SILVICULTURAL OPTIONS FOR EARLY-SUCCESSIONAL STANDS IN MAINE: 6-YEAR RESULTS OF THE SILVICULTURAL INTENSITY AND SPECIES COMPOSITION EXPERIMENT

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Abstract.—The Silvicultural Intensity and Species Composition (SIComp) experiment was installed in 2003 on a recently clearcut mixedwood site within the Penobscot Experimental Forest in east-central Maine. This study was initiated because the response of early-successional stands to various intensities of silviculture was poorly understood in the region. The goal of SIComp is to shift stand development and composition in multiple directions through a factorial combination of three silvicultural intensities (low, medium, and high) and three objectives for species composition (hardwood, mixedwood, and conifer). To date, the experiment has documented the survival, growth, and yield of hybrid poplar and planted white spruce plantations, the effects of precommercial thinning in juvenile aspen stands, the response of early-successional stands to conifer release treatments, and alternative approaches for managing young mixedwood stands. Current investigations are focused on mechanistic responses to the heterogeneous growing conditions created by the varied treatments in the experiment. Energy (labor, petroleum, and pesticide) inputs required to establish and maintain the experiment also will be incorporated into models estimating net carbon balance and value of the various treatments over time.

INTRODUCTION

Young, naturally regenerated stands dominated by shade-intolerant hardwoods mixed with conifer species compose approximately 13 percent of the forest land in Maine (McWilliams et al. 2005). The majority of these stands originated after the large-scale, post-budworm clearcuts during the 1980s and subsequent partial harvesting that continues today. Although these stands are prevalent in the region, their response to silviculture has not been well studied, which limits our ability to implement appropriate silvicultural systems to promote desirable composition and increase stand productivity. Additionally, without a firm understanding of early-successional stand responses to silviculture, current growth and yield models cannot accurately project stand development; therefore, the contribution of these stands to increasing regional wood fiber demands is poorly understood. In response to these concerns, the Silvicultural Intensity and Species Composition (SIComp) experiment was established in 2003 on a recently clearcut mixedwood site on the Penobscot Experimental Forest (PEF) in east-central Maine. Experimental plots were put on different trajectories by manipulating tree species composition and applying various intensities of silviculture, with the overall goal of documenting the resulting dynamics of young Acadian Forest stands.

Long-term silvicultural experiments in Maine are limited, but the various experiments on the PEF have served as a basis for understanding the response of northern conifer stands to traditional silviculture (U.S. Department of Agriculture, Forest Service Compartment Study), ecological silviculture (Acadian Forest Ecosystem Research Program Expanding Gap Experiment), and intermediate treatments such as precommercial and commercial thinning (Commercial Thinning Research Network). The SIComp experiment complements these other long-term studies on the PEF. Long-term silvicultural experiments in the region provide a basis for comparing the effectiveness of various treatments, such as clearcutting, shelterwood, and selection systems, and intensities of management on residual stand structure and regeneration dynamics (Brissette 1996). Responses to these various treatments will typically vary depending on species composition (Sendak et al. 2003). For example, clearcut-harvested stands in northern and central Maine typically regenerate to aspen (*Populus* spp.) and birch (*Betula* spp.), but future composition and structure may differ depending on the density of conifer advance regeneration.

The intensity of silviculture applied to a stand is directly related to the desired financial investment. In early-successional mixedwood stands in Maine, unmanaged stands often remain dominated by shade-intolerant hardwood species and growth rates may be inhibited by high stem densities. With a comparatively modest financial investment, desirable species can be promoted and growth rates can be increased with treatments such as conifer release (Newton et al. 1992) or hardwood thinning (Rice et al. 2001). Additional silvicultural investment, such as enrichment planting, can increase stand productivity and accelerate composition to mid- to late-successional species (Greene et al. 2002, Paquette et al. 2006). Currently, there are no long-term experiments in the Acadian region documenting the response of early-successional stands to different intensities of silviculture. Without these long-term data, it is difficult to assess the potential benefits of different treatments in early-successional stands.

The lack of information on the responses of early-successional stands to silviculture was the impetus for the establishment of SIComp. The three major objectives of the study are to: (1) quantify the growth and yield response of early-successional stands in central Maine to varying intensities of silviculture under different compositional objectives, (2) document the mechanisms affecting the dynamics and productivity of these young forest stands, and (3) compare the energy requirements and financial returns associated with implementation and eventual harvest under differing silvicultural intensities and compositional objectives. These objectives are long-term and require interdisciplinary collaboration. Currently, productivity is being investigated by modeling allometry, resource availability, and ecophysiological response in relation to the various growing conditions created by the treatments. Ongoing efforts to document the energy inputs (labor, petroleum, and pesticides) of the different treatments will provide managers with the costs and financial returns associated with the silvicultural strategies being tested.

