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Red Oak in Southern New England and Big-Leaf Mahogany in the Yucatán Peninsula: Can Mixed-Species Forests Be Sustainably Managed for Single-Species Production?

MATTHEW J. KELTY[1], LUISA CÁMARA-CABRALES[2], and JAMES GROGAN[3]
[1]*Department of Environmental Conservation, University of Massachusetts, Amherst, Massachusetts, USA*
[2]*División Académica de Ciencias Biologicas, Universidad Juárez Autónoma de Tabasco, Villahermosa, Tabasco, México*
[3]*Yale School of Forestry & Environmental Studies, New Haven, Connecticut, USA*

Complex mixed-species forests are the focus of conservation efforts that seek to maintain native biodiversity. However, much of this forestland is privately owned and is managed for timber income as well as for conservation. Management of these high-diversity forests is particularly difficult when only one tree species produces the majority of high-value timber. We examined the past and current management of two regions which have those characteristics: Massachusetts, USA, with red oak (Quercus rubra *L.) as the key timber species, and Quintana Roo, México, with big-leaf mahogany* (Swietenia macrophylla *King) as the most valuable species. These regions have different ecological characteristics, forest ownership types, landowner income, and importance of timber in total income, yet the silvicultural approach (low-intensity selective cutting) is surprisingly similar, and is generally failing to provide the conditions needed for regeneration and growth of key species. In both situations, the reluctance to harvest low-value species and interest in minimizing forest disturbance complicates management. Successful balance of timber harvest and forest conservation may be an important factor in preventing conversion of these lands to agriculture or residential development, but socioeconomic*

Address correspondence to Matthew J. Kelty, Department of Environmental Conservation, 160 Holdsworth Way, University of Massachusetts, Amherst, MA 01003, USA. E-mail: kelty@nrc.umass.edu

conditions (property tax policies and landowner affluence) play an important part in the outcome.

KEYWORDS México, Quercus rubra*, reduced impact logging, silviculture, sustainable forest management,* Swietenia macrophylla

INTRODUCTION

In what ways are red oak (*Quercus rubra* L.) in southern New England and big-leaf mahogany (*Swietenia macrophylla* King) in México's Yucatán Peninsula similar? Both occur in complex mixed-species forests, and produce high-value timber that far exceeds the worth of any other species. Their current distribution and density patterns may be partly anthropogenic artifacts: Maya swidden agriculture is thought to have fostered mahogany recruitment across the Yucatán by creating persistent large-scale growing space mimicking its natural regeneration requirements (Snook, 1998); industrial clear-cutting and burning in New England at the turn of the 20th century promoted red oak regeneration (Kelty & D'Amato, 2006). The ecology of both species has been well studied. In both regions, past harvest practices have systematically high-graded these species from natural forests, and their natural regeneration after logging is often observed to be sparse or completely absent (Snook, 1998; Dickinson & Whigham, 1999; McDonald, Motzkin, & Foster, 2008). Both species promise sharply reduced or even failed future production of valuable sawtimber under current management regimes (Loftis & McGee, 1993; Snook, 2003). These are very different trees inhabiting forests within different historical and socioeconomic contexts, and yet their unsustainable treatment aimed at timber production from natural forests is similar in surprising ways. Concern regarding management methods has been growing within the forestry sector in both regions.

We use red oak and big-leaf mahogany as examples to frame a broader question: Is sustainable forest management for timber production possible in complex mixed-species assemblages where the value of one species far exceeds all others? In this discussion we define "sustainable" simply as the maintenance of commercial production capacity of the key species over multiple cutting cycles (including the establishment of new cohorts) that does not contribute to losses in biodiversity. Silvicultural systems tend to be most successful in natural low-diversity forests or in single-species plantations. In highly diverse stands, when a single species occurring at low densities relative to other species becomes the focus of commercial operations, financial returns on a per-unit-area basis can decline to the point where the cost of managing future crop trees becomes prohibitive. Further, if a standard silvicultural system is implemented in these kinds of stands, it may contribute to the “domestication” of natural forests, altering species composition and possibly reducing community diversity by eliminating species whose regeneration requirements are unlike those of the target commercial species.

