Roads and Mangrove Deforestation in Eastern Azuero Peninsula, Panama

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Introduction

The growth of the human population causes an increase in land use conversion (Meyer et al. 1992), which accounts for a large percentage of biodiversity loss worldwide (Sala et al. 2000; Hansen et al. 2004; Krauss et al. 2010). The extremely diverse neotropical areas are particularly at risk due to their high density of population (Cincotta et al. 2000). Furthermore, as the poverty level increases the threat to conservation of biodiversity (Sachs et al. 2009), unequal income distribution (Hammill 2007) makes this region even more at risk. Many ecosystems are affected by this phenomenon, including mountains (Martínez et al. 2008), lowland forests (Rompré et al. 2008), and mangroves (Lacerda and Schaeffer-Novelli 1999; López-Angarita et al. 2016). The latter ecosystem is critically endangered in Panama, since intense coastal development causes habitat loss (Benfield et al. 2005; Rompré et al. 2008), and degradation (D'Croz 1988; Defew et al. 2005). Furthermore, as it is the case with most tropical forests, these forests are affected by land conversion such as deforestation for agriculture (Geist and Lambin 2002). The urgency of the situation requires rapid implementation of conservation measures to restrict coastal development in order to conserve mangrove forests.

Mangroves are generally seen as an economic resource, for example red mangroves are used for poles, black mangroves for planks and pilings (Blanco et al. 2012), as well as being generally used for firewood and charcoal (Warren-Rhodes et al. 2011). Nonetheless, the ecosystem services these forests provide are numerous. For instance, they act as crucial nursery habitat for fish communities, many of which are commercially harvested (Mumby et al. 2004; Nagelkerken et al. 2007), and they are resilient to sea-level rise and, to some extent, tsunamis (Kathiresan and Rajendran 2005, Alongi 2007) by reducing shoreline erosion (Rönnbäck 1999).

Mangrove forests are also capable of storing and sequestering atmospheric carbon better than other coastal habitats (Chumra et al. 2003; Komiyama et al. 2007).

Ecotourism is often a suggested option as a way to protect ecosystems at risk while managing increasing human interactions with these ecosystems. Allowing both biodiversity protection and economic growth, ecotourism has been proven to be successful across the globe (Masberg and Morales 1999; Stronza and Pegas 2008; Dodds et al. 2018; Howitt and Mason 2018; Deacon and Tutchings 2019). More specifically, community-based ecotourism is used as a sustainable management of the mangroves in different parts of the world (Foucat 2002; Satyanarayana et al. 2012), but participation of the community is needed in order to successfully achieve the objectives (Jones et al. 2005; Datta et al. 2012; Idajati et al. 2015).

Nonetheless, during the last two decades, the conservation success of ecotourism has been questioned due to its environmental impact on the ecosystems (Weaver and Lawton 2007; Donnelly et al. 2011; Wabnitz et al. 2017). The creation of trails in remote areas can promote forest destruction through access facilitation, which raises questions about the extent of damage the construction of a road or trail can do to a protected area. Indeed, many studies have shown the impact of the implementation of a road on local fauna (Garriga et al. 2012), flora (Godefroid and Koedam 2004), and human activity (Clapham et al. 2008). Although, the creation of roads in remote areas is not always related to ecotourism, this latter activity generally promotes implementation of infrastructure in isolated areas (He et al. 2008). Additionally, the outcome is the same no matter the cause of the construction of a road. Incidentally, investigating the subject can be relevant to any kind of development project in remote areas, including ecotourism.

Thus, this research project aims to assess the effect of road vicinity on mangrove deforestation. In particular, we want to determine the number of tree cuts and the tree size classes between a mangrove close to a road to one far from a road. We expect to directly notice the effect of deforestation on forests closer to roads by finding a higher number of tree cuts. Furthermore, as the abundant Red Mangrove (*Rhizophora sp.*) is often used as firewood (Ewel et al. 1998), we expect small trees, more convenient for firewood use (Abbot and Lowore 1998), to be more frequently cut. We thus also hypothesize that small trees will have lower frequency in areas close to the road, a pattern observed in Walters 2005.

