The NEBIE plot network: Background and experimental design

by F. Wayne Bell^{*1}, Margo Shaw², Jennifer Dacosta¹ and Steven G. Newmaster³

ABSTRACT

The Intensive Management Science Partnership: NEBIE Plot Network is a stand-scale, multi-agency research project designed to compare the ecological effects of a range of silvicultural treatments in northern temperate and boreal forest regions of Ontario. The NEBIE plot network was established in 2001 with randomized complete block experiments installed at eight sites. The NEBIE acronym stands for Natural disturbance, and Extensive, Basic, Intensive, and Elite silviculture. Each NEBIE treatment was replicated at least three times at each site, using large experimental units (2-ha plots).

The NEBIE plot network provides researchers with an opportunity to conduct long-term scientific studies at multiple scales and disciplines. The operational-scale treatment plots allow assessment of a variety of forest values in a context directly relevant to informing forest planning and management. In this paper, we document the experimental design and describe the sites and silviculture treatments. Information about sampling designs is provided, along with preliminary results, in a companion paper published in this edition of *The Forestry Chronicle*.

Keywords: forest research, silviculture, sustainable forest management

RÉSUMÉ

Le réseau de placettes NEBIE de l'*Intensive Management Science Partnership* (partenariat scientifique sur l'aménagement intensif), est un projet de recherche à l'échelle du peuplement regroupant plusieurs organismes et destiné à comparer les effets écologiques d'une gamme d'interventions sylvicoles dans les régions tempérée et boréale de l'Ontario. Le réseau de placette NEBIE fut mis en place dès 2001 et comporte des dispositifs expérimentaux en blocs aléatoires complets situés à huit endroits différents. L'acronyme NEBIE signifie *Natural disturbance, and Extensive, Basic, Intensive, and Elite silviculture* (Perturbations naturelles, traitements de sylviculture extensifs, primaires, intensifs et élite). Il y a au moins trois répétitions pour chaque traitement NEBIE sur des blocs expérimentaux importants (placettes de 2 ha).

Le réseau de placettes NEBIE donne aux chercheurs la possibilité de réaliser des études qui s'étendent sur de longues périodes de temps à plusieurs échelles et englobant une multitude de disciplines. Les placettes de traitement à l'échelle opérationnelle se prêtent bien à l'évaluation d'une variété de valeurs forestières dans un cadre particulier qui aideront à apporter des réponses aux questions des planificateurs et des aménagistes. Cet article présente les dispositifs expérimentaux, les stations ainsi que les interventions sylvicoles. On trouvera plus de renseignements sur le plan expérimental et les résultats préliminaires dans un autre article de ce numéro du *The Forestry Chronicle*.

Mots-clés : recherche forestière, sylviculture, aménagement forestier durable

Introduction

In ecology, large-scale, long-term experiments are considered an essential means for advancing science and improving policies and management (Carpenter 1998). Relevant spatial and temporal contexts are designed into such experiments; thus, results can be directly interpreted at appropriate spatial and temporal scales of management (Carpenter 1998). Large-scale plots help ensure that treatments more closely emulate forest operations and long-term assessments ensure that slow dynamics, high variability, subtle processes, and complex phenomena are accounted for (Franklin 1989).

During the past three decades, several long-term studies were initiated in northern temperate and boreal forests in response to contentious resource management debates such as clearcutting and herbicide use. For example, the *Fallingsnow Ecosystem Project* was initiated in 1993 to com-

pare conifer release alternatives in response to concerns about aerial application of herbicides in Ontario (Lautenschlager *et al.* 1998). The *Ecosystem Management Emulating Natural Disturbance* (EMEND) project, started in 1998, is a large-scale variable retention harvesting experiment designed to test effects of residual forest structure on ecosystem integrity and forest regeneration at forest stand-scale in response to concerns about lack of structural diversity following clearcutting (Volney *et al.* 1999). The *Stand Level Adaptive Management* (SLAM) project, initiated in 2001, is another example of a large-scale variable retention harvest experiment. SLAM was designed to develop sustainable mixedwood practices in boreal forests (MacDonald *et al.* 2003). More recently, Urli *et al.* (2017) studied a large plot network using the NEBIE framework (Bell *et al.* 2008) to classify harvesting and silvicultural treatments into silviculture intensities. Their study

¹Ontario Forest Research Institute, Ontario Ministry of Natural Resources, Sault Sainte Marie, Ontario; *corresponding author: wayne.bell@ontario.ca

²Manitoba Environmental Industries Association (MEIA), Winnipeg, Manitoba

³Centre for Biodiversity Genomics, Biodiversity Institute of Ontario (BIO), University of Guelph, Guelph, Ontario

was originally established to determine the effects of careful logging around advanced growth. In addition to these operational studies, numerous smaller-scale studies, such as the *International Diversity Experiment Network with Trees* (IDENT) (Tobner *et al.* 2014), were initiated to advance knowledge about specific aspects about forest practices on forest ecosystems. Although many studies have been conducted and the results published in the literature, considerable uncertainty remains about the effects of intensification of silviculture (Bell *et al.* 2000).

In the late 1990s, a need for a large-scale, long-term study to determine the effects of intensification of silviculture in northern temperate and boreal forests of Ontario was identified. This need was identified after the Ontario government expanded its network of parks and protected areas. Intensive forest management (IFM) was proposed as a means to offset the loss of fibre production resulting from the withdrawal of land available for forestry (OMNR 1999, OFAAB 2002). Concerns were raised about conservation of biological diversity, maintenance of productive capacity and forest ecosystem health and vitality, conservation and maintenance of soil and water resources, and maintenance and enhancement of long-term multiple socio-economic benefits, and the feasibility of sustaining these multiple values under an intensive forest management program (see Bell *et al.* 2000). These concerns echoed those raised in other jurisdictions. For example, Roberts and Gilliam (1995) suggested that experiments should be established to predict the effects of silvicultural practices on species diversity to identify treatments that could lead to localized plant extinctions.

