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Distribution and population patterns of the threatened palm *Brahea aculeata* in a tropical dry forest in Sonora, Mexico

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ABSTRACT

The use of non-timber forest products (NTFPs) has great potential for the conservation of natural resources and rural development. Palms are important NTFPs, providing numerous products, including leaves. The harvest of palm leaves rarely results in the immediate death of individuals and can be considered one example of the sustainable use of forest resources. However, in most cases basic ecological information, such as distribution and abundance of the species is unknown, as is information on the ecological implications of human impacts, such as leaf harvest and livestock grazing. In the tropical dry forests of northwest Mexico, leaves from the threatened palm *Brahea aculeata* are harvested for roofing material and represent an important NTFP. In this study, we assessed the distribution and abundance patterns of this species across 52 plots in the tropical dry forest of Sierra de Álamos-Rio Cuchujaqui Reserve (SARCR) in Sonora, Mexico. We also evaluated patterns of leaf harvest and cattle browse intensity on palm populations. We found that *B. aculeata* density is highly variable across the landscape with a mean (±SE) of 121.7 ± 36.3 ha^{-1}. Results indicate that *B. aculeata* is primarily distributed near to arroyos and rivers. The highest densities were found in sites with low incidence radiation (<0.06 MJ cm^{-2}) and narrow stream width of arroyos/rivers (<9.5 m). Palm abundance also varied within the plots, and *B. aculeata* attained its highest densities near to the arroyo edge (first 20 m from the edge), perhaps indicating a microhabitat effect on palm demography. Overall, fewer than 6% of the stems were seedlings. Leaf harvesting and browsing appear to affect demographic vital rates of the species; specifically we found a significant effect of harvesting and browsing activity on the proportion of reproductive active adults. Thus, low levels of seedlings in the populations may be the result of reduced fruit production by adults and higher mortality rates of seedlings due to livestock herbivory. Result from interviews with land owners also indicated that past land use, especially along arroyos might also have important impacts on the observed distribution, low densities and absence of recruitment in some areas. We believe current distribution and abundance of NTFP, such as *B. aculeata* at SARCR may be a result of combined effects of environmental factors and human impacts. Results from this study will be used to develop appropriate conservation, management and restoration plans of *B. aculeata* in the area.

1. Introduction

Thought to have low impacts on plant populations and ecological communities, the extraction of non-timber forest products (NTFPs) has been suggested as a good ecological and economic option for sustainable development. The extraction of NTFP can contribute to the livelihood and welfare of people living in or near to forests and is thought to be less ecologically destructive. Therefore, the use of NTFP has great potential in the conservation of natural resources and rural development, particularly in and around protected areas, where other development/land use activities are often constrained (Zuidema, 2000; Arnold and Perez, 2001).

Palms exemplify NTFPs potential as they represent a very important botanical family throughout the tropics and subtropics, providing food, building material, medicines, fibers, oils and more for subsistence, commercial and cultural uses (Joyal, 1996a; Henderson et al., 1997). Palm leaf harvesting rarely results in the immediate death of individual palms and has been considered a great opportunity for sustainable use of forest resources (Oyama and Mendoza, 1990; Endress et al., 2004; Zuidema et al., 2007). However, only in certain cases harvesting has been evaluated and for many species we lack information on the ecological impacts of harvesting and whether extraction is sustainable. The effects of harvesting on palms depend on the intensity, frequency and dura-

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tion of harvesting. Thus, single or few removals of leaves had no negative effect and even increases in growth and leaf and fruit production has been reported (Oyama and Mendoza, 1990; Anten and Ackerly, 2001). However, over time, this can change as effects accumulate and as demonstrated in several studies, the sustained harvest may have important effects in the demographic vital rates and in the population growth rate (Endress et al., 2006; Martinez-Ramos et al., 2009). For many palm species used as NFTP, basic information such as distribution, abundance and their conservation status is unknown even in areas where their populations are exploited (Ticktin, 2004).

Often, NTFP have been extracted without management plans based on ecological data. For example, the palms *Geonoma macrostachya*, *Euterpe edulis* and *Mauritia flexuosa* have been exploited for leaves, stems and fruits, and resulted in negative impacts on harvested populations (dos Reis et al., 2000; Zuidema, 2000; Svenning and Macia, 2002; Zuidema et al., 2007; Holm et al., 2008). As a consequence, these practices have diminished their populations and their long-term conservation is compromised.

We believe that one of the prerequisites for implementing sustainable harvest management programs, especially for species that are suspected to be declining in abundance or are threatened by anthropogenic activity, is an understanding of their distribution, abundance, conservation status, and response to harvest. This information is particularly essential for *Brahea aculeata*, as this palm species represents one of the more important non-timber forest products in the Northwest Mexico tropical dry forest. Furthermore, due to over-exploitation, habitat conversion and its restricted range, it is considered a threatened species and it is listed in the Mexican and IUCN Red List (Quero, 1998; Felger et al., 2001; SEMARNAT, 2002).

In the mountains of southern Sonora, Mexico, leaves of *B. aculeata* are harvested for thatching roofs. *B. aculeata* and another palm, *Sabal uresana*, whose leaves are used to make baskets and other handicrafts represent the two most important NTFP in the area (Joyal, 1996a,b), but harvest pressure is intense and may be negatively affecting palm populations. In addition, the use of unplanned silvopastoral systems in the region, where livestock graze throughout the forest, has resulted in overgrazed areas, and the evergreen nature of *B. aculeata*, uncommon for trees in the tropical dry forest, seems to lead to intense browsing on *B. aculeata* during the long dry season (8 months with monthly rainfall <100 mm) (Borchert et al., 2004; Vasquez-Leon and Liverman, 2004).

Within the Sierra de Álamos-Rio Cuchujaqui Reserve (SARCR), *B. aculeata* is patchily distributed and its abundance varies throughout the area. For palms in humid environments, previous research has demonstrated that distributions of palms are strongly influenced by microhabitat heterogeneity, especially topography and edaphic factors (Clark and Clark, 1995; Svenning, 1999; Svenning et al., 2009). For dry forest and arid environments, microhabitat heterogeneity has also been documented as one of the more important factors influencing plant populations and communities as a result of limitations imposed by lack of water and high temperatures (Arriaga et al., 1993). Therefore, we hypothesize that the distribution and abundance of *B. aculeata* is shaped by microhabitat. Moreover, palms may respond to harvest, browse or other disturbance events differently under different microhabitat conditions. This ecological information is critical not only to determine the main environmental factors affecting its distribution, but it will also help inform management plans. The study of microhabitat can help identify those areas with higher densities where extraction can occur and areas requiring protection and/or restoration (Lopez-Toledo et al., 2011).

In this study, we collected basic ecological data to inform the conservation and sustainable use of *B. aculeata*. We assessed the distribution and abundance patterns of this species in the tropical dry forest of Sierra de Álamos-Rio Cuchujaqui Reserve (SARCR) in Northwest Mexico and evaluated the factors affecting its distribution and abundance. Additionally, we estimated the harvest and browse impacts on palm populations across the landscape. Results from this study will be used to better understand the factors affecting *B. aculeata* abundance, distribution and stage structure and develop appropriate conservation, management and restoration plans.

