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The impact of shifting agriculture on the availability of non-timber forest products: the example of *Sabal yapa* in the Maya lowlands of Mexico

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Abstract

Understanding the effect of agriculture on the availability of non-timber forest products (NTFP) is currently relevant. Many landscapes are dominated by agricultural fields and fallow lands, so we should understand the status of NTFP in these landscapes. We studied the availability of leaves of *xa'an* palm trees (*Sabal yapa* Wright ex Beccari) in the shifting cultivation systems among the Yucatec Maya in Mexico. The mature leaves of this species of palm have been widely used for roofing since prehispanic times until present days; in the year 2000, approximately 90,000 people used *S. yapa* in Quintana Roo, and 360,000 used *Sabal* spp. in the Yucatán peninsula. This palm is managed by Maya farmers who spare palm trees when clearing a forest patch to turn it into maize fields (*milpa*). We compared the population structure and leaf production rate in different stages of the shifting cultivation cycle (*milpa*, fallow lands and forest), and quantified the domestic leaf demand in the village of X-Maben, state of Quintana Roo. In addition, we projected future availability of *xa'an* leaves, and estimated the period after which this might not be sufficient enough to cover the local demand of some villages and municipalities of Quintana Roo. Our results suggest that one of the consequences of shifting cultivation is the decrease in the availability and quality of this NTFP. Decreasing availability is a result of variations in population structure and leaf production rates between agriculture and forest patches. These negative effects may increase as agriculture becomes more intensive. Currently, the complete mosaic landscape created by this practice still offers sufficient resources for the local inhabitants in many communities. Besides, this NTFP has a high commercial potential in the tourist area. Our study suggests that the harvest of *S. yapa* in natural systems is sustainable for nine more decades and will be compatible with shifting cultivation as long as land tenure remains communal, there are long fallow periods and other factors remain unchanged.

Keywords: Non-timber forest products; Sustainability; *Sabal yapa*; Population structure; Quintana Roo; *xa'an* palm; *Milpa*

1. Introduction

The use and management of non-timber forest products (NTFP) has generated great interest because of their potential role in both ecosystem conservation and rural development. However, this fact has not yet been confirmed (O'Hara, 1999; Belcher and Ruiz-Pérez, 2001) by basic biological and economic research. Additional efforts to document the ecological implications of harvesting on multiple ecological levels are requiered (Ticktin, 2004). Also, comparative studies of the processes and tendencies associated with the use and management of NTFP are necessary (Ruiz-Pérez et al., 2004). One of the aspects in need of further analysis is the impact of land-use change, mainly for agriculture, on the availability of NTFP's (Shanley et al., 2002; Alexiades and Shanley, 2004). Today, it is a priority to improve our knowledge about the anthropogenic effects on tropical ecosystems (Bawa et al., 2004).

Shifting cultivation, which consists of the alternation between a short phase of cultivation and a long period of fallow, is one of the main inducers of land-use change (Ruthenberg, 1976; Van der Wal, 1998). Agricultural plots are cultivated during a short period of time after which they are abandoned, and through processes of secondary succession, become fallows. Simultaneously, new plots are established. In this way, shifting cultivation transforms homogeneous landscapes into mosaic landscapes with farm land, fallow lands of different ages, and mature vegetation. This kind of anthropogenic disturbance is very common in tropical regions; with at least 240 million people practicing it (Attiwill, 1994) it is the dominant food production system (Juo and Manu, 1996).

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The impact on useful plant populations of forest conversion into mosaic landscape may depend on a variety of factors such as biological features, the plant species' capacity to tolerate disturbances, as well as of human management practices that affect the plant populations involved. These factors may either limit the availability of NTFPs to restricted ecosystems, or allow them to exist not only in both mature and secondary forests, but also in a variety of agroforestry systems (Arnold and Ruiz-Pérez, 2001). Both positive and negative effects on the availability of NTFP's in relation to land use change have been documented for a number of species. For instance, with the conversion from forest to other land uses, *Endopleura uchi* becomes scarcer (Shanley et al., 2002). In contrast, the transformation from forest to other land uses is advantageous to palm trees such as *Orbygnia phalerata* (May et al., 1985; Pinheiro, 2004) and *Astrocaryum tucuma* (Schroth et al., 2004).

Transforming tropical forests into shifting cultivation landscapes has an impact on availability of NTFP's, which is shown in the use of *xa'an* palm trees (*Sabal yapa* Wright ex Beccari) in the shifting cultivation system among the Yucatec Maya (Caballero, 1994). Shifting cultivation was one of the foundations for the development of the antique Maya civilization, and today it is still the predominant farming system of the Maya living in the lowlands of Mexico and Guatemala (Barrera-Bassols and Toledo, 2005). Prehispanic and present production systems are structurally very similar (Teran and Rasmussen, 1995).

Over at least 3000 years, *xa'an* palms (called *palma de guano* in Spanish and *xa'an* in Maya) have provided a number of products for the household economy, mainly mature leaves for thatching houses and other domestic constructions (Voorhies, 1982; Caballero, 1994). For the last four decades, *xa'an* leaves have also been used to thatch tourist constructions in the Mexican Caribbean (Caballero et al., 2004). This species grows best in the closed canopy forest, even though it can also successfully grow in environments with high light intensity (Zona, 1990). *Sabal yapa* individuals are not cut down when clearing a forest patch to turn it into maize fields (*milpa)*. So, the Maya management allows the presence of individuals of the same species in the *milpa*, fallow lands (of different ages) and mature forest. Additionally, in the Yucatán Peninsula as a whole, *Sabal yapa* is managed through plantations and homegardens (Caballero, 1994).

The main objective of this study was to evaluate the impact of shifting cultivation on the availability of *Sabal yapa* leaves used for roofing purposes. For this, we compared the population structure and leaf production rate among different stages of shifting cultivation (in *milpa*, fallow lands and forest), with the leaf demand in the X-Maben region, Quintana Roo, Mexico. By comparing leaf production with leaf demand, we evaluated if the landscape modified by shifting agriculture offers the local inhabitants sufficient amounts of useful resources like the *xa'an* palm tree. Based on estimates of local demand, the surface area and leaf productivity we projected the future availability of *xa'an* leaves and estimated after how many years this might not be sufficient enough to cover the local demand in the studied village and other municipalities of Quintana Roo. Based on the example of *Sabal*, this paper discusses the exploitation of NTFP in a place where shifting cultivation is the predominant land-use.