A careful analysis of reviews by Kimball and Hunter (1990) and Lieffers *et al.* (2003) will reveal that many studies have been conducted to determine the effects specific silviculture treatments (e.g., site preparation, vegetation management, or thinning) on forest ecosystems but not silviculture intensities *per se*. To date, very few studies have been specifically designed to test the effects of intensification of silviculture on northern temperate and boreal forest ecosystems. Fu *et al.* (2007) and Wang and Chen (2010) studied the effects of intensification of silviculture on fibre production and tree diversity, respectively, using data from 20 m x 20 m plots. Thus, knowledge about the effects of intensification of silviculture on forest ecosystems has remained elusive.

In this paper we provide background information about the Intensive Forest Management Science Partnership: NEBIE plot network. NEBIE is a medium-scale, long-term experiment designed to improve our knowledge about the effects of intensification of silviculture on northern temperate and boreal forest ecosystems. More specifically, we (i) provide the rationale for the study, (ii) describe the experimental, treatment and plot designs, and (iii) document background information about each of the study sites. In the following paper (i.e., Bell *et al.* 2017) we provide highlights of long-term scientific studies.

The NEBIE Plot Network Background

In 2001, in response to a knowledge gap about the effects of intensification of silviculture on northern temperate and boreal forest ecosystems, the Ontario Ministry of Natural Resources and Forestry (OMNRF), forest industries, the

Canadian Forest Service (CFS), non-governmental organizations, universities, and forest industries partnered to design and implement the NEBIE plot network. This network is a stand-scale, multi-agency, experimental research project designed to improve understanding of the effects of intensification of silviculture on the overall sustainability—long-term health, diversity, and vigour—of northern temperate and boreal forests.

The NEBIE plot network is, to our knowledge, the only experimental project specifically designed to determine the effect of a range of silviculture intensities on northern temperate (commonly referred to as Great Lakes–St. Lawrence) and boreal forest ecosystems. The NEBIE plot network was initiated after a review of international conventions as well as Ontario forest policies and discussion papers, the Crown Forest Sustainability Act, Timber Class Environmental Assessment, Ontario Forest Accord, and proceedings of the IFM science workshop (Bell *et al.* 2000). The NEBIE acronym refers to the intensity of the silvicultural treatments, Natural (unharvested) and, in order of increasing stocking levels from 40% to 80%, Extensive, Basic, Intensive, and Elite (Bell *et al.* 2008) as described in Table 1.

The goal of the NEBIE plot network is to reduce uncertainty related to managing emerging issues including: (1) maintaining or enhancing fibre quantity and quality; (2) enhancing carbon sequestration; (3) maintaining forest ecosystem health and vitality and soil and water resources; (4) conserving biological diversity; (5) maintaining or enhancing stand composition and structure for wildlife habitat; (6) reducing the risk of losses to natural disturbances (fire, herbivory, insect, disease, and severe weather); and, (7) maintaining or enhancing long-term multiple socio-economic benefits to meet the needs of society. The objectives of the NEBIE plot network are to:

- Determine the effects of natural disturbances and silvicultural practices on a full range of tree responses: species and genetic diversity, physiology, survival, growth, and product/wood quality
- Determine the effects of silvicultural practices on a range of abiotic environmental factors: microclimate, soil moisture, nutrient cycling, floral diversity, and wildlife habitat (vegetation structure and composition)
- Develop an accurate, defensible database that can be used with other research and monitoring information to calibrate stand-scale models that will accurately forecast allowable cut, and ecological and economic viability

Experimental design

The NEBIE plot network was originally designed to include eight independent, randomized, complete block experiments referred to as NEBIE sites near Sioux Lookout, Dryden, Thunder Bay, Wawa, Kapuskasing, Timmins, North Bay, and Petawawa, Ontario (Fig. 1). At each site, a range of forest management intensities were applied as treatments (Fig. 2). Treatments (i.e., silviculture intensities; see Table 1 for descriptions) were replicated four times on each site. Several areas in the plot network were not harvested as intended, resulting in fewer than the planned four replications. The North Bay site was reduced to three replications; the Thunder Bay and Wawa sites have one replication. Experimental plots of each treatment measure 100 m x 200 m (2 ha) including a

Table 1. Objectives and criteria for success for the range of silviculture intensities applied in the Ontario NEBIE plot network [adapted from Bell *et al.* 2000, Park and Wilson 2007, and Bell *et al.* 2008]

Intensity	Objective(s)	Criteria for success
Natural (N)	<ul style="list-style-type: none"> No human interventions 	Forest ecosystem responds (e.g., to fire, insects, and disease) without human interventions
Extensive (Ex)	<ul style="list-style-type: none"> Manipulate species composition 	Stocking of desired tree species is greater than 40% and desired tree species are free of major insect pests
Basic (B)	<ul style="list-style-type: none"> Manipulate species composition Achieve full site occupancy 	Stocking of desired tree species is greater than 60% and desired tree species are free of inter-specific competition and major insect pests
Intensive (I)	<ul style="list-style-type: none"> Manipulate species composition Achieve full site occupancy Control density to optimize individual tree growing space 	Stocking of desired tree species is greater than 80% and desired tree species are free from inter- and intra-specific competition and major insect pests
Elite (El)	<ul style="list-style-type: none"> Manipulate species composition Achieve full site occupancy Control density to optimize individual tree growing space Achieve higher product value, and/or ameliorate site productivity 	Stocking of desired tree species is greater than 80% and desired tree species are free from inter- and intra-specific competition, nutrient deficiencies, and major insect pests

Fig. 1. Location of the NEBIE plot network sites within Ontario, Canada.

Extensive

Basic

Intensive

Elite

Fig. 2. Illustration of silviculture prescriptions for the Dryden, Ontario (boreal mixedwood) site of the NEBIE plot network. (Each shift to the right represent and increment of about one decade). Thus the elite treatment could be commercial thinned and harvested in the 4th and 8th decade post-establishment, respectively.

20 m buffer zone (white squares in Fig. 3). To accommodate sampling needs, all experimental plots were divided into destructive and non-destructive sampling zones. To ensure that researchers would not be interfering with each other's work, 20 x 20 m sub-plots (grey squares in Fig. 3) were randomly assigned to specific types of monitoring (e.g., growth and yield, soils, biodiversity).

