# An Exploratory, Post-Harvest Comparison of Ecological and Economic Characteristics of Forest Stewardship Council Certified and Uncertified Northern Hardwood Stands

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**ABSTRACT.** As more forest entities worldwide consider pursuing Forest Stewardship Council (FSC) certification, a critical question remains on whether stand-level management impacts differ between certified and uncertified forests. To begin to answer this question, we measured forest structure on three FSC-certified stands, three uncertified stands, and six adjacent unharvested reference stands (12 stands total) composed primarily of sugar maple (*Acer saccharum*) on non-industrial private properties in

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central Vermont, USA. The certified and uncertified partial harvests reduced total tree biomass and live tree carbon storage by one-third compared to reconstructed pre-harvest conditions. Both treatments also contained significantly lower densities of saplings and some mid-size trees compared to non-harvested references due to similar impacts from harvesting. The net present value of merchantable sugar maple over 10 year projections was consistently lower on certified than uncertified stands, but this difference was insignificant at discount rates from 4–8%. The certified stands contained significantly greater total residual volumes of coarse woody debris (standing and downed) than uncertified stands, although the debris was smaller than that found in unmanaged mature forests. Overall, our data suggest that FSC-certified harvested stands in northern hardwood forests have similar sugar maple timber value, aboveground live tree carbon storage value, similar live tree structure, and greater residual coarse woody debris than uncertified harvested stands.

**KEYWORDS.** Forest certification, Forest Stewardship Council (FSC), forest structure, northern hardwoods, sustainable forest management

# *INTRODUCTION*

## *FSC Certification*

Since the 1992 United Nations Commission on Environment and Development (UNCED) conference, over 150 initiatives on sustainable forest management have developed around the world (Holvoet and Muys, 2004). Many of these initiatives involve the Forest Stewardship Council (FSC), the first established international certification program (Sedjo et al., 1998), and the program most actively promoted by environmental organizations such as the World Wildlife Fund (WWF). Although FSC-certified forests represent only 5–7% of total productive forest land in North America (over 21 million hectares), the certification program has grown rapidly, more than 15-fold in a decade from 1996 to 2006 (WWF, 2007).

The voluntary "soft law" of certification protocols theoretically involves higher standards than the mandatory "hard law" set by governments (Hickey, 2004). Indeed a primary aim of FSC is to implement standards that "make certified management practices better than traditional practices" (Cauley et al., 2001). However, empirical studies have not been conducted to determine whether certified forests yield greater ecological and socio-economic benefits than similar uncertified forests. Several studies have used auditors' field reports on preconditions that must be fulfilled prior to certification as evidence of improvement in management practices. These studies demonstrated that FSC-certified entities, relative to their pre-certified condition, improved management plan documentation and monitoring, reduced soil erosion from roads, widened streamside buffers, increased coarse woody debris retention, and improved designation and protection of high conservation value forests (Gullison, 2003; Newsom et al., 2006). Yet, neither of these studies showed whether these improvements were significant enough to distinguish certified from uncertified forests in the field.

The economic and ecological benefits of certification seem particularly difficult to distinguish in the northern hardwood region of the northeastern United States (U.S.) where partial harvests (i.e. shelterwood, group selection, single tree selection, and thinning) are commonly employed to regenerate intermediate and shade-tolerant merchantable tree species. Investigating whether certification has stand-level impacts is particularly important here as high grading or timber mining–selective removal of commercially valuable trees on the basis of size, species, and merchantability grade–is widely practiced on non-industrial private properties in the northeastern U.S. (Kittredge et al., 2003). High grading reduces future stand economic value and homogenizes stand structure (which may consequently reduce biodiversity and retard tree regeneration). Our exploratory study, meant to spur additional research, investigates whether northern hardwood stands harvested under FSC standards differ economically and ecologically from similar uncertified stands.

## Study Approach

The objective of our study was to compare the economic and ecological conditions of recently harvested stands on FSC-certified properties against uncertified harvested stands. We chose to focus on the stand spatial scale because it remains the primary scale for silvicultural applications (Smith et al., 1997). We chose several aspects of stand structure as comparative metrics because stand structure can provide information on live tree characteristics, economic timber value, and ecological fine-scale habitat for amphibians, birds, small mammals, and soil fauna (McGee et al., 1999; MacNally et al., 2001; McElhinny et al., 2005). Stand structure metrics also prove germane to certification. The 10 FSC criteria include: (1) compliance with laws and FSC principles, (2) tenure and use rights and responsibilities, (3) indigenous peoples' rights, (4) community relations and worker's rights, (5) benefits from the forest, (6) environmental impact, (7) management plan, (8) monitoring and assessment, (9) maintenance of high conservation value forests, and (10) plantations. The sixth criteria on environmental impact specifically involves coarse woody debris retention in the U.S. northeast regional standards ("6.3.c.1 Coarse woody debris in the form of large fallen trees, large logs and snags of various sizes is maintained in accordance with scientifically credible analyses") (FSC, 2007).

