont été spécifiquement élaborés pour une sylviculture portant sur le reboisement des forêts boréales équiennes.

Mots clés : sylviculture intensive, aménagement adaptatif, aménagement forestier

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Introduction

The degree to which intensification of silvicultural effort in the managed forest is beneficial, required, or desired has been debated in Ontario for the past several decades (ODLF 1967; Armson 1972, 1976, 1979; Reed and Associates 1978). The introduction of Ontario's Living Legacy, a strategy for expanding the province's systems of parks and protected areas by an additional 2.4 million hectares (ha), represented a 12% reduction in the area available for industrial forest management. This expansion of protected areas combined with predicted timber supply shortfalls between 2020 and 2040 that are associated with the age class structure of the historic and existing forest estate (Armson 1972, 1976; Reed and Associates 1978) was anticipated to further reduce the availability of wood supply from Crown lands by approximately 4% to 5% (OFAAB 2001). To mitigate the potential social and economic effects of this reduction, intensive forest management (IFM) was suggested in the 1999 Ontario Forest Accord as a possible means to offset wood supply losses associated with a reduction in the area managed for timber (OMNR 1999, 2004a).

As IFM is not commonly practised in Ontario, a workshop was convened to discuss associated knowledge gaps, research needs, and expectations. The 204 participants had very diverse understanding of IFM. They thought of it as everything from plantation forestry (including monocultures, forests void of diversity, and tree farming) to a continuum where forests are composed of a mosaic of species complexes managed under a range of intensities designed to achieve overall forest objectives (Bell *et al.* 2000). Such diverse views would inevitably hinder the development of IFM-related policy and legislation and communications with stakeholders. An overarching framework and clear, unambiguous definitions for IFM and intensive silviculture were needed. In 2000, the Canadian Ecology Centre – Forestry Research Partnership (CEC-FRP[9]) required a framework and definitions to relate management activities, including silviculture, to growth and yield models used in forest management planning.

In this paper, we provide an overview of the framework and approach used to develop definitions that incorporate harvesting, silviculture, and protection into 5 management intensities (i.e., natural disturbances and extensive, basic, intensive and elite silviculture) to which the acronym NEBIE is applied. We suggest that this approach can be used to reflect assumptions about forest development, treatment costs, response to treatment, and success rates resulting from application of intensity-based strategic silvicultural options and relate our experience to date in incorporating it into Ontario's forest management planning process. The need for monitoring and ongoing adaptive management to test the assumptions inherent in this framework is also highlighted.

[9]The CEC-FRP is a partnership between Tembec Inc., the Ontario Ministry of Natural Resources (MNR), Natural Resources Canada (NRCan) and the Canadian Ecology Centre (Bruemmer et al. 2008, thi sissue). Its mission is to identify, develop and implement ecologically sustainable and scientifically defensible leading edge forestry practices required to maintain and enhance an economically viable supply of quality fibre to Tembec mills, and to the communities those mills support, over the long term. (CEC-FRP 2000).

NEBIE Framework and Definitions

Developing a framework and definitions for even-aged silviculture in boreal forests involved 5 steps: (1) reviewing historical use of the terms, (2) reviewing factors that affect productivity and yield, (3) developing a framework for categorizing management practices, (4) proposing definitions for a range of management intensities (NEBIE) using information from (1) to (3), and (5) incorporating the NEBIE framework and definitions into Ontario's forest management planning process.

Review of historical use of terms

Rather than simply developing new definitions, we thought it best to review the historical use of IFM-related terms to determine whether the intent of the definitions remained the same through time. A brief history of the use of the terms in Ontario is provided in Bell *et al.* (2000, 2006). Older definitions are provided in Appendix A to allow the reader to follow the development of the definitions and judge for themselves whether our efforts were warranted.

For over 60 years, forest managers have classified forest management practices into various intensity classes (Chapman 1950; Duerr 1960; Reed and Associates 1978; OMNR 1986, 1989, 1997; Hodge *et al.* 1989; NRCan 1995; Dunster and Dunster 1996; Côtè 2000; Park and Wilson 2007). During this time, the definitions have changed somewhat but neither the rationale for the definitions nor the changes were documented. Despite this, the basis for the definitions remained constant. Extensive implied cut and leave to natural regeneration without further intervention. Basic implied combinations of natural and/or artificial regeneration free of inter-specific competition without further interventions. Intensive implied combinations of regeneration free of inter- and intra-specific competition. Elite or highly intensive was essentially an extension of intensive that included pruning and site amelioration treatments. A chronology is provided for those interested in greater detail (Appendix A).

Review of factors that affect productivity and yield

The second step in developing a management framework and common set of definitions was to review the factors affecting forest productivity and yield to identify those that would be critical. The factors reviewed were: (1) site productivity, (2) time, (3) silviculture, (4) protection, and (5) harvest. Of these, only silviculture and protection are referred to in previously published definitions (Appendix A).

Site productivity refers to the availability of resources (light, water, and nutrients) needed to sustain healthy tree and vegetation growth on a particular site. It involves the complex interaction of physical, chemical, and biological conditions and processes: physical conditions include soil moisture, texture, and temperature; chemical conditions include soil pH, amount and availability of carbon, nitrogen and other essential nutrients; and biological conditions include the existing plant community, soil micro-organisms, and fauna (e.g., insects, worms) responsible for biological processes including decomposition and mineralization (NRCan 2007). Some of these conditions and processes can be altered by management practices and, where successful, improve yield of desired forest products (or services).

When managing forests for fibre production, time is a critical factor. Three time-related factors are of particular importance: regeneration lag, rotation age, and when silvicultural practices are applied. Every additional year added at the regeneration phase is assumed to lengthen the rotation by a year. In practice, the longer it takes for a tree to establish and become free of inter-specific competition, the longer it will take for it to produce a commercial wood product and provide economic returns but the effect is not 1:1. In Ontario, rotations in forest management plans typically exceed 70 years; with proper timing of silvicultural practices, however, rotations of 35 to 45 years are possible.

Silviculture can be defined in many ways. Here we define it as the theory and practice of managing the species/genotype composition of forest stands and the site resources through all phases of stand development to meet management objectives.

Most of Ontario's tree species yield relatively low wood volumes (Bonnor and Nietmann 1987), which affects economic returns on investments in silviculture. Markets change, however, and trees must survive long periods through seasonal changes in temperature and precipitation and rare or infrequent events such as extreme weather, insect infestations, or severe fires (Fernum *et al.* 1983, Smith *et al.* 1997). Thus, it is important to maintain a breeding population with a broad genetic base at the forest level. Species choices are essentially selection of genetic material on a coarse scale. Within-species selections can be used to improve traits such as faster growth, stem quality characteristics, winter hardiness, disease resistance, wood density, and/or product uniformity (OMNR 1997, 1998a, b; Joyce *et al.* 2001; McInnes and Tosh 2004).

Stand composition (i.e., both species and genotype makeup of a stand) is influenced by the chosen silviculture system and associated management practices (Matthews 1989, Smith *et al.* 1997). Poor judgement in selecting and implementing either the silviculture system or management practices can reduce the economic value of future stands (Smith *et al.* 1997). Artificial regeneration provides the greatest likelihood that the composition of a stand at maturity can be predicted. It also allows the establishment of single- or multiple-species plantations. Release, cleaning, and thinning activities can be extremely selective, when used in combination, and can be adjusted to remove species or low-grade stems at whatever level is considered desirable. In effect, thinning is a form of mass selection (OMNR 1998b).

How a tree species responds to management practices is a function of all the adaptive mechanisms it has evolved (e.g., regeneration strategies and physiological traits) to respond to natural disturbances (Grime 1977, Sims *et al.* 1990). Silviculture can be used to emulate such disturbances and to improve tree growth by controlling the availability of site resources. To effectively manage site resources, forest managers require knowledge of species' autecology, particularly shade tolerance thresholds (Bell *et al.* 1998).

