Journal of Geoscience and Environment Protection, 2023, 11, 151-162
https://www.scirp.org/journal/gep
ISSN Online: 2327-4344
ISSN Print: 2327-4336

The Harvesting of the Endangered Palm *Euterpe edulis* in the Brazilian Atlantic Forest: The Case of Linear Canopy Openings

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How to cite this paper: Rodrigues, P. J. F. P., de Andrade Iguatemy, M., & Reis, T. (2023). The Harvesting of the Endangered Palm *Euterpe edulis* in the Brazilian Atlantic Forest: The Case of Linear Canopy Openings. *Journal of Geoscience and Environment Protection, 11,* 151-162.
https://doi.org/10.4236/gep.2023.1112008

Received: November 9, 2023
Accepted: December 26, 2023
Published: December 29, 2023

Abstract

The palm *Euterpe edulis* was historically very exploited by humans and even today, many individuals are cut down by collectors to harvest the edible palm hearts. The ecological aspects of this anthropogenic pressure and its related effects are poorly understood. Here we investigate if linear canopy openings in a fragment of Brazilian Atlantic Forest can cause edge effects and facilitate predatory harvesting by humans. We sampled in Tinguá Biological Reserve (Southeastern Brazil) native palm populations at forest edges adjacent to two linear canopy openings, and in the forest interior far from any edge. Our 8-year monitoring showed that the linear canopy openings negatively affected the palm populations reducing its density and regeneration mainly on edges, but no local extinction was observed. Thus, the direct human impact from harvesting, adverse survival conditions on edges and interspecific competition causes population declines with no local extinction, so this suggests that *E. edulis* may resist even under strong anthropogenic pressure.

Keywords

Extinction, Exploitation, Forest Product, Species Survival, Sustainability

1. Introduction

Exploitation of forest's natural resources may alter species abundance and cause profound changes in ecosystems, especially when they are close to human populations. Many other human activities such as the expansion of cities, mining and agriculture, also lead to species loss and cause habitat degradation, extinction and forest fragmentation. In such cases remnant forest fragments may be directly damaged and/or subjected to edge effects. Besides the direct damage to the species on the edges, these peculiar edge effects may lead to changes such as increases in vegetation dynamics and tree mortality (Malcon, 1994; Laurance et al., 1998a, 1998b; Haddad et al., 2015). Thus, endangered tree species like the Neotropical palm *Euterpe edulis* (CNCFlora, 2023), which is a very important non-timber product, may eventually disappear from these forests, especially if they are permanently impacted (Reis et al., 2000; Silva-Matos & Bovi, 2002).

Many structural and functional changes in vegetation arising from shifts in abiotic and biotic conditions can be expected along forest edges (Bierregaard Jr. et al., 1992; Murcia, 1995; Harper et al., 2005). Moreover, edge-interior micro climate gradients occur, mainly because light and wind intensity increase near the edges (Lovejoy, 1998), which can raise the air temperature and reduce the vapor-pressure deficit and soil moisture (Kapos et al., 1997; Pohlman et al., 2007; Magnago et al., 2015), leading to high mortality (Laurance et al., 2000), low recruitment, damage and falling of trees (Lovejoy, 1998; Ferreira & Laurance, 1997; Pütz et al., 2011).

In view of these changes in the forest, would be expected some increase in the density of small trees, followed by losses in biomass by the big trees exclusion (Kapos et al., 1997; Laurance et al., 2000; Ries et al., 2004; Pütz et al., 2014), as well as species extinctions (Saunders et al., 1991; Tilman, 1999; Tabarelli & Gascon, 2004), impoverished communities on edges and in small fragments and biotic homogenization (Lobo et al., 2011). However, there are forest fragments, where populations of this endangered palm species survive, despite the great human pressure.

Brazilian Atlantic Forest in the past covered 1.1 million km^2, extending from the states of Rio Grande do Norte to Rio Grande do Sul (Morellato & Haddad, 2000) and today this forest is reduced to only 11% of its former area (Ribeiro et al., 2009). Still this small portion of remnant forests is home to a large number of species and represents a global hotspot with high diversity and concentration of threatened endemic species (Myers et al., 2000). In tropical forests worldwide, many species are at risk of extinction, mainly due to direct exploitation, agriculture, global warming, construction of highways and expansion of cities (Mittermeier et al., 2004), which also lead to habitat loss and fragmentation (Myers et al., 2000; Morellato & Haddad, 2000; Rodrigues & Nascimento, 2006; Haddad et al., 2015).

