

Timber Exploitation and Mangrove Ecosystem Dynamics in the Tristao Islands Marine Protected Area, a Ramsar Site in the Republic of Guinea

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How to cite this paper: Fofana, M.Y., Sidimé, N., Bangoura, K. and Sakho, A.M. (2026) Timber Exploitation and Mangrove Ecosystem Dynamics in the Tristao Islands Marine Protected Area, a Ramsar Site in the Republic of Guinea. *Journal of Environmental Protection*, 17, 1134-1158. <https://doi.org/10.4236/jep.2026.1710058>

Received: September 16, 2026

Accepted: October 26, 2026

Published: October 29, 2026

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Abstract

Mangroves are essential coastal ecosystems for maintaining biodiversity, protecting the coastline, supporting local livelihoods, and storing carbon. This study aims to analyze the effects of timber harvesting on mangroves, identify the main human activities responsible for their degradation, and estimate the quantities of timber biomass harvested by local communities. The methodology is based on a literature review, direct field observations, and semi-structured interviews with forty (40) stakeholders distributed across four activity groups. The main activities studied are rice cultivation, salt production using natural gas, fish smoking, and logging. The qualitative impact assessment was carried out using a matrix inspired by Leopold's method. The volumes of wood transported by boats were estimated using the Newton-Simpson method, while consumption related to salt production and fish smoking was estimated based on the quantities of wood used per operation and the frequency of activities. The results show that logging constitutes the main direct pressure on the mangrove, with a very strong impact on the mangrove forest. The perception of the local population confirms this hierarchy: 90% of respondents identified logging as a major factor in degradation. The harvesting primarily concerns species of the genus *Rhizophora*. Estimates of landings reveal a monthly volume of 1,902.384 m³ of mangrove timber at the two main landing sites studied. These results highlight a strong socioeconomic dependence of the local population on mangrove timber resources and an anthropogenic pressure likely to compromise natural regeneration, stand structure, wildlife habitats, and the ecological functions of the ecosystem. The study therefore recommends strengthening community-based monitoring and

management of the mangroves, promoting alternative energy sources for salt production and fish smoking, restoring degraded areas, and regularly monitoring timber harvesting. These measures would help reconcile the livelihoods of local communities with the sustainable conservation of the Tristão Islands mangroves.

Keywords

Mangrove, Tristão Islands, Ramsar Site, Timber Harvesting, Woody Biomass, Salt Production, Fish Smoking, Rice Cultivation, Degradation, Guinea

1. Introduction

Mangroves are among the most productive coastal forest ecosystems in tropical and subtropical regions. Covering approximately 147,000 km² globally, according to FAO estimates, they develop primarily in the intertidal zones of estuaries, deltas, lagoons, and sheltered coasts [1]. They thrive in environments influenced by tides, particularly in estuaries, deltas, lagoons, and sheltered coastal areas. Despite their relatively limited global area, mangroves provide numerous ecological and socioeconomic functions essential to the functioning of coastal zones and the well-being of coastal populations [2]. Ecologically, mangroves contribute to sediment stabilization and coastal protection against erosion, storm surges, and certain effects of marine flooding. Their complex root systems promote sediment retention and provide habitats, refuges and nursery areas for many species of fish, crustaceans, molluscs and other aquatic organisms. They also participate in maintaining the productivity of adjacent coastal ecosystems and in regulating the flow of matter and energy between terrestrial and marine environments [3].

Mangroves also play a major role in climate regulation due to their capacity to capture and store significant amounts of carbon. They are thus considered key ecosystems for “blue carbon”. Carbon is stored in aboveground and belowground biomass, but especially in soils, where organic matter can accumulate over long periods. Carbon stocks in mangrove ecosystems can reach an average of approximately 1000 Mg C ha⁻¹, with values varying considerably depending on the species, stand structure, and soil characteristics [4]. The destruction or conversion of these ecosystems can therefore lead to a significant loss of stored carbon and promote greenhouse gas emissions, in addition to causing the loss of numerous ecosystem services [5].

This climatic function gives mangroves particular importance in climate change mitigation policies. However, when mangroves are cleared or degraded, some of the carbon stored in biomass and soils can be released into the atmosphere. [6] estimate that the conversion and degradation of vegetated coastal ecosystems could be responsible for annual emissions of between 0.15 and 1.02 billion tons of CO₂. [7] already estimated that approximately 35% of the world’s man-

groves disappeared between 1980 and 2000, mainly due to land conversion, resource exploitation, and the development of human activities. Mangrove conservation is therefore simultaneously a matter of biodiversity, coastal protection, and combating climate change.

Despite their importance, mangroves are subject to significant anthropogenic pressures. The main causes of their degradation are linked to the conversion of natural areas for agriculture and aquaculture, urbanization, infrastructure development, and the exploitation of timber resources. Demand for fuelwood, timber, and fuel for certain processing activities constitutes a particularly significant pressure in many tropical regions [8]. Timber harvesting can have major consequences for the structure and functioning of mangrove stands. Repeated harvesting can reduce stem density, aboveground biomass, and the regeneration capacity of stands. When certain species or diameter classes are preferentially harvested, this pressure can also gradually alter the structure and floristic composition of mangrove formations [9]. Furthermore, reduced vegetation cover can decrease sediment stabilization capacity and increase the vulnerability of coastal areas to erosion and other degradation processes.

