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silviculture

Sustainability of the Selection System in Northern Hardwood Forests

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The selection silvicultural system is widely recommended for sustainable management of North American cool-temperate tolerant hardwood forests, yet concerns about high-grading, excessive removals, and adequate regeneration persist. We used field measurement of 96 recently harvested stands in the Great Lakes Region of the United States, under corporate, nonindustrial private, and state ownership, to appraise the observance of accepted standards. Current overstory and stumps from harvest were used to estimate pre- and postharvest stand composition, structure, and stocking. Preharvest condition was fully or overstocked in all stands irrespective of ownership. Neither pre- nor postharvest classification of stocking by size class showed statistical differences among landowners, although in absolute terms the greatest removals were on state forests and the least on corporate lands. However, only 23% of harvests overall conformed to accepted standards. Potential consequences in the 41% of stands cut heavily include diminished future yield due to low stocking, and the 36% of stands cut lightly may have compromised regeneration through insufficient disturbance. Hypotheses about landowner differences were not supported, suggesting that many are either unaware of standard practices or choose alternatives; the consequence is possible diminished long-term sustainability in the tolerant hardwood type.

Keywords: silviculture, Arbogast, northern hardwoods, selection system, nonindustrial private forestland (NIPF)

The North American northern hardwood forest has an extensive range, spanning New England and the Great Lakes region of the United States and the St. Lawrence and Acadia regions in Canada. These forests are a significant resource for both forest products and ecosystem services and are actively managed throughout their range. Ownership and objectives vary across the extent of the forest type, making generalizations about the current and future conditions and management of these forests difficult. Despite this, assumptions about the state of the forests, contemporary management regimes, and consequences of management are widespread.

Northern hardwood silviculture has been studied for decades, resulting in published management guidelines that are assumed in academic and government agency publications to be commonly followed and accepted. In uneven-aged systems managed for continued growth and yield, especially those dominated by shade-tolerant species, the single-tree selection system is recommended (Nyland 2002). Long-term studies and simulations have shown that this system ensures a regular supply of timber and improves stand quality over time (Reed et al. 1986, Nyland 2005, Kenefic and Nyland 2007). Although this silvicultural system has been validated repeatedly, concern remains that diameter-limit cutting and excessively high removal levels are more widely used. Harvests of that sort threaten the future reproductive capacity of the forests, especially in nonindustrial private forestland (NIPF) landholdings (Nyland 1992, 2005, Hull 2011).

We used field measurement of actively managed stands across a range of ownership types to assess contemporary silviculture in northern hardwood forests of the Great Lakes region. We sampled harvested stands from a broad geographic area and compared harvests with available guidelines to determine the extent to which they were followed. The dominance of shade-tolerant sugar maple in this forest type and the prevalence of a well-vetted marking guideline make this region an excellent location for a study of modern compliance with a historically recommended silvicultural system.

Northern Hardwood Silviculture

Northern hardwood forests are a prime source of valuable sawtimber and other forest products, including wood and harvest residues for bioenergy production (Munsell and Germain 2007, Davis et al. 2012). Fragmentation of large parcels and a diversity of private

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landowner objectives put increasing pressure on a diminishing managed land base to provide these products (Haines et al. 2011). Although many silvicultural guidelines for sustainable production of sawtimber and pulpwood have been developed and published, a shared antecedent is the Arbogast (1957) guideline.

In 1957, Carl Arbogast, a research forester with the USDA Forest Service, published the "Marking Guides for Northern Hardwoods under the Selection System." This guide has become a central part of northern hardwood silviculture, especially in the Great Lakes–St. Lawrence region in which it was developed. The clearly stated purpose was to instruct practicing foresters on the development of stand conditions that would lead to continuous growth and yield of sawtimber. The target residual stocking and structure were derived from cutting trials in old-growth northern hardwoods in Michigan, first published by Eyre and Zillgitt in 1953. Recommended postharvest stocking for a 10-year cutting cycle consists of a total of 21.8 m^2 ha^{-1} of basal area in trees from 5 to 61 cm, with 14.9–17.2 m^2 ha^{-1} in trees >25 cm. Although the Arbogast guide popularized these recommendations, Arbogast notes that Eyre and Zillgitt's (1953) work was the original source of the target stand structure.

