

# Demographic structure of a threatened palm (*Euterpe edulis* Mart.) in a fragmented landscape of Atlantic Forest in northeastern Brazil

Melina Oliveira Melito<sup>1,2,5</sup>, José Cláudio Faria<sup>3</sup>, André Márcio Amorim<sup>1,4</sup> and Eliana Cazetta<sup>1</sup>

Received: 23 March, 2013. Accepted: 7 November, 2013

## ABSTRACT

At the northern limits of the range of the palm species *Euterpe edulis* there is an endemic ecotype, known as the “Bahia” ecotype, which is distinguished by its reddish crownshaft and low seed production. Unfortunately, little is known about its demographic characteristics. Therefore, we contrasted the density of *E. edulis* populations in the Una region, in the southern part of the Bahia state, Brazil, with that of other populations of the species in southern and southeastern Brazil. In addition, within the Una region, we compared a long-protected forest fragment (F1) with three recently protected fragments (F2, F3, and F4), in terms of demographic parameters and plant size, in order to determine what influence, if any, time since protection has on *E. edulis* populations. Population densities within the Una region were higher than in regions where *E. edulis* populations are stressed by harvesting or intense seed predation but much lower than in regions with well protected populations. Among the Una fragments, density was highest in F1 and lowest in F2. The proportion of individuals at the various developmental stages differed among the fragments ( $\chi^2=25.219$ ,  $df=12$ ,  $p=0.014$ ). Diameter at ground level, height, and number of leaves correlated positively among themselves and negatively with population density. For all developmental stages, F1 surpassed the other fragments in terms of densities and plant sizes. It is likely that the newly protected populations suffer the lingering effects of previous harvesting, which are reflected in their demography and in the size of their individual members. The viability of this low-density endemic ecotype must be established in order to assess the conservation status of the species on a regional scale.

**Key words:** Juçara palm heart, forest fragment, life stages, recruitment, population structure

## Introduction

Palms (Arecaceae) are important components of tropical and subtropical ecosystems (Uhl & Dransfield 1987; Scariot 1999) and have key ecological functions in providing resources for vertebrate frugivores (Galetti & Aleixo 1998; Galetti *et al.* 2006; Andreazzi *et al.* 2009). Because they are easily recognizable and of significant ecological importance, palms are highly appropriate subjects for demographic studies (Uhl & Dransfield 1987).

The palm *Euterpe edulis* Mart. is considered a key species in fragmented forests and habitats with restricted resource offerings (Fadini *et al.* 2009) because it provides food resources for a variety of frugivorous vertebrates, including birds (Galetti & Aleixo 1998; Matos & Watkinson 1998), large mammals (Keuroghlian & Eaton 2008), and rodents (Vieira *et al.* 2003). By attracting seed dispersers that can transport seeds from neighboring forest fragments,

*E. edulis* facilitates the recovery of degraded forest patches (Reis *et al.* 2000).

Commercial harvesting of *Euterpe edulis* palm trees may have serious effects on their population structure, especially in the context of fragmented landscapes (Portela *et al.* 2010a). Palm heart harvesting has resulted in declining natural populations of *E. edulis* (Galetti & Fernandez 1998), and has negative effects on natural regeneration and the maintenance of their demographic structure (Reis *et al.* 2000). *Euterpe edulis* populations are believed to be decreasing even in protected forest fragments (Portela *et al.* 2010b). Palm heart harvesting has a negative impact on biodiversity, not only through the direct effects that palm heart gatherers have on the forest by hunting (Matos & Bovi 2002) but also through the indirect effect of a loss of resource availability for local animals (Galetti & Aleixo 1998; Matos & Bovi 2002).

*Euterpe edulis* occurs in the Atlantic Forest, which extends along the coast of Brazil, from the state of Rio Grande do

<sup>1</sup> Universidade Estadual de Santa Cruz, Departamento de Ciências Biológicas, Programa de Pós-Graduação em Ecologia e Conservação da Biodiversidade, Ilhéus, BA, Brazil

<sup>2</sup> Universidade de São Paulo, Instituto de Biociências, Programa de Pós-graduação em Ecologia, São Paulo, SP, Brazil

<sup>3</sup> Universidade Estadual de Santa Cruz, Departamento de Ciências Exatas e Tecnológicas, Ilhéus, BA, Brazil

<sup>4</sup> Herbário Centro Pesquisas do Cacau, Ilhéus, BA, Brazil

<sup>5</sup> Author for Correspondence: melinamelito@gmail.com

Norte to the state of Rio Grande do Sul, as well as stretching into inland areas of central Brazil and into the Misiones region of Paraguay and Argentina (Henderson *et al.* 1995). Although *E. edulis* is widely distributed, studies focusing on its demographic structure have largely been concentrated on southern and southeastern Brazil (Reis *et al.* 1996, Silva Matos *et al.* 1999, Portela 2008). In northeastern Brazil, the population structures of *E. edulis* have been analyzed only in the Una region (Silva *et al.* 2009), which is in the southern portion of the state of Bahia.

Southern Bahia contains some of the last remaining forest fragments of the northeastern Atlantic Forest (Faria *et al.* 2009), a region considered to be of great biological importance because of its high levels of species richness and plant endemism (Thomas *et al.* 1998; Martini *et al.* 2007; Thomas *et al.* 2008). The tropical lowland rain forest in the Una region shows very high plant diversity and endemism, with distinct canopy, understory, and emergent layer structures, together with a rich epiphytic flora of bromeliads, orchids, ferns, and lianas (Thomas *et al.* 1998; Amorim *et al.* 2008). However, the forests of the Una region have suffered from massive deforestation and intense logging activities since the 1970s (Alger & Caldas 1994), and the remaining forest fragments are estimated to represent only 9.4% of the original cover (excluding open water, according to Saatchi *et al.* 2001).

The best approach to determining population viability is the estimation of demographic rates by studies of population dynamics (Virillo *et al.* 2011). Analyses of population dynamics generally require long-term studies and there are always difficulties in implementing, managing, and financially supporting this type of research, as was pointed out by Bruna & Kress (2002) and Bruna *et al.* (2009). Although the current demographic structure of a population allows only limited insights (Virillo *et al.* 2011), it may be a useful measure for the immediate evaluation of conservation status (Bruna & Kress 2002). When evaluating multiple populations of a single species, deviations in certain demographic attributes can be observed (Bruna & Kress 2002). Therefore, the current structure of a population can provide information for making recommendations regarding the sustainable management of tropical forest products.