2. Methods

2.1. Study area

The study area is conformed by the X-Maben *ejido* (a form of collective land tenure in Mexico), a community belonging to the Municipality of Felipe Carrillo Puerto, in Quintana Roo, Mexico (the community's full name is ''X-Maben and anexos'', here referred to as X-Maben). X-Maben is covered by semi-ever green seasonal forest ('selva mediana subperenifolia' *sensu* Miranda and Hernández-X, 1963; Breedlove, 1973), with a maximum stature of 15 m, shedding approximately 25% of its foliage in dry season. The mean annual precipitation is 1294 mm, with a 4-month dry season (January to April). Limestone land and karst topography result in a mosaic of lithosol and rendzina.

In 2000, the 73,400 ha of X-Maben were inhabited by 2980 people of Maya origin. As in many other communities in Quintana Roo, the X-Maben inhabitants are culturally still conservative, but in the last decades, a marked shift in their cultural and economic system has been taking place (Villa Rojas, 1992; Hostettler, 1996a,b; Juárez, 2002). They still speak their native language, practice some traditional rituals (for example, ''*Ch'a-cháak*'' when petitioning for rain) and thatch their traditional houses with *xa'an* leaves. The X-Maben people are direct descendants of the Maya rebels who were the protagonists in the Caste War in 1847–1901. There is also a small component of Chinese migrants who fled Belize in 1860 and who, after dwelling some years in Chan Santa Cruz (now called Felipe Carrillo Puerto), moved to X-Maben (Villa Rojas, 1992, pp. 152). In X-Maben, the economic activities involve subsistence agriculture, honey production, extracting timber and *chicle* (latex of *Manilkara zapota*-Sapotaceae). Additionally, some people are temporarily employed in the tourist zone of Cancún, Playa del Carmen and Tulúm, now called the Riviera Maya. Others run small corner shops.

In X-Maben the agricultural cycle includes the following practices. To grow the *milpa*, all the vegetation is slashed in December or January, but individuals from useful species such as *Sabal yapa* (Arecaceae), *Swietenia macrophylla* (Meliaceae), *Manilkara zapota* (Sapotaceae), *Cedrela odorata* (Meliaceae) are not cut down. The vegetation debris is left to dry in the sun and then burned in April or May. After this, maize (*Zea mays*-Poaceae), beans (*Phaseolus* spp.-Fabaceae) and squash (*Cucurbita* spp.-Cucurbitaceae) are planted. Each *milpa* plot is occupied for only 1 or 2 years (obtaining 1 or 2 harvests), after which it is abandoned. Then, succession begins and the secondary vegetation is established. This practice of ''slash and burn'' agriculture results in a fragmented landscape with patches of *milpa*, fallow lands of different ages and forest.

2.2. Population structure, leaf production and harvest rates

In order to evaluate the leaf availability of *S. yapa* within the mosaic landscape, we selected three phases: "*milpa*", *fallow lands* and *forest*. The *milpa* plots were cleared for agriculture in 2001, a few months before this research began, and after that they were burned. The *fallow* plots are old *milpa* plots abandoned 9–17 years ago, therefore they are young forests formed by natural regeneration. The *forest* plots have been managed by peasants for many years (see below), but the land has not used as *milpa* at least for the last 40 years. In the region's context, our *forest* plots represent the oldest vegetation cover, although for decades they have been managed with the purpose of extracting timber, firewood and NTFP (mainly *chicle* and *xa'an*). The environmental characteristics of the selected plots varied in relation to the regeneration cycle in which they were found, and did not vary in any evident way in other environmental conditions. The size of each plot varied between 2.7 and 8.0 ha due to the differential density of *S. yapa* individuals. The forest plots (rectangular in shape) measured 3.7 ha + 4.4 ha + 2.7 ha; the fallow plots (rectangular) measured 8.0 ha + 6.3 ha; while the *milpa* plots (rectangular or square) measured 5.0 ha + 6.8 ha (strictly, each studied *milpa* plot is constituted by two and four *milpas* which belong to different farmers; the distance between *milpas* in one plot is less than one kilometer, while the distance between *milpa* plots is 9 km). Therefore, the total area sampled per phase was 10.8 ha of forest, 14.3 ha of fallow lands and 11.8 ha of *milpa*. The size of each plot was calculated based on the UTM coordinates (measured with a GPS) on the limits of each plot. In these plots, the juvenile and mature adult trees were registered, while seedlings and saplings were counted in sub-plots of 2 m $\times$ 10 m (n = 10–12). The population structure between plots was compared using chi-square statistics, and the *a posteriori* adjusted residual analysis described by Haberman (1973). Individual counts were used for the statistical tests; to produce graphics of population structure we standardized the data to one hectare.

The leaf production rate from juvenile and adult trees was quantified in the same plots except for one of the forest plots. In the beginning, all individuals in the plots were labeled and assigned to a category according to the height of their trunk (Table 1). Presence/absence of signs of leaf harvest was recorded. Every 6 months for 2 years, the youngest leaf was marked and the number of produced and/or harvested leaves was counted. The former (expressed annually) was used to calculate the *annual leaf supply*, while the latter was considered as the *observed harvest*. The *annual leaf supply* represents the number of leaves potentially *available* to be harvested (expressed as leaves/ha/year). The leaves were harvested by local people according to their traditional techniques and needs. Not all juvenile and mature adult tree individuals were adequate for harvesting. The smaller and some of the taller individuals had leaves, which were not appropriate for thatching. Although some taller individuals produce appropriate leaves for thatching, they are rarely harvested because their slender stems are highly difficult to climb. We calculated the *density of useful individuals* by including only those with previous signs of harvest. Due to harvest, natural senescence and the appearance of new leaves, the number of live leaves varied in each census. In order to find the *cumulative supply* (leaves/ha), we multiplied the average number of live leaves observed in each census by the density of useful individuals. This number represents the number of leaves that can be found in one hectare. We used generalized linear models to evaluate and to compare the leaf production rate per plot. A linear model is an equation with mathematical variables, parameters and random variables, in which the parameters and the random variables are necessarily linear (Crawley, 1993). Some models are non-linear, but can be transformed into linear models using a transformation function, in which the equation becomes $f(y) = \beta_0 + \sum \beta_i x_i$. We found a function that models the rate of leaf production (y) as a function of plant height (h), applying a function of the type $\ln(y) = \beta_0 + \beta_1 h + \beta_2 h^2$, (where β are the parameters and h the variables). Because our data are leaf counts, the error structure follows a Poisson distribution. We therefore used a chi-square function to evaluate the significance of the variables. We applied a link function log, with a Poisson error structure using the package GLIM 4 (Numerical Algorithms Group, UK).