We use the terms "certified stands" and "certified harvests" throughout our paper with the recognition that forest properties in our study, rather than individual stands or forest managers, were certified. We acknowledge that certification assessments are based on entire properties outside of the scope of our research including at a minimum: ecological factors such as road condition and protection of high conservation value areas, management system factors such as GIS maps and pre- and post-harvest inspection checklists, and social factors such as public recreation access and worker compensation and safety.

Our study takes a retrospective approach to investigate whether FSC certification is correlated with particular stand-level features–whether FSC forests has a distinguishable stand-level identity–regardless of whether certification actually caused those features by changing pre- and post-certification management practices. Alhough studies show that certification changes some management practices (Gullison, 2003; Newsom et al., 2006), we cannot eliminate in our study the possibility of self-selection of those owners and managers who customarily employ ecologically oriented management practices predisposing themselves to FSC certification.

## *METHODS*

### *Study Properties*

Three properties were selected from a master list of fifteen FSC certified properties in Vermont provided by Rainforest Alliance's Smartwood program. Each of the three properties was under separate ownership and managed by a separate consulting forester. These three properties were the only ones that met four criteria characteristic of harvested property in the state: (1) sugar maple dominated-northern hardwood cover type; (2) non-industrial private ownership (including family and non-profit organization ownership, but excluding governmental, timber industry, or timber investment management organization (TIMO) ownership), (3) 5–25 ha harvest size in one homogeneous stand, and (4) partial harvest treatment.

Ten uncertified properties also meeting these criteria were identified from Vermont current use property tax lists provided by state foresters for the same harvest time period (April-October, 2003) as the FSC certified properties. We limited our selection to the same counties (Addison and Windsor counties in the Green Mountains of central Vermont) as the FSC-certified properties to improve the likelihood that the uncertified properties would share these four characteristics. This area receives approximately 1,000 mm of annual rainfall-equivalent precipitation and the soils are composed primarily of sand and silt derived from glacial till. We randomly chose three of these ten uncertified properties for our study. Selecting comparable certified and uncertified properties on the basis of forest type, ownership, and silvicultural treatment (size and type) reduced potentially confounding variables but also reduced sample size.

All of the stands were dominated by sugar maple, but also included a variety of other species (in approximate order of occurrence): yellow birch (*Betula alleghaniensis),* American beech *(Fagus grandifolia),* white ash (*Fraxinus americana*), eastern red cedar (*Juniperus virginiana*), eastern hemlock (*Tsuga canadensis*), and American basswood (*Tilia americana*). Cores from trees in separate canopy positions indicated that all of the stands contained at least two cohorts separated by 20+ years (multi-aged stands). Stands were harvested using chainsaws and cable skidders, and commercial harvesting had not occurred in any of the stands for at least 15 years prior to the recent harvests, based on an assessment of visible stumps and land manager accounts. Analysis of biogeophysical characteristics also indicated that the stands were similar, and thus comparable in terms of elevation (450–550 m with slopes between 20 and 30%), mean soil pH (4.0–4.6), and dominant sugar maple age (60–70 years) (Table 1).

## Data Collection

Forest inventory plots were established during June-July, 2004 on the three uncertified harvested and three certified harvested properties. Two stands were selected for measurement plots at each of these six properties (12 stands total): (1) the stand of northern hardwood cover type harvested during spring to fall of 2003; and (2) a portion of the same stand greater than 5 ha, or an adjacent stand of northern hardwood cover type, that had not been recently harvested to use as the reference stand. These non-harvested

TABLE 1. Biogeophysical characteristics of recently harvested certified and uncertified stands (mean ± one standard error)

| | Cert1 | Cert2 | Cert3 | Mean Cert (n = 3) | Uncert1 | Uncert2 | Uncert3 | Mean Uncer (n = 3) |
|---|---|---|---|---|---|---|---|---|
| Elevation (m) | 500 | 500 | 600 | 530 (±33) | 500 | 400 | 550 | 480 (±44) |
| Slope (%) | 33 | 24 | 27 | 28 (±2.7) | 27 | 20 | 17 | 21 (±3.0) |
| Soil pH ($-\log(H^+)$) | 4.3 | 4.6 | 3.8 | 4.4 (±0.2) | 4.1 | 5.2 | 4.0 | 4.2 (±0.4) |
| Dominant tree age (yrs) | 75 | 55 | 75 | 68 (±6.7) | 65 | 65 | 55 | 62 (±3.3) |

reference stands were established following Carey (2000) to characterize pre-harvest conditions–in this case, coarse woody debris volumes, merchantable timber value, and some aspects of tree diameter distributions–that would be difficult to reliably reconstruct in a retrospective study. We rely on reconstructed stands whenever possible for pre- to post-harvest comparisons, but use the six non-harvested reference stands for more reliable information on these three variables.