The handbook of Tubbs (1977), a commonly used publication, reiterates the stand structure recommended by Eyre and Zillgitt (1953). Public agency guidelines from Michigan, Wisconsin, and Ontario either repeat or localize the same basic structure as a target for northern hardwood management (Michigan Department of Natural Resources [MDNR] 1986, Ontario Ministry of Natural Resources 1998, Wisconsin Department of Natural Resources 2010). It is therefore no surprise that Seymour et al. (2006) stated that this structure is "virtually institutionalized" in the Great Lakes region and widely used throughout the applicable range. Millington et al. (2010), Nyland (2003), and Niese and Strong (1992) also described it as one of the most commonly used approaches for the selection system. Goodburn and Lorimer (1999) sampled stands in northern Wisconsin, managed using the selection system, and found that 70% of northern hardwood stands (7 of 10) and 80% of northern hardwood-hemlock stands (4 of 5) were harvested in close accordance with Arbogast's guidelines.

Silvicultural guidelines in eastern northern hardwood forests are more varied, although still emphasizing single-tree selection for long-term management of sugar maple-dominated forests. Leak et al. (1987) and Filip (1973) described a target stand structure with a smaller maximum diameter and a lower residual basal area than that described by Arbogast and Eyre and Zillgitt. This accommodates regeneration of less shade-tolerant species that are more common in the eastern range of the forest type. However, Leak et al. (1987) specified that where a stand has a higher proportion of sugar maple, larger sawtimber diameters and higher volumes may be retained. Thus, as stand conditions approach those more common in the Great Lakes-St. Lawrence region, silvicultural recommendations approach those described by Eyre and Zillgitt (1953) and Arbogast (1957).

The Arbogast guide is intended to create or promote uneven-aged conditions in northern hardwood stands. However, the selection system does not require that stands be explicitly uneven-aged when it is first applied. Northern hardwood forests occur in even- and uneven-aged conditions throughout their range. Many even-aged stands have a common history of establishment after clearcutting in the early 20th century (Erdmann and Oberg 1973). Both even- and uneven-aged silvicultural systems have been applied to these forests (Crow et al. 2002), although uneven-aged silviculture by selection system more closely mimics the natural disturbance regime for this forest type (Janowiak et al. 2008).

Arbogast's guidelines specifically accommodate multiple preharvest stand conditions. The conditions are based on size distribution, not age distribution, and thus encompass both even- and uneven-aged stands. Application of the system for converting even-aged northern hardwood stands to an uneven-aged condition was described by Eyre and Zillgitt (1953) and numerous others (e.g., Tubbs 1977, Erdmann 1986, Leak et al. 1987). Further, Eyre and Zillgitt state that "since northern hardwoods attain ages in excess of 200 years without necessarily becoming defective, the question of age can be subordinated. It is the size-class distribution of sound trees that really matters in management of northern hardwoods, and age is not a limiting factor" (p. 27). Erdmann and Oberg (1973) applied the Arbogast guide to even-aged northern hardwood stands in northern Wisconsin and found that the system was effective at rapidly regulating structure toward the ideal condition described by Eyre and Zillgitt. Due attention to tending based on quality in the pole and sapling classes is essential during conversion, as is the effective regeneration of new cohorts, because many intermediate and suppressed trees in even aged stands may have poor future sawtimber potential (Erdmann 1986, Nyland 2003).

Northern Hardwood Ownership

Throughout the northern hardwood forests in the United States, the vast majority of growing stock removals are from state, municipal, and privately owned lands (USDA Forest Service 2012). Harvesting on private lands, both industrial and nonindustrial, far exceeds that of other ownerships. In the United States, NIPF ownership is increasing, and the management of NIPF lands is an important factor in current and future timber supply (Kluender and Walkingstick 2000, Munsell et al. 2008). In Michigan, removals from state lands are also substantial; in 2009, sugar maple removals per unit area on state forests were 1½ times greater than those in Wisconsin and almost 7 times greater than those in New York or Minnesota (USDA Forest Service 2012).

Many studies have shown that NIPF owners are a diverse group, without a set of common traits (Kluender and Walkingstick 2000, Erickson et al. 2002, Potter-Witter 2005). The results from the US National Woodland Owner Survey (NWOS) showed that, in 2004, only 27% of family forest owners had undertaken timber harvesting in the previous 5 years (Butler and Leatherberry 2004). The most recent NWOS in Michigan revealed diverse reasons for timber harvests that occurred in the past 5 years (Butler et al. 2010); primary objectives varied and included improving residual quality, improving hunting or recreation, salvage logging, and cutting solely because "the price was right." Potter-Witter (2005) reported a modal parcel size of 16.2 ha (40 acres) for NIPF landowners in Michigan, smaller than the most common size parcel size (40–202 ha [100–499 acres]) for the United States overall (Butler et al. 2010).

