Northern Hardwood Management in Michigan

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Chapter 1: Beyond Arbogast - describing current northern hardwoods management

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Introduction

Northern hardwood (maple-beech-birch) forests are a significant resource of forest products and ecosystem services. These forests are actively managed throughout the northeastern and Great Lakes region of the United States, and in Canada. Ownership and objectives vary throughout the extent of the forest type, making generalizations about the current and future states of these forests difficult. Despite this, assumptions about the state of the forests and the typical management taking place are widespread.

Northern hardwood silviculture has been studied for decades and clear management guidelines have been published, and are assumed by many to be followed. In uneven-aged systems managed for continued growth and yield, single tree selection system management is recommended. Long-term studies and simulations have shown that this system ensures a regular supply of timber and improves stand quality over time. It has been argued that single-tree removal does not appropriately mimic natural disturbances, and that selection system management only allows the regeneration of shade-tolerant species such as sugar maple. Some argue that single tree selection fails to regenerate even desirable shade-tolerant species. The weight of these arguments stems from the assumption that such management systems are widely employed. Simultaneously, however, researchers and practitioners are concerned that widespread diameter limit cutting and excessively high removal levels threaten the future reproductive capacity of the forests, especially in non-industrial private landholdings.

Field mensuration of actively managed stands allows this seemingly contradictory set of concerns to be considered in light of what is observably taking place in the region. Comparison of recent harvests to available management guides suggests what management is occurring, and which set of concerns is more relevant for a region. This study synthesizes available recommendations for managing northern hardwood stands, and describes northern hardwood harvesting practices in Michigan in light of available marking guides and management objectives.

Northern hardwoods stand management

In 1957, Arbogast, a researcher forester with the US Forest Service, published the “Marking guides for northern hardwoods under the selection system”. This marking guideline has become a central part of the northern hardwoods selection system of management, especially in the Great Lakes region in which it was developed. The clearly stated purpose of this guideline was to develop stand conditions that would lead to continuous growth and yield of sawtimber from a productive forest.

Despite the development and publication of numerous marking guides since 1957, the Arbogast (1957) structure is commonly assumed to be widely used in the Lake States. Seymour et al. (2006) referred to it as “virtually institutionalized”. Nyland (2003) termed it the only available marking guide for northern hardwoods; Millington et al. (2010) and Niese and Strong (1992) also consider it the one of the most commonly used selection system management approaches in the region. Goodburn and Lorimer (1999) sampled stands in northern Wisconsin, and found that 70% of northern hardwood stands (7 of 10) and

80% of northern hardwood-hemlock stands (4 of 5), were managed in accordance with Arbogast's guidelines. Webster and Lorimer (2002) used Arbogast's guidelines as the standard against which to compare diameter distributions, and determined that those following Arbogast were "well-regulated". The Arbogast marking guide also continues to be recommended for use in managing northern hardwood forests by the Michigan and Wisconsin DNR(E) on their respective websites.

Recent research continues to validate the goal stand structure described by Arbogast (1957). Crow et al. (2006) found 70 ft^2 of basal area in trees 4.6 inches dbh and larger, with 90 ft^2 overall, to be the ideal basal area for sugar maple stands in Wisconsin and the upper peninsula of Michigan. Relative to stands cut to residuals of 30 ft^2, 50 ft^2, and 90 ft^2 of sawtimber, the 70 ft^2 stocking level had high survivor growth and low mortality. This is very close to the Arbogast structure. Another comparison found that the net present value of a stand cut to Arbogast's suggested structure was the highest of seven treatments, after forty years and four harvests (Niese and Strong, 1992).

Long term studies in New York and Michigan show that marking and harvesting according to Arbogast's recommendations does lead to a consistent yield of sawtimber over time (Bohn and Nyland, 2006; Erickson et al., 1990). A 12 ha stand in western New York's Cuyler Hill State Forest was partially cut in 1973 and again in 1993 (Bohn and Nyland, 2006; Kenefic and Nyland, 2000). A strong relationship between diameter and age in trees of all size and age classes suggests ingrowth (Kenefic and Nyland, 1999).

Cutting trials in Michigan, described by Reed et al. (1986) and Erickson et al. (1990) compared a variety of cutting methods, of which a 70 ft^2 residual basal area cut most closely resembled Arbogast's recommended stand condition. The 22-year (Reed et al., 1986) and 32-year results (Erickson et al., 1990) show that the 70 ft^2 residual cut is soundly in the middle of the different types, using metrics including yield, growth, present worth, and mean future value. These results suggest that while maintaining the target structure described by Arbogast does yield a consistent flow of timber, it may not always be maximized. Publications describing the results of the cutting trials in Michigan have not described the age distribution or age diameter relationships.

Despite its proven strengths and sustainability, there are some purported shortfalls to the management system recommended by Eyre and Zillgitt (1953) and Arbogast (1957). One major concern is the increasing dominance of shade-tolerant species, such as sugar maple, following selection system management (Nyland, 2002). Loewenstein et al (2000) clarified the design of the Arbogast-style management system as intended "for shade-tolerant trees", and Crow et al. (2006) specifically displayed its ability perpetuate and increase the growth of shade-tolerant sugar maple. This shift in species composition, including the increasing dominance of shade-tolerant trees and decreasing prevalence and importance of mid- and intolerant species, has been noted repeatedly (Crow et al., 2002; McGee et al., 1999; Schwartz et al., 2005), although not found in all studies (cf. Niese and Strong, 1992).

Structural homogeneity and simplification do result from this type of management. This homogeneity is intentionally designed by managers, due to the recognized relationship between wood production and tree spacing (Franklin et al., 2002). Management activities and financial predictions are made simpler with spatial and structural uniformity. This sacrifices some of the heterogeneity and diversity in standing and downed dead wood which supports non-timber resources such as wildlife. Arbogast's guidelines do not leave future snags or cavity trees, because the marking guide directs managers to select against any tree that will not live through the next cutting cycle (Arbogast, 1957; Crow et al., 2002; Goodburn and Lorimer, 1998). Several studies have noted differences of ecological significance between managed and unmanaged uneven-aged stands (Crow et al., 2002; Goodburn and Lorimer, 1999; Gronewold et al., 2010). However, Kenefic and Nyland (2007) showed that in the Cuyler Hill long-term study, after two entries, cavity tree and snag densities were still in accordance with published guidelines.

It is certainly likely that landowners are managing in ways contrary to those described by Arbogast- after all, landowners may be managing for objectives other than long-term production of valuable timber. However, a more accurate assessment of activities requires the knowledge of what management is currently occurring. An assessment of compliance with what is perceived to be the most common management system will also elucidate the extent to which that management system is common.

Methods

Study Area

The northern hardwood (maple-beech-birch) forest type is a significant forest resource in Michigan. Northern hardwood forests cover 5.6 million acres of timberland in Michigan, the largest component of Michigan's 20 million acres, according to 2010 Forest Inventory and Analysis data (FIA, 2011). Of this, more than 4 million acres are privately owned, by both industrial private (corporate), and nonindustrial private (NIPF) landowners. Approximately 732,000 acres are US Forest Service lands and 883,000 acres are owned by state and local governments. Average annual removals by species show that the some of the highest volumes of growing stock removed are from the species which dominate this forest type- sugar maple, red maple, American basswood, yellow birch, and American beech. Along with high removal levels, however, the average annual net growth of sugar maple in Michigan is an order of magnitude higher than any other species in the state- 70 million cubic feet of sugar maple are estimated to be added to the growing stock each year (FIA, 2011).

The majority of the northern hardwood forests in Michigan are privately owned, either by individuals and families or by corporate or investment entities. Large tracts of land are also owned and managed by the Michigan Department of Natural Resources. Each landowner type has different goals and objectives. The largest owner-type of private forestland in the Upper Peninsula are timber investment management organizations (TIMO); the second largest landowner-type is Real Estate Investment Trusts (REIT) (Froese et al., 2007). These corporately owned lands are often third-party certified for sustainability through the Forest Stewardship Council (FSC) and the Sustainable Forestry Initiative (SFI). Their primary goal in management is to generate revenue for investors.

Nonindustrial private forestland owners are expected to have a broad range of goals. Repeatedly, studies have shown that non-industrial private forestland owners are a diverse group, not one with a set of common traits (Bliss et al., 1994; Erickson et al., 2002; Kluender and Walkingstick, 2000; Potter-Witter, 2005). For example, Erickson et al. (2002) found that aesthetics were the primary reason for owning woodland, motivating both nonfarmers and farmers. Both groups of landowners also placed environmental protection and aesthetics above economic motivations for either active or passive management. The results from the National Woodland Owner Survey (NWOS) showed that in 2004, only 27% of family forest owners had harvested in the previous 5 years (Butler and Leatherberry, 2004). Similarly, the results of the most recent NWOS in Michigan show that landowners gave a range of reasons for a timber harvest which occurred in the past five years. Those landowners who have harvested their land are the minority. Further, within the group of landowners who have recently harvested, diverse and conflicting objectives exist. It is difficult to aggregate actively managing landowners into any single group.

The Michigan DNR's stated goal is to harvest a minimum of 53,000 acres a year. Northern hardwoods forests are intended to be managed as all-aged stands "with an emphasis on quality saw log production", while also considering economics and biodiversity (Price, 2008). Individual Forest Management Units are responsible to implement this goal on the forests they manage. Michigan's state forests have been dual-certified for sustainable management since 2005. They are certified by both the FSC and SFI.

Stand Selection

A pseudorandom sample of 96 recently harvested stands was selected and measured in 2010. State stands were within State Forests managed by the Department of Natural Resources (DNR). NIPF properties were owned by private landowners; most harvests were conducted through consulting foresters. Corporate stands were sampled from the holdings of three different owners in the Upper Peninsula.

Sampled stands were all of the northern hardwoods cover type, had a harvested area 20 acres or larger in size, and had been harvested within the last 6 years. State timber harvests were sampled proportionally, based on the number of northern hardwoods timber sales open in each Forest Management Unit (FMU) in 2009. The stands meeting our criteria were identified by DNRE employees. A total of 41 stands on state land were sampled.

Non-industrial lands were located using two different methods. Initially, landowners were selected randomly from a previously compiled list of Michigan forest landowners. They were contacted and asked if their properties met the study criteria, and then asked to include their lands in the study. The sample of stands generated from this approach was supplemented by contacting consulting foresters working throughout the Upper Peninsula and northern Lower Peninsula. A total of 28 non-industrial 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 obtained by contacting foresters working for corporations who own or manage large acreages of forest land in the Upper Peninsula; there are no large corporate landholdings in the Lower Peninsula. Three different corporations were included, across which 27 stands were sampled.