Treatment design

Site specific silviculture strategies that were hypothesized to achieve stand-scale objectives, e.g., enhancing fibre quantity, conserving biodiversity, maintaining soil and water quality, and contributing to economic development of each intensity level, were selected as treatments. Forest industry partners and researchers formulated detailed prescriptions using a crop planning approach (Day and Bell 1988, Willcocks *et al.* 1990). Several factors were considered when developing silviculture prescriptions including: (1) forest type, soils, and silviculture intensity; (2) species and genetic composition of the desired future stand; (3) availability of resources (light, nutrients, and water) to crop trees versus other vegetation that contributes to biodiversity and wildlife habitat; (4) protection

from fire, insects, disease, and severe weather; and, (5) utilization standards for desired future crop trees.

The clear cut and seed tree retention systems were applied to boreal conifer and boreal mixedwood stands, respectively. The shelterwood system (see Smith *et al.* 1997) was applied to northern temperate hardwood and northern temperate mixedwood stands (Appendix A). Attempts were made to retain biodiversity in all forests. For example, multiple species were planted: black spruce (*Picea mariana* [Mill.] B.S.P.), white spruce (*P. glauca* [Moench] Voss), and white pine (*Pinus strobus* L.) in elite treatments at Dryden, and Canada yew (*Taxus canadensis* Marsh.) at North Bay. Guidelines for emulating natural disturbance patterns (OMNR 2001), i.e., a minimum of 25 stems ha⁻¹ left unharvested (Fig. 3), were applied at all but the boreal conifer site. Residual strips and patches were retained during site preparation and release treatments. The use of artificial regeneration ensured near complete implementation of the regeneration phase of a silviculture intensity at most sites. However, implementation of natural regeneration on the Petawawa site was delayed due to late occurrence of an abundant seed crop (see Bell 2015 for details).

Fig. 3. Schematic of standard plot layout at all sites that illustrates post-harvest natural disturbance pattern emulation at the Kapuskasing, Ontario site.

Undisturbed forest plots are randomly located as a treatment within each block and referred to as natural disturbance or natural plots. The goal for the natural disturbance plots was to have a disturbance applied (i.e., prescribed fire) at the same time as the sites were being harvested to enable a comparison of results from the various silviculture options with those from forests regenerated following natural disturbance. However, disturbance was not implemented and the plots have been left untreated. These “controls” provide a reference for treatment effects and a baseline for resistance and resilience research.

NEBIE sites

The sites within the NEBIE plot network span 45° 58' to 50° 0' N, and 77° 26' to 92° 46' W, within a geographic area measuring 300 km north–south and 1100 km east–west. The sites are distributed across a broad climatic gradient in several forest types with differing natural disturbance regimes (Table 2). They include a northern temperate hardwood site near North Bay; a northern temperate mixedwood site near Petawawa; three boreal mixedwood sites near Timmins, Kapuskasing, and Dryden; and a boreal conifer site near

Sioux Lookout, Ontario. Due to operational constraints, the boreal hardwood sites near Thunder Bay and Wawa were not fully implemented.

Average daily temperatures in the study area range from 0.7 to 4.3° C and annual rainfall varies between 517 and 775 mm. Soils vary greatly among sites with depths ranging from 40 to >120 cm, average organic matter depth from 1.8 to 7.4 cm, and soil moisture regime from moderately dry to very moist. Effective textures, the substrate texture deemed to have the greatest influence on substrate moisture regime and drainage, were determined by field sampling in 2011. The effective soil textures are mainly sandy at the Sioux Lookout site, coarse loamy at the Dryden, Petawawa, and North Bay sites, clayey at the Kapuskasing site, and silty at the Timmins site.

Sioux Lookout

The Sioux Lookout site is located 35 km east of Sioux Lookout, Ontario (50° 01' N, 91° 28' W), on Crown land in the boreal forest region of Canada (Rowe 1972). In 2002 when the site was harvested, it was dominated by a 90-year-old jack pine (*Pinus banksiana* Lamb.) stand with a few pockets of black spruce. It was an even-aged, fire-origin stand classified

Table 2. NEBIE plot network site descriptions

	Sites							
	Sioux Lookout (SL)	Kapuskasing (Kap)	Timmins (Tim)	Dryden (Dry)	Petawawa (Pet)	North Bay (NB)	Thunder Bay (TB)	Wawa
Broad forest type	Boreal conifer	Boreal mixedwood	Boreal mixedwood	Boreal mixedwood	Northern temperate conifer	Northern temperate hardwood	Boreal hardwood	Boreal hardwood
Mean precipitation (mm) ^a	716.1	831.8	831.3	705.4	853.4	1007.7	764.6	1002.2
Mean rainfall (mm) ^a	517.2	544.6	558.1	565.8	651.4	774.6	565.7	727.4
Mean daily temp. (°C) ^a	1.6	0.7	1.3	1.8	4.3	3.8	2.3	1.7
Soil texture ^b	mS ₇ LcS ₁ LmS ₁ fS ₁	SiC ₅ C ₅	SiL ₇ Si ₂ SivfS ₁	LmS ₂ C ₂ L ₂ CL ₁ LfS ₁ SifS ₁ SiL ₁	L ₄ SiL ₂ SifS ₂ SimS ₁ mSL ₁	CL ₂ mS ₂ SifS ₁ mSL ₁ cS ₁ L ₁ SimS ₁ fS ₁	SiL ₆ SiCL ₂ L ₂	S ₁₀
Soil depth range ^c	moderately deep to deep	deep	moderately deep to deep	moderate to deep	moderate to deep	deep	moderately no data deep to deep	
Silviculture system	clearcut	seed tree with residuals	seed tree with residuals	seed tree with residuals	2 crown spacing shelterwood	1 and 2 crown spacing shelterwood	seed tree with residuals	seed tree with residuals

^aInformation obtained from Environment Canada website: "http://climate.weatheroffice.gc.ca/climate_normals/index_e.html" (accessed August 2011).

^bSoil texture codes: S-sand or sandy, Si-silt or silty, L-loam or loamy, C-clay, vc-very coarse, c-coarse, m-medium, f-fine, vf-very fine.

^cSoil depth classes (cm of mineral material): moderate >30 to 60 cm, moderately deep >60 to 120 cm, deep >120 cm;

as site class 2. The understory was mainly composed of black spruce, red-stemmed feather moss (*Pleurozium schreberi* (Brid.) Mitt.), blueberry (*Vaccinium myrtilloides* Michx. and *V. angustifolium* Ait.), and creeping snowberry (*Gaultheria hispida* [L.] Muhl. ex Bigelow).