2. Materials and methods

2.1. Study site

The study was conducted in the Sierra de Álamos-Rio Cuchujaqui Reserve, a 92,890 ha protected area in the northern Mexican state of Sonora (Fig. A of Appendix). SARCR is part of Mexico's network of natural protected areas and is also recognized by the UNESCO Man and the Biosphere Program (UNESCO). While the Reserve is a federally recognized protected area, nearly 60% of the land remains private property. Elevations range from 300 to 1600 m asl and gives rise to a vegetation gradient ranging from tropical deciduous to pine-oak forest. Nearby meteorological stations indicate annual rainfall in the area is highly variable with a mean of 650 mm and 190 and 1120 mm as the lowest and highest records between 1940 and 2005. The 8-month dry season (November to June) is very pronounced, receiving only 25–35% of the total annual rainfall, and many intermittent rivers and arroyos dry out during this time. Mean annual temperature is 21–22 °C with 10 °C and 41 °C as minimum and maximum temperatures. Our study was focused within the upper watershed of the Cuchujaqui River, focusing on five properties part of Rancho Ecológico Monte Mojino (REMM) and one private property. REMM is owned and managed by Nature and Culture International (NCI). As part of its mission, NCI has acquired land within SARCR to conduct conservation, applied research and community development (Fig. A of Appendix).

2.2. Study species

B. aculeata (Brandegee) H.E. Moore (basionym of *Erythea aculeata* Brandegee) is a solitary-trunk palm with hermaphrodite reproduction. It has flabellate leaves with palmate lamina and large inflorescences (100–150 cm length). *B. aculeata* is an endemic palm species native to northern Mexican states of Sonora, Sinaloa, Chihuahua and Durango. It has a patchy distribution and can be found in a range of habitats, from sunny mountains slopes, to shadier areas along arroyos and canyon bottoms in tropical dry forest and lower oak and pine-oak woodlands among 300–1500 m asl. In the tropical dry forest of SARCR, *B. aculeata* grows up to 10 m in height and 25 cm in diameter (Quero, 2000; Felger et al., 2001). *B. aculeata* is listed in the IUCN Red List as "Vulnerable" (A1c) and as "Endangered" in the Mexican Red List (Quero, 1998; Felger et al., 2001; SEMARNAT, 2002).

2.3. Management of *B. aculeata*

In the area of SARCR, leaf harvest is intense as leaves are harvested and used for thatching roofs and many other products both locally and in the tourist resorts along the coast of Sonora (Joyal, 1996a). Depending on the quality of the roof 10,000–20,000 leaves are required to thatch a 20 m × 20 m roof. Spear leaves are also harvested as part of the thatching process (they are used to tie the leaves to the roof) and also used in the construction of some handicrafts. In the region, some property owners sell between 20,000 and 100,000 leaves every year. For harvesting, the *palmilleros* (people harvesting leaves) use a machete for short palms and a hook for large palms cutting all mature leaves as well as 1–2 spear leaves. As described in previous studies, depending on the ecological and traditional knowledge (Joyal, 1996b) of *palmillero* 0–2 leaves are left in the palm. During harvesting the meristem, dead leaves and reproductive structures can be damaged or cut. Heavy damage to the meristem might also cause the death of the palm.

2.4. Sampling design

To explore the distribution, abundance and population patterns of *B. aculeata* at the Sierra de Álamos Reserve, we generated random sample points with 200 m or greater spacing along stream drainages occurring within the six study-area properties using ArcGIS 9.2. Spatial data came from the Instituto Nacional de Estadística y Geografía e Informática, and random points were generated using Hawth's Analysis Tools (spatialecology.com) (INEGI, 2000). At each point, three 4 m × 50 m transects, separated by 10 m were established from the 'greenline' (bank-full stage of the stream or arroyo) perpendicular to the arroyo. This resulted in a total of 600 m^2 sampled at each point. In total, 52 points were sampled with a total area sampled of 3.12 ha. Sampling was completed between January and March of 2010, which represent the flowering–fruiting season of *B. aculeata.*

Each 4 × 50 transect was divided into five 10 m × 4 m segments. For each 10-m long segment along the transects, we recorded the following environmental variables: forest canopy height, slope, and number of tree species > 10 cm DBH (grouped into columnar cacti, *Quercus* spp., *Lysiloma watsoni*, *Bursera* spp. and "Others" which included the rest of species). Additionally, we measured stream width (of the river or arroyo) and plot aspect. With plot aspect and slope we estimated the potential annual direct incident radiation (MJ cm^{-2} year) following the equations proposed by McCune and Keon (2002), with the correction of McCune (2007). For each palm rooted within the plot we recorded the stem's distance from the arroyo edge, length (m), diameter at the base of the trunk (root crown), number of leaves (alive and dead), the number of spear leaves, number of cut leaves (evidence of past harvest), reproductive status (based on presence of reproductive structures), evidence of browse damage (number of browsed leaves), and number of fruits. We measured stem length of palms as opposed to their height because many palms have curved stems and grow horizontally from the slopes for several meters before growing upward. Thus, their length is more representative of their size than height.

2.5. Data analysis

2.5.1. Distribution and abundance

Abundance data of *B. aculeata* was analyzed using two independent and complimentary methods: (i) classification and regression trees (CART analysis) and (ii) multiple regression generalized linear model (MRGLM). We used CART analysis to evaluate the structure of the relationships among abundance and the environmental variables. CART analyses are nonparametric models, which use binary recursive partitioning on the dataset. The data are successively split along coordinate axes of the explanatory variables so that, at any node, the split which maximally distinguishes the response variable is selected. Splitting continues until nodes are pure or the data are too sparse. Each explanatory variable is assessed, and the variables explaining the greatest amount of deviance in *y* are selected. Deviance is calculated on the basis of a threshold in the explanatory variable; this threshold produces two mean values for the response one above and the other below the threshold. For continuous variables CART estimates model fit by calculating r^2 which is a percentage of the variance explained by each split (De'Ath and Fabricius, 2000). We conducted CART analyses to identify the most important variables explaining the abundance of *B. aculeata* in SARCR. These analyses were performed using the 52 plots testing all the environmental variables (direct incidence radiation, stream width, canopy height, and the number of tree species in the plot (*Quercus*, *L. watsoni*, columnar cacti, etc.). The property where each plot was located was also included as another variable since land use activities can vary along property boundaries. There were between 9 and 15 plots per property. We conducted CART analyses using the Tree package version 1.0-28 (Ripley, 2010) for R version 2.10.0 (R Development Core Team, 2009). Cross validation was conducted to select the classification tree size and estimate error rates for trees of a given size.

Our second type of analysis, MRGLM, is more appropriate when variance in the response variable is not constant and when errors are not normally distributed (Crawley, 2007), as was the case of our response variable, the number of palms. We conducted the MRGLM in the statistical package R 2.10.0 using a Poisson error and a logarithmic link function (R Development Core Team, 2009). For this analysis, direct incidence radiation and stream width were log transformed to meet normality assumptions on the explanatory variables (Faraway, 2005; Crawley, 2007).

To evaluate if palm density is affected by the microhabitat provided by the edge of arroyos and proximity to water, we explored the relationship between the density of palms in each 10-m sections and distance from the arroyo to each 10-m section. Similarly, we explored the relationship between distance from the arroyo edge and the proportion of reproductive active adults (estimated as the number of reproductive palms divided by the total number of adults) as well as the amount of fruit produced per segment. These data were analyzed by fitting generalized linear models (GLM) using the R version 10.0. We used the distance 10-m sections (DIST) as a fixed effect. For the palm density and number of fruits we used Poisson errors and a logarithmic link function. Proportion of reproductive active adults was analyzed as a binary response variable (reproductive vs. non-reproductive for every plot) with binomial errors and a logit link function.