Field mensuration

A sample of 10 randomly located plots were measured in the harvested area of each stand. At all measured plots, a circular 100 m^2 plot was established. Species and dbh were measured for all trees over 5 in dbh. Grade (Acceptable or Unacceptable Growing Stock [AGS or UGS]), live crown ratio, and stump diameter and height were measured and recorded for randomly selected trees. All stumps appearing to have been cut in the most recent harvest were also measured. Species, diameter (the average of two perpendicular diameters), and stump height were recorded for each stump. At five 4 m^2 subplots in each stand, species and dbh were measured on stems from 0-5 in dbh.

Approach and hypotheses

Our objectives were to compare management among corporate, NIPF, and state landowners, using current northern hardwoods management in Michigan to available marking guides for the region. Further, to specifically assess the extent to which the Arbogast (1957) marking guidelines are widely applied.

We hypothesized that a comparison of northern hardwoods harvests to the goal structure described by Arbogast (1957) would show that most stands are managed in accordance with the Arbogast guidelines, concurring with results published by similar studies (Goodburn and Lorimer, 1999; Webster and Lorimer, 2002). State lands would be most commonly managed following this guideline; corporate and NIPF harvesting practices would be more variable, with corporate harvesting tending to be heavier in larger size classes.

We further hypothesized differences in land management among state, corporate, and NIPF owners. State harvests would be focused on removal while retaining sufficient or more-than-sufficient stocking for continued growth and yield; corporate harvests would be primarily driven by short-term profit, and NIPF harvests would be more variable in nature, due to the heterogeneous nature of this group of landowners.

Analytical methods

Pre-harvest stocking was estimated using Westfall (2010)'s equation, which predicts diameter at breast height from stump height and diameter at stump height. Localized coefficients for the seven most common species groups were used for predictions for 95% of measured stumps, and Westfall's published coefficients for the remaining underrepresented species. Basic summary statistics were calculated, including forest stocking variables such as basal area and trees per acre, pre- and post-harvest. Species composition was examined and summaries about specific stands and the entire data set were created.

Stand management guidelines

Of the published marking guidelines available for the region, three were distinct. The most comprehensive target stand structure was outlined 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 diameter distribution has a rotated sigmoid shape. The residual basal area recommended is 95 ft^2/acre, in trees ranging from two to 24 inches in diameter. Comparisons were made on the basis of stand basal area by broad size classes (sapling, pole, sawtimber). Arbogast outlines a target structure in terms of both basal area and trees per acre. Margins of error are provided for only for basal error within that management guide, and more emphasis is placed on this attribute as a metric for assessment and marking.

The most succinct was Michigan's "The Compleat Marker", which states simply "mark to 85 ft^2 [per acre] and you'll do fine" (Botti, 1994). Residual basal area of 80 to 90 ft^2 per acre was considered to meet this guideline. The Michigan DNRE also published a brief description of northern hardwood management, which recommends Arbogast's guidelines for northern hardwood stands with at least 100 good quality crop trees per acre (Michigan Department of Natural Resources, 1986). The Wisconsin DNR publicizes a stocking guide for even-aged stands and suggests following Arbogast's structure for uneven-aged stands (Wisconsin Department of Natural Resources, 2010).

Table 1: Target stand structure according to Arbogast (1957)

Size class	Basal area (ft^2/acre)	Basal area (m^2/ha)
Saplings (<10 cm dbh)	10	2.296
Poles (10-25 cm dbh)	15	3.444
Sawtimber (>25 cm dbh)	70	16.072

Arbogast's guidelines set forth five pre-existing stand conditions, and recommended treatments. Stands were first classified by stand condition. Condition 1,"Fully regulated", denotes 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" were applied when one size class was above the recommended range ("overstocked") and another was below the midpoint of the recommended range("understocked"). The acceptable range is ± 10 ft^2/acre, as per Arbogast (1957).

Following this classification, the treatment recommended for each stand condition was compared to the treatment measured in harvested stands. For stands of Condition 1, the treatment recommended is to harvest mature timber, reducing stocking to within the recommended range in all size classes. For Conditions 2 and 3 the recommended treatments are different- stands of Condition 2 are recommended to have sawtimber basal area reduced to the recommended 70 ft^2; stands of Condition 3 are to be harvested down to a total of 85 ft^2/acre basal area of poles and sawtimber. Stands were categorized by their level of compliance with these guidelines, using post-harvest stocking levels, into the following categories:

As recommended- residual stocking fell within Arbogast (1957)'s recommended range (Condition 1), or, residual stocking met guidelines for stands of Conditions 2 and 3

Heavily cut- at least two size classes were cut to below the recommended range

Heavily cut in poles- pole basal area fell below recommended range, sawtimber fell within recommended range

Lightly cut- at least two size classes retained basal area above the recommended range

Lightly cut in poles- pole basal area fell above recommended range; sawtimber basal area fell within recommended range

Sawtimber cut heavily- sawtimber cut to below recommended range; pole basal area fell within recommended range

Pearson's chi-squared test was used to test statistical differences among harvest practices and landowner types.

Results

Initial quantitative comparison of stands showed that there were not significant differences between the management practices on corporate, state, and non-industrial stands. Figures 1 show pre- and post-harvest basal area levels. State removal levels were statistically greater than NIPF and corporate levels; however, state pre-harvest basal area estimates were also higher. There was no significant difference in residual stocking among landowner types, though substantial variation exists within each group. The mean removal overall was 49 ft^2/acre, with a standard deviation of 22 ft^2/acre.

Stands were first compared to those publicly available marking guides for northern hardwoods that differed substantially from Arbogast's guidelines. These were those developed by the Michigan DNRE (The Compleat Marker) and the Wisconsin DNR (the even-aged stocking guide). The even-aged stocking guide was used because stand ages were not known, although it would be inappropriate to use with an uneven-aged stand. More than half of the harvested stands were in compliance with the recommendations from both sources. Table 2 shows the results of comparison of the stands against those two publications.

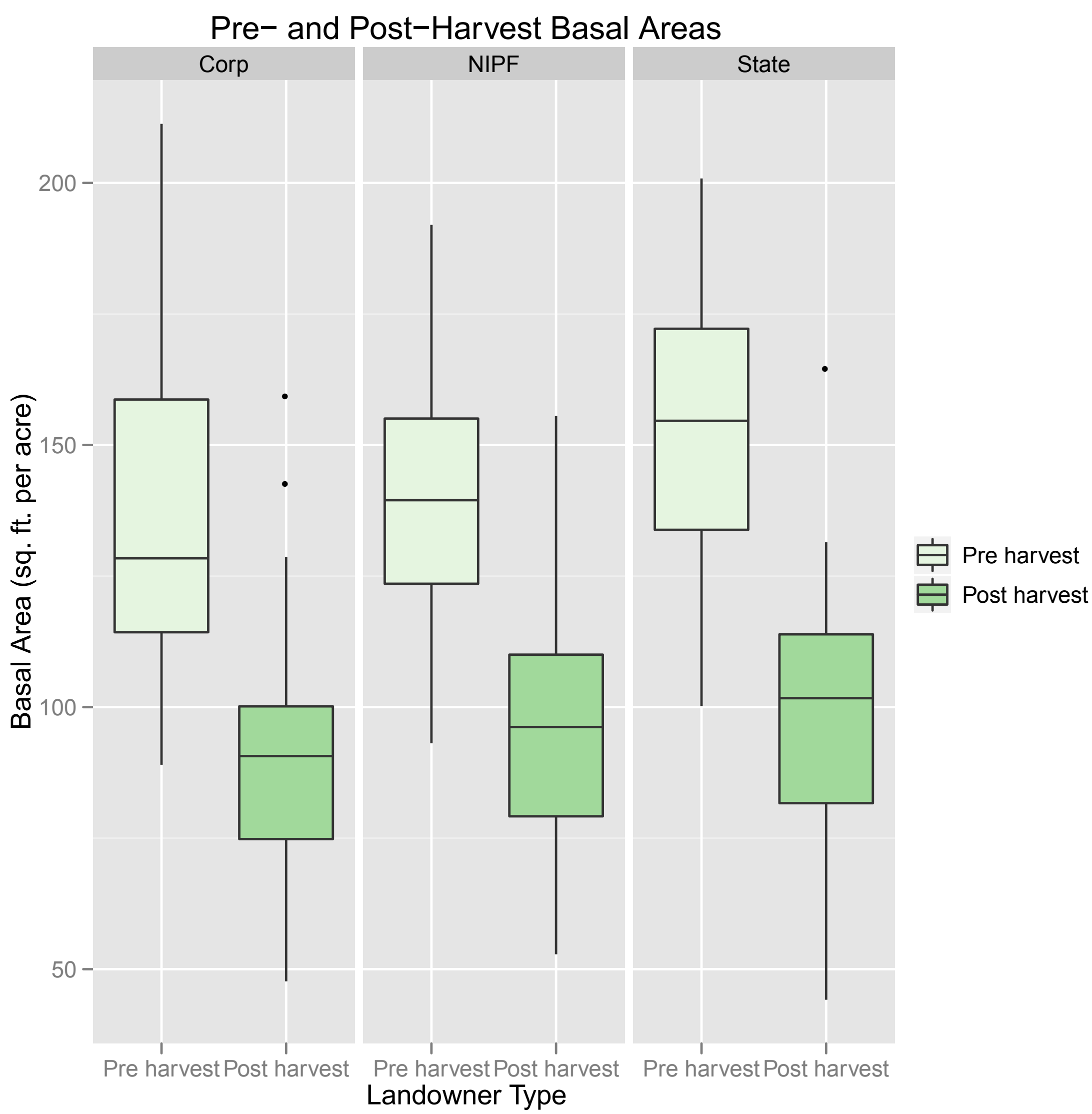

Figure 1: Comparison of pre- and post-harvest levels by ownership

Table 2: Comparison of stands to two management guidelines

	Stands over recommended stocking after harvest	Stands under recommended stocking after harvest	Stands meeting guidelines
The Compleat Marker			
Corporate	14	8	5
NIPF	15	8	5
State	27	9	5
Wisconsin DNR Silviculture Handbook			
Corporate	5	6	16
NIPF	7	4	17
State	8	5	28

The Arbogast guidelines are more comprehensive and allow for a variety of treatments for different initial conditions. The assessment of pre-harvest conditions showed that 81 of 96 northern hardwoods stands were fully stocked or overstocked in all size classes (Table 3). These stands were in a condition where they could readily have been harvested according to the marking guideline published by Arbogast (1957). Seven stands were overstocked with sawtimber and understocked with smaller timber; eight stands were understocked with sawtimber but overstocked with smaller timber. Differences were tested using a Pearson's Chi-Square test. No significant differences among landowner type were found ($\boldsymbol{\alpha}$ =0.05).