In the case of the *E. edulis* palm, a native species of the Atlantic forest, which occurs along the entire Brazilian coast with an upper altitudinal limit around 1,000 m, its exploitation was historically very intense and it is currently considered a vulnerable species (CNCFlora, 2023). Its use by humans occurs mainly through felling to obtain the palm heart, which is formed by the apical meristem with undifferentiated young leaves (Reis et al., 2000). Today, in some areas, one person may cut more than 100 individuals per day to harvest the edible palm hearts (Silva-Matos & Bovi, 2002). These impacts can result in even smaller and more-degraded palm populations with genetic erosion (Santos et al., 2015). On the other hand, other uses may provide some type of sustainable management if only the palm fruits were collected. In this case it is necessary to consider local population patterns and the demographic and ecological dynamics (Brancalion et al., 2012). However, preventing man-made damage is not a simple task. Forest-based livelihoods in some cases may improve nutrition and food security, and increase household incomes (Reis et al., 2000). Nevertheless, the harvest is a criminal activity when it is done inside a legally protected area.

While oil-pipeline canopy openings represent a threat to biodiversity in tropical forests, they can also be used as field experiments (Prieto et al., 2014). Here, such man-made openings, created inside a protected area, were suitable to determine if linear canopy openings cause edge effects and facilitate the harvest of the endangered palm *E. edulis*. How well this species can survive in these forests and what kind of transformation they might undergo are still unanswered questions.

2. Methods

Tinguá Biological Reserve in the state of Rio de Janeiro, Brazil, includes 26,000 ha of old-growth Atlantic Forest fragments (22˚28'S to 22˚39'S and 43˚13'W to 43˚34'W). The relief is hilly and the climate is Cwb (Köppen) with temperature ranging from 13˚C to 23˚C and mean annual rainfall of 1500 - 2600 mm. The palm tree *E. edulis* is found in the Atlantic forest, mainly in wet forest sites, and its populations with spatial aggregate distributions usually exhibit extensive seedling stands (Silva-Matos et al., 1999), as observed in the Tinguá Reserve. Its fruits are very appreciated by birds (Galetti & Aleixo, 1998) and its recalcitrant seeds usually germinate when they drop to the forest floor (Roberto & Habermann, 2010).

The forest in the Tinguá Reserve is fragmented but relatively well preserved compared to other Atlantic Forest sites, and human pressures consist primarily of selective harvest of palm hearts, hunting, small roads, pollution and the construction of linear canopy openings. These openings (width 25 meters) are here termed Old Pipeline (OldP), which was built on a 300-year-old road, and New Pipeline (NewP) which is about 40 years old (Rodrigues et al., 2016).

In order to evaluate the edge effects and direct human impact on *E. edulis* populations densities, in the year 2007 we established 37 permanent plots (each 10 m × 30 m; total sampled area 1.1 ha; ranged from 500 - 700 meters a.s.l.) inside local palm populations distributed in one treatment with three levels: edges of OldP (10 plots), edges of NewP (9 plots), and Forest Interior (18 plots; control sites more than 400 m from any edge). Inside each sample plot, all palm trees with a diameter at breast height (DBH) ≥ 5 cm were counted annually during the 2007-2014 study period. The palm density was provided for each year and treatment level with 95% confidence intervals estimated through a non-parametric bootstrap analysis. This consisted of resampling plots with replacement from the datasets and recalculating the statistics (N = 1000 trials). We inferred whether there were significant differences among treatment levels by checking for non-overlapping confidence limits. Size distributions were compared between treatment levels each year using DBH measures and the Kolmogorov-Smirnov test with a Bonferroni correction for multiple comparisons (Sokal & Rohlf, 1995).

3. Results

Euterpe edulis palm populations in all years showed a clear pattern of lower density in the edges (**Figure 1**; **Table 1**) and felled individuals were observed in all the populations sampled, including in the forest interior (**Figure 2**). But even in the most impacted sites no populational extinctions were observed during the study period (**Figure 3**).