There are two facets to the question of how management can be made sustainable in these kinds of forests: (a) What changes in silvicultural approach are needed to maintain establishment and growth of key species?; and (b) Given that social, economic, and regulatory contexts affect what management is possible, how have these conditions in such different places resulted in management practices that are similarly unsustainable, and how might they be changed? To address these questions, we first review the ecological characteristics of the two species and their ecosystems, as well as the history of land ownership and timber harvesting in both regions (summarized in Table 1). Then we address the current status of forest management, including landowner objectives, economics, and silviculture regulations and practices. The southern New England region in the northeastern United States includes Connecticut, Massachusetts, Rhode Island, and the southern parts of Maine and New Hampshire. The region of interest in the Yucatán Peninsula includes the Mexican states of Quintana Roo and Campeche as

TABLE 1 Summary of Ecological, Ownership, and Management Characteristics of Forests in the States of Massachusetts, USA, and Quintana Roo, México. Descriptions are for the Most Common Conditions Occurring in Each State. See Text for Data and References

	Massachusetts	Quintana Roo
Ecological characteristics		
Latitude	42° N	19° N
Seasonality	Hot/cold	Wet/dry
Annual precipitation	1,100 mm	1,300 mm
Soils	Recent glacial origin	Weathered clays
Geomorphology	Granitic origin, rolling hills	Limestone plateau
No. of tree species	$\sim$15 species ha^{-1}	$\sim$30 species ha^{-1}
Forestland ownership		
Ownership type	family	Community (ejido)
Ownership size (range)	4–4000 ha	1,000–50,000 ha
Ownership size (mean)	20 ha	4,500 ha
Main reason for ownership	Privacy, aesthetics	Timber income
Timber as part of total income	0 to 10% for most	Up to 50%
Forest management		
Management plans	Optional	Required
Silvicultural methods	Wide range, often light selective harvest	Selection harvest, polycyclic (25 yr)
Highest value species	Red oak (*Quercus rubra*)	Big-leaf mahogany (*Swietenia macrophylla*)
Timber value ratio of highest value species to other species	8:1	6:1

well as the nations of Belize and Guatemala. Our specific geographical focus is on the states of Massachusetts and Quintana Roo, where much of the research on these species and the associated management issues has been conducted.

ECOLOGICAL SETTINGS AND SPECIES

Massachusetts

Climate in southern New England is cold temperate, with a mean annual temperature of 7°C. There are distinct seasonal temperature differences with warm summers (July mean of 19°C) and cold winters (January mean of −6°C; Hall, Motzkin, Foster, Syfert & Burk, 2002). Annual precipitation of 1,100 mm is evenly distributed throughout the year. Bedrock consists primarily of ancient metamorphosed granitic materials interspersed with areas of sandstone and limestone. The landscape is dominated by rolling hills. Soils are of recent glacial origin and therefore generally coarse and nutrient-rich. Forests are species-rich by temperate standards, with many stands containing 10 to 20 tree species attaining stem sizes larger than 10-cm diameter. The deciduous angiosperms provide most of the tree diversity, with oak (*Quercus*), birch (*Betula*), maple (*Acer*), and beech (*Fagus*) being the most common genera across the region. Two evergreen conifer species—white pine (*Pinus strobus* L.) and hemlock (*Tsuga canadensis* [L.] Carr.)—make up a substantial part of many stands.