Sandy soils over rolling bedrock with varying amounts of gravel and cobbles derived from esker and ground moraine landforms, (see Northern Ontario Engineering Geology Terrain Study [NOEGTs]), occur at the site. The effective texture is mainly medium sand, with areas of loamy coarse and medium sand, silty fine sand, and fine sand also occurring. The moisture regime is moderately dry with smaller areas of moderately fresh soil. The drainage class is rapid with very rapid and well drained soils less common. The humus form is mainly a moder, on average 5.8 cm thick (st. dev. 2.4 cm, n=20).

Dryden

The Dryden site is located approximately 30 km southeast of Dryden, Ontario (49° 38' N, 92° 46' W), on Crown land in the boreal forest region of Canada (Rowe 1972). In 2005 when the site was harvested, it was dominated by black spruce and trembling aspen (*Populus tremuloides* Michx.) ranging in age from 64 to 104 years. It was a combination of site class 1 and 2 stands, with minor components of other species including paper birch (*Betula papyrifera* Marsh.), white spruce, balsam fir (*Abies balsamea* [L.] Mill.), red pine (*Pinus resinosa* Ait.), and eastern white pine (*Pinus strobus* L.). Common species in the understory include mountain maple (*Acer spicatum*

Lam.), raspberry (*Rubus pubescens* Raf. and *R. idaeus* L. ssp. *strigosus* [Michx.] Focke), and red-stemmed feather moss.

The soil at this site is derived from glaciolacustrine and glaciofluvial deposits (Source: NOEGTs) and is highly variable due to the undulating bedrock that dominates the area. The most common effective textures at the site are loamy medium sand, clay, and loam. Moisture regimes range from moderately dry to very moist with a fresh regime most common. The site drainage, in order of most to least common, is imperfect, well-drained, very rapid, and moderately well-drained. The organic matter is on average 4.8 cm thick (st. dev. 2.6 cm, n=20) with a moder humus form.

Thunder Bay

The Thunder Bay site is located 75 km northwest of Thunder Bay, Ontario (Block 1 – 48° 47' N, 89° 53' W), on Crown land in the boreal forest region of Canada (Rowe 1972). Block 1 is included in the plot network as it was fully harvested in 2008; Block 2 was partially harvested and Blocks 3 and 4 remain unharvested. Tree species that occurred on Block 1 pre-harvest included trembling aspen, paper birch, balsam fir, spruce, and jack pine. The understory included mountain maple, wild sarsaparilla (*Aralia nudicaulis* L.), balsam fir, and bush honeysuckle (*Diervilla lonicera* Mill.).

Morainal deposits (Source: NOEGTs) over a bedrock knob influence the soil. The dominant effective texture is silty loam with silty clay loam and loam also present. The moisture regime at the site is fresh, with areas of moderately fresh and

very fresh regimes. The site is well-drained. On average the depth of organic matter is 1.6 cm (st. dev. 1.4 cm, n=5) with mor humus forms most common.

Kapuskasing

The Kapuskasing site is located approximately 45 km south-east of Kapuskasing, Ontario (49° 09' N, 82° 28' W), on Crown land in the boreal forest region of Canada (Rowe 1972). It was a mixed hardwood stand that established after an 1895 fire. Several tree species occurred on the site including balsam poplar (*Populus balsamifera* L.), trembling aspen, white spruce, paper birch, black spruce, and balsam fir. The understory included balsam fir, speckled alder (*Alnus incana* subsp. *rugosa* [Du Roi] R.T. Claus.), red raspberry, and large-leaved aster (*Eurybia macrophylla* [L.] Cass.).

Overall, the soil is fairly uniform, representing conditions typical of glaciolacustrine plains and ground moraine land-forms (Source: NOEGTS) in the northeastern Ontario clay belt. The effective textures at the site are calcareous silty clay and clay. The site ranges from very fresh to very moist with very fresh and moist being the most common conditions. The drainage class is moderately well and imperfect. Moder and mor humus forms are present with an average organic matter depth of 7.4 cm (st. dev. 5.5 cm, n=20).

Timmins

The Timmins site is located approximately 15 km south of Timmins, Ontario (48° 21' N, 81° 18' W), on Crown land in the boreal forest region of Canada (Rowe 1972). When the site was harvested in 2002, the stand age was 85 to 90 years, with tree species including trembling aspen, white spruce, paper birch, balsam poplar, balsam fir, black spruce, and jack pine. Common species in the understory included large-leaved aster, beaked hazelnut (*Corylus cornuta* Marsh.), speckled alder, and raspberry. Generally uniform, deep silty soils derived from a glaciolacustrine plain (Source: NOEGTS) are present.

Silty loam is the most common effective texture with areas of silt, silty fine and very fine sand, and silty clay loam also occurring. There are many clay lenses at depth. Moisture regimes range from moderately fresh to very moist, with fresh and moderately moist conditions most common. The site is mainly imperfectly drained with well and moderately well-drained areas also present. The organic matter is on average 3.1 cm deep (st. dev. 2.5 cm, n=20) when present, with mull and moder humus forms.

Wawa

The Wawa site is located approximately 70 km southeast of Wawa, Ontario (Blocks 1 and 2 - 47° 47' N, 84° 20' W, Blocks 3 and 4 - 47° 40' N, 84° 27' W), on Crown land in the transition between the boreal and Great Lakes-St. Lawrence (GLSL) forest regions of Canada (Rowe 1972). The site is a mixed-wood stand. This site is not being assessed as part of the NEBIE plot network because Block 1 was only partially harvested in 2002 and all other blocks remain unharvested. Common tree species found on the site include paper birch, sugar maple (*Acer saccharum* Marsh.), red maple (*Acer rubrum* L.), balsam fir and yellow birch. The most common species in the understory include sugar and red maple, eastern bracken fern (*Pteridium aquilinum* [L.] Kuhn var. *latiusculum* [Desv.] Underw. ex A. Heller), balsam fir, and wild sarsaparilla.

The Wawa site is situated on a bedrock knob with areas of till from ground morainal deposits (Source: NOEGTS). The site has moderate local relief with areas of jagged, rugged, or cliffed topography. The soil is dry, fine to coarsely textured sand with approximately 5 cm of organic matter.