Previous studies have indicated that the populations of *Euterpe edulis* found in the state of Bahia constitute an endemic ecotype, with a phenotype (Bovi *et al.* 1987) and genotypes (Coelho 2010) that are distinct from those of the *E. edulis* populations in Atlantic Forest fragments in southeastern and southern Brazil. This “Bahia” ecotype (Bovi *et al.* 1987) is principally characterized by its reddish crownshaft and the reduced numbers of rachillae—which implies lower seed production (Silva *et al.* 2009). Low seed production can lead to reduced recruitment of seedlings into the population, ultimately resulting in a population with fewer individuals. Plant demography is also negatively affected by time since the onset of protection of the population, which reflects in the vulnerability of a forest to selective logging, game hunting,

and palm heart extraction. Forests from Una region has a historical of selective logging (Mesquita 1996) which could lead to disturbed areas by removal of big trees and soil disturbances reflecting, ultimately, in seed limitation process (Clark *et al.* 2007). Illegal game hunting species is also an activity practiced by nearly 40% of the families in the surroundings of the protected areas under study, being one of the major threats to the fauna of the region (Pardini 2001). Depletion of game species can promote compensatory increases in the guild of granivorous, which can increase seed predation rates (Donoso *et al.* 2003). Seed predation is a process that directly affects plant demography (Hulme 1998) by limiting the recruitment of new individuals into the plant population. Palm exploitation also affects plant demography by increasing the mortality of reproductive individuals. In addition, palm exploitation affects the tree size average because it is focused on the tallest individuals (Matos & Bovi 2002) and could result, in the long term, in populations composed of shorter individuals.

Within this context, we compared the density of *E. edulis* in this distinct edaphic-climatic Una landscape with that reported for *E. edulis* populations in southern and southeastern Brazil. We hypothesized that the “Bahia” ecotype characteristic of the Una region would show a low number of individuals in comparison with the other populations. Furthermore, we analyzed the demographic structure of *E. edulis* to compare a long-protected forest fragment in the Una region with three other fragments that had only recently been granted protected status, in terms of demographic parameters and plant sizes. We assumed that the long-protected forest fragment would provide the best conditions for the growth and development of *E. edulis*. Therefore, we expected the values for the demographic parameters—density, reproductive output, and population structure—as well as for the plant size parameters—height, diameter at ground level (DGL), and number of leaves—to be higher in the long-protected forest fragment than in the newly protected forest fragments. Consequently, the objectives of the present study were to compare *E. edulis* populations in the Una region with those in southern and southeastern Brazil, in terms of density; to determine whether the population structure in the long-protected forest fragment in the Una region is similar to that of the more recently protected forest fragments in the same region; to compare the reproductive outputs of the seedling and sapling banks in the forest fragments in the Una region; and to compare the long-protected and newly protected forest fragments in the Una region, in terms of plant size patterns.

## Materials and methods

### Study site

The present study was conducted in two contiguous federally protected areas: the Una *Reserva Biológica* (RE-BIO, Biological Reserve); and the surrounding Una *Refúgio*

*de Vida Silvestre* (RVS, Wildlife Refuge). The Una REBIO is a highly protected area established in 1980, designated for scientific research and biodiversity protection. This protected area incorporated additional forest fragments in 2007 and now covers a total of 18,900 ha. The Una RVS was established in 2007 with less rigorous protection that allows private ownership in an integrated system of land use, which promotes the recuperation of disturbed areas to reconnect and protect forest fragments.

Employing land use and land cover estimates obtained from radar imagery (of an area roughly 100 km × 50 km), Saatchi *et al.* (2001) showed that the landscape of the Una region (excluding open water) comprises old-growth forest (9.4%), surrounded by a matrix composed principally of flooded vegetation (15.4%), shade cacao plantations (15.0%), rubber plantations (10.9%) and pasture (4.3%). Forest fragments in the Una region show an irregular shape increasing the contact with the non-forested matrix (Pardini 2001).

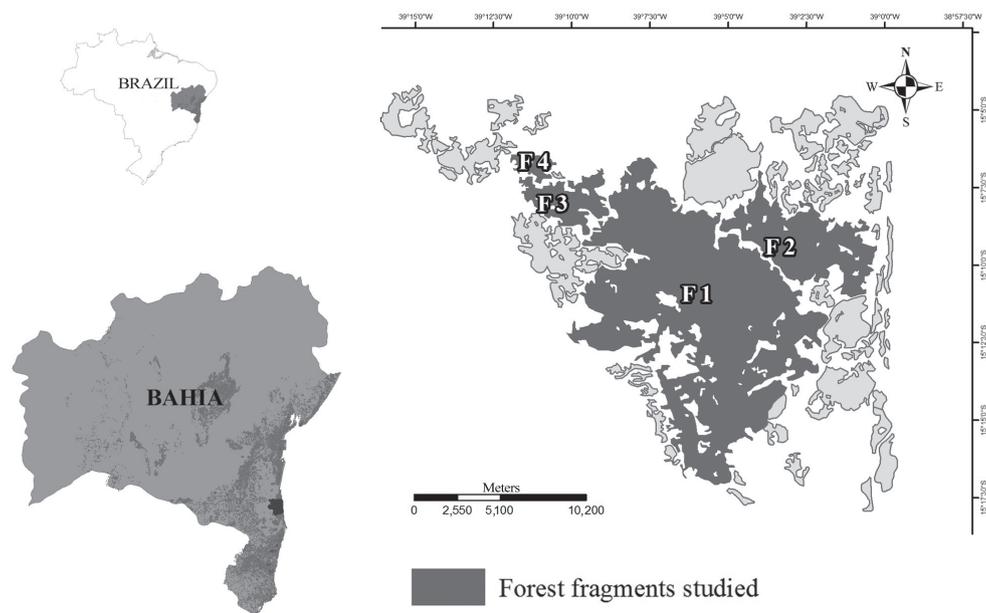
Within the two protected areas, there is a mosaic of forest fragments. We sampled four fragments that showed no visible signs of palm heart harvesting, designated F1, F2, F3, and F4 (Fig. 1), with total areas of 12,334 ha, 2,655 ha, 946 ha, and 210 ha, respectively. The largest fragment (F1) has been a protected area since 1980, whereas the other fragments were not granted protected status until 2007. Areas F1 and F3 now belong to the Una REBIO and F2 and F4 are within the legally protected domain of the Una RVS. Based on the radar imagery of the region (Saatchi *et al.* 2001), all of the fragments sampled are categorized as old-growth forest.

The study area is characterized by two principal soil types: spodosols (variety Cururupe [Tropodult]) in the east; and oxisols (laterites, variety Tabuleiro [Haplorthox]) in the west (Carvalho Filho *et al.* 1987). The average annual temperature in the region is 24°C, and the mean annual rainfall is ca. 2000 mm, without any distinct seasonality, although there is often less precipitation from December to March (Mori *et al.* 1983).

#### Demographic census samples

At each sampling site, we established three 25 m × 25 m plots (0.19 ha each), spaced at least 50 m apart. The plots were distributed along pre-existing trails but always more than 50 m from any fragment edge. The F1 sampling site was accessible by a trail through the interior of a forest fragment near a river. We assumed that the density of *Euterpe edulis* was unrelated to its proximity to the river, because, in a previous study conducted at Una (A. M. Z. Martini, unpublished data), no such correlation was found, probably because of the already high levels of humidity in the region.