Silvicultural treatments used in Ontario and their general intent are described briefly below in the context of potential effects on productivity and yields:

1. Site preparation is used to direct resources towards specific trees within a stand. The effect of site preparation (e.g., prescribed fire or mechanical treatments) on forest productivity and yield can be complex. For example, fire removes surface organic matter, releases mineral nutrients, increases soil temperature, exposes mineral soil, and stimulates the production of nitrogen, but typically does not remove large organic debris (Fernum *et al.* 1983, Matthews 1989, McRae *et al.* 2001). Mechanical site preparation can be used to facilitate planting or natural regeneration by exposing or disturbing moderate amounts of mineral soil (Sutherland and Foreman 1995, OMNR 1997). However, it can negatively affect a site by causing rutting and compaction, exposing excessive amounts of mineral soil, and making substantial area inoperable when slash is piled.
2. Natural and/or artificial regeneration can be used to establish a new stand, and the method used influences site occupancy. Too few of a desired tree species reduces site occupancy, and too many can reduce growth rate and/or cause undesirable stem quality. Natural regeneration (i.e., the establishment of a tree crop by natural seeding, sprouting, suckering, or layering) generally produces clumped regeneration. Artificial regeneration permits even distribution of trees across a site reducing gaps and voids (Andison and Callaghan 1988, Bell *et al.* 1990).
3. Release and cleaning operations in a young stand reduce, eliminate, or suppress undesirable competing vegetation, increasing the availability of resources and improving growing conditions (Walstad and Kuch 1987, Brand 1991). Maximum benefits occur when treatments are applied before competing vegetation impedes growth of desired crop trees (Pitt *et al.* 1999, Wagner *et al.* 2006).
4. Precommercial and commercial thinning reduce stem density increasing availability of resources for the most desirable trees (OMNR 1997). These treatments can be regarded as tools to increase the value of the residual stems (Fernum *et al.* 1983). In overstocked stands, thinning is recommended to reduce competition and direct site resources towards producing fewer larger stems. Thinning in the winter and leaving felled trees on site ensures that nutrients in the needles and small branches are recycled back into the soil (Burger 2002).
5. Pruning live branches redirects resources within individual stems, increasing log quality and opportunities for producing high value products (Zhang and Gingras 1998). Pruning can be used to control disease (e.g., white pine blister rust [Cronartium ribicola]) by preventing the spread of cankers, changing the microclimate, and reducing the surface area where the infection occurs (Hodge *et al.* 1989).
6. On sites where simply allocating existing resources is insufficient to achieve desired objectives, treatments that ameliorate site conditions may need to be considered. Site productivity can be increased through fertilization (Meyer *et al.* 1997), drainage, and irrigation.

Hawley (1947) states the role of protection in forest management as follows: *Protection is in reality just one phase of crop tending but one which must constantly be kept in mind. In fact, often times the details of successful silvicultural practice for a given species are determined by the protection factor.* Hawley and others (Gross *et al.* 1992) have long recognized that tree species vary in their susceptibility and vulnerability to fire, mammalian herbivory (browse), insects, disease, and severe weather as a factor of climate change (together referred to as FhIDS factors), and anthropogenic disturbances.

Forest managers need to model the frequency and intensity of natural disturbances because they affect subsequent regeneration (Matthews 1989, OMNR 2002a). Frequent, moderate disturbances affect forest structure and growth rates and favour shade-intolerant tree species while infrequent disturbances favour shade-tolerant species (Waring and Schlesinger 1985). Information about disturbances can be used to direct forest protection activities and reduce losses through careful analysis of risk and the development of adequate protection strategies (Hodge *et al.* 1989, De Groot *et al.* 2005). Forest managers cannot completely eliminate or predict all of the risks associated with forest management (e.g., climate change, invasive species). Unless protection strategies are extended to all forests, fire and pest outbreaks will spread from less valuable stands to those deemed worthy of protection (Smith *et al.* 1997).

Harvesting is the simplest form of silviculture, and harvesting practices can affect subsequent forest productivity and yield in several ways. Harvesting creates growing space for new trees, determines the quantity and quality of seed trees, and can be used to preferentially select trees that exhibit genetically superior traits for retention. Felling and skidding can lead to physical damage of residual trees resulting in a decline in bole quality and subsequent loss of value. Harvesting practices that leave some downed woody material support the maintenance of biodiversity by providing habitat and structure for many plant and animal species, prevent soil erosion, and store carbon (Stevens 1997). Light screefing that occurs when harvested trees are dragged across a site can increase soil aeration and microbial activity in the organic layer, thereby releasing nutrients. However, compaction can reduce macroporosity, gas transfer potential, and microbial activity, alter moisture regime, and increase resistance to root penetration, all of which negatively affect tree growth (Morris 2001). Proper planning of harvesting practices (e.g., harvest block layout, equipment selection, and timing) can substantially reduce potentially negative effects.

Developing a framework for categorizing forest management practices

If it were possible to monitor the development of all stands within a forest, a classification system would not be necessary since the development and yield of each stand could be modelled. However forest managers in Ontario rely on a far less intensive monitoring program. Prior to the development of the NEBIE framework and subsequent intensity-based yield curves (Penner *et al.* 2008, this issue; Sharma *et al* 2008, this issue), forest growth and development was modelled using normal yield tables (Plonski 1981), which were developed in natural stands (see Penner *et al.* 2008, this issue; Sharma *et al.* 2008, this issue) and thus may not have reflected the effects of silviculture on yield. In Ontario, extensive, basic, and intensive yield curves are used within a strategic forest management model (SFMM; Davis 1999) as a discrete or categorical variable when assigning yield curves. All areas of the productive forest landbase within each forest unit[10] are assigned a planned silviculture intensity prior to model runs. This assignment of silviculture intensity, and choice of the associated yield curve, is thus critical to wood supply calculations. In addition, the categories help to track stands with and without investment and are therefore useful for economic analyses. To ensure that stands are accurately assigned to yield curves, clear concise definitions are needed for the associated silviculture intensities.

As recommended by participants of the IFM science workshop (Bell *et al.* 2000), application of these definitions would be most efficient with a common intensity-based framework for forest management planning and practice. We propose adopting a modified version of a framework published by Burger (2002) that includes objectives and specific metrics associated with forest protection, harvesting, and silviculture practices (Fig. 1). In developing the framework, we assumed that forest managers will continue to increase investments in harvest, silviculture, and protection simultaneously as documented in Armson (2001).

Once the objectives and metrics were agreed on, a framework was developed (Table 1), appropriate practices selected (Table 2), and the definitions were revised.

[10]A classification system that aggregates forest stands for management purposes that will normally have similar species composition, will develop in a similar manner (both naturally and in response to silvicultural treatments), and will be managed under the same silvicultural system (OMNR 2004b).