Red oak is an important component of forests in southern New England and the most valuable timber species in the majority of forest types in the region. White oak (*Quercus alba* L.) also produces valuable timber, but is much less common. Red oak occurs across a wide range of sites, but grows most rapidly on deep, well-drained soils on lower slopes (Abrams, 1990; Ashton & Larson, 1996). Red oak is a strong competitor and may dominate the main canopy of a stand, or occur in mixture with other hardwood species and white pine in the main canopy; it may occur at densities of 10 or more commercial-sized trees per hectare (Oliver, 1978; Stephens & Ward, 1992). More shade-tolerant species occupy lower canopy levels, forming a stratified canopy structure. The red oak regeneration syndrome includes animal-dispersed seeds (acorns) with distinct masting years, and closed or partial canopy cover for germination and seedling establishment (Crow, 1988). Red oak seedlings are intermediate in shade tolerance, and stems often die back and resprout repeatedly when growing in the understory. Growth into the sapling layer is limited mainly by shading from shrubs and mid-canopy trees (Lorimer, Chapman & Lambert, 1994). Overstory removal during harvest operations has been shown to release red oak advance regeneration, but only where it is of sufficient size to rapidly exploit the newly opened growing space. Red oak grows relatively slowly in this northern edge of its range; it requires 90–120 yr to attain commercial size of 50-cm diameter (Stephens & Ward, 1992). Its wood is dense yet easily milled, and is used for flooring, furniture, and veneer. In the recent past, most of the best red oak logs were exported to western Europe and Japan for use in high-end furniture industries.

Quintana Roo

Climate in the Mexican state of Quintana Roo is tropical, with year-round temperatures averaging over 25°C. Annual rainfall is approximately 1,300 mm with a dry season from February to April during which little or no rain falls. The Yucatán Peninsula is a karst or marine sediment-derived limestone plateau that is quite flat, with no permanent surface streams. Soils are dense clays and nutrient-rich by tropical standards due to their marine origins. Forests are complex semi-evergreen communities of over 100 tree species in the region, and with 30 species or more in a hectare. Chicozapote (*Manilkara zapota* [L.] P. Royen) and ramon (*Brosimum alicastrum* Sw.) are the most abundant species (Bray, 2004; Vester & Navarro-Martínez, 2005).

Mahogany is the most valuable neotropical timber species. It is associated with seasonally dry tropical forests from México to Bolivia. In Quintana Roo, mahogany occurs at approximately one commercial-sized tree per hectare at landscape scales; this is a greater density than in most of its range (Snook, 1998). Spanish cedar (*Cedrela odorata* L.) is the only other species with high timber value in this region, but it occurs at lower densities. Mahogany develops into a canopy emergent tree in mature stands, with wind-dispersed seeds that germinate at the onset of the rainy season. Seedlings require high light levels for robust growth, which can attain 3-m annual height growth during the early years; seedlings germinating in the forest understory cannot successfully recruit without some form of overhead canopy disturbance. Diameter growth rates of healthy trees can exceed 1 cm yr^{-1} over decades, shortening the time required to attain commercial size to 50 yr or less (Shono & Snook, 2006; Grogan & Landis, 2009). While its habitat associations in Quintana Roo are poorly understood, mahogany typically occurs in aggregations separated by forest areas with lower densities. This distribution pattern may result from its regeneration requirements, especially disturbances that open growing space at large spatial scales—such as hurricanes, fires, and slash-and-burn agriculture (Lamb, 1966; Snook, 2003). Mahogany timber is valued for its strength, structural stability, durability, and great beauty. The principal export markets historically have been England and the United States, but most domestic production is currently consumed within México.

HISTORICAL PERSPECTIVES ON OWNERSHIP AND USE OF FORESTS

Massachusetts

Forestland in southern New England has largely been in private family ownership since the first townships were established by European colonists in the 17th century. This was in contrast to the practices of the indigenous Indians of the Algonquian nation, who had previously held these lands in communal ownership. They had long used fire to shape forest structure and species composition, maintaining forests with open understories, particularly along the coasts and major rivers where population centers were located (Cronon, 1983). However, they lacked the technology to readily fell large trees. The earliest European settlers began harvesting trees for local use and for export. The most valuable species for trade were oaks for ship timbers and barrel staves, and white pine for ship masts and clapboards. Diameter-limit cutting of the select species was the standard harvest method (Kelty & D'Amato, 2006). The largest trees were first cut from major river drainages throughout the region for these specialty products, but harvesting then expanded across the region, which became the source of basic oak construction materials for export to England.

