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GREEN FORESTRY? CASE STUDIES OF SUSTAINABLE FORESTRY AND FOREST CERTIFICATION

A Dissertation Presented

by

Bryan Conrad Foster

to

The Faculty of the Graduate College

of

The University of Vermont

In Partial Fulfillment of the Requirements
for the Degree of Doctor of Natural Resources
Specializing in Forest Ecology and Management

May, 2008

Accepted by the Faculty of the Graduate College, The University of Vermont, in partial fulfillment of the requirements for the degree of Doctor of Philosophy in Natural Resources, specializing in Forest Ecology and Management.

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Abstract

This dissertation explored sustainable forest management from multiple perspectives: a literature-based investigation to define management practices that sustain ecological, economic, and social forest resources over time; a field-based research project to identify management practice differences between Forest Stewardship Council (FSC) certified, Sustainable Forestry Initiative (SFI) certified, and uncertified properties in Maine; and a field-based research project to identify stand structural differences between FSC certified and uncertified properties in Vermont.

Based on an extensive literature review, we developed an iterative decision-making framework of goal-setting/implementation/ monitoring/review that could assist forest owners in choosing management practices to sustain ecological, economic, and/or social capital over multiple time frames. Our unique contribution is the identification of six concrete management concepts at the implementation phase: (1) BMPs/RIL, (2) biodiversity conservation, (3) community forestry, (4) forest protection, (5) sustained forest product yield, and (6) triad forestry. Forest owners can implement practices under one or more of these concepts to achieve their sustainability goals. We illustrate a hypothetical application of our framework with a case study of an FSC certified managed natural forest in the lowland tropical region of Costa Rica.

In the white pine forests of south-central Maine, we compared three FSC, SFI, and uncertified private properties against local scale Montreal criteria using triangulation of evidence from management documents, staff interviews, and field inspections. Certified properties were associated with improved internal management systems and improved practices for biodiversity conservation. However, our data suggest that certification does not necessarily involve fulfillment of all Montreal criteria, such as adherence to sustained timber yield, consideration of multiple social issues, or ecological monitoring at multiple temporal and spatial scales.

In northern hardwood stands in central Vermont, we compared three FSC certified and three uncertified that were analogous in terms harvesting date, silvicultural treatment type, forest type, and general location. The uncertified sites were randomly selected to remove bias. We conducted stand structural analysis of both live trees and standing and downed coarse woody debris, and also developed 10-year growth projections using FVS/NE-TWIGS. Our data suggest that FSC certified stands had similar timber economic value, similar live tree structure, and similar tree carbon storage, but significantly greater residual coarse woody debris than comparable uncertified harvested stands.

Citation

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PREFACE

My dissertation investigates sustainable forest management (SFM) from two main perspectives. First, what are the management practices that constitute SFM from the literature? Second, how do certified forests differ from uncertified forests in the field? The strength of my research (in collaboration with Deane Wang, William Keeton, and others) is that it is among the first papers examining certification on-the-ground. Certification research has traditionally only examined motivations for pursuing certification, economic impacts of certification, and differences between certification standards.

My literature review discusses concrete practices to implement sustainable forest management. I grouped practices into six concepts, which most sustain: ecological capital (Best Management Practices (BMPs)/Reduced Impact Logging (RIL), biodiversity conservation); economic capital (forest protection, sustained forest production, triad forestry); and social capital (community forestry). I hope that this first section of my research spurs additional clarification in discussions of sustainable forestry on which resources are being sustained, over what areas, across what time frames, and particularly employing which specific management practices.

My field research in the northern forest clearly documents that certified forests compared to uncertified forests provide greater biodiversity habitat in terms of unharvested conserved land at the forest management unit scale, and coarse woody debris retention at the stand scale. Such findings are supported by studies of FSC certified forests employing RIL in the neotropics, where non-target tree mortality has been reduced by half compared to non-RIL managed forests (Schulze and Zweede, 2006), thus maintaining greater live tree biodiversity (though potentially hindering gap-based regeneration of commercial tree species (Kukkonen et al., 2008)). I hope that this second section of my dissertation research spurs additional field-based research to assess full benefits and costs of certification.

CHAPTER 1 COMPREHENSIVE LITERATURE REVIEW:

Implementing sustainable forestry using six management concepts in an adaptive management framework:

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ABSTRACT Certification and criteria and indicators describe desired ends for sustainable forest management (SFM) but do not address potential means to achieve those ends. As a result, forest owners and managers participating in certification and criteria and indicator programs may achieve only some of their objectives, and those not participating in these programs receive little guidance. In this literature review, we propose six concepts to implement SFM—Best Management Practices (BMPs)/Reduced Impact Logging (RIL), biodiversity conservation, community forestry, forest protection, sustained forest production, and triad forestry. We place these concepts within an iterative decision-making framework of planning, implementation, and assessment, provide brief definitions of and practices delimited by each concept, and offer a case study in the neo-tropics that illustrates a potential application of our concepts. Overall our paper provides an approach for forest owners and managers to begin to implement the challenging but ambiguous concept of SFM.

KEYWORDS Best management practices (BMPs), biodiversity conservation, community forestry, forest health, natural disturbance based forestry, reduced impact logging (RIL), sustainable forest management, sustained yield, triad forestry, variable intensity forestry

INTRODUCTION

Sustainable forest management (SFM) has developed many different meanings but fundamentally involves perpetuating ecological, economic, and/or social forest assets (Aplet et al., 1993, Goodland, 1995, Floyd, 2002). The types of assets or capital that could be perpetuated include at a minimum: biodiversity at multiple spatial scales (FAO, 1993), capacity for ecological goods and services production (Franklin, 1997), and sustained ability to satisfy human management objectives (Helms, 1998).

Over the past quarter century, two parallel developments in SFM have occurred: an expansion in the meaning of sustainable forestry—from sustained yield to sustaining ecological, economic, and/or social capital—and a development of evaluative programs—including descriptive criteria and indicators on the regional to global scale and prescriptive certification principles on the forest management unit scale (Rametsteiner and Simula, 2003). The criteria and indicator and certification programs suffer from two deficiencies. First, by describing desired ends but not means, the programs could create trial-by-error inefficiencies compared to initially implementing management practices that target ends. Evaluative criteria have left a gap of implementation techniques. Second, certification programs, despite rapid recent growth, have limited applicability to approximately 7% of global productive forest land (approximately 25% of global roundwood production), 60% of which lies in North America and 30% of which lies in Europe (UNECE/FAO, 2006). Certification has limited utility to entities in many parts of the world that do not need to secure social license for forest management and timber export (Overdevest and Rickenbach, 2006).

To address these deficiencies, we propose six concepts that delimit SFM practices. Our concepts, ordered alphabetically, include: (1) Best Management Practices (BMPs)/Reduced Impact Logging (RIL) in terms of protecting live vegetation, soil quality, and water quality; (2) biodiversity conservation in terms of emulation of natural disturbance regimes, development of structural complexity, and variable retention of live trees; (3) community forestry in terms of neighbors participating in and benefiting from forest management; (4) forest protection, a subset of forest health, in terms of acceptable tree mortality; (5) sustained forest production in terms of commercial goods and carbon storage; and (6) triad forestry in terms of allocating protected areas, plantation forests, and managed natural forests at forest management unit and larger landscape spatial scales.

The following literature review attempts to fill the gap between goal setting and monitoring via our SFM implementation concepts, and to clarify options for striving for sustainable forestry outside of formal certification programs. In the first section of the review, we describe our decision-making framework in terms of planning, implementation, and assessment. Next, we offer proposed definitions and simplified practices for each of our six concepts based on a brief literature review. Finally, we offer a brief case study of a neo-tropical forest company as a hypothetical illustration of how our decision-making framework and management concepts might be utilized.

Iterative decision-making framework

A major challenge to sustainable forestry is that humans may not be able to accurately forecast which capital stocks need to be sustained for the future. Uncertainty comes from many sources, including changes in human population levels and densities, ecological understanding and conditions, economic demands and technology, and social institutions and values. One response to this dilemma is to employ the iterative process of adaptive management in SFM decision-making (Norton, 2005). Adaptive management, which involves four decision-making stages of planning, implementation, evaluation, and modification (plan, do, check, and act (PDCA)) (Walters and Holling, 1990), is easy to promote but difficult to implement. Successful implementation often requires institutionalization of the adaptive management process so that it is used routinely and systematically. In addition, emphasis should be placed on closing the loop of adaptive management via periodic monitoring and revision (Bormann et al., 2007).

In Fig. 1, the two semi-circular arrows at the top show that iterative decision-making process can occur either at the post-activity evaluation phase due to unsatisfactory results, or at the pre-activity planning phase due to changing management context. An example of the former is loosening machinery operation restrictions under RIL after determining that vegetative competition limits tree growth more than soil compaction. An example of the latter is switching from emphasis on sustained yield to emphasis on biodiversity conservation with the establishment of a working forest conservation easement on a property.

Capital objectives

The first column in Fig. 1 lists the forest capital stocks that could be sustained for future human well-being, including ecological, economic, and social components from Aplet et al. (1993), which could also be sub-divided into natural, built/financial, and human/social components from Vemuri and Costanza (2006).

Ecological capital according to de Groot et al. (2002) consists of four major components: (1) regulatory functions, including disturbance mediation and nutrient and water cycling; (2) habitat composition and structure, which supports biological and genetic diversity; (3) production functions, including primary and secondary productivity (foundation of economic capital); and (4) information provision, including aesthetic enjoyment, cultural representation, recreational use, scientific research, and spiritual use (foundation of social capital). Economic capital, the most quantifiable capital type, includes net present value of: (1) cash and cash equivalents from forest activities; (2) built/manufactured goods, such as buildings, roads, and machinery; and (3) natural resources with current market value (as distinguished from ecological capital) including stocks of goods such as land

and timber, and funds of services such as carbon storage and wildlife provision. Social capital according to Baker and Kusel (2003) consists of three major components that may be encouraged by forests: (1) human development in terms of education, health, and innovation; (2) cultural beliefs, historic interests, and social norms; and (3) political relationships in terms of family members, friends, and professional networks.