2.3. Leaf demand

In July 2000, we made a map of the houses in X-Maben's biggest town (*Señor*). Using the method called 'probability proportional to size' (on the map, the town was subdividied into several clusters, then some clusters were randomly chosen and, in these, family units were randomly selected) 58 households were randomly chosen to apply semistructured interviews (a written list of questions and topics that need to be covered in a particular order; Bernard, 1994). The interviews were conducted annually (in August) to the same 58 households

Table 1
Size categories used to describe the availability of *Sabal yapa*

Category		Aerial stem	Height of aerial stem (cm)	Leaf form	Harvest event
S	Seedlings	×		Lanceolate	×
I1	Saplings I	×		Bifid	×
I2	Saplings II	×		Semi-palmate	×
J1	Juvenile 1	✓	1–52	Costapalmate	✓
J2	Juvenile 2	✓	53–99	Costapalmate	✓
J3	Juvenile 3	✓	100–299	Costapalmate	✓
A1	Adult 1	✓	300–499	Costapalmate	✓
A2	Adult 2	✓	$\geq$500	Costapalmate	✓

during a 4 year period (2000–2003). In each household we asked about *xa'an* management and *milpa* practices, and gathered social and economic information. Additionally, we recorded information on roof material, approximate construction date, total *xa'an* leaves used in each roof (August 2000) and the annual number of leaves added (2001–2003) in each sampled family dwelling. This information allowed us to estimate the domestic *xa'an* leaf demand.

The domestic *xa'an* leaf demand was divided into two components: *cumulative* and *annual demand*. The *cumulative demand* is the sum of *xa'an* leaves used in all kinds of dwellings as recorded in the initial census (August 2000). Those leaves were found on the construction as added by the household during the indeterminate period of time before August 2000. In contrast, the *annual leaf demand* is the number of *xa'an* leaves added in 1 year. It was calculated by averaging the annual demand in the years 2001, 2002 and 2003. The *annual leaf demand* is the sum of (a) partial roof renewal of existing constructions, (b) total roof renewal of existing constructions and (c) leaves used for the roof of a new construction. To compare supply and demand, we used *annual supply* and *annual leaf demand* for the whole set of households.

2.4. The future tendencies of xa'an leaf availability

Future leaf demand and supply was projected for other *ejido*s of the Municipality of Felipe Carrillo Puerto to which X-Maben belongs to, as well as for other municipalities in the state of Quintana Roo. For this, we calculated the *potential annual supply* in each territory (according to their surface area and leaf production rates for each vegetation cover), and the *prediction of annual demand*, which represents the future demand that the (present and future) inhabitants could require (calculations made based on the rate of human population growth and on data of *cumulative* and *annual demand* per household; Table 4). It was considered that the system is sustainable for *t* years while the *potential annual supply* was higher than the *prediction of annual demand*. In each case, we evaluated that value of *t*. Details of the calculation and data sources are shown on Appendix A.

3. Results

3.1. Population structure

The population structure of *Sabal yapa* was statistically different in the three studied phases of shifting cultivation ($\chi^2 = 167.04$, $P < 0.05$, d.f. = 14, Fig. 1). The A2 adults were proportionally more abundant in the forest and remarkably scarce in the *milpa*. The J1 and J3 juveniles and A1 adults were proportionally more abundant in the *milpa*, while seedlings were scarce in the *milpa* and abundant in fallow lands (Fig. 1). Although our results are limited to a few replicas per each studied phase, our observations in many other areas of the *ejido* and the perception of Mayan peasants consistently suggest that the pattern found in our sample adequately reflects the pattern of population structure in the X-Maben landscape.

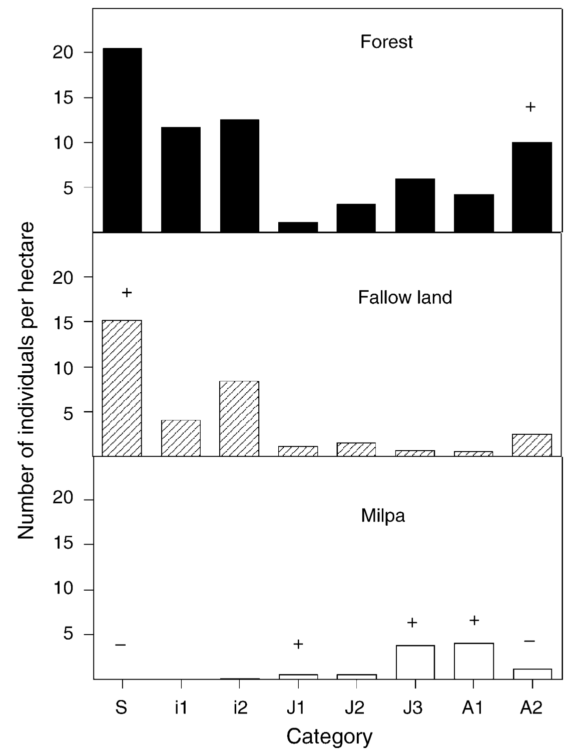

Fig. 1. Comparison of *Sabal yapa* population structure in patches of forest, fallow lands and *milpa*. Statistical differences between structures were significant ($\chi^2 = 167.04$, $P < 0.05$, d.f. = 14). The symbols (+) and (−) show excess or lack of individuals obtained by the adjusted residual analysis of Haberman. The number of S, I1, I2, J1 were expressed as 1/100.

Small intra-habitat variations could be expected to occur as a result of variations on the soil conditions, dampness of the terrain and history of land use.