North Bay

The North Bay site is located approximately 50 km east of North Bay, Ontario (Block 3 - 46° 22' N, 79° 00' W), on Crown land in the GLSL forest region of Canada (Rowe 1972). In 2004 when the site was harvested, it was a tolerant hardwood stand dominated by sugar maple, yellow birch (*Betula alleghaniensis* Britt.), and red maple aged 104 to 130 years. Evidence of prior logging was visible. Other tree species included American beech (*Fagus grandifolia* Ehrh.), eastern hemlock (*Tsuga canadensis* [L.] Carr.), and paper birch. Understory species included sugar maple, yellow birch, spinulose wood fern (*Dryopteris carthusiana* [Vill.] H.P. Fuchs), and hobblebush (*Viburnum lantanoides* Mich.).

Rolling morainal deposits (Source: NOEGTS) with variable soil depth dominate the site. Dominant effective soil textures include clay loam, medium sand, silty fine sand, medium sandy loam, and coarse sand. The moisture regime ranges from moderately dry to moderately moist with fresh to very fresh regimes most common. Drainage classes at the site range from very rapid to imperfect with well-drained soils most frequent. The humus form is a moder with an average organic matter thickness of 1.9 cm (st. dev. 1.1 cm, n=15) when present.

Petawawa

The Petawawa site is located approximately 20 km northwest of Petawawa, Ontario (Block 1 - 45° 59' N, 77° 28' W), on the federally owned Petawawa Research Forest in the GLSL forest region of Canada (Rowe 1972). When harvested in 2005, the site was an 80 to 115 year old mixedwood stand that comprised eastern white pine, red maple, balsam fir, trembling aspen, red pine, and white spruce. There was no evidence of previous logging activities. Understory species included balsam fir, red maple, and beaked hazel.

Coarse loamy morainal deposits (Source: NOEGTS) of varying depths over bedrock are found at the Petawawa site. The main effective texture is loam, with silty loam, silty fine sand, silty medium sand, and medium sandy loam also present. Moderately fresh and very fresh are the most common moisture regimes with moderately dry, fresh, and moderately moist conditions also present. The site is well to moderately well-drained with areas of rapid and imperfect drainage. The organic matter averages 3.6 cm thick (st. dev. 1.7 cm, n=20) with a moder humus form.

Summary

The NEBIE plot network is designed to support evaluation of the suitability and sustainability of intensive forest management practices across a range of ecological regions in Ontario. While silviculture treatments have been previously evaluated, the NEBIE plot network does this at a much broader scale, and with a wider range of intensities, across a variety of common forest types. At this stage of the project, the experimental design has been established at six of eight sites. Although extensive and basic silvicultural intensities are fully implemented, additional treatments will need to be carried out

(e.g., thinning) before the intensive and elite treatments are fully implemented.

Acknowledgements

We thank the Ontario Ministry of Natural Resources and Forestry (MNRF), Upper Lakes Environmental Research Network, University of Guelph, Canadian Ecology Centre–Forestry Research Partnership (CEC-FRP), and Forest Ecosystem Science Co-op (FESC) for supporting and co-managing the NEBIE plot network. The network was supported by financial grants from the Living Legacy Trust (LLT), Forestry Futures Trust (FFT)’s Enhanced Forest Productivity Science Fund, National Science and Engineering Research Council of Canada (NSERC), the Canada Foundation for Innovation/Ontario Innovation Trust, and Campbell Scientific.

We gratefully acknowledge the dedication and support provided by Clergue Forest Management Inc., Domtar Inc., EACOM Timber Corporation Inc., FPInnovations – FERIC Division, Green Forest Management Inc., Natural Resources Canada–Canadian Forest Service (CFS), Nipissing Forest Resource Management Inc., Resolute Forest Products (formerly Abi-Bow), Tembec Inc., and Weyerhaeuser Inc.

We are indebted to Chad Anderson, Peter Arbour, Robert Auld, Don Bazeley, Bill Cole, Steve D’Eon, Parthena Fotiadis, Rick Groves, Mark Hall, Janet Lane, John Lawson, Jeff Leach, Tom MacLean, Andree Morneau, Glen Niznowski, Tom Noland, John Parton, Dan Samis, Al Stinson, Peter Street, Bill Towill, John Winters, and Nikki Wood for their roles in developing and implementing harvesting and silviculture activities presented in Appendix A.

We are indebted to Sharon Cuddy and Dianne Miller for management of LLT funds and FFT funds, respectively; Jim Baker, David DeYoe, and Dan Puddister for administrative support within MNRF; Doug Pitt for advice on experimental design; John Winters, Monique Wester, Ray Ferguson, Amy Bolduc, Mya Rice and many others for installation of the plot network; and Lisa Buse, Nelson Thiffault, Laird Van Damme and Monique Wester for reviewing and commenting on earlier versions of this manuscript.

References

Bell, F.W. 2015. Effects of intensification of silviculture on plant diversity in northern temperate and boreal forests of Ontario, Canada. Sch. Environ. Sci., Univ. Guelph, Guelph, ON. PhD Diss. 408 p.

Bell, F.W., J. Parton, N. Stocker, D. Joyce, D. Reid, M. Wester, A. Stinson, G. Kayahara and B. Towill. 2008. Developing a silvicultural framework and definitions for use in forest management planning and practice. *Forest. Chron.* 84: 678–693.

Bell, F.W., J. Dacosta, S.G. Newmaster, A. Mallik, S. Hunt, M. Anand, J. Maloles, C. Peng, J. Parton, J. McLaughlin, J. Winters, M. Wester, and M. Shaw. 2017. The NEBIE plot network: Highlights of long-term scientific studies. *Forest. Chron.* (in Press).

Bell, F.W., D.G. Pitt, M. Irvine, B. Parker, L. Buse, N. Stocker, B. Towill, H. Chen, F. Pinto, K. Brown, D. DeYoe, T. McDonough, G. Smith and M. Weber. 2000. Intensive forest management science workshop summary. Ont. Min. Nat. Resour., Sault Ste. Marie, ON. Sci. Dev. Trans. Ser. No. 003. 45 p.

Carpenter, S.R., 1998. The need for large-scale experiments to assess and predict the response of ecosystems to perturbation. pp. 287–312 *In:* Pace, M.L. and P.M. Groffman (eds.). *Successes, Limitations and Frontiers in Ecosystem Science.* Springer-Verlag, NY.