2.5.2. Population patterns

To explore population patterns of *B. aculeata* we conducted (i) a population structure analysis and (ii) evaluate reproductive traits at each of the properties studied. Population structure analysis was conducted classifying palms based on leaf morphology, reproductive status, and stem length: seedlings (stems with 1–3 singles blades with no leaflets and ≤2 cm stem height), juveniles (non reproductive stems 2.1–25.0 cm stem length), and adults (which are potentially reproductive stems of varying length: Ad1 (Adults1: 25.1–100 cm); Ad2 (Adults2: 100.1–250 cm); Ad3 (Adults3: 250.1–400 cm); Ad4 (Adults4: >400.1 cm). We examined the population structure for the overall population in SARCR, and for each of the six properties studied since their land use histories (clearing, ranching, harvesting, etc.) vary along property boundaries.

We tested if the proportion of reproductive active adults differs between properties and if the difference correlates with harvest or livestock browse activity. First, we compared differences in proportion of reproductive active adults among properties with a GLM. Proportion or reproductive active adults was analyzed as a binary response variable with binomial errors and a logit link function. Next, as a measure of harvest and browse pressure (HBP) among the properties, we evaluated the proportion of palm stems in a plot that were damaged either by (i) harvesting, (ii) browsing or (iii) both. These proportions were analyzed as a binary response variable with binomial errors and a logit link function. In these analyses property (PROP) and harvest–browse pressure (HBP) were used as fixed factors. We then examined the relationship between the proportion of stems damaged, either by (i) harvesting, (ii) browsing and (iii) harvesting–browsing pooled together, and proportion of

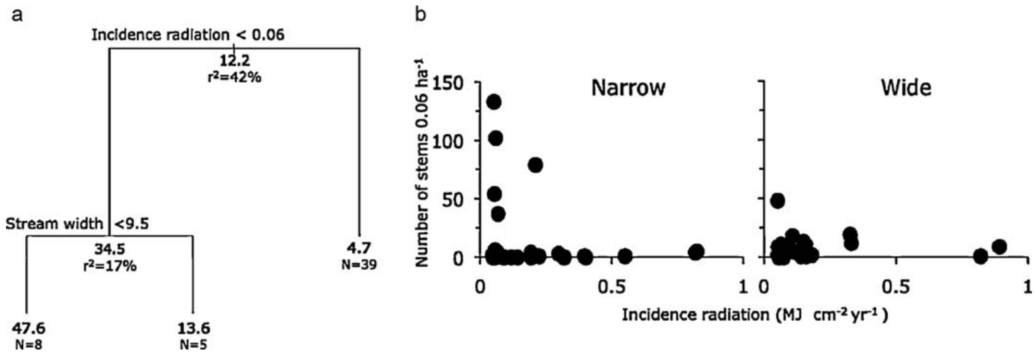

Fig. 1. Distribution and abundance of *Brahea aculeata* at Sierra de Álamos Reserve, Sonora, Mexico. (a) Classification tree for *B. aculeata* stems. The labels at each split indicate the explanatory variables used in the model, the mean number of stems (bold numbers), number of plots at each split (*N*) and the proportion of variance explained by the split (r^2). The tree explained (r^2) 59% of the total variance. (b) Relationship of density of *B. aculeata* stems and incidence radiation at two different stream widths: narrow (≤9.5 m stream width) and wide (>9.5 m stream width).

Table 1
Results of the multivariate regression model for the abundance of *B. aculeata* at Sierra de Álamos, Sonora, Mexico. The explanatory variables included in the model were log transformed to meet the criteria of the model. *B*: coefficient, SE: standard error, *t* and *p* refer to the statistical significance of the variable in the model.

Predictors	*B*	SE	*t*	*p*
Intercept	5.39	0.593	9.09	<0.001
Incidence radiation	−0.83	0.13	6.34	<0.001
Stream width	−0.31	0.13	2.26	<0.02
Interaction	0.17	0.06	3.17	<0.001

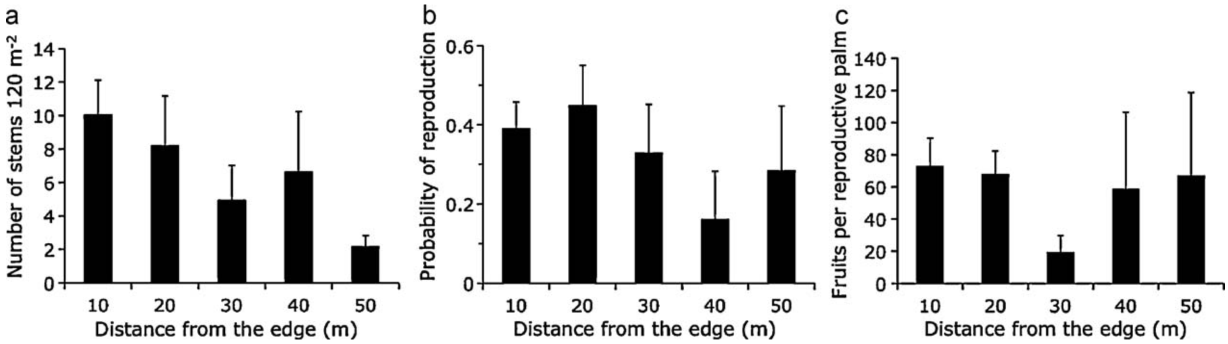

Fig. 2. Distribution and reproductive patterns of *B. aculeata* within the plot in relation to water streams (a) mean number of stems per 10 m section, (b) proportion of reproductive adult stems per 10 m section and (c) number of fruits per reproductive palm per 10 m segment.

reproductive adults. For browsing analysis we used (i) stems <2 m height, which represent stems accessible to cattle and (ii) all stems.

2.5.3. Palm management and land use

Cultivation along arroyos, cattle grazing and leaf harvest in the past may influence current patterns of abundance and population structure and condition of *B. aculeata*. To explore this we conducted interviews with the current and past landowners, land managers, tenants and *palmilleros*. For each property we interviewed 2–3 current or past landowners or land managers. We conducted semi-structured interviews to determine the duration and intensity of (i) agriculture, (ii) livestock ranching and (iii) leaf harvesting for each property. We then related this information to data from our plots, including palm density, population structure, and the number of living and dead leaves per palm (evidence of present and past harvest).

3. Results

3.1. Distribution and abundance

Of the 52 plots sampled, 73% (38) had *B. aculeata* stems. Density of *B. aculeata* across the six sampled properties was highly variable. The smallest and largest densities were found at El Guayabo and Los Llanos with a mean density (mean ± SE) of 13.3 ± 5.4 and 1250 ± 450 individuals per ha, respectively. The CART analysis indicated incidence radiation and stream width were the two variables that best explained the abundance of *B. aculeata* across the landscape, explaining 59% of the total variation (Fig. 1a). The remaining environmental variables did not explain significant variation and were not included in the final model. Specifically, CART analysis identified that the highest abundances of *B. aculeata* are found at localities with low incidence radiation (<0.06 MJ cm^{-2}). This analysis further split low incidence radiation plots in localities with differences in stream width. Areas with narrow arroyos had higher number of palm stems (Fig. 1a). A further relationship between the density of stems/plot and incidence radiation width showed clearly the highest densities at arroyos (stream < 10 m) and very low at rivers with wider widths (Fig. 1b). Results from the MRGLM model supported the CART findings and indicated that incidence radiation, stream width, and their interaction were significant (Table 1).