3.2. Leaf availability

The greatest availability of leaves per unit area was found in forest plots, followed by *milpa* and, finally, fallow lands (Table 2). The forest showed the highest density of useful individuals to harvest (Table 2), even though it had the lowest leaf production rate per individual (Fig. 2). *Milpa* plots had a low density of individuals but the highest leaf production rates of individual palm trees measuring less than eight meters in height (Table 2, Fig. 2). Fallow plots had less availability per unit area because they had low densities of individuals and intermediate production rates. In conclusion, the stage in the shifting cultivation cycle offering the highest availability of the product is the forest (Table 2, Fig. 2). Although we think that the pattern of leaf availability by habitat shown in our results reflects the general pattern, we expect there is a relatively high variation within habitats. However, we could not quantify this due to our low number of replicas.

Leaf production rates (y) showed variation according to plant height (h) (43% of the variation) and site (10% of the variation, Table 3). The log-linear model used [$\ln(y) = \beta_0 + \beta_1 h + \beta_2 h^2$], explained 71% of the leaf production rate (Table 3). Optimum leaf production was found in individuals measuring seven to nine meters in height in all plots (Fig. 2).

Table 2
Density of individuals, *annual leaf supply* (the number of leaves potentially *available* to be harvested) and observed harvest of *xa'an* leaves by size category as recorded in six plots with *milpa* (M), *fallow lands* (FA) and forest (FO)

Category	Phase of shifting cultivation					
	M 1	M 2	FA 1	FA 2	FO 1	FO 2
Density of total individuals (ind/ha)						
J1	23.1	30.3	100.0	108.3	130	100
J2	0.8	0.2	1.6	1.3	2.4	3.7
J3	5.7	1.8	0.1	1.3	4.2	7.8
A1	4.0	4.0	0.0	1.1	4.2	4.1
A2	0.7	1.6	2.6	2.2	8.8	11.1
Sum	34.4	37.9	104.3	114.2	149.6	126.7
Density of useful individuals (ind/ha)						
J1	12.8	19.3	20.0	22.7	27.3	43.5
J2	0.8	0.2	1.6	1.3	2.4	3.7
J3	5.7	1.8	0.1	1.3	4.2	7.8
A1	3.0	3.5	0.0	0.8	4.2	3.3
A2	0.4	1.1	0.1	0.0	6.5	9.4
Sum	22.7	25.9	21.8	26.1	44.6	67.7
Observed harvest (leaves/ha)						
J1	19.9	54.2	58.3	80.0	17.5	91.7
J2	0.3	0.4	2.4	2.7	1.3	8.5
J3	7.7	6.9	0.4	3.6	4.4	22.0
A1	2.9	11.4	0.0	5.5	14.0	15.4
A2	0.3	4.9	0.1	0.0	20.6	82.8
Sum	31.1	77.8	61.2	91.8	57.8	220.4
Annual leaf supply (leaves/ha/year)						
	80.7	82.2	45.7	45.2	98.7	171.3
Cumulative supply (leaves/ha)						
	68.9	84.0	52.0	54.8	131.8	183.3

Size categories as in Table 1.

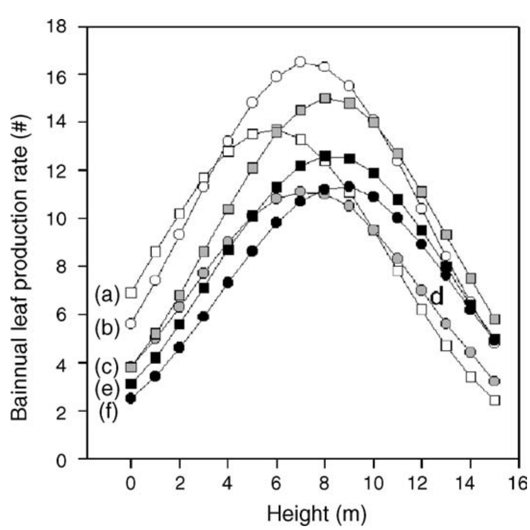

Fig. 2. Biannual *Sabal yapa* leaf production rate in six plots. White symbols are *milpa*, grey symbols are fallow lands and black symbols are forest. The mathematical functions that estimate biannual leaf production rate (y) in function of plant height (h) to every plot (letters a to f) are:
$f(y)_a = \exp^{1.9301+(0.2378\times h)+(-0.02055\times h^2)}$;
$f(y)_b = \exp^{1.718+(0.2985\times h)+(-0.02055\times h^2)}$;
$f(y)_c = \exp^{1.3282+(0.3365\times h)+(-0.02055\times h^2)}$;
$f(y)_d = \exp^{1.3335+(0.2976\times h)+(-0.02055\times h^2)}$;
$f(y)_e = \exp^{1.1257+(0.3404\times h)+(-0.02055\times h^2)}$;
$f(y)_f = \exp^{0.8988+(0.3541\times h)+(-0.02055\times h^2)}$

Table 3
Contribution of different variables to the explanatory model of biannual leaf production

Source	χ^2	Explained	d.f.	P
Height	426.9	0.43	1	<0.0001*
Height^2	161.7	0.16	1	<0.0001*
Site	103.2	0.10	5	<0.0001*
Height × site	23.48	0.02	5	<0.0005*
Total	1003	0.71		

* Statistically significant.

Individuals measuring eight meters or less had a higher leaf production rate in the *milpa*, followed by individuals in fallow lands and forest (Fig. 2). The most important individuals for leaf harvest were the J1 juveniles because of their high density, and A2 adults measuring 6–9 m in height, owing to the fact that they presented the best leaf production rate (Table 2, Fig. 2). The total supply of *xa'an* leaves in the mosaic landscape generated by shifting cultivation was approximately six million and a half leaves per year (Table 4). The forest provides 89% of the total supply, as it covers 79% of the X-Maben territory (Table 4).

3.3. Leaf demand

For X-Maben households, *xa'an* leaves were the most common material to thatch all kinds of domestic constructions (Table 5). Public buildings such as churches and bars also had *xa'an* roofs. In average, each one required between 5000 and 8000 leaves. In the year 2000, the village Señor had three catholic churches thatched with *xa'an* leaves and two temples thatched with other material. In 2005 there were a total of four bars in *Señor* also thatched with *xa'an* leaves.