The sampling plots were subdivided into 5-m grids in which all individuals of *Euterpe edulis* were counted and measured. We evaluated the following morphometric characteristics: number of leaves; type of leaves (palmate or pinnate); height at leaf insertion; and DGL above the root cone, a measurement shared by all individuals (Silva Matos *et al.* 1999). The individuals were then classified into development stages that were based on biological criteria—signs of reproduction and plant size (adapted from Silva *et al.* 2009): seedling—one palmate leaf and an endosperm



**Figure 1.** Locations of the fragments of Atlantic Forest studied (F1, F2, F3, and F4) in the Una region, located in the state of Bahia, Brazil. On the left, the Una region is highlighted, and the right panel shows the forest fragments that compose the two contiguous protected areas (the Una Biological Reserve and the Una Wildlife Refuge).

reserve; sapling—pinnate leaves, although palmate leaves might still be present, height  $\leq 0.15$  m; juvenile—pinnate leaves only, height  $\leq 1$  m; immature—stem  $> 1$  m with no sign of reproductive events; and adult—stems with signs of reproductive events. The survey was undertaken near the end of the fruiting season, from August to October 2010.

### Data analyses

We compared the density of *Euterpe edulis* populations in the Una region with that of those in the southern and southeastern regions of the Atlantic Forest biome by calculating the numbers of plants per hectare, on the basis of data presented in previously published studies. A list of the studies analyzed is shown in Tab. 1.

The data were analyzed using traditional parameters of descriptive statistics, including means, standard deviations, and confidence intervals (Zar 2009). We used the confidence intervals around the mean to compare plant densities within the different forest fragments. Means and confidence intervals were calculated considering the numbers of individuals per subplot (0.0025 ha).

Reproductive output was quantified by calculating the seedling/adult and sapling/adult ratios. The population structures of the fragments were analyzed considering the proportions of individuals in each developmental stage, using Pearson's chi-square test ( $\chi^2$ ). In addition, we used cluster analysis to group the fragments on the basis of similarities in the proportions of plants at each development stage.

To summarize the variances and covariances of plant size parameters and densities among the developmental stages and fragments, we used ordination techniques, constructing a biplot obtained from principal component analyses that represented simultaneously the sample units and variables of an  $n \times p$  correlation matrix (Gabriel 1971). In the analyses, points lying close together indicated similarities among objects (sample units) related to the scores of the principal component axes. The response variables were the vectors, and the angulations formed between them indicated the degrees of correlation among the variables (Gabriel 1971). We considered the density of *Euterpe edulis* and plant size parameters (DGL, height, and number of leaves) as the multivariate variables (vectors). For each fragment, the development stages were considered sampling units; we

**Table 1.** Locations, forest fragment sizes, areas sampled in each fragment, and densities of natural populations of *Euterpe edulis* studied within the Atlantic Forest Biome of Brazil.

Municipality (state)	Forest area (ha)	Area(s) sampled (ha)	Density (ind./ha)	Reference
Una (BA), Fragment 1	12,334	0.19	4,677	Present study
Una (BA), Fragment 2	2,655	0.19	1,104	
Una (BA), Fragment 3	946	0.19	2,981	
Una (BA), Fragment 4	210	0.19	2,661	
Una (BA)	383	0.61	4,232	Silva <i>et al.</i> (2009)
Una (BA)	12,334	0.12 and 0.004*	4,559	Martini**
Casimiro de Abreu (RJ)	19	0.81	112***	Portela (2008)
Casimiro de Abreu (RJ)	21	0.81	162***	
Casimiro de Abreu (RJ)	57	0.81	176***	
Casimiro de Abreu (RJ)	3,500	0.81	974***	
Silva Jardim (RJ)	2,400	0.81	22***	Reis <i>et al.</i> (2000)
Sete Barras (SP)	164	ND	17,914****	
Campinas (SP)	252	0.25	3,780	Silva-Matos (2000)
Anchieta (SP)	806	0.8	154	Fadini <i>et al.</i> (2009)
Caraguá (SP)	39,800	0.8	1,860	
São Francisco do Sul (SC)	9	1.0 and 0.04*	2,350	Meyers & Dornelles (2003)
Blumenau (SC)	ND	5.44	17,200	Reis <i>et al.</i> (1996)
Blumenau (SC)	2,200	ND	8,450	Reis <i>et al.</i> (2000)
São Pedro de Alcântara (SC)	35	ND	17,966****	
Maquiné (RS)	ND	0.26	5,343	Raup <i>et al.</i> (2009)

ind. – individuals; BA – Bahia; RJ – Rio de Janeiro; SP – São Paulo; SC – Santa Catarina; RS – Rio Grande do Sul; ND – no data.

\* The first value is the area for individuals with exposed stem  $> 100$  cm in height; the second value is the area for individuals  $< 100$  cm in height.

\*\* Unpublished data collected in 2000.

\*\*\* Values represent the means of three years.

\*\*\*\* Values represent the means of two years.

excluded the seedling class from analyses because there were no plant size measurements for that class. For biplot construction, the mean values were centered and standardized because of the different measurement scales used. All statistical analyses were performed using R environment software, version 2.13.1 (R Development Core Team 2009).

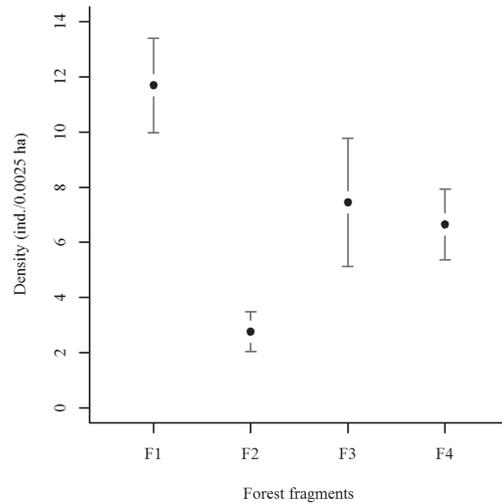
## Results

The study sites and populations compared are detailed in Tab. 1. Density (individuals per hectare) was highest in F1 ( $n = 4,677/\text{ha}$ ), followed by F3 ( $n = 2,981/\text{ha}$ ), F4 ( $n = 2,661/\text{ha}$ ), and F2 ( $n = 1,104/\text{ha}$ ). All *Euterpe edulis* populations in the Una region showed densities that were lower than those reported for *E. edulis* populations in other states: by Reis *et al.* (2000) for São Paulo ( $n = 17,914/\text{ha}$ ); by Reis *et al.* (1996; 2000) for Santa Catarina ( $n = 17,200/\text{ha}$  and  $17,966/\text{ha}$ , respectively); and by Raupp *et al.* (2009) for Rio Grande do Sul ( $n = 5,343/\text{ha}$ ). Densities for F2, F3, and F4 were also lower than the 3,780 individuals/ha reported for the state of São Paulo by Silva-Matos (2000), as well as being lower than the 4,232 individuals/ha and 4,559 individuals/ha previously reported for other areas sampled in the Una region by Silva *et al.* (2009) and A. M. Z. Martini (unpublished data), respectively. Although density was lower in F2 than in the other Una region fragments, it was higher than a number of areas studied in the state of Rio de Janeiro (Portela 2008) and on an island in the state of São Paulo (Fadini *et al.* 2009).

