Silviculture of the Mahogany Forest of Quintana Roo, Mexico

Criteria and recommendations

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Preface

Silviculture is the art, science and practice of controlling the establishment, composition, health, quality and growth of forests to accomplish a set of management objectives. This publication offers an approach to silviculture of the forests of Quintana Roo in which mahogany (*Swietenia macrophylla* King), the commercially most important tree species in Latin America, is found (Whitmore 2003). We designate these forests as *mahogany forests*. Much silvicultural knowledge has been gained by studying and observing which practices have or have not achieved the expected results in practice. This publication functions as a road map of technologically feasible options for the management of mahogany forests. It offers suggestions on how to develop silvicultural regimens for multiple objectives that are compatible with production of multiple forest products with emphasis on wood for industrial uses. It is hoped that by combining theory with context, those responsible for managing mahogany forests can create their own designs as well as validate and apply local knowledge and experience that they gather as they manage the mahogany forests of Quintana Roo.

Currently, a diversity of commercially important tree species is harvested in the forests of Quintana Roo, with mahogany the most emblematic and a lead species for timber utilization. The publication contains ecological and silvicultural information for management of mahogany forests that have the potential to produce timber from a large group of species, including mahogany. The publication does not contain quantitative silvicultural prescriptions, information on harvest regulation, financial evaluation or extraction technology, although specifications for forest regulations are considered.

The most important land issues in Quintana Roo and the Yucatan peninsula are not related to forestry activity. The issues include tourism infrastructure, chicle production, slash and burn, etc. Some of these issues often cause a change of land use that is effectively irreversible. The changes generate wealth and satisfaction for the local people and those who come to the region as investors, developers, technicians, administrators, workers and bureaucrats. This publication will not address these issues and concerns.

In no way is this publication an exhaustive source of silvicultural information on mahogany forests. It is presented as an educational tool that offers a synthesis of the current knowledge and interpretive conceptions available in 2012. Nonetheless, it attempts to be authoritative with informed and defensible judgment of the relevant features of technically possible silvicultural practices, and on the frontier of the biologically and technically feasible management options for the mahogany forests in Quintana Roo, Mexico.

Abbreviations

APC	Canopy cover
BA	Basal area (m^2/ha)
CONAFOR	National Forestry Commission
DBH	Diameter at breast height (1.30 m from the base)
FMP	Forest management plan or program
GIT	Group of interacting trees (minimal treatment unit)
GSI	Growing stock inventory
IV	Importance value
MSF	Medium semievergreen forest
PI	Prescriptive inventory
PPFQR	Pilot forestry plan of Quintana Roo
SBSA	slash and burn shifting agriculture
SEMARNAT	Secretariat of Environment and Natural Resources (SEMARNAT)

CONTENT

Chapter I. Historical synopsis of the mahogany forests of Quintana Roo

The forest resources of Mexico consist of 144 million hectares of forestland, of which the Comisión Nacional Forestal (Conafor, 2012) considers 23 million to be commercial timberlands. All the forested lands in Mexico are subject to regulations derived from the Agrarian Law. Practically all of the land with commercial timber resources is privately owned and can take one of three tenure modes: individual, ejidal and communal. The last two are forms of collective ownership. The three types of ownership are communal in the sense that they are not corporate industrial forests, public lands, or openly accessible, which are the most common tenure modes in the rest of the world. In the case of forestry operations, an authorized forest management plan (Fmp) is required. Responsibility for decision making in timber management resides with the landowner, though regulations mandate the co-responsibility of a licensed forester who drafts the Fmp. The same or other licensed foresters may supervise Fmp execution.

The case of land clearing to change the use of the land requires a distinct authorization procedure, which is conditional upon avoiding certain environmental impacts. Authorization for clearing is more dynamic when the intended new use is not forest related, such as a new population center or expansion of a preexisting urban area. In the case of a change of land use from forest to another use, it is irrelevant if wood or other commercially valuable biological materials are extracted or used or if they are considered to be residue of the process of land development.

In the tropical region of Mexico, it is important to keep in mind the different geographic regions and distinct parallel dynamics of the Yucatan Peninsula, Chiapas, the South Sierra Madre, Nayarit, Veracruz, the Isthmus of Tehuantepec and the dry forests dispersed in much of the Mexican territory south of the Tropic of Cancer (for example, those of Morelos, Tamaulipas, the Huastec, etc.) (figure 1). In this work, attention is centered on the Yucatan Peninsula, with occasional mentions of the rest of the Mexican tropics.

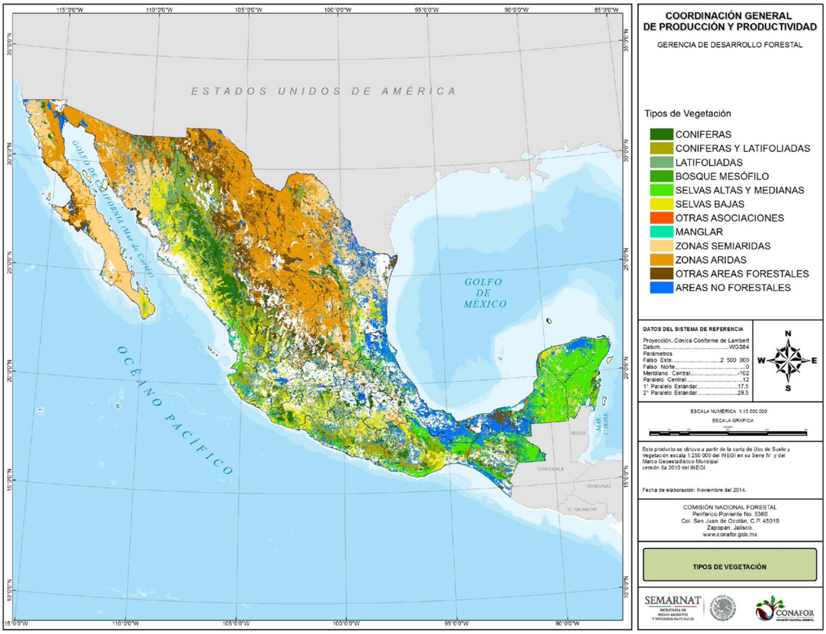


Figure 1. Vegetation of Mexico (CONAFOR, 2014).

The vegetation of the Yucatan Peninsula is spatially influenced by the region's geomorphology and climate. Soils developed from calcareous rock along an ecological gradient that extends from the humid and fertile portions of the south to the drier, less fertile and more populated portions in the northeast (Márdero and others 2012). This region has minimal topographic relief with the highest point being 350 meters above sea level in the Sierra of Ticul, at the junction of the states of Campeche, Yucatan and Quintana Roo. The composition, structure, life forms and mechanisms of regeneration of the ecosystems of Quintana Roo reflect the effects of a long history of social and economic development and natural disturbances, as well as the high capacity for resilience of some of those ecosystems (Dickinson and others 2001; Edwards 1986; Gliessman and others 1981; Goode and Allen 2008; Gómez-Pompa and others 1987; Hernández-Xolocotzi 1958; Porter-Bolland and others 2008; Secaira 2000; Toledo and others 2008; Whigham and others 1999).

The major events that have contributed to the present state of the forests of Q. Roo are listed below."

1. The traditional use of the forest by the ancient and current Maya culture.

The low population density of the ancient Maya culture, concentrated near the coast and in very few locations in the interior of the peninsula, makes it improbable that complete regional effects exist. The sophistication of slash and burn shifting agriculture (SBSA) has created a firm base for many of the recent explanations of the natural Mayan landscape. The traditional land use, mainly SBSA, could very well have increased in modern times, given the expansion of forest roads network, but it is also equally possible that it could have decreased because infrastructure development often permitted migration and lifestyle change of the Mayan peasants, especially since the 1980s with the accelerated growth of the tourist zones of Quintana Roo.

2. Henequen haciendas.

The hacienda system for henequen (*Agave* spp.) plantations occurred in the northern and eastern portions of the peninsula, in particular around Mérida. The cultivation of henequen has declined and the land abandoned or used for other purposes, such as ranching. Presently, henequen haciendas form a sort of a northeastern edge for the forest that has persisted for the most part in this 21^{st} century.

3. Concessions.

This is the system of timber harvest in which the federal government awarded large timber usufruct 'concessions', at times more than a million hectares, for extraction of valuable species, such as "tint tree" (*Hematoxillum campechana*) and mahogany. For the most part the concessions were awarded to foreign companies, but there were also Mexican companies involved. In either case, the logging companies did not own the land, but purchased stumpage from land owners. Termination of this system of timber extraction left the forest intact because the system focused on the efficient procurement of high value and large dimension commercial trees.

These trees represented a small percentage of the total stems, but because of their large diameter their removal modestly decreased total basal area. Their extraction also created single to multiple-tree canopy gaps. Given the shade intolerant nature of mahogany, it generally was unable to reproduce in these gaps, which were eventually filled with less economically desirable, often shade tolerant species. Despite the absence of evidence about the rate of change in the structure of the Yucatan peninsula forests, such "high-grading" practices typically result in loss of species diversity and decreased timber value (Larson and Oliver 1996). Given the high diversity of the forests, however, the reduction in diversity due to removal of a few large mahogany per hectare should have been small.

4. Chicle harvest.

The sapodilla tree (*Manilkara zapota*), harvested by the Mayans for pyramid construction, has been used since the end of the decade of the 1880s for extraction of its resin (chicle) in the central and southern portions of the peninsula. The chicle-collecting activity operated because of a complex social organization that was antagonistic to the timber-harvesting and henequen activities, and that had a marked and decisive ethnic cultural component. Chicle extraction and commercial processing continues to be part of the forest products in the present century, concentrated mainly in the state of Quintana Roo.

5. Integrated industrial center in Zoh Laguna, Campeche.

Zoh Laguna was founded in 1947 as a place to process mahogany, which was abundant in that Mexican region. The firms "Caobas Mexicanas S.A." and "Impulsora Forestal Peninsular" opened a mahogany processing and particle board manufacturing facility in Zoh Laguna. The village of Zoh Laguna was built to resemble "Colonia Yucatan", the place where mills of other timber firms were located in the Yucatan state. Zoh Laguna demonstrated the feasibility of systematically harvesting a diverse mix of industrial and lesser known timber species to manufacture high-value-added products.

6. Forest industrial unit.

"Maderas Industriales de Quintana Roo" Inc. (Miqro), a public utility with a concession of more than 500,000 ha, operated from 1954 to the beginning of the 1980s. It was the most successful example of an integrated tropical forestry business in the Yucatan Peninsula, concentrating its activity in the center and south of the peninsula. At the termination of the concessions (around 1983), Miqro became a buyer of local and imported logs. The legacy of Miqro was the creation of a forest work culture, a trade and a guild. Miqro's road infrastructure is the backbone of the present road network. Research funded by Miqro accumulated empirical experience in forest ecology and forest health. This knowledge was used to develop the silviculture of numerous timber species.

7. Community enterprises.

In 1983, the government took over direct control of forestry technical assistance by means of a program called Pilot Forestry Plan of Quintana Roo (Ppfqr). Eventually, Ppfqr led to the formation of the current system of community silvicultural forest enterprises. In this type of enterprise, forest management is in the hands of ejido members with the joint responsibility of a licensed forester. Forest operations of social enterprises focused on timber harvesting mainly of mahogany, although today other species, such as tzalam (*Lysiloma latisiliquum*), have become as important as mahogany. In 1994 the Canadian government sponsored the introduction of the "model forest" concept to the Yucatan peninsula (Riabm 2008). In Canada, the program successfully involved ethnic groups in forest management activities. In the Yucatan, the program strengthened the managerial skills of the social firms in the peninsula, although it remained in place for only 3 years.

8. Forest plantations.

A few large-scale plantations in Campeche represent an important component of the 100,000 hectares of plantations that exist today in Mexico. The current output of the forest plantations (forests farms) contributes almost 4% of the Mexican harvest of industrial timber (Velázquez and others 2003).

9. Passive Conservation.

The creation of two biosphere reserves, Calakmul in 1989 (723 000 ha) and Sian Ka´an in 1987 (528 000 ha) combined biotic elements with Mayan archeological sites. A limited amount of timber harvesting occurs in the buffer zone around the reserve, and loggers must comply with a set of protective measures. Until now, deforestation is not a threat to the reserve in Calakmul, but it is in Sian Ka´an because it located on the border of the most important coastal Mexican tourist destination.

10. Tourism development.

Intense tourism activity exists in the Mayan zone, which includes the Yucatan Peninsula as well as the tri-national zone of Mexico (Chiapas, Tabasco, Campeche, Yucatan, and Quintana Roo), Belize and Guatemala. This activity is located principally along the coasts and around the most well-known archeological sites. Development for tourism is the primary cause of land use changes in the region, and has an impact on forest activities. On one hand, there is the increased demand for poles for “rustic looking” tourist constructions, and on the other hand, there is the loss of a large number of workers, who leave their rural lives to participate in the service sector and in other urban activities. Finally, the phenomenon of tourism development gives a push to local agriculture as a source of fresh produce, which is the only part that undoubtedly results in a retreat of the legal forest frontier in the region. However, because local economies cannot support the entire tourism infrastructure, large quantities of food and other supplies come from outside the region.

Chapter II. Ecological characteristics of the mahogany forests

2.1 Introduction The mahogany forest

"The mahogany forests" correspond to a type of vegetation known as "medium semievergreen forest" (MSF) (figure 2) which is the main vegetation of Quintana Roo (74%). Eleven other vegetation communities composed the remaining 26% and include: medium semievergreen forest, high semievergreen forest, medium semideciduous forest, low semievergreen forest, semideciduous forest, deciduous forest, palm forest, mangrove forest, savanna, vegetation of coastal dunes, petén and tular.

Figure 2. Mahogany forests.

The distribution is determined by climate, geology, soil, topography and nearness to the Caribbean Sea (Ek 2011; Flores and others 2010; Miranda 1978; Tetetla-Rangel and others 2012). All the vegetation communities present a complex structure that is manifested in the distribution of species in distinct strata. The wide crowns of the tallest trees intermix, creating a very dense canopy that from the sky gives the illusion of a continuous carpet without gaps.

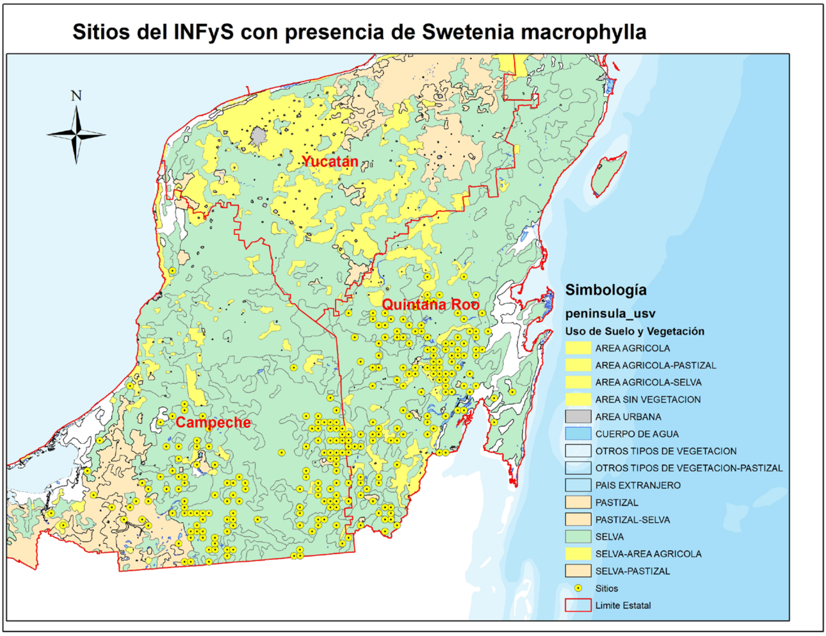


Figure 3. Distribution of mahogany in the Yucatan Peninsula overlaid on vegetation types (Conafor, 2014).