The weighting of ecological, economic, and social capital in the face of trade-offs depends both on the priorities of landowners and managers, and also on capital substitutability or fungibility. The weak sustainability perspective (Solow, 1974) holds that increased economic and/or social capital can entirely substitute for loss of ecological capital. This perspective is exemplified by Hartwick's rule which holds that nonrenewable ecological capital (which may include biodiversity, forest area, and air, soil and water quality) may be depleted, but the economic (Ricardian) rents from depletion—earnings above resource extraction, conversion, and distribution costs—must be re-invested in other forms of capital, rather than being consumed, to maintain non-declining consumption and production over time (Hartwick, 1977). An intermediate perspective, the safe minimum standard (Ciriacy-Wantrup, 1952, Crowards, 1998), only allows depletion of nonrenewable ecological capital when the costs of preservation are socially immoderate or intolerable—defined by Berrens et al. (1998) as reducing historic economic growth by more than one-half of one standard deviation. Finally, the strong sustainability perspective introduced by Daly (1990) holds that ecological capital provides the foundation for development of social capital, and social capital provides the structure for development of economic capital, and therefore all ecological capital must be preserved. Daly proposed three rules for strong sustainability: renewable resource harvests equaling rate of regeneration; nonrenewable resource depletion equaling rate of substitute creation; and waste emission not exceeding natural assimilation capacity. Technological innovation and economic discounting diminish the imperative of strong sustainability, while other factors increase the imperative including: population growth, which creates increased scale of human disturbances and demands on natural resource stocks (Toman and Ashton, 1996); economic institutional deficiencies, including costs of production external to market transactions and government intervention subsidies, both of which artificially inflate returns; and government subsidies, which create delayed price signals; and information uncertainty, which creates option loss in consuming resources immediately (Graham-Tomasi and Bromley, 1995), particularly considering prospects for improved information in the future (Arrow and Fisher, 1974). Forest owners and managers will need to consider weak sustainability limitations when considering conversion of ecological to economic and/or social capital.

Management concepts

Our six management concepts form the second column in Fig. 1. We organized this column so that landowners and managers who choose to prioritize ecological, economic, or social capital objectives can then choose among a subset of management concepts to achieve those objectives. The concepts may be applied at various spatial scales: BMP/RIL at sub-stand scales; forest protection and sustained forest production at stand scales and larger; biodiversity conservation and community forestry at forest management unit scales and larger; and triad forestry at landscape scales.

We incorporated into our management concepts a number of SFM practices from the literature (Table 1). We incorporated community-based ecosystem management in community forestry; low/positive impact forestry in BMPs/RIL; natural forestry in triad forestry; and both natural disturbance based forestry (formerly ecological forestry) and variable retention forestry (formerly new forestry) in biodiversity conservation. In nearly every case we used a broader term for our concept, except in the case of low/positive impact forestry where we found the relative measure of *reduced* impact to be less ambiguous than the absolute measure of *low/positive* impact.

Assessment categories

The third column in Fig. 1 involves categories of assessment from certification and criteria and indicator programs. The four most wide-spread criteria and indicator programs globally (in alphabetical order) are the Helsinki (Pan-European) Process, International Tropical Timber Organization (ITTO) Initiative, Montreal Process, and Tarapoto Proposal. The four largest certification programs globally are the Canadian Standards Association (CSA), Forest Stewardship Council (FSC), Program for the Endorsement of Forest Certification Schemes (PEFC), and Sustainable Forest Initiative (SFI) (Rametsteiner and Simula, 2003). We summarized the content of these programs in the third column by using ten categories from McDonald and Lane (2004) and Holvoet and Muys (2004). We organized the first eight categories to correspond with capital objectives. Two categories involve over-arching institutions and management systems and therefore do not correspond with any one particular capital objective.

MANAGEMENT CONCEPTS

Best Management Practices (BMPs)/Reduced Impact Logging (RIL)

Definition– BMPs/RIL are the most technical and spatially limited of the concepts since they focus on the operations aspect of forest management. BMPs for logging operations in the United States originated from the 1972 Clean Water Act mandate for states to develop performance standards to control non-point source pollution. BMPs involve a number of recommended practices to prevent sediment discharge, including: site preparation procedures (e.g. timber inventory and road and trail planning); erosion control guidelines for haul roads and skid trails (e.g. dip and water bar placement relative to road slope); stream crossing procedures (e.g. crossing angle and bridge structure recommendations); corridor retention guidelines near major water bodies (e.g. minimum corridor size requirements relative to streamside slope); and site closure procedures (e.g. erosion control, road closure, and slash dispersal recommendations). RIL adds to BMPs recommended practices for protecting standing live trees, such as directional felling and vine cutting.

BMPs/RIL have not only ecological, but also economic impacts. BMPs generally cost 1-5% of gross harvest revenue, due largely to restrictions in wood removal in streamside buffers (Cubbage, 2004). RIL is cost prohibitive in high densities of commercial trees (>20-30 m^3/ha) where even-aged silvicultural treatments are often implemented, such as stands of greenheart (*Chlorocardium rodiei*) in Guyana and Dipterocarpaceae in southeast Asia (Van der hout, 2000), due to the opportunity costs of foregone removal. Under partial harvests, in contrast, RIL can boost net present values by one-third to one-half compared to conventional logging at discount rates up to 20% by protecting future growing stock, diminishing wood waste, and increasing operations' efficiency (Holmes et al., 2002). Even in these cases, however, RIL is rarely applied due to short-term timber concessions on public land and insecure tenure on private land (Repetto and Gillis, 1988), high up-front training costs combined with high seasonal labor turnover, and lack of developed export markets with high quality standards (Putz et al., 2000).

Practices– (1) Protection of standing live trees In Brazilian Amazon forests, conventional logging damaged or killed 124 trees/ha, while RIL damaged or killed half as many, primarily due to inventory planning, directional felling, and vine cutting (Pereira et al., 2002). Retaining trees may prevent dispersal limitation otherwise common with heavy, animal dispersed seeds (McEuan and Curran, 2004). Live tree retention may also help maintain bat, bird, and primate populations responsible for long-distance (>1000 m) seed dispersal (Wang et al., 2007).

Practices– (2) Protection of soil quality Compaction from machinery may prevent tree root anchoring, hydration, and oxidation (Siegel-Issem et al., 2005). Soil compaction (particularly at 20-30 cm depth) is generally harmful if bulk density rises more than 15% (Lacey and Ryan, 2000), however thresholds may occur. High sand texture (Gomez et al., 2002) and/or soil dryness (McNabb et al., 2001) generally offset the impacts of compaction. The displacement of topsoil due to logging operations has confounding effects: litter loss reduces nitrogen and phosphorus levels thus inhibiting seedling and sapling growth (Tan and Chang, 2007), while removal of competing vegetation may also stimulate seedling and sapling growth (Fleming et al., 2006).

Practices– (3) Protection of water quality A review of nearly all U.S. state BMPs revealed that riparian buffer requirements are typically 15 meters on each bank with 50-75% canopy cover retention (Blinn and Kilgore, 2001). Buffers at least 11 meters wide (on slopes <10%) maintain habitat for macroinvertebrates (Vowell, 2001) and moderate mean water temperature fluctuations to 0.5-0.7^{o} C per day compared to 1.5-3.6^{o} C per day without buffers (Wilkerson et al., 2006). Riparian filter strips also retain eight times more sediment than clearcut harvest areas on an area-adjusted basis, and more total sediment volume than road water bars (Wallbrink and Croke, 2002). However, rainfall quantity (Hartanto et al., 2003) and road sizes and locations (Sidle et al., 2006) far outweigh either harvest intensity or BMPs/RIL practices in determining sediment discharge into water bodies.

Biodiversity conservation

Definition– Biodiversity conservation involves retaining tree composition and/or structure to maintain or restore organism diversity from individual tree to stand to watershed to region to global spatial scales. Forest owners and managers must be explicit not only in their spatial objectives, but also in their diversity objectives in terms of endemic species, threatened species, commercial species, or others (Ceballos and Ehrlich, 2006). Management for biodiversity conservation primarily involves coarse filter mechanisms in terms of forest structure, but includes the fine filter strategy of measuring populations of particular organisms (most commonly amphibians, birds, mammals, or vascular plants) as a monitoring tool (Schwartz, 1999). Wildlife management in terms of maintaining game species is a subset of this concept.

Practices– (1) Emulation of natural disturbance frequency, intensity, and magnitude
Disturbance has been defined as "any relatively discrete [non-autogenic] event in time that disrupts ecosystem, community, or population structure and changes resources, substrate availability, or the physical environment" (White and Pickett, 1985). Disturbances are typically characterized by their frequency (periodicity), intensity (energy release, which is often proportional to mortality), magnitude (spatial influence), and timing (phenology). Disturbance emulation proves difficult, due to the fact that the last, most reliable information on natural forest conditions from pre-European settlement comes from cooler climatic conditions at the end of the Little Ice Age (Landres et al., 1999) and also because the timing of natural disturbances can be difficult or costly to emulate, such as fires during dry weather. Nonetheless, natural disturbances often need

to be considered because of the major role they play in determining forest composition, structure, and function.

Low intensity harvests have greatest applicability when such harvests emulate the magnitude (less than 0.1 ha gaps) and frequency (50-200 year return intervals) of historic natural disturbance regimes (Seymour et al., 2002), including the temperate northern hardwoods with a history of ice and wind disturbances and the temperate longleaf and ponderosa pine forests with a history of surface fire disturbances. Such low intensity disturbances do not provide gaps of early successional forest habitat necessary for many bird species in northern hardwood forests (Faccio, 2003). Such harvests may also be inappropriate in other biomes, as these partial harvests do not mimic 50-150 year crown fire regimes to which pyrophytic trees have adapted in boreal biomes, and hurricane and fire disturbances to which commercially valuable, long-lived tree colonists have adapted in tropical biomes (Hall et al., 2003).

Low intensity harvesting (<25% canopy cover reduction) in sub-boreal and temperate biomes often has minor impacts on vascular plant species richness after 25 years (Reich et al., 2001). More intensive harvesting (>50% canopy cover reduction) in these biomes typically results in losses of mycoheterotrophic species in Orchidaceae, Monotropaceae and Pyrolaceae families that require large overstory trees for nutrition or structure, along with nonvascular mosses, liverworts, and lichens that root in large diameter moist, decaying wood (Humphrey et al., 2002).

Although silvicultural treatment intensity may be adjusted to mimic disturbance regimes, silvicultural treatments necessarily involve trade-offs in terms of intensity, frequency, and magnitude to supply a given wood volume. For example, replacing high-intensity coppicing in France with low-intensity single tree selection required more frequent entries across a larger forest area, which resulted in a significant reduction in shade-tolerant perennial plants (Decocq et al., 2004). An additional consideration with partial harvesting to mimic natural disturbance regimes is the impact of secondary disturbance effects on biodiversity, including colonization, hunting, and wildfire, all of which are particularly common in the neotropics (Laurence, 2001).

Practices– (2) Development of structural complexity including coarse woody debris retention Natural disturbances characteristically leave standing and downed coarse woody debris (CWD) (Franklin and MacMahon, 2000). Though logging also leaves coarse woody debris, the typical logging slash of undecayed small diameter residual tops and branches differs substantially from the large standing snags and downed logs deposited after natural disturbances. CWD in clearcuts in temperate and boreal zones particularly lacks moderately decayed standing snags greater than 30 cm diameter that provide habitat for cavity nesting birds (Pedlar et al., 2002). In addition, large downed logs are often lacking, which otherwise boost microsite moisture conditions and inhibit competing vascular plants, often accelerating tree population recovery from disturbance, even in tropical biomes where decomposition rates are high (Beard et al., 2005). In addition to manipulating CWD volumes, mature forest structure can be developed in silvicultural treatments by employing variable density marking and targeting rotated sigmoid rather than inverse J diameter distributions (Keeton, 2006).