Day, R.J. and F.W. Bell. 1988. Development of crop plans for hardwood and conifer stands on boreal mixedwood sites. *In:* Management and Utilization of Northern Mixedwoods. Can. For. Serv., North. For. Cent., Edmonton, AB. Info. Rep. NOR-X-296. p. 87–98.

Franklin, J.F. 1989. Importance and justification of long-term studies in ecology. pp. 3–19 *In:* G.E. Likens (ed.). *Long-term Studies in Ecology: Approaches and Alternatives.* Springer-Verlag, New York, NY.

Fu, S., F.W. Bell, and H.Y.H. Chen. 2007. Long-term effects of intensive silvicultural practices on productivity, composition, and structure of northern temperate and boreal plantations in Ontario, Canada. *Forest Ecol. Manage.* 241: 115–126.

Kimball, A.J. and M.L., Hunter. 1990. Intensive silviculture. pp. 200–234 *In:* M.L. Hunter, Jr. (ed.). *Wildlife, Forests, and Forestry.* Prentice Hall Career & Technol., Englewood Cliffs, NJ.

Lautenschlager, R. A., F. W. Bell, R.G. Wagner, and P. E. Reynolds, 1998. The Fallingsnow Ecosystem Project: Documenting the consequences of conifer release alternatives. *J. For.* 96(11): 20–27.

Lieffers, V.J., C. Messier, P.J. Burton, J.-C. Ruel, and B.E. Grover. 2003. Nature-based silviculture for sustaining a variety of boreal forest values. pp. 481–530 *In:* Burton, P.J., C. Messier, D.W. Smith, and W.L. Adamowicz (eds.). *Towards Sustainable Management of the Boreal Forest.* NRC Research Press, Ottawa, ON.

MacDonald, G.B., J.A. Rice, J. McLaughlin, J. Pearce, L. Venier, K. Nystrom, and P. Meek. 2003. Developing sustainable mixedwood practices in a stand-level adaptive management (SLAM) framework: Project establishment. Ont. Min. Nat. Resour., Ont. For. Res. Inst., Sault Ste. Marie, ON. For. Res. Inf. Pap. No. 157. 17 p.

[OFAAB] Ontario Forest Accord Advisory Board. 2002. Room to grow: Final report of the Ontario Forest Accord Advisory Board on implementation of the Accord. Ont. Min. Nat. Resour., Sault Ste Marie, ON. Final Rep. 28 p.

[OMNR] Ontario Ministry of Natural Resources. 1999. Ontario’s Living Legacy land use strategy. Ont. Min. Nat. Resour., Toronto, ON. 136 p.

[OMNR] Ontario Ministry of Natural Resources. 2001. Forest management guide for natural disturbance pattern emulation, Version 3.1. Ont. Min. Nat. Resour., Toronto, ON. 40 p.

Roberts, M.R. and F.S. Gilliam. 1995. Patterns and mechanisms of plant diversity in forested ecosystems: Implications for forest management. *Ecol. Applic.* 5(4): 969–977.

Rowe, J.S. 1972. Forest regions of Canada. Can. For. Serv. Publ. 1300.

Smith, D.M., B.C. Larson, M.J. Kelty, P.M.S. Ashton. 1997. *The Practice of Silviculture: Applied Forest Ecology.* John Wiley, New York, NY, USA.

Tobner, C.M., A. Paquette, P.B. Reich, D. Gravel, and C. Messier, 2014. Advancing biodiversity-ecosystem functioning science using high-density tree-based experiments over functional diversity gradients. *Oecologia* 144: 609–621. DOI 10.1007/s00442-2815-4.

Urli, M., N. Thiffault, M. Barrette, and D. Chalifour. 2017. Key ecosystem attributes and productivity of boreal stands 20 years after the onset of silviculture scenarios of increasing intensity. *Forest Ecol. Manage.* 389: 404–416.

Volney, W.J.A., J.R. Spence, M.G. Weber, D.W. Langor, K.I. Mallet, J.D. Johnson, I.K. Edwards, G.R. Hillman, and B.E. Kishchuk. 1999. Assessing components of ecosystem integrity in the EMEND experiment. pp. 244–249 *In:* Veeman, T.S., D.W. Smith, B.G. Purdy, F.J. Salke, and G.A. Larkin (eds.), *Proc. 1999 sustainable forest management network conference: Science and Practice: Sustaining the Boreal Forest*, 14–17 February, 1999. University of Alberta, Edmonton, AB.

Wang, S. and H.Y.H. Chen. 2010. Diversity of northern plantations peaks at intermediate management intensity. *Forest Ecol. Manage.* 259: 360–366.

Willcocks, A.J., W. Bell, J. Williams, and P.N. Duiker. 1990. A crop planning process for northwestern Ontario: Determining stand silvicultural ground rules responsive to the objectives of the forest. Ont. Min. Nat. Resour., NW. Ont. For. Tech. Dev. Unit, Tech. Rep. #30. 159 p.

Appendix A: Silviculture plans by site within the NEBIE plot network

Table A1. Objectives and silvicultural activities for the Sioux Lookout Ontario NEBIE site

	Extensive	Basic	Intensive	Elite
Objectives	>40% stocking of any species, free of major insect pests	Pj and Sb stocking >60%, free of interspecific competition and major insect pests	Pj and Sb stocking >80%, free of intra- and interspecific competition and major insect pests	Pj and Sb stocking >80%, free of nutrient deficiencies, intra- and interspecific competition and major insect pests
Harvest	Summer 2002: clear-cut, full tree logging to roadside, no residual trees left on the harvested treatments			
Site preparation	none	May 2004: 2 string skidder configuration spaced at 2 m. Each string started with a shark-finned barrel followed by a 4 m spiked anchor chain and 1 m length of backhoe pads, 0.5 m wide.		
Aerial seeding	none	April 2005: aerial seed of jack pine at 50,000 seeds ha ⁻¹ onto a 80 cm+ snow layer		
In-fill tree plant	none	none	May 2007: in-fill 9000 jack pine seedlings with an average of 550 trees ha ⁻¹	
Vegetation management	none	none	none	none
Future options	none	none	pre-commercial and commercial thin	pre-commercial and commercial thin, fertilize