Shortly after the study was established, the wide range of micro-environmental conditions created by the experiment allowed Kanoti (2005) to determine how silvicultural intensity can influence the natural regeneration (germination and survival) of Acadian tree species. He hypothesized that silviculture could be used to mitigate the possible negative effects of climate change on soil temperature and moisture regimes in a way that can encourage the germination and establishment of Acadian Forest tree species. Results showed that moisture availability was the most important factor influencing germination success. Drought tolerance decreased in the following order: trembling aspen (*Populus tremuloides* Michx.) > red spruce (*Picea rubens* Sarg.) = hybrid larch (*Larix* x *eurolepis* Henry) > Norway maple (*Acer platanoides* L.) = paper birch (*B. papyrifera* Marsh.) = white pine (*Pinus strobus* L.) > balsam fir (*Abies balsamea* L.) = red maple (*Acer rubrum* L.). Additionally, Kanoti (2005) found that predator protection and sowing date strongly influenced emergence success, with a fall sowing date being detrimental to exotic species. After seedlings emerged, greater densities of grass competition and overstory density reduced survival of many of the species.

The importance of understanding the response of early-successional stands in Maine to various silvicultural intensities is increasing, yet no long-term silvicultural studies have previously addressed these issues. Additionally, given the young age of the SIComp experiment, details of the study have not been documented elsewhere. Therefore, the goals of this paper were to: (1) describe the experimental design of the SIComp experiment, and (2) present initial findings on the difference in composition and individual tree size among species and treatments 6 years after the experiment was started.

METHODS

Study Area

This study was installed within the PEF near the towns of Bradley and Eddington (44°49'N, 68°38'W) between 2003 and 2004. Natural forest composition on the PEF is dominated by shade-tolerant conifer species, including balsam fir, eastern hemlock (*Tsuga canadensis* L.), and red spruce, and shade-intolerant hardwood species, such as trembling aspen, bigtooth aspen (*Populus grandidentata* Michx.), red maple, and paper birch (Sendak et al. 2003). Soils at the forest are of Wisconsin glacial till origin and the soil classifications at the study site range from loamy, mixed, active, acid, frigid, shallow, Aeric Endoquepts to coarse-loamy, isotic, frigid, Aquic Haplothods. The climate of eastern Maine is cool and humid. February is the coldest month on average (–7.1 °C) and July is typically the warmest (20.0 °C). Mean precipitation is 1070 mm, and the average growing season lasts approximately 160 days (Sendak et al. 2003).

In 1995, the 9.2-ha site of the experiment was clearcut with approximately 2.3 m^2 ha^{-1} of residual basal area. Following harvest, the site naturally regenerated to shade-intolerant hardwoods (trembling aspen, bigtooth aspen, red maple, and paper birch) and smaller balsam fir, red spruce, white pine (*Pinus strobus* L.), and white spruce (*Picea glauca* [Moench] Voss). Shortly after harvest, Norway (*Picea abies* [L.] Karst.), red, black (*Picea mariana* [Mill.]), and white spruce were planted to increase the density of desirable conifer species, but much of the planting failed due to hare clipping during the first winter.

Study Design

The SIComp experiment is based on a mix of treatments needed to achieve the desired level of silvicultural intensity and tree species composition (Table 1). A specific set of regeneration and vegetation management treatments was then designed to achieve each treatment objective (Fig. 1). The treatment objectives consisted of three levels of silvicultural intensity (low, medium, and high) crossed with three species compositional objectives (conifer, mixedwood, and hardwood), plus an untreated control. Prior to the installation of the treatments, a vegetation survey across the site revealed a patchy pattern of conifer composition that required blocking of the treatment plots by species composition. Therefore, the experimental design is a 3 x 3 +1 factorial, restricted-randomized complete block design, with four replicates of each treatment. Abbreviations for the array of treatments are: low conifer (LC), low mixedwood (LM), low hardwood (LH), medium conifer (MC), medium mixedwood (MM), medium hardwood (MH), high conifer (HC), high mixedwood (HM), high hardwood (HH), and untreated control (C).

Each of the ten treatments was replicated four times for a total of forty 30 m by 30 m treatment plots (Fig. 2). In each low- and medium-intensity treatment plot, manipulations were applied to individual crop-trees within each 2 m by 2 m growing space in the treatment plot (i.e., an average of 225 spaces per plot). Depending on treatment, these growing spaces were assigned one of four crop-tree types: naturally regenerated hardwood, planted hybrid poplar (*Populus* clones), naturally regenerated conifer, or planted white spruce (Fig. 3). Naturally regenerated hardwoods and conifers were selected from high-quality, large individuals in each growing space using the following orders of priority: hardwoods—bigtooth aspen > trembling aspen > paper birch > sugar maple (*Acer saccharum* Marsh.) > red maple; conifers—eastern white pine > balsam fir > spruce species.

