



DEMOGRAPHY OF *Astrocaryum malybo* H.Karst. (ARECACEAE) IN COLOMBIA, RECOMMENDATIONS FOR ITS MANAGEMENT AND CONSERVATION

Demografía de *Astrocaryum malybo* H.Karst. (ARECACEAE) en Colombia, recomendaciones para su manejo y conservación

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Abstract

The palm *Astrocaryum malybo* is an endangered species growing in forest remnants in the Caribbean lowlands of Colombia, where its spear leaves provide fiber for a flourishing artisanal activity. We studied the palm's population structure and dynamics near the town of Chimichagua, Cesar, in order to provide ecological information required for its management and conservation. We modeled population growth and fiber production in the next 20 years under different management scenarios using Integral Projection Models. Although there was a low proportion of seedlings and population structure was variable, the population would grow for the next 20 years, with an annual growth rate of 7.1%, yielding ca. 35 spear leaves/ha/year for artisanal activity. Simulations of the model show that the population is susceptible to alterations that affect the survival of individuals; removal of as few as 34 palms of any size per ha/year would cause the population to decrease, and spear leaf production will decline accordingly. Conversely, any increase in seedling growth or survival would lead to population growth. If properly managed, A.

malybo is a key species for conservation of the dry forest relicts in the Caribbean lowlands of Colombia.

Keywords: Arecaceae, handicraft, Integral Projection Model, NTFP, plant fibers.

Resumen

La palma *Astrocaryum malybo* es una especie en peligro que crece en relictos de bosque en las tierras bajas del Caribe colombiano, donde sus cogollos suministran fibra para una próspera actividad artesanal. Se estudiaron su estructura y dinámica poblacional en Chimichagua, Cesar, con el fin de suministrar información ecológica para su manejo y conservación. Se modeló el crecimiento poblacional y la producción de fibra durante los próximos 20 años bajo diferentes escenarios de manejo, usando modelos de Proyección Integral. Aunque se encontró una baja proporción de plántulas y variaciones en la estructura poblacional, la población tenderá a crecer en los próximos 20 años, con una tasa anual de 7.1 %, suministrando cerca de 35 cogollos/ha/año para la actividad artesanal. La modelación de escenarios muestra que la población es susceptible

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a alteraciones que afecten la supervivencia de los individuos; con la eliminación de solo 34 palmas de cualquier tamaño por ha/año, la población tenderá a decrecer y como consecuencia la producción de cogollos decaerá. En contraste, cualquier aumento en la supervivencia o el crecimiento de las plántulas

llevaría a un crecimiento de la población. Si se maneja adecuadamente, *A. malybo* es una especie clave para la conservación de los relictos de bosque seco en el Caribe colombiano.

Palabras clave: Arecaceae, artesanía, fibras vegetales, Modelo de Proyección Integral, PPNM.

INTRODUCTION

Astrocaryum malybo, locally known as *palma estera*, is an acaulescent spiny palm endemic to the warm lowlands of northern Colombia, where it forms small populations in dry or wet forest relicts (Galeano & Bernal, 2010). These populations have decreased more than 50% during the past decades, due to forest fragmentation or total deforestation, for establishing crops or pastures. As a result, this species is now categorized as Endangered (Galeano & Bernal, 2005).

In the area surrounding the Zapatosa lagoon complex, in the departments of Cesar and Magdalena, remnant populations of *A. malybo* are the base of a flourishing handicraft activity upon which many households rely (Barrera *et al.*, 2007; García *et al.*, 2011; García, 2013). This activity is based on the harvest of leaflets from unexpanded leaves, which provide a fiber used for weaving mats and other products (Linares *et al.*, 2008; García *et al.*, 2011; García, 2013). Because of its subterranean stem, access to the unexpanded leaves is easy, and harvesters do not cut down the palms, as is done with other fiber-producing *Astrocaryum* species (García *et al.*, 2013; García *et al.*, 2015). Besides this, leaf harvest involves other actions aimed to reduce damage to the harvested leaves, and, as a result, local management is considered sustainable (García *et al.*, 2011; García, 2013).

Although leaf harvest probably does affect the development of individual palms to some extent, overall impact is minimal, compared to the wholesale devastation of populations resulting from forest clearing for agriculture or cattle ranching (Barrera *et*

al., 2007; García *et al.*, 2011). Landowners prefer to eradicate the palms, due to the potential harm inflicted by the long spines, and the purported annoyances caused by intruding harvesters. Even in the forest fragments surviving along creeks, palms suffer damages from cattle, which wander freely and tread on seedlings. Yet, these forest fragments are the only areas where palm populations regenerate (García, 2013).