NEBIE definitions

Our objective in developing new definitions was to ensure they were intent-based, as free from ambiguity as possible, broad enough to include a range of practices, applicable to both afforestation and reforestation, and focused on boreal, even-aged silviculture. They are:

Silvicultural intensity: *The degree to which the factors influencing growth and yield are manipulated. One of four classes (extensive, basic, intensive, and elite) representing increasing silvicultural effort expended to increase the yield and value of forest stands.*

Natural disturbance: *Intervention applied following fire, insect, disease, or severe weather events. Regeneration and stand development are determined by the incidence, type, and intensity of the natural disturbance and the availability of plant propagules, and by the composition of the residual stand.*

Extensive silviculture: *Intervention characterized by selection of harvesting method and scarification. Species composition of the recruitment cohort, stand development, and stand dynamics are determined by plant propagules present naturally and micro-sites created during harvesting or by scarification or by the residual stand characteristics. Stand dynamics and development are similar to natural disturbance.*

Basic silviculture: *Intervention intended to shorten the rotation length/cutting cycle by: increasing residual stand quality; ensuring the availability of suitable micro-sites for propagule establishment; influencing species composition of the recruitment cohort; and reducing inter-specific competition retarding the development of the recruitment cohort.*

Intensive silviculture: *Intervention intended to control the quality and quantity of fibre grown on a given site and to meet a specific short rotation length/cutting cycle target by tightly controlling species composition and quality of residual stems while closely managing both inter- and intra-specific competition during all stand development phases.*

Elite silviculture: *Intervention intended to maximize the quality and quantity of fibre grown on a given site and to meet a specific short rotation length/cutting cycle target by extending intensive silvicultural intervention options to include site ame-*

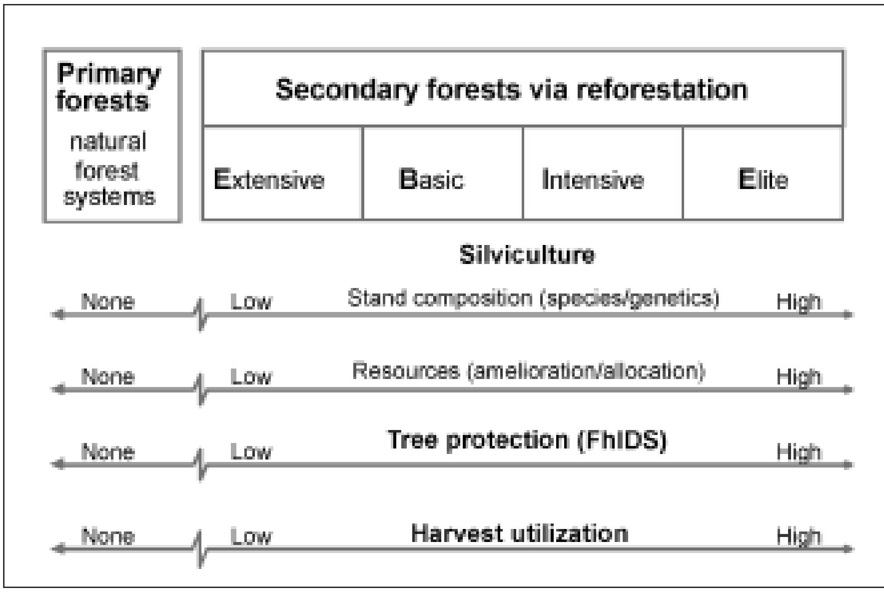


Fig. 1. Range of managed systems and the degree of manipulation of factors influencing forest productivity (Adapted from Burger 2002). The level of control of specific factors is denoted by a scale from none to high.

Table 1. Preliminary framework used to develop intensity-based forest management definitions and renewal standards

	Intensity			
	Extensive	**Basic**	**Intensive**	**Elite**
Objectives				
Management objective (at age to operability/ cutting cycle)	Acceptable species and composition, fixed volume and threshold quality requirements	Preferred species composition and volume		
		Medium value, some quality improvement	High value	Maximize wood value
			Specific wood products, volumes and qualities expected	
Biodiversity basis for consideration	Stand level		Landscape (within limits of silviculture requirements)	
Age to operability/ cutting cycle	≈ the same (considerable variability tolerated)	<80%	<60%	<50%
		…of the "natural" rotation age		
Stand yield (product quantity and quality) predictability (at planning):	Low confidence	Moderate confidence	High confidence	
Harvest scheduling options	Low flexibility (area-based drivers) (single-pass harvest)		High flexibility (to maximize return on investment and capitalize on current market values) (multiple entries possible, even desirable)	
Silviculture – species, quality, and genetic selection				
Species	Preferred and acceptable tree species		Preferred tree species	
Quality	AGS:UGS[a] ratio increases with intensity			
Genotype (genetic quality at stand level)	Maintained (high-grading not tolerated)	Remains same or is improved	Uniformly high	Highest[b]
Silviculture – resource management/amelioration				
Regeneration delay tolerance[c]	<10 years[d]	<7 years[d]	<3 years	<2 years

Table 1. Preliminary framework used to develop intensity-based forest management definitions and renewal standards (con't)

	Intensity			
	Extensive	**Basic**	**Intensive**	**Elite**
Silviculture – resource management/amelioration (con't)				
Density range at FTG[e] (well-spaced stems/ha)	1800 +	1800–4200[f]	2400–3600[f]	Acceptable density range = target +/-5%
Inter-specific competition	Managed, if needed	Managed (up to Free-to-Grow)	Managed as required	Managed continuously throughout rotation[g]
Intra-specific competition	Not managed			
Gap (areas $>16m^2$) tolerance[h]	<10%[i]		<5%[j]	0%[j]
			(uniform distribution)	
Countable voids[k]	≥4 ha		≥1 ha	≥0.2 ha
Amelioration… … fertilization … drainage	Not permissible		Permissible	
Protection				
Priority for protection (general)	Lowest	Medium[l]	High	Highest[m]
Fire and Insects	Landscape-level operations; outbreaks managed to protect wood supply		High priority sites for prevention and suppression	Highest priority sites for prevention and suppression
Disease	Managed on a stand/landscape basis		High hazard areas avoided	High and medium hazard areas avoided
			Managed on a stand basis	Individual diseased trees treated or removed
Herbivory (mammalian)	High tolerance		Priority for prevention and suppression	
			Low tolerance	No tolerance
Severe weather (i.e., blowdown)	Focus on salvage		Treatment designed to minimize risks.	
Harvest				
Tree removal diameter limits[n]		To CFSA standards	>10 cm	>4 cm Full utilization
Tolerance for residual stem harvest damage	Meet minimum obligation under CFSA		Low (AGS <7%; all stems <10%)	<1%; continuously decreasing
Tolerance for compaction rutting and erosion			Low; conservation of nutrient capital fundamental	Very low (i.e. <1%) and decreasing

[a]UGS stock does not count as allowable minimum density but as excess trees at these intensities.
[b]May include exotics/genetically modified trees and clones.
[c]After harvest; does not apply to uneven-aged management.
[d]Species- and site-specific.
[e]Free-to-grow exclusive of inhospitable areas (those that can't support tree survival - e.g., poorly drained shallow soils).
[f]Excess trees to be removed (thinned), stand de-intensifies; or stand to be declared stagnant.
[g]Managed at each cutting cycle in uneven-aged systems.
[h]Net area (exclusive of roads landings and inhospitable sites).
[i]More than 10% of area in 16 m^2 or larger gaps means site is below regeneration standards (BRS).
[j]More than permissible areas means stand de-intensifies.
[k]Definable areas within stands with BRS stocking requiring retreatment/reclassification; failing that, stand de-intensifies.
[l]Losses minimized through better planning and operational practices; treatments discretionary.
[m]The same as private recreational property (i.e., cabins) for protection purposes; site engineering/design applied to minimize threats; treatments subject to pre-planned threat assessments; emergency response plans prepared; health monitoring and mitigation give precedence over other sites.
[n]In selection and shelterwood systems

Table 2. NEBIE treatments (includes high-grading for reference only) in clearcut system

Treatment	Natural	Extensive	Intensity Basic	Intensive	Elite
Harvest	–	Clearcut leaving	NDPEG trees	Clearcut leaving NDPEG trees that will contribute in a positive way to the next rotation[a]	
Site preparation	– –	Scarify	Mechanical and/or chemical site prepare		
Regeneration	Natural	Natural	Plant or direct seed	Plant with highest genetic material available	
Tending (weeding)	–	–	1 release treatment	Release as required	
Tending (thinning)	–	–	–	Precommercial and commercial (up to several entries, as desired)	
Pruning	–	–	–	If required for protection	For protection and improved value
Site amelioration	–	–	–	–	Fertilize, drain, irrigate
Protection	Reactive		Preventative	Proactive	Proactive

[a]Minimize presence of trees with high probability of contributing to disease in future crops.

lioration (fertilization and/or drainage) and enhance stem quality through pruning.