Situated in a region undergoing coastal development and encompassing many mangrove forests, the Pablo Arturo Barrios Wildlife Refuge (Fig 1) is a local example of mangrove's worldwide stakes. The absence of regulation and management plan for the refuge makes it difficult to protect (Gagné-Landmann 2017) and the deforestation ongoing in Panama added to the local touristic development (Proyecto Ecologico Azuero 2010) threatens even more the forest within the refuge.

Fig. 1 Map of the Pablo Arturo Barrios Wildlife Refuge

The Proyecto Ecologico Azuero (PEA), an NGO located in Pedasí aims to promote sustainability and conservation in Panama and works on the development of a more environmentally conscious youth by organizing activities for kids of the community. Moreover, PEA considers making a mangrove trail in the area (R. Metzel, personal communication, January 14, 2019) as an attempt to protect the mangrove forests in the refuge. This trail would be an incentive for the community to protect the forest and keep them intact as well as promote a new, more sustainable tourism in the area while educating tourists and locals about the importance of mangrove forests. Nevertheless, pressures on the refuge need immediate management plan, which itself needs an evaluation of the benefits and the drawbacks of the possible options.

Hence, this paper aims to examine the general effect of coastal development and ecotourism on mangrove forest deforestation near Pedasí, through an impact assessment of road creation.

Methods

The study area is situated in the Eastern Azuero Peninsula, in Panama (Fig. 2). This part of the country is characterized by a drier climate, with very limited precipitations during the dry season extending from January to April. Most of the landscape consists of agricultural fields and pastures (Suzan et al. 2006). The population is sparsely distributed with 68.2% of it living in rural areas. Population growth rate in the province (2%) is lower than in the country (14%) (City Population, 2019). Tourism is an important source of revenue in the main cities, which are located near the coast. This sometimes conflicts with the protection of mangrove forests that are also situated on the coast, bordering the main rivers going into the Pacific Ocean.

Sites were chosen with Google Earth Pro, the search being based on the following criteria: 1) a forested area near the coast, 2) a river runs through the forest area, 3) has to be situated in the province of Los Santos. This last criterion was chosen to reduce variability in mangrove tree composition and other biotic factors between sites. We found eight sites corresponding to these three criteria for the study, but only three were not accessible by road, reducing the number of possible sites to six for the purpose of this study. In order to assess the impact of a trail on the mangrove forests, we compared three sites with a nearby road (less than 1 km) to three sites without such road (more than 1 km), acting as control sites (Table 1). Unfortunately, two of the seven sites found with Google Earth Pro were not actual mangrove forests, thus only four sites could be used for data analysis. Consequently, Punta Mala was excluded from the statistical analysis randomly between the experimental sites in order to obtain equal sample sizes.

For the survey, we made three 10 m by 10 m plots for each of the six sites. Plots were made at an interval of 200 steps from the entrance of the mangrove. A coin toss was then made to determine if the quadrant would be right or left and in front or behind our current position, assuring randomization of the plots. Each tree more than a meter high was counted, identified and its diameter at breast height (dbH) (Brokaw and Thompson 2000) was measured. Furthermore, each plot was inspected to locate any tree cut and any type of litter, which would then be counted as well.

Before the analysis, each tree diameter was grouped into four diameter classes of a range of five centimeters from zero to twenty (Table 2). In order to compare variation from a normal distribution, random points (expected) were generated in Excel, equal to the number individual data points collected in the field (observed). We used Pearson's Chi-Square (χ^2) with an *a priori* significance level of $\alpha = 0.05$ for the statistical analyses, comparing within each site and within both experimental and control groups as well. We mostly looked at variation from the normal distribution of the smallest tree classes. Comparison of significant variation from a normal distribution could then be made between the control sites and the experimental sites to test the validity of the sampling. All statistical analyses were conducted in R 3.5.1.

The cut analysis was made by comparing the number of tree cuts between control and experimental sites using a one-way ANOVA.

The entirety of this study, including census, research and transportation to study sites, has been performed in accordance with the *Code of Ethics* of McGill University research and with the Canadian Panel on Research Ethics (Appendix 3).

Results

Tree Class Distribution

The distribution of tree classes followed the same pattern in the control and experimental forests (Fig. 3). The pattern observed in the far from the road, control forests, with more trees of smaller size and fewer trees of larger size, was consistent with the assumption of a normal forest, forming a J shape curve (Roberson et al. 1978). Contrarily to our hypothesis, the distribution of tree classes in the experimental, close to the road, forests followed the same curve (Fig. 4).