In order to provide ecological information required for management and conservation of *A. malybo* in this region, we studied its population structure and transient dynamics in forest fragments near the town of Chimichagua. In particular, we addressed the following questions: What is the population structure and density of *A. malybo* in these fragments? How is the demographic behavior under these conditions? How would population growth and fiber production behave in the next 20 years under different management scenarios?

MATERIALS AND METHODS

Study species

Astrocaryum malybo is a solitary palm with underground stem, or rarely up to 3 m tall, covered with black spines up to 10 cm long. An adult individual has 15-20 leaves up to 4.5-6 m long, densely armed with dark brown to black, flattened spines up to 20 cm long. Flowers are arranged in an erect, branched inflorescence up to 1.4 m long; fruits are yellowish when immature, becoming violet or almost black when ripe (Galeano & Bernal, 2010). The

species is endemic to Colombia, where it grows in wet to moderately dry lowland forests in the Magdalena River basin, and around the northern end of the Andes, west to the northern Pacific Coast (Galeano & Bernal, 2010).

Study area

Chimichagua is located in the southern department of Cesar (9° 15' 19.3 "N, 73° 48' 51.9" W), in an area classified as tropical dry forest, although most of the former forest cover has now disappeared. Average temperature is 27°C and average annual rainfall is 2448 mm; September and October are the rainiest months, with an average of 391 mm/month, while the driest season spans from December to March, with an average of 54 mm/month (Ideam, 2015).

Natural vegetation in the region has undergone a severe transformation into cattle pastures or subsistence crops (Estupiñán-González *et al.*, 2011). The former dry forest is now represented by small strips of secondary vegetation along waterways, and is dominated by trees as *Spondias mombim* L. and the palms *Attalea butyracea* (Mutis ex L.f.) Wess.Boer, *Elaeis oleifera* (Kunth) Cortés and *Astrocaryum malybo*. These forest relicts are within private land and are subjected to permanent disturbance resulting from cattle, fires, or the extraction of firewood, timber, fibers or other forest products useful to local people.

Study design and data collection

We characterized population structure of *A. malybo* in eight 20 x 50 m plots established in six secondary forest remnants near Chimichagua (table 1). The relicts were selected with the help of artisans, which are also involved in leaf harvest. We censused all individuals in each plot, and recorded for each the number of leaves and the number of main veins in the youngest leaf. Since individuals of this species usually do not have an aerial stem, we used the number of main veins as the state variable related to size, as often used in acaulescent palms (Galeano *et al.*, 2010). The main veins were always counted on the right side of the youngest expanded leaf.

We studied population dynamics in a 1.5 ha forest remnant located on the banks of a creek in finca La Cabaña (9° 16' 19.6" N, 73° 51' 15.9" W), where we tagged and censused 361 individuals of *A. malybo* between July 2012 and July 2013 (195 seedlings, 64 juveniles and 102 adults). We selected this forest remnant because it harbored the largest population of the species in the region. Thirty-seven adult palms at this site had evidence of leaf harvest. We marked the youngest expanded leaf in each palm and counted the number of main veins on its right side; in the second census (July 2013), we measured annual leaf production. We then estimated age of the individuals by combining number of veins, annual leaf production rate, and

Table 1. Description of plots used for determining the population structure of *Astrocaryum malybo* near Chimichagua, Cesar, in northern Colombia.

Plot	Location	Coordinates (N-W)	Habitat	Canopy cover	Number of palms showing evidence of leaf harvest
1	Relic 1	9°14'16,2"-73°51'27,3"	Along creek	Open	3
2	Relic 2	9°14'20,0"-73°51'23,7"	Along creek	Open	7
3	Relic 3	9°14'21,5"-73°51'20"	Isolated relic in pasture	Closed	3
4	Relic 3	-	Isolated relic in pasture	Closed	8
5	Relic 4	9°16'27,5"-73°51'10,4"	Along creek	Open	3
6	Relic 5	9°16'20,8"-73°51'16,5"	Along creek	Closed	7
7	Relic 5	9°16'19,6"-73°51'15,9"	Along creek	Closed	9
8	Relic 6	9°15'13,3"-73°51'15,8"	Along creek	Open	1

average increase in vein number from one leaf to the next. We recorded the number and stage of reproductive structures in all adult palms.