Dividing plantations into basic, intensive, and elite categories is somewhat unique to Ontario. In other parts of the world (e.g., Finland, Sweden, New Zealand, southern United States) forest managers use the term "intensive" to describe most if not all planted forests (e.g., Florence 1996). They probably practice intensive silviculture for several reasons. Land value is high in these jurisdictions and forestry may be economically viable only when it can compare favourably against all other economic uses for the landbase. In these areas, planted forests are located on private lands and mostly rely on highly intensive afforestation practices, including high initial planting densities, use of genetically improved stock, multiple release treatments, commercial thinnings, fertilization, and pruning. This level of management intensity is in sharp contrast to practices used in Ontario's Area of the Undertaking where the most intense practices, such as planting of exotic species and genetically modified organisms, and site amelioration treatments, such as fertilization and drainage, are not permitted "unless they become regulated" under the Crown Forest Sustainability Act (Statutes of Ontario 1995). In much of Ontario, economic uses for the landbase as alternatives to forestry are severely restricted due to a relatively harsh climate, low site productivity, and limited access. The varied distances to markets and extremely varied alternative land use potentials, however, broaden the range of possible forest management intensities, depending on location.

Although the definitions were developed for shorter rotation, even-aged boreal silviculture they may have broader application. Intensive and elite practices are generally applied to shorten rotations, as implied in the new definitions; however, intensive practices can also be used to meet a range of objectives, both in the short and long term, by influencing the desired composition, structure, and ecological characteristics of the future forest (Florence 1996). Since it is impossible to develop definitions that capture all possible uses of intensive practices, we chose to base the NEBIE definitions on the time of first possible commercial harvest as illustrated in Fig. 2.

Applying the definitions to afforestation seems reasonable. Abandoned farm fields can become forested through ingress of seed from adjacent stands or they can be scarified to encourage ingress (extensive) or planted, weeded, thinned, pruned, and fertilized (elite).

Applying the definitions to uneven-aged silviculture also seems reasonable. The Allegheny Section of the Society of American Foresters first proposed intensity-based definitions for uneven-aged stands in 1950 (Chapman 1950) (see Appendix A for details) and Florence (1996) uses the terms "extensive" and "intensive" to describe silviculture methods in selection-type harvesting in eucalypt forests. Thus, precedent exists to apply intensity-based terms and their intent in uneven-aged silviculture.

Incorporating NEBIE Framework and Definitions into Ontario's Forest Management Planning Process

As described above, the NEBIE concept is not new to forest managers in Ontario (OMNR 1986, 1989, 1997; Bell *et al.* 2000). What is new is that a common understanding of the implied terms has been reached through a systematic process. The changes to the definitions, although subtle, will have implications for forest management planning. In Ontario, forest management planning requires the identification of strategic silvicultural options. These options are groups of silvicultural treatments and objectives that exhibit similar characteristics including initial forest unit, silvicultural intensity, expenditures, and growth projections. The Forest Management Planning Manual for Ontario's Crown Forests directs that each strategic silvicultural option identify: (1) the

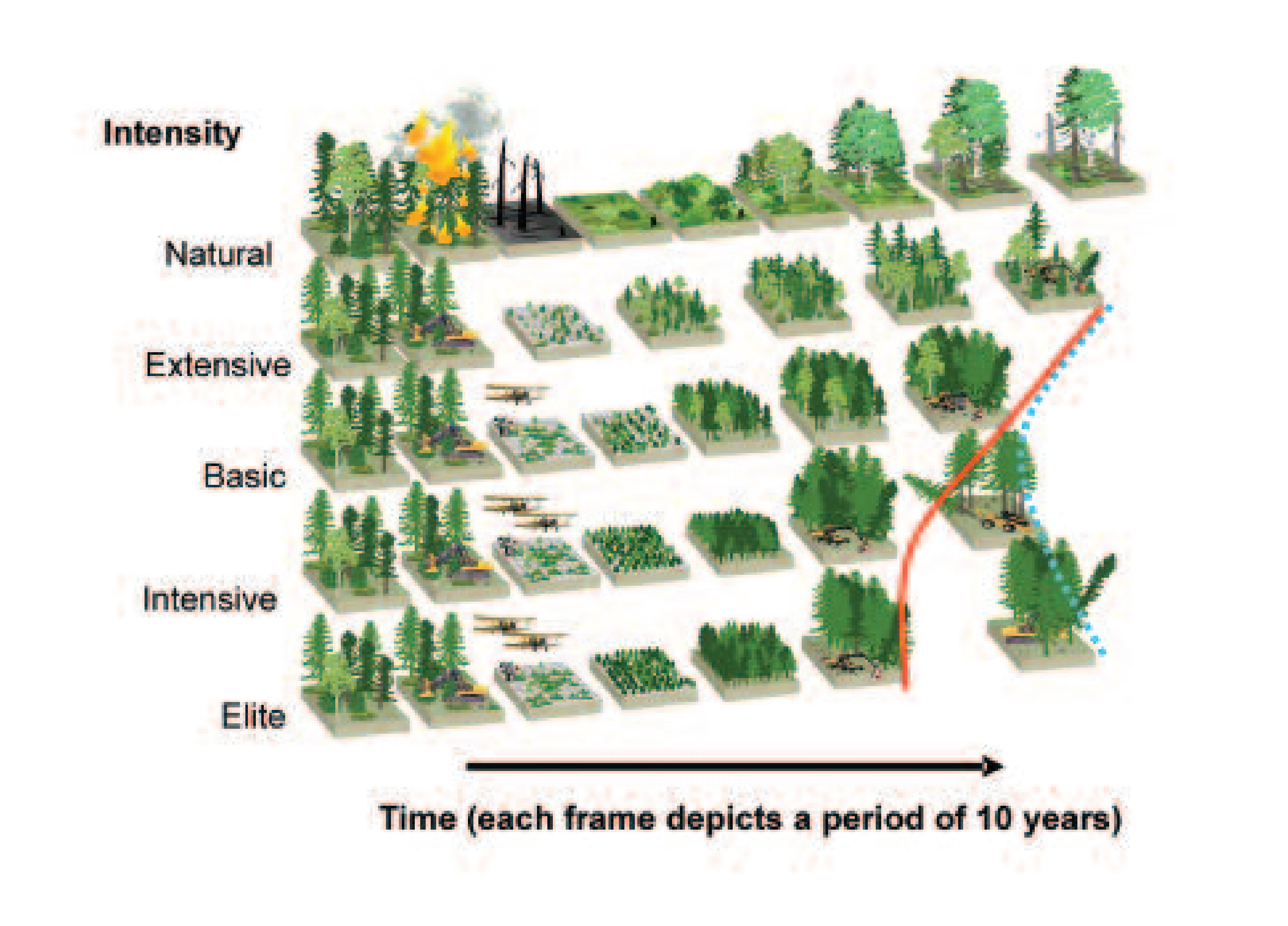


Fig. 2. Illustration of management intensities in a boreal forest showing earliest rotation (red line) and probable rotation if thinning applied (dotted blue line).

forest unit to which it applies, (2) associated assumptions, and (3) extent to which the option can be applied on a forest management unit (OMNR 2004b). The first 2 points are discussed below; the third is discussed in McPherson *et al.* (2008, this issue) in relation to forests of interest to the CEC-FRP.