Medium semievergreen forest (Msf) (figure 2) is composed of a mixture of around 200 tree species, with heights up to 24m, and high diversity of vegetation and animal life forms. In Quintana Roo, the MSF is characterized by the abundance of two species in the main canopy: *Manilkara zapota* (chicozapote) and *Bursera simarouba* (chaca rojo) (Vester and Navarro-Martínez 2005). In these forests, the natural mahogany populations occur in the central and the southern parts of the state (figure 3) in the Priority Terrestrial Region 149 of Mexico´s Priority terrestrial host spots system (Arriaga and others 2000). In this region, mahogany finds the best conditions for development on moderately deep calcareous or alluvial soils (figure 4). In some places, densities of up to 29 individuals/ha larger than 10 cm DBH (diameter at breast height 1.37 m above the ground) can be found (Vester and Navarro-Martínez 2007).

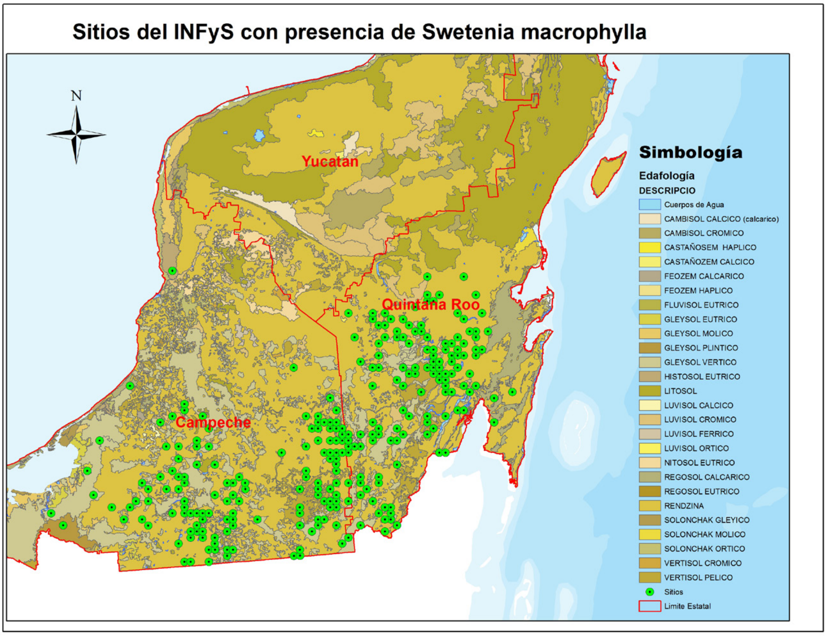


Figure 4. Distribution of mahogany in the Yucatan Peninsula in relation to soil type (Conafor 2014).

These high densities have been attributed to the presence of catastrophic disturbances (fire following a hurricane) that created large openings in the canopy with the temporary reduction of undergrowth, exposed mineral soil, and increased solar radiation that favors mahogany regeneration (Gullison and others 1996; Snook 2000). Mahogany also persists in areas where more frequent, small-scale disturbances occur like Sbsa in the Yucatan peninsula (Negreros-Castillo and others 2003) or in small gaps (400 m^2), as happens in Pará, Brazil (Grogan 2001; Grogan and others 2003). The mean density of harvestable mahogany (≥55 cm in DBH) in the forest ejidos of Quintana Roo fluctuates between 0.3 and 1.9 trees per hectare and is similar to results found in other countries (Grogan and others 2002; Traffic-Wwf 2006).

2.2 Environmental Description

The state of Quintana Roo is located in the eastern side of the Yucatan Peninsula, with coordinates of 21°31' and 17°49' north latitude and 86°43' and 89°25' west longitude; it occupies a surface of 5 084 300 ha, of which 4 732 500 ha are considered forested. Geomorphically, Quintana Roo forms part of a slightly fractured, compact mass known as the Yucatan slab, with scarce superficial streams but abundant subterranean rivers and sink holes (Tello and Castellano 2011). The climate is warm subhumid with an annual mean temperature of 26° C. January is the coldest month and the months of May to August are the warmest. The rainy season includes the months of May to October. Annual precipitation varies from 800-1500 mm with an increase from north to south and from west to east and with the greatest rainfall on the east coast (from Playa del Carmen to the Xcalak Peninsula) (Orellana and others 1999). The region also suffers the incidence of annual hurricanes that occur during the months of July-November.

The dry season extends from November to April, during which "nortes" occur, caused by masses of cold air and clouds, accompanied by squalls. Mean annual potential evaporation is 1650 mm with monthly variation from 105 mm in December to 193 mm in May (Herrera 2011). The soils are young, undeveloped and the majority of little depth, argillic and well drained (except in areas near the coast where the drainage is scarce to nonexistent). The four principal soil types in the Yucatan Peninsula are: 1) leptosols (59% in the municipalities of Solidaridad Benito Juarez and the northern part of Felipe Carillo Puerto; 2) vertisols (10%) in the south of the state, the municipality of Othón P. Blanco, in general in the flat parts, such as the cane zone; 3) phaeozem (9%) in well-drained sites with level to wavy topography and slightly pronounced slopes; and 4) luvisols (7%) cover the central and northeastern portion of the state in the localities of Kantunilkin, Chiquilá, Tihosuco, Santa Rosa, Polyuc and Jose María Morelos (table 1) (Bautista and Zinck 2010; Bautista and others 2011; Pérez-Villegas 1980; Tello 2011).

Table 1. Description of the principal soil types in Quintana Roo. WRB = Worldwide Reference Base for Soil Resources (Tello 2011).

WRB (2000)	Mayan name	Principal characteristics	Importance (%)	Vegetation type supported	Locality
Leptosol (lithic or rendzoic	Tzek'el	Young soils, clayey, with rocky, superficial outcrops, with a high presence of products of carbonates mixed with mineral material, from dark brown to black, very clayey, at times with abundant organic material, well drained and with a depth of <2.5 cm.	59	High and medium semi-evergreen forest	Municipalities of Solidaridad, Benito Juárez and the northern part of Felipe Carillo Puerto
Vertisol	Ak'alche	Soils of mixed, heavy clay, colored black, gray or reddish brown, very hard when dry, forming wide, deep cracks.	10		South of the state, Othón P. Blanco and Bacalar
Phaeozem	Pus-lu'um	Relatively young soils, dark, rich in organic material and nutrients. It develops in well-drained areas with topography that varies from level to undulating with slightly pronounced slopes.	9	Medium semi-evergreen forest	In all the state, alone or associated with other groups (leptosols or luvisols)
Chromic luvisols	K'ankab	Mature soils formed over limestone from the Tertiary, with a superficial horizon characterized by the loss of clay, which is deposited in the lower horizon, colored dark red, at times with the presence of continuous hard rock to <50 cm deep.	7		Central (from Felipe Carillo Puerto to José Maria Morelos) and northeast of Quintana Roo

2.3 Structure and composition

Based on forest inventories of five ejidos in Quintana Roo, *mahogany forests* are composed of a diversity of tree species that did not vary much among the five ejidos (table 2). From a total of 200 tree species, 24 are the most abundant ones, based on number of trees and basal area per hectare, as well as the commercially most important (figures. 5 & 6), e.g *Manilkara zapota* (chicozapote), *Bursera simarouba* (chaca rojo), *Metopium brownei* (chechem negro), *Lysiloma latisiliquum* (tzalam), *Pseudobombax ellipticum* (amapola), *Dendropanax arboreus* (sakchaca) and *S. macrophyllaare.* The 24 species represent between 65 and 68% of the total biomass in the forest. Mahogany is among these 24 species with a density of 0.7-5.2 individuals per ha for trees ≥ 30 cm in DBH, and a density of 1.5-6.1 individuals per ha for trees ≥ 10 < 30 cm in DBH. The rest of the species compose 12-15% of the biomass, and a subgroup is becoming important for rustic tourist construction and includes: *Alseis yucatanensis* (jache or papelillo), *Caesalpinia gaumeri* (kitamché), *Vitex gaumeri* (ya'axnik), *Cocoloba spicata* (boob) and *Guettarda combsii* (ta'astab). The increasing demand for rustic tourist construction poles is also increasing the diversity of utilized species. Fifty-four endemic species have been identified in the Yucatan Peninsula, nine of which are found in Quintana Roo, the majority in dry ecosystems, sand dunes and some inland wetland systems.

Mahogany generally forms associations with *Manilkara zapota* (chico zapote) and *Buida buceras* (pukté) in rather shallow soils as well as somewhat deep ones, dark or red and well drained. The total basal area (BA) in the forests of Quintana Roo varies from 16.6 to 33.0 m2/ha (table 2). The BA for the 15 most abundant species ranges from 70-77% of the total. The species with the highest basal area are *M. zapota, L. latisiliquum, B. simaruba, P. reticulate,* and *M. brownei* (figure 6). Mahogany has a mean BA of 0.67 m2/ha.

The DBH distribution of tree species with a DBH ≥10 cm is an indicator of the stability and permanence of a species and a vegetation community (Moret and others 2008). It is also an indicator of the habitat functions and resources availability of the ecosystem (Wehenkel and others 2014). The DBH distribution of the mahogany forests in Quintana Roo is in the shape of an inverted J (figure 8), interpreted as typical of balanced natural forests with a great abundance (density) of small-dimension individuals (presumably young) that decreases as DBH increases (presumably older). Under the single-cohort disturbance model of hurricane followed by fire, this J-shape is representative of multi-species invasion (Larson and Oliver 1996). The resulting diameter distribution reflects species shade tolerances and differential growth rates. Shade tolerant, slower growing trees are more abundant in the smaller diameter classes and rapid growing, shade intolerant species (mahogany) occupy the larger diameter classes and a greater proportion of the basal area.

When the DBH distribution is done by species, however, the shape of the graphs varies greatly. For mahogany the diameter distribution generates two types of distribution curves. The first is *Gaussian* (Dzula and Xhazil) (figure 9), which in agreement with Synnott (2007), has commonly been interpreted as an indication that the species became established during a short period of time in the past, but now does not have enough small trees to maintain the population of larger trees. A typical species for this type of curve is a pioneer species that colonizes open sites and remains in the mature forest but is unable to regenerate, so no young trees of the species are present. The second type is Irregular as in the forests of the ejidos of Petcacab, Naranjal and Santa Maria (located in the center of the state) in which, there exists nearly the same number of individuals among some of the DBH categories. These irregular structures are more typical of the multiple-cohort model of stand development where numerous, smaller disturbances (partial harvest for large trees) created a mosaic of new age classes with representative species and sizes (Larson and Oliver 1996). In Quintana Roo, however, the small disturbances are created by the continuous harvesting of diverse sizes of trees, and very seldom the large ones; creating instead of a mosaic a continuum

Table 2. The number of individual trees, number of species, density, total basal area and basal area of mahogany, maximum DBH and dominant vegetation type in five forested ejidos in Quintana Roo.

Ejido	N	Total number of species	Trees/ha (Ind≥10 cm)	Total BA (m^2/ha)	Mahogany BA (m^2/ha)	DBH Max (cm)	DBH Max mahogany	Dominant Vegetation	Source
Dzulá	12,196	100	250	16.6	0.46	93	80	SMSP	IF, PMF (2007)
Petcacab	22,172	117	380	24.3	0.85	100	94	SMSP	IF, PMF (2011)
Xhazil Sur	12,496	107	67	19.6	0.61	137	137	SMSP	IF, PMF (2011)
Naranjal Poniente	14,439	108	122	33.0	0.64	120	120	SMSP	IF, PMF (2011)
Santa María Poniente	8,999	93	90	28.2	0.81	160	160	SMSP	IF, PMF (2011)

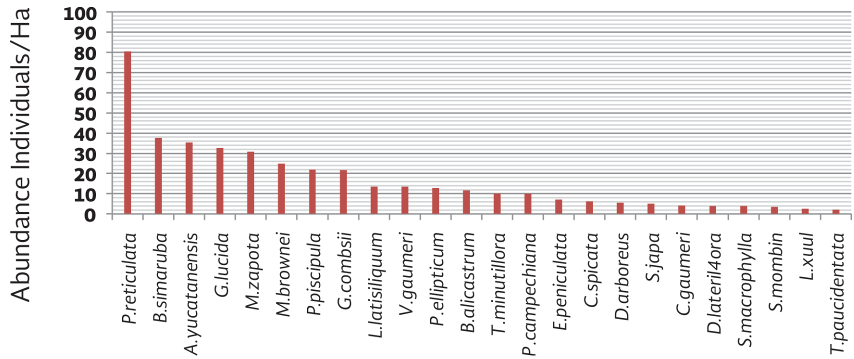


Figure 5. The number of individuals per hectare of the most abundant species in the mahogany forests of Quintana Roo.

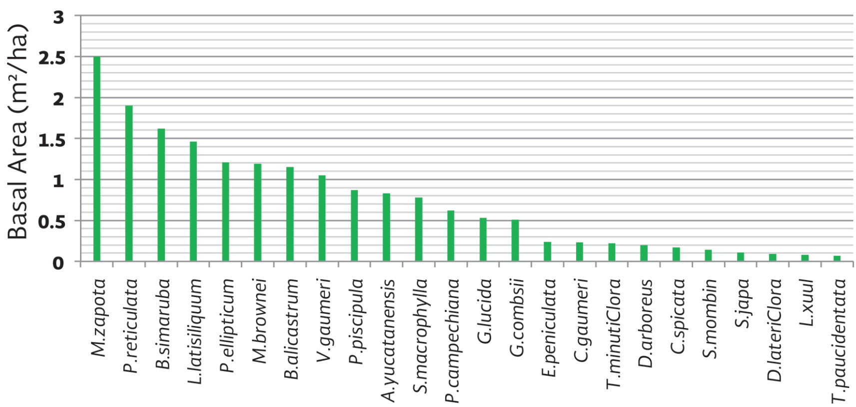


Figure 6. Basal area (m^2/ha) of the most abundant species in the mahogany forests of Quintana Roo.

2.4 Importance value index and dominance

Importance value index (IVI) indicates the phytosociological importance of a species within a community and is used as an indicator of species dominance. The species with the greatest IVI in the mahogany forests of Quintana Roo are chicozapote (*M. zapota*), chaca rojo (*B. simarouba*) and zapotillo (*P. reticulata*) (table 3). For the majority of the forest communities and for nearly all the species analyzed, the greatest contribution to IVI of each species depends mainly on the abundance (the number of individuals per hectare) and the basal area (m^2/ha) (figures 5 and 6). The difference among locations is noticeable (table 3). Figure 7 presents the highest IVI values of 16 species, integrating the data of five ejidos. Note that mahogany occupies the 13th place.

Table 3. Species dominance (largest to the smallest) in five ejidos where mahogany forests exist in Quintana Roo.