Table 1.—Description of the different levels of silvicultural intensity applied to treatment plots in the SIComp experiment.

Silvicultural intensity	Control of species colonization (regeneration)	Control of relative species performance (vegetation management)	Control of spacing among desired trees (thinning)
Zero	None	None	None
Low	Selection among natural regeneration for desired tree species at desired spacing; "holes" without desired trees not filled	Minimum control of neighboring woody plants needed to maintain desired trees in main canopy (i.e., one-time release)	None
Medium	Selection among natural regeneration for desired tree species; "holes" fill-planted with desired tree species where needed to achieve desired spacing	Periodic control of neighboring woody plants around all desired trees that overtop or threaten to overtop desired trees	After crown closure of desired species, periodic thinning of desired trees to maintain a 0.3 spacing:height ratio
High	Genetically improved stock of desired tree species planted at desired spacing	Complete removal of all non-crop plants (woody and herbaceous) just before planting and through early stand development until crown closure of desired species	Periodic thinning of desired trees to maintain a 0.3 spacing:height ratio throughout life of stand

Silvicultural intensity	Pure conifer	Conifer/hardwood	Pure hardwood
Zero		Natural succession (no composition target)	
Low	Naturally regenerated balsam fir and red spruce depending on relative abundance; "holes" without desired conifers not managed	Naturally regenerated conifers (balsam fir and red spruce) and hardwoods (aspen, red maple, or sugar maple) at 67:33 mixture depending on relative abundance	Naturally regenerated aspen, red maple, or sugar maple depending on relative abundance; "holes" without desired hardwoods not managed
Medium	Naturally regenerated balsam fir and red spruce depending on relative abundance; "holes" fill-planted with white spruce	Naturally regenerated conifers (balsam fir and red spruce) and hardwoods (aspen, red maple, sugar maple) at 67:33 mixture; "holes" fill-planted with white spruce and hybrid poplar	Naturally regenerated aspen, red maple, or sugar maple depending on relative abundance; "holes" fill-planted with hybrid poplar
High	Planted white spruce	White spruce and hybrid poplar planted in 67:33 mixture	Planted hybrid poplar

Treatment Regime for Intensity of Silviculture Experiment

REGENERATION

Intensity Objective:		Compositional Objective: Conifer – Planted	Conifer – Natural	Mixedwood – Planted	Mixedwood – Natural	Hardwood – Planted	Hardwood – Natural
Low	Conifers		100.0%		66.7%		100.0%
	Hardwoods				33.3%		
Medium	Conifers	50.0%	50.0%	33.3%	33.3%		
	Hardwoods			16.7%	16.7%	50.0%	50.0%
High	Conifers	100.0%		66.7%			
	Hardwoods			33.3%		100.0%	

VEGETATION MANAGEMENT

Intensity Objective:	Non-crop vegetation	Conifer – Area	Conifer – Duration	Conifer – Method	Mixedwood – Area	Mixedwood – Duration	Mixedwood – Method	Hardwood – Area	Hardwood – Duration	Hardwood – Method
Low	Herbs									
	Shrub & hardwoods	S	1X	H_t	S	1X	H_t or BS	S	1X	BS
	Conifers							S	1X	BS
Medium	Herbs	S_p	2X	H_g	S_p	2X	H_g	S_p	2X	H_g
	Shrub & hardwoods	B	1X	H_t	S	1X	H_t or BS	S	1X	BS
	Conifers							B	1X	BS
High	Herbs	B	CC	H_g	B	CC	H_g	B	CC	H_g
	Shrub & hardwoods	B	CC	H_t + BS	B	CC	H_t + BS	B	CC	Ht + BS
	Conifers	B	CC	BS	B	CC	BS	B	CC	BS

LEGEND

Area
- S_p = Spot treatment (1m radius) only around planted crop trees
- S = Spot treatment (1m radius) around all crop trees on a 2m x 2m grid
- B = Broadcast treatment of entire 30m x 30m plot

Duration
- 1X = Single treatment in the first year of planting or immediately after selection of crop trees
- 2X = Two treatments during the first two years after planting or after selection of crop trees
- CC = Complete control until crown closure by crop trees

Method
- BS = Brushsaw cutting of all shrubs and hardwoods at ground level
- H_t = Herbicide basal spray of all shrubs and hardwoods using triclopyr in mineral oil
- H_g = Herbicide foliar application using glyphosate

Figure 1.—Treatments applied to achieve the various silvicultural objectives of the SIComp experiment.