In X-Maben, the average *cumulative demand* of *xa'an* leaves was 3612 leaves per household (Table 5). A large proportion (85%) of the *cumulative demand* was used to thatch the house and the kitchen (Table 5). This percentage includes some dwellings that combine house and kitchen in the same structure. The average *annual demand* was 366.9 leaves per household

Table 4
Supply/demand comparison of *xa'an* leaves for domestic use in the X-Maben *ejido*

Demand	Per household	Households (#)	X-Maben
Annual (leaves/year)	366.9	426	156299
Total (leaves)	3612.0	426	1538712
Supply (leaves/ha/year)	**Leaves/ha/year**	**Cover (ha)**	**X-Maben**
Milpa	80.7	841	67869
Fallow land	45.2	14230	643196
Forest	98.7	57936	5718283
Others	0	393	0
Sum			6429348
Supply/demand			41

Data for the years 2000–2003.

Table 5
Total demand of *xa'an* leaves for different kinds of constructions in the X-Maben ejido

Dwellings		Leaves				
Type	Total # (*xa'an* #)	Sum (#)	Distribution (%)	*X*	S.D.	CV
House	85 (64)	114545	55	1789.8	850.2	0.48
House and kitchen[a]	18 (18)	24091	12	1338.4	410.9	0.31
Kitchen	45 (37)	37881	18	1023.8	595.3	0.58
Store	7 (2)	2169	1	1084.5	355.7	0.33
Storage	23 (21)	10262	5	488.7	439.2	0.90
Wash house	47 (19)	5036	2	265.1	326.8	1.23
Other	48 (37)	6216	3	168.0	241.6	1.44
Animal dwellings	93 (70)	9348	4	133.5	122.3	0.92
Total demand per household ($n = 58$)		209548	100	3612		

Year 2000, $n = 58$ households. X = mean; S.D. = standard deviation; CV = coefficient of variation.
[a] House and kitchen: those dwellings that combine the house and the kitchen in the same structure.

(Table 6), including 37% to renew old roofs and 63% to thatch new constructions (Table 6). A comparison of the two types of leaf demand showed that the annual demand was 10% of the cumulative one.

3.4. Availability versus demand

Considering the lowest observed value of leaf production per plot (98.7 for forest, 45.2 for fallow lands and 80.7 for *milpa*, see Table 2), one hectare of forest offers the same amount of leaves as 1.22 ha of *milpa* or 2.18 ha of fallow lands. As such, the harvest area needed to construct a house varies between 18.1 and 39.6 ha according to the plot type (Table 7). Other constructions require less harvest area (Table 7). The mosaic landscape caused by shifting agriculture in X-Maben offered a annual leaf supply 41 times greater than annual demand (6′429.348/156.299; Table 4). In conclusion, the mosaic landscape offers sufficient resources to meet the current domestic needs.

Table 6
Mean annual demand of *xa'an* leaves (leaves/ha/year) per household of the X-Maben *ejido*

Type of dwelling	Type of renewal			Total
	Partial	Total	New	
House	53.6		130.5	
House and kitchen	12.6		10.7	
Kitchen	11.1	47.2	47.7	
Store	0.1		0.0	
Storage	4.2		17.2	
Wash house	0.6		0.4	
Other	1.3	0.2	6.5	
Animal dwellings	1.1	4.0	17.9	
Annual demand (# leaves)	84.6	51.4	230.9	366.9
Annual demand (%)	23	14	63	100
Total number of renewals	115	12	45	172

Type of renewal in composed by: *partial* roof renewal of existing constructions, *total* roof renewal of existing constructions and leaves used for the roof of a *new* construction; $n = 58$ family households, years 2001–2003.

3.5. Future demand

The *potential annual supply* and the *prediction of annual demand* shows that if the human population keeps on growing at the actual rate in the territory of Quintana Roo (5.94% annual, while the national average is 1.8% annual for the period 1990–2000; INEGI, 2003), *xa'an* leaf availability will be sufficient to keep up with local demands for approximately nine decades starting today (Table 8). Therefore, the commercial potential of this NTFP is high in Quintana Roo. Our results indicate that the *potential annual supply* is already insufficient in the Municipality of Benito Juarez, that is reflected by the low frequency (2%) of *xa'an* roofs in 1990 (INEGI, 1990).

4. Discussion

4.1. Resource availability

Our results show that shifting agriculture diminishes the availability of resources in patches of *milpa* and fallow, even though the complete mosaic landscape created by this practice still offers sufficient resources for the local inhabitants. We can see that *xa'an* leaf supply is low in fallow lands, intermediate in the *milpa* and high in the forest. In X-Maben, the total leaf supply in the mosaic landscape is 41 times greater than the

Table 7
Area needed to satisfy the *xa'an* leaf demand according to each plot type and kind of construction

Construction	Needed leaves	*Milpa* (ha)	Fallow lands (ha)	Forest (ha)
House	1789.8	22.2	39.6	18.1
House and kitchen	1338.4	16.6	29.6	13.6
Kitchen	1023.8	12.7	22.6	10.4
Store	1084.5	13.4	24.0	11.0
Storage	488.7	6.1	10.8	5.0
Wash house	265.1	3.3	5.9	2.7
Others	168	2.1	3.7	1.7
Animal dwellings	133.5	1.7	3.0	1.4

Table 8
Projection of the time t_n (t_0 = 1995) when *Sabal* leaves would become scarce in the municipalities of Quintana Roo and all *ejidos* of the Municipality of Felipe Carrillo Puerto