Dominance	Dzula	Petcacab	X-Hazil	Naranjal	Sta. María
1	*Bursera simaruba*	*M. zapota*	*M.- zapota*	*P. reticulata*	*P. reticulata*
2	*Manilkara zapota*	*P. reticulata*	*B. simaruba*	*M. zapota*	*M. zapota*
3	*Lysiloma latisiliquum*	*L. latisiliquum*	*M. brownei*	*A. yucatanensis*	*L. latisiliquum*
4	*Gymnanthes lucida*	*P. ellipticum*	*G. lucida*	*B. alicastrum*	*B. simaruba*
5	*Pouteria reticulata*	*B. simaruba*	*P. reticulata*	*P. campechiana*	*P. piscipula*
6	*Swietenia macrophylla*	*V. gaumeri*	*L. latisiliquum*	*P. piscipula*	*G. combsii*
7	*Guettarda combsii*	*M. brownei*	*P. ellipticum*	*B. simaruba*	*M. brownei*
8	*Piscidia piscipula*	*A. yucatanensis*	*B. alicastrum*	*G. lucida*	*B. alicastrum*
9	*Metopium brownei*	*Brosimum alicastrum*	*V. gaumeri*	*Trichilia minutiflora*	*V. gaumeri*
10	*Pseudobombax ellipticum*	*G. combsii*	*C. gaumeri*	*Exothea paniculata*	*P. ellipticum*
11	*Vitex gaumeri*	*P. piscipula*	*C. spicata*	*S. macrophylla*	*S. macrophylla*
12	*Caesalpinia gaumeri*	*Sabal japa*	*S. macrophylla*	*P. ellipticum*	*A. yucatanensis*
13	*Coccoloba spicata*	*Pouteria campechiana*	*Lonchocarpus xuul*	*M. brownei*	*P. campechiana*
14	*Dendropanax arboreus*	*S. macrophylla*	*A. yucatanensis*	*V. gaumeri*	*Spondias mombin*
15	*Alseis yucatanensis*	*D. arboreus*	*Tohuinia paucidentata*	*Drypetes lateriflora*	*T. minutiflora*

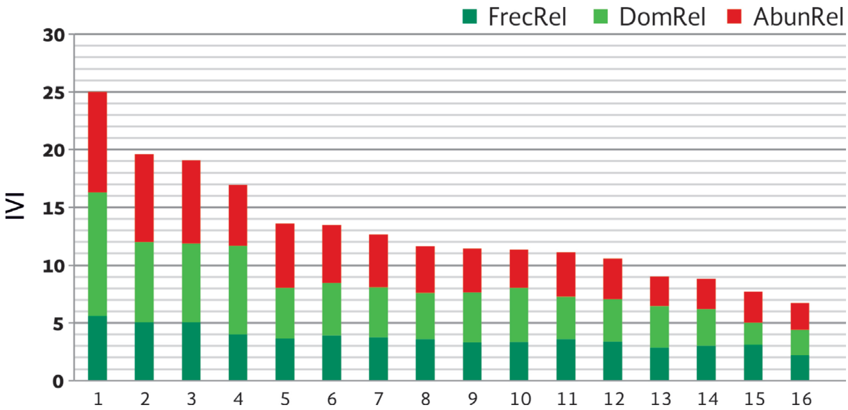


Figure 7. Importance value for the 16 most abundant species in the mahogany forests of Quintana Roo. **1.***Manilkara zapota,* **2.***Pouteria reticulata,***3.***Bursera simaruba,* **4.***Lysiloma latisiliquum,* **5.***Brosimum alicastrum,* **6.***Gymnanthes lucida,* **7.***Guettarda combsii,* **8.***Metopium brownei,* **9.***Piscidia piscipula,* **10.***Pseudobombax ellipticum,* **11.***Alseis yucatanensis,* **12.***Vitex gaumeri,* **13.** *Swietenia macrophylla,* **14.***Caesalpinia gaumeri,* **15.***Coccoloba spicata,* **16.** *Dendropanax arboreus.* Frec_Rel = Relative frequency, Dom_ Rel = relative dominance, Abun_Rel = relative abundance.

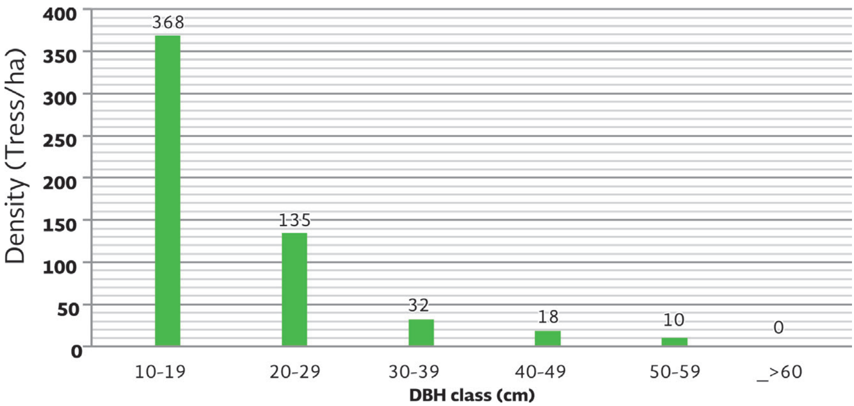


Figure 8. Dbh structure of the mahogany forests of Quintana Roo.

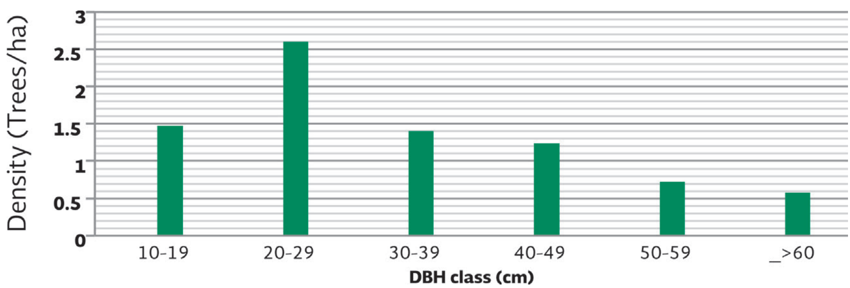


Figure 9. Dbh structure of mahogany in the managed forests of six ejidos in Quintana Roo.

Chapter III. Mahogany and commercially and ecologically important associated species

3.1 Silvical characteristics of mahogany (*Swietenia macrophylla* King)

3.1.1 Distribution

In North and South America and the Caribbean basin, three mahogany species of the Meliaceae family are known: *Swietenia mahogani, S. humilis*, and *S. macrophylla*. The first is distributed in the Caribbean area and the second along the Mexican Pacific. The third, big-leaf mahogany or mahogany is a native of Central America and parts of South America (figure 10).

Figure 10. Mahogany tree

Mahogany is distributed in Mexico in forests on the Atlantic coast from the north of Veracruz to the Yucatan Peninsula, principally in Campeche and Quintana Roo (figure 11); it continues in Central America, Columbia, Venezuela, Bolivia, Peru and Brazil (Lamb 1966; Patiño-Valera 1997). It is found in different types of tropical forests, from medium evergreen forest to medium semievergreen forest (Mayhew and Newton 1998). In Chiapas, it forms part of the tropical rain forest where it is evergreen, and in Quintana Roo, it forms part of the medium semievergreen forest where it loses its leaves during the dry season. Mahogany grows in diverse soil types from soils rich to poor in nutrients with humidity regimens from dry to very humid with an excess of moisture, and in karst soils rich in calcium and magnesium. In general, mahogany develops better in soils low in calcium and magnesium, which is reflected in the adult distribution pattern (Grogan and others 2003). In Quintana Roo, mahogany is reported to occur preferentially on level sites compared to sloped, with wavy relief, on the crest and bottom of slopes and shows a preference for black soils (Negreros-Castillo and Mize 2012).

3.1.2 Reproductive biology of mahogany

Mahogany is a monoecious species with inflorescences in panicles at the base of new leaves (Pennington and Sarukhán 1998; Pennington and others 1981). Its flowers are fragrant, green-yellowish, measure less than one cm in diameter, and they are bisexual. In the male flower, the ovary is rudimentary, and in the female flower the anthers do not contain pollen. Pollination is by insects, such as thrips, bees and moths, and by the wind (Chavelas 2004; Lamb 1966; Styles 1972; Styles and Khosla 1976).

In Quintana Roo, mahogany flowers between April and June, a little before the production of new leaves, which occurs before the beginning of the rainy season (Patiño-Valera 1997). Typically, only one flower of each inflorescence becomes a fruit. The start of flowering is variable; it occurs at early ages and sizes, in some cases at 12 years of age (Lamb 1966). In Bolivia, trees can produce fruit when they have a DBH of 30 cm (Gullison and others 1996), and in Quintana Roo at 23 cm in DBH (Cámara-Cabrales 2005). The fruits mature after 10 or 12 months (Pennington et al 1981). They are dehiscent woody capsules, ovoid to oblong, 12-18 cm long, five-valved (Pennington and Sarukhán 1998) (figure 12), and they mature during the dry season, when the tree is leafless (in Quintana Roo between February and April). The mature capsules open on the tree, and each capsule contains 45-49 developed seed that are 1 cm long with a wing of 6-7 cm (Niembro 1995; Rodríguez-Santiago and others 1994). Seed remain attached to the central column until they fall or are blown off by wind, which disperses them (Parraguirre 1994; Snook and others 2005). In Quintana Roo, seed weigh an average of 0.66 gm (approximately 1 500 seeds per kilo) (Niembro 1995).

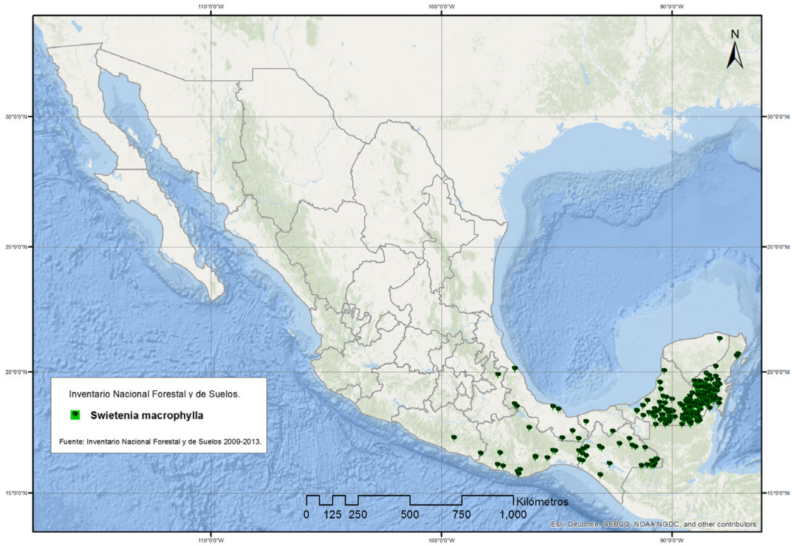


Figure 11. Distribution map of mahogany in Mexico (CONAFOR, National Forest and Soils Inventory.

3.1.3 Seed production and its relation to tree size

In Quintana Roo, mahogany is an emergent tree that can reach up to 3.5 m in DBH and a height of 30 m. The commercial height (clear bole) is greater in trees with DBH ≥75 cm (height = 16 ± 0.3 m), than in trees with DBH <75 cm (height = 10 ± 0.2 m). The mean volume of the crown can be up to four times larger and the area of the crown nearly three times as large (63 ± 3m^2 to 180 ± 4m^2) for trees with DBH ≥75 cm compared to trees with DBH <75 cm. The size of the crown directly affects the quantity of fruit produced annually. For example, fruit production of trees (figure 12) with DBH ≥75 cm can be three times greater than that of trees with a DBH of <75 cm. Each year 80% of the trees with a DBH <75 cm produce fruits compared to 90% of the trees with a DBH ≥75 cm. As the production of fruit is associated with crown size, pruning a tree to reach fruit is not recommended, because the effect of pruning and the effects of hurricanes can require more than 14 years for the crown volume to recuperate, if it ever does. To increase the availability of seed, large hollow trees, which have little commercial value, should not be harvested. Twenty five percent of trees with a DBH ≥ 75 cm have heart rot and are valuable as sources of germplasm and habitat for certain birds, such as toucans and parrots (Cámara-Cabrales and Snook 2005).

Figure 12. Mahogany fruits

To increase the availability of seed, large hollow trees, which have little commercial value, should not be harvested. Twenty five percent of trees with a DBH ≥ 75 cm have heart rot and are valuable as sources of germplasm and habitat for certain birds, such as toucans and parrots (Cámara-Cabrales and Snook 2005).

3.1.4 Seed dispersal

For the majority of tropical forest tree species, seed are dispersed by bats; however, for mahogany the medium is wind. The predominant direction of the wind in Quintana Roo is from the east and southeast, and the velocity varies by the time of the year. Seed dispersal patterns are strongly affected by the direction of the predominant wind and the size of the trees (a combination of height and crown size) (Cámara-Cabrales and Kelty 2009). A tree 30 m in height and located in a zone free of neighboring trees can disperse 80% of its seed up to 60 m toward the west (Rodríguez-Santiago and others 1994). Within the forest, trees with DBH ≥75 cm can disperse their seed a distance of 30 m, while those with a DBH of ≤75 cm disperse seed a distance of 22 m (Cámara-Cabrales and Kelty 2009).

3.1.5 Germination

The seeds that come from large and small trees germinate in 10 to 40 days (figure 13), and seed are not viable after one growing season so there are no mahogany seed in a forest's seed bank (Lamb 1996; Morris 1998; Morris and others 2000; Snook 1993, 1996). In Quintana Roo, seed are dispersed between the months of February and March, remaining in the forest soil for a number of months until the rains begin in June. The initial survival of new mahogany germinants is related to the percentage of seed that is consumed in approximately 50 days after germination (Filho and Duarte 1998). After that time, survival depends on the photosynthetic ability of a young plant, which is affected by the availability of light, water, nutrients and neighboring vegetation competition.

Figure 13. Mahogany new germinants.

3.1.6 Seed predation

In Quintana Roo, 5% of dispersed seeds are consumed by predators in a period of 5-25 days after dispersal (Cámara-Cabrales and Kelty 2009), and the percentage rises to 20% during a period of five months (Negreros-Castillo and others 2003). In Pará, Brazil, the loss can be up to 40% during several months. The intensity of predation seems to be independent of the distance from the mother tree (Grogan and Galvão 2006; Norghauer and others 2006). Mahogany seed consumers include parrots and toucans that consume the nearly green seed on the tree, and on the ground, ants, rodents, insect larvae and fungi have been identified as predators (Gutiérrez-Granados and others 2011).