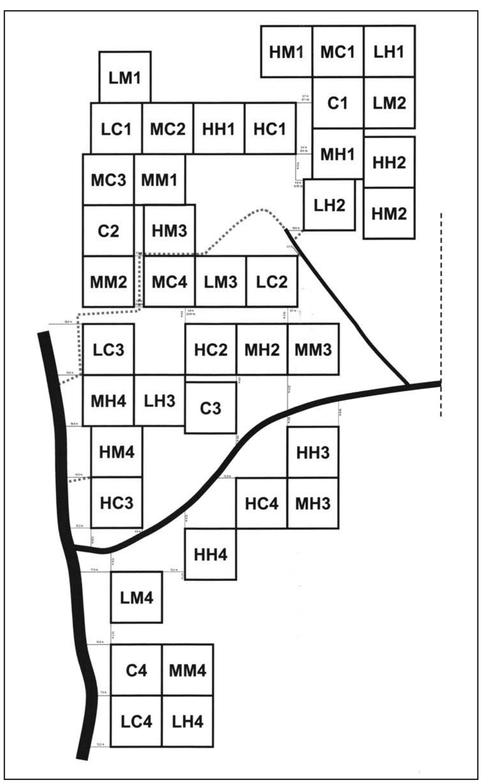

Figure 2.—Layout of the SIComp 30 m by 30 m treatment plots across the 9.2-ha clearcut site on the PEF. Treatment abbreviations are: C – untreated control, LC – low conifer, LM – low mixedwood, LH – low hardwood, MC – medium conifer, MM – medium mixedwood, MH – medium hardwood, HC – high conifer, HM – high mixedwood, and HH – high hardwood.