Vital rates

We used regression models for relating stem length with vital rates. We studied growth $g(x, y)$ through linear regression models that related initial size (x) to final size (y). Survival $s(x)$ was studied through logistic regression models that related initial size (x) to survival probability. For reproduction $f_2(x, y)$ we used logistic regression models relating initial size (x) with the probability of having offspring of size y .

Integral Projection Models (IPM)

Because the studied population was small, especially for some size classes, we decided to use IPM for the demographic analysis, since that method is suitable for relatively small datasets, explicitly incorporates variation in growth rate between individuals and is very suitable for trees and palms (Zuidema *et al.*, 2010). IPMs are used to describe changes, over a discrete period, in a population whose structure is characterized by a continuous or semi-continuous variable, or by a combination of discrete and continuous variables (Easterling *et al.*, 2000; Metcalf *et al.*, 2014). The initial stage of the population is described by a probability density function (distribution function), $n(x, t)$, which represents the proportion of individuals of size x at time t . Thus, the model for knowing the proportion of individuals of size y at time $t + 1$, i.e., for describing population change after a discrete period of time, is defined by

$$\begin{aligned} n(y, t + 1) &= \int_{\Omega} [p(x, y) + f(x, y)]n(x, t) dx \\ &= \int_{\Omega} k(y, x)n(x, t) dx \end{aligned}$$

where $k(y, x)$ represents all transition probabilities of an individual of size x at time t into an individual of size y at time $t + 1$, including new recruits. This function, called *kernel*, is integrated over a set of all size possibilities (Ω), and is made up of two components –a survival-growth function $p(x, y)$, and a fecundity function $f(x, y)$. The fecundity function $f(x, y)$ is positive for large individuals at time t (parents, x) and small individuals at time $t+1$ (offspring, y), and it is zero for all others; the function $p(x, y)$ incorporates growth and survival of all individuals (Easterling *et al.*, 2000).

The survival-growth and the fecundity functions are based on the regression models that describe the relations between size and vital rates. The survival-growth function is made up of two components:

$$p(x, y) = s(x)g(x, y)$$

The first one represents the survival probability of an individual of size x , $s(x)$; and the second represents the growth probability from size x to size y , $g(x, y)$. The fecundity function is also made up of two components:

$$f(x, y) = f_1(x)f_2(x, y)$$

The first one represents the average number of offspring produced by an adult of size x , $f_1(x)$, which was estimated by relating number of reproductive individuals in two 50 x 20 m plots in one year with the number of seedlings recruited by the next year. The second one represents the probability that a size x adult produces offspring of size y , $f_2(x, y)$; an individual was considered adult if it could reproduce (Easterling *et al.*, 2000).

The IPM was built based on regression models. The kernel $k(y, x)$ was discretized into a transition matrix using the midpoint rule proposed by Easterling *et al.* (2000). For this, we used 108 mesh points. Based on this transformation, the population dynamics of *A. malybo* was described as in standard matrix models: $n(t + 1) = K n(t)$. Transient

population growth rate (λ_t) was calculated as in Groenendijk *et al.* (2012):

$$\lambda_{20} = \sqrt[20]{n_{20}/n_0}$$

where n_0 and n_{20} represent population size at $t = 0$ and $t = 20$, respectively. We estimated 95% confidence interval (CI) for lambda by bootstrapping, as done by Li *et al.* (2011). We calculated 400 bootstrap estimates, each of them obtained by resampling the data set with random replacement. For each iteration we calculated the regression coefficient, the survival-growth and fecundity functions, the kernel, and λ_t . The 95% CI for λ_t was derived from the frequency distribution of these values. All analyses were conducted using IPMPack (Metcalf *et al.*, 2014) and Popbio (Stubben & Milligan, 2007) packages in the statistical software R, version 3.2.1 (R Development Core Team, 2015).

Management Scenarios

We modeled the fate of the palm populations in forest fragments under two scenarios. We performed these simulations by changing the values in the survival-growth matrix according to each case. In the first scenario, we modeled the removal of individuals in different proportions (5%, 10%, 20%), simulating the effect of actions taken by the landowners, who often kill the palms or allow the free entry of cattle into the palm stands. In the second scenario, we modeled management consisting in the protection of seedlings from trampling, and in planting new seedlings; this simulation was made by increasing seedling survival and growth in different proportions (5%, 10%). We analyzed changes in population size and leaf production in the model over the next 20 years.