State lands are the most actively managed public holdings in US northern hardwood forests (USDA Forest Service 2012), with management goals and policies set at the state level. For example, the MDNR aims to manage northern hardwood forests as "all-aged stands with an emphasis on quality saw log production," while also considering economics and biodiversity (Price 2008, p. 20). Michigan's state forests have been dual-certified by both the Forest Stewardship Council and the Sustainable Forestry Initiative since 2005 (Stokes 2011).

Corporate forest ownership in the United States has changed dramatically, as large, vertically integrated companies have restructured. Ownership by timber investment management organizations (TIMOs) and real estate investment trusts (REITs) is now far more common. In 1994, the 10 largest landowners in the United States were industrial owners; by 2007, all but 1 of the 10 largest private landowners in the United States were TIMOs and REITs (Bliss et al. 2010). For these owners, the primary management goal is to generate revenue for investors, while also considering ecological function and ecosystem services (Ravenel et al. 2002). Especially for TIMOs, most of the anticipated revenue from forestland ownership is through land appreciation, not forest management (Froese et al. 2007). Corporate forestlands are, however, commonly certified for sustainability by the Sustainable Forestry Initiative or Forest Stewardship Council.

Objectives

Our overarching goal was to test whether the selection system recommended in Arbogast (1957) is widely applied across Great Lakes northern hardwoods. Given the prominence of the system in published literature and management guidelines, assessing harvests at the stand level serves to test how widely it is actually used. We hypothesized that a comparison of northern hardwood harvests with the recommended goal structure would show that overall most stands, regardless of preharvest age structure, are managed using the selection system in accordance with guidelines. We further hypothesized that comparisons would reveal variation among ownership types, because of the varied nature of landowner objectives described in the previous section: State lands would be most commonly managed following published guidelines; corporate and NIPF harvesting practices would be more variable, with corporate harvesting tending to be heavier in larger size classes and NIPF harvesting practices ranging from lighter than recommended to heavier than recommended.

Methods

Stand Selection

A pseudorandom sample of 96 recently harvested stands was selected and sampled in 2010, spanning about 2 million ha of northern hardwood forests bordering lakes Superior, Michigan, and Huron in the United States. All sampled stands were of the northern hardwood cover type (Society of American Foresters [SAF] Cover Types 25, 26, and 27), had a harvested area 8.1 ha or larger in size, and had been harvested within the prior 6 years. Stands under public ownership were within state forests managed by the MDNR. NIPF properties were owned by private landowners, although most harvests were conducted with assistance from consulting foresters. Corporate stands were sampled from the holdings of the three largest owners in Michigan.

State timber harvests were identified through contact with MDNR foresters across the region. A total of 41 stands on state land were sampled across 12 different forest management units (FMUs). NIPF harvests were located using two different methods. Initially, landowners were selected randomly from a previously compiled list. This sample was supplemented by contacting consulting foresters working throughout the study area. A total of 28 nonindustrial private forest stands were sampled, representing the population of NIPF holdings actively managed by individuals who are willing to communicate with researchers and provide access to their lands. Corporate stands were identified by contacting foresters working for three different corporations who own or manage large areas of forestland in Michigan. A total of 27 corporate stands were sampled.

Field Measurements

Ten randomly located 100-m^2 circular plots were identified in the harvested area of each stand, the area identified through conversations with managers and landowners and verified by evidence of marking and harvesting. On each plot, the species and dbh were recorded for every tree 10 cm dbh or larger. All stumps appearing to have been cut in the most recent harvest were also measured. Species, diameter (the average of two perpendicular diameters), and height were recorded for each stump. Diameter at an arbitrary position below breast height was measured for a subsample of standing trees, selected randomly, with the sample size equal to the number of stumps in the plot and the range of heights approximately matching the range of heights of cut stumps. The height at which this lower-stem diameter was taken was also recorded. In addition, a 4-m^2 subplot was established within every other main plot for the sampling of species and dbh on stems $>$1.37 m in height and $<$10 cm dbh.