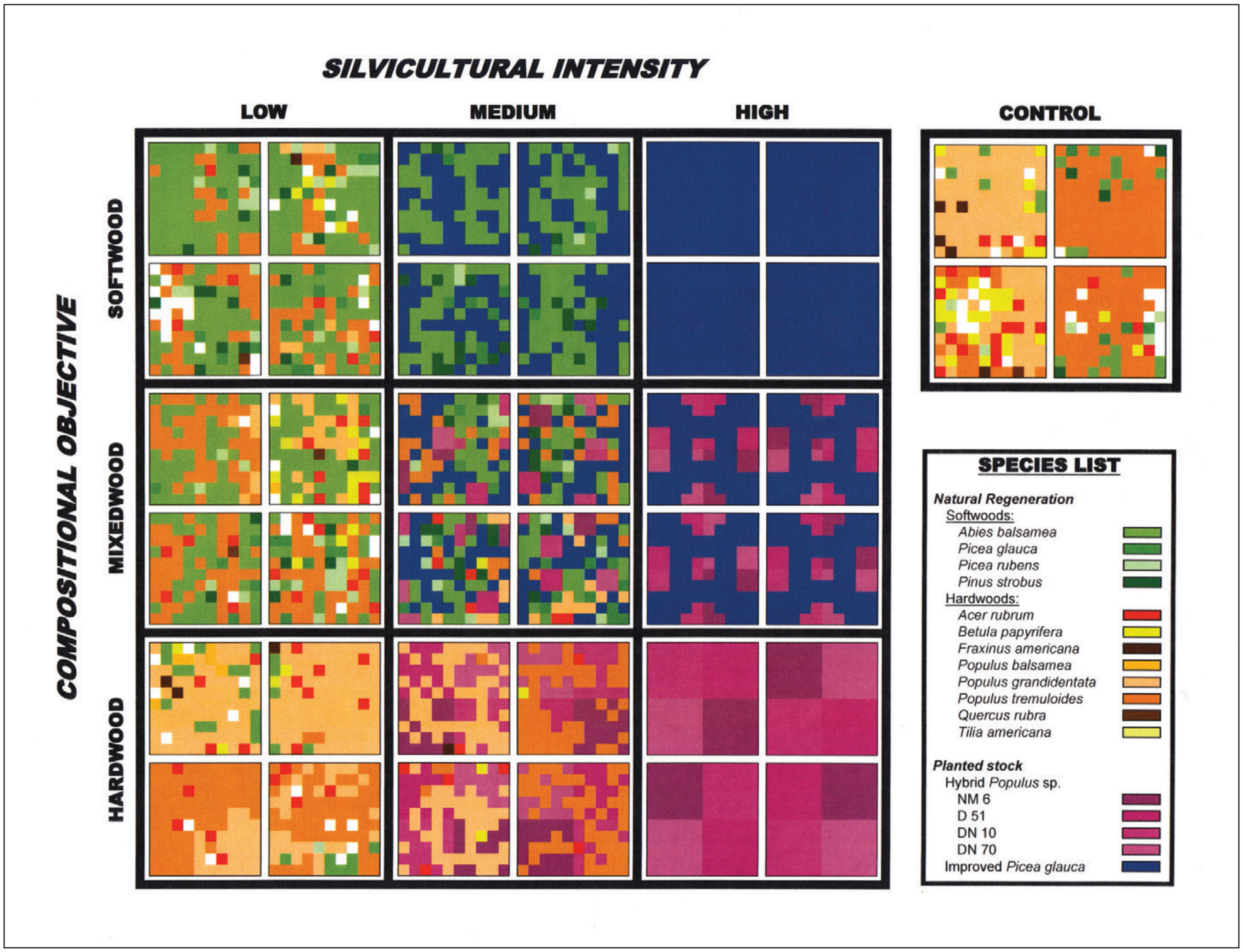

Figure 3.—Growing space allocation map for the SIComp experiment at study inception. The figure depicts each 2 m by 2 m growing space within measurement plots (20 m by 20 m) for each of the four replicates of a treatment. Cells are color-coded to species.

For both naturally regenerated crop-tree types, all woody vegetation within a 1-m radius around crop-trees was chemically or mechanically controlled in 2004. Hardwood competitors around conifer trees were killed using a basal application of 20 percent Garlon 4® (triclopyr ester) (Dow AgroSciences, Indianapolis, IN) mixed with Bark Oil Blue® (UAP Distribution Inc., Greeley, CO) (Table 2). Aspen trees of root-sucker origin were common across the site, so hardwood competitors around hardwood crop-trees were removed with motorized brushsaws to avoid potential herbicide damage to crop-trees through shared root systems with controlled trees. All conifer competitors were killed using brushsaws.

Growing spaces assigned to fill-planted hybrid poplar and white spruce in the medium- and high-intensity treatments were treated with herbicides (triclopyr basal-bark applications and glyphosate foliar treatments) and manually cleared of all pre-existing woody and herbaceous vegetation. In 2003 the high-intensity treatments underwent a follow-up broadcast application of 2.80 acid equivalent (a.e.) kg ha^{-1} glyphosate (Accord® Concentrate, Dow AgroSciences) to control herbs, and residual sprouting by shrub and tree regeneration. Planted growing spaces within the MC, MM, HC, and HM treatments were then planted in spring 2004 with containerized white spruce obtained from a J.D. Irving, Ltd., tree nursery in

Table 2.—Species composition (calculated as a proportion of total basal area) 6 years after the start of the experiment by treatment and for all treatments combined shown as least squares means. Treatment abbreviations are: C – untreated control, LC – low conifer, LM – low mixedwood, LH – low hardwood, MC – medium conifer, MM – medium mixedwood, MH – medium hardwood, HC – high conifer, HM – high mixedwood. The between-treatment standard error is also shown.

	Proportion of basal area (%)										
Species	C	LC	LM	LH	MC	MM	MH	HC	HM	HH	Standard error
Paper birch	22.5	1.8	3.7	8.5	7.8	9.7	13.3	-	-	-	5.6
Gray birch	4.4	3.4	2.9	17.8	1.4	13.3	6.5	-	-	-	8.8
Bigtooth aspen	19.8	13.8	12.7	10.0	2.6	4.8	16.2	-	-	-	6.3
Trembling aspen	13.2	2.1	1.9	9.5	1.1	2.3	8.6	-	-	-	4.0
Red maple	17.6	12.3	8.8	23.9	5.2	13.0	27.0	-	-	-	6.6
Other hardwood species	10.4	12.1	10.3	21.0	15.9	11.3	21.8	-	-	-	7.0
Balsam fir	8.8	48.6	53.1	8.5	44.1	30.1	1.9	-	-	-	7.7
Red spruce	1.2	3.1	3.2	0.1	0.3	2.5	-	-	-	-	1.2
Natural white spruce	0.2	1.4	1.8	-	0.3	-	0.9	-	-	-	0.5
Eastern white pine	1.6	1.4	1.4	0.6	4.1	5.7	1.5	-	-	-	1.1
Planted white spruce	-	-	-	-	17.1	6.3	-	100.0	80.7	-	3.2
Hybrid poplar	-	-	-	-	-	0.6	2.2	-	19.3	100.0	1.8

New Brunswick, Canada. The white spruce seedlings were 2+0 half-sib individuals grown in MP67 multi-pots with a 65-cm^3 rooting volume and planted with a Pottiputki® (a device with a hollow tube and duck-billed end that levers open a hole in soil suitable for seedling planting; BCC, Landscrona, Sweden).