Pj=jack pine, Sb = black spruce

Table A2. Objectives and silvicultural activities for the Dryden Ontario NEBIE site

	Extensive	Basic	Intensive	Elite
Objectives	>40% stocking of any species, free of major insect pests	>60% stocking of Pw, Pr, Pj, Sb, and Sw free of interspecific competition and major insect pests	>80% stocking of Pw, Pr, Pj, Sb, and Sw free of intra- and interspecific competition and major insect pests	>80% stocking of Pw, Pr, Pj, Sb, and Sw free of nutrient deficiencies, intra- and interspecific competition and major insect pests
Harvest	March 2005: clear cut using full tree logging to roadside. Leave 25 trees ha ⁻¹ (at least 2 white spruce ha ⁻¹ [6 in extensive] and 5 to 6 wildlife trees ha ⁻¹)			
Site preparation	None	Oct. 2005: disk trench at 3 m spacing	Oct. 2005: disk trench at 2.5 m spacing	
Tree plant	None	May 2006: 1200 Sb ha ⁻¹	May 2006: 1250 Sb ha ⁻¹ and 1250 Sw ha ⁻¹ as 2 rows of Sb followed by 2 rows of Sw	May 2006: 1000 Sb ha ⁻¹ , 1000 Sw ha ⁻¹ and 500 fertilizer enhanced Pw ha ⁻¹ as 2 rows of Sb, 1 row of Sw, 1 row of Pw, and 1 row of Sw
Vegetation management	None	Aug. 2007: Broad cast	ground spray of glyphosate to control broadleaved trees and shrubs	
		none	Aug. 2010: Backpack ground spray of glyphosate	
Cleaning			Nov. 2011: Clean to 2500 stems ha ⁻¹ with the priority Pw, Pr, Pj, Sw, Sb, Bf and leave 6 hardwood species ha ⁻¹	
Future options	None	none	commercial thin	commercial thin, apply fertilizer

Pj=jack pine, Pr= red pine, Pw = white pine, Sb = black spruce, Sw = white spruce

Table A3. Objectives and silvicultural activities for the Kapuskasing Ontario NEBIE site

	Extensive	Basic	Intensive	Elite
Objectives	>40% stocking of any species, free of major insect pests	>60% stocking of Sb and Sw free of interspecific competition and major insect pests	>80% stocking of genetically superior Sb and Sw free of intra- and interspecific competition and major insect pests	>80% stocking of genetically superior Sb and Sw free of nutrient deficiencies, intra- and interspecific competition and major insect pests
Harvest	Fall 2003: clear cut using full tree logging to roadside. Leave 25 trees ha ⁻¹ (at least 5 to 6 seed trees and 5 to 6 wildlife trees ha ⁻¹)			
Site preparation	none	none	August 2004 - Aerial spray with Vision® herbicide	
Tree plant	none	May 2005: regular Sb and Sw at a 2:1 ratio, 1.8 m x 1.8 m spacing, approx. 2400 trees ha ⁻¹ actually planted	May 2005: Sb F2 enhanced and Sw F1 regular at 1:1.5 ratio, 1.5 m x 1.5 m spacing, approx. 3200 trees ha ⁻¹ actually planted	May 2005: Sb F2 enhanced and Sw F1 regular at 1:1.5 ratio, 1.5 m x 1.5 m spacing, approx. 3000 trees ha ⁻¹ actually planted, species planted in rows for future silviculture options
Vegetation management	none	August 2006: Aerial spray Vision® herbicide		
Refill tree plant	none	none	August 2010: Aerial spray Vision® herbicide	
		May 2007 - refill selected spots with Sb (18,000 total), Basic spacing 3.3 m x 3.3 m, Intensive and Elite spacing 2.8 m x 2.8 m.		
Future options	none	none	commercial thin leaving large diameter Sw	commercial thin leaving large diameter Sw, fertilizer application, pruning

Sb = black spruce, Sw = white spruce

Table A4. Objectives and silvicultural activities for the Timmins Ontario NEBIE site

	Extensive	Basic	Intensive	Elite
Objectives	stocking >40% of any species, free of major insect pests	stocking >60% of Sw, Sb and Po free of interspecific competition and major insect pests	stocking >80% of Sw, Sb and Po free of intra- and interspecific competition and major insect pests	stocking >80% of Sw, Sb and Po free of nutrient deficiencies, intra- and interspecific competition and major insect pests
Harvest	Fall 2002: full tree log to roadside (block 1), cut to length (blocks 2-4), leaving 25 residual trees ha ⁻¹			
Site preparation	none	Sept. 2003: power disc trench	Sept. 2003: power disc trench with second trench pass at 90° to the first pass	
Tree plant	none	Spring 2004: 1800 white spruce ha ⁻¹	Spring 2004: 2200 white spruce ha ⁻¹	
Vegetation management I	none	Sept. 2005: back pack application of glyphosate to control all broadleaved trees and shrubs	Sept. 2005: back pack application of glyphosate with 3 to 6 m wide no spray strips 27 m apart	Sept. 2005: back pack application of glyphosate leaving a quality aspen every 5 m
Vegetation management II	none	none	Aug. 2007: back pack application of glyphosate with 3 to 6 m wide no spray strips 27 m apart	Aug. 2007: back pack application of glyphosate leaving a quality aspen every 5 m
Re-fill tree plant	none	May 2008: 583 white spruce ha ⁻¹ , only block 2	May 2008: 730 white spruce ha ⁻¹	May 2008: 1020 white spruce ha ⁻¹
Future options	none	none	commercial thin	prune dead branches, commercial thinning

Po = trembling aspen, Sb = black spruce, Sw = white spruce

Table A5. Objectives and silvicultural activities for the Petawawa Ontario NEBIE site