Strategic silvicultural options and forest units to which they apply

Since 1964, forest managers in Ontario have been required to provide a description of specific silvicultural treatments to be used in each working group[11] in forest management plans. These descriptions incorporated the harvesting, restocking, and tending methods if applied (Plonski 1964). Today, strategic silvicultural options are required (OMNR 2004b). They are used to describe the planned silvicultural activities and associated yield curve that will be used to model the growth and yield of a particular forest unit (or portion thereof) that is planned to be harvested and regenerated.

Strategic silvicultural options describe the range of treatments and objectives that are possible, such as matching species to site, planting fast-growing conifers or genetically improved stock, regenerating the site as fast as possible, maximizing the use of available growing space, practising density regulation, and maintaining non-crop vegetation below critical values. If forest managers consider all the permutations and combinations of treatments associated with these objectives, an overwhelming number of options are possible. Monitoring this many options is not financially feasible. Effectively communicating the purpose of each of the 1600 or more options presented in current forest management plans to stakeholders is also very difficult. Thus, combining these into groups of options is key for effective management, communication, and monitoring.

The CEC-FRP is in the process of incorporating ecosite-specific, intensity-based strategic silvicultural options into forest management plans in northeastern Ontario (McPherson *et al.* 2008, this issue). There are 21 northeast ecosites (Taylor *et al.* 2000) and strategic silviculture options were developed by intensity for 14 of these ecosites for the Romeo–Malette Forest. An example is provided in Table 3 for 5 ecosites to illustrate the application of the NEBIE framework in forest management practice.

Assumptions associated with silvicultural options

Ontario's forest management planning manual also requires that for each strategic silvicultural option, associated assump-

[11]Working group is defined as an aggregate of stands, including potential forest areas assigned to this category, having the same predominant species, and managed under the same rotation and broad silviculture system.

Table 3. Strategic silviculture options for 5 ecosites managed on the Romeo-Malette Forest (ecosite classification is based on Taylor *et al.* 2000)

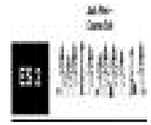
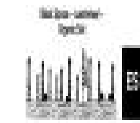
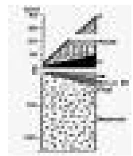
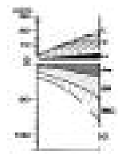
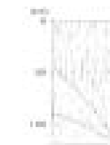
Ecosite						
Soil Profile						
Northeast Standard FU	**SP1**	**PJ1**	**BW1/MW3**	**SB1/SP1**	**SB1**	**BOG**
- Description	Very shallow soils ≤ 30 cm mineral soils	Jack pine - black spruce upland mineral sites	Mixedwood upland sites	Transitional sites - moist mineral soils 20 to 40 cm organic	Lowland organic soils ≥ 40 cm	Bog
- Preferred harvest	Protection forest or winter or summer high floatation equipment - 1 pass clearcutting/ conventional/ CLAAG harvest	Winter or summer - 1 pass clearcut/ conventional/CLAAG harvest	Winter harvest to promote aspen natural regeneration - Greatest summer harvesting opportunity - Caution on fine soil types during spring or late fall conditions	Winter or summer high floatation equipment - 1 pass conventional/HARP/CLAAG harvest	Winter or summer high floatation equipment - 1 pass conventional/HARP and or CLAAG harvest	Transitions from productive forest to wetland
"Natural"	Leave unharvested - Natural succession "insects, fire, windthrow"					
"Extensive"	Clearcut/conventional/CLAAG - Leave 25 wildlife trees/ha >40% stocking to all species - Tend as required					Clear cut/CLAAG
- Slash management	Slash management for fire protection purposes only if adjacent to all weather roads					
- Tending	Site is typically ericaceous, tending may not be required	Promote conifer regeneration - high potential for Pj ingress	Promote hardwood regeneration and advanced conifer regeneration	Site is typically ericaceous, tending may not be required	Site is typically ericaceous, tending may not be required	Tend as required
"Basic" <1.6 km from an all-weather road	Clear cut/conventional/ CLAAG - Leave 25 wildlife trees/ha >60% stocking to all species	Clear cut/conventional - Leave 25 wildlife trees/ha – C/MSIP - Plant 1500-2000 stems/ha >60% stocking	Clear cut/conventional one pass conifer and hardwood-leave 25 wildlife trees - CSIP - Mixedwood strategy - Plant 1500-2000 stems/ha >60% stocking	Clear cut/conventional/HARP/CLAAG - Leave 25 wildlife trees - Plant only on sites < 30 cm organic depth or aerially seed "WINDOWS" >60% stocking	Clear cut/conventional/HARP/CLAAG - Leave 25 wildlife trees - Plant 1000-1500 stems/ha or aerially seed >60% stocking	
- Slash management	Slash management for fire protection purposes only if adjacent to all weather roads					
- Site preparation	Harvest	Promote scarification during harvesting	CSIP conifer dominated sites - Duff layer <10 cm	Full tree harvest	Full tree harvest	
- Regeneration	Pj aerial seeding (SMR 2-3) or Sb aerial seeding (SMR 3-6)	Pj aerial seeding @30-50,000 seeds/ha (SMR 2-3)	Plant 1500-2000 Sb/Sw/Pj stems/ha "Room for aspen ingress"	Sb aerial seeding @100,000 seeds/ha if > 30 cm organic depth	HARP - Uneven aged lowland Sb -stems to be retained generally between 10-14 cm	
- Tending	Tend as required -ericaceous "herb poor" site is typically, tending may not be required	Tend as required - Herb poor" aerial herbicide - glyphosate @1.5-2.0 kg/ha	Tend as required - Aerial herbicide broadcast application - glyphosate @1.5-2.0 kg/ha	Tend as required -Ericaceous site, nutrient poor, tending not generally required	Tend as required - Ericaceous site, nutrient poor, tending not generally required	

Table 3. Strategic silviculture options for 5 ecosites managed on the Romeo-Malette Forest (ecosite classification is based on Taylor *et al.* 2000) (*con't*)

Northeast Standard FU	SP1	PJ1	BW1/MW3	SB1/SP1	SB1	BOG
"Intensive" < 50 km from a mill facility		Clearcut/conventional aggregate wildlife trees - C/MSIP - Plant 2000-2400 stems/ha improved stock >80% stocking - Tend as required - CT	Clearcut/conventional 1 pass conifer & hardwood/ aggregate wildlife trees - C/MSIP- Mixed wood strategy - Plant 2000-2400 stems (SB7SW3)/ha improved stock >80% stocking - Tend as required - CT	Clear cut/aggregate wildlife trees - C/MSIP - Plant 2000-2400 stems/ha improved stock >80% stocking only on sites <30cm organic depth - Tend as required - CT		
- Slash management		Slash management for fire protection purposes and microsite creation i.e. upland sites where artificial regeneration is going to take place				
- Site preparation #1		Light MSIP	Glyphosate CSIP 2 growing seasons after disturbance	CSIP conifer dominated sites - Duff layer < 10cm		
- Regeneration #1		Pj aerial broadcast seeding @ 50,000 viable seeds/ha	Plant 2000-2400 improved Pj/Sb with Sw (max 30%) stems/ha	Plant 2000-2400 Sb stems/ha if < 30cm organic depth		
- Tending		"Herb poor" aerial herbicide - glyphosate @ 1.5-2.0 kg/ha	Aerial herbicide broadcast application - glyphosate @ 1.5-2.0 kg/ha			
- Stand improvement		PCT seeding areas to 1,800 stems/ha	Additional glyphosate application as required			
"Elite" < 20 km from a mill facility		Clearcut/conventional aggregate wildlife trees - C/MSIP - Plant 2500 - 3000 stems/ha improved stock >80% stocking - Tend as required - CT	Clearcut/conventional one pass conifer and hardwood/aggregate wildlife trees- C/MSIP - Mixedwood strategy - Plant 1000 stems Sw/ha with aspen >80% stocking - Tend as required - Manage sawlog products	Clear cut/aggregate wildlife trees – CSIP- Plant 2500-3000 stems/ha improved stock > 80% stocking - Tend as required - CT		
- Slash management		Slash management for fire protection purposes, microsite creation and biomass opportunities i.e. upland sites where artificial regeneration is going to take place				
- Site preparation #1		Mineral soil exposure - B&C/disc trenching/Bracke	Chem-mechanical mulching in corridors	Chemically site prepare conifer dominated sites - Duff layer < 10 cm		
- Regeneration #1		Pj aerial broadcast seeding @50,000 viable seeds/ha	Plant 1000 Sw stems/ha in treated corridors adjacent to aspen	Plant 2500-3000 improved Sb stems/ha		
- Tending		"Herb poor" aerial herbicide - glyphosate @1.5-2.0 kg/ha	Tending as required - 2,4-D for mixed wood/glyphosate for conifer	Aerial herbicide broadcast application - glyphosate @1.5-2.0 kg/ha		
- Stand improvement #1			PCT seeding areas to 1800 stems/ha	Additional 2,4-D/glyphosate application as required	PCT seeding areas to 1,800 stems/ha	