Table 3: Pre-harvest conditions of northern hardwood stands, after Arbogast (1957)

		Total	Corporate	NIPF	State
Class 1	Fully stocked or overstocked in all size classes	81	23	23	35
Class 2	Over stocked with sawtimber; understocked with smaller timber	7	1	1	5
Class 3	Understocked with sawtimber; overstocked with smaller timber	8	3	3	2

Comparison of pre- and post-harvest stocking for each stand showed that 20 stands in total were harvested in a manner compatible with Arbogast (1957)'s guidelines. Forty stands were harvested heavily in some or all size classes; 36 stands were harvested lightly in some or all size classes. More detailed classifications are presented in Table 4. Post-harvest classifications also show no statistical difference among landowner type (Pearson's Chi-Squared test, p=0.4775, $\boldsymbol{\alpha}$=0.05). Data were also pooled into three broader categories ("As recommended", "Lightly cut", and "Heavily cut") and tested. No coarser-scale significant differences were found with these larger counts (Pearson's Chi-Squared test, p=0.4794, $\boldsymbol{\alpha}$ =0.05).

Table 4: Post-harvest assessments relative to Arbogast's marking guide

	Total	Corporate	NIPF	State
As recommended	20	4	7	9
Lightly cut	29	8	7	14
Lightly cut in poles only	7	0	3	4
Heavily cut	7	2	1	4
Heavily cut in poles only	1	0	0	1
Heavily cut in sawtimber only	32	13	10	9

Discussion

Our findings suggest that the Arbogast (1957) management guide is not employed in the region as widely as is assumed. Only 20 of 96 stands were harvested in a manner that may have been following Arbogast's marking guideline. This differs substantially from the findings of Goodburn and Lorimer (1999), who found 70-80% compliance with the guideline. Our sample size was much larger, and our sample selection process was less strict, which may account for some of the differences. Overall, however, it seems that management in Michigan is less consistent than what they observed in Wisconsin.

The focus of this study on the ideal structure published by Arbogast was for several reasons. First, Arbogast's marking guide and the associated target structure are widely publicized and reproduced. The states of Michigan and Wisconsin both rely on that guideline and suggest that management in northern hardwoods forests follow it. Second, there is a precedent in peer reviewed literature for use of this guide as a standard for appropriate management. Thirdly, and perhaps more importantly, it provides an opportunity to address some of the often-voiced concerns about the sustainability of this structure in northern hardwoods.

The discussion of Arbogast's guidelines in the literature is often whether it represents what should be the target structure for modern management. This question is of course predicated on the assumption that Arbogast's management guidelines are in fact a widely used management system. These findings suggest that statewide, validated marking guidelines such as those from Arbogast are not being followed.

Arbogast's recommended stand structure has been shown to be a balanced and sustainable structure– one that "can be reconstructed again and again at each stand entry with essentially constant yields from each cut" (Leak, 1996). Moreover, deviating substantially from this structure, either by cutting more heavily or more lightly, could substantially hinder the future potential of the stand to regenerate, produce a steady supply of sawtimber, and respond to other disturbance. Cutting more heavily than the Arbogast guidelines recommend suggests diminishing yields and possibly diminishing stand quality over time. It may also hinder future regeneration, by removing the seed source for the next cohort of seedlings.

Of equal concern is cutting substantially more lightly than Arbogast's guidelines suggest. If standard single tree selection systems may 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 assessed were cut more lightly than recommended for regeneration, an ecological concern to be considered apart. Pulpwood and timber products could have been removed from these stands without jeopardizing the future growth of the stand. Thus to harvest more lightly than management guidelines suggest both costs potential revenue from the most recent harvest and reduces the likelihood that this harvest was a successful regeneration method.

There was much more substantial variation within each landowner type than between types. Fifteen, or 52%, of corporately owned stands were cut more heavily than management guidelines suggest. This matches expectations that these owners are more strongly motivated by short-term profit generation. However, there were also 8 stands cut more lightly than recommended, so no widespread conclusion can be made. The diversity present in the management of NIPF stands was as expected. 10 of 28 stands were heavily cut in sawtimber, indicative of potential high-grading. At the same time, however, 10 of 28 stands were cut more lightly than Arbogast's guidelines recommend. Lighter harvesting could indicate non-timber management objectives, though it might also be indicative of a highly selective cut. The expected diversity in management, therefore, was evident. Concerns about rampant high-grading on NIPF properties are not supported by these findings.

For state stands, the forest management unit is locally responsible for developing and implementing management plans. The FMUs with the highest removal levels were also those with the highest residual volume. This suggests that these FMUs may be managing using a longer rotation than other FMUs, but is not indicative of overly intense harvesting. The vast majority of stand stands measured were cut less intensely than northern hardwoods marking guidelines suggest. This is again surprising, because of the state's goal of saw log production. Marking guidelines developed to meet this goal generally recommend more intense harvesting than found on most state stands.

The two most significant findings from this study are that Arbogast (1957)'s marking guideline is not widely applied throughout the state, and that there are not significant differences among the three landowner types compared. We recognize that our sampling procedures were not entirely random, and any attempt to extrapolate these findings to state-wide trends must carry with it this caveat. The NIPF properties in particular were largely identified with the assistance of consulting foresters. However, the variation in removal levels and post-havest basal areas in stands from landowners who worked with consultants was quite high. It could reasonably be expected that NIPF harvests taking place without consulting foresters would be even more varied, and are probably even less likely to follow a sustainable management system. Similarly, the state FMUs and corporations with whom we worked identified individual stands for us to visit; however, the variation present within each group suggests that they made no attempt to select stands with a certain set of characteristics or to which a certain prescription was applied.

Conclusions

Because our hypotheses were incorrect, it seems likely that the generalizations on which they were based are also inaccurate for northern hardwoods forests of Michigan. There is little difference between the management trends and harvest intensities of NIPF, corporate, and state landowners in this area. All three landowner types show varying management, with some stands being cut more heavily than recommended, some more lightly, and some being managed in ways that have been shown to sustain timber supplies over time.

Assessment of northern hardwoods silviculture requires going beyond Arbogast. This doesn't imply that management has moved beyond what Arbogast described. Long-term studies have validated the stand structure he described. As management objectives have diversified, however, so have management strategies. Individual landowners may have goals that are compatible with the marking guide and residual structure described by Arbogast, or they may not. The results of this study suggest that we might very well wonder if the Arbogast guideline is unsustainable because it is no longer being sustained- not because the proven guideline is no longer working, but because modern managers may have moved beyond Arbogast into other systems which may be more- or less- sustainable. Additional possible management objectives should be quantified and compared to develop a more complete understanding of the current management and future possibilities of northern hardwoods forests.

Our data provide empirical evidence that northern hardwood products are and will likely continue to be widely available in this region. Currently managed forests could in fact be cut more heavily in many places without stocking being reduced beyond recommended limits. There is a continued need for implementation or adherence to sustainable harvesting practices, to improve the quality of residual stands by taking more of the worst trees and leaving more of the best.

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Chapter 2: Development and Testing of a Literature-Based Harvest Taxonomy

Nan C. Pond, Robert E. Froese and Linda M. Nagel

Introduction

Management objectives are increasingly diverse, as landowner aims shift and land ownership patterns change. In the middle of the 20th century, management of northern hardwoods forests was focused on maximizing profit and yield. Researchers began to investigate the best ways to do this while ensuring continued growth in the residual stand. Eyre and Zillgitt (Eyre and Zillgitt, 1953) typified the prevailing attitude when they asked, "the forest needs treatment by the ax, but how?" Such questions led to the development of a marking guide by Arbogast (1957), designed to develop stands which continually produced high-quality sawtimber. The guideline allows for continuity in forest cover, continued ecosystem functioning, and the maintenance of trees in many age and size classes.

Other marking guidelines and target structures for production of volume or specific products have also been published. Adams and Ek (1974) developed mathematically optimized diameter distributions for northern hardwoods at various basal area levels. Martin (1982) optimized Adams and Ek's observations using a Weibull function. Both Martin and Adams and Ek published balanced diameter distributions ($q \approx 1$). All three publications had smaller maximum diameters than Arbogast's. Bare and Opalach (1988) and Gove and Fairweather (1992) revisited Adams and Ek's observations and optimized then for investment efficiency. They also used Weibull functions, and found that unbalanced structures ($q > 1$) were more investment-efficient. Niese and Strong (1992) recommended a management system which optimized the tradeoff between net present value and tree species diversity within a stand. Active management may have short-term or long-term profit horizons; maximizing short-term profit will not result in the same management plan as maximizing returns over a longer time frame.

As management objectives become more and more diverse, new approaches to northern hardwood management have been suggested. It has been argued that the United States has now entered a "social" stage in the evolution of forestry, wherein yield cannot be the main objective in management; from this viewpoint Arbogast's and similar systems would be obsolete because they were designed purely to maximize sawtimber yield (O'Hara, 2002). Citing concerns about the dissimilarity between selection system management and natural disturbances, Hanson and Lorimer (2007) recommended an uneven-aged management system designed to mimic moderate-severity disturbances from wind and fire. Concepts of managing for "old growthness" were discussed by Bauhus et al. (2009); Keeton (2006) proposed a more quantitative management guide to accelerate the development of old-growth structural characteristics.

Forest management activities change stand attributes, both intentionally and unintentionally. Harvesting, a tool used in active management, is presumed to move the development of a stand in a direction deemed desirable by the owner or manager; alternately, harvesting activity may be pre-emptive and seek to avoid the development of undesirable structural or compositional characteristics. Landowner objectives are varied, and while the specific objectives cannot be discerned by field observation, certainly the results of a given harvest can be used to determine the direction in which the stand is being moved.

We have developed a quantitative dichotomous key which classifies harvests based on pre- and post-harvest stand characteristics. Results of this classification across the harvested landscape offer the proportion of harvests which seem to have been conducted for profit maximization, long term volume production, and ecological considerations. Given that management activities flow from landowner objectives and goals, this type of assessment suggests the potential diversity in landowner objectives throughout the region, and will offer insight into future management and landscape conditions.

Classification systems

Classification systems have been used in the past as a tool for rapid differentiation between management activities, especially for large numbers of stands. A classification chart for categorizing hardwood stands based on their current management and future potential was developed for stands in West Virginia (Fajvan et al., 1998). This decision-making tool determines future potential for a stand based on change in mean stand diameter, percentage of acceptable and unacceptable growing stock (AGS and UGS) removed and remaining, and total post-harvest basal area.

Fajvan et al. (1998) concluded that for their study area in West Virginia, silvicultural harvests were carried out on 19% of NIPF stands, 25% of corporate stands and 67% of publicly owned stands. 31 of 101 stands had sufficiently low residual stocking and quality to recommend management other than complete regeneration. Diameter-limit cutting was prevalent, and the removal of large-diameter trees directly influenced the predicted potential for future harvesting. Munsell et al. (2009) found similar results applying the decision chart of Fajvan et al. (1998) for hardwood stands in New York. Using the chart to classify management practices, they found that complete regeneration cuts were recommended for 42% of the stands.