Planted growing spaces within the MH, MM, HH, and HM treatments were planted with hybrid poplar cuttings obtained from the Woody Biomass Program at the State University of New York's College of Environmental Science and Forestry. Four hybrid poplar clones were planted with dibbles using a split-plot design with equal proportions of each clone. Knowing asymmetry would occur early with the fast-growing hybrid poplars in the HM treatment, we spatially grouped the hybrid poplar into 4-10 individuals each to minimize early interactions with the spruce (Fig. 3). Three *Populus deltoides* x *Populus nigra* clones (D51, DN10, and DN70) and one *Populus nigra* x *Populus maximowiczii* clone (NM6) were selected because it was unclear which variety would perform best under Maine soil and climatic conditions.

Stubborn natural vegetation in the high-intensity plots required various treatments to ensure the success of the plantations. In 2004, a subsequent 1.68 a.e. kg ha^{-1} glyphosate broadcast was applied, but natural vegetation persisted. Following planting, a broadcast pre-emergent herbicide mixture was applied in 2005 using backpack sprayers with a waving-wand method. The prescription consisted of 1.40 active ingredient (a.i.) kg ha^{-1} of isoxabin (Gallery® 75, Dow AgroSciences), 3.36 a.i. kg ha^{-1} of orayzalin (Surflan A.S.™, Dow AgroSciences), and 0.56 a.i. kg ha^{-1} of oxyfluorfen (Goal® 2XL, Dow AgroSciences). The initial treatment was not completely successful in controlling all vegetation, requiring a subsequent 1.68 a.e. kg ha^{-1} glyphosate broadcast application. Annually thereafter, all competition in the high-intensity plots has been controlled with applications of glyphosate (2 to 5% concentration in water), which will be applied until crop-trees in all plots reach crown closure. Seedlings were protected from herbicide exposure using plastic bags for each application until they reached sufficient size for a directed application. Vegetation control in the southern plots has been relatively successful, but the northern plots still support high densities of sedge (*Carex* spp.). Replanting of both poplar and spruce occurred during spring 2005 because of high initial mortality likely due to the poorly-drained soils across the site.

Measurements

Within each treatment plot is a nested 20 m by 20 m measurement plot where 100 crop-trees were initially selected (Fig. 4). Two types of measurements are made annually from late spring to early summer (May-June). The crop-tree inventory measures the height, height to the base of the live crown, diameter at breast height (d.b.h.), basal diameter, and survival of the 100 crop-trees in each measurement plot. The composition plot inventory consists of five 16-m^2 circular plots which are used to document changes in species composition and stand structure. Each of four composition plots is located 1.14 m inward from a measurement plot corner; the fifth is in the middle of the measurement plot. All woody vegetation ≥1.37 m tall within the subplot is tallied annually by species and d.b.h. is measured. For trees and shrubs <1.37 m tall, species and number of stems are recorded.

Crown diameter, stem form, and damage rating of the crop-trees are measured periodically. Crown widths are measured in the north-south and east-west directions. Stem form is evaluated on the butt log (bottom 3 m) of the trees and placed into one of four categories: no defect, correctable form (e.g., minor crook), questionable form (e.g., moderate crook or minor sweep), or cull (e.g., major crook, sweep, or presence of forks). In conjunction with stem form, damage is periodically measured. Damage to the foliage and main stem including crown dieback, cracks or damage to bole, and decay are examined during this assessment.