3.1.7 Ecological associations

A wide discussion exists about which ecological association mahogany should be placed in (Swaine and Whitmore 1988). It has been classified as moderately shade tolerant (Ramos and Grace 1990), as a long-lived pioneer (Whitmore 1991, 1996), as a light-demanding climax species (Whitmore 1998), as not a pioneer (Gerhardt 1996), as not a light-demanding pioneer (Brown and others 2003) and as an intolerant species that requires severe disturbance and large clearings to regenerate (Negreros-Castillo and others 2003, 2005, 2006; Snook 1993, 1996), as intermediate to shade intolerant with plasticity and acclimatization (Cámara-Cabrales 2005) and as a gambler that germinates in the underbrush and responds to clearings (Vester and Navarro-Martínez 2007). The variation is due to the plasticity of the species to adapt to certain light conditions during its life, the diverse type of soils, moisture regimes and competition levels (table 4). In Brazil, mahogany is classified as a late secondary that responds to periodic releases and to intermediate size clearings. After 8 years of growth, 2% survival is reported in the undergrowth and at 6.8 years 43% survival on average in clearings of 314 m^2 (Grogan and others 2003, 2005). These studies indicate that mahogany, in its juvenile state from new germinant to young seedling, is a species of intermediate to intolerant associations with plasticity and acclimatization. But the key to survival for mahogany is multiple releases, because if after germination, a new germinant remains under a closed canopy, it can die in three years or less. If multiple releases are done (providing increasing light), a fertile and humid environment permits the young seedlings, older seedlings, saplings, and poles to respond rapidly and compete favorably. In severe disturbances that open a young mahogany to full solar radiation, mortality due to water limitation can be high. In natural settings, seed germinate as long as rain falls and secondary vegetation is established in 2-3 months, which modifies the microenvironment, favoring mahogany and species ecologically associated.

3.1.8 Pests and diseases

Hypsipyla grandella is an apical bud borer of meliaceae, both in natural conditions and in plantations. In the latter case, it can cause an important decrease in growth in addition to lessening the quality of the wood. The moth deposits eggs on the apical bud. When the larvae hatch, they feed on the bud, open a gallery several cm long in the pith of the stem, and pupate in site. The adults perforate the stem to exit and fly away to complete their life cycle. When stems and buds are thin, the stem dies. Hormones accumulate in branches of the immediate inferior internode, and they modify their orientation to grow upward. If one bud is a little higher than the others, it will accumulate more hormone and other resources that permit the branch to become dominant, and the rest return to their tendency of horizontal expansion. If several buds are more or less at the same height, as is common, however, the tree will tend to bifurcate into many stems as branches compete for leadership. The death of the leader and the struggle for its replacement deforms the architecture of the stem and can result in reduced timber yield and less vigor to compete with neighbors for crown space (Macías-Sámano 2001).

3.2 Characteristics of mahogany and associated species

Because of its commercial importance, mahogany is the emblematic species of the Mayan forest. At the same time, because of its plasticity, it shares ecological characteristics with other commercially important species. This section provides available information, although incomplete, about mahogany and other tree species of ecological and commercial importance that are associated with mahogany. First, Table 4 summarizes the ecological characteristics of mahogany in Quintana Roo, and Tables 5 and 6 compare various ecological indicators, such as shade tolerance, reproduction and regeneration, growth, etc., of mahogany with associated species, in particular those of commercial importance.

Table 4. Principal ecological characteristics of mahogany in Quintana Roo.

Characteristic	Description	Source
Habitat		
Physical environment	In the undulating and level relief of Quintana Roo, mahogany prefers level sites in low or high areas and black soils. It is found in diverse soils from rich in nutrients to poor with humidity regimens from dry, well drained soils to very humid soils with excess humidity, in karst soils rich in calcium and magnesium.	1,2

Characteristic	Description	Source
Dynamic		
Sociology	Assuming that seed are available, the type of disturbance that favors natural regeneration of mahogany is one that creates large canopy openings with sufficient light in the undergrowth and reduces competition to a minimum, such as hurricanes followed by fires, fires and slash and burn. Regeneration is also present in small gaps resulting from small disturbances, such as timber harvest, opening of roads, skid trails and landings. It appears with less success in open patches, either caused by the death of neighboring trees or small natural disturbances.	5, 6, 7, 8, 3, 4
Shade tolerance	Shade tolerance of new germinants and young seedlings is intermediate to intolerant for periods not longer than two years. They require multiple releases.	9, 10,
	Young seedlings and poles are intermediate to intolerant. Intermediate with conditions of humidity, nutrients and low competition. They also require multiple releases.	9, 10, 2, 3, 4
	Intolerant is its most natural and favorable condition in sites that provide disturbances that create conditions of total opening and low competition. In its best state of growth, it is an emergent tree whose crown overtops the general forest canopy.	5, 6, 7, 11
	Mature tree, intolerant.	
Beginning of reproduction – regeneration		

Characteristic	Description	Source
Mode of reproduction by seed		
Production of fruit and seeds	Best producing trees ≥75 cm in DBH with well-developed crowns, dominant in the canopy. Produce from 3 to 4 times more than trees of smaller DBH (61 fruits per year). Annually variablity is moderate. Up to 30% of trees ≤75 cm in DBH do not produce each year; trees <50 cm produce on average 15 fruits per year, which will contain 675 seed.	12, 13
Sexual maturity	Begins when trees reach 20 cm in DBH if the crowns are not damaged and they receive light.	10, 13
Size of maximum seed production	The best producers are trees ≥75 cm in DBH with well-developed crowns.	10, 12, 13
Frequency of good seed years	Irregular annual production, trees ≥75 cm in DBH have few years with zero production.	10, 12, 13
Dispersal and time of seed production	Wind dispersal up to 30-60 m from seed trees, but it can reach 80 m. Trees ≥75 cm in DBH have dispersal areas of 0.47 ha and smaller ones have areas of 0.37 ha. Seed dispersal in March-April.	14, 15
Duration of seed viability	5 months; seeds contain a large amount of lipids.	16, 17
Diseases and seed predators	In the trees, parrots and toucans; on the ground ants, various insect larvae, rodents, as well as diverse fungi.	10, 15, 16
Germination	Germination with fresh seeds is more than 90% and occurs in environments with sufficient humidity, with or without shade, preferably with buried seeds.	8, 10, 15, 16, 17

Characteristic	Description	Source
Development and growth of new germinants and young seedlings		
Water requirements	Humid substrate for germination. Greater survival in black soils and in red soils, greater mortality with lack of humidity.	8, 16, 17
Light requirements	Intermediate to intolerant species, more intermediate in the new germinant and young seedling stage, intolerant in the older seedling and pole stage.	2, 4, 10, 6, 7, 8, 11
Growth	New germinants and young seedlings growth moderate, growing in gaps (of 314 m^2, 115 cm tall at 3.5 years, gaps of 0.5 ha, 5 m tall in 3 years). Growing in 50% light at nine months of age, 75-95 cm tall, 40% survival at 7 years in favorable conditions of nutrition and humidity.	2, 10
Response to release	New germinants: very good; young seedlings: very good	
Sensitivity to competition for light and soil resources	New germinant is highly sensitive to competition for light and humidity. Young seedling is highly sensitive to competition for light and humidity.	5, 11,19
Principal harmful agent	*Hypsipyla grandella*, the larva of the moth, attacks the new germinants, young seedlings and older seedlings, causing deformation and reduction in growth.	4, 20
Mortality	New germinants and young seedlings have high mortality in closed canopy environment, with competition from other species and vines after the first year.	2, 7, 8, 10

Characteristic	Description	Source
Growth of trees		
Site index	No information	
Rotation	In Quintana Roo there are no elements to define rotation	
Typical natural longevity DBH growth	1.0 - 0.38 cm yr^{-1}	4, 18
Stress factors, tolerance and resistance		
Tolerance to wind	Mature trees: high tolerance due to buttresses.	
Tolerance to hurricanes	Intermediate and mature trees: very little tolerance, great loss of branches from the canopy in emergent trees.	
Tolerance to drought	Very low in new germinants growing in red soil, moderate in new germinants growing in black soil.	
Tolerance to floods and high water table	Good tolerance, withstands periodic floods, but growth is reduced.	
Other stress factors	No information.	

Note: Reference numbers appear at the end of the correspondent citation in the bibliography

Table 5. Shade tolerance, reproduction, establishment and growth of mahogany and associated species.

Species	Shade tolerance: new germinants, young seedlings & poles	Method of reproduction	Seed years	Preferred seed bed	Reference
Mahogany (*Swietenia macrophylla* King)	New germinants and young seedlings, intermediate to intolerant. Older seedlings, poles, more intolerant	Seeds, advance regeneration	Apparently without periodicity, information scarce. Irregular annual production	Mineral soil	3, 4, 5, 6, 7, 8, 10.
Chechem negro (*Metopium brownei (Jacq.) Urban)*	New germinants and young seedlings, intolerant, gamblers	Seeds, advance regeneration	No information available	Mineral soil	19, 3, 4
Amapola (*Pseudobombax ellipticum (Kunth) Dugand)*	New germinants and young seedlings, gamblers (intolerant)	Seeds, advanced regeneration, sprouts	No information available	Mineral soil	3, 4
Chaca rojo (*Bursera simarouba L. Sarg.)*	Extreme gamblers (very intolerant)	Seeds	No information available	Mineral soil	3, 4
Tzalam (*Lysiloma latisiliquum (L.) Benth.)*	New germinants and young seedlings, intolerant	Seeds, advance regeneration	No information available	Mineral soil	19, 4

Species	Shade tolerance: new germinants, young seedlings & poles	Method of reproduction	Seed years	Preferred seed bed	Reference
Jabin (*Piscidia piscipula* (L.) Sarg.)	New germinants and young seedlings, very intolerant	Seeds	No information available	Mineral soil	19, 4
Sakchaca (*Dendropanax arboreus (L.) Decne. &Planch.*)	New germinants and young seedlings, moderately intolerant, gamblers (intolerant)	Seeds, advance regeneration, sprouts	No information available	Mineral soil	19, 3, 4
Guano (*Sabal yapa C. Wright ex H.H. Bartlett*)	New germinants and young seedlings, tolerant	Seeds, great seed production, advanced regeneration	No information available	Indistinct	19
Zapote (*Manilkara zapota (L.) P. Royen*)	New germinants and young seedlings, tolerant (fighters)	Seeds, advanced regeneration	No information available	Indistinct	19, 10, 4
Boob (*Coccoloba spicuta Lundell*)	New germinants and young seedlings, moderately tolerant to tolerant	Seeds, advance regeneration, sprouts	No information available	Indistinct	19

Species	Shade tolerance: new germinants, young seedlings & poles	Method of reproduction	Seed years	Preferred seed bed	Reference
Ta´astab (*Guettarda combsii Urb.*)	New germinants and young seedlings, moderately intolerant	Seeds	No information available	Indistinct	19
Granadillo (*Platymiscium yucatanum Standl*)	New germinants and young seedlings, fighters (intermediate or moderately intolerant)	Seeds	No information available	Indistinct	4, 19
Siricote (*Cordia dodecandra A. D. C.)*	New germinants and young seedlings, intermediate to intolerant, fighters (intolerant)	Seeds, advanced regeneration	No information available	Indistinct	10, 4, 3

Note: Reference numbers appear at the end of the corresponding citation in the bibliography

Table 6. Shade tolerance, reproduction, regeneration and growth of mahogany and associated species

Species Common name Scientific name	Development and growth of new germinants and young seedlings			
	Growth	Response to opening of the canopy	Sensitivity to competition	Mortality
Mahogany *Swietenia macrophylla* King	New germinants and young seedlings, moderate. Older seedlings, poles	Very good Very good	New germinants: very high Young seedlings: high	New germinants: very high the first year with competition and drought. Young seedlings: high with shade, without sufficient soil moisture and with high competition
Chechem negro *Metopium brownei* (Jacq.) Urban	New germinants and young seedlings, moderate. For individuals ≥10 cm, 0.23 cm/yr	Very good	Moderate	No information available
Amapola *Pseudobombax ellipticum* (Kunth) Dugand	New germinants and young seedlings, moderate or rapid	Very good	No information available	No information available
Chaca rojo *Bursera simaruba* L. Sarg.	moderate or rapid	No information available	No information available	No information available
Tzalam *Lysiloma latisiliquum* (L.) Benth.	New germinants and young seedlings, moderate or rapid	Very good	No information available	No information available
Jabin *Piscidia piscipula* (L.) Sarg.	New germinants and young seedlings, moderate or rapid	Very good	No information available	No information available

Species Common name Scientific name	Development and growth of new germinants and young seedlings			
	Growth	Response to opening of the canopy	Sensitivity to competition	Mortality
Sakchaca *Dendropanax arboreus (L.) Decne. &Planch.*	New germinants and young seedlings, moderate or rapid	Very good	No information available	No information available
Guano *Sabal yapa C.* Wright ex H.H. Bartlett	New germinants and young seedlings, slow	No information available	No information available	No information available
Zapote *Manilkara zapota* (L.) P. Royen	New germinants and young seedlings, slow	Very good	Low	Low mortality
Boob (*Coccoloba spicuta* Lundell)	New germinants and young seedlings, moderate	No information available	No information available	No information available
Ta´astab *Guettarda combsii* Urb.	No information available	Very good	No information available	No information available
Granadillo *Platymiscium yucatanum* Standl)	No information available	No information available	No information available	No information available
Siricote *Cordia dodecandra* A. DC.	New germinants and young seedlings, moderate. Older seedlings, poles and pole timber, moderate	Very good	Moderate	New germinants: moderate the first year; young seedling: moderate

Note: Reference numbers appear at the end of the corresponding citation in the bibliography

Chapter IV. Theoretical principles for a silviculture guide for mahogany forests

4.1 Premises

The forest producer (individual, community or business) is assumed to have legal tenure of the land and is responsible for decision making. The expected management policy is to grow and sell trees for timber and produce other products from the land, subject to current regulatory constraints about resource stewardship and values of public interest.

4.2 The natural mahogany forests

The mahogany forests of Quintana Roo are extensive, and within them there are patches in which abundant quantities of mahogany are found in nearly all its life stages. Inventories indicate that regeneration is very limited or nonexistent, but there is a lack of studies to scientifically determine the proper proportion and balance of all the stages. Considering the last 4 000 years of history of the Yucatan peninsula, it is difficult to know if the forests are natural or Mayan gardens. For now, the accepted conclusion is that there is no true natural forest, only vegetation resulting from 4 000 years of Mayan culture (Vogt and others 1964). In the case of mahogany, as a guiding species in a mixed forest, a reasonable management policy is to strive to sustain a flow of seedlings of all species that will be systematically growing, which will maintain the natural species mix, perhaps enriched with the favorite species. Should a species become scare, there will be the option of enrichment planting or even tree farming as a means to secure its continuous presence.

4.3 Basic scenario

Assume there is a forest estate occupying at least 10 000 ha. Let there be recognized property rights for all ownership types (private, ejido, community).

Assume the owners objective is the long-term management of the forest estate to produce commercially useful logs of diverse species and features (size, defects, quality, etc.).

Also assume that appropriate harvest technology is available that will allow the producer to do the felling, bucking and yarding of the logs and the construction of permanent roads, skid trails, and landings. Logging will use mainly, but not exclusively, skidders and chainsaws.

Forest owners may either hire logging contractors or carry out all or part of the process, from the harvest to the delivery of the product at the landing area.

The landing should be the point of sale and of administrative control of product movement.

The management objective will be the realization of potential opportunities that are feasible, given the current biological and regulatory scenario. The objective will strive to maximize the owners' assets without exceeding their risk tolerance. For practical purposes and for performance assessment, the objective translates to the optimization of the current value of the sum of the net revenues over an unlimited future horizon (principle of M. Faustmann, 1849). This objective will be implemented by means of the FMP.

The silvicultural objective will be to strive for full-occupation of the soil with a natural mix of tree species, but with an increasing number of preferred species (for now the 24 in Table 3) over time. Special attention will be placed on increasing the presence of mahogany until the biologically viable full-occupation is reached, without putting at risk the presence of other species. In the majority of the mahogany sites, this implies aiming for a target of 80% of the BA being from the 24 priority species, with mahogany being not less than 5% of the basal area. This translates to 10 juvenile or mature trees mahogany >10 cm DBH per hectare in juvenile and mature stands or 100 well established saplings in young stands.