The initial plot size selections were from a design for an unrelated monitoring study and used a relatively low sampling intensity (total area 0.1 ha/stand) that could be insufficiently precise for a study of stand structure (Guillemette et al. 2012). To test the effect of plot size on the results, a subset of the stands sampled in 2010 was revisited in 2011 (48 of 96 stands). Plots were relocated, and the plot sizes were expanded from 100 to 400 m^2 for the overstory and from 4 to 100 m^2 for the sapling layer. Resampled stands were selected arbitrarily from the original set in equal proportion across owner classes and throughout the original geographic range. The same tree and stump attributes as in the original sample were recorded.

Analytical Methods

The best available data were used for each stand, meaning that data from 400-m^2 plots were used for 48 stands, and data from 100-m^2 plots were used for the remaining 48 stands. Preharvest stocking was estimated using Raile's (1978) equation for predicting dbh from stump height and stump diameter. Localized coefficients for the seven most common species groups were obtained by refitting the equation to field data. These were used for predictions for 95% of measured stumps, and generic coefficients were used for the remaining species. Traditional summary statistics were calculated, including stocking variables such as basal area and trees per hectare, pre- and postharvest. Differences among landowner types in pre- and postharvest basal areas and harvest practices were tested using analysis of variance (ANOVA) and Pearson's χ^2 test. Effect size estimates appropriate for individual tests (η^2 for ANOVA and Cramér's V for χ^2 tests) were also calculated. All statistical analyses were completed in the R environment (R Core Team 2012) with use of the "vcd" package (Meyer et al. 2012) for χ^2 tests.

Stand Management Guidelines

The benchmark stand structure was published by Arbogast (1957) (Table 1); this structure was developed by Eyre and Zillgitt (1953) and republished by Tubbs (1977), as well as reiterated by others. The target structure is defined in terms of both basal area and trees per unit area by size class, and the diameter distribution has a rotated sigmoid shape. Targets for number of stems are given as single values, whereas targets for basal area are given as ranges, with

Table 1. Arbogast's (1957) recommended target postharvest stand structure.

	Residual stocking			
Size class	Basal area (m^2 ha^{-1})	Basal area (ft^2 ac^{-1})	Trees per ha (stems ha^{-1})	Trees per ac (stems ac^{-1})
Saplings (<10 cm dbh)	1.1–2.3	5–10	81	202
Poles (10–25 cm dbh)	2.3–4.6	10–20	26	65
Sawtimber (>25 cm dbh)	14.9–17.2	65–75	21	53
Total	21.8	95	128	320

more emphasis placed on the latter attribute as a metric for assessment and marking. Arbogast defined the target range for basal area as a general rule where "throughout the report…a tolerance of plus or minus 10 square feet per acre [2.3 m^2 ha^{-1}] is permissible" (p. 1). However, this rule is not entirely consistent, because later it was suggested that a narrower range may be appropriate for saplings. We deferred to the general rule (±2.3 m^2 ha^{-1}) because it provided a more liberal criterion against which correspondence with guidelines could be judged.

Comparisons with Arbogast's marking guide were made using pre- and postharvest basal area by product class. Arbogast's guidelines describe five preexisting stand conditions and recommended treatments. Condition 1, "Fully regulated," includes any stand with at least two size classes within or exceeding the acceptable range. Condition 2, "Overstocked with sawtimber but understocked with smaller timber," and condition 3, "Understocked with sawtimber but overstocked with smaller timber," includes stands for which one size class was above the recommended range ("overstocked") and another was below the midpoint of the recommended range ("understocked"). Conditions 4 and 5, "Understocked throughout entire structure" and "Hemlock and/or yellow birch predominate," respectively, were not present in our sample.

Following this classification, the treatment recommended by Arbogast for each stand condition was compared with the treatment measured in sampled stands. For stands of condition 1, the recommended treatment is to harvest mature timber, reducing stocking to within the recommended range in each size class. For conditions 2 and 3 the recommended treatments are different; stands of condition 2 are treated to reduce sawtimber basal area to the recommended 16.1 m^2 ha^{-1}, whereas stands of condition 3 are harvested to a residual basal area of 19.5 m^2 ha^{-1} in poles and sawtimber. Stands were categorized by their level of compliance with these guidelines, using postharvest stocking levels. The following categories were used to classify harvests based on the preharvest condition:

As recommended: Residual stocking fell within Arbogast's (1957) recommended range (condition 1), or residual stocking met guidelines for stands of conditions 2 and 3.

Heavily cut overall: Poles and sawtimber cut to below the recommended range.

Heavily cut in poles: Pole basal area fell below the recommended range; sawtimber fell within the recommended range.