As the Euro-American population grew, widespread forest clearance associated with agricultural development in the 18th and early 19th centuries reduced forest cover across Massachusetts to approximately 40% at the lowest point in 1880 (Hall et al., 2002). Agriculture declined rapidly after that date as farmers abandoned their land for better prospects in the American Midwest or in local cities, and forests naturally recolonized this open land. Clear-cutting became common in this period because trees of all sizes could be used to provide fuelwood, charcoal, boxboards, tannic acid, and other wood-based chemicals in the industrialized economy (Kelty & D'Amato, 2006). This heavy cutting and burning favored oak within the mixed-species regeneration. It also favored chestnut—*Castanea dentata* (Marsh.) Borkh.—but nearly all chestnut greater than sapling size died from a human-introduced, invasive fungal pathogen, thereby ceding more growing space to oaks. As a result, most of the forestland had been cut over and was of little value in the first half of the 20th century. Land changed ownership frequently, and many owners were land or timber speculators, with no connection to stewardship of their properties (King, 1998). This period of clear-cutting from 1880–1930 led to the natural establishment of even-aged stands that make up most of today's forests in Massachusetts.

Quintana Roo

Maya kingdoms flourished on the Yucatán Peninsula from 1800 BC to the arrival of the Spanish in the 16th century. Little is known about the extent to which the Maya cleared or managed forests. Though widespread deforestation in Quintana Roo did not occur until the mid-20th century, shifting slash-and-burn agriculture enhanced by new technology—the iron axe, introduced by the Spanish—likely created a landscape-scale patchwork of forests at different successional stages, opening growing space for gap-dependent species like mahogany, and altering forest structure and composition. In 1629 the Spanish established their principal New World shipyard in Veracruz in part to take advantage of abundant supplies of mahogany from the Yucatán Peninsula. Mahogany was the main reason the British founded British Honduras (Belize), where they began harvesting as early as 1683. In fact, the Maya resisted Spanish and later Mexican rule with support from England in return for British access to mahogany (Snook, 1998).

The pattern of mahogany's exploitation in this region has been repeated many times across its natural range. First, mahogany trees along the Rio Hondo (the border between Quintana Roo and then-British Honduras) were felled and floated to Chetumal for export by ship to England. Then loggers moved progressively farther from riverbanks using slave and, by 1805, oxen and mule labor to haul logs to rivers for transport. Eventually narrow-gauge railroads and crawler tractors opened up interior forests far from rivers for exploitation (Lamb, 1966; Snook, 1998). After the Mexican government finally conquered the Maya in 1901, concessions for timber harvesting in Quintana Roo were granted to British and American companies. This arrangement continued until 1947 when foreign concessions were suspended (Andersen & Barnes, 2004). The Mexican state largely ignored local community (*ejido*) claims to timber resources from the early 1950s to the early 1980s, granting a 25-yr concession to the parastatal company Maderas Industrializadas de Quintana Roo (MIQRO), with access to 550,000 ha of forest spread across state lands and *ejidos* in central and south Quintana Roo. MIQRO's forest management system consisted largely of high-grading mahogany and Spanish cedar. During this period, the main forest resource harvested by community members was *chicle* latex tapped like rubber from chicozapote trees (Flachsenberg & Galletti, 1998; Snook, 1998).