The central silvicultural principle is that each target-tree in the forest succeeds in occupying a space in which it receives direct solar light. This principle, albeit not the only one, is sufficient to steer the dynamics of the forest stand and its reaction to silvicultural treatments. As a consequence, the most important functions of the silviculturist will be regeneration, ingrowth, mortality, growth and yield.

4.4 Forest administration

Harvest regulation is a process that generates a cutting plan assigning silvicultural treatments to govern the dynamics of successive forest blocks in order to complete cycles of X years (for now, X = 20). The practice employed in Quintana Roo of dividing the total forest area into 20 sections is maintained, and each section is the annual cutting area (stand). The minimum treatment unit will be the 'group of interacting trees' (GIT) in which individual trees interact with each other, causing mutual interference in crown expansion. The annual cutting area will be composed of a mosaic of distinct GITs. When practical, any given treatment will be applied over large, contiguous areas. The administrative control can be individualized by GIT or larger territorial units can be used where probability functions make it unnecessary to maintain separate records by GIT. The recommendation, nevertheless, is to control each GIT, whenever possible, even locating each one on maps to facilitate the application of the proposed system and to acquire sufficient experience (Curiel and Mendoza 2007).

4.5 Diagnosis

The process of silvicultural planning is initiated with a diagnostic, applying a prescription inventory (PI) and a growing stock inventory (GSI). Technical details (sampling, instruments, protocols, etc.) of GSI are well-known and flexible; hence they will not be discussed here. PI gathers information to feed the quantitative control and prediction algorithms dealing with growth, mortality, natality, ingrowth, health and yield (content of commercial products). PI and GSI are done on a sample of the annual harvest area. Both inventories have similar sample sizes and could potentially be conducted simultaneously. For practical and control reasons, PI could be applied in parcels of 900m^2 that for efficiency would be 30x30 m. GIT within PI plots are identified, and one by one 100% of individuals (from young seedlings up) is assessed and graded as high or low quality and its stage of development are recorded (Section 4.6). Each GIT in the inventory is associated with a site description. Site features usually occur over large areas, so the site description may be shared by several PI plots. Site indicators that describe the microtopography and elevation of the land in relation to probability of flooding, the extent that might be under water in the rainy season, or what portion of the year the area might be flooded. When describing the type of soil, especially physical qualities, such as color, rockiness, drainage, homogeneity, depth of woody layer, leaf litter, humus, and organic layer should be included. It is advisable to use the Mayan soil classification, which considers most of the mentioned attributes. The site description is accompanied by observations on fire, erosion, stumps, signs of logging damage, and blow down, as well as the presence of indicator species (plants, animals, lesser organisms). Sufficient sample plots per annual cutting area should be measured, in order to have reliable and unbiased statistics.

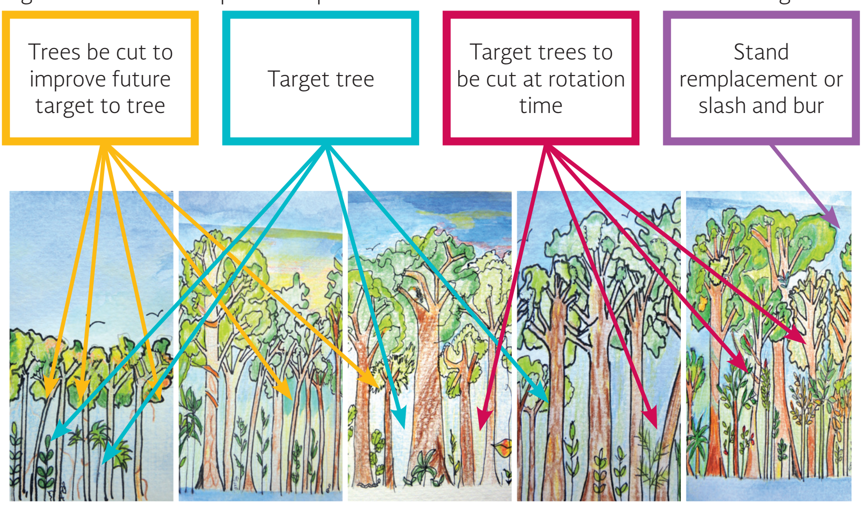
Simulation Silvicultural models should generate recommendations that will help forest inventory staff prescribe treatments in the field at the time of measurement. Most prescriptions will include targets about the percentages of area coverage by diverse forest types and successional stages (structures) (figure 14). Additional quantitative and discrete supporting information from silvicultural models will be used in the field to help design prescriptions. Supporting information will include site quality, natural and desired disturbance regimens, and silvicultural system recommended, along with multiple scenario forecasts for regeneration, growth, ingrowth, mortality, health and yield. The level of statistical power should be more than enough to indicate clear choices between alternative feasible silvicultural treatments (figure 15).

The Pɪ procedure will be repeated during the process of marking, except it will not be sampling, but census. Marking rules will be followed as tightly as needed to evenly distribute the treatments over the cutting area without exceeding allowable cut targets. The trees of rare or endangered species will be maintained regardless of quality. In short, Pɪ will provide estimation of the current percentages of the different development stages and a prioritized list of the possible and necessary different silvicultural treatments. This type of diagnostic requires a visit to each Gɪᴛ in a given cutting area. Pɪ must be conducted by an experienced regional silviculturist capable of determining priorities among feasible treatments.

Young forest high occupation	Mature forest without commercial trees	Mature forest with few commercial trees	Young forest with high occupation of commercial trees	Mature forest with high occupation of commercial trees
20%	10%	30%	20%	20%

Figure 14. Idealized depiction of successional stages that may appear during a PI (percentages of the total area of sampling plots in a cutting area).

Figure 15. Idealized depiction of prescribed treatments identified while conducting a PI.



4.6 Quality, vigor and vitality of a desirable tree

Achieving full-occupation of the land implies that the site is 100% occupied by high quality trees of preferred species (table 3) at any stage of development or the evidence that in due time a tree like that will occupy the entire growing space. In the rest of this work, we identify these trees as "target-trees". The quality of a tree is defined by the combination of its vitality (dominance) and quality ranking (high or low). Most high-quality individuals have been high status in previous developmental stages. A dominated or intermediate individual is unlikely to respond to release, so it may be incapable of returning to the codominant and dominant classes even though it may be allowed to live a long time and it could progressively improve its prospects. The time needed to pass from one stage to another will be variable, and for decision making purposes is irrelevant.

The stages of development of each tree can be grouped into the following categories:

1. **New germinant:** recently germinated, without true leaves or crown.
2. **Young seedling:** shoot without distinguishable crown but with branches and anatomical development that show, it has survived more than one dry season.
3. **Sapling:** juvenile with a well distinguishable crown, without indications of possible dominance.
4. **Older seedling:** nonreproductive juvenile, without products, capable of reaching the canopy level, old enough to display indications of dominance.
5. **Pole:** beginning productiveness, few products of low quality and size. Flowering begins at this stage in most species.
6. **Sawtimber:** high reproductive strength, high viability of seeds and propagules, and high quality of products.
7. **Overmature tree:** indications of senility and decrepitude, less reproductive strength and low viability of seeds and propagules, products prone to deterioration, damage and defects. Abundant epiphytes and other indications of bole rot.

Tree vitality is reflected in dominance levels, as follows:

a. **Wolf tree, open-grown tree:** unimpeded crown expansion, wide space available, light reaching the tree during whole day; crown generally branchy, leafy, and with less height than it would have at the same age if it were directly competing with other trees.

b. **Dominant:** the size of the crown is average for an individual that until now has developed without limitation in crown expansion during its life; symmetrical crown of circular projection; strong apical dominance.

c. **Codominant:** the size of the crown is similar to dominants, but the three dimensional symmetry of the crown will be somewhat affected by neighbors; maintains apical dominance.

d. **Intermediate:** crown size considerably smaller than dominant and codominant; limited branch development, such that the major part of the crown does not have space to expand; the total height of the tree permits it to be in the higher canopy or at least to receive direct light on the top during the major part of the day.

e. **Overtopped:** shorter than neighbors that interact with it; it will be shaded nearly all day; its crown will be three dimensionally asymmetric.

f. **Suppressed:** so overtopped that it begins to bend and could die in a short time. This is the tree of the lowest quality possible.

Evaluation of the quality of the forest development stage

1. **Regeneration.** Trees established, having reached at least the sapling stage, but with DBH less than the minimum for the inventory.

2. **Juvenile.** Trees with DBHs larger than the minimum measurable size, not reproductive, with trunks formed only of sapwood or with less than half the volume in heartwood. Rarely epiphytes, crown lesions or defects. The bark is generally smooth or with few defined plates, and for some species anatomical defense structures, such as spines, are present. This type of forest can have any age, dimensions or dominance. Occasionally, there are

opportunities for extracting commercial products, such as chips, firewood and special products. If it is not feasible to log and sell products from marked trees, they must be felled anyway, and the cost will be carried as an investment until the final harvest.

3. **Mature.** Forest with trees containing at least half of their volume in heartwood and DBHs above the minimum for the inventory. Physiologically suitable for reproduction, and with clear expressions of abundant fertility in the flowering and fruiting season. The bark is rougher than in juveniles, and its defensive structures have been lost. Rarely, it will have epiphytes or some other indication of stagnation or moisture accumulation in its branches. Mature trees are the ones with most commercial value, and volume removal is concentrated on them. Cutting other companion trees that are not mature or that have already passed this stage is possible and desirable if the silvicultural prescription specifies it, but it is not necessary to extract or try to sell this low value material.

4. **Overmature.** Trees are decrepit, at times bent over, some branches with little foliage or dead, with signs of bole rot and the presence of epiphytes and cavities with wildlife, as well as indications of termites. Reproductively, a senile tree is hardly active, but due to the size of its crown, it contributes regularly to the soil seed bank, although many of its seed and fruits are not viable. Given enough time, the quantity of seeds produced by these trees is usually sufficient to reoccupy a site. The senile forest is not suitable for harvest, but it is suitable as a source of seed and propagules, as well as for shade and full-occupation of a site. Although the indicators of decrepitude accumulate with age, they can be expressed in all species at any age, size and level of dominance.

Chapter V. Silviculture practices for the mahogany forest

5.1 Introduction

This chapter contains the recommended silviculture systems applicable for the management of the mixed and uneven-aged forests of Quintana Roo in which mahogany develops (mahogany forests). In general, the silviculture terms and definitions used in this work correspond to what is known in Mexico, but the silviculture of mahogany forests requires nontraditional strategies. Therefore, where known terms have little application, new terms and concepts will be used. The silviculture parameters and specifications for road technology, machinery and logistics of timber harvesting of the forest proposed are those currently available in the Yucatan Peninsula. The predominant institutional and legal environment, the market factors (money, workers, machinery, infrastructure, data, and technology) and the products of round timber currently in use are also present.

The silviculture system proposed in this work seeks to reshape the disturbance regime that occurs spontaneously in the mahogany forest to one that favors regeneration, health and growth of commercially important species, including mahogany. Silviculture disturbances include timber harvesting, production of charcoal (when applicable), creation of regeneration conditions (gaps), and supplemental treatments (site prep, slash disposal, weeding, and postharvest tending). The applied system will be used to create stands with high-quality trees, mixed species, and an even-aged structure in which mahogany is a leading species.

Two silviculture systems are proposed to create this type of forest:

1. **Stand replacement**. This implies removal of all the trees and understory vegetation in one operation. The treatment is intended to efficiently harvest all available products, while opening space to develop a new even-aged stand, containing the species mix characteristic of the region with a preponderance of desired species. This may be necessary when the PI indicates a deficient stocking of target trees.

a. Prescription for the stand replacement system.
The marking crew will consider the prescription and data from PI as a first approximation for treating the annual cutting area. The actual treatment may depart from the prescription recommended by the PI and GSI, because the sample used to develop the prescription do not include situations found while marking the entire cutting area.

2. **Slash and burn (SBSA).** Slash and burn is an ancestral silviculture system that has shown to be the most reliable technique for the establishment of mahogany and companion species (table 3). The practice of this silviculture system varies across the Yucatan Peninsula. It is a sound silvicultural system whether it is conducted with a long cycle (25 years) that systematically moves through the forest attending the cropping plots as well as the fallow forested areas or with a short cycle (7-12 years), intensively tending only the areas with corn (2-6 ha annually). The key feature is that the cropping fields are surrounded by forest at all times, and corn fields will always return to natural tree cover and will remain forested for very long periods.

a. Prescription for the slash and burn system.
In slash and burn, after agreement with the producer about the appropriate sites that have potential for corn cultivation, the felling blocks are chosen and the order in which they will be cultivated is decided. The size of each corn field will be the traditional one for each region, generally 0.5 to 6 contiguous hectares. Farming will establish polycrops, while tolerating naturally established mahogany, as well as those that are seeded or planted. Within the fallow grounds, annually the producer will pick fields that can be entered to extract firewood, poles and other products. Besides collecting products, the farmer will release target trees when needed. Through time, forest composition and density of target trees will improve up to the time when the area will be cleared for cornfields once again, although there is the possibility of maintaining constant forest cover and managing trees on an unenven-aged basis.

5.2 Concurrent prescriptions

Each GIT should have only one of the five concurrent prescriptions and one of two complementary prescriptions. The concurrent prescriptions are mutually exclusive and refer to the feasible actions for the following cycle. One or several of the complementary prescriptions can be applied to each of the concurrent prescriptions.

Concurrent prescriptions:

1. **Nothing.** The site is forested and has ideal site conditions, that is, the site has full-occupation with target trees. To continue with the natural development, without alteration by silvicultural treatments, is appropriate. Also, a null prescription is in order for sites in which the individuals to be removed were killed during recent natural disturbances, so there is no need to correct anything, not even in isolated groups not affected by the disturbances. Finally, a null prescription can be an administrative recommendation to maintain the desired distribution of desired successional stages.

2. **Intermediate cut.** These treatments control species composition and/or stand density when doing so releases target trees. The intermediate cut also reduces competition to quantitative targets and eliminates vines and other plants aggressively competing with target trees. The essential rule of this treatment is that the space freed by cutting individuals should be promptly reoccupied by preexisting trees. No opening should be so large that trees can successfully regenerate, though it is entirely possible that the opening intentionally frees and permits development of trees that were previously established in the inferior strata. The rule about the intensity of cutting will be maintaining full-occupation by target trees (high quality). If the initial conditions do not permit reaching full-occupation immediately, the objective of partial occupation for a reasonable time is accepted, subject to an outcome of eventually achieving full-occupation (100%). The minimum occupied space will be that corresponding to the typical crown size of a sawtimber-sized tree (~150 m^2). If the ground is occupied by a sawtimber-sized tree, it is fully occupied, but if it is occupied by trees of younger stages, full-occupation is expected if there are enough high quality trees that one of them will reach sawtimber size without losing its quality.

3. **Final cut and regeneration.** Harvest of commercial trees of any species, carried out in such a way that it is anticipated that the spaces freed will be occupied by regeneration of a mix of species characteristic of the forest type for the site. Apart from cutting the trees in the GTI, additional trees will be cut to create a large enough opening for successful regeneration. Complementary labors after logging and for several years afterwards will be applied when needed. These complementary efforts include mechanical or fire preparation of a seedbed, slash control, and prevention of invasion by undesirable herbs and vines. The size of the opening recommended to favor establishment of the 24 priority species and mahogany is no less than 0.5 ha and no more than 6 ha, with 2 ha as a general recommendation. The choice will depend on the criteria of the professional with experience in the region and on market opportunities to sell the diverse products that will come from the complete removal of the canopy.