Practices– (3) Retention of live trees as biological legacies Biological legacies have been defined as "the organisms, organic material, and organically-generated patterns that persist through a disturbance and are incorporated into the recovering ecosystem" (Franklin and MacMahon, 2000). Even intense natural disturbances seldom result in complete tree mortality. For example, after forest fires, unburned areas or "fire skips" frequently lie within 50-200 m of severely burned areas in pine forests (Kashian et al., 2005), and, though pine forests require frequent fires (<100 years) to maintain their dominance, few such fires were historically stand-replacing (Kuuluvainen, 2002). Retention of mature trees to emulate this variability can increase song bird populations (Norton and Hannon, 1997), increase shade- and moisture-dependent vascular plant populations, and provide microsites and mycorrhizae inoculum (Lazaruk et al., 2005) for natural regeneration.

The Montane Alternative Silvicultural System (MASS) compared dispersed retention (via irregular shelterwood) against aggregated retention (via patch cuts) in temperate coniferous forests. Economically, dispersed retention was most viable as diminished regeneration growing space was offset by a 30-40% increase in basal area growth of retained trees (Mitchell, 2001). Ecologically, aggregated retention of leave patches greater than 1 ha, with a composition analogous to natural fire skips in hydric to mesic areas, most resembled unlogged old-growth composition in terms of forest-dwelling birds (Tittler et al. 2001) and non-vascular plants (Rheault et al., 2003).

Community forestry

Definition– Community-based forestry involves formal vestment of responsibility for forest management activities (planning, implementation, and/or assessment) with unrelated people, living in close proximity to the forest, for their own socio-economic benefit (Glasmeier and Farrigan, 2005). Endowing communities with control over nearby forests is promoted as the most direct method of responding to community interests and providing community members with economic returns. One variant of community-based forest management is community based ecosystem management, which adds the goal of improving ecological conditions, such as biodiversity conservation (Gray et al., 2001). A review of 69 case studies on community forestry found the following four variables most effective predictors of success in terms of achieving community-defined objectives (Pagdee et al., 2006): (1) clear and well-defined property rights; (2) effective community institutions and developed community capacity; (3) motivating incentives which align with community interests; and (4) fully stocked and productive lands.

Practices– (1) Community management- In addition to production costs of management activities and opportunity costs of foregone land use options, forest management involves transaction costs arranging, bargaining, monitoring and/or enforcing exchanges. Co-management between forest ownership entities and community members can mitigate these transaction costs. Evidence from multiple sources (Ostrom and Nagendra, 2006) indicates that "when (local forest owners) have a role in making local rules, or at least consider the rules to be legitimate, they are frequently willing to engage themselves in monitoring and sanctioning of uses considered illegal (on private or public property)."

Co-management can involve a variety of tools to gather community input (Lynam et al., 2007), but to be effective all tools generally require at a minimum (Sheppard and Meitner, 2005): (1) choosing a small but representative sample of neighboring community participants; (2) improving capacity or functioning of participants through education and training so that participants can meaningfully contribute to decision-making; and (3) offering participants a meaningful role in final outcomes. Examples of community forestry from the United States (Hibbard and Madsen, 2003) show the difficulty of fulfilling these three elements. The Applegate Partnership formed in 1992 with community members who lived or worked in the 200,000 ha Applegate Valley in Oregon and were concerned about timber harvest reductions on federal land due to spotted owl habitat protection. However, the partnership failed to have a meaningful role in final outcomes: the partnership's plan to develop a timber sale to met their own interests failed under administrative court scrutiny, both due to lack of wider public input under National Environmental Policy Act (NEPA) requirements and due to public agency conflict-of-interest under Federal Advisory Committees Act (FACA) requirements. The

Quincy Library Group in California had more success as their management plan was implemented under special federal legislation, however the plan was opposed by state environmental organizations, indicating the tension inherent in decisions from communities that are heterogeneous in social structure and divergent in value norms, which raises issues regarding whether community members can be representative (Agrawal and Gibson, 1999).

(2) *Community ownership-* Forest ownership rights are sometimes passed from public to community owners. For example, in British Columbia, Canada, legal and local entities such as tribes, municipal governments, NGOs, and business cooperatives can apply for tenure of crown forests (after a trial period) via a 25-99 year lease (Teitelbaum et al., 2006). Although generally owner-managers will make greater economic returns than managers, returns could be less than anticipated due to: long rotation lengths or intensive mechanization (Charnley, 2005); rent capture by community members with economic resources and political power (Edmunds and Wollenberg, 2003); and creation of state and local level bureaucracies under decentralization rather than true devolution of ownership (Wittman and Geisler, 2005).

One of the largest models of community forestry in the world is the ejido system of Mexico as documented by Bray et al. (2005). The Mexican Revolution of 1910-17 resulted in land reform in article 27 of the Mexican constitution. The government appropriation both re-distributed private land to indigenous people as *comunidades* and also gave neighboring communities indefinite usufruct rights as *ejidos* to use public land for farm or forest commodity production. A post-NAFTA constitutional amendment in 1992 terminated additional land appropriation. Today, at least half of Mexico's approximately 60 million hectares of temperate and tropical forest is held collectively by over 30,000 ejidos. The ejidos both improve economic well-being of rural communities and protect forests from clearing. For example, mean annual income per person on ejidos is correlated not only with family size, but also with forest type and stocking, timber volume, and value-added milling and manufacturing. The ejidos provide full-time, permanent employment for one-quarter to over three-quarters of residents, and a portion of annual profit is typically invested in building community clinics, meeting houses, and schools to develop equity. Annual rates of forest loss on ejidos are 0.6-1%, compared to 1-4% for non-ejido rural areas, and 0-0.5% for protected areas in Mexico. These low deforestation rates may be due to enforced cultural and social pressures that maintain commercial forest land for the future (Dalle et al., 2006). However, this ecological advantage of community forestry must be tempered by the fact that other characteristics —such as forest type and condition, distance to settlement, economic and population growth rates, soil fertility and land slope—also strongly influence deforestation rates.

Forest protection

Definition– Forest protection involves instituting management practices that maintain acceptable rates of plant mortality and morbidity/die-back. The acceptability threshold for tree mortality in particular will differ depending on managers' objectives, likely having the least amplitude with an economic capital objective (perhaps <3% annual mortality for commercial trees in plantations), and the most amplitude with an ecological objective. In addition, the threshold will vary with forest type. In plantations, manager objectives dominate, while in natural forests these objectives will necessarily be limited by historic range of variability of natural disturbances, such as fires (Aplet and Keeton, 1999).

The silvicultural practices to modulate tree mortality described below include all of those that define the field of silviculture—"control of forest establishment, composition, structure, and growth" (Smith et al., 1996). Non-silvicultural treatments may also be necessary including chemical applications of fertilizers and pesticides, and mechanical treatments such as log yard irrigation or soil scarification.

The various disturbances that incite mortality can be classified in terms of visible internal damage tree damage from low to high as predisposing, inciting, or contributing factors (Manion, 1996). These etiological factors were first proposed to act hierarchically, but the factors interact in multiple ways: for example, the predisposing factor of high stand density in a natural forest (Bragg et al., 2003), along with the contributing factor of fungal bark disease (Rhoads et al., 2002), increase likelihood of the inciting factor of bole breakage from ice.

Many predisposing factors are determined more by site selection than by silvicultural treatments. For example, *Acer saccharum* growth rates are largely associated with soil calcium levels (Schaberg et al., 2006). Similarly, damage from large, high-intensity disturbances (LIDs characterized by a return interval > 50 years across 50-100,000 km^2 (Foster et al., 1998)), including fires, floods, and hurricanes, is largely correlated with atypical weather events and geophysical characteristics of elevation, aspect, and edge proximity (Kulakowski and Veblen, 2002).

Practices– (1) Forest composition Mixed tree species provide resistance against disturbances primarily through two mechanisms. The first mechanism is structural diversity, such as a mix of deciduous and conifers trees in the Northeast providing resistance against both wind and ice damage (Rhoads et al., 2002). This mechanism emerges from tree species differing in resistance (susceptibility to attack and mortality) and resilience (ability to recover pre-disturbance characteristics) to the same etiological factor. For example, palm (*Arecaceae* spp.)-dominated forests have high wind resistance because of their flexible stems, while tabonuco (*Dacroydes excelsa*)-dominated forests have high wind resilience because their litter, with high isoterpenes and low polyphenols, decomposes relatively quickly (Beard et al., 2005).

The second mechanism is host dilution, such as angiosperm volatiles disrupting scolytid olfactory cues from monoterpenes and thus increasing Norway spruce (*Picea abies*) resistance to bark beetle infestation (Zhang, 2003). Another example of host dilution is angiosperm roots interrupting gymnosperm root grafting and thus discouraging spread of *Heterobasidion annosum* and *Armillaria* fungal root diseases in western pine and cedar (Rizzo and Slaughter, 2001).

In addition to providing structural diversity and host dilution, mixed species forests can also improve stand-level wood production in certain cases. Complementary mixtures of species with at least two different light tolerances, and additive mixtures of at least one nitrogen-fixing species in nitrogen-poor soils, often result in increased stand-level growth compared to monoculture plantations because of delayed density-dependent thinning (Kelty, 2007).

Practices– (2) Forest vigor Many tropical and subtropical plantations of eucalyptus (*Eucalyptus globulus*), gmelina (*Gmelina arborea*), radiata pine (*Pinus radiata*), and teak (*Tectona grandis*) have low levels of mortality, not only because of their relocation outside of the native pest range, but also because of their vigor due to periodic thinnings (Gadgil and Bain, 1999). Increased tree vigor most often improves tree resistance to insect infestations. For example, oak with the highest live crown ratios were five times less likely to suffer severe defoliation and mortality from gypsy moth (*Lymantria dispar*) than those with the lowest live crown ratios (Gottschalk et al., 1998). Similarly, tree losses to secondary beetles (e.g. mountain pine beetle (*Dendroctonus ponderosae*), engraver beetles (*Ips* spp., *Scolytus* spp.)) can often be reduced by thinning which not only boosts tree pitch-out defenses due to increased vigor, but also increases microclimatic drought and increases flight distance between infected and neighboring trees (Baier et al., 2002). During the switch from endemic to eruptive population phases, beetle densities increase, beetle physiology changes, and beetle behavior changes by expanding host range to healthy trees, but even during these eruptions, beetles most favor dead and dying trees (Wallin and Raffa, 2004).