Several options exist for Intensive and elite treatments; however, we've limited the presentation to option #1 because of limitations on available space.
Seeding rates and planting densities to be adjusted to account for expected levels of ingress.
Pj – jack pine, Sw = white spruce, Sb = black spruce
HARP = Harvest around regeneration potential, CLAAG = Careful logging around advanced growth, MSIP = mechanical site preparation, CSIP = chemical site preparation, PCT = pre-commercial thinning, CT = Commercial thinning

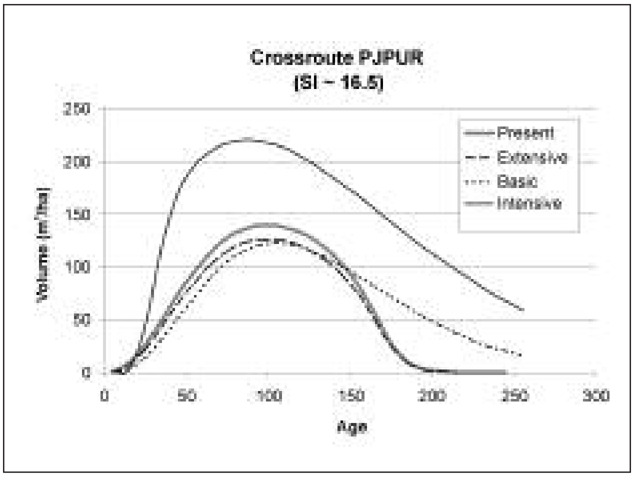


Fig. 3. Draft intensity-based empirical yield curves for merchantable volume for the pure jack pine forest unit (PJPUR) on the Crossroute Forest in northwestern Ontario, assuming a site index (SI) of 16.5 m and equivalent regeneration delay (Source Crossroute Forest Management Plan).

tions about (i) forest development, (ii) treatment costs, (iii) response to treatments, and (iv) expected success rates are clearly stated (OMNR 2004b).

Forest development

Assumptions about forest development are expressed in terms of growth and yield curves (see Penner *et al.* 2008, this issue). Silvicultural effort that is successful in establishing fully stocked single- or mixed-species stands has the potential to produce merchantable volume sooner, and possibly even increase merchantable yield of desired species (Fig. 3).

In Ontario, forest growth and yield is modelled using SFMM, which uses yield curves that describe changes in merchantable volume with age. Growth and yield models are generally sensitive to site productivity, species, management intensity, and utilization standards. As a result, the CEC-FRP sponsored the development of new stand- and tree-level growth and yield models that encompass these factors (Penner *et al.* 2008, this issue; Sharma *et al.* 2008, this issue). Those labelled with higher levels of management (or silviculture) intensity rise to their maximum merchantable yield sooner, and tend to achieve higher maximum yield. Site quality (as measured by site index[12]) is a key determinant of shape for these curves, but because SFMM is an aspatial model, a single average site index is generally used for all intensities within a given forest unit across a management unit. We draw upon an example from the Crossroute Forest (~1.6 million ha in northwestern Ontario) (Fig. 4). Although not one of the 6 CEC-FRP forests, the example is applicable. For the jack pine pure forest unit all modelled intensities use a site index of 16.5 m. To allow more site-specific calculations, research is underway to develop growth intercept models that will help to assign young plantations to actual rather than average site indices (Sharma *et al.* 2008, this issue).

It is recognized that not all silvicultural interventions will achieve the intended result. Based on data (where available) and/or the opinions of the planning team members and their advisors, the frequency with which a particular yield curve/forest unit combination will be achieved is included in the model. For example, where a particular silvicultural treatment is designed to achieve the basic curve for a jack pine-dominated forest unit, the model can be modified to reflect the anticipated results: the planning team can assign 70% of the area treated to the basic curve, 10% to an intensive curve, and the remaining 20% to a mixedwood extensive curve within SFMM. This approach allows generic yield curves to be used that reflect the anticipated impact of the strategic silviculture options described in forest management plans.

Treatment costs

The financial return on investment from intensive silviculture is deemed negligible except on very productive sites (Benson 1988, Willcocks *et al.* 1990, Adamowicz *et al.* 2003). To remain competitive, forest managers must produce high-value wood products as inexpensively as possible. Benson (1988) advocated the use of extensive practices as their inherent lower costs keep wood and stumpage costs low. However, extensive practices are also associated with longer rotations, higher incidence of mixed species composition, variable densities, and thus variable quality. Benson's argument was based on a stand-level analysis and assumed much longer rotations for intensive silviculture than is currently assumed necessary.

In Ontario, forest renewal charges are based on volume harvested, are prorated by species, and, in the case of white pine, red pine, and hardwoods, by quality (Fig. 4). Charging a single rate for most species and wood qualities effectively provides incentive to use the least expensive strategic silviculture options to renew the forest. Reduced renewal charges can and have been negotiated, which has led to large discrepancies in renewal charges across forest management units for some species (Fig. 4). These discrepancies may or may not be related to differences in intensity and/or renewal standards.

Monitoring of treatment effectiveness (response to treatments and expected success rates)

Forest management success rates can only be determined through systematic monitoring that includes the collection of reliable data. In Ontario, under the forest management planning manual (OMNR 2004b), forest managers are required to assess and report on the success of their regeneration efforts to ensure that the obligations and silviculture standards outlined in a forest management plan are met. Environmental Assessment Term and Condition (T&C) 96 provides broad direction on how the work is to be done, specifically "information on success and failure, and more important, the reasons for those successes and failures must be available on a consistent basis across the province…" and "… in order to track silviculture effectiveness, a mechanism is needed to trace the results of prescriptions back to the initial action taken" (OMOEE 1994). In 2002, recognizing that silviculture is the responsibility of the sustainable forest license holders (SFLs), the Ontario Ministry of Natural Resources (OMNR) recommended that T&C 96 be replaced with Condition 29 (OMNR 2002b). Based on Condition 29 of the Declaration Order MNR-71 (OEAB 2003), OMNR was mandated to ensure that silviculture effectiveness monitoring continues and to provide direction for systematic reporting of the results. That direction is to include: *(a) a description of the*

[12]Height of dominant trees at 50 years breast height age.