Overall, the mean density of *Euterpe edulis* was greater in F1 ( $292 \pm 62$  plants/ha) than in the other Una fragments: F2 ( $69 \pm 27$  plants/ha); F3 ( $186 \pm 123$  plants/ha); and F4 ( $166 \pm 42$  plants/ha). Plant density per plot was highest in F1 and lowest in F2 (Fig. 2). The reproductive output of seedlings was at least four times greater in F4 than in the other Una fragments (Fig. 3a). The sapling/adult ratio varied relatively little among the fragments but was nearly two times higher in F3 (Fig. 3b).

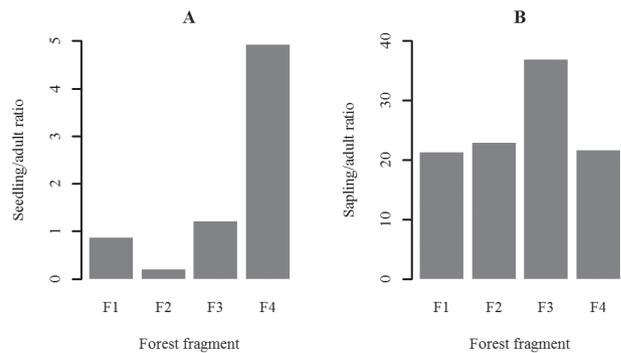
The population structures varied significantly among the Una fragments ( $\chi^2=25,219$ ,  $df=12$ ,  $p=0.014$ ). In general, at least half of all individuals were concentrated in the sapling stage (Fig. 4). The lowest proportions of plants were observed at the seedling and adult stages (Fig. 4). On the basis of the proportions of individuals (Fig. 4 and 5), F1 and F2 showed similar structures; F4 formed an intermediate group, largely due to the higher proportion of seedlings (11.8%); and F3 showed the greatest dissimilarity in relation to the other fragments, with the highest proportion of saplings (65.8%), resulting in the lowest proportions of juvenile plants (26.5%), immature plants (3.8%), and adults (1.8%).

The biplot showed a weak association between density and plant size in *Euterpe edulis* (Fig. 6). The morphometric variables showed strong positive correlations with each other and negative correlations with plant density (Fig. 6, Tab. 2). The first principal component (PC1) explained

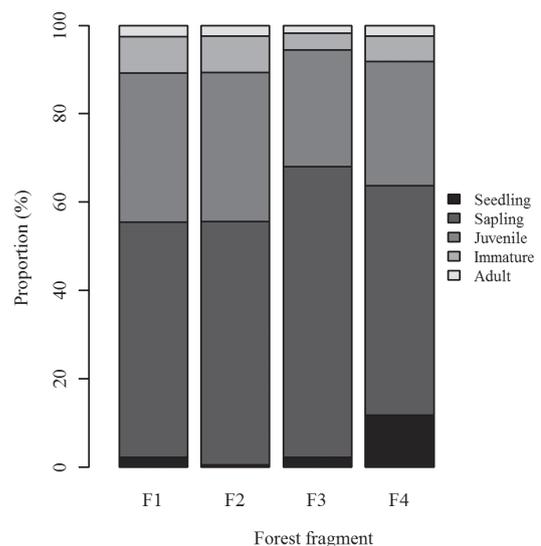


**Figure 2.** Mean density (individuals per 0.0025 ha) of *Euterpe edulis* in forest fragments in the Una region, located in the state of Bahia, Brazil.\* ind. – individuals.

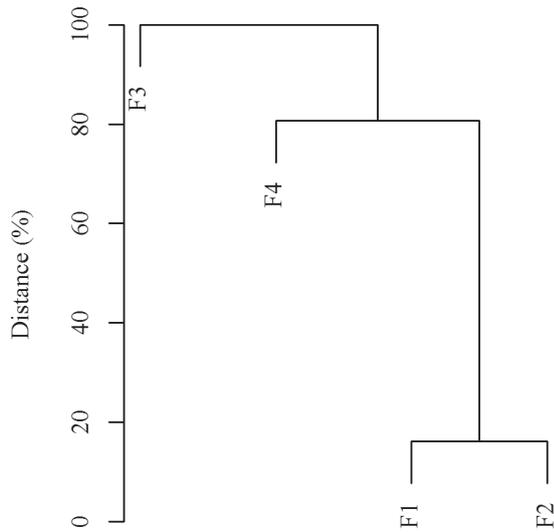
\*The bars indicate the confidence intervals around the means.



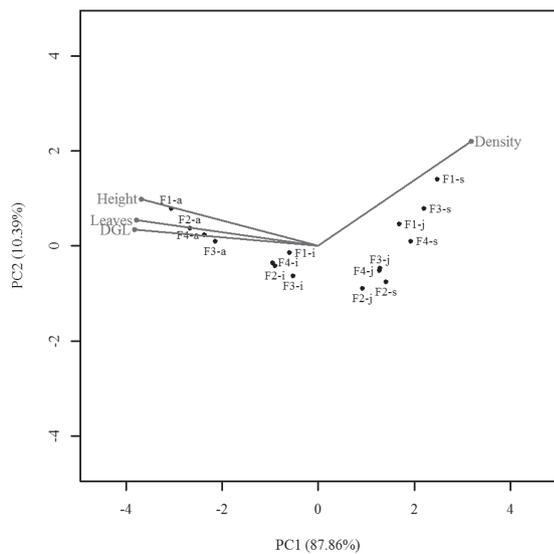
**Figure 3.** Seedling/adult ratio (A) and sapling/adult ratio (B) of *Euterpe edulis* in four forest fragments in the Una region, located in the state of Bahia, Brazil.



**Figure 4.** Population structure of *Euterpe edulis* based on the proportions of plants at five developmental stages in forest fragments in the Una region, located in the state of Bahia, Brazil.



**Figure 5.** Cluster analysis, illustrating the similarities among *Euterpe edulis* populations, based on the proportions of individuals at the five developmental stages monitored in forest fragments in the Una region, located in the state of Bahia, Brazil.



**Figure 6.** Biplot based on principal component analyses of the relationships that density has with the variables (vectors) of plant size (diameter at ground level, leaf number, and height) at the various developmental stages in *Euterpe edulis* populations in four forest fragments (F1, F2, F3 and F4) in the Una region, located in the state of Bahia, Brazil.

PC – principal component; DGL – diameter at ground level; Leaves – number of leaves; Density – number of individuals *per* ha; s – sapling stage; j – juvenile stage; i – immature stage; a – adult stage.

87.9% of the variation, discriminating the sample units on the right side of the first axis with greater values of plant density, contrasting with greater plant sizes (DGL, height, and number of leaves) on the left side (Fig. 6). In PC1, we observed a consistent pattern of the number of individuals decreasing in parallel with increases in plant size (Fig. 6). The sapling stage had the greatest number of individuals, followed by the juvenile stage, and there were overlaps in

**Table 2.** Correlation matrix of plant size parameters and densities of *Euterpe edulis* populations in four forest fragments in the Una region, located in the state of Bahia, Brazil.