Palm abundance also varied within the plots. Specifically, we found a significant relationship between the distance from the edge of the water stream to the 10-m segment and the number of palm stems (DIST: $\chi^2 = 74.9$, $df = 5$, $p = 0.04$; Fig. 2a). The highest abundances were found in segments nearest the stream. By contrast, the

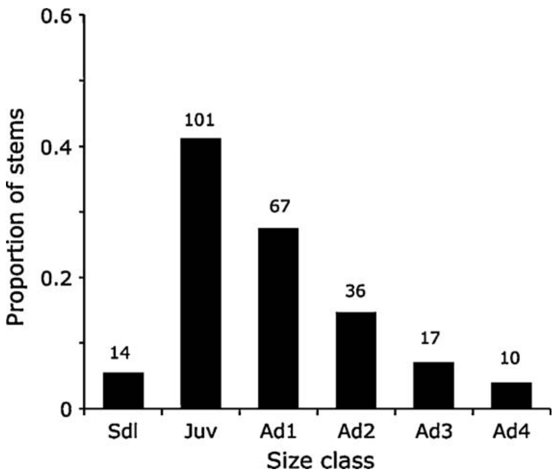

Fig. 3. General population structure of *Brahea aculeata* at the Sierra de Álamos Reserve in six size classes. The bars and the numbers above the bars represent the percentage and the number of individuals in each size class, respectively. Individuals were assigned to one of six size classes of stem length: sdl (seedlings: 1–2 cm with single blades); Juv (juveniles: 2.1–25 cm no reproductive); Ad1 (Adults1: 25.1–100 cm); Ad2 (Adults2: 100.1–250 cm); Ad3 (Adults3: 250.1–400 cm); Ad4 (Adults4: >400.1 cm). Adults are reproductive individuals.

variation in proportion of reproductive active adults was high and there was not any relationship with distance from the edge to the 10-m segment (DIST: $\chi^2 = 3.4$, *df* = 5, *n.s.*; Fig. 2b). Fruit production was also variable with the lowest seed production at intermediate distances, which produced the significant differences indicated by the GLM (DIST: $\chi^2 = 34.9$, *df* = 5, $p < 0.001$; Fig. 2c).

3.2. Population patterns

Pooling the data from all transects showed that its population is dominated by adults in different stages accounting for 53% of the population, while 41% were juveniles and only a few seedlings (6%). Seedling density was only 14 seedlings/ha. The most abundant size class was juveniles with 101 stems/ha (Fig. 3). Analyzing by property indicated low seedling recruitment in all properties, with ≤20% of the stems were seedlings for each population. With exception of El Guayabo, all populations included stems in each of the size classes. However, there were large differences in adult (Ad1–Ad4) density with a range from 10 to 791 stems/ha (mean = 231.6). Los Llanos was the population with the highest number of stems in all size classes. The Palmarito population has similar number of stems through all size classes. At El Guayabo we recorded the lowest number of stems, with no stems at Ad1 and Ad2 recorded (Fig. 4). In general, in all properties we found individuals with harvest and browse damage, although browsing was higher in Los Llanos, where a high proportion of palms had evidence of both harvesting and browsing. Harvesting is concentrated in size classes that have harvestable leaves: juveniles and adults. By contrast in the properties with livestock, damage is concentrated on individuals <200 cm height, including seedlings, juveniles, and smaller adults (Fig. 4).

We found differences in proportion of reproductive active adults between the properties (PROP: $\chi^2 = 24.5$, *df* = 5, $p = 0.04$) with the lowest probability at Los Llanos with a mean (±1 SE) of 12 ± 1% and the highest at Palo Injerto with 50 ± 18% (Fig. 5a). In general, we found differences in impacts between properties (PROP: $\chi^2 = 74.9$, *df* = 5, $p = 0.04$), being harvesting higher than browsing (HBP: $\chi^2 = 68$, *df* = 5, $p = 0.04$). We found a significant interaction PROP–HBP ($\chi^2 = 46.9$, *df* = 5, $p < 0.001$) indicating that the proportion of stems damaged either by harvesting/browsing varied depending on the property (Fig. 5b). For example, we found evidence of cut leaves in all the six properties with the lowest values at Palo Injerto and the highest at Los Llanos, while browsing was lower than harvesting at most properties, with exception of Los Llanos where more than 50% of stems were damaged. At El Guayabo we did not find any evidence of browsed leaves (Fig. 5b). Browsing was found to be concentrated on small stems (<2 m), such as seedlings, juveniles and small adults.

Data suggest that harvest pressure is likely to be responsible for the low proportion of reproductive adults and this was especially the case for harvesting alone and harvesting and browsing combined, but not browsing (Fig. 5c and d). This makes sense since browsing is restricted to smaller size classes such as seedlings, juveniles and small adults (below the browse line of approximately 2 m), most of which are non-reproductive. Los Llanos had the highest level of harvesting and livestock proportions and the lowest proportion of reproductive adults. By contrast, Palo Injerto had the lowest proportion of harvested or browsed palms, but the highest proportion of reproductive active adults (Fig. 5).

3.3. Palm management and land use

We found that in the area, commercial harvesting of *B. aculeata* has been carried out for at least 50 years. Our interviews indicate that *palmilleros* harvest depending on the availability of leaves, they cut from two to 30 leaves from a single palm. As previously reported by Joyal (1996b) we found that *palmilleros* harvest based on their ecological and traditional knowledge. In general, local *palmilleros* (residents of the Reserve) harvest differently than harvesters who come from nearby cities. For example, local *palmilleros* leave at least 2 fully expanded leaves when harvesting, which they indicate are left to help the palm recover. Additionally, they will not harvest a spear leaf (used for tie the leaves on the roof or for handcraft making) unless two are present, thus leaving a palm with at least two leaves and one spear leaf after harvest. By contrast, outside harvesters completely defoliate palms and take all spear leaves present on the palm. There are also differences in harvest frequency, with local *palmilleros* harvesting only once a year (during the wintertime), and outsider *palmilleros* harvesting up to twice a year in a single population. *Palmilleros* indicated that leaves are harvested from stems varying in height from 30 cm to 8 m. All sources concurred that improper cutting might cause palm death. Harvesters indicated that older leaves with large blades are most desirable, and several indicated that over harvesting or browsing results in leaves with smaller blades, decreasing their quality for thatching.

Palm management in the past differed between properties. For example, at Sotorijaqui, Lajas and Palo Injerto harvesting was carried out only occasionally or at a very low intensity during 1970–2000. By contrast, at Los Llanos there has always been very intensively harvested; in the 1960s about 600,000 leaves were harvested annually from this single property, and now this amount has been reduced by 80–90% as indicated by owner and harvesters. This drastic decrease in harvest is mainly a result of the reduction of the palm population, but may also be a result from a decline in commercial demand. In a single area leaves are harvested only once a year, although at Los Llanos harvesting has occasionally occurred twice a year. Harvest occurs in the fall-winter (November through February) when, according to the traditional knowledge of local *palmilleros*, leaves are mature enough and can last for longer time on thatched roofs. In some areas harvesting happens year-round mainly to demand along the coast.