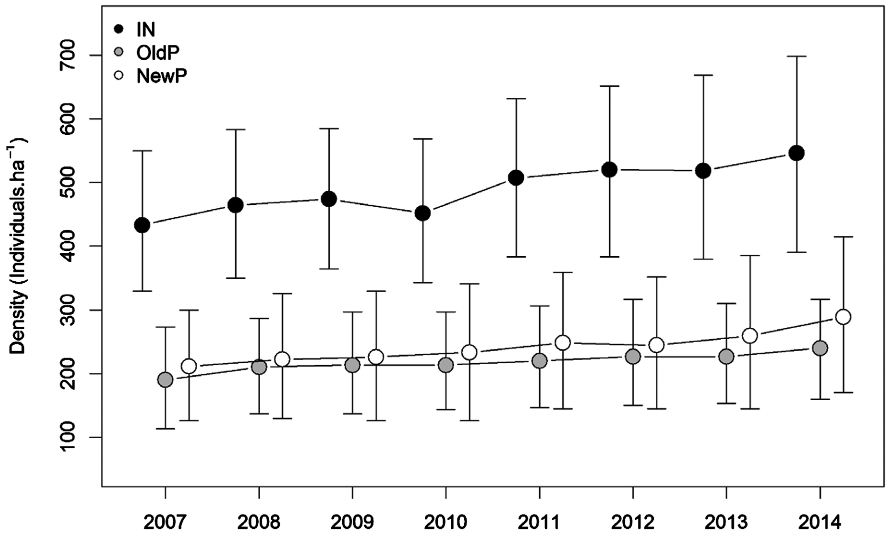

Figure 1. Palm density with bootstrapped 95% confidence intervals for the palm *Euterpe edulis* in each census year and treatment level in the Atlantic Forest of southeastern Brazil.

Table 1. Comparisons between populations size distributions of the palm *Euterpe edulis* in the treatment levels Old Pipeline (OldP), New Pipeline (NewP) and Forest Interior (IN), in the Atlantic Forest of Brazil during the 2007-2014 year demographic censuses. The maximum differences between cumulative size distributions (Dmax) after Kolmogorov-Smirnov tests are presented.

	IN vs. OldP	IN vs. NewP	OldP vs. NewP
2007	0.135^{NS}	0.419**	0.326*
2008	0.121^{NS}	0.416**	0.344*
2009	0.130^{NS}	0.400**	0.342*
2010	0.175^{NS}	0.386**	0.292*
2011	0.128^{NS}	0.318**	0.240^{NS}
2012	0.140^{NS}	0.285*	0.210^{NS}
2013	0.172^{NS}	0.345**	0.311*
2014	0.143^{NS}	0.227*	0.157^{NS}

Significance codes: ^{NS} Non-significant, * $P < 0.05$, ** $P < 0.002$ (Bonferroni α-corrected).

Figure 2. Individuals of the palm *Euterpe edulis* cut down in 2006 year to harvest the palm hearts in the treatment Forest Interior (IN) in the Tinguá Biological Reserve (Brazil).

The persistence of local *E. edulis* populations suggests that this species can resist even on impacted edge sites. The reduction in population densities seems to be related to the ease access of collectors and the maintenance of the forest abrupt limit caused by the linear canopy opening (where the two oil pipelines are located). Still, the number of palms in the forest interior sites, over the years, was about two times higher when compared to edges. In addition, palm populations showed better structure in the forest interior with size structure skewed toward smaller individuals. Small individuals, which represent future generations, had a low density in the New Pipeline in all years (**Table 1**) suggesting a very low recruitment on edges.

In 2007-2014 period the size structure along Old Pipeline was similar to that in the Forest Interior, which might indicate that the Forest Interior had a higher frequency of juveniles and consequently greater regeneration (**Figure 3**; **Table 1**).