Practices– (3) Forest re-establishment, accompanied by browsing and invasive species control Re-setting forests to early successional stages can maintain low mortality rates by avoiding senescence—for example, in coastal Douglas-fir (*Pseudotsuga menziesii*) forests, the percent basal area cull due to fungal decay typically increases from 10% at 120-160 years to 85% at over 250 years (Tainter and Baker, 1996). During forest re-establishment, browsing animals and exotic plant species may also need to be controlled. Browsing animals attracted to regeneration flushes can shift tree species composition from species with less to more recalcitrant foliage and thereby reduce long-term soil fertility (Cote et al., 2004). Furthermore, invasive exotic tree species can establish after a stand-replacing disturbance and persist even after stocking and vertical stratification have recovered (Brearley et al., 2004). Together browsing and exotic species invasions can generate positive feedbacks that retard forest regeneration—in one such case, hemlock wooly adelgid (*Adelges tsugae*) created light openings that spurred hardwood regeneration, high deer populations browsed the palatable hardwood saplings, and the vacated growing space became occupied by invasive understory species including intermediate fern (*Dryopteris intermedia*) and Japanese barberry (*Berberis thunbergii*) (Eschtruth et al., 2006).

Practices– (4) Forest structure Forest structure affects disturbances in various ways so that forest structure may need to be either diversified or simplified depending on the disturbance of concern. In terms of biotic disturbances, retained overstory trees provide canopy shade necessary to prevent invasion of pine weevil (*Pissodes strobi*) into white pine (*Pinus strobus*) leaders, and mahogany shoot borer (*Hypsipyla grandella*) into mahogany (*Swietenia* spp.) and cedar (*Cedrela* spp.) leaders (Mahroof et al., 2000). On the other hand, overstory trees infected with dwarf mistletoe (*Arceuthobium* spp.) and Douglas-fir tussock moth (*Orgyia pseudotsugata*) might release infestations into the lower canopy.

In terms of abiotic disturbances, fine and coarse fuel loads directly affect fire behavior and tree mortality (Odion et al., 2004). Harvesting can ameliorate this impact via felling of ladder fuels (Stephens, 1998) but only if such harvesting also involves treating woody slash, which otherwise persists for up to 30 years in xeric conifer forests (Stephens and Moghaddas, 2005).

Sustained forest production

Definition Sustained forest production is based on sustained timber yield, but this concept should be expanded to consider net present economic returns over time and carbon storage. Sustained timber yield involves removing a quantity of timber based on growth rates that can be maintained in perpetuity, with given entry frequencies, over a given spatial area. Timber is removed at rates of culminating mean annual increment (MAI) per rotation for one and two cohort (even-aged) silvicultural systems, and at rates of average net vegetative growth per entry for three or more cohort (uneven- or all-aged) silvicultural treatments and non-timber forest product harvests. MAI on an individual tree or tree group rather than a stand spatial scale may also be used as a basis for uneven-aged sustained yield systems.

Practices– (1) Biological rotation With even-aged silvicultural systems, sustained timber yield is established where biological tree growth is maximized—the intersection of diminishing periodic annual increment (PAI) and culminating MAI (Smith et al., 1996). However, intensive harvesting may diminish soil nutrients and thus long-term productivity, shortening the length of the rotation period. Southeastern mixed forests are relatively resilient in terms of available soil carbon, nitrogen and phosphorus (C-N-P), as these all recover at rates proportional to the forests' age after clearcutting (Palmer et al., 2005), although older soils may have retarded phosphorus recovery (Tanner et al., 1998, Paoli and Curran, 2007). Many cations including calcium, magnesium, potassium, and sulfur, recover at half the rate of C-N-P, which could delay the recovery time to restore original nutrient levels to one and a half times the age of the forest at harvesting (Elliott et al., 2002). Whole tree harvesting of removing tops and limbs from the stand is an aggravating factor that can more severely reduce soil nutrients and expand rotation length (Belleau et al., 2006).

Under uneven-aged silvicultural treatments, sustained timber yield for anticipated entry cycles can be established by determining biological tree growth rates minus mortality (for particular species and size classes). Removal can occur in aggregated spatial patterns through area regulation or in dispersed spatial patterns through volume regulation. Volume regulation is more complicated than area regulation but necessary in forests with irregular spatial distributions of commercial trees. Post-harvest monitoring is critical under either regulation system to ensure that not only species-specific rates of recruitment and regeneration, but also commercial quality, meet targets (Smith et al., 1996). Removal of coarse woody debris could also reduce habitat via simplification of forest structure.

Sustained timber yield in terms of tree growth can also be used for maximizing carbon storage, as trees contain between 10% (boreal) to 40% (tropical) of total forest ecosystem carbon, with the majority of the remainder stored in soils (Lal, 2005). Total forest ecosystem carbon storage is highest in boreal forests at 120 years and temperate and tropical forests at 200+ years (Pregitzer and Euskirchen, 2004). However, carbon uptake in terms of net ecosystem productivity (NEP, Mg C/ha/yr) peaks at approximately 70 years in all of these forest types (Pregitzer and Euskirchen, 2004), so a number of rotations of this length could theoretically equal mature forest storage, once adjustments are made for post-disturbance coarse woody debris and soil respiration, carbon storage in harvested products, and carbon emissions from fossil fuel emissions from management activities.

Practices– (2) Economic rotation A limitation of sustained timber yield is its static focus on volume growth at one point in time, rather than a dynamic focus on timber yield over multiple rotation or entry cycles. In 1849, Faustmann developed an equation to calculate the economically efficient timber rotation over time on even-aged stands (also called willingness to pay for land (WPL) or land expectation value (LEV)). This Faustmann equation has also been adapted to uneven-aged stands (Adams and Ek, 1974). The equation calculates net present value (NPV) of all future timber revenues minus all future management costs at a particular discount rate. Discounting future benefits and costs is necessary to account for inflation and risk (Price, 1993). Because of the nature of forestry with its short-term costs and long-term benefits, the discount rate strongly influences the type and amount of forest that will be sustained into the future. For example, a change from 6% to 4% in real (inflation-adjusted) discount rates in Sri Lanka changed the most profitable silvicultural treatment from exploitive diameter-limit to regenerative shelterwood, though neither proved as profitable as tea cultivation (Ashton et al., 2001). Risk in developing countries, private ownership that concentrates risk and externalizes benefits, and time frames less than 20 years can all shift standard discount rates from less than 5 to 10% to more than 10 to 15% per year (Newell and Pizer, 2004). High discount rates that exceed the rate of timber in-growth, volume growth, and real timber price growth convert the economically efficient decision from treating timber as an annuity into treating it as a lump sum. However, a number of circumstances may extend the economically efficient rotation, including: yield as opposed to *ad valorem* property taxes; loss of productive capacity over time through soil nutrient losses (Erickson et al., 1999); high regeneration costs (Binkley, 1987); and inclusion of non-timber amenity values, assuming such values increase with forest age (Hartman, 1976).

Triad forestry

Definition– Another approach to sustainable forest management involves landscape level zonation (Seymour and Hunter, 1999). This approach has been termed “specialized forestry” and “triad forestry” and involves allocation of protected reserves, intensively managed forest plantations, and extensively managed mixed-use natural forests in various locations and proportions across the landscape.

Specialized forestry is supported by the economic law of absolute advantage, which holds that forest owners will gain economically if they specialize management for each forest property on a spatial basis toward the products each is best able to produce (Vincent and Binkley, 1993). The economic benefits are apparent in tree growth rates of 5-20 m^3/ha/yr in plantations compared to 1-3 m^3/ha/yr in natural forests (Sedjo and Botkin, 1997). Protected area networks are considered to be the strongest method of reducing biodiversity loss (Noss and Cooperrider, 1994). Natural managed forests provide a critical addition to these two components both by supplying large, high-value sawlogs which plantations typically do not produce, and also by supporting beta-scale biodiversity, which cannot be maintained in the small number of existing protected areas (Soule and Sanjayan, 1998). Triad forestry's success in achieving ecological objectives will depend on a variety of factors including whether products supplied by intensive forest management alleviate deforestation/degradation pressure, whether managed areas can be converted into effective reserves, and whether climatic change and natural disturbances reduce the habitat value of reserves over time (Friedman, 2005, Lindenmayer and Franklin, 2003).

Practices– (1) Land use planning across forest management units Triad forestry can be a useful concept for forest owners planning land use across their ownerships on a landscape scale. To maintain biodiversity, for example, various organism characteristics (potential abundance, percent landscape suitability, species-specific habitat connectivity and population growth potential) can be compared against Maine natural and planted forest types and age classes using a small-scale spatially explicit (SSA) model to determine cutting intensity and reserve establishment (Higdon et al., 2005). Similarly, to maximize timber revenue, linear programming can be used to balance discounted net returns from hardwood versus softwood harvests, within constraints for establishing reserves in areas with close proximity to waterbodies, high deer wintering use, and steep slopes (Montigny and MacLean, 2006).

(2) Land use policy across states and countries New Zealand, where the majority of forest land is owned by the federal government, provides an example of two of the three components of triad forestry. The 1991 New Zealand Resources Management Act called for nation-wide "protection of areas of significant indigenous vegetation and significant habitats of indigenous fauna" which effectively sequestered forest production to standing plantations and pasture land that could be converted to plantations. Today the forest products industry contributes 4% of New Zealand's GDP (Statistics NZ, 2002), approximately one percentage point greater than forest industries in the U.S. or Canada. Nearly all of this production comes from 1.8 million ha of New Zealand pine (*Pinus radiata*) plantations, while 6 million ha of native forest stands protected (primarily composed of mixed broadleaf species such as mountain beech (*Nothofagus solandri*) and mixed evergreen species such as rimu (*Dacrydium cupressinum*)) (Statistics NZ, 2002). However, these indigenous forests generally occur in relatively inaccessible mountainous areas distant from population centers so may have lower ecological and social value than the lowland forests that were largely converted to agricultural use in the late 19th and early 20th centuries. The deliberate use of the triad concept in planning at the country spatial scale, enabled by public landownership, might result in more efficient land use in terms of minimized opportunity cost of alternative land uses and maximized timber or environmental amenity benefits than in other countries (e.g. Australia and Brazil) and states (e.g. Georgia and Maine) where planning only occurs at forest management unit levels.

CASE STUDY

Background

We chose one case study, Masonite Costa Rica (hereafter referred to as Masonite C.R.), to illustrate how our decision-making framework and management concepts (Fig. 1) might be utilized. Although our case study is hypothetical because our framework has not been actually implemented, the study provides a concrete example of abstract concepts. This particular case was selected because the company manages natural neotropical forests—a target for our management concepts, where certification has not developed widely. The company has been FSC certified for over 15 years. Therefore our concepts would hypothetically have less importance as means, than as more efficient means, for implementing sustainable forest management.