In the harvested stands, measurement plots were established using randomly determined distances and directions. Ten to 12 plots were established based on variance of tree basal area. If at least two harvested stumps did not fall within a 0.02 ha circular subplot, plot centers were relocated immediately adjacent to the closest recent stump to more fully capture the impact of harvesting. Although this relocation procedure could result in biased sampling, the procedure was only used in one of the 12 stands where occasional rock outcrops caused patches of uncut forest to be retained within the harvested stand.

In the non-harvested reference stands, sample measurement plots indicated that structural characteristics were less variable than recently harvested stands, therefore five to seven measurement plots were randomly established in these stands. The non-harvested reference data were pooled together from all six stands on certified and uncertified properties for streamlined statistical comparison and also to develop reliable pre-harvest conditions typical of a northern hardwood stand, independent of minor differences in site characteristics and management history. The pooled non-harvested reference stands were compared statistically to all six pre-harvest stands (reconstructed from stumps) to establish their validity in terms of live tree characteristics.

Mean basal area, tree biomass, average diameter, stem densities, and relative densities of sugar maple were not significantly different between pre-harvest reconstructed stands and pooled non-harvested reference stands (Tukey-Kramer HSD test, $p \geq 0.41$) (Table 2), and thus we hold that the references provide reasonably accurate analogues of pre-harvest conditions.

Forest vegetation was sampled using a nested plot design. The use of different sampling methods tiered to ecological characteristics is common in nested plot designs (Shivers and Borders, 1996). For example, we used large fixed radius plots to sample rare standing woody debris, variable radius plots to expedite sampling of stems ≥ 10 cm dbh, and fixed radius plots to accurately sample small stems and downed woody debris. In the largest, fixed area 0.1 ha circular plots, snags (≥ 25 cm dbh) were measured for dbh and assessed for height class (3 m intervals from 12 to 36 m). In the variable radius subplots established with a 2 $m^2$ basal area factor prism, trees ≥ 10 cm dbh were measured for diameter at breast height (dbh) at 1.4 m; height class, live crown ratio (percentage of bole covered by live crown), and species were also recorded. Sugar maple trees ≥ 25 cm dbh were assigned to one of three merchantability classes (select, common or cull) based subjectively on stem straightness, height to

TABLE 2. Live tree (≥ 10 cm dbh) characteristics in non-harvested reference and pre-harvest reconstructed stands (mean ± one standard error)

| | Certified Pre-harvest Reconstruction (n = 3) | References (n = 6) | P | Uncertified Pre-harvest Reconstruction (n = 3) | References (n=6) | P |
|---|---|---|---|---|---|---|
| Mean stand diameter (cm) | 36 (±3.9) | 37 (±1.2) | 0.73 | 35 (±1.6) | 37 (±1.2) | 0.41 |
| Basal area ($m^2$/ha) | 18 (±1.3) | 18 (±2.0) | 0.97 | 18 (±1.3) | 18 (±0.8) | 0.70 |
| Tree density (#/ha) | 310 (±63) | 290 (±39) | 0.81 | 320 (±57) | 290 (±39) | 0.69 |
| Biomass (metric tons/ha) | 140 (±4.0) | 140 (±6.3) | 0.90 | 130 (±8.1) | 140 (±6.3) | 0.50 |
| Relative density *Acer saccharum* (%) | 68 (±11) | 64 (±8) | 0.76 | 61 (±4) | 64 (±8) | 0.84 |

Note: Reported P values are the result of ANOVA/Tukey-Kramer HSD tests.

branches, and visible defects, such as rot or mechanical damage. Two basal diameters of merchantable trees (≥ 25 cm dbh) were also measured for stump reconstruction. In the smallest, fixed area 0.02 ha circular subplots, saplings (0.1–4.9 cm dbh) and pole-sized trees (5.0–9.9 cm dbh) were tallied by species, recent stumps were measured for diameter and recorded by species, and downed woody debris was measured for large and small end diameters (≥ 10 cm) and length for any portion that fell within the plot boundaries. At every third circular subplot, we gathered site information, including: percent slope (measured with a clinometer), dominant understory herbaceous species (determined by ocular estimation within the plots), and A-horizon soil pH (assessed with an electrode in the lab after a Shoemaker-McLean-Pratt (SMP) soil extraction from three mixed soil samples per plot (Shoemaker et al., 1961)).