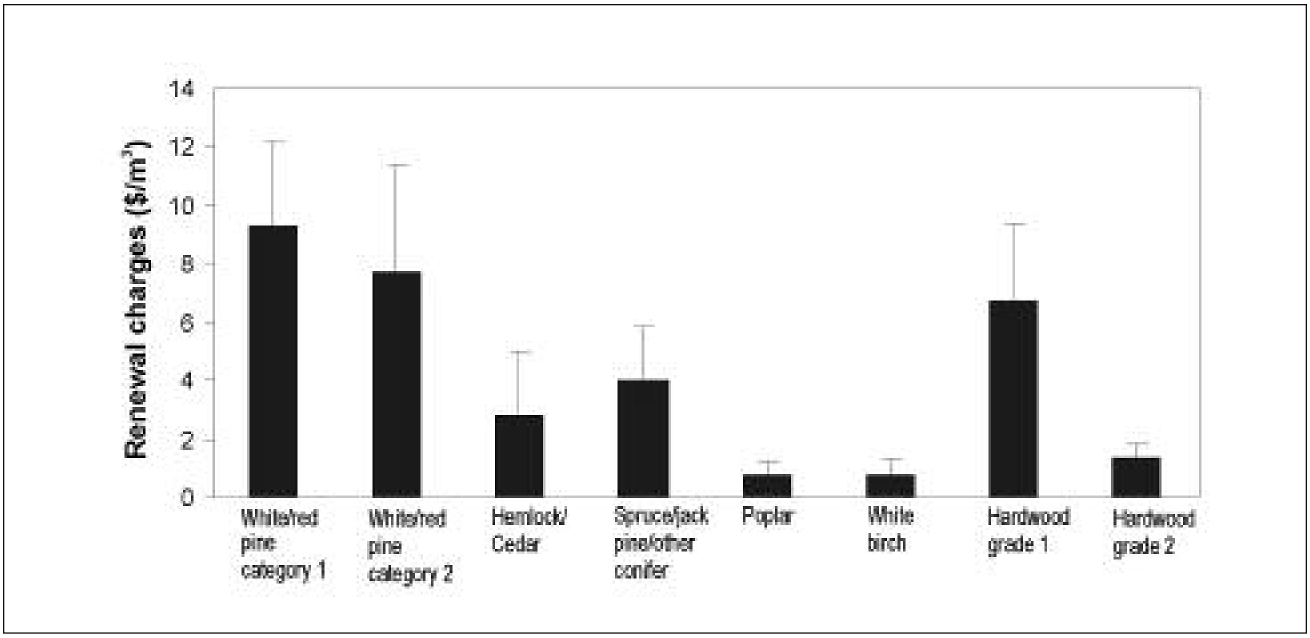


Fig. 4. Forest renewal charges for 49 forest management units in Ontario as of March 31, 2007 (Data source: OMNR 2008). Shown are means and standard deviations.

standards and acceptable assessment methodologies that ensure the appropriate linkages among the silviculture guides, silvicultural ground rules, project records, assessment and forest resource inventory updating; (b) a description of the timing of monitoring activities and the systematic reporting of the results to the general public; and (c) requirements for the maintenance of silvicultural records and analysis, and the evaluation of the effectiveness of the silvicultural activities. Information provided by SFLs is used to track the number of hectares harvested, the number of hectares treated (including planting, seeding, site preparation), and the number of hectares declared free-to-grow (FTG; free from overtopping competition). The Silvicultural Effectiveness Monitoring Manual for Ontario (OMNR 2001) describes the detailed methods that can be used to evaluate FTG status and will be used to resolve disputes.

When an area is assigned to a specific forest unit and yield curve within a forest management plan, the planning team also agrees to renewal standards. These standards are described within silvicultural ground rules (SGRs) that include specifications, standards, and other instructions to direct silvicultural activities on a management unit during the period of the forest management plan (OMNR 2004b). The determination of whether or not the intent of an SGR has been met is made through FTG assessments. However, OMNR does not require a licensee to report the results of FTG surveys for individual stands. Licensees are only required to report total areas managed (e.g., area harvested, treated, or declared FTG) within an SFL. At present, there is no requirement for quantitative data to be collected or reported on a stand-by-stand basis. Stocking, density, and species composition are not reported at the FTG stage. Many licensees employ ocular surveys, even for areas that are modeled using the intensive yield curve. Though some SFLs have very good treatment records, it is sometimes difficult to trace the results back to the initial prescriptions or actions taken. It is difficult to identify the reasons for failures where they occur as failures are generally not reported. At present, there is also no requirement for monitoring beyond the FTG stage. As a result, quantitative data that could be used to confirm (or deny) the achievement of growth projections used in forest management plans are not available. As a result, it is unclear whether Ontario's monitoring programs are sufficient to evaluate the effectiveness of silvicultural practices accurately.

The intensity-based yield curves are derived using data from permanent plots established in managed stands. The inherent assumption is that the results of past practices can be repeated. It is important to note that the permanent plots are established after the stands reach 20 years of age, which means monitoring silvicultural practices that were used over 20 years ago. There have, however, been substantial changes in the techniques (planting density, scarification) and technology (improved stock, herbicide) used in plantation establishment in recent decades (Sharma *et al.* 2008, this issue).

The process used to establish renewal standards during the development of each new forest management plan is also a concern. Based largely on historical precedent, the minimum height requirement for conifer stands is generally 1 m and 40% stocking is the typical minimum for a boreal conifer stand to be declared FTG for all silviculture intensities across all forest units (Table 4). It is unclear whether projected differences in growth and yield can be achieved when similar minimum renewal standards are used for all intensities. Hearnden *et al.* (1992) found that where only 40% stocking was achieved, open, poorer-quality, low-volume, mixed-species stands tended to develop. It is thus difficult to determine whether or not future yield objectives will be met with an acceptable degree of certainty (Buda and White 2007).

To address uncertainties regarding the effectiveness of silviculture within an adaptive management approach to forest management, renewal standards must be objective-based, have measurable responses, and not limited to the period between harvest activities and when regeneration meets the renewal standard (i.e., FTG). In response, OMNR is in the

Table 4. Representative renewal standards for the jack pine 1 forest unit (PJ1)[a] by management intensity from recent forest management plans in Ontario's northeast administrative region, and a possible approach to renewal standards by intensity

Intensity	Existing PJ1 renewal standards		Possible approach to renewal standards						
			Stand-level objectives		Metrics				
	Stocking	Well-spaced free-growing (#/ha)	First commercial harvest	Acceptable species	Min. density (#ha)	Density of all species (#ha)	Regeneration delay (years)	Height at free-to-grow (m)	Years to reach free-to-grow
Extensive	0.4–0.5	1000–1330	regular rotation	several	low	minimum + (no max.)	a few	1.0	up to a decade
Basic	0.4–0.5	1000–1330	shorter rotation	fewer	medium	higher (broad range)	fewer	1.0	fewer
Intensive	0.4–0.5	1000–1330	1st thinning (and shorter rotation)	1 or 2	high	highest (narrow range)	none	taller	fewest

[a]PJ1 – Jack pine working group

process of reviewing existing renewal standards and silvicultural effectiveness monitoring efforts. One possibility is that new provincial minimum renewal standards will be developed that are species-, site-, and intensity-specific. An example of what intensity-based renewal standards may look like is provided in Table 4. Regenerating stand characteristics associated with strategic silviculture options that can be reliably assessed should assist forest managers in planning for and monitoring treatment outcomes as well as communicating their intentions and achievements to stakeholders. We recommend that the provincial silvicultural effectiveness monitoring program be enhanced so that the data are more objective (i.e., statistically defensible) and the process adaptable, particularly for areas assigned to higher yield curves. Surveys that include quantitative and qualitative data of areas declared FTG, as well as growth performance and stand condition beyond the FTG stage will provide the data needed to link renewal standards to future growth and yield. The collection and analysis of height growth data in managed stands will be of particular importance since management activities are known to influence height growth, particularly for conifers (Sharma *et al.* 2002, Huang *et al.* 2004). Permanent growth plots can also be used to monitor stand development in juvenile stands and to provide a benchmark for natural forest conditions, including forest structure, soil fertility, and relation to soil moisture and nutrient regime gradients, against which to contrast treatment responses (Sharma *et al.* 2008, this issue).