After statistical analysis, comparing the observed distribution of tree classes for each site with a random tree class distribution, no significant variation from the normal distribution was found (Table 3). Analysis of the control and experimental plots showed once again no significant variation for either of the forest groups (Table 4). This thus meant that the control forest did not significantly follow the expected pattern of a higher number of smaller size trees than expected by normal distribution. It also meant that the experimental forest did not meet the hypothesis that there would be a lower number of smaller size trees.

Tree Cuts

The number of trees found with a cut on them was significantly higher in the forests close to a road than those who were not (Table 5, Fig. 5) even though half of both the experimental and the control site did not have any cut. The sites with the highest number of cuts were both close to communities with lower income (Table 1).

Discussion

Sample Site Selection

The tree size class analysis showed no significant different variation between the forests close to the roads and the ones far from the road. Part of this can be due to the reduction in the sample size, as some forests bordering the coast selected for the study were not mangrove forest reducing the sample size. It is possible that the pattern could not be denoted due to random variation between the sites. Furthermore, selecting sites using Google Earth did not show the type of road leading to the forest, creating different levels of isolation within the chosen sites. Indeed, some sites considered close to an official road on Google Earth had poor-quality roads whereas some sites considered as far from the official road on the software had good quality secondary roads. Even though this might not have skewed the results toward one conclusion or another, it could have simply changed the significance of the group distribution.

Biological Factors

When comparing tree size classes, it is also important to consider possible variation due to biological factors. Mangrove forests are characterized by low tree diversities, with a very well-distributed species composition: flood-tolerant red mangroves closest to the water, followed by black mangrove, and finally farthest from the water the flood-intolerant white mangroves (Ball 1996). As the different species have different growth rates and maximum sizes (Clough, 1992), the distance of sample plots from the water can affect the distribution of tree diameters, with some tree species possibly growing faster and thus obtaining a larger diameter before other trees in the forest. This distance variation between plots of a single site and the variation in species composition of these plots could have created a tree size pattern that is not representative of the pattern observed among a single species.

Additionally, as soil composition varies greatly from the mouth of a river to the interior of a river, as well as from the border of the river to the interior of the forest (Chen and Twilley, 1999), and given that soil composition affects the size mangrove trees can reach (Lovelock et al. 2005), this factor needs to be considered in the analysis. Indeed, forming a path for our three plots per site that went from the entrance of the mangrove to the side of the river might also have induced a J-shaped distribution of three sizes. In this case, each of the three plots for a site would bear a different tree size class eventually forming a distribution that is more representative of the soil composition gradient than other factors. Therefore, the formation of this pattern through the sampling strategy could have hidden the effect of tree cutting on trees size distribution.

Finally, the age of the forest is another factor that can influence the distribution of the trees in the forest. For instance, older forests will generally have fewer trees but of larger size, caused by the dominance of older trees (Franklin et al. 1981, Tyrrel and Crow, 1994). As differently aged forest could have the same pattern but at different scales, where an old-growth forest would follow a J-shaped pattern but with trees all larger than 30 cm diameter, pooling the data into standard sizes could have masked the size class patterns of older forests. Furthermore, this trend also creates a sparser tree distribution, as coexistence does not permit the density of younger forests (Tappeiner et al. 1997). Therefore, the more sparsely distributed old grown forests could have fewer individuals per sample plot, reducing again the proportion of their significance in the analysis.

Human Factors

Following on the old, grown forests, the size of the trees makes it harder for people to cut them down and to use them as firewood, smaller sized trees generally being preferred for firewood (Shackleton et al. 1994, Abbot and Lowore 1998), thus possibly reducing the probability that they would be cut by local people. The oldest forest of our sites being also the farthest from the road, the explanation that such old forest can have been reached partly because of this distance from human activity through deforestation avoidance could be considered. However, it is also possible that the size of the trees combined with the distance from the road, forming a situation where people would not only have a long distance to travel with the wood but also to carry large-sized, heavy wood to the road is an even stronger disincentive. This is shown in the tree cuts results (Table 5).