## *Data Processing and Analysis*

All comparisons between stands were made using parametric statistical tests (Zar, 1999). Stand means were calculated via ANOVA analysis from measurement plots, and then stand means were compared by Tukey-Kramer hsd for statistically significant differences ($p \leq 0.05$) (most commonly: uncertified vs. certified, uncertified vs. reference, certified vs. reference). F test ratios ≥ 0.20 for homogeneity or equality of variance assured the validity of the Tukey-Kramer hsd tests. All statistical operations were executed in SAS JMP 5.1.

## *Live and Reconstructed Tree Values*

The dbh of cut trees was reconstructed using least squares linear regression formulas derived from measured dbh and basal diameters ($R^2 = 0.90$). The cubic volume of all trees ≥ 10 cm dbh was calculated using regional, species-specific cubic volume equations based on dbh and total height (Scott, 1981). Relative density was calculated based on the density of sugar maple ≥ 10 cm dbh compared to total stem density. Diameter distributions of all standing trees ≥ 0.1 cm dbh were generated using 5 cm size classes.

Live tree carbon storage was calculated based on 50% (Gower, 2003) of total tree biomass determined from allometric equations for U.S. tree species (Jenkins et al., 2003). To calculate economic value, we converted carbon to $CO_2e$ by multiplying by 3.67, then multiplied this figure by voluntary market rates of $3 per metric ton $CO_2e$ from

Chicago Climate Exchange (CCX, 2007). Market rates for carbon have already doubled to $6/ton in 2008 according to the CCX website, so these figures could be considered conservative estimates of net returns to forest owners after transaction costs.

Residual timber value was calculated for merchantable sugar maple using regional, one-quarter inch international log rule equations (Scott, 1979) based on dbh and bole height to mid-crown. Sugar maple was chosen for economic analysis because it is the dominant species in these stands (> 50% of stems) and because it represents the majority of the value in these forests, with stumpage prices typically two to four times those of other northern hardwood tree species. Average stumpage values for common and select grades of sugar maple in central Vermont were used in the calculations to eliminate variation in actual prices received due to distance to mill, forest road density, and other factors (2003–04 prices of $444/mbf for select grade sugar maple and $297/mbf for common grade sugar maple (UVM, 2007)). None of the managers in the certified forests had an opportunity to sell wood for premium certified prices, so standard market prices were used for all calculations. Merchantability standards were assumed to be the same across properties. Harvest costs were not included in the calculations because stumpage prices include the costs of felling, delimbing, skidding, bucking, and hauling. Replanting costs were also not included because natural regeneration methods were employed post-harvest. Annual certification audit costs (an average of five year re-certification and annual inspection audits) were deducted from stumpage value in certified stands. These costs were estimated at $6/ha/yr by forest managers in our study excluding internal administration and management costs, a figure that was comparable to published figures from Cubbage et al. (2003). Annual certification audit costs were assumed to increase at the rate of inflation of 3.4% (the determination of inflation rate is explained in section 3.5).

Reconstructed stand information was not reliable for calculating timber value because tree height, an important component of volume, was poorly correlated with diameter ($R^2 = 0.10$). Furthermore, sugar maple timber prices differ by 44% between common and select grades, and such differences in bole quality could not be assessed from the stumps. Therefore, estimated recent harvest returns were calculated by deducting residual standing value in certified and uncertified stands from standing value in non-harvested reference stands (reference returns were set to zero).

### Timber Growth Projections

Tree diameter growth, height growth, and mortality rates of sugar maple were projected 10 years into the future, using the Northeast (NE) variant of U.S. Forest Service's Forest Vegetation Simulator (FVS) spatially independent equations (Teck and Hilt, 1991). Future timber prices were calculated based on average annual increases from the longest period of historical data on stumpage prices (from 1982–1985 to 2002–2005) from the University of Vermont (UVM, 2007). These nominal prices were adjusted by producer price indices of lumber over the same time period from the U.S. Bureau of Labor Statistics to account for inflation (BLS, 2007). These data showed 5.0% annual real rates of change for select grade sugar maple prices and 4.1% annual real rates of change for common grade sugar maple prices, after subtracting 3.4% annual inflation. Prices 10 years into the future were calculated at discount rates of 4, 6 and 8%. These discount rates fall within the 2–10% commonly used in forest economics literature (e.g. Ashton et al., 2001; Boltz et al., 2001; Boscolo and Vincent, 2003).

### Coarse Woody Debris Volumes

Downed woody debris ($\geq$ 10 cm diameter) volumes were calculated based on the equation of the frustum of a cone. Standing woody debris or snag ($\geq$ 25 cm dbh) volumes were calculated using generic hardwood cubic foot volume equations (Scott, 1981) based on dbh and total height. Coarse woody debris densities and volumes in both uncertified and certified stands were compared to non-harvested reference conditions, as precut coarse woody debris could not be reliably reconstructed.