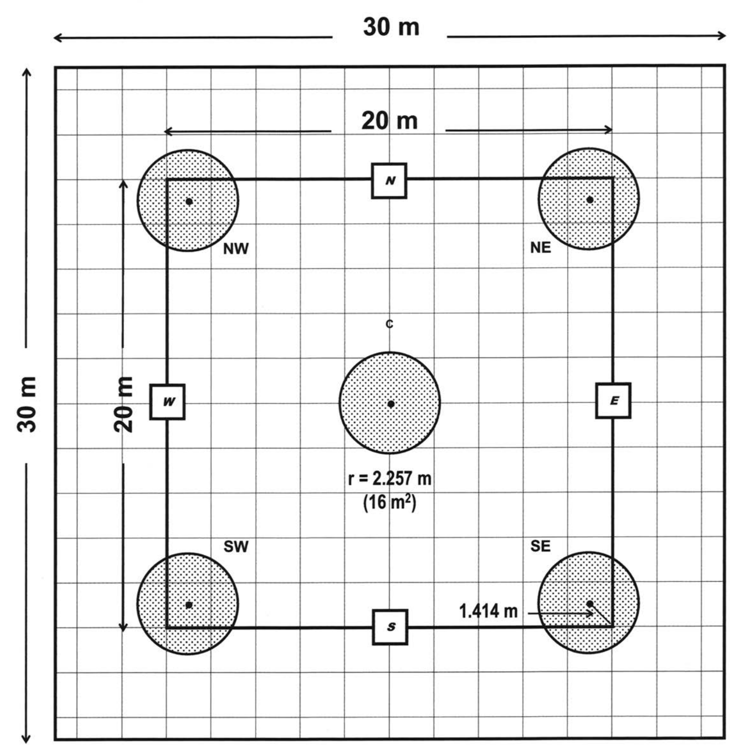

Figure 4.—Layout of 20 m by 20 m measurement plots within each 30 m by 30 m treatment plot. The five shaded areas are compositional plots and total 80 m^2. One crop or "pseudo-crop" tree is designated within each cell of the 2 m by 2 m grid (light dotted lines).

Since the start of the experiment, all of the energy inputs required to install and maintain the experiment have been measured. The energy inputs are herbicide a.i. (kg ha^{-1}), petroleum (L ha^{-1}), and labor (h ha^{-1}).

Analysis

In this paper, the composition plot inventory from the sixth post-treatment growing season (2009) was used to calculate species composition (calculated as proportion of basal area) and mean d.b.h. by species and treatment. These two variables were analyzed with analysis of variance by species, where the independent variable in the models was treatment. Significance was assessed at the $\alpha = 0.05$ level, and all analyses were performed in R version 2.13.2 (R Development Core Team 2011). Additionally, the energy inputs (herbicide, petroleum, and labor) were summed over the 6 years of the experiment and expressed as a unitless energy index to document the energy requirements of the various treatments.

FINDINGS

Tree Composition and Performance 6 Years Post-treatment

Annual measurements of the SIComp experiment have documented the responses of individual crop-trees as well as stand-level compositional and structural changes to the wide range of early silvicultural treatments. Species composition and mean tree d.b.h. by species from the sixth post-treatment season (2009) composition plot inventory are shown in Tables 2 and 3. The treatments were successful in promoting the desired species composition (expressed as a proportion of total basal area by species) after 6 years. The untreated control (C) and naturally regenerated hardwood treatments (LH and MH) were dominated by hardwood species, primarily trembling and bigtooth aspen, paper birch, and red maple (Table 2). The naturally regenerated conifer treatments (LC and MC) were dominated by balsam fir, but hardwood species were also well represented, especially bigtooth aspen and red maple with 13.8 percent (± 6.3%) and 12.3 percent (± 6.6%) in the LC treatment and 2.6 percent (± 6.3%) and 5.2 percent (±6.6%) in the MC treatment, respectively.

Balsam fir was the dominant species in the LM treatment, accounting for 53.1 percent (± 7.7%) of the composition, followed by bigtooth aspen (12.7% ± 6.3%) and red maple (8.8% ± 6.6%). Similarly, balsam fir was the most prevalent species in the MM treatment (30.1% ± 6.3%), followed by gray birch (*Betula populifolia*; 13.3% ± 8.8%), red maple (13.0% ± 6.6%), and paper birch (9.7% ± 5.6%). The

Table 3.—Least squares mean d.b.h. (cm) of the most common species 6 years after treatment. Treatment abbreviations are: C – untreated control, LC – low conifer, LM – low mixedwood, LH – low hardwood, MC – medium conifer, MM – medium mixedwood, MH – medium hardwood, HC – high conifer, HM – high mixedwood, and HH – high hardwood. The between-treatment standard error (cm) is also shown.

	Mean tree d.b.h. (cm)										
Species	C	LC	LM	LH	MC	MM	MH	HC	HM	HH	Standard error
Paper birch	1.1	0.6	0.6	1.3	0.6	1.5	1.0	-	-	-	0.4
Gray birch	1.4	0.2	0.4	0.3	0.2	0.4	0.5	-	-	-	0.4
Bigtooth aspen	3.8	6.3	6.3	3.5	1.9	7.2	4.8	-	-	-	1.6
Trembling aspen	2.5	4.0	3.0	7.8	0.6	3.4	3.5	-	-	-	1.6
Red maple	2.6	1.5	1.5	2.5	0.9	1.4	1.6	-	-	-	0.6
Balsam fir	1.9	3.5	3.2	1.7	3.3	3.3	0.6	-	-	-	0.4
Red spruce	1.3	2.2	1.7	0.1	1.5	3.9	-	-	-	-	1.1
Natural white spruce	0.2	1.4	3.3	-	0.4	-	0.3	-	-	-	0.9
Eastern white pine	2.7	1.3	2.5	0.5	2.2	4.8	0.3	-	-	-	1.0
Planted white spruce	-	-	-	-	0.8	1.0	-	1.2	1.1	-	0.2
Hybrid poplar	-	-	-	-		0.6	0.6	-	6.1	4.6	0.8

high-intensity treatments (HC, HM, and HH) were all successful in maintaining species composition, but in the HM treatment the proportion of white spruce had shifted to 80.7 percent (± 3.2%) from the initial proportion of 68.0 percent, likely due to the low hybrid poplar survival.