Another land use, subsistence agriculture, occurred in the SARCR region in the past, and slash and burn were common practices. Currently agriculture is not practiced in areas with palms, however, before reserve declaration (1996), many areas along arroyos were cleared annually for agriculture, although big trees and palms were often left. At some properties, including Sotorijaqui, agriculture was never or rarely practiced. Cattle ranching is also a common prac-

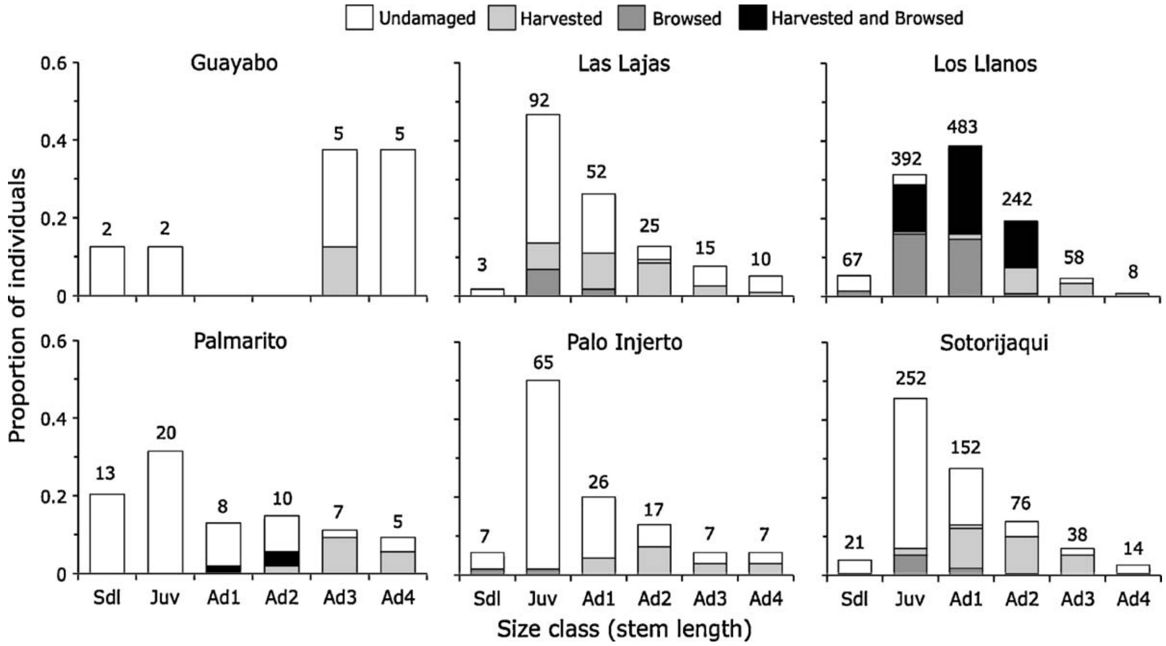

Fig. 4. Population structures of *Brahea aculeata* at SARCR. The bars indicate the proportion of individuals in six different length size stages: sdl = seedlings, Juv = juveniles, Ad1–Ad4 = Adults1 to Adults4. Numbers above the bars represent the density of individuals per hectare in each size class. The colours within the bars indicate the proportion of undamaged, harvested, browsed and harvested and browsed individuals in each of the size classes. Density of individuals were calculated with the sum of the plots from each property and then estimated per ha.

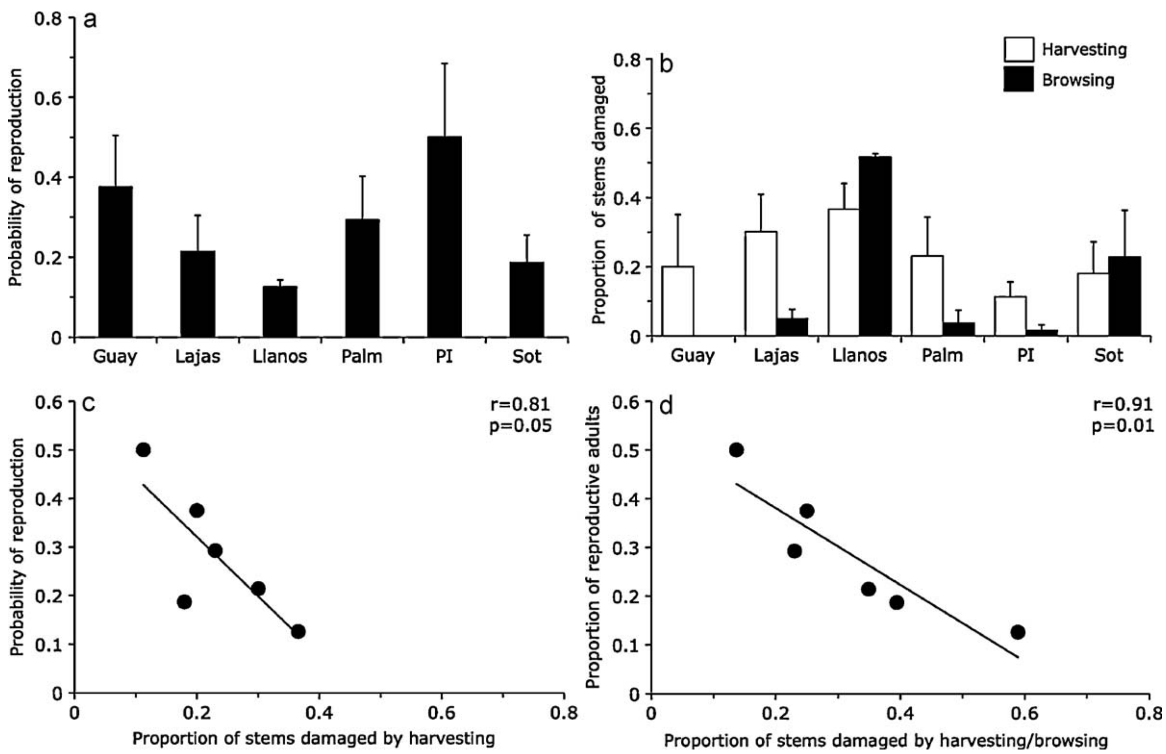

Fig. 5. Effect of harvesting and browsing on the proportion of reproductive active adults of *Brahea aculeata* in Sierra de Álamos, Sonora, Mexico. (a) Proportion of reproductive stems at each property, (b) proportion of stems damaged by harvesting and browsing, (c) relationship of stems damaged by harvesting and proportion of reproductive individuals and (d) proportion of stems damaged by both harvesting and browsing versus proportion of reproductive active adults. The abbreviations in the *X*'s axis referee to the properties: Guay = El Guayabo, Lajas = Las Lajas, Llanos = Los Llanos, Palm = Palmarito, PI = Palo Injerto and Sot = Sotorijaqui all located within the Sierra de Álamos-Rio Cuchujaqui Reserve.

tice. Owners/ex-owners used to run about 50–150 head of cattle on their properties, and some farmers cleared the forest for pastures. Most kept cattle in the forest, as silvopastoral system, the whole year round, even during the dry season. Cattle are kept in the same area for 2–5 months depending on food availability. During the dry season, cattle diet is complimented with fodder. Additionally, cattle browse on *Brahea* <2.0 m tall; this palm is one of the few evergreen species in the region. Cattle eat the blade of most available leaves. Additionally, they might trample and kill seedlings. We found that all the six properties had livestock for at least 50–60 years, but

Table 2
Land use (agriculture and livestock ranching) and *Brahea aculeata* management on the six properties studied. Palm density/ha, alive and dead leaves per palm are also presented. Values represent mean values ± 1 SE.