## RESULTS

### Live Tree Characteristics

Both certified and uncertified harvests were similar in terms of their impact on live tree structure. Neither certified nor uncertified harvests significantly ($\alpha = 0.05$) decreased average tree diameter or relative density of sugar maple compared to pre-harvest reconstructed conditions (Table 3). However, both harvests significantly reduced both biomass ($p < 0.01$) and basal area of live trees $\geq$ 10 cm dbh ($p < 0.01$) by approximately one-third compared to pre-harvest reconstructed conditions. Harvesting apparently reduced total tree

TABLE 3. Live tree (≥ 10 cm dbh) characteristics in pre-harvest reconstructed and recently harvested stands (mean ± one standard error)

| | Certified Pre-harvest Reconstruction (n = 3) | Certified Post-harvest (n = 3) | Uncertified Pre-harvest Reconstruction (n = 3) | Uncertified Post-harvest (n = 3) |
|---|---|---|---|---|
| Mean stand diameter (cm) | 36 (±3.9) | 34 (±3.7) | 35 (±1.6) | 36 (±2.0) |
| Basal area ($m^2$/ha) | $18^a$ (±0.74) | $13^b$ (±0.51) | $18^a$ (±1.4) | $12^b$ (±1.0) |
| Tree density (#/ha) | 310 (±63) | 220 (±34) | 320 (±57) | 220 (±48) |
| Biomass (metric tons/ha) | $140^a$ (±4.0) | $110^b$ (±9.4) | $131^a$ (±14) | $94^b$ (±10) |
| Live tree carbon storage (metric tons/ha) | $70^a$ (±2.0) | $53^b$ (±4.7) | $65^a$ (±4.0) | $47^b$ (±2.8) |
| Carbon credit value for aboveground live tree storage (\$/ha/yr $CO_2$e) | \$$771^a$ (±25) | \$$584^b$ (±48) | \$716 (±48) | \$$518^b$ (±35) |
| Relative density *Acer saccharum* (%) | 68 (±11) | 71 (±12) | 61 (±4.0) | 60 (±8.0) |

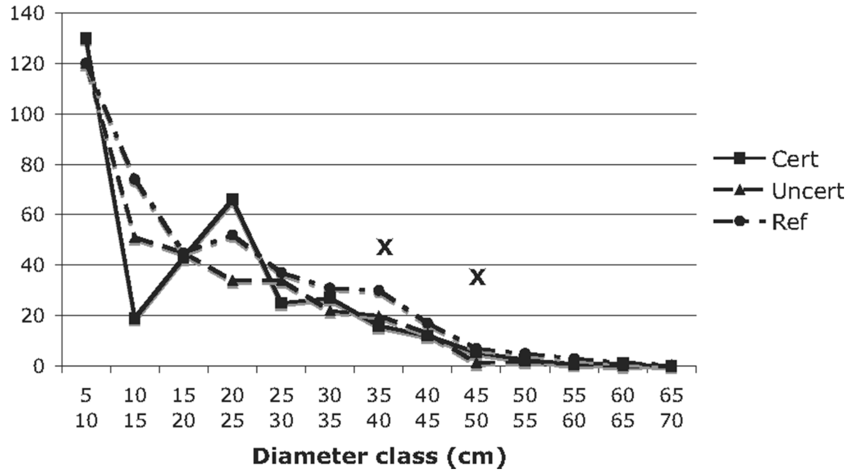
Note: Significant differences (Tukey-Kramer HSD, $p \leq 0.05$) are marked with different superscript letters.

density by one-third (from 320 to 220 trees/ha) as well, but this difference was not statistically significant ($p = 0.26$). The impact of both harvests, translated to even-aged stocking charts from the U.S. Forest Service Northeastern State and Private Forestry, involved a reduction from 95% to 65% stocking.

Decreased biomass translated to decreased live tree carbon storage in both treatments compared to pre-harvest reconstructed stands ($p < 0.01$). All harvests lowered potential economic carbon storage values by 25–30% compared to pre-harvest reconstructed conditions ($p < 0.02$).

In terms of diameter distributions, both certified and uncertified stands held sapling densities (0.1–5.0 cm dbh) approximately half those found in non-harvested references, likely due to harvesting operation activity. Post-harvest sapling densities were 590 stems/ha in certified stands and 720 stems/ha in uncertified stands compared to 1510 stems/ha in reference stands ($p = 0.02$). In addition, each harvest type held significantly lower densities of trees in one mid-size class compared to non-harvested reference stands (Figure 1). Certified stands contained 16 trees/ha at 35–40 cm dbh compared to 30 trees/ha in references ($p = 0.04$). Uncertified stands contained 1 tree/ha at 45–50 cm dbh compared to 7 trees/ha in references ($p = 0.01$).

FIGURE 1. Diameter distributions of certified stands, uncertified stands, and non-harvested reference stands.