An active adaptive management approach that uses reliable data collected with standard quantitative sampling methodologies is likely the most efficient means to determine success rates. At the time of writing, a monitoring program that reflects the intent of silvicultural intensities is being considered, and is expected to be in place by 2009 following the implementation of Tembec's most recent forest management plans. We recommend that the approach to silvicultural effectiveness monitoring incorporate natural controls (Weetman 1996) and controlled experiments to help illuminate the causes of success and/or failure.

Under condition 31 of the OEAB (2003) declaration order 71, OMNR is required to maintain a program of scientific studies to assess the effectiveness of guides. The 1999 IFM science workshop participants recommended that priority be given, wherever possible, to larger multidisciplinary studies backed by a solid research team, since these types of studies are more cost-effective and synergistic in generating long-term, multivariate, multidimensional data than are smaller single-problem-focused studies (Bell *et al.* 2000). Also recommended was that new studies should apply a common suite of treatments across different species and site types. The CEC-FRP partners have implemented these kinds of controlled experiments (Bell *et al.* 2008, this issue, McPherson *et al.* 2008, this issue) and are actively engaged in the NEBIE plot network, wherein the full suite of silvicultural intensities is being applied across a broad range of forest units in large (100 m ? 200 m) plots ensuring that treatments could be applied in an operational manner. Site and management intensity specific prescriptions are being implemented by forest industry partners. In addition, large plot (i.e., greater than 500 ha) experimental installations of intensive silviculture have been established on the Gordon-Cosens, Romeo Malette, and Nipissing SFLs (McPherson *et al.* 2008, this issue). The combination of the NEBIE plot network and large plot experimentation will help the partners understand the factors that contribute towards silviculture success or failure. They are also indicators that an active adaptive management approach is already being considered (Baker *et al.* 2008, this issue).

Summary

Ontario's forest management planning process requires that strategic silvicultural options (i.e., groups of silvicultural treatments that exhibit similar characteristics including initial forest unit, silvicultural intensity, expenditures, and growth projections) be defined. For each option, forest managers must identify: (1) the forest unit(s) to which it applies, (2) associated assumptions (forest development, treatment costs, response to disturbance, and expected success rates), and (3) extent to which it can be applied on the forest management unit. The NEBIE framework and definitions provide an approach whereby the effects of management activity of forest growth and development can at least partially be captured.

Ideally, forest managers would monitor the development and thus project the growth and yield of each forest stand; however, this kind of monitoring program is not possible given the financial realities of forest management in Ontario. Instead, growth and yield models are generated for combinations of species, ecosite, and management (or silviculture) intensity and assigned to forest areas. One of the difficulties in this process has been the assignment of silviculture intensity, due in part to a lack of common definitions. To reduce this uncertainty, we have reviewed the factors affecting forest productivity and yield and historical use of terms, developed a framework for classifying management practices, and proposed definitions for natural disturbance, as well as extensive, basic, intensive, and elite silviculture. We have described how the NEBIE framework and definitions can be incorporated into forest management planning in Ontario. This framework provides a starting point, or hypothesis, which can be continually refined through adaptive management using systematic monitoring designed to test the assumptions. By taking this approach, the NEBIE framework offers an opportunity to ensure that forests are managed sustainably, and that the benefits of silviculture are recognized. Without the systematic collection and analysis of reliable data through monitoring, however, this approach is nothing more than an elegant and well thought out hypothesis.

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Appendix A

The need to categorize forest practices by level of intensity was proposed as early as 1950 when the Allegheny Section of the Society of American Foresters published the following definitions (Chapman 1950, pp. 558–565):

Intensity "A" management practices included the most intensive methods which can be applied in order to obtain the highest profitable production on the area. It will require the marking of individual trees for cutting and necessitate supervision by technical foresters. In order to obtain maximum production of high-quality material it may be necessary to make thinnings and improvement cuttings in the young stands before it is possible to obtain any revenue from such cuttings. Cutting should be made if the cut material will pay for the labor or when the investments in labor will increase the value of the stand to such an extent that the added later return will pay back this capital investment with compound interest.

Intensity "B" management practices. The second highest order of intensity will also require considerable supervision by technical personnel. The amount cut in each operation will be somewhat greater, making each cutting cycle longer. Areas managed under INTENSITY "B" management practices will not be suitable for long-term investments such as planting, cleanings, improvement cuttings and thinnings which will not pay for themselves. However, if the products removed will pay for the labour of cutting, such operations may still be included in this intensity.

Intensity "C" management practices. This intensity imposes only limited restrictions on the cutting operations such as leaving a scattered residual stand and cutting to certain diameter limits. No intensive practices such as marking trees for cutting or improvement thinnings will take place, since it will require too high an investment. A certain limited amount of management may be employed such as marking trees to be left in cutting operations.

Economists, silviculturalists, forest pathologists, and other specialists have continued to modify these definitions based on their particular area of interest. Between 1950 and 1960, forest management intensities started to be coined as extensive, basic, and intensive forest management (Duerr 1960). By 1978, these terms had become part of the forestry lexicon across Canada. Reed and Associates (1978) presented them as follows:

Extensive forest management: Using Duerr, in extensive management the ratio of variable to fixed inputs is low. In other words, nature is left to produce or reproduce a timber crop with little or no assistance from the forest land manager.

Basic forest management: Somewhere in between extensive and intensive there may be a place for "basic" forest management. In Canada (at that time) this usually included standard protection activities together with some assistance in artificial regeneration. It has as its objective the maintenance of the resource and accomplishes that by keeping within the allowable cut and by ensuring regeneration of commercial tree species on all depleted areas. Any treatment beyond basic management is, by definition, more intensive management.

Intensive forest management: "that which combines a large quantity of variable inputs with the fixed output" (Duerr 1960). The fixed input is the forest land base and the variables are treatments. Implied in this definition is an objective of intensive forest management which might be expressed as raising, over time, the average net growth and yield from a given area to a level above that which nature could achieve unaided.

The full complement of NEBIE definitions was introduced by OMNR in 1986 and soon incorporated into forest management planning via the white pine silviculture guides (OMNR 1986, 1989; Hodge *et al.* 1989). By 1995, the elite term had been dropped and other terms further modified by NRCan (1995) as:

Extensive forest management: Protection from fire and insects; reliance on natural regeneration.

Basic forest management: Extensive forest management plus artificial regeneration where necessary. cf. extensive forest management

Basic silviculture: All the silvicultural practices required to achieve free-growing (or established) regeneration of desired species at specified densities and stocking.

Intensive forest management: Basic forest management plus juvenile-stand improvement plus acceleration of artificial regeneration.

Intensive silviculture: Application of cultural measures which, in addition to simply maintaining the forest cover, will allow an increase in the value or volume of the cut. The term incremental silviculture is defined in the British Columbia Forest Act and thus "intensive silviculture" is no longer used there. In Ontario, intensive silviculture may be considered to include plantation establishment, e.g., using genetically improved planting stock; intensive site preparation, such as spraying herbicides to reduce competing vegetation before mechanical preparation; and manual weeding of plantations at early stages.

The above definitions were incorporated into more recent definitions by Dunster and Dunster (1996), Côtè (2000), and Park and Wilson (2007). Although OMNR continues to incorporate intensity classes into silviculture guides (OMNR 1997), the terms were further modified as follows:

Extensive: i.e., natural regeneration

Basic: i.e., assisted natural: cone scattering, scarification and direct seeding

Intensive: i.e., site preparation, planting, vegetation management, natural and pre-commercial thinning

Highly intensive: i.e., site preparation, vegetation management, natural and pre-commercial thinning with multiple tendings and cleanings