Property	Agriculture	Livestock ranching	Palm leaf harvesting	Palm density	Number of leaves	
					Alive	Dead
El Guayabo	High	Medium	Low	13 ± 5	17.8 ± 4.2	18.3 ± 5.1
Las Lajas	Low	Low	Low	399 ± 126	10.5 ± 0.6	10.2 ± 0.7
Los Llanos	None	High	High	1250 ± 450	5.2 ± 0.3	4.6 ± 0.2
Palmarito	High	Medium	Medium	64 ± 18	10.4 ± 1.3	11.1 ± 1.6
Palo Injerto	High	Low	Low	130 ± 68	9.5 ± 0.8	7.1 ± 1.1
Sotorijaqui	None	Low	None	555 ± 299	10.1 ± 0.4	9.1 ± 0.6

at the moment only Los Llanos has them. The rest of the properties, now owned by NCI, are cattle free with the exception of cattle from surrounding properties occasionally entering the properties, likely causing incidental seedling damage. In general, properties with intensive management, either from cattle, agriculture or leaf harvesting, currently have low palm stem densities and lower number of alive and dead leaves (Table 2), although palms at Los Llanos are still abundant.

4. Discussion

4.1. Distribution and abundance

Several studies have demonstrated the strong effects of environmental factors, such as topographic and edaphic atributtes, on palm species distribution, especially in humid forests (Clark and Clark, 1995; Svenning et al., 2009). The highly variable distribution and abundance of *B. aculeata* in the Sierra de Álamos indicates the significant environmental variability found in tropical dry forests (Arriaga et al., 1993). River edges and arroyos are important environments for some species as they provide humidity and shade, which protect them from solar radiation, and excessive water loss. For palms, these environments might provide a good microhabitat for germination and early establishment and this microhabitat can be one of the factors contributing to higher *B. aculeata* densities at the river and arroyo edges (Fleury and Galetti, 2004). However, *B. aculeata* density had high variation and was absent in some localities within the same properties even with very similar environmental characteristics, which indicates the effects of other variables. This result and the low explained variation of the abundance CART analysis indicate that effectively there are other variables which were not considered in this study. Here we propose some other factors, which may be affecting the abundance and local distribution of *B. aculeata* causing higher abundances near to arroyos and streams.

One of these factors might be related to post-dispersal seed removal. For *Brahea armata* in Baja California, a species found in similar environments, it has been suggested that the presence of nurse plants and canyon physiography has the potential to affect post-dispersal seed removal activity patterns by rodents, as well as to provide vital protection for palm seedling establishment from the floods of the rainy season (Wehncke et al., 2010). In the case of *B. aculeata* in our study, the highest density of stems was in nearest distances to rivers and arroyos in spite of similar fruit production and probability of reproduction along the plot. This pattern might be a result of the excessive runoff in the rainy season, which might drag the seeds to the bottom of the canyon structuring the distribution patterns we found.

An additional explanation to the higher abundance of stems nearer to the edge of rivers and arroyos in the plots may be a potential microhabitat effect. This pattern might be a consequence of higher soil moisture availability and shade, as well as lower temperatures. In fact, in a experiment recording temperature and humidity along the same plot design in six different sites within SARCR, we found lower temperatures and higher relative humidity in distances near to the edge of rivers and arroyo (Lopez-Toledo et al., *unpublished data*). Additionally, informal excavations at the edge of rivers revealed that important stream groundwater are found no more than 30 cm deep even during the dry season. We believe these micro-environmental factors may be related to the measured distribution patterns of *B. aculeata*.

Finally, as we discuss in the next section, it is likely that land use, browsing and harvesting have had important effects on the species. Therefore, as it has been described in other species, not only the present distribution and abundance, but the demographic patterns of the species should be looked as a result of the interaction between environmental factors and human impacts (Olmsted and Alvarez-Buylla, 1995; Pulido and Caballero, 2006). We should remark that more research is needed to better understand and distinguish the effects of the human and environmental factors and their interaction on the distribution and abundance of plant species (Godínez-Alvarez et al., 2008).

4.2. Population patterns

Environmental, and specifically microhabitat factors and may also contribute to the high variability in population structure of *B. aculeata* across the study area. Yet irrespective of this variability, the most remarkable finding is that all populations have very low numbers of seedlings. Density and the developmental stage of individuals at each site may give us a broad idea on how the species is regenerating (Medel-Narvaez et al., 2006; Pulido et al., 2007). For example, for long-life cycle species, such as *B. aculeata*, a large amount of seedlings and juveniles in their population can indicate a stable population with sufficient regeneration, giving the demographic structure the form of an inverted "J" (Condit et al., 1998). By contrast, populations with poor regeneration (low numbers of seedlings) or with discontinuous distributions (i.e., entire size or age classes without a single individual) may be interpreted as populations in decline or affected by strong disturbances. Our results indicate that under the current conditions, *B. aculeata* fits roughly the second scenario, likely indicating a stressed population. This damage might be a result from past land use and current harvesting and browsing practices. As indicated by the results, harvest reduces reproduction and probably growth and survival of adults, while browsing mostly impact seedling and juvenile survival, similar to that found in *Chamaedorea radicalis* (Endress et al., 2004). Some properties studied, such as Los Llanos, have been subjected to harvest and browse for a long time. Additionally in some of the properties, semi-intensive agriculture was also very important 30–40 years ago and therefore it is reasonable to think that these human impacts may have had an important impact on distribution, abundance, and population structure of *B. aculeata* (Vasquez-Leon and Liverman, 2004).

In a demographic study in crop fields of the Yucatan Peninsula with *Sabal yapa*, a palm species with a similar life cycle to *B. aculeata*, Pulido et al. (2007) found that lack of regeneration and low seedling survival is the main factor contributing to a negative population growth rate. By contrast, in the undisturbed forest high densities of seedlings and a growing population rate were found (Pulido et al., 2007). Given the single time frame of our study, we cannot conclude that *B. aculeata* population is decreasing. However, these preliminary results likely indicate that if current conditions continue, the future of *B. aculeata* might be compromised. Therefore long-term studies are required, especially those indicating the effect of leaf harvesting, browsing and the interaction of these two factors on demographic vital rates and population dynamics.

The effects of harvesting on palms depend on the intensity, frequency and duration. For example, in a classic defoliation study, the single removal of leaves had no negative effect (Oyama and Mendoza, 1990). Even more, an overcompensation response (Anten and Ackerly, 2001) leads to reports of faster growth or leaf production and increases in fruit production. However, over time, this can change as effects accumulate and this may be the case of *B. aculeata* in Sierra de Álamos (Endress et al., 2006). As demonstrated in several studies, the sustained harvest has important effects in the demographic vital rates and in the population growth rate. Specifically in *B. aculeata*'s case sustained harvesting over a long time period (at least 50 years) might be one of the responsible factors contributing to reduced seedling density (Endress et al., 2006; Martinez-Ramos et al., 2009). We did not detect any relationship among harvesting intensity and fruit production, but it is likely that continuous leaf harvesting might have an impact on fruit production or seed viability. Consequently harvesting might affect the number of recruitment seedlings and this can contribute to shape the current population patterns observed. Again, with the data collected in this study, we cannot conclude the sustained harvesting is having effects on the demographic patterns of *B. aculeata*. Nevertheless, our findings suggest that population structure and reproductive patterns observed reflect in part the long-term effects of harvesting and browsing, and more research is needed to clarify the effects of harvest and browse on palm demography and population dynamics.