Note: Significant differences (Tukey-Kramer HSD, p ≤ 0.05) are marked by “x”s.

## *Coarse Woody Debris*

Both certified (800 pieces/ha) and uncertified (440 pieces/ha) stands held total downed woody debris densities two or three times greater than non-harvested reference stands (240 pieces/ha) ($p < 0.01$) (Table 4), primarily due to greater densities of small logs from logging debris (10–25 cm) ($p = 0.01$). When examined by size class, certified stands (95 pieces/ha) contained significantly greater densities of medium-sized logs (25–50 cm) than either uncertified (42 pieces/ha) or reference (39 pieces/ha) stands ($p=0.04$). Certified stands also held significantly ($p = 0.05$) more large snags (15 stems/ha) in the 25–50 cm dbh size class than uncertified stands (5 stems/ha). Overall, total coarse woody debris volumes (standing and downed) were significantly greater in certified stands (65 $m^3$/ha) compared to uncertified stands (37 $m^3$/ha) ($p = 0.02$).

## *Sugar Maple Timber Value*

We estimated changes in merchantable sugar maple volume by comparing harvested stands with non-harvested reference stands. Uncertified stands held approximately half the merchantable sugar

TABLE 4. Coarse woody debris densities and volumes in certified, uncertified, and non-harvested reference stands (mean ± one standard error)

| | Certified (n = 3) | Uncertified (n = 3) | References (n = 6) |
|---|---|---|---|
| **Down woody debris (≥ 10 cm diameter)** | | | |
| Residual density (#/ha) | | | |
| 10–25 cm diam. (small end) | $690^{a}$ (±170) | $390^{a}$ (±34) | $200^{b}$ (±24) |
| 25–50 cm diam. | $95^{a}$ (±10) | $42^{b}$ (±14) | $39^{b}$ (±8.9) |
| 50+ cm diam. | 15 (±8.4) | 5 (±2.9) | 3 (±2.8) |
| Total | $800^{a}$ (±170) | $440^{a}$ (±43) | $240^{b}$ (±30) |
| Residual volume ($m^3$/ha) | | | |
| 10–25 cm diam. (small end) | 29 (±4.9) | 18 (±3.4) | 16 (±5.8) |
| 25–50 cm diam. | 23 (±3.4) | 12 (±3.0) | 12 (±3.9) |
| 50+ cm diam. | 2.7 (±1.7) | 1.6 (±0.8) | 1.7 (±1.7) |
| Total | $54^{a}$ (±3.9) | $32^{b}$ (±6.7) | 30 (±8.9) |
| **Snags (≥ 25 cm dbh)** | | | |
| Residual density (#/ha) | | | |
| 25–50 cm dbh | $15^{a}$ (±2.3) | $5^{b}$ (±2.5) | 10 (±2.4) |
| 50+ cm dbh | 2.1 (±1.2) | 1.7 (±0.9) | 2.2 (±0.6) |
| Total | 17 (±3.5) | 6.7 (±2.7) | 12 (±6.9) |
| Residual volume ($m^3$/ha) | | | |
| 25–50 cm dbh | 7.8 (±1.5) | 4.3 (±2) | 7.4 (±2.3) |
| 50+ cm dbh | 2.8 (±1.7) | 1 (±0.8) | 3.4 (±1.3) |
| Total | 11 (±3) | 5.2 (±2.7) | 11 (±3.5) |
| Total CWD | | | |
| Residual volume ($m^3$/ha) | $65^{a}$ (±3.9) | $37^{b}$ (±5.8) | 41 (±11) |

Note: Significant differences (Tukey–Kramer HSD, $p \leq 0.05$) are marked with different superscript letters.

maple volume as non-harvested reference stands, which was a significant difference ($p = 0.02$) in present terms (55 $m^3$/ha versus 110 $m^3$/ha) and in 10 (56 $m^3$/ha versus 120 $m^3$/ha) year projections (Table 5). Residual merchantable sugar maple volume in certified stands was intermediate between uncertified harvested and non-harvested reference stands and not significantly different from either.

The estimated recent harvest stumpage value averaged $1900 per ha for certified versus $3,300 per ha for uncertified stands–a difference that was large but also highly variable and therefore not significantly different ($p = 0.42$). Similarly the mean internal rates of return over 10 years (6% uncertified, 5.6% certified, and 5% uncut reference) were statistically