Masonite C.R. was founded as Portico in 1982 by a group of investors with their purchase of Puertas y Ventanas de Costa Rica. The company grew through vertical integration in the 1980s by purchasing forest land and saw mills, and subsequently expanded into the U.S. market through a niche of selling solid royal mahogany doors to both contractors and home improvement centers. In the mid-1990s, the global door manufacturer Masonite acquired the Costa Rica company. Nearly all of Masonite C.R.'s wood comes from 7,000 ha involving more than two dozen parcels owned in fee simple by its subsidiary Tecnoforest Del Norte. These broadleaf forests (wet to moist tropical forest types *sensu* Holdridge (1971)) lie in the lowland Atlantic region of northeastern Costa Rica. Mean annual rainfall is approximately 400 cm in this region, elevation is 15-

50 m, and soils are inceptisols and ultisols with a pH near 4.0 (Lieberman and Lieberman, 1987). Characteristics of trees >10 cm dbh in the nearby La Selva research station include 80-110 species/ha with a mean height of 30-40 m and mean age of 60-80 years. The forest density is typically 400-530 stems/ha with a basal area of 25-30 m^2/ha, allocated 36% to *gavilan* (*Pentaclethra macroloba* Mimosaceae), 5% to *caobilla* (*Carapa guianensis* Meliaceae), and 3% to *palma* (*Welfia georgii* Palmae), with the remaining 56% of basal area filled by a diversity of tree species, each constituting less than 1% of the total (Lieberman and Lieberman, 1987).

Selection of capital objectives

Masonite C.R.'s primary objective is non-declining economic capital, which it plans to achieve by maintaining its solid door sales in the U.S. and by expanding its molded panel door sales in Central America. The 100,000 doors produced annually by Masonite C.R. contribute approximately 1% to the $2 billion annual revenues of the parent company. Masonite C.R. receives government payments of approximately $22/ha/yr in return for suspending logging over a 15-year contract period on a maximum of 1500 ha as a public payment for bundled environmental services of biodiversity, carbon storage, scenic beauty, and water flow regulation and quality. Masonite C.R. is not subject to property taxes, but must pay income taxes, and must acquire government permits at a cost of $25/ha to harvest and transport wood.

Implementation of management concepts

Masonite C.R. most utilizes the concepts of BMPs/RIL and sustained production to achieve its economic capital objectives, and utilizes to a lesser extent biodiversity conservation, community forestry, and forest protection to meet legal and FSC certification obligations. Masonite C.R. does not utilize triad forestry because it only manages natural forests.

In terms of BMPs/RIL, Masonite C.R. has made Geographical Information System (GIS) maps based on inventory information for all of its properties which identify property boundaries, designate road and trail locations, identify water bodies (including full retention 10 m riparian buffers required by law on perennial streams with less than 25% slopes), and identify all trees over 60 cm dbh by number. The tree numbers, corresponding to a species list, include red numbers on reserve trees and blue numbers on target trees with shaded parabolas showing desired felling directions to minimize live tree damage. The target trees are also marked at dbh and vines are cut during on-the-ground inventory. Bole-only skidding is done with Caterpillar D5 or D6 bulldozers using 200 m cable winches. Skid trails are limited to 5% of total treatment area, while haul roads and landings are limited to 3%.

By law, in order to protect biodiversity, Masonite C.R. cannot harvest tree species with mean population densities less than one individual (> 60 cm dbh) per three hectares, and also cannot harvest Cola de Pavo (*Hymenolobium mesoamericanum* Papilionoideae). Portions of Masonite C.R. properties serve as human disturbance buffers for national parks, including Parque Nacional Tortugero. The biological integrity of the properties is boosted by its staff of five full-time permanent guards which travel through Masonite C.R. properties to discourage illegal logging, and to discourage hunting of agoutis (*Dasyprocta punctata*), peccary (*Pecario tajacu*, *Tayassu pecari*), and tapir (*Tapirus bairdii*).

Masonite C.R. partially addresses community forestry by employing 30 Costa Rican nationals on a full-time, temporary basis during the dry operating seasons of Jan.-March and Sept.-Oct. The employees are re-trained every year over a number of weeks so that they can continue to supplement agricultural livelihoods with periodic employment from Masonite C.R. The company also provides temporary housing for employees working far from home.

Masonite C.R. partially addresses forest protection by monitoring invasive tree species populations (which are currently below 0.5% of basal area), and average annual tree mortality rates (which is currently below 2% of basal area, with the highest levels in trees less than 30 cm dbh).

Sustained production is practiced by Masonite C.R. by removing 60% of commercial stems greater than 60 cm dbh, of which approximately 60% is gavilan, 30% is caobilla, and 10% is a mix of *Vochysia guatemalensis* and *Virola* spp. The silvicultural target is to reduce the total volume of commercial species by half, removing 25-30 m^3/ha during the first entry and 15-20 m^3/ha during subsequent 15-year entries (based on a growth rate of 0.5-1 cm dbh/yr). The volumes are regulated by diameter class to maintain an inverse J curve, where half the volume comes from 60-95 cm dbh classes, and half from 95-150 cm dbh classes to remove a total of 10,000 m^3 annually from 400 ha. Although polycyclic, diameter-limit cutting systems are common in the neotropics, such systems may cause: failure of recruitment due to stratified even-aged stands (Ashton and Peters, 1999), which does not seem to be the case in these forests, because second entry harvests of recruited trees are exceeding targets; or failure of regeneration due to inadequate direct light and high competition from understory vegetation, which may be an issue here, as the company does not monitor regeneration directly. Due to paucity of information on regeneration requirements of *C. guianensis* and *P. macroloba* in the literature, we can only postulate on regeneration success based on other managed tropical forests. On the positive side in terms of creation of available growing space, average annual timber removal in the Masonite C.R. forests is four times volumes in Bolivia where regeneration of commercial species has been inadequate (Howard et al., 1996). On the negative side in terms of available growing space, gaps of 50 m^2 (0.005 ha) common in the Costa Rican forests are only one-quarter to one-hundredth the size recommended to ensure sufficient regeneration of true mahogany (*Swietenia macrophylla*) (Webb, 1999). Future monitoring must assess whether the Masonite C.R. forests can support sustained production of commercial grade species via both regeneration and recruitment. Furthermore, uneven-aged silviculture focused on galivan and caobilla may lead to uniformity in tree species and age classes over time (Okuda et al., 2003). Future monitoring must also assess whether forests managed for commercial tree species can maintain historic diversity of non-commercial species.

Assessment via certification and criteria categories

FSC certification was pursued primarily to provide a social license to operate, as formalized third-party assessment helps ensure continued access to both timber harvesting in Costa Rica and to consumer markets in the United States. Direct costs of certification in terms of five year, on-site audits, are equivalent to $1/ha/yr. Indirect costs of certification are estimated at $14/ha/yr, primarily involving data collection and documentation. These indirect costs include, for example, verifying legal chain of custody with bar codes that must be affixed to stumps, raw timber, and finished wood products. The assessment categories used to evaluate Masonite C.R.'s performance under FSC certification include all of those shown in the third column of Fig. 1, except for the first (forested land area) and sixth (carbon storage) categories.

Iterative review and revision

The adaptive management mechanism employed by Masonite C.R. involves written reports required after each harvest. Details on tree harvests and road systems from the reports, in particular, inform subsequent management decision-making—such as why trees marked for cutting were retained, or why a section of road needed to be re-located. Under FSC certification, contract foresters also conduct periodic supervisory audits that include worker safety practices, rare tree species populations, standing tree mortality, and riparian buffer width. The iterative decision-making process may be successful in terms of sustained yield and RIL/BMP: nearly one-third of the forest property is undergoing second entry harvests with commercial yields exceeding the 15 m^3/ha target, and the initial establishment of roads and trails has reduced second entry per-volume harvest costs by approximately one fifth. However, future harvests will provide more definitive evidence on whether regeneration is sufficient to meet commercial yield targets, and whether initial roads and trails continue to function as planned.

Conclusion

Many elements of Masonite C.R.'s management, such as its monitoring program for road conditions and sustained yield, were developed over 15 years of trial-and-error modification through external audit findings rather than through deliberate internal planning. Our framework, in contrast, could have assisted Masonite C.R. in strategically aligning itself at inception with practices that target external certification standards. Furthermore, our framework could have indicated to the company that its monitoring programs for biodiversity, community forestry, and forest protection, compare poorly to the sustained yield and RIL monitoring that more directly contribute to Masonite C.R.'s financial objectives.

Overall, our concepts provide discrete practices for managers to begin to implement the ambiguous concept of SFM. Our iterative framework of selecting capital objectives, implementing practices via management concepts, and assessing outcomes via certification and criteria categories provides a strategic decision-making process for managers in various forest biomes, regardless of their participation with forest certification and criteria and indicators, to accomplish their objectives for non-declining forest capital.

Table 1: Terms widely used to describe sustainable forest management practices.

Terms	Definition and source	Relationship to our concepts
Community-based ecosystem management (CBEM)	Local community involvement in ecological protection and restoration activities, based upon conviction that human communities and natural ecosystems are interdependent (Gray et al., 2001).	Integrated into community forestry
Low/positive impact forestry	Reduction of soil compaction, reduction of residual tree damage, reduction of road sizes and densities, minimization of water quality degradation, and consolidation of harvest treatments to minimize wildlife impacts (Lansky, 2003, McEvoy, 2004).	Integrated into BMPs/RIL
Natural disturbance based forestry (formerly termed ecological forestry)	Emulation of natural disturbances via management in terms of intensity, return interval, and spatial pattern (Seymour and Hunter, 1999).	Integrated into biodiversity conservation
Natural forestry	Management of native tree species via natural regeneration, generally with two or more age cohorts (Peterken, 1999).	Integrated into triad forestry
Variable retention forestry (formerly termed new forestry)	Retention of old growth structure of large live trees, logs, and snags within harvested stands (Lindenmayer and Franklin, 2002).	Integrated into biodiversity conservation

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CHAPTER 2

Gaps between Montreal criteria and FSC and SFI certification standards: Three exploratory case studies from Maine

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Provincial, regional, state and national governments with high private land ownership may consider certification a policy tool to increase conformance with their own goals for sustainable forest management, such as Montreal Process criteria and indicators. We undertook a case study comparing forest management practices among comparable uncertified, Forest Stewardship Council (FSC) certified, and Sustainable Forestry Initiative (SFI) certified industrial private landowners in southern Maine, USA against forest management unit scale adaptations of Maine and Montreal criteria. Our exploratory study suggests that both FSC and SFI certification are associated with improved management systems in terms of documentation and review of practices. In addition, both certification systems are associated with improved practices for biodiversity conservation, such as protection of high conservation value areas, and improved practices for water quality, such as operation restrictions on saturated soil. However certification does not necessarily require fulfillment of all Montreal criteria, such as adherence to sustained timber yield, consideration of multiple social issues, or ecological monitoring at various temporal and spatial scales. If our conclusions are

substantiated by more extensive surveys of forest management systems, government signatories may need to address gaps in Montreal criteria through alternate mechanisms than private forestland certification.

Keywords: certification, Forest Stewardship Council (FSC), Montreal criteria and indicators, Sustainable Forestry Initiative (SFI), sustainable forest management

Introduction

Two major programs have emerged since the United Nation's Earth Summit of 1991 to assess sustainable forest management (SFM) practices—(1) certification and (2) criteria and indicators. These two programs are similar in that they are both voluntary and involve collection and reporting of ecological, economic, institutional, and social data (Table 2). However, criteria and indicators are largely descriptive explanations of forest conditions and trends designed for governments at the spatial scale of provinces, regions, states, and nations, while certification standards are prescriptive assessments of management activities designed for market participants at the spatial scale of forest management units (Rametsteiner and Simula, 2003).