	Extensive	Basic	Intensive	Elite
Objectives	>40% stocking of all species, free of major insect pests	> 60% stocking of Pw, Pr, and Sw free of interspecific competition and major insect pests	> 80% stocking of Pw, Pr, and Sw free of intra- and interspecific competition and major insect pests	> 80% stocking of Pw, Pr, and Sw, free of nutrient deficiencies, intra- and interspecific competition and major insect pests
Harvest	Fall 2005 / winter 2006: harvest using Pw shelterwood system.			
Post-harvest cleaning salvage	Winter/spring 2007: salvage blowdown from severe windstorm on July 16, 2006			Fall 2006: lop and drop all uncut marked trees and windthrown trees. Winter/spring 2007 - salvage blowdown from severe windstorm on July 16, 2006
Post-harvest and salvage basal area (m ² /ha)	total 12.3 pine 7.1	16.9 9.2	15.2 7.3	12.5 8.9
Site preparation	none	June to August 2007: Ground apply Vantage Plus Max [®] herbicide by skidder-mounted sprayer		
Infill tree plant	none	May 2008: Block 2 only - 1,750 Pw (Zone 30, 3+0)	May 2008: Block 2 only - 2,650 Pw (Zone 30, 3+0)	May 2008: Blocks 1 to 4 - Sw (Zone 36, G+1.5), 1,000 per treatment plot, plant in open pockets, Block 2 only - 2,300 Pw (Zone 30, 3+0)
Vegetation management	none	Aug. 2008: Block 4, only - Ground apply Vision [®] in a 1% solution by backpack sprayer	Sept. 2010: Ground apply Release [®] in a 2% solution by backpack sprayer	
Refill plant	none	none		
Future options	none			2028: prune 200 Pw ha ⁻¹ at 8 to 10 cm DBH based on market evaluation, 2034: commercial thin Sw
Overstory removal	none	Overstory removal expected to occur in 2034		

Pr = red pine, Pw = white pine, Sw = white spruce

Table A6. Objectives and silvicultural activities for the North Bay Ontario NEBIE site

	Extensive	Basic	Intensive	Elite
Objectives	>40% stocking of all species, free of major insect pests	> 60% stocking of By and Mh free of interspecific competition and major insect pests	> 80% stocking of By and Mh free of intra- and interspecific competition and major insect pests to provide quality stems for the veneer market	> 80% stocking of By and Mh free of nutrient deficiencies, intra- and interspecific competition and major insect pests. Enhance opportunity for non-timber products to increase revenue.
Harvest	Fall 2004: harvest using shelterwood system. Harvest only Crown Forest Sustainability Act grade stems	Fall 2004: harvest using shelterwood system. Tree mark and cut all marked trees ≥ 10 cm diameter. Maintain 15 to 20% mid-tolerant (birch) species.		Fall 2004: harvest using shelterwood system. Tree mark and cut all marked trees ≥ 10 cm diameter. Selection cut to control diseases. Maintain 15 to 20% mid-tolerant (birch) species
Post-harvest cleaning	none	none	Fall 2005: additional tree marking and remove unmarketable and diseased trees, fell and buck into 2.5 m lengths	Fall 2005: additional tree marking and remove unmarketable and diseased trees, fell and buck into 1.25 m lengths
Post-harvest and salvage basal area (m ² /ha)	total 19.6 By 6.8	11.9 1.6	16.0 2.4	11.4 2.0
Site preparation	none	Fall 2005: blade by bulldozer with multi-directional blade to obtain 21% mineral soil exposure	Fall 2005: blade by bulldozer with multi-directional blade to obtain 51% mineral soil exposure	Fall 2005: blade by bulldozer with multi-directional blade to obtain 56% mineral soil exposure
Non-timber values	none	none	none	Aug. 2006: plant 800 Canada yew
Supplementary site preparation	none	none	May 2008: Block 3 only - reblade and seed with By seed	
Vegetation management	none	none	none	none
Future options	none	none	commercial thin	commercial thin, apply fertilizer, prune

By = yellow birch, Mh = hard maple

Table A7. Objectives and silvicultural activities for Block 1 at the Thunder Bay Ontario NEBIE site

	Extensive	Basic	Intensive	Elite
Objectives	>40% stocking of all species, free of major insect pests	>60% stocking of Sb and Sw, free of interspecific competition and major insect pests	>80% stocking of Sb and Sw, free of intra- and interspecific competition and major insect pests	>80% stocking of Sb, Sw and Pj, free of nutrient deficiencies, intra- and interspecific competition and major insect pests
Harvest	Oct. 2008: Clear cut using full-tree chipping to roadside. Leave 25 representative residual trees ha ⁻¹			
Residuals	mark randomly throughout the treatment	align in 4 rows, 6 to 8 marked for full retention, 20 for topping to 3 m, leave spruce and Pj outside rows		same as intensive and basic, except align in 2 rows
Site preparation	none	Oct. 2009: Disk trench at 2.5 m spacing		
Tree plant	none	May 2010: 1800 to 2000 stems ha ⁻¹ ; 70% Sb, 30% Sw	May 2010: 2700 to 3000 stems ha ⁻¹ ; 50% Sw, 50% Sb in planned thinning rows	May 2010: 2700-3000 stems ha ⁻¹ ; 65% Sw, 25% Sb, 10% Pj in planned thinning rows
Vegetation management	none	Sept. 2012: Aerial release, 1.62 kg ha ⁻¹ of Glyphosate		
Future options	none	none	2040: commercial thinning Sb and Sw	fertilize; prune 500 to 800 Sw; 2040: commercial thin, removing Pj and thinning Sb and Sw

Pj = jack pine, Sb = black spruce, Sw = white spruce

Table A8. Objectives and silvicultural activities for the Wawa Ontario NEBIE site

	Extensive	Basic	Intensive	Elite
Objectives	>40% stocking of all species, free of major insect pests	>60% stocking of Bp, free of interspecific competition and major insect pests	>80% stocking of Bp, free of intra- and interspecific competition and major insect pests	>80% stocking of Bp, free of nutrient deficiencies, intra- and interspecific competition and major insect pests
Harvest	2003: Block 1, 2007: Block 2 - Clear cut using full tree to roadside. Leave 25 trees ha ⁻¹ (at least 5 to 6 seed trees and 5 to 6 wildlife trees ha ⁻¹)			
Residuals	2003: Mark for no harvest - 10 Bp seed trees, 15-20 other species, all Ce and Pw and a 10 m x 10 m clump of Bf ha ⁻¹			
Planned site preparation	none	Light-medium straight blade, small machinery; hexazinone, max. 3 L Velpar-Lha ⁻¹ , backpack application		
Planned tree plant	none	1400 to 1800 stems of Bp ha ⁻¹		
Future options	None			fertilize, prune
Future thinning	none		target 250 to 400 quality Bp ha ⁻¹ final rotation	

Bp = paper birch