   The possibility of planting a complementary number of desirable species or even direct seeding should be contemplated as an option. When seeding, the use of seed coated with nutritional and protective covers is advised. At sites with currently occupied by mahogany or in potential mahogany sites (dark soil, good moisture, no flooding, with or without exposed rock, good drainage, slightly above the mean soil elevation), planting should preferably include mahogany (see Table 7 for more details about mahogany). The recommended planting density is one tree of any priority species each 50 m^2 (200 plants/ha). Trees should not be planted in a systematic manner, rather by taking advantage of favorable microsites. Not less than 10% (n = 20) of the planted trees are recommended to be mahogany, considering that planted trees will complement the composition of the retained trees, plus the natural ones established after treatment.

   For planting, soil is prepared by digging a wide, deep hole in which one 4-5 month old seedling will be planted. Seedlings should be grown from local seed in nurseries where the regimen includes a finishing, hardening phase that fosters lignification (a minimum of 4 mm in diameter at the base). Seedling should have a stem height of 30 to 40 cm, a main root of no more than 25 cm, an abundant mass of rootlets, no indication of coiling, and with healthy branches, each one at least 15-25 cm long. The harvest of the cutting area can be complete or occasional legacy trees can be left, but the opening should not be more than 25% occupied. The area should be evaluated annually, 2-3 months before the rainy season to detect additional work necessary regarding what% of full-occupation is being successfully accomplished.

Leaving some parent (seed) trees of desirable species (table 3) is an alternate option. Leaving seed trees does not mean leaving the most prolific or largest trees. The trees that are left should be distributed so as to provide an even seed rain over the entire cutting area. If seed trees are not homogeneously dispersed or if they fail to establish regeneration, regeneration can be complemented with planting to assure full occupation in a reasonably short time. The specifications for complementary treatments and the criteria for marking are essentially the same as in the treatment of stand replacement that is described above.

The objective of the regeneration cut and follow-up treatments is to accomplish full-occupation of the site with a mix of species. Around 80% of the occupation should be by the 24 priority species (mahogany >5%), equivalent to the density of the mature stage of 100 to 200 trees per hectare which will have a basal area of 20 to 35 m^2/ha and >200 m^3/ha standing volume. The time to reach these conditions will depend on the site mixture of species, the natural disturbance regimen, and the intensity of management. Presently, this length of time cannot be established. More experience is needed for reliable estimation.

4. **Forest protection.** These are labors to prevent or remediate the incidences or exposure to risks, especially meteorological risks, such as hurricanes, fires and blowdowns, as well as effects of extraordinary flooding. This also refers to the recuperation and return to production of extensively burned areas (>20 ha).

5. **Special regimen.** This refers to sites where mixed farming occurs with windbreaks or trees tolerated within the parcel, backyard gardens, agroforestry plantings, commercial plantations and other uses of the land that maintain portions of commercial forest without being part of the managed forest.

5.3 Complementary prescriptions:

1. **Nothing**. This policy is the one to follow when the prescribed treatment will cause sufficient and adequate site modification.

2. **Risk control.**

   2a. Reduction of fire risk through prescribed burns.

   2b. Reduction of health risks by eliminating unhealthy and susceptible trees when conditions of exposure to a health risk factor has been detected.

5.4 Implications of the silviculture system on harvest regulation

Regulation of the cut can follow any method as long as it allows each GIT (or group of GITs) a separate treatment. By default, it is understood that the method of regulation will be that of inventory control, which monitors, assesses and manages the probability distribution of GITs by successional stage and content of target trees. Areas to be cut are assigned to zones that most urgently need harvesting. Silvicultural priority is a ranking that derives from PI field recommendations and quantitative simulation forecasts of likely outcomes about what could happen to each site if not treated in the upcoming cycle. Silvicultural priorities must be weighted by spatial criteria that involve biological concerns (fragmentation, for instance) and convenience in the logistics of the timber procurement operations. The existing road network should be taken advantage of to define an entry sequence that complies with biologic and operational restrictions, while maintaining the rhythm of extraction of commercial logs above 7m^3/ha per entry.

5.5 Logging implications

Silviculture treatments require the following measures:

- Careful directional felling, trying to minimize harm to the residual trees. Do not fell a tree if there is evident risk of harming any target trees or trees marked to leave (seed trees or valuable trees).
- Bucking at felling point.
- Skid trails traced and cleared in advance. Trails should be no more than 15 m from the felling point, unless lateral skidding mechanisms are available (animals or crawlers are fine, but no rubber tired skidders).

- Residue disposal will use any method that leaves at least two standing dead trees per hectare (if they exist) of > 40 cm DBH.
- On finishing with a cutting area, prepare permanent roads and skid trails to withstand rainy seasons with minimum maintenance.
- Do not remove large woody material (>40 cm in DBH) if it is rotten, standing or down and the fuel load is less than 200 tons/ha. Add large-size logging residue to complete the desired coarse woody debris load (at least to maintain 80 tons/ha).
- Comply with mandatory rules and regulations regarding environmental impacts, stewardship of biodiversity, and attention to fragile sites and protected species.

Other desirable optional measures:

- Maintain the natural mix of species of the forest type, preferentially with target trees. Retain the very large individuals of every species, whether or not they are of high quality but with a desired density of one large tree per species every 10 ha.
- Control fires and other natural disasters only when the prediction algorithms indicate a high possibility of extensive harm to systems or risk to humans. The control of fire in forested sites will depend on the actual fire recurrence, the preferred type of GITs and the predicted effect of a specific wildfire event.
- Salvage after a natural disaster of great magnitude, such as a hurricane and catastrophic fire. From the silvicultural point of view, the site should be evaluated according to regular silvicultural policies to define the necessary actions.

Table 7. Synthesis and sequence of cultivation labors for the silviculture system of stand replacement or SBSA.

Stage	Treatment	Brief Description
Year 1		
Selection of treatment site		Identification of site with preferred characteristics for mahogany: dark soil, good moisture, no flooding, with or without exposed rock, good drainage, slightly above the mean soil elevation
Harvest	Harvest individuals of all trees, woody plants, and understory	• Harvest commercial mahogany • Harvest mature trees of other species • Harvest all trees in the pole size category • Production of charcoal with the remaining trees
Site preparation	Controlled burn	Burn in the favorable season (May)
Regeneration	Natural regeneration	The labors described above must be carried out before the month of March. That is to say, before the seed trees drop their seed, a process that occurs on average between the beginning of February and the end of March.
	Assisted regeneration	If the work is carried out after the end of March, it will be necessary to depend on direct seeding and to place seed directly in the soil. Five buried seeds or a seedling every 50 m2 is recommended. (Fig. 16 and 17)

Stage	Treatment	Brief Description
Year 2		
Regeneration	Selection of mahogany new germinants	In the case of assisted regeneration with direct seed in the month of May (rains begin in June), select two new germinants at each sowing site.
	Elimination of shade	In May, eliminate shade over the mahoganies. At this stage, secondary vegetation is small. In general, it is only necessary to cut the branches of trees that are producing shade over mahoganies. Be sure that the trimmings are placed around the plant to form a mulch layer that will retain moisture. This is particularly important at sites with red soil.
	Selection of mahogany new germinants	In the case of assisted regeneration with direct seed in the month of May (rains begin in June), select two new germinants at each sowing site.

Stage	Treatment	Brief Description
Year 3		
Establishment of new germinants	Selection of mahogany seedlings and elimination of shade	In the case of assisted regeneration, in May leave only one new germinant at each sowing point. In the case of natural regeneration, eliminate shade as described in the preceding stage.
Year 5		
Growth	Elimination of competition	In May, eliminate competition from each tree. This can require eliminating single branches that generate shade above each mahogany. At times, it will be necessary to eliminate complete neighboring trees when their architecture and size impede free growth of the mahogany or any other target tree. Leave a circle of brush and residues a meter wide around the mahogany. The straightness of the trunk characteristic of mahogany makes it especially attractive to deer for scraping their antlers, and woody residue can offer good protection.
Composition	Selection of species	In the month of May, verify complete occupation in each 100 m^2. Assure that a tree of a species with commercial value exists, preferentially mahogany. Liberate target trees from competition as described for mahogany.

Stage	Treatment	Brief Description
Year 10 -15- 20		
Development of the unit of intervention	Thinning	Monitor whether the selected mahogany, as well as other species, are growing without competition. Eliminate competition to the target trees where necessary. Every three years would be acceptable.
		It is hoped that in the 20th year the mahoganies and other species selected have reached the overstory and no further intervention is necessary.

Figure 16. One-year-old mahogany, established after slash and burn. Secondary succession is noticeable (Quintana Roo).

Figure 17. Three-year-old mahogany, established after slash and burn. Secondary succession is noticeable (Quintana Roo).

5.6 Monitoring

In due time, permanent experimental control plots should be established and examined regularly. The network of experimental sites is required to produce data to build models of growth, mortality, ingrowth, regeneration, composition, variability, risks and yield. Whenever possible, plots should be placed in each cutting area, remeasured and assessed three times a year for 5 years, then once each 5 years until the end of the rotation or until the maximum longevity of the local species (in the case of control plots). Plots complement timber surveys to gather a complete set of responses to treatment and natural variability. A decision support system that can be used in the future to refine decisions about cycle length, residual stocking for full-occupation, silvicultural treatment parameters, and forest health strategies can be developed from information gathered by the permanent plots.

Chapter VI. New research required

The proposal, as presented, implies knowledge about commercial species (including mahogany, Table 8) and noncommercial species of the mahogany forest.

The relationship of the DBH, age and height of trees to crown length and radius and branch architecture should be known for the commercially important species. Also, the quantity of flowers, fruits and propagules that each species will produce as a function of tree characteristics, such as age, is needed. Available product distribution models need improvements and greater geographic coverage. Because the best bucking pattern is a problem with multiple solutions, forest planning decisions may use one of the most commonly used ones, like the rule of maximum value mix.

The three dimensional crown expansion dynamics of a tree of a species with respect to other trees of the same or other species in relation to the size of both is a process that needs to be quantified. The effect of this phenomenon on the vigor of an individual and its capacity to survive another year is also important to know.

The minimum size of a canopy opening in which a new germinant on the forest floor can develop successfully to its mature size is a key feature that needs local calibration, as well as the size of the canopy opening large enough to exhibit adverse conditions for the establishment of regeneration. This information is complemented with knowing the size of openings that favor or make it possible for colonization by aggressively competitive species or parasites of the commercial or desirable species. Perhaps light that enters the opening is sufficient to permit the appearance of undesirable vegetation, or perhaps there is some other requirement (fire, drought, microtopography, soil type, etc.).

The relation of microtopography, soils and the organic layer needs to be known. The connection between site features and the actual and potential presence of each commercial or desirable species is a topic that is not well understood. Information about how successional pathways are linked to topographic pattern would be useful.

Functions representing natality, mortality, incorporation, and growth and yield of mixed crops of all forest species in the Yucatan Peninsula are needed. These functions should respond to variation in geography, site, environment, and above all to labor of cultivation and natural disasters. In addition, the aggregate performance of these models should fulfill the requirements for analysis, especially to have decreasing yields at the scale and with respect to each factor of production, including the time and value of money. It does not matter for the moment if the models are theoretical, fitted to empirical data, or supported by biological, silvicultural or economic functions as long as they are statistically valid at a level of reliability that they can distinguish among the most common silvicultural decisions to be made.

Functions representing performance of equipment and manpower when applied for timber logging and for environmental engineering are also needed. These functions are required to facilitate assignment decisions about equipment to carry out silvicultural treatments.

Table 8. State of silvicultural and ecological knowledge of mahogany in Quintana Roo.

Area of Knowledge	Availability of the information in Quintana Roo
Silvics of mahogany	Moderate
Natural regimen of disturbances	Yes
Probability of size, fecundity, health and vigor of the trees expected in the stand, according to the forest inventory and management plan	Moderate
Production function or silvicultural simulation model	No
Ecological dynamics of the forest type	Moderate
Genetics	Limited
Influence of silviculture of mahogany on the fauna and vice versa	Limited
Social and cultural values linked to the mahogany forests	Moderate
Showcases	Limited

Area of knowledge	Availability of the information in Quintana Roo
Existence and availability of equipment and workers with the skill to execute the treatment with dexterity	Moderate
Market demand for products and subproducts expected from the silvicultural labor	Moderate
Number of stands and size of the smallest compatible with the minimum harvest: 7 m^3/ha/intervention, 4000 m^3 annual removal, 500 ha minimum surface area of cut	Moderate
Financing	Moderate
Legality of the treatment parameters and term of the permits	Yes

Chapter VII. Appendices

Appendix 1. Glossary of terms used

Affected area. The set of noncontiguous cutting areas assigned to harvest in the same year.

Annual plan. Minimum period of planning and of administrative recording and mapping. Usually not 12 months but one dry season that can be part of one or two calendar years.

Complementary tasks. All the tasks and individual activities that constitute a silvicultural treatment are grouped under this term. These activities include: the method of felling, bucking, skidding, and loading; design of roads; season of work; preventive control of site damage or damages to residual trees and understory vegetation (or its opposite level of removal and prescribed disturbance as a treatment goal); control and disposal of the residue; inventory of firewood, leaf litter and standing combustibles; site preparation (chemical, mechanical, with fire); preventive control or remediation of erosion; sowing design and cultivation of associated cultivars (if there are any, i.e.) corn, squash, beans, bananas, citrus, etc.); determination of policies about legacies (bushes, wetlands, coarse woody debris in the soil, live and standing dead tree layer that remain within the treated area and that should be considered as something that should remain on the site without being damaged or moved); and control of weeds, especially grasses and vines, including aggressive invasive species. Other activities that could be prescribed for the stand and could be executed in the course of the work of actual treatment are also included.

Cutting area. The cutting area is made up of various groups of interacting trees (GITs).

Cutting cycle. Lapse between successive interventions, usually a fixed quantity for each cultivation regime. Some treatments might be needed outside the return schedule.

Forest Management. Administration of the activities on forested lands with the purpose of seeking certain objectives and preferences that have been hierarchically defined by someone with authority to do so. In the Mexican case, the responsibility is legally shared by the owner of the forest and a licensed professional forester. The role of the forester is to prepare and oversee execution of an officially sanctioned management program. For practical purposes, the landowner is the chief executive officer, and the forester is the manager of a forest business.

Forest. Although a legal definition exists for purposes of national and international statistical reporting, for the purposes of silviculture the forest is the land whose intended use is forestry and its content of soils, species, structures and processes is compatible with the intended forestry use. The latter concept is usually associated with a large time scale (>2 000 years) and surface (>10 000 ha).

Full-occupation. The condition when the site is 100% occupied by target trees of desirable species at any stage of development of the forest.

Group of interacting trees (GIT). Minimum treatment unit composed of trees with mutual interactions (i.e. mutual interference in crown expansion). In the GIT trees originated from the same disturbance in time and space and have grown together in similar environmental conditions. A GIT can be considered an ecological subdivision of what is traditionally the stand. A GIT can be a wolf tree, a small group of trees, up to a large group of trees that might cover several hectares. The GIT will be identified based on the experience and expertise of the silviculturist in charge of the forest inventory.