4. Discussion

Population patterns, species interactions and resource availability may be changed by edge effects (Saunders et al., 1991; Laurance et al., 1998a; Gascon et al., 1999; Laurance, 2000) which are changes in vegetation structure and functioning on the anthropogenic edges caused by the new abiotic and biotic conditions of these sites (Murcia, 1995; Rodrigues & Nascimento, 2006) and other human activities (Chure et al., 2022), leading in some cases to increases in mortality or recruitment (Lovejoy et al., 1986; Ferreira & Laurance, 1997). In tropical forests, edge effects and human influence can profoundly alter successional pathways (Laurance et al., 2007; Joly et al., 2014; Pütz et al., 2011) and the proximity to cities, or other types of human settlements, increases the risk of anthropogenic transformation (Pena-Rodrigues & Lira, 2019) and direct damage. In the Tinguá Biological Reserve, some native tree species (Iguatemy et al., 2017) showed high density of recruits and juveniles, probably because of the higher light availability on the edge sites. Otherwise, the *E. edulis* palm exhibited in all years a clear pattern of lower density and regeneration in the edge sites. Other

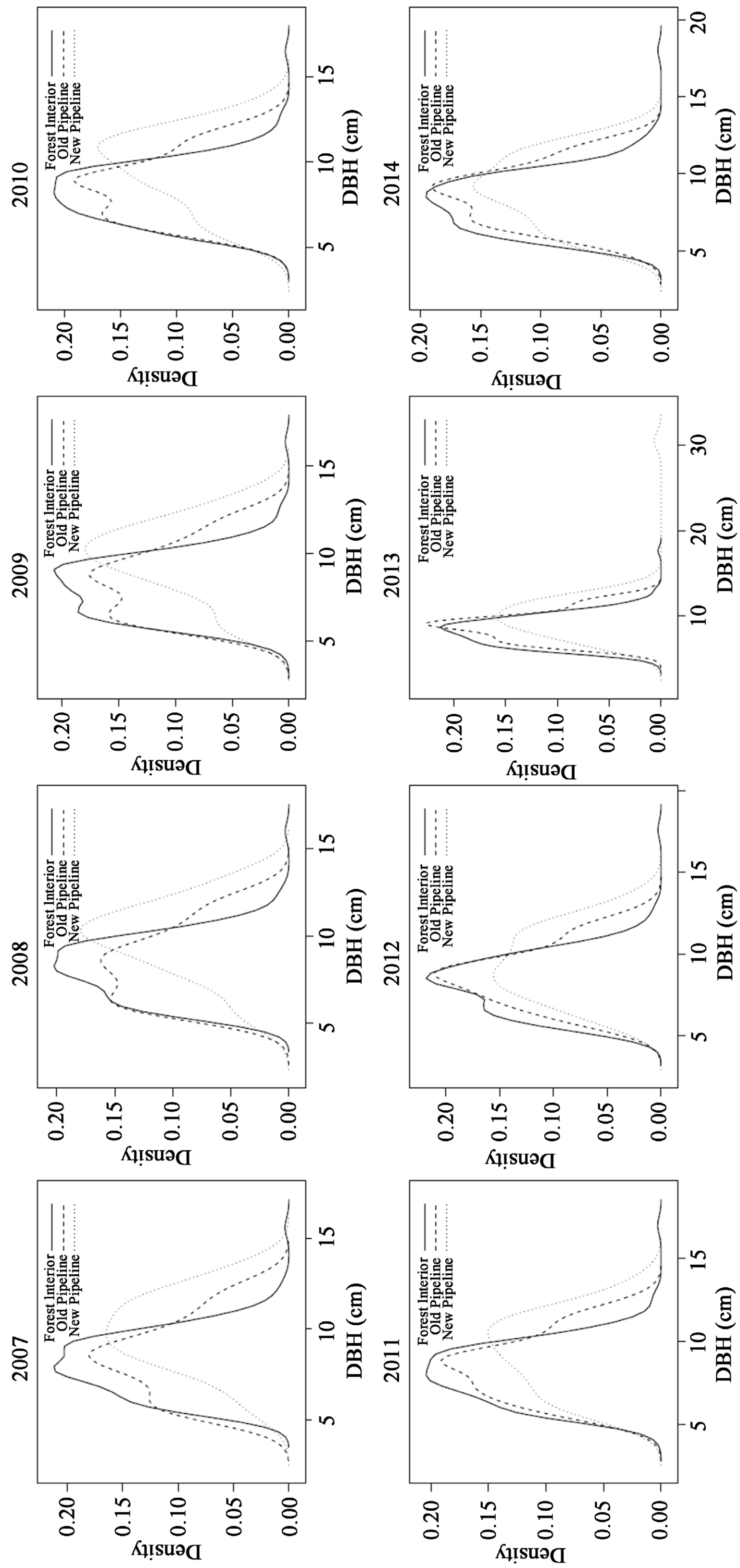

Figure 3. Population size structure of the palm *Euterpe edulis* in the treatment levels Old Pipeline (OldP), New Pipeline (NewP) and Forest Interior (IN) in the Atlantic Forest of Tinguá Biological Reserve (Southeastern Brazil) during the 2007-2014 demographic censuses.