Aside from tree age, species composition can also influence the use of the forest by the nearby human population. As shown in several studies (McKee 1995, Yáñez-Espinosa et al. 2001) the different species of mangrove trees, bearing different wood characteristics, are cut and used for different purposes (Ewel et al. 1998, Dahdouh-Guebas et al. 2000). This makes some forest more dominated by a certain species more likely to be cut based on the demand for nearby communities. The Pedasí and Arenal mangroves forest for instance, both had zero cuts. These two forests were also the ones with the highest tree diversity and lowest red mangrove

(*Rhizophora sp*) proportion (Table 6), which could partly explain the reduction in cut number, as they might have a lower timber interest (Ewel et al. 1998).

The different sites also had varying types of neighboring population. The mean income of the community can have an impact of the land use, where lower income communities generally have a greater interaction and reliance on the natural resources of the area (Coomes et al. 2004). Lower income levels in communities have been shown to be a factor in mangrove deforestation. Indeed, while lower-income communities will rely more on mangrove trees as firewood, higher-income communities will often use gas or propane as combustible. Even though we do not have the data to draw correlations from this, the two sites with the highest income communities were also the two sites with absence of deforestation signs (Table 5). A combination of this factor and the species composition factor could account for the cut counts results. Additionally, the main economic driver of a community can also possibly influence the deforestation outcome of nearby mangroves. If a community relies on ecotourism, it will make more effort to avoid the depletion of the natural surroundings of the area (Stem et al. 2003). This could explain why the El Arenal mangrove had zero cuts, despite the proximity of roads and the numerous paths within its forest.

Finally, while looking for tree cuts is a good indicator of deforestation level and is more direct than assessing tree size class distribution, it is not flawless either. As mangroves are used or cut for many reasons by humans such as timber, firewood, fishing and hunting, and agricultural expansion (Walters 2003), different people could cut the trees or the branches of the forest for different purposes. Looking only at the result of a cut, the absence of clear distinction between the cause of the cut does not meet the assumption that all cuts are for firewood or timber. Indeed, trail creation is possibly another major source of tree cutting. Therefore, the significant number of cuts in the experimental forest (Table 5) could only be the result of tree cut misidentification.

Moving Forward

The question therefore arises: is there an impact of roads on mangrove deforestation? While this study cannot confidently answer the question, it helped understanding the complexity of the problem. Consequently, if the study had to be repeated, considering the numerous factors changing the shape, distribution, and health of mangrove forests, the best way would probably be to use historical data in order to compare a forest against itself, to see change before and after the construction of nearby infrastructure such as roads. Comparison between sites could therefore be made more easily, since the it would be based on the level of change.

Nonetheless, the study has two main conservation implications. On the one hand, the absence of significant results in trees class distribution highlighted the many biological factors playing a role in mangrove forest’s health and the difficulty to make a comparative study between mangrove forests. It also demonstrated that such factor might not be the most effective to assess deforestation level and that trends in lower numbers of smaller trees in highly cut forests could simply be the result of other factors. On the other hand, significant but heterogeneous results in tree cuts emphasized the importance to investigate the underlying causes of deforestation, such as community poverty level and main economic activity, more than results from these causes, such as roads. This is even more relevant when it comes to assessing the possible impact of ecotourism in an area, since the results obtained in this study seem to suggest a positive community impact.

More locally, this study provides basic information on forest land use in this segment of the Azuero Peninsula, where even in this limited area, deforestation levels show local variation. This highlights the importance of a management plan for the Pablo Arturo Barrios Wildlife Refuge. Even though there is little data to draw conclusions from, the lowest number of tree cuts being closer to more tourism-focused or more wealthy neighborhoods, as opposed to being those farther from the road, indicate that ecotourism could be beneficial for the conservation of mangroves in the area. Many studies have shown that ecotourism has increased economic activity and income in local communities (Stem 2003, Stronza and Gordillo 2008). Implementing a mangrove trail in the area as well as other activities, such as mangrove tours, could improve the status of the mangroves forest of the area. Furthermore, although an increased amount of debris is often a problem in touristic areas (Abdullah et al. 2001), the supplemental data from this study reveals that there is no significant variation between the quantity of debris in the different mangrove forests (Annex 2). We suggest that since debris are generally widespread in the forests, no matter the level of income, tourism activity or road vicinity of the site, that this factor should not discourage the instauration of mangrove ecotourism in the area.