Irregular forest system. Stands containing multiple groups of interacting trees involving at least three canopies (cohorts) (Smith and others 1997). As small stands are necessarily even-aged, irregular stands should be medium to large in size. Among the largest, it is most likely that at any given moment there will be multiple groups of different ages and development stage. The extreme case of fully regulated selection forests is a theoretical case hardly plausible, but mathematically viable, because there can appear small canopy openings, but ones sufficiently large that each one can support one and only one seedling that can endure up to maturity. If the stand and the complete forest were formed of these small contemporary stands of only one tree, that would be the most irregular selection forest imaginable.

In the GIT trees originated from the same disturbance in time and space and have grown together in similar environmental conditions. A GIT can be considered an ecological subdivision of what is traditionally the stand. A GIT can be a wolf tree, a small group of trees, up to a large group of trees that might cover several hectares. The GIT will be identified based on the experience and expertise of the silviculturist in charge of the forest inventory."

Land planning. The part of forestry that is concerned with the spatially explicit features of management decisions. Decisions may lead to a certain scheme of territorial organization of management operations.

Mahogany site. Sites with abundant mahogany (>5% of live trees or their equivalent in precommercial forest), as well as potential mahogany sites: dark soils, good humidity, not wetlands, with or without exposed rocks, good drainage, and slightly above the average elevation of the soil.

Management method. The model of control of inventories (stock) of products in the forest that complies with the general guides proposed by the forester to the businessman (forest owner) as regards legality, production, productivity, profitability, variability of the productive dynamics, risk, amount of investment, intensity of management and flexibility of strategic decisions. The elemental decision is the evaluation of the probable sale price of the forest and the forest business in case of actual liquidation or in case of being at the point of looking back over the fulfillment and the conditions in which the work has been carried out.

Management program. Given that there can be and surely are differences between the standing inventories (the amount, distribution, prospect of future stand by stand) and the inventory goal, the management program establishes the need for a calendar of silvicultural interventions, as well as a sequence of geographically defined intervention priorities. The management program, no doubt, implies investment and disinvestment plans, financial performance and financial risk management, but these later elements are rarely a priority or a concern to the owner. At the most, the management plan will introduce policies about output flow in volume or value and sometimes costs controls. In a legal sense, the management program is an alternate option of land use. Other frequent options in Mexico include conservation programs, restoration programs, plantation programs (the well-known tree farm), and set-aside easements. In this legal sense, the forest management program is a combination of distinct, at times independent programs: one for harvest, another for forest protection, another for aforestation, another for multiple uses and one more for designated private reserves.

Management series. The largest territorial divisions are the series. They are created to manage independently dispersed geographical regions, each one of a sufficiently large amount (>1 000 ha) to sustain its own planning scheme. Each series may have its own road network and other infrastructure necessary to maintain decisions independent from the rest of the property. In multi-farm groups, a series is composed of a complete ownership. If there is only one woodlot, series are used to represent distinct forest types, each using a given silvicultural system or regime.

Method of development. The origin of germplasm used to renew the tree layer of a stand in natural form. The classic options are high forest (by seed), low forest, and coppice (by vegetative reproduction).

Product distribution. Estimated theoretical frequency of the potential yield in certain wood products (species, dimensions, defects, quality) if each tree marked for felling in a stand or all trees in the stand are harvested at a given moment. As bucking rules cause an intractable mathematical problem, there is not a unique best distribution of products, so for the purpose of making decisions, a certain group of desired products is chosen, nearly always maximizing higher-priced products.

Regular forest system. Silvicultural system that creates stands in which most of the time the trees are in the same development stage and approximately the same age. Because of physical necessity, at some point in time the terrain will not be forested. At another point in time and unless the regrowth comes from a plantation or sowing, there will be adult trees in the overstory and regeneration in the understory.

The smallest stands necessarily are a single cohort. The very large stands and the forest itself necessarily are multiple cohorts, with very few exceptions (e.g. tundra can have only one entire forest of the same age).

Regulation of the cut. As cutting trees is a daily activity in silviculture, the planning process is known as harvest regulation. Monitoring and assessment data from actual operations and sometimes also mathematical simulation forecasts serve as input to analytic schemes for devising alternative courses of action that are handed over to decision makers and stake holders, so they can make informed choices.

Rotation. Indicator of maturity to recommend a moment for final harvest of a forested stand if the stand were cultivated since its establishment. In concrete terms, the rotation is the estimated time between establishment and the time of harvest. In some classic texts, it is said that rotation only is pertinent for even-aged stands, but because a natural forest commonly has wide biological variability, stands will have to be especially small so that they can comply with the rule that they be single age and pure. Therefore, for reasons of scale of the harvest, the result will be extraction of as many ages and species in each stand as there are. The importance of the rotation is that it is used to choose the pace at which a silvicultural regime proceeds, and this rhythm is the basis to assess performance of the forest business. Therefore, it is not necessary that there be unchangeable and finite definitions for the age at which each tree is harvested, but it is absolutely mandatory that there be a decision about the administrative parameter that the rotation implies. A rotation defined in a punctual way is as useful as a probabilistic rotation, given the ends for which a number is chosen for such a parameter.

Saplings. Successful regeneration.

Silvicultural regime. Concrete list of scenarios through which the structure of a stand will pass sequentially, together with the list of factors that drive or identify the transitions from one stage to another. The most obvious factors of change are the silvicultural treatments. The regimen considers site quality, simultaneously with the intensity of management (productivity), and probabilistically the environment created by natural variability, circumstantial events and risks of disasters.

The silvicultural regime defines a calendar of planned interventions and monitoring activities to detect random situations that call for a certain treatment or response (i.e. prescribed fire, direct seeding).

Silvicultural system. Theoretical concept concerning the dynamics of forested stands. A silvicultural system implies a general abstract strategy to guide stands to a desired state or purpose. The classic silvicultural systems are denoted according to the harvest method used, and traditionally for their study and application they have been divided into regular systems (even-aged, single cohort) and irregular systems (uneven aged, multicohort) (Smith and others 1997).

Silvicultural treatment. Any series of concurrent actions in a forest scene (stand) that drive its future condition towards a course distinct from the current trend. The treatment may achieve one of several alternative purposes: to halt current dynamics, persisting under the actual structure without major alterations; to change to one of several feasible scenarios; to change drastically to another scenario of another distinct sequence; to respond in a preventive form; or to react to a chronic or incidental spontaneous or accidental disturbance. Sometimes the desired dynamics could be a spontaneous natural effect, because it could be that the target condition is the actual one, and therefore there would be null treatments. For the purpose of regulation of the cut, null treatments are as real as any other action in which the tree layer is removed or the site is modified. Any treatment, including the null treatment, is an investment of capital that is entered in the forest account books. The amount of this investment is the value of actual expenditures during the treatment minus the value of the products extracted and sold as a result of the labor. All treatments, without exception, are investments because the harvest as such is only conceived of as the liquidation of the forest by completely removing all its products and changing the use of the soil irreversibly. This is due to the fact that the most important cost of an individual treatment, including the null treatments, is the cost of retaining the residual standing inventory plus the net future growth for an infinite period of time, with the stock measured in products (not the tree biomass). A correction to the cost of treatment that must be considered includes the effects of interaction (indirect costs) in time and space with respect to the rest of the forest and the business environment.

Silviculture. Silviculture is the art, science and practice of controlling the establishment, composition, health, quality and growth of forest stands to accomplish a set of management objectives. The management objectives are attained through the spontaneous dynamics of the forest stand and its probabilistic environment of perturbations. The fundamentals of silviculture permit a wide range of possible scenarios in the forest, diverse sequences of time and space requirements to attain them and multiple control activities that can be applied to define a particular sequence of results distinct from those that would occur under natural conditions. Feasible sequences are a series of scenarios that occur, last, and finally give way to new subsequent scenarios due to the accumulated effect of time elapsed (as for example, the aging of trees) in response to factors and natural stimuli (the disturbance regimen) and to concrete actions of management (cultural practices).

Stand. An arbitrary portion of forest, defined for administrative purposes, that is sufficiently large to contain a prescription for silvicultural treatment. Every stand needs a unique characterization on maps and data, such that performance can be assessed. The smallest stand will not be less than the area occupied by a large tree, nor less than the area needed by a logging rig to operate. For practical purposes, consider the minimum stand as the area logged daily by a jammer and its peripheral equipment (chainsaws) or the terrain that a skidder and its associated felling and bucking equipment could successfully harvest in one day. For statistical purposes, the stand does not need to have homogeneous biological conditions or land features, nor does it need to have only one type of biological scenario or stand structure, because there are statistical designs that efficiently and effectively provide the quantitative, qualitative and historical estimates needed to model the future options and its possible performance and risks, in spite of the variability contained in the stand. Nevertheless, it is a tradition and a help to facilitate the statistical estimations that the stands contain only one scenario with minimum internal variability and clear physiognomic and parametric delimitation with respect to the structure of the neighboring stands.

Stewardship. Search for the target forest. Actions and policies that create new wealth, maintain low levels of exposure to risks, and maintain continuous growth, stability and liquidity that pay for other productive initiatives and to attend to emergencies. Concerning the performance of any individual activity and group of activities or policies, it should be considered that: no action is recommended if it does not justify postponing or canceling the decision to liquidate the enterprise or to leave the forestry business. This means that the partial contribution of an isolated decision must add value to the forest beyond the value added by other contributions and other factors. This evaluation also permits one to consider the effects of the business environment, legal and institutional milieu, and the vicissitudes due to environmental variability and natural disasters.

Stratum. A group of discontinuous stands that have similar structures. Given that powerful computing capacity is widely available today, it is possible to individually manage any quantity of stands. It is also simple to track down and assess distinct stand structure dynamics under various intervention schedules, including those in which the treatment or natural occurrences modify only part of the stand. Today, strata are not only redundant, but an unnecessary source of statistical error because of discarded information, although in the tropics worldwide there are many cases that still use this type of forest division.

Target tree. A high quality tree of any of the main commercial tree species.

Timber-producing forest. Forest that contains sufficient commercial trees and the biological capacity to respond to silvicultural cultivation in order to sustain a lasting stream of wood extraction without exceeding the legal, technical, logistic and financial parameters that the forest enterprise and the economic environment have established. In terms of the mahogany forest, the smallest timber-producing forest must sustain an extraction of more than 7 m^3 per hectare per intervention of commercial-dimension timber in logs of any commercial species for at least 100 years. Harvesting will be done in cutting cycles of not more than 20 years (or its proportional equivalent, if the cycle is longer) with annual harvest (or its proportional equivalent if intervention is not annual). That is to say, the forest must produce a net yield of >35 m^3 per hectare per rotation (presently 100 years). A 10 000 ha forest like this can sustain an annual harvest of 3 500 m^3 of logs equivalent to 4 000 m^3 in standing volume when managed with the technologies available today and partially described in this work.

Treatment method. Set of silvicultural treatments that comprises a complete cycle of production - from establishment to final harvest. It usually is known by the name of the final treatment. The classic treatments and methods are clearcut, seed tree, shelterwood, and selection.

Bibliography

Argüelles, S. L. A. 1991. Plan de manejo forestal para el bosque tropical de la empresa ejidal Noh Bec. México, Texcoco: Universidad Autónoma de Chapingo División de Ciencias Forestales. 125 p. Tesis Ingeniero agrónomo especialidad en bosques. (18)

Arriaga, L.; Espinoza, J. M.; Aguilar, C.; Martínez, E.; Gómez, L.; Loa, E. 2000. Regiones terrestres prioritarias de México. Comisión Nacional para el Conocimiento y Uso de la Biodiversidad, México.

Bautista, F.; Zinck, J. A. 2010. Construction of an Yucatec Maya soil classification and comparison with the WRB framework. Journal of Ethnobiology and Ethnomedicine. 6:7. DOI:10.1186/1746-4269-6-7.

Bautista, F.; Palacio, G.; Páez-Bistraín, R.; Carmona-Jiménez, M. E.; Delgado-Carranza, C.; Cantarell, W.; Tello, H. 2011. Geografía de suelos regional: península de Yucatán. Geografía de Suelos de México. Facultad de Ciencias, Unam, México. Capítulo 16.

Brown, N.; Jennings, S.; Clements, T. 2003. The ecology, silviculture and biogeography of mahogany (*Swietenia macrophylla*): a critical review of the evidence. Perspectives in Plant Ecology, Evolution and Systematics. 61 (1/2): 37-49.

Cámara-Cabrales, L. C. 2005. Seed production, seed dispersal, and seedling ecology of mahogany (*Swietenia macrophylla* King) in Quintana Roo, Mexico. Amherst, MA, USA: Univerity of Massachusetts, Amherst. University Microfilms International, Ann Arbor, MI, USA. 257 p. Ph.D. dissertation. (10)

Cámara-Cabrales, L.; Kelty, M. J. 2009. Seed dispersal of big-leaf mahogany (*Swietenia macrophylla*) and its role in natural forest management in the Yucatán peninsula, Mexico. Journal of Tropical Forest Science. 21 (3): 234-245. (14)

Cámara-Cabrales, L.; Snook, L. K. 2005. Producción de semillas de caoba en México. Patrones de variación e implicaciones para la sustentabilidad. Recursos naturales y ambiente. 44: 60-67. (13)

Chavelas, H. M. 2004. Biología Floral de *Swietenia macrophylla* King (Meliaceae). México: Universidad Nacional Autónoma de México. 132 p. Tesis de licenciatura.

Curiel, G. M.; Mendoza, M. A. 2007. Método de ordenación plan Costa de Jalisco. En: talleres regionales aspectos técnicos del manejo forestal sustentable [Video]. Secretaría de medio ambiente y recursos naturales: Morelia, Michoacán.

Dickinson, M. B.; Hermann, S. M.; Whigham, D. F. 2001. Low rates of background canopy-gap disturbance in a seasonally dry forest in the Yucatan Peninsula with a history of fires and hurricanes. Journal of Tropical Ecology. 17: 895-902.

Edwards, C. R. 1986. The human impact on the forest in Quintana Roo, Mexico. J. For. Hist. 30: 120-127.

Ek, D. A. 2011. Vegetación. In: Pozo, C.; Armijo, C. N.; Calmé, S., eds. Riqueza biológica de Quintana Roo: un análisis para su conservación. México: MECOSUR/Conabio/GOB. EDO. DE QUINTANA ROO/PPD: 62-77.

Filho, L. J. P.; Duarte, R. J. 1998. Seed reserves partition and light compensation point of mahogany (*Swietenia macrophylla* King) seedlings growth under low photosynthetic active radiation. Brazilian Archives of Biology and Technology. 41 (2): 207-211.

Flores, J. S.; Durán, G. R.; Ortiz, D. J. J. 2010. Comunidades vegetales terrestres. In: García, R. D.; González, M. E. M. 2010. Biodiversidad y desarrollo humano en Yucatán. Biodiversidad y desarrollo humano en Yucatán: 125-129.

Gerhardt, K. 1996. Germination and development of sown mahogany (*Swietenia macrophylla* King) in secondary tropical dry forest habitats in Costa Rica. Journal of Tropical Ecology. 12 (2): 275-289.

Gliessman, S. R.; Garcia, R. E.; Amador, M. A. 1981. The ecological basis for the application of traditional agricultural technology in the management of tropical agro-ecosystems. agro-Ecosystems.
7: 173-185.