Parameter	Parameter		
	Density	DGL	Height
Density	-		
DGL	-0.76	-	
Height	-0.64	0.95	-
Leaves	-0.72	0.98	0.94

DGL – diameter at ground level; Height – plant height; Leaves – number of leaves.

the densities of these stages between the different fragments (Fig. 6, Tab. 3). In F1 and F2, the density of juvenile plants was similar to that of saplings (Fig. 6, Tab. 3). Adults showed larger plant sizes but lower densities, the density of adults being highest in F1 (Fig. 6, Tab. 3). The second principal component (PC2) explained 10.4% of the remaining variation, discriminating the stages and fragments by plant density and height (Fig. 6, Tab. 3). The PC2 scores for all of the development stages were highest for F1, indicating that the plants there had higher densities and were taller (Fig. 6, Tab. 3). The lowest PC2 scores were for the seedling and juvenile stages in F2, as well as for the immature and adult stages in F3 (Fig. 6, Tab. 3).

## Discussion

The densities of *Euterpe edulis* were higher in the Una forest fragments than in heavily impacted forest remnants (Portela 2008) and protected forest fragments in the state of Rio de Janeiro (Portela *et al.* 2010b), as well as in a forest patch where there was extensive seed predation by agoutis (Fadini *et al.* 2009). However, the densities of the Una populations of *E. edulis* were considerably lower than the 17,000 individuals/ha and 18,000 individuals/ha reported for *E. edulis* populations in fragments of Atlantic Forest in southern and southeastern Brazil, respectively (Reis *et al.* 1996; 2000). This corroborates our hypothesis that the phenotypically and genetically differentiated populations of *E. edulis* in the Una region—constituting the “Bahia” ecotype (Coelho 2010)—have lower densities than do other populations of the species in Brazil, except for the heavily impacted populations.

Although the plant density observed in F1 in the present study was the highest in the Una region, it was significantly lower than that of the high-density areas in the states of São Paulo and Santa Catarina (Reis *et al.* 1996, 2000). However, F1 had a higher density than did a swampland population in the state of São Paulo, where the species was considered abundant (Silva-Matos 2000). These patterns corroborate our assumption that the F1 fragment has the *E. edulis* population in a better conservation status in Una region.

**Table 3.** Density of plants, plant sizes, and eigenvalues of the first and second principal components for the four development stages of *Euterpe edulis* in forest fragments in the Una region, located in the state of Bahia, Brazil.

Stage	Fragment	Density (ind./ha)	Plant size			Eigenvalues	
			DGL (cm)	Height (cm)	N° of leaves	PC1	PC2
			Mean ± SD	Mean ± SD	Mean ± SD		
Sapling	F1	2490	0.74 ± 0.31	8.34 ± 3.68	2.81 ± 1.01	24.80	14.03
	F2	608	0.80 ± 0.32	8.29 ± 3.23	2.64 ± 0.86	14.14	-0.76
	F3	1962	0.80 ± 0.33	8.14 ± 3.17	2.51 ± 0.81	22.06	0.78
	F4	1381	0.66 ± 0.33	8.11 ± 3.28	2.32 ± 0.72	19.24	0.10
Juvenile	F1	1578	2.50 ± 1.50	34.52 ± 19.53	3.28 ± 1.09	16.85	0.46
	F2	373	2.74 ± 1.35	32.28 ± 16.56	3.41 ± 0.79	0.93	-0.90
	F3	789	2.47 ± 1.32	28.47 ± 15.07	2.96 ± 0.86	12.93	-0.47
	F4	746	2.48 ± 1.22	33.48 ± 15.70	2.90 ± 0.85	12.72	-0.52
Immature	F1	389	9.42 ± 2.97	437.11 ± 281.16	6.30 ± 2.40	-0.60	-0.15
	F2	90	9.19 ± 3.50	410.92 ± 224.29	7.29 ± 2.52	-0.90	-0.42
	F3	112	8.74 ± 3.31	275.10 ± 133.37	5.71 ± 1.71	-0.52	-0.63
	F4	154	10.08 ± 3.23	396.43 ± 199.09	6.76 ± 1.86	-0.94	-0.35
Adult	F1	117	14.66 ± 2.62	1291.67 ± 323.63	10.27 ± 2.75	-30.58	0.78
	F2	26	17.10 ± 3.01	948.56 ± 161.90	9.00 ± 3.54	-26.65	0.37
	F3	53	13.74 ± 2.94	696.81 ± 154.61	10.10 ± 1.29	-21.40	0.09
	F4	64	14.08 ± 2.67	773.74 ± 165.04	10.50 ± 1.62	-23.72	0.23

ind. – individuals; DGL – diameter at ground level (above the root cone); SD – standard deviation; PC – principal component.

As expected, the fragment with most restrictive protection status and longer history of protection (F1) had densities similar to those of populations sampled in other long-protected areas in the Una region (Martini, unpublished data; Silva *et al.* 2009), in contrast with F2, F3, and F4, which had lower densities. The Una region is a mosaic of forest fragments and secondary effects of disturbance gradients have been observed within this landscape (Faria *et al.* 2009). During the process of forest fragmentation, many threats to the ecosystem are facilitated, including logging, game hunting, and extraction (Tabarelli *et al.* 2004). Although we attempted to avoid visibly harvested areas, we cannot exclude the possibility that palm hearts were exploited at any given site, especially because such activity has often been observed at Una (A.M.Z. Martini, personal communication). Albeit important, legal protection status alone cannot guarantee the survival and maintenance of palm populations across fragmented landscapes in the Atlantic Forest Biome (Portela *et al.* 2010a). Brazilian law allows the creation of conservation areas with different degrees of protection, from fully protected public sites to sustainably managed private areas (SNUC 2000). Therefore, the degree of protection status combined with the time since gaining that status apparently greatly influences plant demography in the Una region, given that higher densities were found for areas that have been more strictly protected for longer periods of time.

In the present study the proportion of *Euterpe edulis* seedlings ranged from ca. 0.5% to 11.8%, well below the 73%

reported by Reis *et al.* (2000). The formation of abundant seedling banks is a characteristic strategy of the species (Reis *et al.* 1996). Similar patterns of low *E. edulis* seedling bank densities have been observed in areas impacted by harvesting (Portela 2008) and intense seed predation (Fadini *et al.* 2009).