Municipality or ejido name	Surface area (ha)	Potential annual supply (leaves per year)	Human population 1990	Human population 1995	Annual human population growth rate	Annual demand will exceed annual supply at	
						t_n>	Year>
Municipalities of Quintana Roo							
Cozumel	145068	13379891	44903	48385	1.0150	103	2098
Felipe Carrillo Puerto	829221	96128428	47234	56001	1.0346	94	2089
Isla Mujeres	57960	7781760	10666	8750	0.9612	Indefinite	Indefinite
Othón P. Blanco	1029293	99045467	172563	202046	1.0320	62	2057
Benito Juárez	113053	7473445	176765	311696	1.1201	0	Exhausted
José María Morelos	353371	37341494	25179	29604	1.0329	90	2085
Lázaro Cárdenas	265011	22231485	15967	18307	1.0277	105	2100
Ejidos of the municipality of Felipe Carrillo Puerto							
X-Maben y anexos	73400	8521740	2377	2189	1.0506[a]	82	2077
F. Carrillo Puerto	47040	5458190	12704	16427	1.0527	31	2026
Dzula y anexos	29400	3411369	1006	1210	1.0376	100	2095
Tepich	33220	3854615	1659	1957	1.0336	101	2096
Noh-bec	23100	2680361	1315	1534	1.0313	105	2100
Chunhuhub	14330	1662752	3453	4028	1.0313	58	2053
Tihosuco	34452	3997567	3354	3889	1.0300	91	2086
X-Hasil (sur) y anexos	80021	9285073	972	1105	1.0260	187	2182
Polyuc	19385	2249299	1078	1112	1.0062	542	2537
X-Pichil	27300	3167700	1430	1322	0.9844	Indefinite	Indefinite
Ejidos with < 1000 inhabitants	447573	51933216	15773	21228	1.0612	60	2055

Potential annual supply in each territory was calculated according to the surface area and average leaf production rates per vegetation type (Table 4). *Prediction of annual demand* is the sum of annual demand by new residents and annual demand by old residents. More details of the calculations are shown on Appendix A. Data sources: vegetation cover (INEGI, 1991a; INEGI, 1993); population 1995 (INEGI, 1999); population 1990 (INEGI, 1991b, 1995).

[a] Calculated with data available in INEGI, 1963, 1995 and the municipality office (*Delegación*).

demand (Table 4). Differences between plots of land are due to the variation in population structure and density, as well as in leaf production rates. The greatest density of individuals was found in the forest and the lowest in the *milpa* and fallow lands. The variation in population density and structure is mainly caused by mortality in all size classes through the act of burning, specifically the seedlings, saplings and A2. The mortality rate, q_x, observed in a demographic study (Pulido, *unpublished data*), for *milpa*, fallow lands and forest individuals, respectively were: 0.870, 0.140, 0.125 for seedlings; 0.286, 0.0, 0.0 for I1; 0.065, 0.0, 0.0 for A1; 0.146, 0.013 and 0.005 for A2; in all the plots, individuals I2, J1, J2, J3 showed low mortality values. Fields are only burned prior to cultivation and as such, the effects of fire are clearer in *milpa* plots (as was mentioned before, individuals of *Sabal* are spared the axe during the establishment of the *milpa*). Concerning leaf production, individuals in the *milpa* are the most productive, potentially due to increased light availability, less competition and/or more availability of nutrients in the soil which are liberated by the fire. Forest individuals showed the lowest leaf production rate which might be due to the shadier conditions under which they grow. Individuals in fallow land showed intermediate leaf production rates. Increased post-fire leaf production has been documented to *Sabal etonia* (Abrahamson, 1999).

4.2. Resource quality

In relation to *xa'an* palm leaves, X-Maben farmers indicated the leaves of *Sabal* that grow in *milpa*, fallow land and forests are different in quality. In general, most farmers prefer to thatch their houses with leaves from the forest or fallow lands instead of using leaves from the *milpa*. Leaves from forest individuals are preferred because they are considered longer-lasting (around 15 years), have larger lamina, which are softer to manipulate and have a very thin costa which is esthetically valued specifically in the tourist zone. Moreover, the farmers recognize a special type of individual belonging specifically to the forest, known as "*bayal*". Its leaves are much appreciated because they have very long (up to 1.6 m) and thin blades, permitting the construction of "thick" and long-lasting roofs. *Bayal* individuals are J1 juveniles which can have approximately ten leaves with a very large and thin petiole. They were infrequent in the observed plots. Leaves from individuals in fallow lands are considered of good quality because of their long duration (almost the same as forest leaves) and a wide costa which provides high resistance. In contrast, leaves from *milpa* individuals are not very highly appreciated as they are short, not durable, and hard to manipulate, even though they present the advantage of being very wide so that less leaves are needed to thatch. Despite these preferences, leaves of all plots are used to thatch. Farmers pointed out that when great numbers of leaves are needed, for example, to thatch a house or a kitchen, leaves were always harvested from the forest and fallow lands. In contrast, when only a few leaves are needed (for example to thatch a hen house, bathroom or for repairs), farmers harvest the leaves in their orchads, homegardens, *milpa* or fallow lands, but never in the forest. The latter is probably due to the more difficult access. The apparent differences between the quality of the *Sabal* leaves from *milpa*, fallow lands and forest could be explained by the perception of the peasants and/or by the morpho-physiological variations that could occur due to the contrasting light conditions present in the places where they grow.

4.3. Agricultural intensification

In the long term, shifting cultivation may cause the extinction of *S. yapa* populations. In particular, agricultural intensification involving decreasing fallow periods possibly modifies processes like the recruitment of new individuals, seed production and dispersal. In the case of the *xa'an* palm tree, we estimated that the future survival of the population is at risk due to fallow periods which are shorter than 7 years. A seedling needs approximately 7 years to become a J1 juvenile. J1 juveniles are less vulnerable to fire ($q_x = 0.03$) compared to seedlings ($q_x = 0.87$) and saplings ($q_x = 0.28$) (Pulido, *unpublished data*). The apparent low resistance of *Sabal yapa* to fire contrasts with the marked resiliency of *Sabal etonia* (Abrahamson, 1999) and *S.palmetto* (McPherson and Williams, 1998). Traditionally, the fallow periods in the Yucatán Peninsula vary from 20 to 30 years (Teran and Ramussen, 1994 cited in Weisbach et al., 2002) even though they have been shortened (Humphries, 1993) to only 12 (Weisbach et al., 2002) or 6–8 years (Barke, 1987; Remmers and de Koeijen, 1992). Fallow period in X-Maben vary according to each farmer, but 72% of the area fallows are 7 years or older (Table 9). As such, we would expect less individuals of *xa'an* palm trees in the most intensively used plots.