Heavily cut in sawtimber: Sawtimber cut to below the recommended range; pole basal area fell within the recommended range.

Lightly cut overall: Poles and sawtimber retained basal area above the recommended range.

Lightly cut in poles: Pole basal area fell above the recommended range; sawtimber basal area fell within the recommended range.

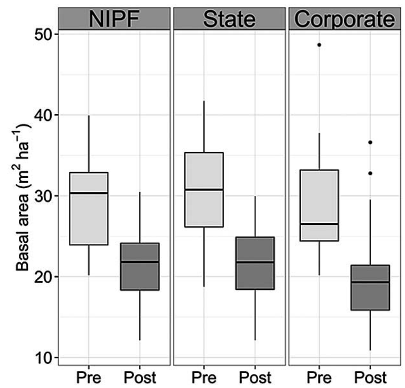

Figure 1. Boxplots illustrating the distribution of pre- and postharvest basal area by ownership class. The top, middle band, and bottom of the boxes represent the 75th, 50th, and 25th percentiles, respectively. Whiskers extend to the furthest data point no more than 1.5 times the interquartile range of the box.

Lightly cut in saw timber: Sawtimber basal area fell above the recommended range; pole basal area fell within the recommended range.

Results

To test the potential impacts of plot size, the analyses were performed using data from both the original 100-m^2 and expanded 400-m^2 plots on the 48 stands that were visited twice. On average, the preharvest basal area estimates were smaller when data from larger plots were used, but differences in the distributions of pre- and postharvest classifications made using data from the two plot sizes were subtle and not statistically significant ($\chi^2(4, N = 48) = 2.91$, $P = 0.57$, Cramér's $V = 0.17$). Because no plot size effect was noted, data from the 400-m^2 plots were used where available, as these data showed less within-stand variance (result not shown).

The median postharvest total basal area was similar across state, NIPF, and corporate ownership classes, at 21.8, 21.8, and 19.3 m^2 ha^{-1}, respectively (Figure 1). Median preharvest total basal area was more variable, with the greatest value for state lands (30.7 m^2 ha^{-1}), followed by NIPF (30.3 m^2 ha^{-1}) and corporate (26.5 m^2 ha^{-1}). As a consequence, removal trends paralleled the preharvest basal area trend. The mean removal over all ownerships was 8.6 m^2 ha^{-1} (median, 7.8 m^2 ha^{-1}), with an SD of 4.7 m^2 ha^{-1}; thus, the average removal was about 28% of preharvest basal area but the range was substantial. ANOVA showed that there was no significant effect of landowner type on preharvest [$F(2, 93) = 2.1$, $P = 0.13$, $\eta^2 = 0.04$] or postharvest [$F(2, 93) = 1.3$, $P = 0.28$, $\eta^2 = 0.03$] basal area.

Although there were no significant differences in residual stocking among landowner types, substantial variation was found within each group. Stand-wise SEs for postharvest basal area by size class

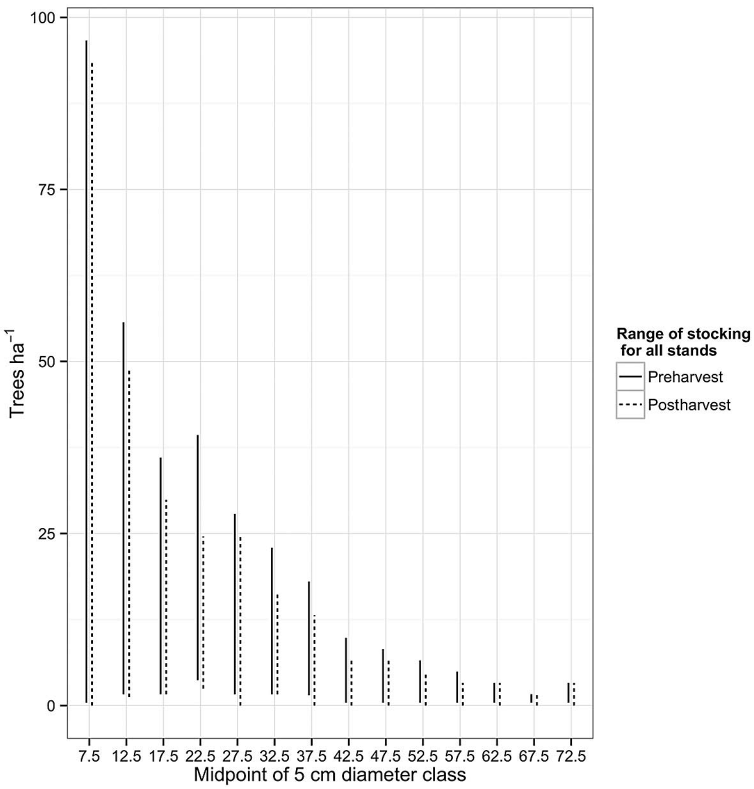

Figure 2. Pre- and postharvest stocking in all stands by size class.