There are a number of factors that could explain the reduced *Euterpe edulis* seed production in the Una region. First, it is possible that reduced fertility (low seed output) is characteristic of the “Bahia” ecotype, which would decrease the probability of successful seed germination at favorable sites, as well as hindering recruitment, thereby limiting the size of the population (Horvitz & Schemske 1995). Second, post-dispersal seed predation rates might regulate seed establishment (Fadini *et al.* 2009). Studies have revealed high rates of seed predation in *E. edulis*, ranging from 71% to 82% in the same forest fragments in the Una region (Melito 2011). Seed predation could lead to a seed-to-seedling bottleneck, given that low probabilities of seedling establishment were observed in the fragments examined (Melito 2011). Recruitment will be greatly affected by high rates of seed predation, as was observed by Fadini *et al.* (2009) in areas of Atlantic Forest on Anchieta Island (in the state of São Paulo). The seeds of *E. edulis* suffer predation by vertebrates such as small rodents (Vieira *et al.* 2003) and white-lipped peccaries (Keuroghlian & Eaton 2008), as well as by specialist scolytid beetles (Allmen *et al.* 2004). These seed predator-plant interactions can vary by season (All-

men *et al.* 2004), by microhabitat (Fleury & Galetti 2004), or even by the level of defaunation (Galetti *et al.* 2006). The foraging behaviors of generalist rodents can respond to *E. edulis* abundance by preying on more seeds at lower (rather than higher) plant densities (Pizo & Vieira 2004). Distinct seed predation patterns in the Una fragments (Melito 2011) could explain the variations seen in the seedling/adult ratio. Third, annual variations in seed production are common in *E. edulis* populations, because the numbers of adults and the numbers of inflorescences per plant both oscillate on a year-to-year basis (Fantini & Guries 2007; Matos & Watkinson 1998). A year of low seed production is usually followed by a reproduction peak, maintaining the influx of individuals into the regeneration bank (Fantini & Guries 2007; Matos & Watkinson 1998). Therefore, the greater density of *E. edulis* in the sapling stage observed for the Una populations in the present study indicate that new individuals were being recruited into the regeneration banks. It is of note that *E. edulis* shows synchronic reproductive phenology (Castro *et al.* 2007). To avoid a potential temporal bias, we sampled all of the forest fragments at the end of the fructification period.

In *Euterpe edulis*, seedling density is usually related to the number of reproductive individuals (Marcos & Matos 2003; Fantini & Guries 2007). However, we did not observe that pattern at the Una sites studied here (except in F2). The survival of *E. edulis* seedlings is generally low and can fluctuate widely among years (Portela *et al.* 2010b). In the Una region, the high rates of seed predation and low rates of seedling recruitment (Melito 2011) are likely to have a negative affect on the seedling/adult ratio (but not the sapling/adult ratio), because of the continuous influx of individuals into the regeneration banks.

The density of *Euterpe edulis* was lower in F2 than in the other Una fragments studied, although the proportional distribution of plants by developmental stage was similar among the fragments. In F2, the density of adults (30 individuals/ha) was lower than the threshold of 50-60 adults/ha considered necessary for the maintenance of natural stands (Freckleton *et al.* 2003). In addition, we found only one seedling in the F2 sample plots. That, combined with the low density of adult plants, resulted in the seedling/adult ratio being lowest for F2, which also had the lowest densities of saplings and juveniles. Although these patterns might have occurred because only a very low-density patch of this population was sampled, they could also indicate that something is limiting seedling establishment. Seedling establishment is affected indirectly by microhabitat heterogeneity and directly by the negative effects of human activities, such as movement through the area and logging (Portela & Santos 2009). The seed limitation processes commonly seen in areas from which adult individuals have been removed or in which the soil has been disturbed lead to restricted seed recruitment (Clark *et al.* 2007). Although we did not observe any signs of palm heart harvesting at the sites evaluated in the present study, it is possible that it was practiced in the

past and that this population is still recovering from the effects of those activities.

The lowest scores for the immature and adult stages were observed in the biplot for F3. Those scores were heavily influenced by the lower values for the plant size parameters, especially DGL and plant height. Sample plots in F3 also showed dissimilarities in the proportions of individuals, especially saplings. Although palm heart harvesting generally focuses on the largest plants (Matos & Bovi 2002), immature individuals will also be taken if there are few reproductive individuals (Matos & Bovi 2002). Reductions in the abundance of larger individuals of *Euterpe edulis* tend to favor the growth of younger individuals (Silva Matos *et al.* 1999; Fantini & Guries 2007).

Certain situations that affect immature plants can be a serious concern, because this stage comprises the future reproductive individuals (Bruna *et al.* 2009). Models estimate more profound impacts on demographic structures when mortality (harvesting) is directed at immature rather than reproductive individuals of *Euterpe edulis* (Freckleton *et al.* 2003). To obtain accurate estimates of the regeneration potential of these populations, recruitment into the immature stage should be monitored, as should survival and growth.

The differences in *Euterpe edulis* plant sizes were generally more accentuated in the larger sizes classes, especially in terms of DGL and height. The number of leaves has been shown to vary less than do diameter and height in *E. edulis* (Reis 1995). The shape of *E. edulis* plants changes over the course of development, because stem diameter does not correlate directly with height (Alves *et al.* 2004). Plants up to 1.25 m in height will allocate resources to widen the stem base, establishing support for later height gains (Silva 1991; Alves *et al.* 2004). Silva *et al.* (2009) suggested that low soil fertility and a closed canopy environment caused by high plant density influences development in *E. edulis* in the Una region, resulting in individuals that are taller and thinner than are those in other populations. As previously noted, harvesting also influences plant size.

Plants in F1 were taller than were those in the other fragments probably because of the absence of harvesting there and higher solar radiation levels along the river bank (Silva 1991). Site quality will influence plant size, as will resource allocation for reproduction (Nathan & Muller-Landau 2000). Fertility has been found to be related to greater access to sunlight (Silva 1991) but not to stem diameter (Matos & Watkinson 1998), and it can positively influence population abundance. The high investment in radial growth seen at F2 might reflect a strategy for competing under the dense canopies observed in older forests or (most likely) might indicate a regenerating population that was affected by past harvesting.

Our results suggest that the Una populations studied, with the exception of the F2 population, exhibit the threshold level of adult densities, as estimated by Freckleton *et al.* (2003), required in order to ensure natural regeneration by the continuous input of seedlings into these populations.

However, it is necessary to quantify the viability of these populations in order to guarantee their temporal persistence, especially because of the low densities observed for all developmental stages, as well as the lower seed production of the “Bahia” ecotype present in the Una region. This approach is especially necessary in the F2 population, which presented the lowest density, not only in the Una region but also in northeastern Brazil at large. The rates of seed predation and seedling establishment influence the demographic rates (e.g., mortality and survivorship) and must be evaluated in order to monitor the continuous recruitment of individuals into those populations. On the basis of this information, the conservation status of *E. edulis* in its northernmost range can be recognized and guidelines for sustainable management can be established. We also underscore the great variations among the forest fragments in the Una region, suggesting that the conservation of *E. edulis* in this landscape must be conducted on a regional scale.

## Acknowledgments

We thank Rodrigo Fadini and Adriana M. Z. Martini, who made their data on *Euterpe edulis* density available; Carolina M. Pinheiro, Fred Hobus, Lukas H. Daneu, and Thiago R. F. Araújo, for their assistance during the fieldwork; and Yonaldo Guedes, for granting us permission to carry out our study on his property. Special thanks go to Bruno Machena, (ICMBio-REBIO Una- Instituto Chico Mendes de Conservação da Biodiversidade da Reserva Biológica de Una) and Tatiana Alves (ICMBio-RVS Una - Instituto Chico Mendes de Conservação da Biodiversidade do Refúgio de Vida Silvestre de Una) for all of their support in conducting this work. We are also grateful to the *Universidade Estadual de Santa Cruz* (UESC), the CEPEC Herbarium of the Centro de Pesquisas do Cacau (CEPLAC), and the ICMBio-REBIO Una, for the logistic support and infrastructure provided. This study received financial support from the *Fundação de Amparo à Pesquisa do Estado da Bahia* (FAPESB, grant no. BOL0524/2009), the UESC (Grant no. 00220.1100.773), the UESC Master's Program in Ecology and Conservation, and the Brazilian *Conselho Nacional de Desenvolvimento Científico e Tecnológico* (CNPq; productivity grant no. DEB 306992/2012-4 to AMA).