Potentially, changes in fallow period in the study region (and possibly in other regions) can be explained not only by changes in the peasants habits, but also by factors such as the decrease in the crop productivity, changes in land tenure, changes in patterns of human settlement and by an increase in human population. For example, since 1992, in Mexico it is legally possible to sell/buy ejidos lands, which, although for the most part continue to be communal property, could become private property, and we expect this would have repercussions on the spatial patterns of shifting cultivation and on the availability of NTFP's.

Table 9
Age of vegetation when cut for agricultural purposes in X-Maben

Fallow period (years)	Frequency (%)	Average area per *milpa* (ha)	Total area of *milpa* (%)
0–6	32	2.5	28
7–20	33	2.8	32
≥21	35	3.4	40

For the *milpa* of the years 2000–2003, which belongs to farmers of 58 households, we calculated the frecuency, average area per *milpa* and total area of *milpa* (the sum) as a function of the fallow period.

4.4. Maya management and sustainability of leaf harvest

The negative impact of shifting cultivation upon the availability of resources is partially counteracted by the specific management practices and non-destructive harvest methods of Maya people. The fact the *xa'an* palm individuals are left standing in agricultural plots permits the maintenance of these populations in *milpa* and fallow lands, and allows their resilience in the agricultural cycle. Leaves are always harvested by climbing the palm tree; harvests are always partial, and one to three leaves are left on the stem to ensure the plants' survival. Maya management contrasts with other forms of indigenous management as is the case of the Emberá-Wounaan from Panamá with leaves of *Sabal mauritiiformis*; these people cut the entire plant (tall trees) with the purpose of harvesting the leaves to build roofs (Potvin et al., 2003). According to our data, the harvest of leaves of *Sabal yapa* was sustainable in all stage of shifting cultivation; on the short term, we did not observe a positive relation between harvest and mortality. Another demonstration of sustainability in the leaf harvest (on an individual scale) was shown by a defoliation experiment that lasted 2 years with 108 individuals of *S. yapa* (measuring between 1 and 500 cm in height), that grow in six homegardens from the Maya town of Maxcanú (Yucatán) (Andrea Martínez, –*personal communication*–). By means of a block design randomly used in each homegarden, it was seen that the most intensively harvested individuals (twice a year, leaving on the plant two or three leaves and the meristem) produced 5.1 leaves per year, while the control individuals (not harvested for 2 years) showed production rates of only 4.4 leaves per year. Sustainability of the leaf harvest of *S. yapa* on an ecosystemic scale has not been evaluated and it could affect key processes such as nutrient recycling. For example, O'Hara (1999) showed that, for *S. mauritiiformis* although on the short term the extraction of leaves apparently does not cause the depletion of limiting nutrients, during some seasons the leaves of this species do play an important role in accelerating the return of P and Zn, and control the liberation of K into the soil in "transition forests" (but not in "upland mesic forests") (O'Hara, 1999). A similar situation could be taking place with *S. yapa*.

4.5. The future of xa'an leaf availability

Our results show that, today, there are sufficient available resources in the X-Maben *ejido*; this *ejido* is characterized by its large surface area (73,400 ha), small human population (2980) and wide forested areas (79% forest, 19% fallow lands, 1% *milpa* and 1% other). However, we wanted to explore the availability of resources in other *ejidos* of Municipality of Felipe Carrillo Puerto (M-FCP) which are different in territorial and human population sizes. We found that, in the *ejidos* with less area per inhabitant, there is more fallow area (Fig. 3). As such, the availability of resources in the *ejidos* is directly related

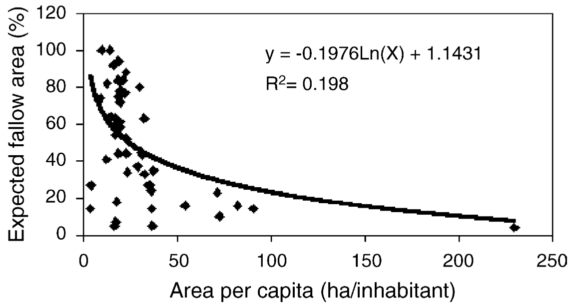

Fig. 3. Expected fallow area in the *ejidos* of the Municipality of Felipe Carrillo Puerto in relation to the area per capita. The surface of the *ejido* was obtained from Hostettler, 1996a. The fallow area was calculated by multiplying the *milpa* area of each *ejido* (data PROCAMPO 2003-PV provided by "Apoyos y servicios a la comercialización agropecuaria") by 16.9 as this represents the relation between *milpa* and fallow lands in X-Maben in 2000 (for each hectare of *milpa* there is 16.9 ha of fallow lands, Table 4).

to the available area and size of the human population. A relationship between periods of fallow and human density has been suggested by Eastmond and Faust (2006).

Regarding future tendencies on the availability of the resource, our estimation shows that, at least for nine more decades, the resource could be sufficient in several *ejidos* of M-FCP and other municipalities of Quintana Roo. The system is sustainable even though, as time passes, the domestic demand (in absolute numbers) of this resource in Quintana Roo tends to increase as a result of the high growth rate of human population in this state (Table 8). Based on official statistics (INEGI, 2000), we calculate that, in the year 2000, approximately 90,000 people in Quintana Roo depended on *S. yapa* and about 360,000 depended on *S. yapa, S. mexicana* and *S. mauritiiformis* in the entire Yucatán peninsula.

Nevertheless, the duration of the system's sustainability could shorten due to a: (1) high incidence of hurricanes in the region (Boose et al., 2003), which entail a total reposition of most of the roofs in the community; (2) the progressive increase of the fallow area with the consequent decrease of the forest area; (3) changes in land tenure (see Section 4.3); (4) an excessive and inadequate exploitation of the resource for commercial purpose; (5) a change in Maya management strategies. Note that the projection made assumes that the results obtained in X-Maben can be extrapolated to other parts of Quintana Roo, in spite of having a limited number of replicas in the X-Maben results. Therefore, more research efforts should be made in order to reach the target of sustainable use and commercial exploitation of *Sabal yapa*.