Information gathered and practices implemented on certified properties may help fulfill larger scale governmental sustainability commitments, such as the Helsinki, Montreal, or International Tropical Timber Organization (ITTO) criteria and indicators (e.g. Eriksson and Hammer, 2006). Furthermore, the voluntary "soft law" program of certification may be more cost effective to develop and enforce than the “hard law” of legal and regulatory mandates (Hickey, 2004) in order to meet sustainability criteria, particularly in regions dominated by private land ownership. In 2003, for example, in the state of Maine, USA, governor John Baldacci initiated the country’s first state-led certification initiative. The goal of the initiative was to double the area of certified land by the end of 2007 to 4 million ha total, representing 60% of the annual wood harvest volume in the state (Whittemore et al., 2005), but the effort fell short, involving certification of approximately 3 million ha according to the Maine Forest Service. Nearly all of the commercial forest area in Maine is privately held, therefore certification could provide a useful policy tool for the state to achieve its sustainability goals.

The purpose of our research was to begin to assess whether the state of Maine benefits from certification in terms of achieving its Montreal and state sustainability goals. To conduct our research, we gathered empirical evidence on actual forest management practices from three analogous industrial private landowners in Maine (Forest Stewardship Council (FSC) certified, Sustainable Forestry Initiative (SFI) certified, and uncertified entities). We included an uncertified entity to represent background conditions, but acknowledge that management practices vary widely on uncertified properties. Once we gathered information on the practices, we compared them against a list of criteria from the Maine State Forest Service and Montreal Process. Our primary research question was: Do forest companies with different certification statuses also differ in Montreal and Maine criteria fulfillment?

Methods

This study involved the case study method, which is an effective approach for exploratory research (Yan, 1994). Case studies are commonly used for examining forest certification because of the small pool of certified landowners (e.g. Eriksson and Hammer, 2006, Hickey et al., 2005). We selected the state of Maine for our study because it has the largest pool of certified landowners in the northeastern forest region of the U.S.

Two of the three companies were chosen from a list of seven certified industrial landowners maintained by the Maine Forest Service: the FSC participant (Company B) and the SFI participant (Company C). We did not have prior knowledge of management practices of any of the companies. However *a priori* selection criteria was used to minimize confounding variables because land ownership size was found by Hickey et al. (2005) to affect documentation of management activities, environmental protection practices, and other factors. The selection criteria included: (1) forest size (8,100 to 16,200 ha), based on a mid-range within the state's definition of small (<2,000 ha) and large (>20,000 ha) landowners; and (2) forest cover type (predominantly mixed white pine (*Pinus strobes)* and mixed northern hardwood (*Acer saccharum*/*Fagus grandifolia/Betula alleghaniensis*)), based on the two most common forest types in the southern half of Maine. We also sought an entity to represent background conditions, and with assistance from the Maine Forest Service, we identified an uncertified entity

(Company A) that met the same selection criteria of landowner type, forest size, and cover type as an uncertified reference.

Each of the companies was offered anonymity to encourage full participation in the study and each was visited in late March, 2007. The primary author who conducted the visits has been formally trained in auditing both FSC and ISO 14001 management systems (SFI is largely based around ISO 14001), and therefore has expertise in documenting management practices employed by each entity. Our criteria, listed on Table 4, included Maine Forest Service, Montreal Process, and adaptations of Montreal Process to the forest management unit scale by Mrosek et al. (2006) and Wright et al. (2002) (the latter known as Local Unit Criteria and Indicator Development (LUCID)). We organized all four criteria (Maine, Montreal, Mrosek, and Wright) into four common categories (ecological, economic, institutional, and social). These categories were then broken into a number of subcategories with explicit management-based interpretations we developed to enable comparison. We acknowledge that our management-based interpretations, though practical, are imperfect reconciliations of broad criteria from four sources into specific management terms.

Each field visit was limited to four hours to emulate certification audit conditions and to demonstrate that our expedited methodology of incorporating Montreal criteria may be viable during audits as a means of providing additional public policy information. We used a triangulation method of written documents, field observations, and staff interviews to gather complete information. Practices pertaining to fulfillment of criteria were gathered from certification audit reports, conservation easement terms and conditions, and management plans. Tours of representative portions of the property, chosen by the companies, were also conducted to confirm these practices. Interviews with managers were conducted to clarify and verify information gathered from written documents and field tours. Fulfillment was determined by confirming implementation of practices via triangulation and quantitatively and qualitatively comparing practices employed by each company for each criterion.

Results

Overall All three companies were family-founded in the late 1800s to supply white pine barrel and box staves. Today the companies supply white pine siding and trim as their primary high value products. Both Companies B and C are vertically integrated with timber supply, manufacturing, and retailing facilities; Company A divested its sawmill in the late 1990s and is now only a timber supply entity (Table 3). The companies all own timber land in 25 to 40 parcels from 40 to 1600 ha in size, but Company C is unique in that it owns one large 8140-ha parcel dominated by mixed white pine that it acquired in the mid-1990s with the assistance of a state conservation easement.

Ecological category *(1) Biodiversity: Maintain forest compositional and structural diversity at multiple spatial scales*

Company A does not intentionally conserve biodiversity via: (1) monitoring native plant and animal populations; (2) retaining tree composition diversity; (3) retaining standing and downed coarse woody debris; and/or (4) intentionally protecting high conservation value habitat. In contrast, Companies B and C monitor populations of endangered species on their properties including peregrine falcon (*Falco peregrinus*) and Acadian swordgrass moth (*Xylena curvimacula*), and have intermittently conducted avian and salamander point counts to determine population status and trends. Both certified companies have management objectives that require maintenance of mid- to late-successional hardwood species in mixed forests, and also require retention of standing and downed coarse woody debris. Neither company, however, has quantitative retention targets. In terms of high conservation value habitat, both Companies B and C hold conservation easements of 5,260 ha and 8,140 ha respectively that include regionally rare pitch pine (*Pinus rigida*) habitat and lakeside bald eagle (*Haliaeatus leucocephalus*) habitat. However, both of these companies assess biodiversity at the stand level within the most recent decade, without considering multiple spatial (such as landscape) and temporal (such as pre-European settlement) scales as additional baselines for biodiversity. In addition, maximum live tree age is near 100 years on all of the properties, so the company lands provide little mature tree habitat or future snag recruitment.

(2) Ecosystem function: Maintain gas exchange, soil productivity, and water quality functions

None of the companies directly measures ecosystem functions of carbon storage, hydrologic cycling, and nutrient cycling. All of the companies use surrogate practices to maintain soil and water quality. In terms of soil quality, all three companies retain treetops and limbs in the forest, and also disperse slash from landings when employing whole-tree logging operations. In terms of water quality, all three companies follow Maine Best Management Practices (BMPs) for perennial water bodies (7.6 to 15.2 m corridors with 40% basal area retention ≥ 10 cm dbh over 10 year average, along 0 to 25% slopes). All three companies also follow Maine Natural Resources Protection Act regulations by maintaining BMP-sized corridors around wetlands and vernal pools greater than 46.5 square meters. All three companies have had one informal complaint issued for BMP noncompliance over the last two years involving degraded roads. The Maine Department of Environmental Quality reports, however, that no formal charges have been issued for sediment delivered into water bodies for any of these companies. Companies B and C provide additional water quality protection practices compared to Company A, including: (1) actively planning road locations and reducing road area; (2) installing temporary bridges on logging sites for water crossings; (3) suspending or relocating logging operations when soils are saturated; and (4) requiring loggers to sign contracts committing to employ BMPs.

(3) Ecosystem health: Maintain tree mortality within targets

All of the companies have management objectives to minimize allogenic and biogenic mortality for all standing trees. All three companies primarily rely on silvicultural practices to achieve these objectives. These silvicultural practices include: (1) presalvage cutting, such as removal of beech, which is susceptible to beech bark disease complex of *Cryptococcus fagisuga* and *Nectria coccinea*, and removal of hemlock (*Tsuga canadensis*) which is susceptible to wooly adelgid (*Adelges tsugae*); (2) sanitation cutting, such as removal of high densities of white pines which occupy a mid-canopy or ladder fuel position; (3) and salvage cutting, such as removal of all trees ≥20 cm dbh with crown cover loss of 30% or more. Irregular shelterwood silvicultural practices—named for irregular heights due to extended retention of reserved trees beyond entry cycles—are used by all of the companies in mixed pine forests. These practices of 40-60% canopy cover retention maintain white pine commercial form since partial light from opened stands discourages propagation of white pine weevil (*Pissodes strobi*). Irregular shelterwood also reduces white pine mortality since reduced humidity from opened stands inhibits white pine blister rust (*Cronartium ribicola*). Only Companies B and C have management objectives to reduce invasive species, which include using chemical and manual programs to control populations of oriental bittersweet (*Celastrus orbiculatus*) and using weed free certified grass and hay mixtures when such mixtures are needed for erosion control.

Economic category *(1) Economic efficiency: Maximize net present returns*

None of the companies was willing to release data to directly compare economic performance. All of the companies are financially viable in that they have existed as family businesses for over 100 years in southern Maine. All of the companies retain ownership of the timber from their own lands, all of which is sent to mills in the state. Company A appears in the most precarious financial position as it has recently emerged from bankruptcy, which required it to divest its value-added sawmill. Company B recently reintegrated its timber supply with its manufacture and retailing divisions, which resulted in staff reductions in the land management division, but will provide long-term economic stability by ensuring a value-added market for raw timber from its lands. Company C has an active mill that is approximately two to three times the size of Company B. Such a large mill provides a substantial additional source of revenue, but also creates economic pressure for the company since it aims to reduce the timber it purchases from non-company lands, which currently satisfy three-quarters of the mill's output.

(2) Sustained yield: Maintain quantity and quality of commercial resources (timber and nontimber) in perpetuity

All three companies have the primary management objective of growing high-quality white pine on all land with sand-textured soils suitable to pine production. All use an irregular shelterwood silvicultural treatment in pure and mixed white pine stands with spacing of approximately one-half dominant tree height. Both Companies B and C have quantified sustained yield as annual allowable cut not exceeding 3-4% of standing volume over a 10-year stand-level average based on computer projections of growth from current inventory information. Company B has purchased nearly a half dozen properties over the last decade and has not been able to obtain conservation easements to offset the purchase expenses. Consequently, the company has exceeded its allowable cut on these properties by 100-200% to repay property purchase costs. Available inventory information revealed reductions in quantity but not quality in terms of proportion of white pine of commercial size and quality. However, Company C has the advantage of owning one large contiguous area (8,140 ha) that contains a large lake with sufficient public conservation value for the company to have offset most of the cost of purchase with a state-funded conservation easement. Though Company C has greater mill pressure, it does not have the short term debt pressure of Company B. Company C has not exceeded its sustained yield harvesting rate relative to standing volume. Company A has not made recent land purchases and has no mill ownership to drive aggressive harvests. However, Company A has a qualitative "desired condition" system in contrast to both Companies B and C which use species-specific stocking targets in terms of residual basal area, tree density, and quadratic mean diameter. The qualitative system involves marking approximate stand boundaries on a Geographic Information System (GIS) map and providing experienced loggers with written objectives such as "Take all overstory, leave all softwood regeneration," and "Take most pine, spruce, fir, and hemlock, but leave softwood regeneration and occasional large healthy white pine." The qualitative system is expeditious but effectively prevents the company from accurately tracking its management progress over time or from accurately comparing its results to quantitative research from journal articles, state and national forest service publications, and other sources.