RESULTS

Population structure

Population structure of *A. malybo* in the six forest fragments near Chimichagua showed very different trends. Two relics (4 and 6) did not have seedlings, and in two other (1 and 2) there were fewer seedlings than adults (figure 1); only in two relics (3 and 5) was the proportion of seedlings greater than that of adults; the latter relics have a continuous canopy cover (table 1). There were no juveniles in relic 2, and all other fragments their number was lower than that adults (figure 2). Overage density among all the relics was 245 (S.D. = 135, $n = 6$); the highest density was found in relics 3 and 5, which had a continuous canopy cover, and harbored 320 and 460 palms/ha, respectively.

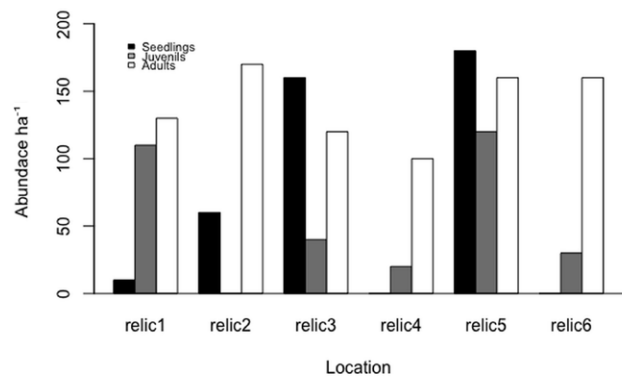


Figure 1. Population structure of *Astrocaryum malybo* in six forest relics near Chimichagua, Cesar, northern Colombia.