4.6. Responses to scarcity

These results show that in the state of Quintana Roo (which represents the most traditional region in the Yucatán Peninsula), we might be observing the last phase in a long history of use of this NTFP on natural vegetation, which dates back to Prehispanic times (in use more than 3000 years ago; Caballero, 1994). Common responses to scarcity of NTFP include increased harvesting area, substitution of the resource, and intensification of the production systems (Alexiades and Shanley, 2004). Therefore, in the near future, it will be possible for local people to counteract any scarcity of the resource in the natural vegetation through intensive production with other management forms like homegardens, orchards and plantations. The implementation of other management forms is a reaction to economic and land use changes in the region (Caballero, 1994). There are indications suggesting that *Sabal* was introduced in Maya homegardens during the colonial period, and apparently this gave origin to management in plantations which date back to the beginning of the 20th century (Caballero, 1994). In fact, during our field work in X-Maben and other nearby ejidos, we have observed the existence of small *Sabal* plantations and the harvest of *Sabal* within orchards practiced by some farmers as a way of facing the forest being progressively further away. As has been observed in other parts of the Yucatán Maya region, especially in more urban areas, the progressive scarcity of the resource could lead to a substitution of *Sabal* for industrialized material in roof building. This is favored by the processes of cultural change (Caballero, 1994). Nevertheless, as this region is the most conservative of the peninsula (although this fact is also changing), we could expect that the use of the *xa'an* palm in roofing will continue for several decades.

4.7. Land use: agriculture versus NTFP

Sabal yapa's example shows that domestic leaf needs can be covered in a sustainable way in the mosaic landscape generated by shifting cultivation for approximately nine more decades. This shows that the use of this NTFP is compatible with shifting cultivation practices as long as they remain traditional and non-intensive. As suggested by a comparative study of 61 world case studies (Ruiz-Pérez et al., 2004) (including *S. yapa*), the exploitation of NTFP within diversified domestic economies has a tendency to have little viability in the long term, especially if this competes with agricultural land use. A detailed analysis of *S. yapa*'s case shows that this resource can be exploited in a sustainable way with purposes of domestic use and possibly for commercial use within the shifting cultivation system.

5. Conclusions

Our results show that the use of *xa'an* leaves is currently sustainable in the *ejido* X-Maben. This is due to the continued predominance in the area of forests, since the data indicate that leaf availability is highest in these settings, although the optimum leaf production takes place in individuals between 7 and 9 m high in all plots. Our ethnographic data suggest that cultural preferences continue to focus on the use of *Sabal* leaves—mainly those from the forest palms—for thatching. Future projections indicate that the use of the leaf harvest could be sustainable in Quintana Roo for nine more decades, but the sustainability must be tested on a population and ecosystemic scale. Nevertheless, the sustainability of the natural system could become shorter because of a shortening of the fallow period (resulting from human population growth, changes in land tenure and/or farmer's customs), the incidence of catastrophic events such as hurricanes that involve the utilization of large numbers of leaves to replace most of the roofs, as well as an excessive and inadequate exploitation of the resource for commercial purposes. Apparently, this suggests that, at least for some decades, harvesting this plant resource may be compatible with shifting agriculture. It is expected that, as time passes, this resource becomes relatively scarce and will be found further away, and other systems of intensive production could be implemented in the Maya region. Ruiz-Pérez et al. (2004), who compared the success of 61 NTFP (including *S. yapa*), concluded that, in general, the most economically successful NTFP's are the domesticated NTFP's and those that come from crops. Results shown in this article suggest that, at least the domestic demand of leaves of *S. yapa* can be sustainable for some decades in natural systems, while their present economic contribution is very limited, although its potential is high.

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Appendix A

Calculation methodology applied to project the future leaf demand and supply shown on Table 8. The example corresponds to Municipality of Felipe Carrillo Puerto (M-FCP).

Potential annual supply = (*milpa* surface × *milpa* leaf production rate) + (fallow surface × fallow leaf production rate) + (forest surface × forest leaf production rate) = (35311 [ha] × (80.7 + 82.2)/2 [leaves/ha/year] + (139037 [ha] × (45.7 + 45.2)/2 [leaves/ha/year] + (643949 [ha] × (98.7 + 171.3)/2 [leaves/ha/year]) = 96128428 [leaves/year].

Annual population growth rate = (Population 1995/population 1990)$^{1/(1995-1990)}$ = (56001 [inhabitants]/47234 [inhabitants])$^{1/5}$ = 1.034637.

Households in 1995 = Population in 1995/average number of inhabitants per household = 56001 [inhabitants]/7 [inhabitants per household] = 8000 households.

Prediction of annual demand [leaves/year in all M-FCP] = *annual demand by new residents* + *annual demand by old residents*.

Annual demand by new residents at t years from 1995 = # leaves need for new construction × # new construction (# population increased in the focal year/average number of inhabitants per household) = 3612 [leaves per household] × (Population in 1995 [inhabitants] 1.03463$^{(t-1)}$ × 0.0346)/7 [inhabitant per household].

Annual demand by old residents at t years from 1995 = # leaves need for maintenance of existing construction × # existing construction (# population at $t-1$ year/average number of inhabitants per household) = 366.9 [leaves per year per household] × (Population in 1995 [inhabitants] × 1.03463$^{(t-1)}$)/7 [inhabitant per household].

Prediction of annual demand [leaves/year in all M-FCP] = (3612 × (Population in 1995 × 1.03463$^{(t-1)}$ × 0.0346)/7) + (366.9 × (Population in 1995 × 1.0346$^{(t-1)}$)/7) = Population in 1995 × 1.03463$^{(t-1)}$ × (((3612 × 0.0346) + (366.9))/7).

Thus,

Annual demand will exceed annual supply at $t > 94$ or 2089. In this example the *annual demand* in 2089 is 93167484, in 2090 is 96393874, the latter is greather that the *potential annual supply* of 96128428.

Data sources: vegetation cover (INEGI, 1991a; INEGI, 1993) [for example for M-FCP the *milpa* surface area = 35311 ha; fallow surface area = 139037 ha; forest surface = 643949 ha; surface area reported for other uses was not included]. Leaf production rates per patch (Table 2). Domestic demand = 3612 leaves per household (Table 4). Population in 1990 (INEGI, 1991b). Population in 1995 (INEGI, 1999). For each FCP-*ejido* we used the same methodology and data sources, except that the data for *milpa*, fallow and forest surface was calculated multiplying their surface (Hostettler, 1996a) by the proportion of vegetation cover of M-FCP (INEGI, 1991a; INEGI, 1993).

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