4.3. Palm management and land use

Based on our interviews, it seems that historic and current human activities such as palm management and the land use, likely have had an important effect on current *B. aculeata* distribution, abundance, and population structure in the area. Unfortunately, we have information of land use and palm management only at the property level and not at plot level. Therefore we were not able to use this information in the CART analysis or conduct any further analysis, except those from Table 2. However, it is reasonable to believe that intensive long-term palm management and land use have had a significant effect on the distribution and abundance of *B. aculeata*. Management or any human modifications are likely to have strong negative effect on populations and ecosystems (Bawa et al., 2004). For the case of *B. aculeata*, which has been used commercially for about 50 years (and used locally even more) in this area, human impacts may have affected its distribution and population patterns, in a manner similar to many other species. For example, for *S. yapa* from the dry forest in Yucatan Peninsula, the shifting cultivation landscape (cultivation areas, fallow and forest) has a significant impact on the population structure and other parameters. In that study, variation in population structure and density was caused by mortality provoked by fire (Pulido and Caballero, 2006). Annual use of fire may have killed seedlings of *B. aculeata*, as some of the localities, especially at the edge of rivers and arroyos, were used for agriculture (Vasquez-Leon and Liverman, 2004). Local inhabitants argue that fire is good for *B. aculeata* because it provokes faster leaf production and higher quality leaves. Some palm species, such as *Sabal palmetto*, are fire tolerant and even fire stimulates growth. However, previous studies shows that fire provoke high mortality in seedlings because they are rooted close to the soil surface and had less leaf base insulation (McPherson and Williams, 1998). For other palm species, such as *S. yapa* and *Ptychosperma macarthurii*, it has also been demonstrated the negative effects of long-term fire on the demographic parameters and population dynamics (Liddle et al., 2006; Pulido and Caballero, 2006). We believe that for the case of *B. aculeata* repeated fire likely killed seedlings and small juveniles and this might be reflected in the population structures observed.

In addition, it is likely that livestock browsing has an effect on *B. aculeata* populations by trampling on seedlings, eating the leaf blade and sometimes uprooting whole individuals while chewing the leaves. A browsing experiment on *C. radicalis*, an understory palm species, found that browsing increased mortality in the population, with seedlings the most likely to die. Browsing also reduced flowering and fruit production in adult individuals (Endress et al., 2004). Therefore, it is likely that the population patterns we observed reflect a mix of the effects of environmental variables, leaf harvesting, and the silvopastoral system used in the Sierra de Álamos Reserve. It is probable that an absence of individuals in some life stage categories at El Guayabo and Palmarito is as a response to these factors. Persistent browsing could explain the absence of smaller size classes in populations such as seedlings, juveniles, and smaller adults (<2 m), since browsing on small *B. aculeata*, one of the few species in the forest that has evergreen leaves, can be very intense in the dry season.

The occurrence of severe droughts can strongly aggravate the negative effects of cattle grazing and leaf harvesting (Martinez-Ramos et al., 2009). This issue is of increasing importance as severe changes are expected under the present global climatic change scenarios (Walther et al., 2002). Records of precipitation and temperature in the Sierra de Álamos Reserve indicate that drought cycles are becoming more common (Lopez-Toledo et al., *unpublished data*) and they should be taken into consideration for future conservation and restoration programs.

As a general remark, we believe that more scientific research is needed to increase our knowledge about the anthropogenic effects on populations and tropical ecosystems. Thus, it is required to develop more techniques to work with local people and design studies to obtain key information, which help us to understand species patterns. We agree with previous requests for researchers and forest managers to work with local harvesters and ranchers in designing and evaluating management practices that can mitigate the negative effects of harvest and browsing and contribute to the conservation and sustainable management of the species (Bawa et al., 2004; Joyal, 1996b).

5. Implications for conservation and management

In this paper we provide information about the distribution and abundance patterns of *B. aculeata* in the SARCR and the factors that seems to be the more important drivers of these patterns. As expected, we found that distribution and abundance respond primarily to environmental factors, with higher densities in areas with lower incidence of radiation near rivers and arroyos. We believe this is related to soil moisture availability, shade, and lower temperature-factors that are especially important in the dry season. Additionally, historic and current palm, livestock, and land management also appear as important drivers of palm distribution, abundance and population patterns. Therefore we believed that distribution and population patterns for this species should be seen as consequence of interactions between environmental and human factors and this should be taken into consideration for future sustainable harvest, conservation and restoration programs.

The extraction of NTFPs has been considered to be a good option for forest conservation and welfare of forest inhabitants. Low seedling abundance, a strong negative relationship between defoliation (from people or livestock) and reproductive activity, and missing size classes of some populations suggest that current harvest and land management activities are negatively affecting *B. aculeata* populations. Alternative harvest techniques, such as those advocated by some local *palmilleros*, in addition to better livestock management to protect palms in the dry season may be warranted, and future research on sustainable resource management is needed. We believe that to achieve a successful conservation and management program of *B. aculeata* in Sierra de Álamos Reserve, a community development, conservation and restoration components should be included. Only after implementation of management plans can NTFP extraction play an important role in promoting conservation and human welfare.

As part of the conservation program, we suggest that the conservation status of *B. aculeata* should be reviewed. The Sonoran populations of *B. aculeata* studied seem to be in a higher risk than it is currently in the IUCN and Mexican Red List (Quero, 1998). Considering that *B. aculeata* is endemic to a small area in northern Mexico, the previous assessments indicating important deforestation rates in the SARC Reserve (FMCN, 2009) and the damages provoked by harvesting and the silvopastoral systems in the area, we believe the categorization of *B. aculeata* in the IUCN and Mexican Red List needs to be reviewed and updated.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at doi:10.1016/j.foreco.2011.02.013.

References

Anten, N.P.R., Ackerly, D.D., 2001. A new method of growth analysis for plants that experience periodic losses of leaf mass. Functional Ecology 15, 804–811.

Arnold, J.E.M., Perez, M.R., 2001. Can non-timber forest products match tropical forest conservation and development objectives? Ecological Economics 39, 437–447.

Arriaga, L., Maya, Y., Diaz, S., Cancino, J., 1993. Association between cacti and nurse perennials in a heterogeneous tropical dry forest in Northwestern Mexico. Journal of Vegetation Science 4, 349–356.

Bawa, K.S., Kress, W.J., Nadkarni, N.M., Lele, S., 2004. Beyond paradise – meeting the challenges in tropical biology in the 21st century. Biotropica 36, 437–446.

Borchert, R., Meyer, S., Felger, R.S., Porter-Bolland, 2004. Environmental control of flowering periodicity in Costa Rican and Mexican tropical dry forests. Global Ecology and Biogeography 13, 409–425.

Clark, D.A., Clark, D.B., 1995. Edaphic and human effects on landscape-scale distributions of tropical rain forest palms. Ecology 76, 2581–2594.

Condit, R., Sukumar, R., Hubbell, S.P., Foster, R.B., 1998. Predicting population trends from size distributions: a direct test in a tropical tree community. American Naturalist 152, 495–509.

Crawley, M.J., 2007. The R Book. John Wiley & Sons Ltd., Chichester.

De'Ath, G., Fabricius, K.A., 2000. Classification and regression trees: a powerful yet simple technique for ecological data analysis. Ecology 81, 3178–3192.

dos Reis, M.S., Fantini, A.C., Nodari, R.O., Reis, A., Guerra, M.P., Mantovani, A., 2000. Management and conservation of natural populations in Atlantic rain forest: the case study of palm heart (*Euterpe edulis* Martius). Biotropica 32, 894–902.

Endress, B.A., Gorchov, D.L., Noble, R.B., 2004. Non-timber forest product extraction: effects of harvest and browsing on an understory palm. Ecological Applications 14, 1139–1153.