population surveys showed that this palm can show lower densities as a function of altitudinal gradients (Souza et al., 2018) and to control for this effect our sample plots were established between 500 and 700 m a.s.l. Then, canopy openness in edge sites, with more-intense light and wind and ease access of collectors, seems to favor human-induced mortality patterns that results in *E. edulis* low densities.

Moreover, under both deep shade and full sunlight, and in high temperatures the palm *E. edulis* shows a growth reduction and a decline in competitive ability (Nakazono et al., 2001). Therefore, it is expected that in typical edge sites or canopy gaps, the higher light and temperature may also reduce the palm performance (Gatti et al., 2014). Long-term studies on tropical forest edges showed an increase in the density of other native tree species, which seems to acclimate more easily to these edge conditions (Rodrigues et al., 2016; Iguatemy et al., 2017; Costa et al., 2021) increasing the competition among species in these sites. Thus, *E. edulis* palm, in addition to experiencing adverse conditions for the survival of its individuals, may also be subjected to inter specific competition, especially with fast-growing pioneer species that are commonly established on these edges. Our study did not evaluate the palm seedlings abundance, which tend to be very high at all studied sites. In this sense, the differences in densities that we found are only relative to fully established juveniles and adults. Thus, lower density at the edges is a pattern that involves many ecological aspects, of *E. edulis* mortality by human pressures, such as the direct damage by harvesting or indirect damage through edge effects, pollution, loose of pollinators, fertilizers, pathogen infestation, and pesticides. Also, other studies carried out in the Atlantic Forest have shown that the forest structure that surrounds the palm populations (Leal et al., 2022) and direct damage caused by primates, especially in edge areas (Portela & Dirzo, 2020), can negatively influence the recruitment of this palm species.

In some tropical forests, nearly 15 to 35% of the biomass is lost in the first 5 - 10 years after fragmentation, due to high mortality mainly on edges (Laurance et al., 1998a). On the other hand the establishment of small pioneer trees and the changes in successional pathways (Pütz et al., 2011; Saunders et al., 1991; Matlack, 1994) lead to a higher density of small individuals that are potentially fragile and exhibit higher mortality (Augspurger, 1984; Turner & Corlett, 1996; Steven, 1997; Rodrigues et al., 2014), and therefore the forest dynamics tends to be accelerated in edges (Laurance, 2002; Haddad et al., 2015). However, as time passes edge effects may be attenuated (Saunders et al., 1991) by some type of protective vegetation. But still, maintenance of the abrupt forest limit (along the pipelines) and the proximity to shrubby or herbaceous vegetation can favor human pressures (Gascon et al., 1999). While these linear canopy openings may appear less harmful, especially when compared to fire-prone sites, agricultural fields (Prieto et al., 2014) and forest islands (Benchimol & Peres, 2015), they also can facilitate human impacts such as the entry of hunters and collectors. On the other hand, *E. edulis* has been managed for many centuries and the human intervention can be also positive through restoration, management (Leal et al., 2022) and fruit harvesting.

5. Conclusion

Monitoring of *E. edulis* palm populations over 8 years showed a pattern of lower density in forest sites along linear canopy openings due to edge effects. On the other hand, the predatory harvesting of the palm, all over the forest remnant for palm heart extraction, suggests that these openings facilitate the entry of palm heart collectors and that this human action may exacerbate the change in the natural density pattern of the palm between the interior and the forest edge. This change, however, has not led to the local extinction of the species, even at the edge sites, indicating that, despite being threatened, the species seems to be highly resistant to human impacts.

Acknowledgements

We thank Walter Silva and Adilson Pintor for fieldwork assistance, ICMBio for logistical facilities, two anonymous reviewers for their suggestions and Thiago F.C.P. Rodrigues for linguistic advice.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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