THE SITUATION TODAY

Massachusetts

Of the 1.25 million ha of forested land in Massachusetts, 69% is privately owned. The size of forest ownerships are strongly skewed to small holdings. The median ownership size is 5 ha, even when excluding the holdings less than 4 ha; only 24% of landowners have forestland greater than 20 ha. These private landowners have an annual median family income of $50,000, with 23% earning more than $100,000; more than half are college educated and only 3% own forestland as part of a farm (Butler, 2008). The great majority of Massachusetts forest landowners—90%—own their forests primarily for the purposes of privacy of residence and aesthetic values such as scenery, nature conservation, and personal recreation (Belin et al., 2005; Finley & Kittredge, 2006). Two-thirds of forest landowners have no objection to timber harvesting, while the rest would prefer that there be none. Income from forestland makes up less than 10% of total family income for 96% of forest owners (D. B. Kittredge, unpublished data, July 21, 2009). For many, this income is likely insufficient to pay even the property taxes for the forestland (D'Amato, Catanzaro, Damery, Kittredge, & Ferrare, 2010). Only a small percentage of landowners actively depend on forest holdings for significant income generation, and these generally have the larger tracts of land.

Most landowners (96%) do not have written plans or forest inventories to guide forest management (Butler, 2008). Rather, harvests often occur when owners have a specific need for income or when a logging contractor suggests the possibility of a harvest to the owner. Landowners generally want to limit harvesting disturbance that would compromise the primary values of their forest (Finley & Kittredge, 2006). The only landowners who are required to have management plans for their forestland are those who participate in a state current-use program. These owners may not convert their land to non-forestry uses without financial penalties, and in return, their land is appraised at timber production value which is much lower than the prevailing development value, thus decreasing property taxes substantially. However, only 15% of eligible landowners in the state participate in this program (D'Amato et al., 2010).

Harvesting practices are closely regulated by the Massachusetts state forestry agency, with much of the focus being on the protection of wetlands, streams, soils, and rare species during harvest operations. There is a strong tradition of private property rights in the management of land, and landowners can choose the silvicultural method to be used and the amount to be cut. Regulations specify that appropriate conditions must be provided for establishment of regeneration following cutting, but there is no requirement to favor any particular tree species (except for selecting species that are ecologically suited for the site conditions). A review of forestry practices in Massachusetts compared planned harvesting with actual harvesting (Patric, 1988). While selection and shelterwood were the most common methods listed on the cutting plans, Patric concluded that most harvests were essentially high-grading (diameter-limit cutting of red oak and other commercial species). A more recent analysis of timber harvests in Massachusetts showed that most were light partial cuts, removing an average of only 25% of stand volume (about 45 m^3 ha^{-1} cut of the initial 170 m^3 ha^{-1}; Kittredge, Finley & Foster, 2003). During 1985–1998, red oak timber was 32% of the total volume (all trees > 12-cm diameter) of hardwood species harvested in the state, with all oak species combined making up 60% of the total (Alerich, 2000). In that period, the unit price of red oak timber was eight times greater than that of birch, maple, and beech. The volume harvested exceeded the volume grown only for oak species statewide; for all other species, growth exceeded harvest volume.

A consequence of low-intensity partial cutting is that regeneration of species with low or intermediate shade tolerance is quite limited. A study of regeneration across the state at sites that had been harvested 2 to 20 yr earlier showed only a moderate increase in red oak seedling density compared to similar unharvested sites, and oak saplings were absent in both the harvested and unharvested stands, even in those with oak-dominated overstories (McDonald et al., 2008). The seedling and sapling density of shade-tolerant black birch (*Betula lenta*) increased in response to these harvests, indicating that light conditions were favoring the more tolerant species. A wide range of silvicultural methods are used in Massachusetts because of the freedom with which landowners can make management choices, yet the overall assessment is that most harvests have not promoted the establishment of oak regeneration.