To conclude, the number of tree cuts over the study area is generally low compared to other places in the world (Walters 2005), and the significant higher number of tree cuts in the sites closer to the roads should not restrain the expansion of activities promoting ecotourism. Furthermore, we propose before and after comparison, rather than between sites comparison for distribution of size class analysis, because of the high number of factors to consider in such study.

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Annexes

Annex 1. Tables and Figures

Table 1. Accessibility of coastal forests in the region of Southeastern Azuero Peninsula. Names mostly associated with the nearest beach name. Road type was determined by the presence or not of a road on Google Earth. Nearby community type estimated by personal observation.

Forest name	Accessibility by official road	Accessibility by dirt road	Distance from nearest official road (km)	Nearby community type
El Arenal	Yes	Yes	0	Touristic
La Garita	No	No	0.8	Touristic
Pedasi	No	No	1.1	Residential
Punta Mala	Yes	Yes	0.7	Agricultural
Los Destiladeros	No	Yes	1.2	Agricultural
El Tigre	No	No	2.7	Agricultural
EL Rincón	Yes	Yes	0.2	Agricultural

Table 2. Tree diameter classes used for the statistical analysis.

Class number	Diameter (cm)
1	[0, 20[
2	[20, 40[
3	[40, 60
4	[60, 80[

Table 3. Distribution of observed and expected diameter sizes of the mangrove trees for each site.

El Tigre		
Diameter (cm)	Observed	Expected
[0, 20[	9	1
[20, 40[	5	5
[40, 60	1	6
[60, 80[	0	3
Total	15	15
		X2= 4.0667
		P<0.6677
Pedasi		
Diameter (cm)	Observed	Expected
[0, 20[	27	13
[20, 40[	5	5
[40, 60	0	5
[60, 80[	0	9
Total	32	32
		X2=1.2962
		P<0.73
Arenal		
Diameter (cm)	Observed	Expected
[0, 20[	12	4
[20, 40[	4	5
[40, 60	3	3
[60, 80[	1	8
Total	20	20
		X2=13.611
		P<0.1368
Rincon		
Diameter (cm)	Observed	Expected
[0, 20[	8	2
[20, 40[	4	3
[40, 60	0	2
[60, 80[	0	5
Total	12	12
		X2=4.35
		P<0.2261

Table 4. Distribution of observed and expected diameter sizes of the mangrove trees for each group. Control sites are El Tigre and Pedasí, experimental sites are El Arenal and El Rincón.

Control		
Diameter (cm)	Observed	Expected
[0, 20[	36	14
[20, 40[	10	10
[40, 60	1	11
[60, 80[	0	12
Total	47	47
		X2=6.6426
		P<0.3552
Experimental		
Diameter (cm)	Observed	Expected
[0, 20[	20	6
[20, 40[	8	8
[40, 60	3	5
[60, 80[	1	13
Total	32	32
		X2=10.212
		P<0.3336

Table 5. Number of tree cuts observed within the plots for each site and the result of the analysis of tree cuts between the sites and the groups.

Group	Site	Number of Cuts	
Control			
	El Tigre	2	
	Pedasi	0	
Experimental			
	El Arenal	0	
	El Rincon	6	
F value			4.571
P value			**0.038**

Table 6. Species composition of each mangrove forest sampled during the study.

Site	Red Mangrove	Black Mangrove	Other
El Arenal	40%	60%	0%
Pedasí	92%	0%	8%
El Tigre	93%	0%	7%
El Rincón	52%	26%	22%

Fig. 2 Coastal forests of the Southeastern Azuero Peninsula. All sites were visited except for the Río Oria forest. The forest near Playa La Garita and the one near Playa Los Destiladeros were not mangrove forests. The Pablo Arturo Barrios Wildlife Refuge follows the coast from Playa El Tigre to just north of Playa Punta Mala.