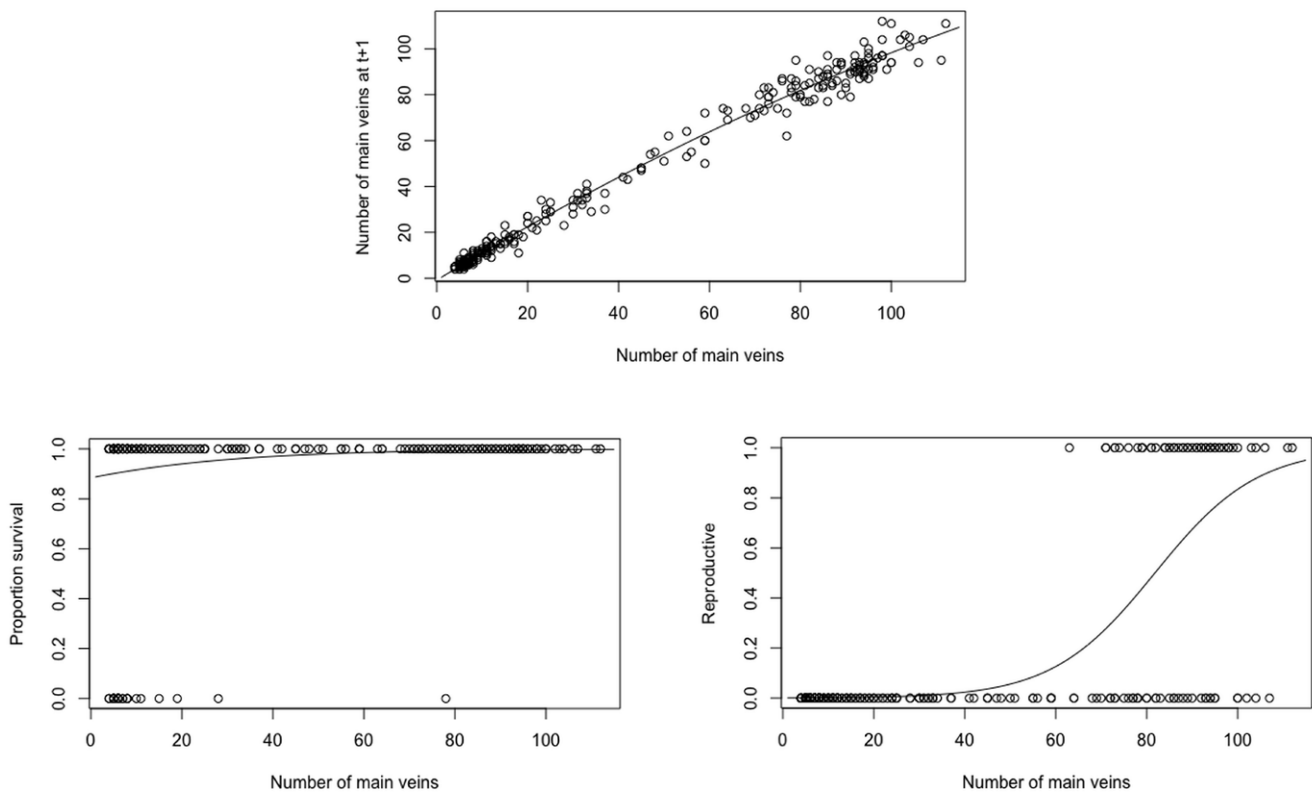


Figure 2. Relation of size (number of main veins in the youngest leaf) to growth (a), survival (b), and reproduction (c) in *Astrocaryum malybo*, near Chimichagua, Cesar, northern Colombia.

Demographic parameters

Size of *A. malybo*, as defined by the number of main veins in the youngest leaf, ranged between 4 veins in the first seedling leaf and 112 in adult palms. As shown in figure 2a, increase in the number of veins is constant during the juvenile stages; in adults, however, vein increase tends to be lower in older individuals. Similarly, survival of individuals is related to their size, with seedlings and young juveniles being less likely to survive than adults (figure 2b). Reproduction was also related to size, increasing as individuals grow (figure 2c). The first reproduction was observed in individuals with about 63 main veins.

Age estimates (table 2) indicated that at our study site *A. malybo* passes 8 years in the seedling stage, 24 years in the juvenile stage, and begins to develop reproductive structures when the palm is 32 years old. After this time, the palm can survive

for at least another 32 years, although it probably lives for more than 100 years.

Results of modeling

Transient dynamics simulations on the IPM show that the population of *A. malybo* would grow for the next 20 years, with a growth rate of 1.07084 (CI 1.07078-1.07090). Under the scenario of removing individuals of any size class, the population grows for the first two or three years, then remains steady, and finally decreases (figure 3a). When 5% of the individuals are removed (i.e. 17 individuals of any size per ha per year), population growth ceases for the next 20 years; when 10% or 20% of the individuals are removed, the population decreases, with a trend to disappearing within the 20 next years (figure 3a). On the other hand, our simulations show that any increase in seedling

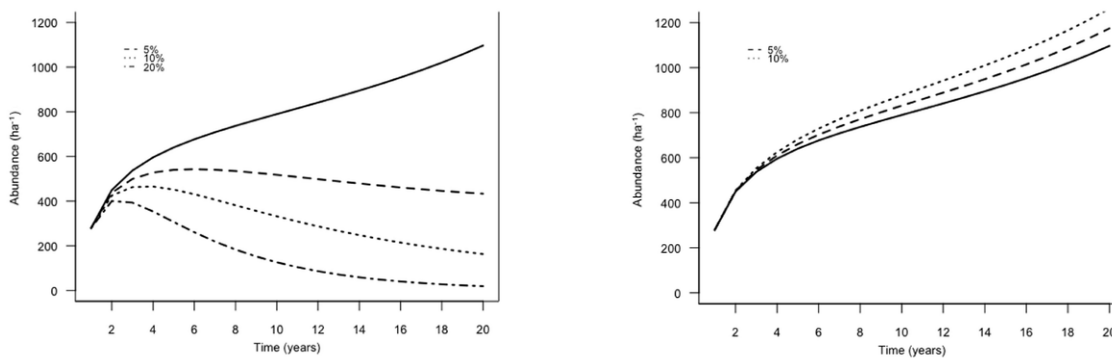
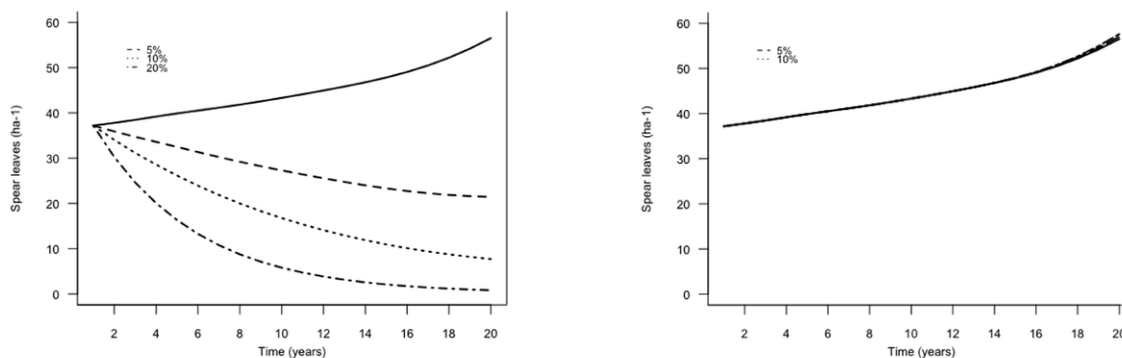
Table 2. Leaf production, growth and estimated age of *Astrocaryum malybo* near Chimichagua, Cesar, northern Colombia.