Quintana Roo

Forests in Quintana Roo by contrast are now common-property, community-managed resources. The transfer of state-owned land to local communities occurred throughout México during the 1930s and 1940s. Forest-owning *ejidos* were obligated by law to conserve and manage forests rationally. The extent of each *ejido* in Quintana Roo was originally determined by the number of hectares (420) deemed necessary for a community member to survive financially by tapping *chicle* latex from chicozapote trees in natural forests (Galletti, 1998), but the market for natural latex has fallen precipitously in recent decades. Today there are 62 forest-based *ejidos* in Quintana Roo ranging in size from 1,000 to 70,000 ha and covering a total of 1.3 million ha, with over 500,000 ha of the area in forest (Snook, 1998). Termination of the MIQRO concession in 1982 and declaration by *ejidos* of permanent forest estates effectively ended land-use change; forest clearing for agriculture slowed dramatically (Bray et al., 2003). After 1983 *ejidos* suddenly found themselves in charge of timber harvests and commercialization. Depending on the percentage of community land in forest and the commercial presence of mahogany and Spanish cedar on the land, *ejidatarios* in Quintana Roo supplemented their incomes by as much as $1,895 in 1999 from timber production, representing 50% of per capita income. But most *ejidos* earned far less from commercial timber production (Bray, 2004; Argüelles, Synnott, Gutiérrez & Angel, 2005).

Termination of the MIQRO concession forced *ejidatarios* with little technical expertise to begin processing timber rather than selling stumpage, first by renting and then by acquiring the necessary heavy equipment. Management practices from the MIQRO era were adopted largely intact for lack of community expertise, with modifications devised by state technical extension agencies. The 75-yr rotation length determined by MIQRO for mahogany was divided into three 25-yr cutting cycles based on limited information about growth and mortality, particularly the expectation that diameter growth rates of 0.8 cm yr^{-1} could be maintained throughout the rotation. The minimum diameter cutting limit was set at 55 cm for mahogany and other large-statured secondary timber species (Flachsenberg & Galletti, 1998). Management plans called for reserve mahogany trees (35- to 54-cm diameter) to supply commercial harvests during the second 25-yr cutting cycle, and for recruits (15- to 34-cm diameter) to supply commercial harvests during the third 25-yr cutting cycle. Up to 18 secondary tree species are logged in these forests, but initial plans to produce 2 m^3 of secondary timber for every cubic meter of mahogany and Spanish cedar foundered because markets for low-value species were insufficient; only 14 and 18% of authorized volumes of secondary species were harvested in Quintana Roo in 1999 and 2000, respectively (Bray, 2004).

Much of the commercial mahogany and Spanish cedar resource logged after 1982 was actually low-quality timber that MIQRO had already rejected during a highly selective first cut for not being sound (hollow or heart-rotted), or straight to 4.2-m height, or larger than 40-cm diameter at the top (Snook, 1998). Mahogany production declined after 1987, and fell to approximately 10,000 m^3 yr^{-1} from all of Quintana Roo during the period 1993–2001 (Bray, 2004; Vester & Navarro-Martínez, 2005). Today, nearing the end of the first 25-yr cutting cycle, *ejidos* are facing the prospects of sharply reduced second-harvest volumes due to slower-than-anticipated growth rates by reserve trees and unexpected mortality associated with logging damages and natural causes. The mahogany resource has essentially been high-graded during recent decades, with insufficient sub-commercial mahogany trees in place to provide equivalent second harvests. Though regeneration pathways are better understood after extensive field research since the early 1990s, current management practices must change and improve, or it is likely that mahogany's commercial status will continue to deteriorate over future cutting cycles (Snook, 1998; Snook et al., 2003).