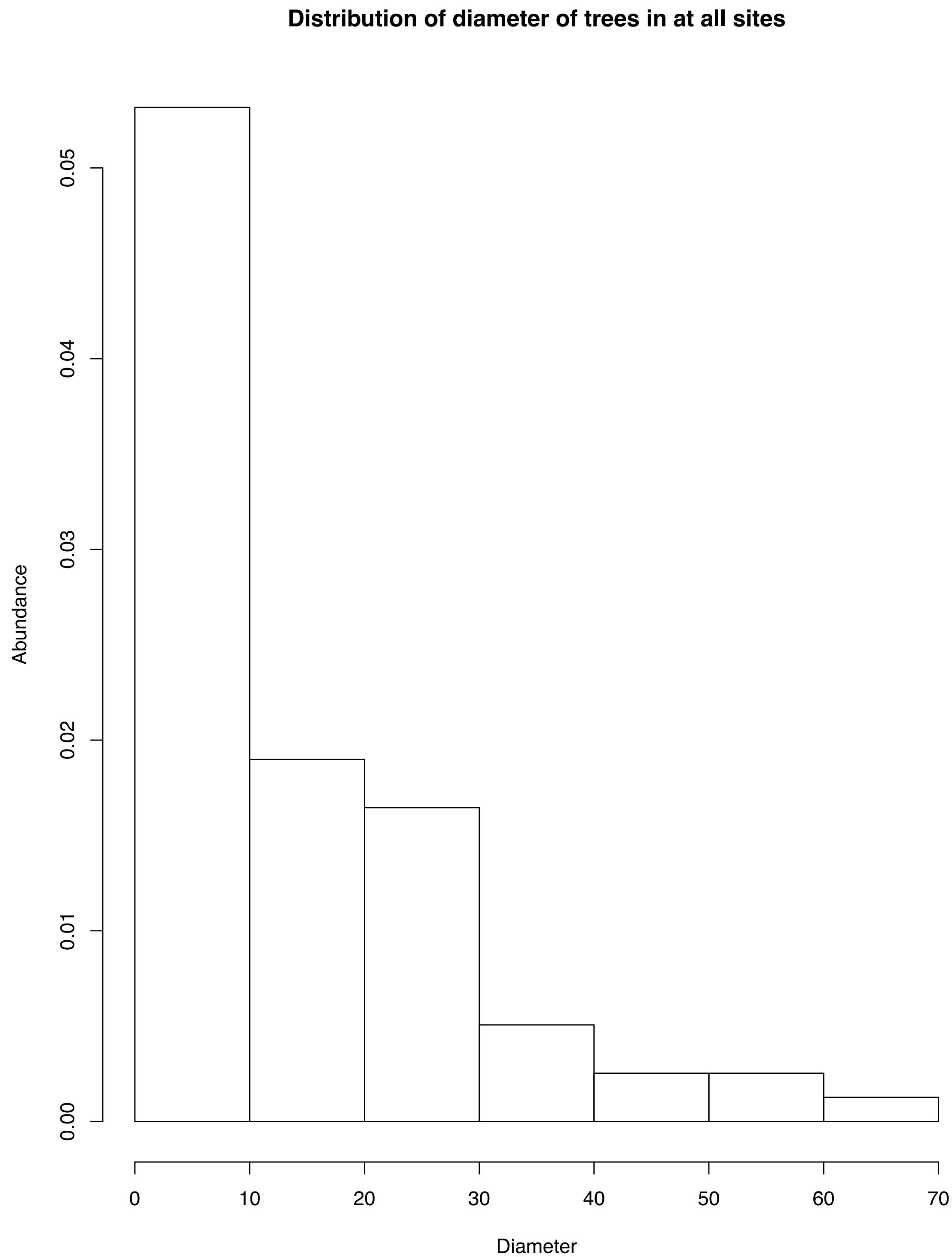