Across the treatments, bigtooth and trembling aspen had the largest d.b.h. among all species (Table 3). Both of these species had larger stem diameters in the LH, MH, LM, and MM treatments than the C treatment. The d.b.h. of paper birch, gray birch, and red maple in the low- and medium-intensity treatments was similar to the C treatment. Among conifer species, d.b.h. of balsam fir was slightly larger in the low and medium treatments compared to the C treatment, but red spruce diameter was similar across treatments. Hybrid poplar d.b.h. was greater in the high treatments than the medium treatments, suggesting that fill-planting these shade-intolerant clones with natural regeneration reduced their performance. In contrast, d.b.h of the planted white spruce did not differ between the silvicultural intensities.

Energy Investment through 2009

The energy input index shown in Figure 5 represents the sum of labor, herbicide, and petroleum inputs for each of the 10 treatment of the SIComp experiment through the 2009 spot-application of Accord® Concentrate in the high-intensity treatments. Among treatments, the high-intensity plots had the greatest consumption of energy, most of which was from initial labor to prepare the sites for planting and the subsequent annual control of competing vegetation. In the low- and medium-intensity treatments, energy investments have been greater in the conifer and mixedwood treatments than the hardwood treatments. The dominance of early-successional hardwood species following the 1995 clearcut required greater energy investment to shift species composition.

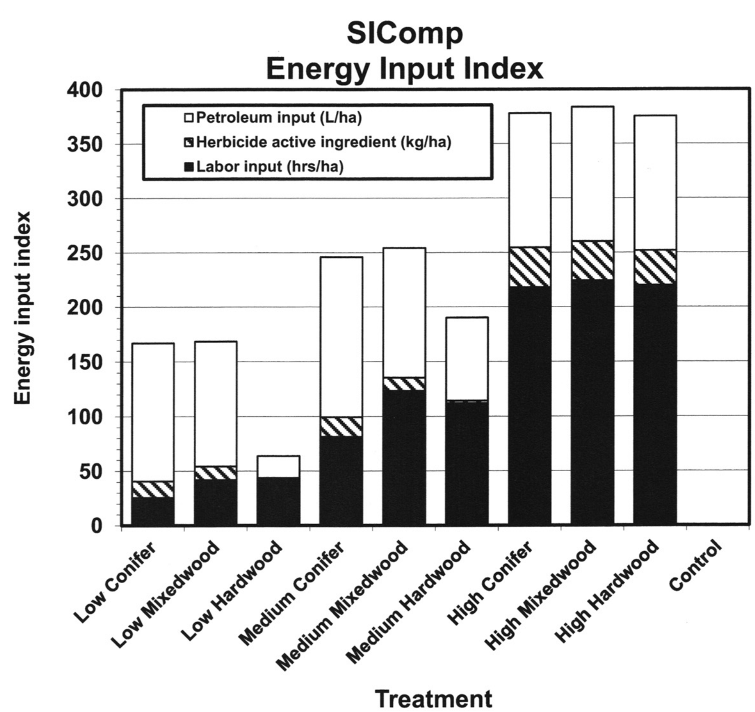

Figure 5.—Energy input index (a unitless measure of energy requirements to initiate and maintain the experimental design) for each of the 10 treatments maintained in the SIComp study through the sixth year of the study. The index is the sum of labor, herbicide, and petroleum inputs.

FUTURE DIRECTIONS

The SIComp experiment is still in its early stages of development. However, the study has already documented substantial differences in the response of young stands to various silvicultural treatments to achieve a range of objectives. It has provided opportunities to use the extreme range of environments created by the treatments to study germination success. Ongoing research will afford other valuable research opportunities, including gaining a better understanding of mechanisms driving forest productivity and carbon accumulation, and collecting data for improving regional growth and yield models. The novel experimental design and unique growing conditions created by the treatments provide a basis for future work on multiple levels. A potential future investigation on the tree level may focus on investigating whether sink or source ecophysiological mechanisms are responsible for the differences observed in productivity. Such an investigation could be linked to environmental conditions and resource availability to assess whether the responses are more closely related to species composition or site-related factors. Plans also call for incorporating the energy data into financial and carbon balance analyses. These analyses will allow us to determine the value of the various species compositions and identify treatments that maximize stand value and carbon sequestration.

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