Gómez-Pompa, A.; Flores, J. S.; Sousa, V. 1987. The "Pet Kot": a man made tropical forest of the Maya. Interciencia. 12: 10-15.

Goode, L. K.; Allen, M. F. 2008. The impacts of Hurricane Wilma on the epiphytes of El Edén Ecological Reserve, Quintana Roo, Mexico. The journal of the Torrey Botanical Society. 135 (3): 377-387.

Grogan, J. 2001. Bigleaf mahogany (*Swietenia macrophylla*) in southeast Pará, Brazil: a life history study with management guidelines for sustainable production from natural forests. Ph.D. thesis, Yale University, New Haven. 421 p.

Grogan, J.; Galvão, J. 2006. Factors limiting post-logging seedling regeneration by big-leaf mahogany (*Swietenia macrophylla*) in southeastern Amazonia, Brazil, and implications for sustainable management. Biotropica. 38: 219–228.

Grogan, J.; Ashton, M. S.; Galvão, J. 2003. Big-leaf mahogany (*Swietenia macrophylla*) seedling survival and growth across a topographic gradient in southeast Para´, Brazil. Forest Ecology and Management. 186: 311–326. (2)

Grogan, J.; Barreto, P.; Veríssimo, A. 2002. Mahogany in the Brazilian Amazon: ecology and perspectives on management. 44 p.

Grogan, J.; Landis, R. M.; Ashton, M. S.; Galvao, J. 2005. Growth response by big-leaf mahogany (*Swietenia macrophylla*) advance regeneration to overhead canopy release in southeast Pará, Brazil. Forest Ecology and Management. 204: 399-412.

Gullison, R. E.; Panfil, S. N.; Strouse, J. J.; Hubbell, S. P. 1996. Ecology and management of mahogany (*Swietenia macrophylla* King) in the Chimanes forest, Beni Bolivia. Botanical Journal of the Linnean Society. 122 (1): 9-34. (12)

Gutiérrez-Granados, G.; Juárez, V.; Alcalá, R. E. 2011. Natural and human disturbances affect natural regeneration of (*Swietenia macrophylla*): implications for rainforest management. Forest Ecology and Management. 262 (2): 161-169.

Hernández-Xolocotzi, E. 1958. La agricultura. In: Beltrán, E., ed. Los recursos naturales del sureste y su aprovechamiento. México, D. F: IMRNR: 1-57. Capítulo 1.

Herrera, S. J. C. 2011. Clima. In: Pozo, C.; Armijo, C. N.; Calmé, S., eds. Riqueza biológica de Quintana Roo. Un análisis para su conservación. México: Ecosur/Conabio/GOB. EDO. DE QUINTANA ROO/PPD: 50-56.

Lamb, B. F. 1966. Mahogany of tropical America: its ecology and management. The University of Michigan press, Ann Arbor. 220 p.

Macario, M. P. A.; García, M. E.; Aguirre, R. J. R.; Hernandez- Xolocotzi, E. 1995. Regeneración natural de especies arbóreas en una selva mediana subperennifolia perturbada por extracción forestal. Acta Botánica Mexicana. 32: 11-23. (3)

Macías-Sámano, J. E. 2001. Interacciones químicas entre Hypsipyla grandella y sus plantas hospedantes. Manejo Integrado de Plagas. 60: 15-21.

Márdero, S.; Nickl, E.; Schmook, B.; Schneider, L.; Rogan, J.; Christman, Z.; Lawrence, D. 2012. Sequías en el sur de la península de Yucatán: análisis de la variabilidad anual y estacional de la precipitación. Investigaciones geográficas. 78: 19-33.

Mayhew, J. E.; Newton, A. C. 1998. The silviculture of mahogany. Wallingford, England: CABI Publishing. 240 p. (20).

Miranda, F. 1978. Vegetación de la península yucateca: rasgos fisiográficos, la vegetación. Colegio de Postgraduados.

Moret, A. Y.; Valera, L.; Mora, A.; Garay, V.; Jerez, M.; Plocksac, M.; Ramírez, N.; Hernández, D. 2008. Estructura horizontal y vertical de Pachyra quinata (Lacq.) W. S. Alverson, (Bombacaceae) en el bosque universitario "El Caimital", Barinas, Venezuela. Ecotrópicos. 21 (2): 62-74.

Morris, M. H. 1998. Mahogany (*Swietenia macrophylla* King) germination studies in Quintana Roo, Mexico. Ann Arbor, USA. The University of Michigan. 48 p. M.S. thesis. (16)

Morris, M. H.; Negreros-Castillo, P.; Mize, C. 2000. Sowing date, shade and irrigation affect big-leaf mahogany (*Swietenia macrophylla* King). Forest Ecology and Management. 132 (2): 173-181. (17)

Negreros-Castillo, P.; Mize, C. 2006. Stand and species growth of a tropical forest in Quintana Roo, Mexico. Journal of Sustainable Forestry. 23: 83-96.

Negreros-Castillo, P.; Mize C. 2012. Soil-site preferences for mahogany (*Swietenia macrophylla* King) in the Yucatan Peninsula. New Forests. 44: 85-99. (1)

Negreros-Castillo, P.; Snook, L. K.; Mize, C. 2003. Regenerating mahogany (*Swietenia macrophylla*) from seed in Quintana Roo, Mexico: the effect of sowing method and clearing treatment. Forest Ecology & Management. 183: 351-362. (8)

Negreros-Castillo, P.; Snook, L. K.; Mize, C. 2005. Regeneración de caoba a partir de siembra directa en aperturas creadas en un bosque natural en México. Recursos naturales y ambiente. 44: 84-90. (7)

Niembro, A. 1995. Producción de semilla de caoba *Swietenia macrophylla* King bajo condiciones naturales en Campeche, México. En: memoria avance en la producción de semillas forestales en América Latina. CATIE: 249-263.

Norghauer, J. M.; Malcolm, J.R.; Zimmerman, B. L.; Felfili, J. M. 2006. An experimental test of density- and distant dependent recruitment of mahogany (*Swietenia macrophylla*) in southeastern Amazonia. Oecologia. 148: 437–446.

Orellana, L. R.; Balam, K. M.; Bañuelos, R. I.; García, E.; González-Iturbe, A. J. A.; Herrera, C. F.; Vidal, L. J. 1999. Evaluación climática. In: Universidad Autónoma de Yucatán. Atlas de Procesos Territoriales de la Península de Yucatán: 163-182.

Parraguirre Lezama, C. 1994. Germinación de las semillas de trece especies forestales comerciales de Quintana Roo. In: Snook, L. K.; Barrera de Jorgenson A., eds. Madera, chicle, caza y milpa. Contribuciones al manejo integral de las selvas de Quintana Roo, México. Proafat, Inifap, Usaid, Wwf-US: 67-80.

Patiño-Valera, F. 1997. Recursos genéticos de Swietenia y Cedrela en los Neotrópicos: propuestas para acciones coordinadas. Roma, Italia: FAO. 58 p.

Pennington, T. D.; Sarukhán, J. 1998. Árboles tropicales de México. Manual para la identificación de las principales especies. México: 2º. Edición. Unam, Fondo de Cultura Económica. 521 p.

Pennington, T. D.; Styles, B. T.; Taylor, D. A. H. 1981. "Meliaceae." Flora neotropica monograph No. 28. New York: The New York Botanical Garden: 388-405.

Pérez-Villegas, G. 1980. El clima y los incendios forestales en Quintana Roo. México: Centro de investigaciones de Quintana Roo y Universidad Nacional Autónoma de México: 65-80.

Porter-Bolland, L.; Sánchez González, M. C.; Ellis, E. A. 2008. La conformación del paisaje y el aprovechamiento de los recursos naturales por las comunidades mayas de La Montaña, Hopelchén, Campeche. Investigaciones geográficas. (66): 65-80.

Ramos, J.; Grace, J. 1990. The effect of shade on the gas exchange of seedlings of four tropical trees from Mexico. Functional Ecology. 4: 667-677. (9)

Rodríguez-Santiago, B. J.; Chavelas-Polito; Garcia-Cuevas, X. 1994. Dispersión de semillas y establecimiento de caoba (*Swietenia macrophylla* King) después de un tratamiento mecánico del sitio. En: Snook, L. K.; Barrera de Jorgenson A., eds. Madera, chicle, caza y milpa: contribuciones al manejo integral de las selvas de Quintana Roo, México. México: Proafat, Inifap, Usaid, Wwf-US: 81-90. (15)

Secaira, E. 2000. La conservación de la naturaleza, el pueblo y movimiento Maya, y la espiritualidad en Guatemala: implicaciones para conservacionistas. PROARCA/CAPAS.

Smith, D. M.; Larson, B. C.; Kelty, M. J.; Ashton, P. M. S. 1997. The practice of silviculture: applied forest ecology 9th edition. Wiley, J.; Sons. New York, NY.

Snook, L. K. 1993. Stand dynamics of mahogany (*Swietenia macrophylla* King) and associated species after fire and hurricane in the tropical forests of the Yucatan Peninsula Mexico. New Haven, CT, USA: Yale University, Yale School of Forestry and Environmental Studies. University Microfilms International, Ann Arbor, MI, USA. 254 p. Ph.D. dissertation. (5)

Snook, L. K. 1996. Catastrophic disturbance, logging and the ecology of mahogany (*Swietenia macrophylla* King): grounds for listing a major tropical timber species in Cites. Botanical Journal of the Linnean Society. 122: 35-46. (6)

Snook, L. K. 2000. Regeneration and growth of mahogany (*Swietenia macrophylla* King) in the forests of Quintana Roo, Mexico. Ciencia Forestal en México. 25 (87): 59-76.

Snook, L. K.; Negreros-Castillo, P. 2004. Regenerating mahogany (*Swietenia macrophylla* King) on clearings in Mexico's Maya forest: the effect of clearing method and cleaning on seedling survival and growth. Forest Ecology and Management. 189: 143-160. (11)

Snook, L. K.; Cámara-Cabrales, L.; Kelty, M. J. 2005. Six years of fruit production by mahogany trees (*Swietenia macrophylla* King): patterns of variation and implications for sustainability. Forest Ecology and Management. 206 (1): 221-235.

Sorensen, N. S. 2006. Regeneration and growth of seven canopy tree species in the Mayan forest of Quintana Roo, Mexico: the role of competition and microhabitat conditions. Oregon State University. 278 p. Ph.D. dissertation. (19)

Styles, B.T.; Khosla, P.K. 1976. Citology and reproductive biology of Meliaceae. In: Burley, J., Styles, B.T. (eds.). Tropical trees: variation, breeding and conservation. Linnean Society Symposium Series 2, 61-68.

Styles, B. T. 1972. The flower biology of Meliaceae and its bearing on tree breeding. Silvae Genetica. 21 (5): 175-182.

Swaine, M. D.; Whitmore, T. C. 1988. On the definition of ecological species groups in tropical rain forests. Vegetatio 75: 81-86.

Synnott, T. J. 2007. Diagnóstico de los sistemas de silvicultura de caoba en los corredores de la Península de Yucatán. Coordinación de Corredores y Recursos Biológicos. Corredor Biológico Mesoamericano-México. Comisión Nacional para el Conocimiento y Uso de la Biodiversidad. Saltillo, Coahuila, México. 22 p.

Tello, T. H. A. 2011. Suelos. In: Pozo, C.; Armijo, C. N.; Calmé S., eds. Riqueza biológica de Quintana Roo: un análisis para su conservación. México: Ecosur/Conabio/GOB. EDO. DE QUINTANA ROO/PPD: 57-61.

Tello, T. H. A.; Castellano, M. E. O. 2011. Características geográficas. In: Pozo, C.; Armijo, C. N.; Calmé, S., eds. Riqueza biológica de Quintana Roo: un análisis para su conservación. México: Ecosur/Conabio/GOB. EDO. DE QUINTANA ROO/PPD: 24-33.

Tetetla-Rangel, E.; Durán, G. R.; Hernández-Stefanoni, J. L.; Dupuy, J. M. 2012. Distribución espacial de la riqueza de especies leñosas raras de la Península de Yucatán y su relación con las áreas naturales protegidas. Tropical Conservation Science 5 (3): 320-339.

Toledo, V. M.; Barrera-Bassols, N.; García-Frapolli, E.; Alarcón-Chaires, P. 2008. Uso múltiple y biodiversidad entre los mayas yucatecos (México). Interciencia. 33(5): 345-352.

Traffic-Wwf. 2006. Análisis de los avances realizados para la implementación de los compromisos derivados de la inclusión de la caoba en el Apéndice II de Cites y la efectividad del Grupo de trabajo de la Caoba como mecanismo de apoyo al proceso Cites a nivel regional, subregional y global. Informe de Trabajo. Lima, Perú.

Velázquez, M. A.; Fierros, G. A. M.; Aldrete, A.; Guerrero, A.; Fernández, C. S.; De Los Santos, P. H. M.; Llanderal, O. T.; González, G. M. de J.; López, U. J.; Ramírez, H. C. 2003. Situación actual y perspectivas de las plantaciones forestales comerciales en México. Comisión Nacional Forestal. Zapopan, Jalisco. México. 448 p.

Vester, H. F. M.; Navarro-Martínez, M. A. 2005. Ecological issues in community tropical forest management in Quintana Roo, Mexico. In: Bray, D. B.; Merino-Pérez, L.; Barry, D., eds. The community forests of Mexico: managing for sustainable landscapes. University of Texas Press, Austin, Tx: 183-213.

Vester, H. F. M.; Navarro-Martínez, M. A. 2007. Fichas ecológicas: árboles maderables de Quintana Roo. México: Ecosur, Conabio, Gob de Quintana Roo, Coqcyt. 139 p. (4)

Vogt, E. Z.; Ruz, A.; Lhuillier, A. R. 1964. Desarrollo cultural de los mayas. Universidad Nacional Autónoma de México. Facultad de Filosofía y Letras. Seminario de Cultura Maya.

Wehenkel, K.; Corral-Rivas, J. J.; Gadow, K. V. 2014. Quantifying differences between ecosystem with particular references to selection forests in Durango, Mexico. Forest Ecology and Management. 316: 117-124.

Whigham, D. F.; Lynch, J. F.; Dickinson, M. B. 1999. Dinámica y ecología de los bosques naturales y manejados en Quintana Roo, México. In: Primack, R. B.; Bray, D.; Galletti, H. A.; Ponciano, I., eds. La selva Maya: conservación y desarrollo. México: Siglo XXI: 312-328.

Whitmore, T. C. 1991. Tropical forest dynamics and its implications for management. In: Gómez-Pompa, A.; Whitmore, T. C. F.; Hadley, M. Rain forest regeneration and management. Unesco and the Parthenon publishing group. Man and the Biosphere Series. 6: 67-90.

Whitmore, T. C. 1996. A review of some aspects of tropical rain forest seedling ecology with suggestions for further enquiry. In: Swaine, M. D., ed. The ecology of tropical forest tree seedlings. Unesco and the Parthenon Publishing Group. Man and the Biosphere Series. 17: 3-39.

Whitmore, T. C. 1998. An introduction to tropical rain forest. Oxford, Clarendon Press. 226 p.

Whitmore, T. C. 2003. Mahogany tree of the future. In: Lugo, A. E.; Figueroa-Colón, J. C.; Alayón, M., eds. Big-Leaf Mahogany: genetics, ecology and management. Springer-Verlag, New York: 1-5.

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