The chart is a rapid, quantitative method for differentiating between harvests based on key attributes. The chart of Fajvan et al. (1998) concludes with either a description of a harvest (shelterwood, crown thinning, or clearcut) or the future potential of a stand (sawtimber potential, fiber potential, or regeneration necessary). Their aim was to describe the future potential for stands, the assumption being that a harvest which was a "silvicultural treatment" will allow the stand to produce sawtimber again in the near future. This is determined by the structure and stocking of the stand. In essence, their chart describes what a harvest was. Why it may have been cut that way is not considered.

Methods

Six possible harvest types and three sub-types were postulated. These types do not speak to actual objectives or motivations. They characterize what a given harvest likely accomplished, regardless of the manager's intention. We hypothesized that a harvest classification system of this fine scale would show clear differences in land management among state, corporate, and NIPF owners.

A binary-decision dichotomous key was constructed. This tool facilitates classification of stands by unique combinations of harvest attributes pointing to plausible silvicultural goals. The chart contents and stand attributes were based off a comprehensive literature review and consultation with silviculturists. The quantities and ranges described were developed solely from the literature, without consideration of the characteristics of the data itself. All harvests were quantitatively classified according to the chart. The distribution of harvest types among landowner types was compared using a Pearson's chi-squared test.

Harvest types were classified using the following dichotomous key (Table 1). Definitions for phrases used in the key and abbreviations used are defined here:

near-complete removal- species of interest is more than 10% of total pre-harvest stocking; more than 80% of species basal area removed

removals even across size classes- at least half of occupied diameter classes have removals within one standard deviation of stand mean; removals occur in 2 or more diameter classes less than 10.8 inches (27.5 cm)

residuals include most large trees- 60% or greater residual stocking, by diameter class, in all diameter classes greater than 18 inches (45 cm); 100% stocking in all diameter classes above 50 cm

significant removal of low-value species- excluding valuable species (sugar maple, yellow birch, black cherry, and oaks), of all species that occupy more than 5 ft^2/acre basal area pre-harvest, as least half of species have 20% removal

MPLY- Maximized short-term profit, low potential for future yield

MPCY- Maximized short-term profit, some potential for continued yield

HeavySan- High removal levels coupled with near-complete removal of white ash or American beech

MRSY- Maximized residual for sustainable yield

Highly Selective Cut- High residual, only valuable trees removed

HRSY- High residual, sustainable yield

LSSC- Late-successional structural characteristics

San- denotes a sanitation cut of white ash or American beech

Table 1: Reticulated dichotomous key of harvest taxonomy

1. Post-harvest BA less than 75 ft^2/acre
    2. No significant removal of low-value species ……………………..…………. MPLY
    2. Significant removal of low-value species
        3. Near-complete removal of WA or AB ……………….Heavy cut, Sanitation
        3. No targeted removal of WA or AB ………………………………… MPCY
1. Post-harvest BA greater than 75 ft^2/acre
    4. Post-harvest BA less than 100 ft^2/acre
        5. Significant removal of low-value species
            6. Near-complete removal of WA or AB ……....MRSY-Sanitation cut
            6. No targeted removal of WA or AB ………………………… MRSY
        5. No significant removal of low-value species ………….……….…. MPCY
    4. Post-harvest BA greater than 100 ft^2/acre
        7. Post-harvest max DBH less than 45 cm
            8. Removals even across size classes
                9. Near-complete removal of WA or AB ……….. ……. HRSY-Sanitation cut
                9. No targeted removal of WA or AB ……………..……HRSY
            8. Removals heaviest in larger size classes
                10. Significant removal of low-value species
                    11. Near-complete removal of WA or AB …..…HRSY-Sanitation cut
                    11. No targeted removal of WA or AB……….. HRSY
                10. No significant removal of low-value species …..….Highly selective cut
        7. Maximum pre- and post-harvest DBH greater than 45 cm
            12. Residuals include most large trees
                13. Mid tolerant species uncut …………………………. LSSC
                13. Mid tolerant species cut
                    14. Near-complete removal of WA or AB……..HRSY-Sanitation cut
                    14. No targeted removal of WA or AB ……… HRSY
            12. Residuals do not include most large trees
                15. Removals even across size classes
                    16. Near-complete removal of WA or AB……..HRSY-Sanitation cut
                    16. No targeted removal of WA or AB ………. HRSY
                15. Removals heaviest in larger size classes
                    17. Significant removal of low-value species
                        18. Near-complete removal of WA or AB..HRSY-Sanitation cut
                        18. No targeted removal of WA or AB …. HRSY
                    17. No significant removal of low-value species ……..

Highly selective cut

Description of harvest classifications

Each unique harvest type was developed through a thorough review of the literature describing uneven-aged northern hardwoods management. The northern hardwoods forest type covers much of the eastern United States and Canada. While the specific numbers and species in the key are unique to this forest type, the concepts and the harvest objectives are similar to those that form the context of management in other regions throughout world.

Type 1: Maximized short-term profit, low potential for continued yield (MPLY)

The maximum profit available to a landowner would theoretically come from cutting and selling all trees in a stand- clearcutting. However, when there is little market for small-diameter trees, it is unlikely that a land manager and operator would choose to remove all trees from a stand. Clearcutting is not a common management practice in the eastern United States. Instead, the goal would be the near-complete removal of valuable trees. This may include removal of all trees above a given merchantable diameter, or a preferential removal of species of higher timber value, leaving behind less-valuable species.

Nyland (2005) compared simulated 14" and 16" diameter-limit harvests to selection system harvests. The initial entry for the diameter limit harvests had a higher financial value than that of two of the three selection system harvests. Over a 90-year simulation, however, the diameter-limit cuts had widely-varied yields. Over the entire 90 years these cuts had neither the highest yield by volume nor by value (Nyland, 2005). Reed et al. (1986) and Erickson et al. (1990) reported the results of an ongoing cutting trial in the Upper Peninsula of Michigan, both showing that the highest revenues were obtained with 12" and 16" diameter limit cuts.

This type of harvest would be evident in part because removals would be concentrated in the larger size classes. Pre-harvest stocking may show a higher maximum diameter than post-harvest stocking; residual stocking would be primarily or entirely in lower diameter classes. Existing management guides such as that published by Arbogast (1957) set a maximum residual diameter of 24". Adams and Ek (1974) used a maximum residual diameter of 18". A residual diameter below 18" may indicate a diameter-limit cut maximizing short-term profit and not a continuous yield of sawtimber over time.

A large decrease in basal area is another strong indication of a harvest aimed at maximizing short-term profit; most management guides developed for field implementation are based on marking to a specific residual basal area for a specific cutting cycle. Arbogast (1957)'s marking guide recommended a residual basal area of 95 ft^2 , (85 ft^2 in trees over 5 inches). Erickson et al. (1990) showed that in a long-term cutting trial, stands with a residual basal area of 50 ft^2 in trees over 10 inches DBH had less residual basal area per acre at each 10-year entry, and thus less

available for harvest, than those cut to 70 ft^2 residual basal area. Fajvan et al. (1998) suggest that there is no sawtimber potential in the next 10 to 15 years in a stand which has less than 50% residual stocking, and has had more than 50% of the AGS removed in more than two diameter classes. A harvest which removes more than 50% of the basal area of at least one high-value species is also suspected to be meeting short-term rather than long-term financial objectives (Fajvan et al., 1998). A decrease in maximum diameter, especially that of more valuable timber species, may also be a characteristic of many stands cut with a diameter limit.

Harvests of this type maximize the profit of one harvest, but will likely not prove the most valuable option over time (Nyland, 2005). They may be dysgenic over time, as a diameter-limit cut may remove the fastest growing trees in an even- or uneven-aged stand (Erickson et al., 1990; Nyland, 2002, 2005). Depending on the severity of the cut and the residual stocking, a harvest of this severity and intensity may leave little potential for the future production of sawtimber (Fajvan et al., 1998). It may also reduce the species diversity in the stand, if less-common but more-valuable species are targeted for removal. Stand structural development may be set back by the removal of the largest trees, with detrimental effects to wildlife communities developing concomitant with the stand.

This type of selective, intense removal does not occur in natural disturbance systems. Hanson and Lorimer (2007) found that moderate-severity windstorms removed on average 41% of stand basal area, however, this included trees in all size classes and species. Natural disturbances of this intensity, heterogeneous in spatial scale, would be expected to allow increased light to reach the forest floor and therefore promote the regeneration of shade-intolerant species. In northern hardwood systems today, some of the less common, shade-intolerant species are yellow birch and black cherry, which are also very valuable. A cut which removes the most valuable timber species could therefore have the opposite effect of an equally severe natural disturbance, as it would remove the seed source necessary for regeneration of those species.

Type 2: Maximized short-term profit, some potential for continued yield (MPCY)

This type of harvest is similar to the MPLY cut, but less severe. It may not be a strict diameter-limit cut, but instead reflect a situation wherein only selected individuals are removed rather than all trees above a certain size. A selective cut of this type focuses primarily on the removal of large, valuable individuals and those of more valuable species. Few if any low-value species are removed. Depending on the initial stand condition, this type of harvest may appear to be severe, if the larger-diameter trees were a significant portion of the overall stand basal area, or it may have a less obvious but still detrimental effect on the stand’s future production potential.

Such harvests have historically been a method of removing only larger stems of one or more desirable species (McGee et al., 1999). This type of harvest is not thought to be an approach which would lead to sustainable growth and yield of a forest, as it includes no directed tending of the residual stand. This type of harvest generally decreases species and structural diversity within a stand.

Type 3: Maximized sustainable yield (MRSY)

Historically, uneven-aged management systems in northern hardwoods were designed to maintain a steady volume yield over time. Management of northern hardwoods is still thought to be focused primarily on this goal. (Crow et al., 2002; Schwartz et al., 2005; Goodburn and Lorimer, 1999; Seymour et al., 2006) and others describe management in terms of this aim, based primarily on the structural conditions described by (Arbogast, 1957). While the balanced age- and size-distribution structure recommended by Arbogast and subsequent managers does have drawbacks, it has been shown repeatedly to be an effective management system for meeting certain goals, specifically, the goal for which it was developed: maximizing the production of “high quality hardwood timber” over time (Arbogast, 1957). Harvesting over relatively short intervals, using a single-tree selection system, is possible.

The level of stocking associated with this harvest type is thought to allow sufficient light to reach the developing understory, while allowing for smaller trees to continually move into dominant positions in the canopy. As with Arbogast (1957)’s system, it may favor the development of shade-tolerant species, specifically sugar maple. Other valuable and locally rare species such as yellow birch and black cherry may be favored, and may be targeted as future crop trees rather than selected for removal. Low-quality stems are selected for removal, which improves the quality of the stand overall, over time (Arbogast, 1957; Erickson et al., 1990; Fajvan et al., 1998).