Table 2. Preharvest conditions of northern hardwood stands, after Arbogast (1957).

Condition	Total	Corporate	NIPF	State
1: Fully stocked or overstocked in all size classes	74	21	23	30
2: Overstocked with sawtimber; understocked with smaller timber	7	1	0	6
3: Understocked with sawtimber; overstocked with smaller timber	15	5	5	5

Table 3. Postharvest assessments relative to Arbogast's (1957) marking guide.

Assessment class	Total (%)	Corporate (%)	NIPF (%)	State (%)
Cut as recommended	22 (23)	4 (15)	7 (25)	11 (27)
Lightly cut overall	4 (4)	2 (7)	1 (4)	1 (2)
Lightly cut in poles	11 (11)	3 (11)	3 (11)	5 (12)
Lightly cut in sawtimber	20 (21)	1 (4)	6 (21)	13 (32)
Heavily cut overall	0 (0)	0 (0)	0 (0)	0 (0)
Heavily cut in poles	0 (0)	0 (0)	0 (0)	0 (0)
Heavily cut in sawtimber	39 (41)	17 (63)	11 (39)	11 (27)

(sapling, pole, and sawtimber), despite relatively small plot sizes, were acceptable for the comparisons with guidelines. Of the 288 potential comparisons (96 stands times 3 size classes), only 2.8% had an SE larger than the 2.3 m^2 ha^{-1} range used for comparisons, suggesting that classification of the average stand was reliable. Far more stand-level variance was present, especially in the sawtimber estimates of preharvest stocking; however, Arbogast's preharvest condition categories were much broader, and therefore this variation had little influence on the comparison of stands with marking guidelines. Preharvest stocking of nearly every stand showed an approximately reverse-J shape (Figure 2). In 95 of 96 harvests, removals were distributed across the range of diameters measured.

The classification of preharvest conditions following Arbogast (1957) showed that 74 of 96 northern hardwood stands were in condition 1, fully stocked or overstocked in all size classes (Table 2). Seven stands were overstocked with sawtimber and understocked with smaller timber; 15 stands were understocked with sawtimber but overstocked with smaller timber. Although stems <10 cm in dbh contributed to values of overall pre- and postharvest stocking, the recommended value for these conditions was 2.3 ± 2.3 m^2 ha^{-1}; thus, the stocking for stems of this size did not influence the actual categorization of any stand. No significant differences were found in preharvest stand classification among landowner types ($\chi^2(4, N = 96) = 6.27$, $P = 0.18$, Cramér's $V = 0.18$).

Comparison of pre- and postharvest stocking for each stand showed that 22 stands in total were harvested as recommended, following Arbogast's (1957) guidelines (Table 3). Of the remaining stands, 39 were harvested more heavily than recommended in some or all size classes, and 35 stands were harvested more lightly than recommended in some or all size classes. Postharvest classifications also showed no statistical difference among landowner type ($\chi^2(8, N = 96) = 13.52$, $P = 0.10$, Cramér's $V = 0.27$). To assess the data more generally, stands were pooled into three broader categories ("As recommended," "Lightly cut," and "Heavily cut") and tested. No coarser-scale significant differences were found with larger counts ($\chi^2(4, N = 96) = 8.95$, $P = 0.06$, Cramér's $V = 0.22$).

Discussion

Idealized Northern Hardwood Silviculture

We emphasized comparisons with the ideal structure, popularized by Arbogast (1957), for several reasons. First, Arbogast's marking guide is widely publicized and reproduced, and the associated target structure has been incorporated into regional guidelines if not recommended outright by state and provincial land management agencies across the northern hardwood region. Second, there is a precedent in peer-reviewed literature for use of this uneven-aged guide as a standard for appropriate silviculture. Third, and perhaps most importantly, the guide provides a clear and quantitative tool with which to assess harvesting and future productive potential of northern hardwoods.