Institutional category *(1) Management systems: Document and periodically revise critical management practices*

All of the companies use GIS containing data layers for property boundaries, roads, stand cover types, and water bodies and thus can easily store, organize and retrieve property information. Company A uses an outline of management goals at the property scale, in lieu of a formal management plan, and employs qualitative desired conditions at the stand scale. In contrast, both companies B and C use detailed, annually reviewed management plans at the property scale, and employ quantitative silvicultural targets for desired conditions at the stand scale. Both certified companies also use pre- and post-harvest management checklists. Pre-harvest checklists include: identification and marking of property lines; designation of roads and trails, riparian corridors, vernal pools/wetlands, and sensitive wildlife habitat; and assessment of advance regeneration. Post-harvest checklists include: completion of road closure and soil stabilization activities; compliance with BMP requirements; conformance with silvicultural prescription; determination of residual tree damage; and subjective assessment of visual appearance.

Social category *(1) Social resource value: Maintain areas with aesthetic, archeological, cultural, educational, historic, spiritual, and recreational value*

None of the companies has policies for identifying and protecting sites with high social resource value outside of recreation, such as sites of archeological, educational, or historic significance. The companies all allow noncommercial, traditional recreation. For example, Company C actively cooperates with the state to maintain recreation campsites and trails on the 8,140 ha property it has eased. All three companies aim to exclude all terrain vehicle (ATV) users because of soil erosion concerns, and to exclude bear bait hunters because of public safety concerns.

(2) Participatory forestry: Enable public involvement in management planning, implementation, and/or monitoring

None of the companies actively engages the public, including indigenous people, for input on decision-making, management implementation, or post-implemetation monitoring. In terms of transparency of operations, all financial information is privately held. Companies B and C maintain Internet web pages and periodically offer public tours of their properties. Both companies have also begun providing information on group certification processes from FSC and SFI to outside landowners to develop additional chain-of-custody networks for mill procurement.

(3) Equity and safety: Ensure safety and just compensation for employees and others of interest All companies hold annual safety review meetings with employees and notify neighboring landowners in advance of logging operations. All companies provide competitive wages to their employees, but none have fixed ratios of upper and lower level employee compensation to ensure equity. All of the companies, due to varying property sizes and forest stocking levels, use a mix of hand crew, mechanical, and cut-to-length logging operation systems and therefore provide employment to a variety of contractors.

Discussion

Our case study is one of only two papers (Foster et al., 2008) that directly (rather than indirectly via certification reports) assess management practices employed on the ground by certified forest entities. Two FSC and SFI certified companies (Companies B and C respectively) are associated with fulfillment of a greater number of criteria compared to an uncertified company (Company A). We cannot prove causality in this retrospective public policy study. For example, the more developed management documentation in Companies B and C may result, for example, from a superior financial position due to mill ownership, rather than from certification. In addition, because our determination of criteria fulfillment was based on surrogates of management practices rather than direct measures of performance, we cannot determine whether these practices were effective in fulfilling the criteria. For example, all three companies have had one informal complaint issued to Maine Department of Environmental Quality for degraded roads, even though only the two certified companies actively plan road locations, reduce road area, and require contract loggers to sign contracts for BMP compliance. Despite these caveats, our findings are consistent with previous studies (Gullison, 2003, Newsom et al., 2006) that found certification to be associated with: (1) improved management systems in terms of quantitative documentation and monitoring; (2) improved practices for maintaining water quality and BMP requirements; and (3) improved practices for maintaining biodiversity.

Because certification is primarily a signaling mechanism for social license to operate, rather than an economic premium-accruing or information- and technology-transferring mechanism (Overdevest and Rickenbach, 2006), certification primarily appeals to entities facing socio-political pressure regarding their timber harvesting and exporting activities (Cashore et al., 2003, van Kooten et al., 2005) while rarely appealing to those who own small areas of forest land or those who primarily sell to domestic markets (Nebel et al., 2005). Therefore, governments intending to satisfy Montreal Process criteria in areas with multiple private landownership types may need to provide cost-sharing subsidies or legally require certification for landownership entities who would otherwise likely not participate in certification.

Certification may fail to ensure implementation of ecological, economic, and particularly social components of sustainable forest management based on the results of our exploratory case studies. Ecologically, none of the companies we examined, regardless of certification status: monitors ecological functions directly, such as soil nutrient levels or water quality; maintains old live trees for wildlife habitat; establishes quantitative targets for downed coarse woody debris and live tree diversity retention; or monitors biodiversity at spatial scales wider than stands over time periods longer than a decade. In addition, socially, none of the companies in our study provides opportunities for public input on decision-making, identifies or conserves socially important areas such as archeological or historic sites, or promotes economic equity. Although private companies do not generally fill these roles in society, such obligations may be expected of companies with lands protected by conservation easements where the public has purchased an ownership stake, or on lands that receive a reduced undeveloped property tax assessment that the public financially supports. Finally, economically, our case studies suggest that certification does not alleviate short-term economic pressures of high capital investment costs from land purchases. These costs, in turn, accelerate the frequency and volume of harvests beyond sustained yield calculated by growth rates. Intensive harvests beyond sustained yield may be privately economically efficient, but socially undesirable in terms of generating boom-and-bust timber cycles.

Conclusion

Our case studies suggest that certification may provide an effective policy tool to help maintain forest biodiversity and water quality in areas with high private land ownership. In addition, certification appears to provide the internal private benefit of improving management documentation and tracking systems. However, based on the companies we studied, certification does not appear to ensure extensive ecological monitoring at multiple scales with quantitative targets, harvesting within annual growth rates, or fulfillment of many social issues outside of employee safety and public recreation. To meet these sustainability criteria in landscapes dominated by private ownership, governments may need to use alternative tools, which could include financial incentives and/or legal requirements. These alternative tools would be most appropriate on ownerships where the public has a financial interest via property title easements or subsidized property tax rates. Future research building on our exploratory study should expand the sample size to more fully represent certified and uncertified entities.

Table 2. Correspondence between Montreal criteria and certification principles.

Montreal Process criteria	**Forest Stewardship Council (FSC) principles**	**Sustainable Forestry Initiative (SFI) principles**
Ecological category		
1.0 Biodiversity conservation 2.0 Maintenance of productive capacity 3.0 Maintenance of forest ecosystem health and vitality 4.0 Conservation and maintenance of soil and water resources 5.0 Maintenance of forest contribution to global carbon cycles	6.0 Environmental impact 9.0 Maintenance of high conservation value forests 10.0 Plantations	4.0 Long-term forest health and productivity 5.0 Long-term forest and soil productivity 6.0 Protection of water resources 7.0 Protection of special sites and biodiversity
Economic category		
6.0 Maintenance and enhancement of long-term multiple socio-economic benefits to meet societal needs	5.0 Benefits from the forest	3.0 Reforestation and productive capacity
Institutional category		
7.0 Legal, institutional and economic framework for forest conservation and sustainable management	1.0 Compliance with laws and FSC principles 2.0 Tenure and use rights and responsibilities 7.0 Management plan 8.0 Monitoring and assessment	8.0 Legal compliance 9.0 Continual improvement
Social category		
6.0 Maintenance and enhancement of long-term multiple socio-economic benefits to meet societal needs	3.0 Indigenous peoples' rights 4.0 Community relations and workers' rights	2.0 Economically, environmentally, and socially responsible practices

Table 3. Characteristics of companies selected for case studies.

Name	History	Location	Property size	Property composition
Company A (uncertified)	Privately-owned since late 1800s; timber supply only	Southern ME	8,100 ha (dispersed across approx. 30 parcels)	40%- mixed white pine (pine-oak-hemlock-red maple); 30%- mixed northern hardwood (maple-beech-birch-hemlock); 30%- spruce-fir
Company B (FSC certified since 2002)	Analogous history; vertically integrated supply, manufacture and retail facilities	Southern ME	13,800 ha (dispersed across approx. 40 parcels)	45%- mixed white pine 35%- mixed northern hardwood; 20%- spruce-fir
Company C (SFI certified since 2002)	Analogous history; vertically integrated supply, manufacture and retail facilities	Southern ME	11,000 ha (8,140 ha in one parcel; remainder dispersed across approx. 25 parcels)	60%- mixed white pine 40%- mixed northern hardwood

Table 4. Criteria used to evaluate forest management companies.

Source:	**Maine State Forest Service criteria for sustainability**	**Montreal criteria**	**Forest management unit adaptation of Montreal by Mrosek et al. (2006)**	**Forest management unit adaptation of Montreal by Wright et al. (2002) (LUCID)**
Ecological category				
(1) *Biodiversity subcategory:* Maintain forest composition-al and structural diversity at multiple spatial scales	5.0 Biological diversity	1.0 Biodiversity conservation	1.1 Landscape patterns 1.2 Ecosystem diversity 1.4 Native species diversity 1.5 Genetic diversity	2.1-2.2 Landscape function, structure, and composition 2.5-2.6 Population function, structure, and composition 2.7-2.8 Organism function, structure, and composition
(2) *Ecosystem function subcategory:* Maintain gas exchange, soil productivity, and water quality functions	1.0 Soil productivity 2.0 Water quality, wetlands and riparian zones	2.0 Maintenance of productive capacity 4.0 Conserva-tion and maintenance of soil and water resources 5.0 Maintenance of forest contribution to global carbon cycles	1.3 Ecosystem function 1.6 Physical environmental factors in terms of soil and water	2.3-2.4 Ecosystem function, structure, and composition
(3) *Ecosystem health subcategory:* Maintain tree mortality within targets	None	3.0 Maintenance of forest ecosystem health and vitality	1.7 Incidence of disturbance and stress	None

Economic category				
(1) *Economic efficiency subcategory:* Maximize net present returns	None	6.0 Maintenance and enhancement of long-term multiple socio-economic benefits to meet societal needs	2.2 Social efficiency	3.4 Economic efficiency
(2) *Sustained yield subcategory:* Maintain quantity and quality of commercial resources (nontimber and timber) in perpetuity	3.0 Timber supply and quality	" "	2.1 Sustainability of goods and services	3.1 Stocks of capital including natural, built, and human 3.2 Flows of both commercial and noncommercial products and services
Institutional Category				
(1) *Management systems subcategory:* Document and periodically revise critical management practices	None	7.0 Legal, institutional and economic framework for forest conservation and sustainable management	4.1 Policy, planning, and institutional framework 4.2 Management plan implemented and effective	None