Type 4: Highly selective cut

This type is similar to the profit-maximization categories MPCY, but with a less substantial amount of stand basal area removed. It occurs when stand residual basal area is relatively high, but removals were very selective. Strictly looking at the residual stand condition can mask that the harvest exclusively removed large trees of valuable species. This type of harvest represents a selective high-grade (Nyland, 2002). The residual stocking is not below sustainable levels, but stand structure and species diversity has been negatively impacted by the selective removal of valuable stems with no tending.

Type 5: High residual, sustainable yield (HRSY)

Observations made during field work suggested that there were stands with a relatively high post-harvest basal area. The HRSY category reflects harvests where the intention was to remove a relatively small proportion of the basal area, or conversely, to leave a relatively large proportion of the basal area. This harvest type includes some tending and removal of poor-quality stems. It is similar to the MRSY type, but has a residual basal area higher than most management guides recommend. A lighter harvest may be the direct result of landowner’s desires and aesthetic preferences. Numerous studies have shown that “lightly managed” stands, in which some dead and dying trees are removed and the understory cleared somewhat, are often preferred by the public (Gobster, 1996). A high residual basal area may also represent an objective of increasing old-forest characteristics in an actively managed stand (Gronewold et al., 2010).

Type 6: Late-successional structural characteristics (LSSC)

This type suggests a more ecologically minded management, which aims to promote structural and functional characteristics of a late-successional stand. Numerous studies have shown that the basal areas of old-growth uneven-aged northern hardwood stands are significantly larger than those of managed stands (McGee et al., 1999; Burton et al., 2009; Crow et al., 2002; Schwartz et al., 2005; Janowiak et al., 2008). Old-growth or late-successional forests are typified by a higher proportion of trees more than 50 cm DBH. Trees with cavities and standing dead trees are common, providing habitat for wildlife (McGee et al., 1999; Keeton, 2006; Burton et al., 2009). Another attribute common to such stands is the prevalence of species such as yellow birch and eastern hemlock (Keeton, 2006; Crow et al., 2002; Burton et al., 2009).

Old-growth stands are more structurally complex and heterogenous than managed stands (Keeton, 2006; Crow et al., 2002; McGee et al., 1999). Management for such characteristics can be accomplished through altering uneven-aged management systems to leave more dead or dying trees, and more trees in the larger size classes (Mladenoff et al., 1994; Gronewold et al., 2010). Alternately, entirely new management approaches have been proposed. Keeton (2006) described a new approach termed “structural complexity enhancement”, which manages to a residual basal area of 34 m^2/ha, a maximum DBH of 90 cm, and a specified rotated sigmoid diameter distribution. Structural complexity enhancement can be combined with production of smaller volumes of timber, assuming a longer entry cycle (20-25 years).

Management for old-growth characteristics is a long-term process. However, certain stand attributes are assumed and are expected to be maintained for it to be evident that a harvest has moved the stand towards this condition.

Sanitation cuts (Sub-category)

A sanitation cutting is defined as “the removal of trees to improve stand health by stopping or reducing the actual or anticipated spread of insects and disease” (Helms, 1998). After disease or insect infection, salvage cutting is often a viable management option. Salvage cutting is “the removal of dead trees or trees damaged or dying because of injurious agents other than competition, to recover economic value that would otherwise be lost” (Helms, 1998). In the northern hardwoods forests of Michigan, two species are threatened by advancing insects and diseases. Beech bark disease (BBD) is the combinatory effect of a scale insect (*Cryptococcus fagisuga*) and a fungal pathogen (*Nectria* spp.) on American beech. The emerald ash borer (*Agrilus planipennis*) (EAB) affects ash species, of which white ash is the most common. Near-complete removal of one of these species, especially if the level of removal is disproportionate to the removal of other species, suggests that the species was specifically targeted for removal. A sanitation cut would be expected to include removal of stems below merchantable size.

Most beech is susceptible to beech bark disease, although some individuals display resistance. Silvicultural recommendations for management of stands soon-to-be affected by BBD include consideration of beech if it is a minor component of the overstory, or potentially targeting a proportion of overstory beech, especially those of lower vigor, to reduce the impact of the disease (McCullough et al., 2001) . Where beech bark disease has already infected some or all trees in a stand, thinning and single-tree selection management systems can be adapted to also specifically target beech of low vigor or high infection levels (Burns and Houston, 1987; McCullough et al., 2001). Silvicultural recommendations do not call for the complete removal of beech from a stand. If most or all beech are infected, however, a beech sanitation or salvage cut may remove most or all of the beech in the stand.

The emerald ash borer is a relatively newly invasive insect, and research is active and ongoing as scientists and forest managers seek the best ways to manage in light of this threat (Poland and McCullough, 2006). The Ash Reduction Model is one example of a management approach which managers can use to obtain a marking guide which would dramatically reduce the ash phloem, the food source, available to EAB without completely eliminating ash from the stand. This model isvintended to be used for pre-salvage thinning, before or immediately after EAB has reached a stand (Storer). Public land management is also being adapted to significantly reduce the presence of ash in northern hardwood stands (of Natural Resources, 2010).

While ash sanitation cutting guidelines do not call for the complete removal of ash in the stand, some go as far as to recommend 99% removal of ash. The Wisconsin DNR suggests maintaining low density of ash species, less than 20% of the stand basal area (Eberhart et al., 2007). An ash sanitation or salvage cut could therefore be identified by the near-complete removal of ash within the stand.

Sanitation/salvage cutting is included as a sub-category for the MRSY and HRSY management types. It may be a contributor to the extreme removal levels which suggest profit maximization (HeavySan). Sanitation cutting is a management technique which seeks to improve stand health and vigor over the long-term, and therefore would be expected to be part of a management approach which maximizes growth and yield over time.

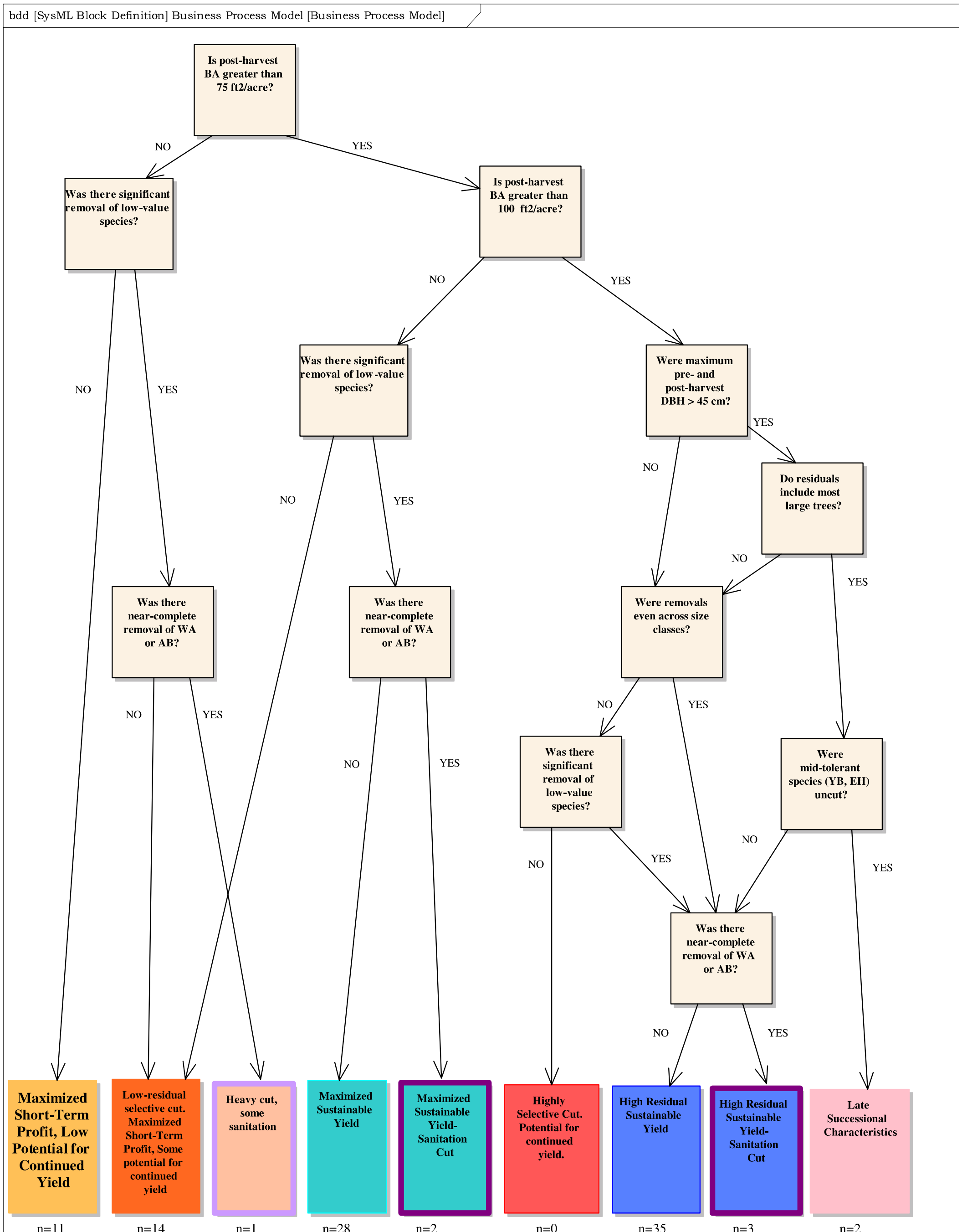
Results

The goal structures from several published target diameter distributions were classified using this key, to test its accuracy. Table 2 shows the results of this test.

Table 2: Assessment of published structures using harvest dichotomous key

Work	Description	Observations and Caveats	Conclusions
Adams and Ek 1974	Optimal diameter distributions for various basal area levels	Assuming that low-value species are harvested:	MRSY
Martin 1982	Investment efficient stocking using several rates of return, by refitting Adams and Ek's work with Weibull function	5% and 3% on Good sites:	MPCY
		All others (1% on Good; 5, 3, 1% on Fair Sites, 3, 1 % on Poor Sites):	MPCY
Bare and Opalach 1988	Re-optimization of Adams and Ek's work to an investment-efficient diameter distribution		MRSY
Gove and Fairweather 1996	Re-optimization of data collected in uneven-aged northern hardwood stands	Not a marking guide-just a definition of structure. If harvests aim to improve the quality of residual, high-value species:	MRSY
		Otherwise:	MPCY
Niese and Strong 1992	Trade-offs between stand diversity and economics	Medium selection treatment is best:	MRSY

The key is presented in graphical form in Figure 1, along with the number of stands falling into each category.