TABLE 5. Merchantable sugar maple volume and net present value in certified, uncertified, and non-harvested reference stands (mean ± one standard error)

| | Cert. (n = 3) | Uncer. (n = 3) | References (n = 6) |
|---|---|---|---|
| **Volume of *Acer saccharum*** | | | |
| Measured stand vol. AGS* ($m^3$/ha) | 79 (±20) | 55$^a$ (±14) | 110$^b$ (±11) |
| Modeled growth minus mortality +10 yrs. ($m^3$/ha) | 81 (±21) | 56$^a$ (±17) | 120$^b$ (±11) |
| **Net present value of *Acer saccharum* timber ($/ha)–10 yrs** | | | |
| 4% real discount rate | | | |
| Recent timber harvest returns (2003) | $1900$^a$ (±1100) | $3300$^a$ (±1000) | $0$^b$ (±0) |
| Residual timber value (+10 years) | $5000 (±1400) | $4000$^a$ (±1300) | $6900$^b$ (±560) |
| Total net present value | $6900 (±1400) | $7300 (±1300) | $6900 (±560) |
| 6% real discount rate | | | |
| Recent timber harvest returns (2003) | $1900$^a$ (±1100) | $3300$^a$ (±1000) | $0$^b$ (±0) |
| Residual timber value (+10 years) | $4100 (±1200) | $2900$^a$ (±890) | $5700$^b$ (±470) |
| Total net present value | $6000 (±1200) | $6200 (±900) | $5700 (±470) |
| 8% real discount rate | | | |
| Recent timber harvest returns (2003) | $1900$^a$ (±1100) | $3300$^a$ (±1000) | $0$^b$ (±0) |
| Residual timber value (+10 years) | $3400 (±1000) | $2400$^a$ (±740) | $4700$^b$ (±400) |
| Total net present value | $5300 (±980) | $5700 (±740) | $4700 (±400) |
| Mean internal rate of return | 5.7% (±0.4) | 6.2% (±0.4) | 5.2% (±0.1) |

*AGS = Acceptable Growing Stock of select or common grade sugar maple ≥ 25 cm dbh.
Note: Significant differences (Tukey-Kramer HSD, $p \leq 0.05$) are marked with different superscript letters.

indistinguishable. Follow-up analyses in the discussion section below show that statistical significance emerges with longer entry cycles and higher discount rates. For example, the uncertified harvest compared to non-harvested references produced higher returns approximately $1,900/ha higher in net present value over 20-year entries (rather than 10) at a 10% discount rate (rather than 8%) ($p = 0.03$).

## *DISCUSSION*

### *Live Tree Structure*

Certified and uncertified harvests had analogous impacts on live tree structure. Both harvest types significantly reduced tree basal area, biomass, and stocking by one third, and only slightly reduced average tree diameters and relative density of sugar maple compared to pre-harvest reconstructed conditions (Table 3).

Diameter distributions in the certified and uncertified stands were both moderately different from non-harvested references. Low densities of saplings in both types of harvested stands were likely due to cable skidder activity, while lower densities in one mid-size class in certified stands and one mid-size class in uncertified stands probably resulted from timber removals. There were no significant differences in large-size trees (> 50 cm dbh) between the stands because, in part, there were few of those trees in these 60–70-year-old stands.

## *Carbon Storage*

International carbon storage pilot projects between electric utilities and forest owners, mediated by government agencies and non-governmental organizations, suggest that forests will play a role in emerging carbon markets. Carbon storage could play a major role in management decisions in the northern forests. If harvest entry is postponed by a decade to maintain carbon storage, an extra $1000/ha could accrue in carbon credit value (this calculation is based on discounting at 6% rate, using prices of $3/tonne/$CO_2$e, and using data of pre-harvest reconstructed compared to harvested stands). This extra $1000/ha represents between 33–50% of net timber returns from the deferred harvest, a difference that will narrow even further with increases in carbon prices.

We also measured carbon storage as one indicator of the affect of forest management on the provision of ecosystem services (Costanza et al., 1997). Live trees account for nearly half of the total forest carbon in temperate forests (Pregitzer and Euskirchen, 2004) with the remainder in forms of coarse woody debris and soil organic and mineral fractions that we did not measure. Our results did not show any significant differences in live tree carbon storage between certified and uncertified harvests (Table 3). Certified and uncertified harvests both reduced total tree biomass by one-third compared to pre-harvest reconstructed conditions, thus diminishing potential economic carbon storage values by approximately $200/ha/yr.

## *Coarse Woody Debris*

Coarse woody debris is an ecologically important component of forests in the northeastern U.S. Prior to European settlement, over three-quarters of northern hardwood forests were over 150 years old (Lorimer and White, 2003), with a concomitant abundance of large snags and downed logs, along with large trees for future recruitment of coarse woody debris (Gore and Patterson, 1986; Tyrrell and Crow, 1994; Neumann and Starlinger, 2001). Even today, standing snags and downed logs are common legacies of the disease, ice, and wind disturbances in the northern hardwood forest that kill standing trees in-place or break branches and boles (Faccio, 2003).