Social category				
(1) *Social resource value subcriterion:* Maintain areas with aesthetic, archeological, cultural, educational, historic, spiritual, and recreational value	4.0 Aesthetic impacts of timber harvesting 7.0 Traditional recreation	6.0 Maintenance and enhancement of long-term multiple socio-economic benefits to meet societal needs	3.1 On-going access to forest resource	1.4 Social and cultural values for multiple resource uses
(2) *Participatory forestry subcriterion:* Enable public involvement in management planning, implementa-tion, and/or monitoring	6.0 Public accountability of forest owners and managers	" "	3.2 Concerned stakeholders have right to participate in open and meaningful process 3.3 Recognition and respect for Aboriginal rights	1.1 Collaborative stewardship 1.2 Institutional/ community capacity
(3) *Equity and safety subcriterion:* Ensure safety and equitable compensation	None	" "	3.4 Equitable access to and distribution of economic rents 3.5 Forest-based human health	1.3 Social equity, access, and health and safety 3.3 Trade and distributional equity

CHAPTER 3

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 nonindustrial private properties in 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 and less decayed than that found in unmanaged mature forests. Overall, our data indicate that FSC certified harvested stands

in northern hardwood forests have similar sugar maple timber value, similar live tree structure, and greater residual coarse woody debris compared with 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). Though 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 over the decade of 1996-2006 (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 in the northeastern U.S. 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 nonindustrial private properties (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 stand-level 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—that is whether FSC forests have a distinguishable stand-level identity—regardless of whether certification actually causes those features by changing pre- and post-certification management practices. Studies based on certification preconditions show that certification results in management changes (Gullison, 2003; Newsom *et al*., 2006), but we cannot eliminate in our study the possibility of self-selection whereby owners and managers who customarily employ ecologically oriented management practices predispose 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 nonprofit organization ownership, but excluding government, timber industry, or timber investment management organization ownership); (3) 5-25 ha harvest size in one homogeneous stand; and (4) partial harvest silvicultural 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 1000 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 were multi-aged containing at least two cohorts separated by 20+ years. 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 20-30%), mean soil pH (4.0-4.6), and dominant sugar maple age (60-70 years) (Table 5).

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 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 5-7 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 6), and thus we aver 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). 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 meter 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 meters. Height class, live crown ratio (percentage of bole covered by live crown), and species of trees were also recorded in these variable radius plots. 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 branches, and visible defects, such as rot or mechanical damage. Two basal diameters of merchantable trees (≥25 cm dbh) were 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). Recent carbon trading rates were used to calculate potential carbon storage value in live trees ($3 from Chicago Climate Exchange (CCX, 2007) and from European Union Carbon Exchange (Point Carbon, 2007) in U.S. dollars per metric ton). Note that prices fluctuate widely in this inchoate market.

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, a figure that was comparable to published figures from Cubbage *et al*. (2003), excluding internal administration and management costs. 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 (≥10 cm diameter) volumes were calculated based on the equation of the frustum of a cone (fine woody debris with small end diameters <10 cm was not measured). Standing woody debris or snag (≥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 7). However, both harvests significantly reduced both biomass ($p<0.01$) and basal area of live trees ≥10 cm dbh ($p<0.01$) by approximately one-third compared to pre-harvest reconstructed conditions. Harvesting apparently reduced total tree 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, roughly translated into 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

(Fig. 2). 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).

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 8), 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 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 9). 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 net present cost of certification at a 6% discount rate over a 10-year period was approximately $47/ha, representing between 1-2% of current harvest returns. Including these costs, the estimated recent harvest stumpage value averaged $1900 per ha for certified versus $3300 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 indistinguishable. Follow-up analyses in the discussion section below show that statistical significance emerges with higher discount rates.

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 7).

Diameter distributions in the certified and uncertified stands were both moderately different from non-harvested references (Fig. 2). 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 nongovernmental organizations, suggest that forests will play a role in emerging carbon markets. However, carbon storage value for live trees was less than one-tenth sugar maple timber value in our study, suggesting that carbon storage will play only a supplementary role in income generation in this region, and only then when transaction costs for market access and monitoring are low.

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 25-50% of the total forest carbon in temperate forests (Pregitzer and Euskirchen, 2004) with the majority of the remainder in 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 7). 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 $50/ha.

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 or harboring secondary bark beetles as in the boreal zone, or accelerating carbon respiration as in the tropical zone. Indeed, leaving standing snags and down logs in this region provides multiple ecological functions: supplying habitat (in addition to 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 (Hammond *et al*., 2001; Jabin *et al*., 2004; Latty *et al*., 2006); 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 8). Nearly all of this debris was relatively un-decayed and the harvests were of similar intensity, suggesting that the more abundant debris in certified stands resulted from differing management practices, such as retaining snags instead of felling them, and leaving bole tops instead of removing them for pulpwood (including biomass, fence poles, firewood, and 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 60-70 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 higher discount rates. Uncertified harvests removed more merchantable sugar maple in the initial harvest as suggested by the significant removal of acceptable growing stock of sugar maple of approximately 50% while certified harvests removed approximately 25% relative to non-harvested references (Table 9). The larger initial removal in uncertified harvests resulted in economic returns approximately $1200/ha higher in present value at a 15% discount rate relative to uncut references ($p=0.04$).

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, though the coarse woody debris differed in decay class and size from old growth stands. 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" but 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 FSC certification, the results of our exploratory study are not definitive.

Future research should expand temporally with economic data on actual tree recruitment and regeneration over a number of years, as well as expanding spatially to include ecological factors such as high conservation value area protection. Future research should also expand into other biomes where even-aged management is commonly employed. 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.

Table 5. Biogeophysical characteristics of recently harvested certified and uncertified stands (mean± one standard error).

	Cert1	Cert2	Cert3	Mean Cert (n=3)	Uncert1	Uncert2	Uncert3	Mean Uncert (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)

Table 6. Live tree (≥10 cm dbh) characteristics in non-harvested reference and pre-harvest reconstructed stands (mean± one standard error). Reported *P* values are the result of ANOVA/Tukey-Kramer HSD tests.

	Cert. Pre-harvest Recon. (n=3)	**References (n=6)**	**P**	**Uncert. Pre-harvest Recon. (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

Table 7. Live tree (≥10 cm dbh) characteristics in pre-harvest reconstructed and recently harvested stands (mean±one standard error). Significant differences (Tukey-Kramer HSD, $p \leq 0.05$) are marked with different superscript letters.

	Cert. Pre-harvest Recon. (n=3)	**Certified Post-harvest (n=3)**	**Uncert. Pre-harvest Recon. (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)
Potential live tree carbon storage value ($/ha)	$210[a] (±6.0)	$160[b] (±14)	$200[a] (±12)	$140[b] (±8.5)
Relative density *Acer saccharum* (%)	68 (±11)	71 (±12)	61 (±4.0)	60 (±8.0)

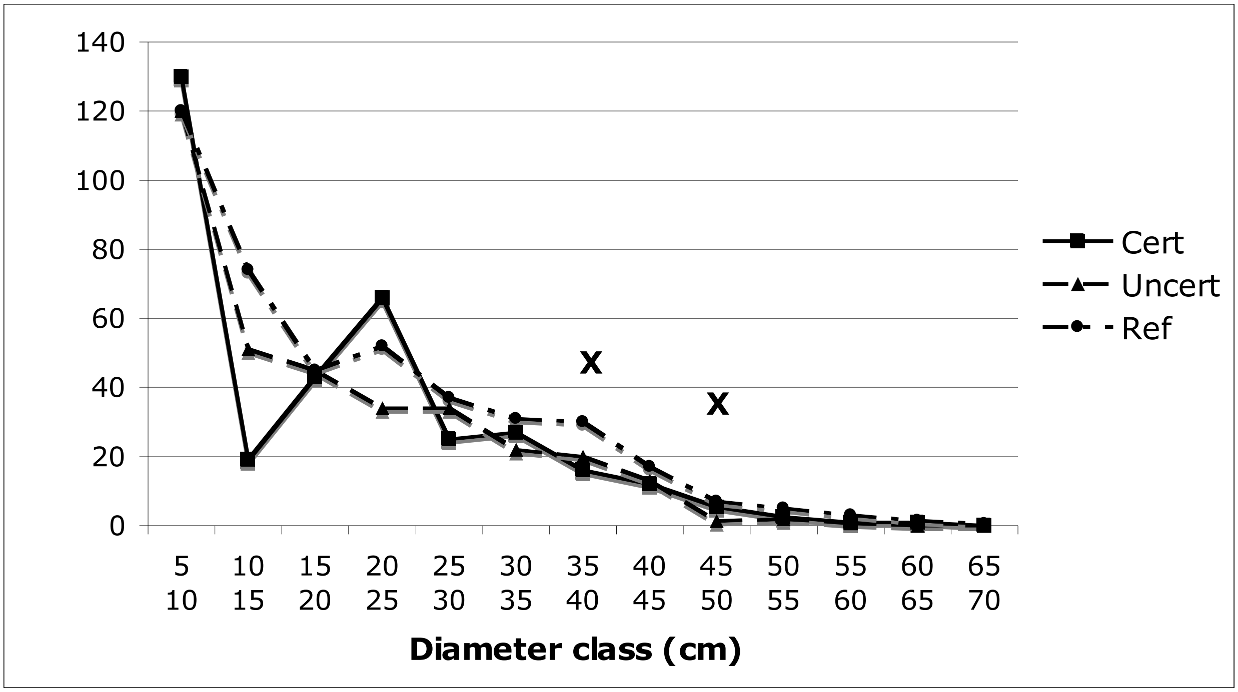
Table 8. Coarse woody debris densities and volumes in certified, uncertified, and non-harvested reference stands (mean±one standard error). Significant differences (Tukey-Kramer HSD, p≤0.05) are marked with different superscript letters.

	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)

Table 9. Merchantable sugar maple volume and net present value in certified, uncertified, and non-harvested reference stands (mean±one standard error). Significant differences (Tukey-Kramer HSD, $p \leq 0.05$) are marked with different superscript letters. AGS signifies acceptable commercial growing stock of select or common grade sugar maple at least 25 cm dbh.

	Certified (n=3)	Uncertified (n=3)	References (n=6)
Acer saccharum			
Measured stand vol. AGS* (m^3/ha)	79 (±20)	55[a] (±14)	110[b] (±11)
Modeled growth minus mortality (+10 years) (m^3/ha)	81 (±21)	56[a] (±17)	120[b] (±11)
Net present value of *Acer saccharum* timber ($/ha)			
4% real discount rate			
Recent timber harvest returns (2003)	$1900[a] (±1100)	$3300[a] (±1000)	$0[b] (±0)
Residual dis. 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 dis. 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 dis. 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)

Fig. 2. Diameter distributions in certified, uncertified, and non-harvested reference stands. Significant differences (Tukey-Kramer HSD, p≤0.05) are marked by "x"s.



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