Definitions

near-complete removal: Species of interest more than 10% of total pre-harvest stocking; more than 80% of species basal area removed

removals even across size classes: at least half of occupied diameter classes have removals within one standard deviation of stand mean; removals occur in 2 or more diameter classes less than 27.5 cm

residuals include most large trees: 60% or greater residual stocking in all diameter classes greater than 45 cm, 100% stocking in all diameter classes above 50 cm

significant removal of low-value species: excluding valuable species (sugar maple, yellow birch, black cherry, and oaks), of all species that occupy more than 5 ft2/acre basal area pre-harvest, at least half of species has 20% removal

Figure 1. Graphical representation of harvest classification key, and results.

Table 3 shows the breakdown of harvest types by landowner. There were no significant differences among owner types (Pearson's Chi-Squared Test, p=0.3004). Corporate stands were, overall, more often harvested in manners reflecting short-term profit goals. 26% of stand were harvested in a manner which maximized short-term profit; 29% were harvested in a manner suggesting maximized yield over time, and 36% were harvested with a higher residual than recommended for maximizing yield and regeneration.

Table 3: Harvest classifications by landowner type

	Corporate		NIPF		State		Total	
MPLY	6	22%	4	14%	1	2%	11	11%
MPCY	6	22%	2	7%	6	15%	14	15%
HeavySan	0	0%	0	0%	1	2%	1	1%
MRSY	7	26%	10	36%	11	27%	28	29%
MRSY-San	1	4%	1	4%	0	0%	2	2%
HRSY	6	22%	10	36%	19	46%	35	36%
HRSY-San	0	0%	1	4%	2	5%	3	3%
LSSC	1	4%	0	0%	1	2%	2	2%
Total	27		28		41		96	

Discussion

Application of this chart to the 96 harvests in question did shed more light on management in Michigan. Six stands, representing a range of removal levels and residual basal areas, were apparent sanitation cuts. Two stands with high post-harvest basal area had characteristics that may indicate management for late successional characteristics. Stands in which only a few trees were removed, if those were the most valuable trees, would also have been distinguishable from the other high-residual stands. Those stands which were cut more heavily than marking guides suggest were also separated into two categories suggesting future potential based on residual stocking. Eleven of 96 stands were cut so heavily that there is likely low potential for continued yield; 14 of 96 stands were cut selectively, having both high- and low-value species removed. This indicates some tending and therefore suggests there is potential for continued yield and stand improvement in the future. The distribution of high-profit and high-residual cuts was very similar for the three landowners (Table 3).

The proportions of harvest intensities are similar to those found when compared to the Arbogast guidelines. One third of stands were cut more heavily than most guidelines suggest; one third were cut more lightly. Both of these extremes are noteworthy because they simultaneously affirm and dispel stereotypes. Corporate landowners are harvesting with greater intensity than NIPF and state managers (44% vs 21 % and 17%). Conversely, 26% of corporate landholdings were cut more lightly than would likely result from an objective of pure profit-maximization.

The corporate landowners had a higher percentage (though not significantly higher) than the others for the MPLY and MPCY harvest types. Three large corporate landowners were included in this study, all of which being privately owned companies would be primarily interested in generation of revenue. Even these companies, however, had 55% of harvests classified as MRSY and HRSY, indicating management conducive to continued growth and yield over time.

NIPF harvests were very diverse, matching possible objectives reported in the NWOS (Butler et al., 2010). Only 6 of 28 NIPF stands were harvested in a manner that suggests that profit-maximization was a bigger factor in management decisions than long-term sustainability. This supports that hypothesis, while opposing the idea that NIPF landowners are high-grading or implementing profit-driven harvests with no concern for future growth and yield.

Perhaps the most surprising was the diversity of management observed in stands owned by the State and managed by the Michigan Department of Natural Resources. Previous studies have suggested that the state has a multiple-use approach, where stands are managed for timber products, wildlife habitat, and aesthetics (Schwartz et al., 2005). This same study expected state stands to be harvested with a residual of 80 ft^2/acre, and in fact found an average residual basal area higher than that; the minimum stand basal area they measured was 74.6 ft^2/acre, whereas the minimum state stand basal area in this study was 44 ft^2/acre. The wide variety in state harvesting practices may indicate differences among Forest Management Units, or widely varying management objectives. Nevertheless, that 19% of these stands were MPLY or MPCY harvests suggests that the management of state land is also subject to profit maximization at the expense of long-term forest growth and yield.

Conclusions

This system of harvest taxonomy facilitates a rapid and in-depth evaluation of pre- and post-harvest characteristics of each stand. The consideration of attributes beyond simple basal area readily differentiated harvests that otherwise appeared similar. The result is a more complete understanding of what effect each harvest had on the stand structure and what objectives may have been.

Both residual stand composition and harvest removals suggest possible management goals, and a consideration of silviculture and landowner intentions beyond those described by Arbogast provides a more complete picture. Recent management in Michigan suggests that there are many harvests that do not remove as much timber as management guidelines allow. However, this behavior may result from non-timber management objectives, and the availability of this additional wood for harvesting is not certain. In 26% of harvests, long-term productive capacity was decreased through short-term profit maximization. This is also somewhat concerning and suggests a need for all members of the supply chain to be conscious of the source of their materials. Overall, the results of this field study and analysis suggest that most of Michigan’s forests are managed for continued growth and sustainability of timber and non-timber resources, though management is diverse within each ownership.

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Chapter 3: Modelling carbon sequestration in managed northern hardwood stands

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Introduction

The effects of forest management on carbon stocks have become increasingly important in the effort to combat climate change with forests (Birdsey et al. 2006). When Europeans began managing North American forests they were mostly concerned with harvesting timber to meet the need of the expanding population. In the latter half of the 20th century more research was focused on the impact management was having on the landscape including wildlife, water resources and nutrient pools.

In northern hardwood forests of Michigan, the most common silvicultural regime is single tree selection. Single tree selection allows managers to prescribe a wide variety of different prescriptions with different harvest intensities for a multitude of objectives (Nyland 2002).

With the growing biofuels industry managers may be increasing the amount of carbon taken from forests. Before managers beginning to harvest vast amounts of currently unmerchantable wood there needs to be sound science investigating the long term impacts of this type of harvesting. There are two ways to accomplish understanding impacts of forest management over time; long term studies, of which few are established, and using forest models to project stands through time.

The USFS Forest Vegetation Simulator (FVS) has been widely used by forest managers and scientists to examine long-term impacts (Crookston and Dixon 2005). This chapter will highlight the importance of proper initialization of the model when projecting over long periods of time for a specific goal and the effect of alternative silvicultural regimes on carbon profiles through 100 years.

Methods

Approach

Our overall approach was to simulate the development of each of the stands that were field measured for 100 years. This allowed us to compare the effects of assumptions used in model initialization on the outputs, and decide on the most realistic scenario. Then, a 100-year simulation under various management regimes could be compared to examine the relationship between silvicultural decisions and the fate and development of various carbon pools.

Site Selection

The same stands sampled by Pond et al. (see Chapters 1 and 2) were used in this study. These included three different ownerships: non industrial private landowners, corporate landowners and land owned by the State of Michigan. After obtaining a list of timber sales on state land from the Department of Natural Resources and Environment (DNRE) the number of stands to be measured were proportionally allocated from the proportion of stand which were harvested in 2009 in each of the forest management units (FMU) and contacted the office of the of the FMU's to find stands to sample. For NIPF land, a mix of consulting foresters and a list of survey respondents from a survey completed by Michigan State University was used to obtain permission to sample 30 stands. Lastly, three local forest management companies were asked for 10 stands each to make sure that one company's management technique was not used as a surrogate for the forest industry as a whole.

After obtaining information from landowners and resource managers, stands were delineated in ArcMap 9.3 or 10 (ESRI, Redlands, CA). Using the random point generator, 12 plot centers were created in each stand to minimize the need to relocate plots in the field. Plot centers were loaded in Garmin GPSmap 76Cx (Garmin International, Olathe, Kansas) using DNRGarmin, a free program from the Minnesota DNR. In all, there were 101 stands that were inventoried.

Field Measurements

We used a fixed area nested plot design to measure vegetation. To increase the number of plots, therefore the number of stands, that could be sampled we split the plots into those deemed "intensive" and "extensive", where on extensive plots fewer measurements were taken.

At intensive plots a 100 m^2 circular plot was established to measure all trees above 10 cm diameter at breast height (dbh). Starting from due north, we measured dbh for each tree that fell in the plot and recorded the tree species. At the first tree of each species encountered in the plot we measured height using an Impulse 200 laser hypsometer (Laser Technology, Centennial, Colorado), estimated crown ratio visually and determined if it was acceptable or unacceptable growing stock according to the definition used by the Forest Inventory and Analysis (FIA) protocol. For each tree where height was measured we also measured a diameter at stump height (dsh) and the height from the ground it was measured at. While measuring the live trees we also measured all stumps that appeared as if they were cut during the previous harvest to estimate stump diameter and height. After finishing the overstory data, we measured down dead wood using the line-intersect distance sampling method (LIDS; Affleck 2008). Finally, a picture was taken from plot center facing north so the plots could be more easily reestablished in the future.

To measure the sapling layer we used a nested 4 m^2 subplot. This plot was located 2.82 m to the east of the center of the main plot to minimize damage before the plot was measured. In this circular plot all woody stems less than 10 cm dbh and greater than 0.5 m in height were measured for dbh (if above 1.37 m tall), diameter at 10 cm and height. The smallest plots used were 1m^2 quadrats. There were two of these plots located 2.82m due north and south of plot center. Here we recorded the percent cover of herbaceous vegetation by species where possible. After that percent cover of the forest floor was recorded in the following classes: leaf litter, bare soil, coarse woody debris, fine woody debris, rocks and other. Near the edge of the quadrat we placed a 25 cm by 25 cm metal frame and measured depth of leaf litter. The leaf litter in the frame was removed and placed in a common paper bag for transport back to the lab. In the middle of the southern sampling frame a 5.08 cm wide by 20.32 cm deep soil core was take using a core sampler and slide hammer from AMS Inc. (American Falls, ID). Those samples were stored in plastic soil bags and brought back to the lab for later analysis.

At the extensive plots only the overstory and ddw measurements were taken.

Model Initialization

After entering the data into Microsoft Excel, we used the program "Format4FVS" to convert the data to the file format used by FVS. FVS requires three distinct files to organize data. The lowest level file has the extension .fvs and contains the individual tree data such as species, dbh, height and so forth. The middle level is called a stand list file and has the extension .slf. As the name implies this file holds data pertaining to the stand and sampling design including site index, geographic location, number of plots and inverse of pot size. The highest level of organization is the location file with the extension .loc. This file simply aggregates .slf files to make them easier to access.

There were four major hurdles to overcome before we could start addressing the effect of silvicultural treatments on carbon pools. First, the Forest Service had recently released a test version of the Lakes States variant of FVS. We wanted to see if using the new version would significantly impact the results by comparing standing volume and differences in carbon pools when the simulation was ran out 100 years. Using a t-test for differences, the results indicated there was a significant difference between the two models. Further exploration of the data showed the test version handles small tree growth much more realistically than the older version.