Size category	Leaf production rate (leaves/year)	Vein increase rate (veins/year)	Interval	Category duration (years)	Final age (years)
Seedlings	1.83 (S.D. = 0.77, n = 157)	0.59 (S.D. = 1.28, n = 154)	8 veins	13.56	13.56
Juveniles	1.94 (S.D. = 0.61, n = 64)	2.10 (S.D. = 3.92, n = 61)	48 veins	22.86	36.42
Adults	2.27 (S.D. = 0.67, n = 102)	1.11 (S.D. = 4.92, n = 98)	52 veins	46.85	83.27

growth or survival would lead to population growth within the next 20 years (figure 3b).

The studied population of *A. malybo* produces ca. 35 spear leaves/ha/year. This figure will increase in the coming 20 years, as the population itself is growing (figure 4). Our simulations show that spear leaf production would decrease dramatically as

the percentage of palms removed increases. When more than 20% of the individuals (i.e. ca. 60-70 palms of any size) are removed, spear leaf production would cease altogether after 12-14 years. On the other hand, a simulated increase of seedling growth/survival, whatever the proportion, would not still increase spear leaf production within 20 years.

**Figure 3.** Projected abundance of *Astrocaryum malybo* in the next 20 years under the observed conditions (solid line) and under two scenarios: (a) removal of 5%, 10% y 20% of the individuals; (b) Increase of seedling survival and growth by 5% and 10%.**Figure 4.** Spear leaf production of *Astrocaryum malybo*, projected under the observed conditions (solid line) and under two hypothetical scenarios: (a) removal of 5%, 10%, or 20% of the individuals in any size class; (b) 5% and 10% increase in seedling growth or survival.

DISCUSSION

The short period of observations of the studied population (one year) might affect estimation of vital rates, for example, adult mortality. This is a common shortcoming in the study of long-lived plants, but there are good reasons to think that it does not affect our conclusions. First, population studies in other *Astrocaryum* species have shown that vital rates do not differ significantly between consecutive years (García *et al.*, 2016). Additionally, a population study of *Chamaedorea radicalis* showed that the trends found in two years did not differ substantially from those found in six years (Endress *et al.*, 2006). Because of this, we consider that the described trends do represent the situation of *Astrocaryum malybo* in the study area.

The demographic structure of populations has been used as an indicator of their conservation status and of the impact caused by the harvest of NTFP (Hall & Bawa, 1993). A population including individuals in all size classes, with a predominance of seedlings and a progressive decrease in the proportion of individuals in higher classes, is considered to be well conserved and growing (Hall & Bawa, 1993; Galeano *et al.*, 2010). Under natural conditions, palm populations have been found to have this kind of structure (Galeano *et al.*, 2010), and any deviations in the proportion of individuals per size class can be interpreted as the result of processes affecting the population (Thompson *et al.*, 2009; Galeano *et al.*, 2010; García *et al.*, 2016; Andrade-Erazo & Galeano, 2016).

Population structure of *Astrocaryum malybo* at all of our study plots shows alterations in the proportion of individuals throughout the size classes. In particular, there is a reduction in the proportion of seedlings or, in some cases, they are even missing altogether. This pattern, typical of populations with low regeneration, is probably related to the poor condition of the forest patches where the palm grows. The negative impact of cattle on seedling survival has been documented for

another palm species in neighboring areas (Andrade-Erazo & Galeano, 2016). The highest proportion of *A. malybo* seedlings in our plots (figure 1) was found in the two best-preserved forest relics near Chimichagua (table 1), where the vegetation still has a closed canopy. These plots had also the highest population growth rates, which supports the usefulness of structure as a proxy for population health in this species.