THE MANAGEMENT PARADOX

Silvicultural Challenges

Highly diverse even-aged forest stands with one or two valuable timber species have historically been high-graded for short-term profit throughout the world. The intent of many landowners at present may not be only to gain short-term profit, but the combined goals of extracting high-value timber while minimizing disturbance to forest structure often lead to a similar result in residual forest condition. These forests and species are extremely difficult to manage sustainably for several reasons. First, silvicultural treatments aimed at maintaining or increasing key species densities must be developed and applied. Some treatments must target pole and mature trees to accelerate growth rates for producing merchantable timber, while others target the regeneration phase, increasing survivorship from seedling to sapling stage. Both are required for forest management to be financially as well as ecologically viable. Second, silvicultural treatments aimed at maintaining the broader tree community must be developed and applied. Optimal growing conditions for high-value species are inevitably in opposition to those required by tree species with different life history profiles. A variety of methods would likely be needed to produce a broad range of forest conditions.

Finally, because light-demanding species like oak and mahogany require the reduction or removal of low-value species to provide growing space, there must be social and economic capital available for investment in silvicultural treatments that may provide little or no short-term financial return. Market conditions are frequently unfavorable for cutting small-diameter low-value timber resulting from thinning operations. But market conditions are not the only factor inhibiting these operations; many landowners and forest regulators stress the desire for minimizing forest disturbance during harvests. This has been promoted as a conservation practice particularly throughout tropical forests under the term "reduced impact logging" (RIL). Fredericksen and Putz (2004) noted that excessive concern with reducing logging impacts can inadvertently work at cross-purposes to producing the high light conditions required for regeneration and growth of many commercial timber species.

Smith (1992) has proposed a number of silvicultural pathways for mixed-species stratified stands. Two of these appear most logical for the situation of valuable timber species that occupy upper forest canopy layers and require high light levels for seedling growth. One pathway maintains the even-aged structure of stands like those in Massachusetts and Quintana Roo by using shelterwood, retaining some trees from all strata. The other pathway initiates a shift to uneven-aged forest structure by creating gaps by means of group selection, removing trees of all species. A range of conditions can be achieved by varying the canopy density of the shelterwood or the size of the group selection gaps. These methods contrast with recent harvesting approaches in much of Massachusetts and Quintana Roo. In both cases, canopy openings have been small (often little more than one tree-crown in area), and thinning to reduce shading of new seedlings has not been a common practice. In Quintana Roo forests, mahogany and Spanish cedar seedlings have been routinely planted in harvest gaps, but survivorship has been poor in the low light conditions.

The need for larger disturbances than those created by selective logging in Quintana Roo has prompted experimental trials of seeding and outplanting of mahogany and Spanish cedar into forest clearings ranging from 0.05 to 0.5 ha in area (Negreros-Castillo, Snook & Mize, 2003; Snook & Negreros-Castillo, 2004). Other studies involve cleaning harvest gaps of understory vegetation, as well as thinning and pruning (Snook et al., 2003). The next step is to move these research treatments into practice in an adaptive management framework, as regulations allow. Tree planting is rarely carried out in Massachusetts, because oaks are abundant enough to produce widespread mast crops of acorns. However, shade-tolerant species continue to dominate the understory. Group selection has been used in management applications in Massachusetts, with gaps ranging from 0.1 to 1.0 ha in area on state watershed lands and on private lands managed by innovative consulting foresters. Shelterwoods are sometimes employed, but understory cleaning is carried out only rarely, so oak seedlings are at a disadvantage.

For both red oak and mahogany, a single disturbance event is unlikely to provide sufficient growing space for seedling recruitment to adult size. Seedlings can be suppressed by competing pioneer vegetation and advance regeneration of other canopy species, and vigorous stump sprouts can be aggressive competitors for mahogany in Quintana Roo. In both cases, some level of follow-up tending and canopy thinning may be necessary for long-term growth to commercial size.

Socioeconomic Contexts

With the substantial differences in the social communities of forest owners in Massachusetts and Quintana Roo, it might be expected that management practices would also differ substantially between regions. In particular, the higher total income levels and the lesser importance of timber within Massachusetts household economies suggest less need for current harvesting of high-value timber, and more emphasis on conservation and, with some landowners, on long-term timber production objectives. By contrast, *ejidos* of Quintana Roo, with greater dependence on cash income from timber harvests to supplement subsistence agriculture, would be expected to harvest all authorized mahogany volume annually and to carry out intensive silvicultural treatments to promote mahogany survival and rapid growth. Yet we see quite similar management methods and outcomes between the two regions, with substantial harvests of valuable species and relatively little silvicultural treatments.