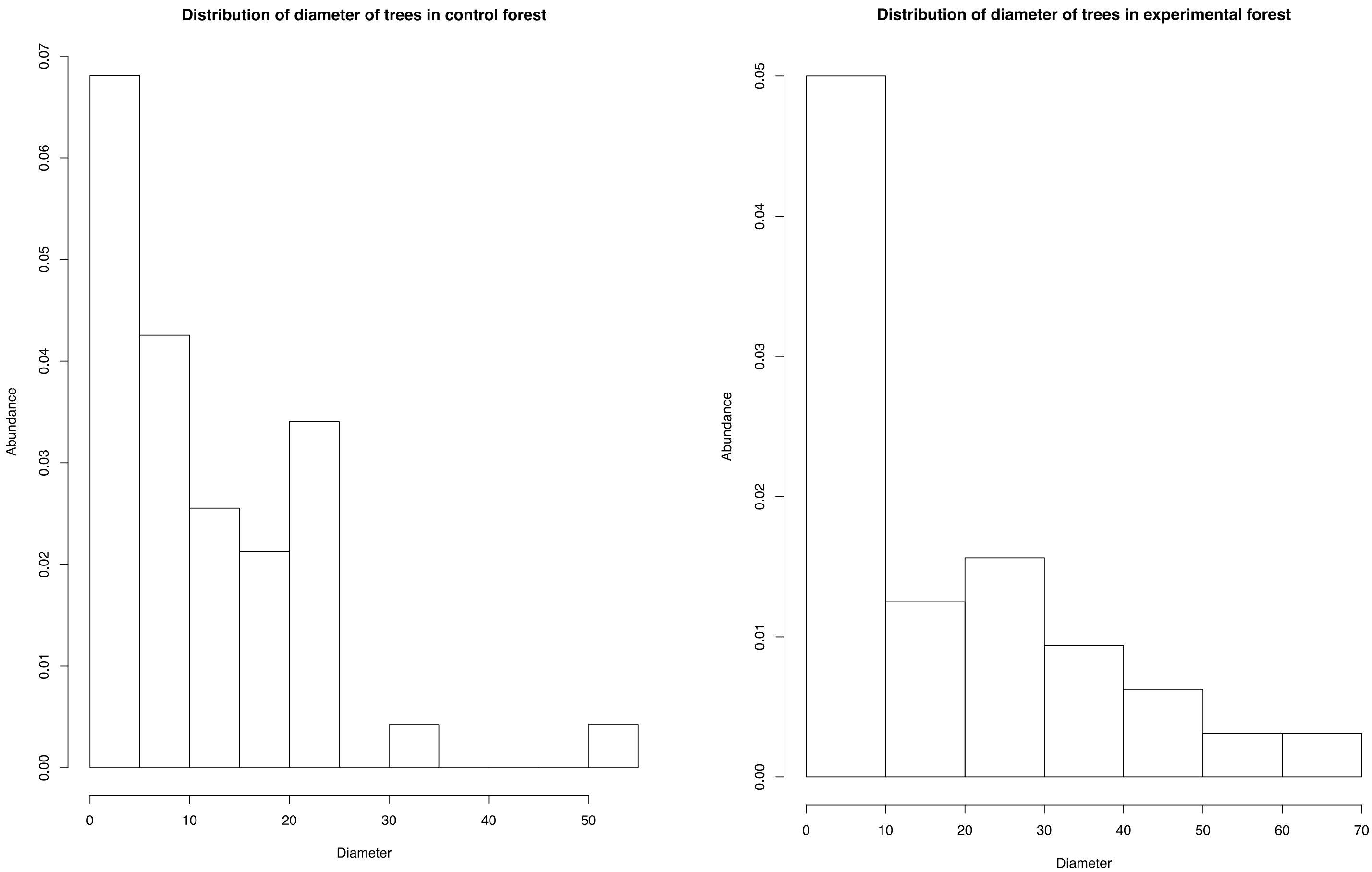