Coarse woody debris in the northern hardwood forest does not carry significant risk of increasing fire hazard, harboring secondary bark beetles, or accelerating carbon volatilization. Indeed, leaving standing snags and down logs in this region provides multiple ecological functions: supplying habitat (though this is also determined by other factors such as forest edge) for vertebrates including grouse, owls, woodpeckers, salamanders, and voles (McComb and Lindenmeyer, 1999; Butts and McComb, 2000; McKenny et al., 2006); maintaining detrital productivity by supporting a diversity of arthropods involved in commuting plant material to soil nutrients (Chandler, 1987; Hammond et al., 2001; Jabin et al., 2004; Latty et al., 2006); creating plant microhabitats by generating heterogeneity in soil carbon and nitrogen levels (Hafner and Groffman, 2005); and stabilizing the soil against erosion (Fernandez et al., 2004).

Coarse woody debris volumes, including standing and downed woody debris, were nearly 60% greater in certified (65 $m^3$/ha) than uncertified stands (37 $m^3$/ha) (Table 4). Nearly all of this debris was relatively undecayed and the harvests were of similar intensity, suggesting that the more abundant debris in certified stands resulted from differing management practices (perhaps spurred by the FSC-NE standard), such as retaining snags instead of felling them, and leaving bole tops instead of removing them for fence poles, firewood, biomass, pallet wood, or paper pulp. Retaining an additional 28 $m^3$/ha of debris in the certified than uncertified stands cost an estimated $47/ha at the time of harvest, based on hardwood pulp prices of $6 per cord (UVM, 2007). This opportunity cost of coarse woody debris retention was equivalent to 3% of mean certified harvest returns. Although coarse woody debris volumes on certified stands (with 54 $m^3$/ha downed wood volume and 17 stems/ha snag density) exceeded uncertified stands (with 32 $m^3$/ha downed wood volume and 7 stems/ha snag density), the characteristics of debris in both of these 60- to 70-year-old forests differ greatly from unmanaged 150+ year old, northern hardwood forests which have double the average volume, double the average diameter, and more advanced decay of coarse woody debris (Goodburn and Lorimer, 1998; Hale et al., 1999; McGee et al., 1999).

## Sugar Maple Timber Value

There were no significant differences in net present value of sugar maple between the harvests, or between the harvests and references, at discount rates of 4–8% over 10 year entry periods. Follow-up analyses, however, showed that statistically significant differences emerged with longer entry cycles and higher discount rates. Uncertified harvests removed more merchantable sugar maple in the initial harvest as suggested by the significant drop in acceptable growing stock of sugar maple of approximately 50% while certified harvests lost approximately 25% relative to non-harvested references (Table 5). The larger initial removal in uncertified harvests resulted in higher economic returns of approximately $1900/ha in present value over 20 year entries at a 10% discount rate relative to unharvested references ($p = 0.03$).

## Conclusions and Future Research Priorities

Uncertified and FSC-certified partial harvests in the northern hardwood forest were similar in many regards. Neither uncertified nor certified harvests had major effects on average tree diameters or relative density of sugar maple compared to pre-harvest reconstructed conditions. Both harvests reduced basal area, biomass, and live tree carbon storage by approximately one-third. In addition, both uncertified and certified stands held lower sapling densities and some mid-size tree densities compared to non-harvested references. Altogether, the similar live tree structure in certified and uncertified stands resulted in aesthetically indistinguishable forests. Certified and uncertified stands also held similar projected net present values of sugar maple over time. Finally, certified stands contained higher coarse woody debris volumes that will likely offer ecological benefits, such as increases in populations of snag- and log-dependent species and net increases in long-term carbon storage. A follow-up comparison of two management plans from certified and uncertified stands in our study re-enforced these findings. Both plans aimed for “long-term production of high-quality hardwood sawtimber” by reducing total stand basal area by one-third, removing first the lowest grade trees, and retaining an acceptable growing stock of sugar maple. However, only the plan for the certified property contained pre- and post-harvest data on standing and downed woody debris volume.

Our study is the first, to our knowledge, to quantify the similarities and differences between certified and uncertified forests in the field. Our findings suggest that FSC certification correlates with the modest ecological benefit of additional coarse woody debris, while retaining economic value under moderate discount rates. However, finding comparable stands proved difficult. This difficulty, which resulted in a small sample size, limited the statistical significance of many apparent differences between the stands such as net present values of sugar maple, residual tree densities, and total snag densities. In addition, we limited our scope to assessing stand-level forest structure in the northern hardwood region. Thus, while our study represents the first field assessment of certification, the results of our exploratory study are not definitive.

Future research should expand temporally with tree recruitment and regeneration over a number of years, and expand spatially to include riparian corridors and other high conservation value areas. Future research should also expand into biomes where dominant timber species are shade-intolerant to intermediate. Field-based research on the impacts of certified forest management presents experimental design challenges, but such research is critical to accurately assess the full benefits and costs of certification.

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