## References

Alger, K. & Caldas, M. 1994. The declining cocoa economy and the Atlantic forest of Southern Bahia, Brazil: conservation attitudes of cocoa planters. *Environmentalist* 14(2): 107-119.

Allmen, C.V.; Morellato, L.P.C. & Pizo, M. A. 2004. Seed predation under high seed density condition: the palm *Euterpe edulis* in the Brazilian Atlantic Forest. *Journal of Tropical Ecology* 20(4): 471-474.

Alves, L.F.; Martins, F.R. & Santos, F.A.M. 2004. Allometry of a neotropical palm, *Euterpe edulis* Mart. *Acta Botanica Brasilica* 18(2): 369-374.

Amorim, A.M.; Thomas, W.; Carvalho, A.M.V. & Jardim, J.G. 2008. Floristics of the Una Biological Reserve, Bahia, Brazil. Pp. 67-146. In: W.

Thomas (Ed.). *The Atlantic Coastal Forest of Northeastern Brazil*, The New York Botanical Garden Press, Bronx, New York.

Andreazzi, C.S.; Pires, A.S. & Fernandez, F.A.S. 2009. Mamíferos e palmeiras neotropicais: interações em paisagens fragmentadas. *Oecologia Brasiliensis* 13(4): 554-574.

Bovi, M.L., Godoy Jr, G. & Sáes, L.A. 1987. Pesquisas com o gênero *Euterpe* e *Bactris* no Instituto Agrônomo de Campinas. *O agrônomo* 39(2): 129-174.

Bruna, E.M. & Kress, W.J. 2002. Habitat fragmentation and the demographic structure of an amazonian understory herb (*Heliconia acuminata*). *Conservation Biology* 16(5): 1256-1266.

Bruna, E.M.; Fiske, I.J. & Trager, M.D. 2009. Habitat fragmentation and plant populations: is what we know demographically irrelevant? *Journal of Vegetation Science* 20(3): 569-576.

Carvalho Filho, R.; Melo, A.A.; Santana, S.O. & Leão, A.C. 1987. Solos do município de Ilhéus. *Comissão Executiva do Plano da Lavoura Cacaueira*, Ilhéus, BA.

Castro, E.R.; Galetti, M. & Morellato, P.C. 2007. Reproductive phenology of *Euterpe edulis* (Arecaceae) along a gradient in the Atlantic rainforest of Brazil. *Australian Journal of Botany* 55(7):725-735.

Clark, C.J.; Poulsen, J.R.; Levey, D.J. & Osenberg, C.W. 2007. Are plant populations seed limited? A critique and meta-analysis of seed addition experiments. *The American Naturalist* 170(1): 128-42.

Coelho, G. 2010. *Estrutura genética populacional em morfotipos de Euterpe edulis*. Master thesis, Ilheus, UESC.

Donoso, D.S., Grez, A.A. & Simonetti, J.A. 2003. Effects of forest fragmentation on the granivory of differently sized seeds. *Biological Conservation* 115(1): 63-70.

Fadini, R.F.; Fleury, M.; Donatti, C.I. & Galetti, M. 2009. Effects of frugivore impoverishment and seed predators on the recruitment of a keystone palm. *Acta Oecologica* 35(2): 188-196.

Fantini, A. & Guries, R. 2007. Forest structure and productivity of palmitheiro (*Euterpe edulis* Martius) in the Brazilian Mata Atlântica. *Forest Ecology and Management* 242(2-3): 185-194.

Faria, D.; Mariano-Neto, E.; Martini, A.M.Z.; Ortiz, J.V.; Montingelli, R.; Rosso, S.; Paciencia, M.L.B. & Baumgarten, J. 2009. Forest structure in a mosaic of rainforest sites: The effect of fragmentation and recovery after clear cut. *Forest Ecology and Management* 257(11): 2226-2234.

Fleury, M. & Galetti, M. 2004. Effects of microhabitat on palm seed predation in two forest fragments in southeast Brazil. *Acta Oecologica* 26(3): 179-184.

Freckleton, R.P.; Matos, D.M.S.; Bovi, M.L. & Watkinson, A.R. 2003. Predicting the impacts of harvesting using structured population models: the importance of density-dependence and timing of harvest for a tropical palm tree. *Journal of Applied Ecology* 40(5): 846-858.

Gabriel, K.R. 1971. The biplot graphic display of matrices with application to principal component analysis. *Biometrika* 58(3): 453-467.

Galetti, M. & Aleixo, A. 1998. Effects of palm heart harvesting on avian frugivores in the Atlantic rain forest of Brazil. *Journal of Applied Ecology* 35(2): 286-293.

Galetti, M.; Donatti, C.I.; Pires, A.S.; Guimaraes, P.R. & Jordano, P. 2006. Seed survival and dispersal of an endemic Atlantic forest palm: the combined effects of defaunation and forest fragmentation. *Botanical Journal of the Linnean Society* 151(1): 141-149.

Galetti, M. & Fernandez, J.C. 1998. Palm heart harvesting in the Brazilian Atlantic forest: changes in industry structure and the illegal trade. *Journal of Applied Ecology* 35(2): 294-301.

Henderson, A.; Galeano, G. & Bernal, R. 1995. *Field guide to the palms of the Americas*. New Jersey, Princeton University Press.

Horvitz, C.C. & Schemske, D.W. 1995. Spatiotemporal variation in demographic transitions of a tropical understory herb: projection matrix analysis. *Ecological Monographs* 65(2): 155-192.

Hulme, P.E. 1998. Post-dispersal seed predation: consequences for plant demography and evolution. *Perspectives in Plant Ecology, Evolution and Systematics* 1(1): 32-46.

Keuroghlian, A. & Eaton, D.P. 2008. Removal of palm fruits and ecosystem engineering in palm stands by white-lipped peccaries (*Tayassu pecari*) and other frugivores in an isolated Atlantic Forest fragment. *Biodiversity and Conservation* 18(7): 1733-1750.