Long-term studies across the northern hardwood forest region continue to validate the target stand structure described by Arbogast (1957) when applied in both even-aged stands (for conversion) and uneven-aged stands (for perpetuation). Crow et al. (1981) found 16.1 m^2 ha^{-1} of basal area in trees 11.7 cm dbh and larger, with 20.7 m^2 ha^{-1} overall, to be the ideal basal area for sugar maple stands in Wisconsin and the Upper Peninsula of Michigan on a 10-year cutting cycle. Niese and Strong (1992) found that the net present value of a stand cut to Arbogast's suggested structure was the highest of seven treatments, after 40 years and four harvests. Application of the selection system in an uneven-aged stand in central New York, produced similar yields in two consecutive entries on a 20-year cutting cycle (Bohn and Nyland 2006). In the same stand, a strong relationship was found between diameter and age in trees of all size and age classes, which suggests ingrowth and shows that the repeated cuts were successful as regeneration treatments (Kenefic and Nyland 1999). Both Erickson et al. (1990) and Erdmann (1986) reported consistent growth of northern hardwoods under the selection system, after four harvests on 10-year cycles, in second-growth northern hardwood stands in Michigan and Wisconsin. The selection system was used for conversion from even- to uneven-aged conditions in two of three stands in the study reported by Erdmann and Oberg (1973) and Erdmann (1986), producing consistent yields and rapid regulation of stand structure toward the Arbogast (1957) ideal.

Northern Hardwood Silviculture in Practice

The selection system following Arbogast's (1957) guideline has been shown to create a balanced and sustainable structure, one that is recommended as a "standard approach" for stands dominated by shade-tolerant species, regardless of age (Leak et al. 1987). The distribution of removals and residual structure that we observed together presented no evidence of intent to manage any stand using even-aged or two-aged silvicultural systems. Shade-tolerant sugar maple was the predominant species in all stands measured, and all stands had abundant preharvest basal area in at least two of three size classes. However, the results of our postharvest analyses showed substantial deviation from the target structure in many stands, raising questions of whether the lack of congruence with the recommended target structure resulted from a wider range of possible management objectives and systems than anticipated.

To better understand these results, we contacted a subsample of landowner representatives and asked general questions about the northern hardwood land base and the landowner's organizational philosophies and objectives for managing this forest type. All (100%) of the managers said their organizations consistently prescribed single-tree selection in northern hardwoods, regardless of the preexisting age distribution in any given stand. Those managers who described their average northern hardwood stand as even-aged stated that they prescribed single-tree selection with the expectation that it would result in conversion to uneven-aged conditions and would produce a consistent supply of sawtimber over time.

For postharvest analysis, we used a fairly liberal interpretation of the margin of tolerance stated by Arbogast (1957). Stands were more likely to fall within recommendations under our interpretation than they would have if the ± 2.3 m^2 ha^{-1} margin were applied to the overall basal area rather than to the stocking within each size class. This flexibility in classification accommodated a wide variety of possible selection system goals within the broad structure suggested by Arbogast. Still, only 22 of 96 stands were harvested in a manner indicating compliance with the guideline. This result differs substantially from the findings of Goodburn and Lorimer (1999), who found 70–80% correspondence with the guideline in stands in the same forest type. Our sample size was much larger, and our sample selection process was less strict, which may account for some of the differences. Goodburn and Lorimer (1999) assumed that the managed stands they sampled were uneven-aged, although the majority were second-growth stands being converted to a regulated structure. They prefiltered their sample population to include only stands managed under the selection system, using specific criteria (residual basal area >16.1 m^2 ha^{-1}, maximum diameter >45 cm). If we applied the same criteria to our stands, the majority (65%) would pass; still, of this subset just 29% were harvested in accordance with Arbogast's guidelines.

The observed deviations from target stand conditions described by Arbogast (1957), by cutting more heavily or more lightly, could substantially hinder the future potential of the stand to regenerate, to produce a steady supply of sawtimber, or to respond to other disturbance. Cutting more heavily than the guidelines recommend, especially in cases of high-grading or aggressive diameter-limit cuts, results in diminishing yield and probably diminishing stand quality over time (Erickson et al. 1990, Nyland 2005). Our data suggest there is some cause for this concern; we identified stands in each ownership type that fell into the category of being "Heavily cut in sawtimber only." Some corporate and NIPF representatives cited short-term profit generation as one of the landowner's primary management objectives, which could readily translate into use of single-tree selection with a more focused removal of sawtimber or a lower maximum diameter than Arbogast's guidelines describe.