Although the studied population of *A. malybo* is growing at an annual rate of 7.1%, which is much faster than that found in rain forest species of *Astrocaryum* (García *et al.*, 2016), the annual death toll required to stop population growth (34 individuals/ha) is relatively low. Death of seedlings by cattle trampling in the unprotected forest remnants could easily cause such toll.

Because of this, it does not seem recommendable to extract seedlings from the forest patches in order to establish plantations, as has been done in the past (García, 2013). Instead, it is advisable to collect ripe fruits from isolated adult palms standing in pastures, where there is no chance for seedlings to establish. These fruits should be spread in forest remnants, in order to increase seedling recruitment. On the other hand, seedlings and juveniles in forest patches should be protected from cattle trampling by isolating these areas from pastures, as our simulations show that even a small increase in seedling survival would lead to population growth within the next 20 years.

Conservation of forest remnants, which are often located among streams, will be directly beneficial to landowners as a means of preserving their water supplies, not to mention the fact that protecting such remnants is required by law. Because of this, it should not be difficult to promote awareness among landowners, even though many of them regard the fiercely armed *A. malybo* as a nuisance and a potential danger to cattle (García, 2013).

Because of the economic importance of the palm to landless peasants, it would be vital to reach some kind of agreement between harvesters,

artisans, landowners, and environmental authorities, in order to manage these forest remnants as some sort of extractive reserves. This, together with the establishment of biological corridors between the largest forest fragments, would make an interesting integrated approach to conservation of dry forest species.

The observed spear leaf production, as well as that projected by our simulation, reveal that population of *A. malybo* in isolated forest remnants like the ones in our study keep a regular supply of fiber for handicraft production. The sustainability of this supply seems guaranteed, particularly as harvesters minimize damage to the palm by harvesting only the usable leaflets (García *et al.*, 2011).

The dramatic fragmentation and severe reduction of dry forest areas in Colombia, as well as their scarce representation in the National System of Protected Areas, has led researchers to suggest that conservation efforts should focus on protecting forest remnants in private lands (Pizano & García, 2014). Under this scenario, *A. malybo* is one of the most interesting species, particularly around the Zapatosa lagoon complex, in the Colombian Caribbean. The sustainable harvest of its spear leaves, the economic importance of handicraft production based on them, and the cultural significance of palm weaving, dating back to the Ete Ennaca or Chimila aboriginal people (Andrade, 2004), all combine to make this plant a key species for conservation of forest relicts. Furthermore, the endemic nature of the species in Colombia and its endangered status give this palm a charismatic appeal that should not be disregarded.

On the other hand, introduction of the species in agroforestry systems should be encouraged, in order both to increase fiber availability, and to reduce pressure on forest fragments. A combination of the species in agroforestry with its role as a key species for promoting protection of forest remnants can turn this palm from an endangered species into a tool for conservation of dry forest areas, and a source of income to local communities.

CONCLUSIONS AND MANAGEMENT RECOMENDATIONS

Populations of *Astrocaryum malybo* in Chimichagua, Cesar, grow in remnants of secondary vegetation along creeks. Under this environment, its population structure shows an alteration in the proportion of individuals per size class, in particular a reduction in the number of seedlings, which is typical of populations with low regeneration. Alterations in population structure are apparently related to the poor conditions of the forest relicts, particularly the free access of cattle.

However, in the best-preserved plots with a continuous canopy, the population of *A. malybo* will grow at an annual rate of 7.1% over the next 20 years, providing up to 35 spear leaves/ha/year for handicraft production. Yet, any situation affecting the survival of individuals of any size can lead to a rapid decrease of population growth, bringing it to zero if 34 individuals of any size die per ha/yr. In contrast, any actions favoring seedling survival and growth would increase population growth rate, although the availability of spear leaves would not increase in the next 20 years, as individuals take a long time to be harvestable.

Our results show that natural regeneration of *A. malybo* near Chimichagua can be favored through management and protection of the forest remnants where it thrives. In this way, a supply of fiber for handicraft production can be maintained, while protecting this endangered species.

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CONFLICT OF INTERESTS

The author declares that he hasn't conflict of interest.

CONTRIBUTION BY AUTHOR

The sole author is responsible for the work in all aspects that led to the development of its publication.

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