- Marcos, C.S. & Matos, D.M.S. 2003. Estrutura de populações de palmitreiro (*Euterpe edulis* Mart.) em áreas com diferentes graus de impactação na floresta da Tijuca, RJ. **Floresta e Ambiente** 10(1): 27-37.
- Martini, A.M.Z.; Fiaschi, P.; Amorim, A. & Paixão, J.L. 2007. A hot-point within a hot-spot: a high diversity site in Brazil's Atlantic Forest. **Biodiversity and Conservation** 16: 3111-3128.
- Matos, D.M.S & Bovi, M. 2002. Understanding the threats to biological diversity in southeastern Brazil. **Biodiversity and Conservation** 11(10): 1747-1758.
- Matos, D.M.S. & Watkinson, A. R. 1998. The fecundity, seed, and seedling ecology of the edible palm *Euterpe edulis* in Southeastern Brazil. **Biotropica** 30(4): 595-603.
- Melito, M.O. 2011. **Efeito da fragmentação florestal na predação de sementes e estrutura populacional de *Euterpe edulis* (Mart.) no sul da Bahia**. Master thesis, Ilheus, UESC.
- Mesquita, A.C. 1996. A atividade madeireira na região cacauzeira. In: **Alternativas para o desenvolvimento e conservação da região de Una**. Resumos de pesquisa. Instituto de Estudos Sócio Ambientais do Sul da Bahia, IESB. Ilhéus, Bahia.
- Meyer, E.S. & Dornelles, S.S. 2003. Demografia do palmitreiro *Euterpe edulis* (Arecaceae) na floresta ombrófila densa de terras baixas em regeneração, na região da Vila da Glória, São Francisco do Sul (SC). **Revista Saúde e Ambiente** 4(2): 7-13.
- Mori, S.A.; Boom, B.B.; Carvalho, A.M. & Santos, T.S. 1983. Southern Bahia moist forests. **The Botanical Review** 49(2):155-232.
- Nathan, R. & Muller-Landau, H. 2000. Spatial patterns of seed dispersal, their determinants and consequences for recruitment. **Trends in Ecology & Evolution** 15(7): 278-285.
- Pardini, R. 2001. **Pequenos mamíferos e a fragmentação da Mata Atlântica de Una, Sul da Bahia - Processos e Conservação**. Ph.D. thesis, São Paulo, USP.
- Pardini, R. 2004. Effects of forest fragmentation on small mammals in an Atlantic forest landscape. **Biodiversity and Conservation** 13(13): 2567-2586.
- Pizo, M. a & Vieira, E.M. 2004. Palm harvesting affects seed predation of *Euterpe edulis*, a threatened palm of the Brazilian Atlantic Forest. **Brazilian Journal of Biology** 64(3b): 669-76
- Portela, R.D.C. 2008. **Ecologia populacional de três espécies de palmeiras em uma paisagem fragmentada no domínio da Mata Atlântica, RJ**. Ph.D. thesis, Campinas, UNICAMP.
- Portela, R.D.C.; Bruna, E.M. & Santos, F.A.M. 2010a. Demography of palm species in Brazil's Atlantic forest: a comparison of harvested and unharvested species using matrix models. **Biodiversity and Conservation** 19(8): 2389-2403.
- Portela, R.D.C.; Bruna, E.M. & Santos, F.A.M. 2010b. Are protected areas really protecting populations? A test with with an Atlantic rain forest palm. **Tropical Conservation Science** 3(4): 361-372.
- Portela, R.D.C. & Santos, F.A.M. 2009. Mortality and mechanical damage of seedlings in different size fragments of the Brazilian Atlantic Forest. **Tropical Ecology** 50(2): 267-275.
- R Development Core Team. 2009. **A language and environment for statistical computing**. Vienna, R Foundation for Statistical Computing.
- Raupp, S.V., Brack, P. & Carvalho Leite, S.L. 2009. Aspectos demográficos de palmitreiro (*Euterpe edulis* Mart.) em uma área da Floresta Atlântica de Encosta em Maquiné, Rio Grande do Sul. **IHERINGIA** 64(1): 57-61.
- Reis, A. 1995. **Dispersão de sementes de *Euterpe edulis* Martius (Palmae) em uma Floresta Ombrófila Densa Montana da encosta atlântica em Blumenau, SC**. Ph.D. thesis, Campinas, UNICAMP.
- Reis, A.; Kageyama, P.Y.; Reis, M.S. & Fantini, A. 1996. Demografia de *Euterpe edulis* Martius (Arecaceae) em uma Floresta Ombrófila Densa Montana, em Blumenau (SC). **Sellowia** 45-48: 13-45.
- 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(4b): 894-902.
- Saatchi, S. Agosti, D., Alger, K., Delabie, J. & Musinsky, J. 2001. Examining fragmentation and loss of primary forest in the southern Bahian Atlantic Forest of Brazil with radar imagery. **Conservation Biology** 15(4): 865-875.
- Scariot, A. 1999. Forest fragmentation effects on palm diversity in central Amazonia. **Journal of Ecology** 87(1): 66-76.
- Silva Matos, D.M. 2000. Herbivore and plant demography: a case study in a fragment of semi-deciduous forest in Brazil. **Journal of Tropical Ecology** 16(1): 159-165.
- Silva Matos, D.M.; Freckleton, R.P. & Watkinson, A.R. 1999. The role of density dependence in the population dynamics of a tropical palm. **Ecology** 80(8): 2635-2650.
- Silva, D.M. 1991. **Estrutura de tamanho e padrão espacial de uma população de *Euterpe edulis* Mart. (Arecaceae) em mata mesófila semidecídua no município de Campinas, SP**. Master thesis, Campinas, UNICAMP.
- Silva, M.D.G.C.P.C.; Martini, A.M.Z. & Araújo, Q.R.D. 2009. Estrutura populacional de *Euterpe edulis* Mart. no Sul da Bahia, Brasil. **Revista Brasileira de Botânica** 32(2): 393-403.
- SNUC. 2000. **Sistema Nacional de Unidades de Conservação**. Lei nº 9.985, de 18 de julho de 2000.
- Tabarelli, M.; Cardoso da Silva, J.M. & Gascon, C. 2004. Forest fragmentation, synergisms and the impoverishment of neotropical forests. **Biodiversity and Conservation** 13(7): 1419-1425.
- Thomas, W.W., Carvalho, A.M.V., Amorim, A.M., Hanks, J.G. & Santos, T.S. 2008. Diversity of woody plants in the Atlantic forest of southern Bahia, Brazil. Pp. 21-66. In: W.W. Thomas (ed.). **The Atlantic Coastal Forest of Northeastern Brazil**. New York, The New York Botanical Garden Press.
- Thomas, W.M.W.; Carvalho, A.M.V.D.E.; Amorim, A.M.A.; Garrison, J. & Arbeláez, A.L. 1998. Plant endemism in two forests in southern Bahia, Brazil. **Biodiversity and Conservation** 7(3): 311-322.
- Uhl, N.W. & Dransfield, J. 1987. **Genera Palmarum. A classification of palms based on the work of Harold E. Moore, Jr.** Lawrence, Allen Press.
- Vieira, E.; Pizo, M. & Izar, P. 2003. Fruit and seed exploitation by small rodents of the Brazilian Atlantic forest. **Mammalia** 67(4): 533-540.
- Virillo, C.B.; Martini, F.R.; Tamashiro, J.Y. & Santos, F.A.M. 2011. Is size structure a good measure of future trends of plant populations? An empirical approach using five woody species from the Cerrado (Brazilian savanna). **Acta Botanica Brasílica** 25(3): 593-600.
- Zar, J. 2009. **Biostatistical analysis**. Englewood Cliffs. Prentice-Hall.