Fig. 3 Distribution of the diameter size of mangrove trees at all sites sampled.



(A) **(B)**

Fig. 4 Distribution of the diameter size of mangrove trees for all sites within the (A) control group and the (B) experimental group.

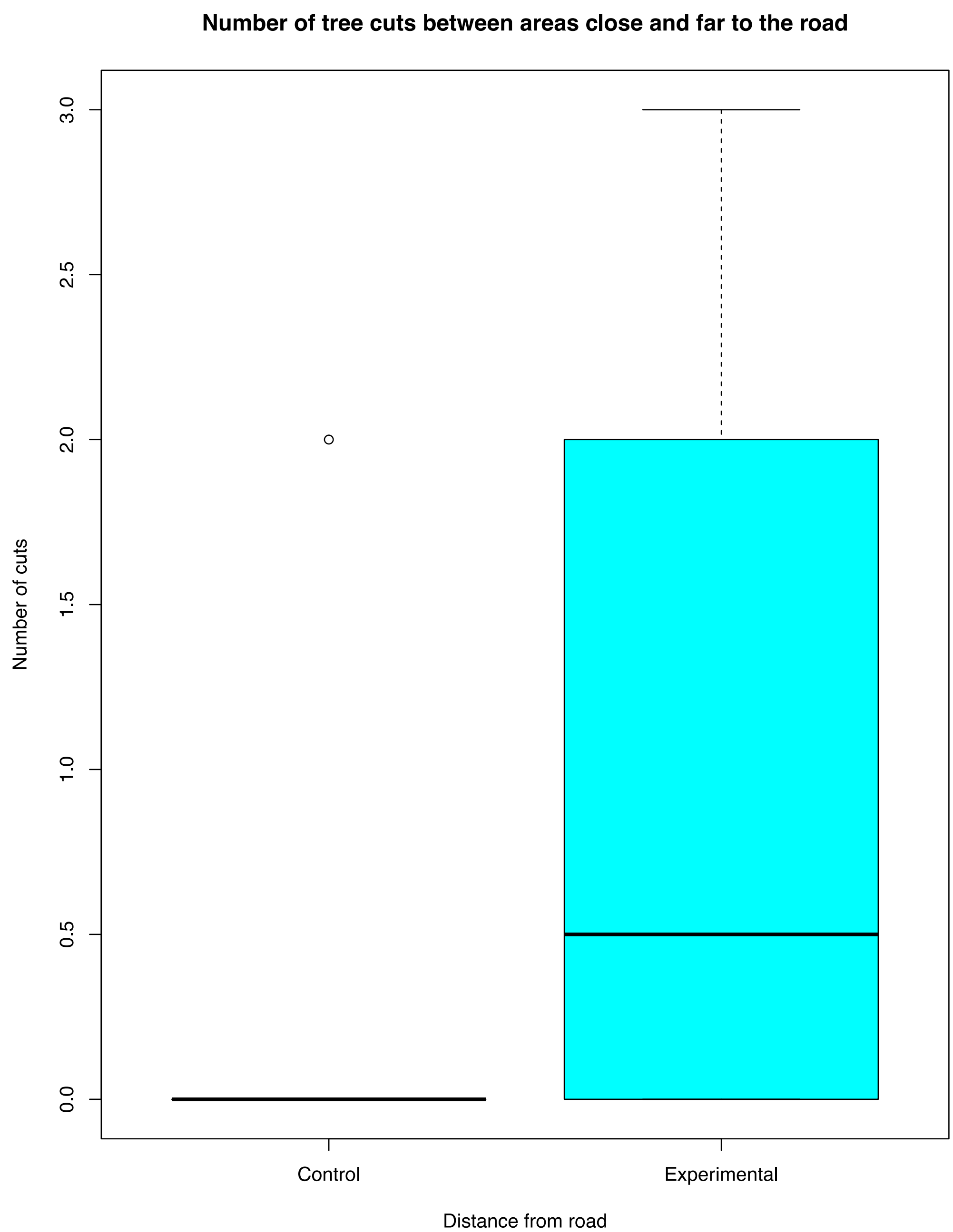


Fig. 5 Boxplot comparing the number of tree cuts in the control and the experimental forest sites.

Annex 2. Supplemental Data

Table 1. Number of debris observed within the plots for each site and the result of the analysis of debris between the sites and the groups

Group	Beach	Debris	
Control			
	El Tigre	1	
	Pedasi	0	
Experimental			
	El Arenal	3	
	El Rincon	3	
F value			1.286
P value			0.344

Annex 3. McGill Code of Ethic

Groupe en éthique de la recherche
Piloter l'ethique de la recherché humaine

EPTC 2: FER

Certificat d'accomplissement

Ce document certifie que

Thierry Grandmont

a complété le cours : l'Énoncé de politique des trois Conseils : Éthique de la recherche avec des êtres humains : Formation en éthique de la recherche (EPTC 2 : FER)

17 janvier, 2019

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Navigating the ethics of human research

TCPS 2: CORE

Certificate of Completion

This document certifies that

Alexandra Friedman

has completed the Tri-Council Policy Statement: Ethical Conduct for Research Involving Humans Course on Research Ethics (TCPS 2: CORE)

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