Of perhaps equal concern is cutting substantially more lightly than even a broad interpretation of Arbogast's guidelines suggests. If standard single-tree selection systems typically do not regenerate shade-intolerant species, that problem is only exacerbated by leaving a higher-than-recommended residual basal area. One-third of the managed stands we sampled were cut more lightly than recommended for regeneration, an ecological concern to be considered apart from loss of possible revenue. Furthermore, pulpwood and timber products could have been removed from these stands without jeopardizing future growth (Crow et al. 1981). Low removals could conceivably indicate management objectives that emphasize nontimber values or a highly selective cut. Regardless, to harvest more lightly than guidelines suggest has opportunity costs of potential revenue and reduces the likelihood that a harvest was a successful regeneration method.

Although our hypotheses were mutually compatible, our findings support neither the assumption that Arbogast's system was widely applied nor our expectations about differences in silviculture among landowner types. Variation was much more substantial within each landowner type than among types. Of the corporate stands, 63% were heavily cut in sawtimber only, whereas 22% were cut more lightly than recommended. Similar results were found in the NIPF stands, congruent with our hypothesis for that owner type. Representatives of both ownership classes with whom we spoke affirmed that average time between entries and average number of previous entries in a given stand were varied, and aspects of stand history were likely to influence the intensity of a selection harvest.

The MDNR develops and implements management plans locally at the FMU. Our results revealed that the FMUs with the highest removal levels were also those with the highest residual volume (data not shown). This finding suggests that these FMUs may be managed with a longer cutting cycle than other FMUs rather than being indicative of overly intense harvesting; Department of Natural Resource employees to whom we spoke described average time between entries ranging from 10 to 20 years. A substantial modification of the target stand structure described by Arbogast (1957) to accommodate a longer cutting cycle and higher residual volume or management using a different target structure may also be implied. Regardless, the vast majority of stands measured were cut more lightly than recommended, although levels were comparable to those found by Schwartz et al. (2005). Therefore, there is conflict among observable harvest levels, the MDNR's promotion of the Arbogast (1957) structure, and their stated goal of sawlog production on State lands.

We recognize that our sampling procedures were not entirely random, and any attempt to extrapolate these findings must carry this caveat. Many NIPF properties were identified with the assistance of consulting foresters, and state and corporate stands were identified by their respective managers. However, we have no reason to suspect that those selections were biased, especially because we communicated neither a priori hypotheses nor opinions for or against any silvicultural regime and because many individuals were involved in the selection process even within each landowner type.

Relevance of Silvicultural Guidelines

Whereas these specific findings are significant in our study area, the potential explanations underlying them are of much broader importance. The results suggest that we might wonder whether the Arbogast guideline has lost relevance, because modern managers choose other systems to meet variable objectives, which may be more or less sustainable. Managers may no longer follow historic silvicultural guidelines designed to meet specific goals because there are consequences that invalidate their relevance; e.g., higher rates of return from alternative guidelines, social pressures resulting in the implementation of alternative rotation lengths or lighter harvest levels, or ecologic motivations such as managing for greater resilience to a changing climate. Those managers to whom we spoke, however, consistently reported production of high-quality sawtimber and revenue, albeit over various management horizons, as primary management objectives. Our results reveal that the selection system as currently implemented is rarely congruent with the historic guideline that was specifically designed to meet those goals. This raises the question of whether the guideline, although widely promoted, has ever been widely and effectively applied. Because stated goals, objectives, and management plans do not necessarily translate to activity in the woods, the implications for future timber and nontimber forest products are quite significant.

Conclusion

The two most significant findings from this study are that selection system guidelines are not widely applied in the northern hardwood forests we sampled and that there are no significant differences among the three landowner types compared. The lack of difference among landowners is primarily due to diversity of realized silvicultural outcomes. We cannot conclude that most stands in any owner type are presently being managed to meet both sustainable harvesting levels and successful regeneration goals by following even a loose interpretation of a proven silvicultural system. Improved education for private landowners and accountability for public managers would help ensure the future productivity of the northern hardwood resource and the integrity of third-party certification programs.

Because harvests do not fall within an acceptable range of intensity for an established silvicultural system, it should not be expected that the future managed landscape will resemble the current conditions or show the improvement in quality and health that would result from widespread implementation of that type of silviculture. This is not a concern unique to our region but rather an important consideration in forecasting the future productivity of the managed land base on any scale. The specific economic and ecological impacts of what is actually occurring are not immediately evident from this study but must be considered in future work.

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