Social conditions may counterbalance differences in wealth when it comes to forest management in these cases. The average Massachusetts landowner has greater formal education than his or her *ejidatario* counterpart, but this does not generally include detailed knowledge of forest and land management. Nor are most landowners in Massachusetts recipients of local knowledge and traditions of forest stewardship passed down through family generations. Today's landowners tend to be commuters tied to businesses and professions in nearby towns and cities, and land ownership is relatively fluid, with the mean tenure being only 21 yr (Belin et al., 2005). There are 32,000 forest landowners in Massachusetts with holdings greater than 4 ha, most of whom consistently express little interest in timber production, much less in improving current management practices. Much of this is a result of the small parcel sizes, which are not large enough for timber management, but still satisfy many landowners' goals for amenity values. Innovative ways must be developed to educate landowners about the long-term implications of today's management decisions. Extension services offered by university, state, and private foresters increasingly emphasize the use of new methods such as the Internet for educational outreach, as well as the selection and education of influential persons within communities or conservation agencies to disseminate ideas about land protection and forestry (Kittredge, 2004).

Although forest management for timber production by *ejidos* in Quintana Roo dates back only to the early 1980s, a much longer tradition of chicle tapping and harvests of minor forest products exists in this region. As well, communal land ownership and the day-to-day reality that family livelihoods must be largely derived from agriculture and forest resources serve to facilitate technical extension and community-based business enterprises. Thus it is not surprising to see widespread investment in logging and sawmill processing equipment, especially by *ejidos* with large forest holdings. In Quintana Roo, future harvests are threatened more by the legacy of historical logging practices which high-graded the primary timber resource, and by current economic need that has encouraged continuation of past management practices, than by plentiful economic alternatives and the lack of knowledge about forests, as in Massachusetts.

CONCLUSIONS

We have focused on forests containing big-leaf mahogany and red oak not to propose detailed management methods for those forest types, but rather to examine the over-arching challenges of managing mixed-species stratified forests with just one or two tree species that produce valuable timber. These kinds of complex forests are not particularly rare; they develop in many regions with high precipitation (generally1,000 to 3,000 mm yr^{-1}) throughout the world (Ashton, 1992). The conservation of these native forests has become an important objective for maintaining the large range of ecosystem services that forested land provides. For lands that are privately owned by families or communities, one approach to limiting the conversion of forests to other uses has been the improvement of the ability of owners to gain income from timber management.

In the regions described in this article, the potential alternative land uses would be agriculture or small-scale cattle production in Quintana Roo (Bray, 2004) or residential and commercial development in Massachusetts (McDonald et al., 2006). A focus on improved timber management is likely more useful for Quintana Roo because of the large landholdings and the current importance of timber in total income. The establishment of permanent forest areas in the *ejidos* effectively halted land conversion (Bray et al., 2003) but such shifts may return in the future if forest income drops substantially. The generally small landholdings in Massachusetts greatly limit harvest income for most landowners. Some will be able to maintain ownership of their forestland from other income sources, but rising land values make in increasingly difficult; many others will likely need to participate in current-use programs to reduce property taxes. Sporadic timber income would assist landowners, but it will likely not be the deciding factor in maintaining forestland for many Massachusetts owners (D'Amato et al., 2010).

In either of the cases of Quintana Roo or Massachusetts, conservation efforts logically promote low impact on forest structure during harvesting, but intensification of some aspects of silviculture is needed in order to allow the appropriate management of commercial timber species (Fredericksen & Putz, 2004). Creating a balance between low levels of forest disturbance and effective timber management for valuable tree species may be critical in conserving these forests.

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