The next hurdle was to determine if site index would affect the model. For the stand list file, soil site indices using the SSURGO soils layer was obtained from Michigan Center for Geographic Information (MI CGI) in ArcMap 10. Unfortunately the SSURGO soils layer does not include all counties in the Upper Peninsula. For stands where no soil data was present the modal average of 63 feet for sugar maple. After finding the site index a simulation of all of the stands for 100 years was ran using site index and compared that to a previous simulation that did not include site index in the stand list file. The simulations in which site index were included were deemed to be more appropriate.

Thirdly, we compared different regeneration models. The eastern variants of FVS use the partial establishment model, which only adds regeneration for species which are known to stump sprout (LSvar Test user guide). This obviously does not represent true on the ground conditions. From the literature we gleaned a regeneration model used by Manomet Center for Conservation Sciences in a report they prepared for the State of Massachusetts. The author of that model also published an article that explained the model in more detail (Nunery and Keeton 2010). We also developed our own regeneration model as an FVS "addfile", in which regeneration was based on overstory species present and the intensity of disturbance. We used the same method as above to test the regeneration models against data from the Bourdo Cutting Trials (Campione, unpublished data). The Bourdo Cutting Trials were established in 1956 as a demonstration woodlot to show landowners different harvesting levels (Bourdo 1957).

The last step in determining the best initialization of the model was to test the affect of down dead wood on the performance of the model. As stated above, down dead wood was measured at a minimum of 5 plots in each stand. LIDS lends itself to reporting down dead wood in total tons/acre however FVS requires the data be put into size classes. To accomplish the transformation we used data from Pfeil et al. (2007). He collected data from similar forests in the northeastern United States on the distribution of down dead wood. In absence of user data FVS does add down dead wood to stands based on cover type. We compared the default to the actual values measured on site to determine if the measured values made a significant difference on the projection.

Modeling Silvicultural Regimes

We used the classification system developed by Pond et al. (see Chapter 2) to identify the silvicultural alternatives practiced in the stands selected for simulation. We identified 5 silvicultural regimes that fit previous harvests of the same stands we are using. The most intensive regime was designed to maximize short term yield (MPLY). To simulate this goal, we used a 16-inch diameter limit thin from above with a residual basal area of 80 ft^2/acre to simulate “high grading”. The next most intensive practice is classified as a selective harvest with some potential for continued yield (MPCY). This prescription is similar to the previous regime but with a high basal area retention. The middle of the range of silvicultural treatments is considered managing for maximized sustainable yield (MRSY). This is accomplished by utilizing the Arborgast (1957) regime with a residual basal area of 75 ft^2/acre in the 6-24” diameter classes. The next step towards less intensive management leads to a high residual basal area sustainable yield by utilizing the Arborgast marking guide with a residual basal are of 90 ft^2/acre in the 6-24” diameter classes (HRSY). The least intensive silvicultural regime is characterized by managing toward late successional characteristics (LSSY). We used individual tree selection harvest using a q-factor approach with a q of 1.2 and a residual basal area of 105 ft^2/acre.

To look for significant differences amongst the silvicultural regimes we used repeated measures ANOVA. To more fully understand the interactions we used Tukey’s Honestly Significant Difference (HSD) post hoc test to see which of the interactions were significantly different. This allowed us to see the effect of both harvest regime and biomass removal.

Results

Model Initialization

The first parameters tested were the model variants used. There were significant differences between the production and experimental variants ($p < 2.2e\text{-}16$). Figure 1 shows the differences in total carbon over a 100-year time interval with the blue line being the experimental version. Since this analysis was completed the FVS staff have made the experimental version the default available on the USDA web page.

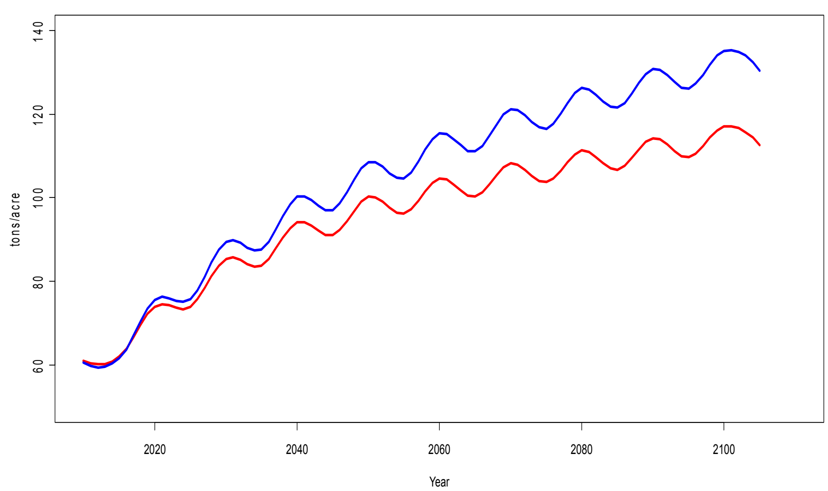

Figure 1. Average projected carbon sequestered using the "experimental" and "production" versions of the Lake States FVS Variant.

Because FVS uses site index as a driver for growth equations we tested the default values against site index values obtained through the SSURGO soils layer for Michigan (Michigan CGI). For stands where no site index value was available we assumed a value of 63 ft (base age 50) for sugar maple, as that was the modal value for those stands where we were able to obtain SI estimates. There was no significant difference between the two model outputs.

Another parameter that can be specified buy the user is the amount of down dead wood in each stand. Using the experimental variant, we simulated carbon sequestration both with and without default values (Figure 2). Again FVS has default values and data was collected in each stand. There was no significant difference between the default and actual values in the model output.

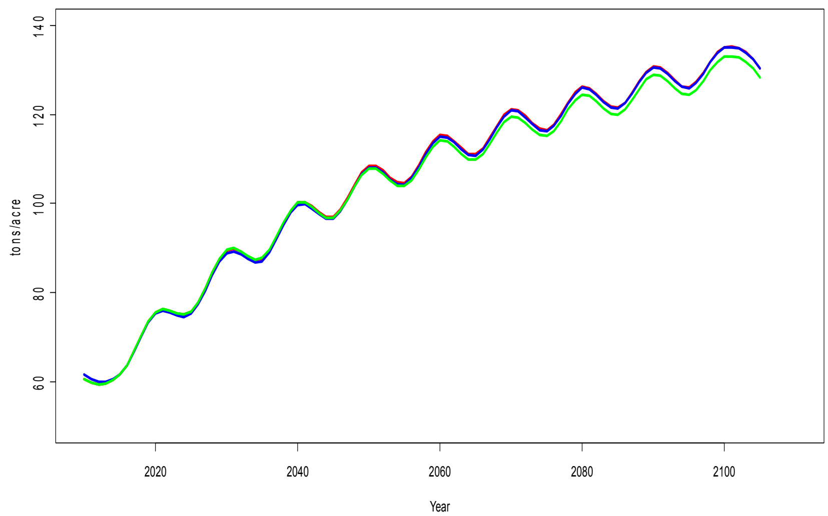

Figure 2. Average projected carbon sequestered using default and stand-specific initialization.

The last initialization parameter tested was amongst regeneration models. We tested the default "stump sprouting" regeneration model against the regeneration model developed by Nunery (2010) and a model we developed. There was a significant difference amongst all three of the models. Both of the developed regeneration models predicted more total carbon at the end of the simulation period.

A summary of all t-tests can be found in Table 1. The choice of variant and regeneration model have a significant impact on model performance while the inclusion of site index and actual down dead wood measurements did not.

Table 1. Summary of results from statistical tests to compare default and stand-specific FVS initialization assumptions.

Parameter	*p*-value
Old vs. New Variant	$< 2.2e^{-16}$
Site Index vs. Default	0.610
Regeneration Models	0.046
Actual DDW vs. Default	0.213

Simulations of Management options

The ANOVA analysis shows a difference firstly among management types and secondly between harvests with biomass and without (Table 2). The results of the ANOVA only tell part of the story. To delve more deeply into the results, the Tukey's (HSD) showed there were significant differences between all of the silvicultural regimes except between low retention single tree selection system and 16 inch diameter limits with low retention.

Table 2. ANOVA output for comparison among managment options.

Factors	Df	Sum of Squares	MSE	F Value	Pr(>F)	Significance
Silvicultural Prescription	4	202233	50558	265.927	$< 2.2^{e-16}$	***
Biomass Removal	1	4214	4214	22.167	2.913e-06	***
Interaction	4	3120	780	4.103	0.00267	**
Residuals	860	163504	190			

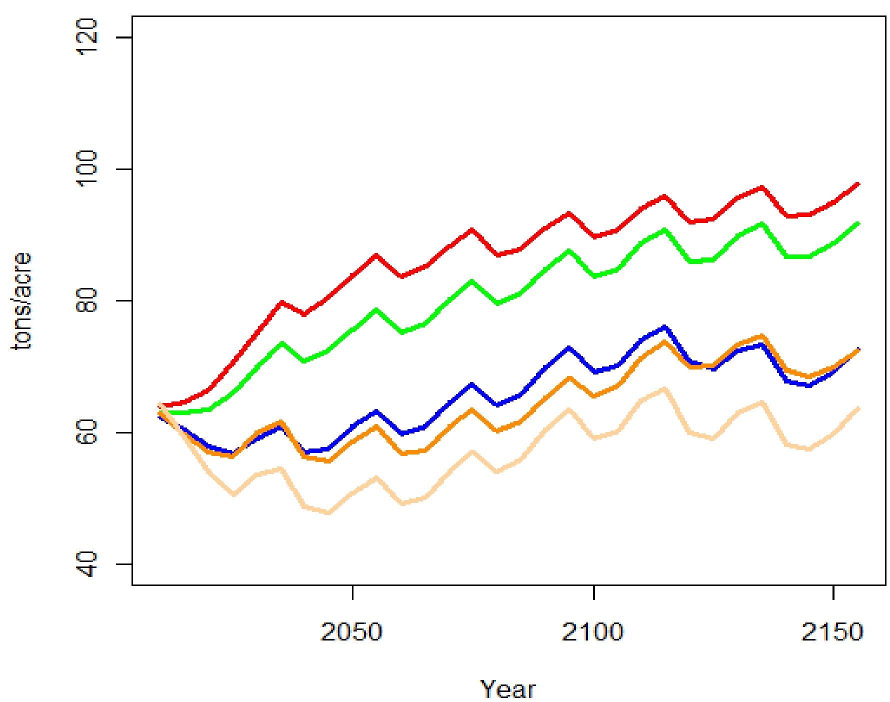

Figure 3. Total forest carbon profiles under alternative management regimes. Legend: red = LSSY; green = HRSY; blue = MRSY; orange = MPSY; peach = MPLY.