Endress, B.A., Gorchov, D.L., Berry, E.J., 2006. Sustainability of a non-timber forest product: effects of alternative leaf harvest practices over 6 years on yield and demography of the palm *Chamaedorea radicalis*. Forest Ecology and Management 234, 181–191.

Faraway, J.J., 2005. Extending the Linear Model with R: Generalized Linear, Mixed Effects and Nonparametric Regression Models. Chapman & Hall, Boca Raton, Florida, p. 234.

Felger, R.S., Johnson, M.B., Wilson, M.F., 2001. The Trees of Sonora, Mexico. Oxford University Press, USA. Arizona.

Fleury, M., Galetti, M., 2004. Effects of microhabitat on palm seed predation in two forest fragments in southeast Brazil. Acta Oecologica: International Journal of Ecology 26, 179–184.

Fondo Mexicano para la Conservación de la Naturaleza (FMCN), 2009. Estimación de la tasa de transformación del hábitat en el Área de Protección de Flora y Fauna en la Sierra de Álamos. Periodo 1990–2005. Comisión Nacional de Áreas Naturales Protegidas, México.

Godínez-Alvarez, H., Jiménez, M., Mendoza, M., Pérez, F., Roldán, P., Ríos-Casanova, L., Lira, R., 2008. Density, population structure, reproduction and survival of four useful plat species in the Tehuacán Valley, Mexico. Revista Mexicana de Biodiversidad 79, 393–403.

Henderson, A., Galeano, G., Bernal, R., 1997. Field Guide to the Palms of the Americas. Princeton University Press, Princeton.

Holm, J.A., Miller, C.J., Cropper, J., 2008. Population dynamics of the dioecious Amazonian palm *Mauritia flexuosa*: simulation analysis of sustainable harvesting. Biotropica 40, 550–558.

Instituto Nacional de Estadística y Geografía e Informática (INEGI), 2000. Mapa de Sonora. Escala 1:50000. Mexico City, Mexico.

Joyal, E., 1996a. The use of *Sabal uresana* (Arecaceae) and other palms in Sonora, Mexico. Economic Botany 50, 429–445.

Joyal, E., 1996b. The Palm Has its Time: An Ethnoecology of *Sabal uresana* in Sonora, Mexico.

Liddle, D.T., Brook, B.W., Matthews, J., Taylor, S.M., Caley, P., 2006. Threat and response: a decade of decline in a regionally endangered rainforest palm affected by fire and introduced animals. Biological Conservation 132, 362–375.

Lopez-Toledo, L., Gonzalez-Salazar, C., Burlsem, D.F.R.P., Martinez-Ramos, M., 2011. Conservation assessment of *Guaiacum sanctum* and *G. coulteri* in Mexico: historic changes and future trends. Biotropica 43, 246–255, doi:10.1111/j.1744-7429.2010.00682.x.

Martinez-Ramos, M., Anten, N.P.R., Ackerly, D.D., 2009. Defoliation and ENSO effects on vital rates of an understory tropical rain forest palm. Journal of Ecology 97, 1050–1061.

McCune, B., Keon, D., 2002. Equations for potential annual direct incident radiation and heat load. Journal of Vegetation Science 13, 603–606.

McCune, B., 2007. Improved estimates of incident radiation and heat load using non-parametric regression against topographic variables. Journal of Vegetation Science 18, 751–754.

McPherson, K., Williams, K., 1998. Fire resistance of cabbage palms (*Sabal palmetto*) in the southeastern USA. Forest Ecology and Management 109, 197–207.

Medel-Narvaez, A., de la Luz, J.L.L., Freaner-Martinez, F., Molina-Freaner, F., 2006. Patterns of abundance and population structure of *Pachycereus pringlei* (Cactaceae), a columnar cactus of the Sonoran Desert. Plant Ecology 187, 1–14.

Olmsted, I., Alvarez-Buylla, E., 1995. Sustainable harvesting of tropical trees-Demography and matrix models of 2 palm species in Mexico. Ecological Applications 5, 484–500.

Oyama, K., Mendoza, A., 1990. Effects of defoliation on growth, reproduction and survival of a netropical dioecious palm, *Chamaedorea tepejilote*. Biotropica 22, 119–123.

Pulido, M.T., Caballero, J., 2006. The impact of shifting agriculture on the availability of non-timber forest products: the example of *Sabal yapa* in the Maya Lowlands of Mexico. Forest Ecology and Management 222, 399–409.

Pulido, M.T., Valverde, T., Caballero, J., 2007. Variation in the population dynamics of the palm *Sabal yapa* in a landscape shaped by shifting cultivation in the Yucatan Peninsula, Mexico. Journal of Tropical Ecology 23, 139–149.

Quero, H.J., 1998. *Brahea aculeata*. In: IUCN 2010. IUCN Red List of Threatened Species. Version 2010.2. <www.iucnredlist.org>. Downloaded on 25 August 2010.

Quero, H. 2000. El complejo Brahea-Erythea (Palmae: Coryphoideae). Informe final Comisión Nacional para el Uso y Conocimiento de la Biodiversidad (CONABIO). Mexico City. Mexico.

Ripley, B., 2010. Package 'Tree' for R: Classification and Regression Trees. Version 1.0-28.

R Development Core Team version 2.10.0, 2009. R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna, Austria. URL: http://www.R-project.org.

Secretaria de Medio Ambiente y Recursos Naturales (SEMARNAT), 2002. Norma official Mexicana. NOM-059-ECOL-2001. Protección ambiental-especies nativas de México de flora y fauna silvestres-Categorías de riesgo y especificaciones para su inclusión, exclusión o cambio-Lista de especies en riesgo. Diario Oficial de la Federación. 6 de marzo de 2002. México.
Svenning, J.C., 1999. Microhabitat specialization in a species-rich palm community in Amazonian Ecuador. Journal of Ecology 87, 55–65.
Svenning, J.C., Macia, M.J., 2002. Harvesting of *Geonoma macrostachys* Mart. leaves for thatch: an exploration of sustainability. Forest Ecology and Management 167, 251–262.
Svenning, J., Harlev, D., Sorensen, M.M., Balslev, H., 2009. Topographic and spatial controls of palm species distributions in a montane rain forest, southern Ecuador. Biodiversity and Conservation 18, 219–228.
Ticktin, T., 2004. The ecological implications of harvesting non-timber forest products. Journal of Applied Ecology 41, 11–21.
Vasquez-Leon, M., Liverman, D., 2004. The political ecology of land-use change: affluent ranchers and destitute farmers in the Mexican municipio of Álamos. Human Organization 63, 21–33.
Walther, G.R., Post, E., Convey, P., Menzel, A., Parmesan, C., Beebee, T.J.C., Fromentin, J.M., Hoegh-Guldberg, O., Bairlein, F., 2002. Ecological responses to recent climate change. Nature 416, 389–395.
Wehncke, E.V., Lopez-Medellin, X., Ezcurra, E., 2010. Blue fan palm distribution and seed removal patterns in three desert oases of northern Baja California, Mexico. Plant Ecology 208, 1–20.
Zuidema, P.A., 2000. Demography of Exploited Tree Species in the Bolivian Amazon. Ph.D. Thesis, University of Utrecht, Utrecht, The Netherlands.
Zuidema, P.A., De Kroon, H., Werger, M.J.A., 2007. Testing sustainability by prospective and retrospective demographic analyses: evaluation for palm leaf harvest. Ecological Applications 17, 118–128.