Figure 3 shows the total forest carbon profiles of the stands under different management regimes through time. Harvested carbon is not included. As expected, old growth management (LSSY) did sequester the most carbon followed by the high residual sustainable yield (HRSY). Both of these options gained carbon even during the initial harvest and continued to gain carbon nearly gaining 150% through 150 years.

The other management options followed in order of harvesting intensity. All three options (maximum sustainable yield [MRSY], maximum profit – continued yield [MPCY], and maximized short term profit [MPLY]) initially lost carbon however by the end of the simulation period MRSY and MPCY had a net gain of carbon.

The MPLY option actually had lower total carbon in 2155 (62.0) then in 2010 (63.0). However, the below ground and forest floor pools of carbon increased from 9.5 and 18.7 tons per acre to 12.2 and 25.3 tons per acre respectively (Figure 4).

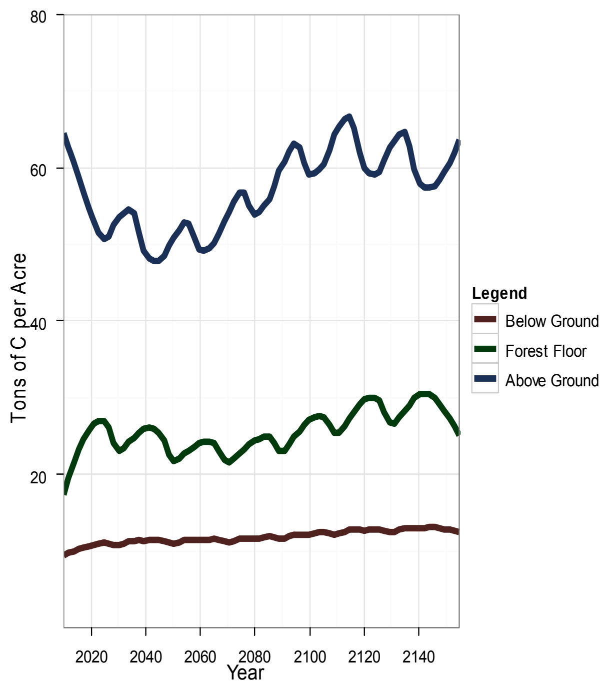

Figure 4. Carbon by pool for the MPLY option.

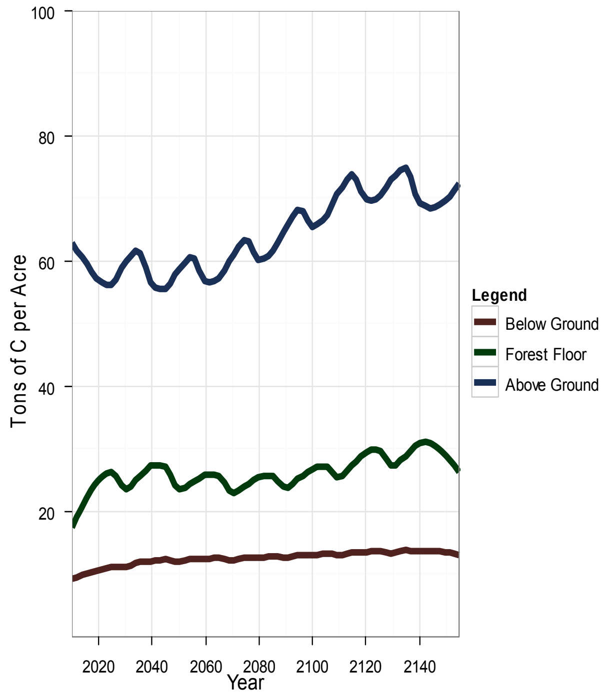

Figure 5. Carbon by pool for the MPCY option.

The maximum profit – continued yield (MPCY) option did gain carbon in all pools however there was enough above ground carbon removed in the first two harvest to reduce the total stand carbon to 52.2 tons per acre (Figure 5). Over the 150 year simulation period aboveground carbon went from 62.0 to 71.2 tons per acre.

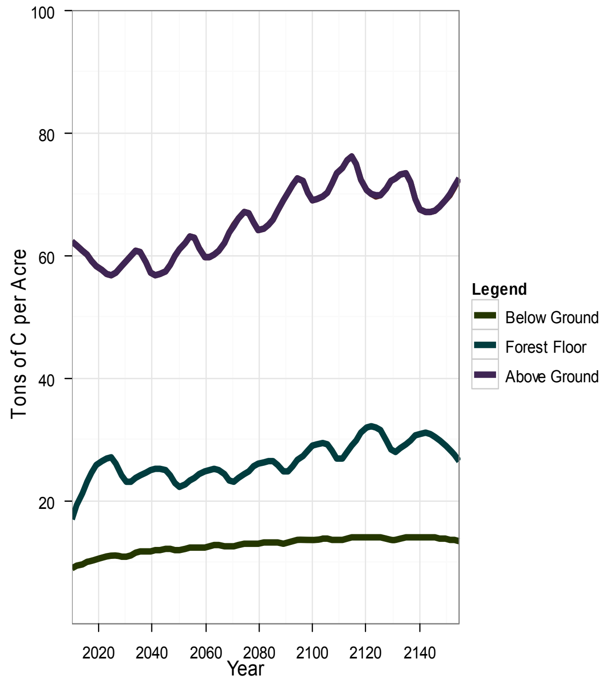

Figure 6. Carbon by pool for the MRSY option.

Managing for maximum sustainably yield (MRSY) produced a similar dip in the carbon stock as MPCY only not as dramatically (Figure 6). Again, total stand carbon grew from 62.0 to 71.2 tons per acre but the total stand carbon trends downward near the near of the simulation. Forest floor carbon grew from 18.7 to 26.7 tons per acre over 150 years.

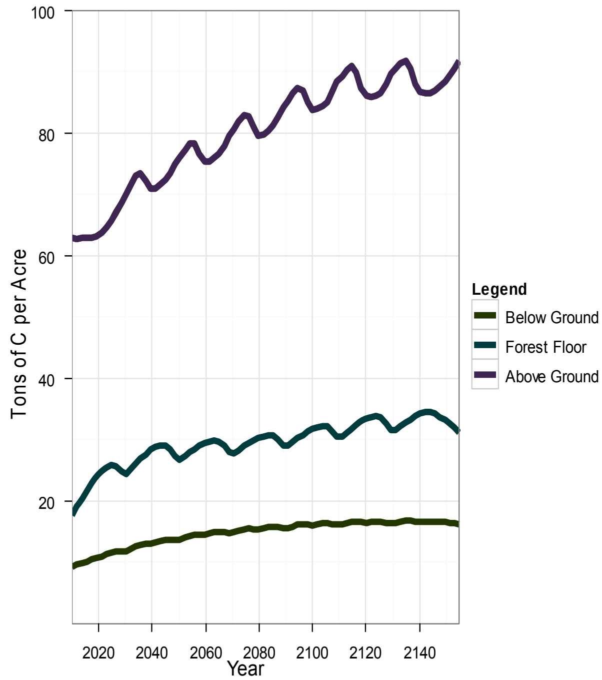

Figure 7. Carbon by pool for the HRSY option.

The HRSY option, which simply retains more basal area than MRSY, increased in all pools throughout the simulation (Figure 7). Starting at 62.0 tons per acre of total carbon, it increased to 90.4 tons per acre over 150 years.

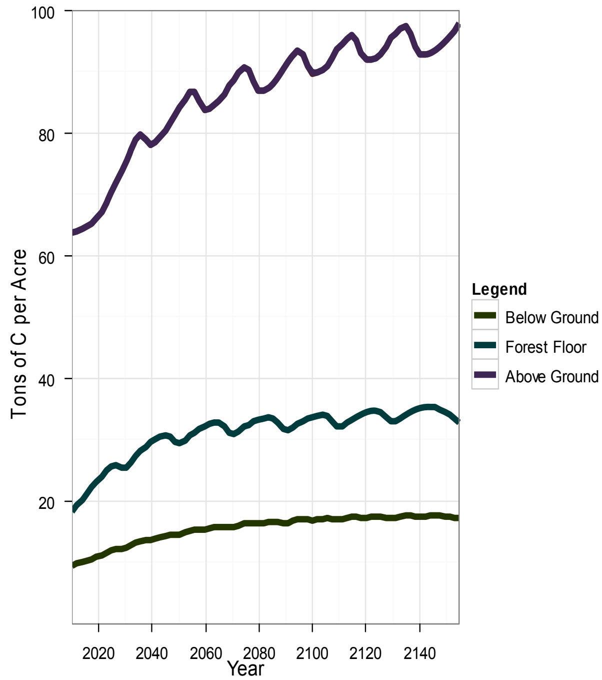

Figure 8. Carbon by pool for the LSSY option.

Managing for old growth characteristics sequestered the most carbon on a per acre basis (Figure 8). The total stand carbon after 150 years of management was 96.6 tons per acre. Looking at the individual pools the below ground carbon grew from 9.7 tons per acre to 17 tons per acre, the forest floor grew from 18.8 tons per acre to 32.9 tons per acre.

Harvest removals from the simulations follow with the most intensive management options removing the most material from the stands (Table 3. Summary of carbon in harvested forest products.).

Table 3. Summary of carbon in harvested forest products.

Management Option	Tons of C/ac Removed	Cords/ac Equivalent
MPLY	108.5	94.9
MPCY	91.7	80.2
MRSY	89.0	77.9
HRSY	80.4	70.4
LSSY	74.8	65.5

Discussion

Much discussion has been had about which forest growth models are appropriate for certain desired outcomes (Stage 2006, Scheller 2007). After the model is picked it is very important to determine the level of initialization one needs in that model to achieve the desired outcome. In FVS there are various levels of simulation initialization that can be used ranging from the default region variant to adding specific growth modifiers from the stands. There were significant differences on a 100-year scale between using default values and improved small tree growth models and including regeneration models (Table 1). There is a trade off in the amount of time it takes to collect the initialization data and the outcomes.

The regeneration model developed for this study has proven to be useful in long time period simulations. However, most variants of FVS do not include a regeneration model beyond stump sprouting. More investigation is necessary to make the simulations more believable.

The results of the modeling exercise show that the high residual sustainable yield (HRSY) option continued to sequester carbon from the first harvest forward in time, and still removes an average of 10 cords per acre during each harvest. When comparing HRSY to the most intensive management (MPLY) the average removed on each acre during harvest is only different by 3.5 cords.

The report by Manomet Center has raised many questions about the long-term sustainability of biomass harvesting and the ability of biomass to be an alternative to fossil fuels. The preceding data suggests that not only are current management techniques not harmfully impacting carbon storage in the northern hardwood stands but even actively managed forests are still gaining carbon. That may be in part due to past land use history in the Great Lakes. The state of Michigan was heavily cut over and subsequently burned at the turn of the 20^{th} century. Most of the forests are second growth forests which have never reached an "old growth" state so have not reached a plateau of carbon accumulation.

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