In Africa, mangroves are particularly important ecosystems for coastal populations, but they are subject to various forms of pressure related to the needs for agricultural land, fuelwood, building materials, and fishing and salt production. However, the situation varies considerably depending on the country, ecological conditions, governance models, and the intensity of human activities [10]. In several West African countries, mangrove wood is used as an energy source for cooking, smoking fish, and traditional salt production, which can increase pressure on mangrove stands when energy alternatives are limited. Fish smoking is thus an important socioeconomic activity in many West African coastal communities. It contributes to the conservation, marketing, and processing of fish products, but its operation often relies on the use of wood fuels. The energy demand associated with this activity can therefore indirectly stimulate mangrove exploitation, particularly when mangrove wood is the main available fuel source [11].

Traditional salt production also exerts pressure on mangroves. Salt production through thermal evaporation requires significant amounts of fuel in fire-based systems. Furthermore, the development of some salt production sites can lead to the conversion or fragmentation of mangrove habitats and locally alter the hydrological and physicochemical conditions of soils and water. The extent of these impacts depends in particular on the size of the developed areas, the techniques used, and the intensity of exploitation [12]. The conversion of mangroves for agricultural purposes represents another significant form of pressure. In West Africa, mangrove rice cultivation relies on the construction of dikes, canals, and rice paddies to control the exchange between fresh and salt water.

While this activity contributes to food security and the livelihoods of local populations, the opening of new oyster beds can lead to the destruction of natural vegetation and alter the hydrological conditions of the environment. The environmental impacts therefore depend on the scale of the development and the man-

agement practices adopted.

In the Republic of Guinea, mangroves play a vital role in the ecological and socioeconomic balance of the coastline. They provide essential habitats for numerous species and supply coastal communities with several natural resources, including timber, fish, and products from agricultural and salt production. Their conservation is therefore of particular importance in a context where coastal communities are heavily dependent on natural resources for their livelihoods.

The Tristão Islands complex, located in the maritime region of northwestern Guinea, is a particularly important area in this regard. The site was designated a Wetland of International Importance under the Ramsar Convention in 1992, number 572. Its area is approximately 104,680 hectares, according to institutional data cited in the site's management documentation. It comprises mudflats, sandbanks, estuaries, and extensive mangrove formations, which provide favorable habitats for a diversity of species and support numerous local socioeconomic activities. The dependence of the local population on the natural resources of this area necessitates a better understanding of the forms and intensity of their exploitation.

In the Tristão Islands, several activities are likely to contribute to the pressure exerted on timber resources, including direct logging, salt production using natural gas, fish smoking, and the creation of new rice paddies. These activities meet essential needs for subsistence and income generation, but their intensification may exceed the natural regeneration capacity of the stands. Assessing their impact therefore requires relating harvesting practices, the quantities of timber harvested, the frequency of use, and the characteristics of the stands concerned. However, quantitative data on the volumes of timber harvested and consumed in the Tristão Islands remain limited. This lack of data is a constraint for the objective assessment of pressure on the mangroves and for the implementation of appropriate management strategies. Estimating the volumes of timber landed at the main landing sites, as well as the quantities consumed for salt production and fish smoking, would therefore allow for a better characterization of the intensity of timber resource exploitation.

It is within this perspective that the present study, entitled "Impact of wood consumption on the mangrove of the Tristão Islands, Ramsar site of the Republic of Guinea", is situated. It aims to contribute to the understanding of the anthropogenic pressures exerted on wood resources and to provide scientific data that can support the sustainable management and conservation of the mangroves of the Tristão Islands.

1.1. The Main Research Question Is as Follows

What is the impact of wood consumption on the mangroves of the Tristão Islands and what are the main activities that contribute to the pressure exerted on wood resources?

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Journal of Environmental Protection

DOI: 10.4236/jep.2026.1710058

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Located approximately 50 km south of the city of Kamsar, this site was designated on November 18, 1992, as RAMSAR Site No. 572 of regional and international importance for waterbirds and marine mammals. It covers an area of 104,680 hectares (according to Article 3 of the decree establishing it). The Tristão Islands Community-Managed Nature Reserve comprises several marine protected areas (MPAs). + ZMP + AT. A central marine zone of 34,930 ha, a peripheral marine zone of 27,140 ha, and a total area of 42,610 ha. Its population is 7,000 inhabitants (RGPH). According to (RAMP AO, 2020), the Tristão Islands are characterized by expanses of sandbanks, mudflats, rocks, estuaries, and mangrove forests.

2.2. Methodology

The methodological approach is based on field surveys conducted with the various stakeholders involved to understand their opinions and identify the factors related to the degradation of the mangrove.

2.2.1. Study Population and Sampling

The survey focused on local actors involved in the main activities likely to exert pressure on the timber resources of the Tristao Islands mangroves, including rice cultivation, logging, salt production using natural gas, and fish smoking. The eligible population consisted of residents actively involved in at least one of these activities during the study period. Temporary actors—that is, individuals staying temporarily in the Tristao Islands solely for socioeconomic purposes—were excluded from the survey, in accordance with the original protocol.

Due to the lack of a comprehensive socio-professional sampling frame to separately identify the different categories of stakeholders, a random sample of 40 people was drawn. The sample comprised 10 people from each of the four activity groups studied, corresponding to the four districts of the marine protected area. Interviewees were conducted during the periods when they were actually carrying out their activities. Surveys and field observations were conducted between March and April 2026, as was the allocation of respondents by district and by activity.

Given that some respondents engaged in multiple activities simultaneously, the number of responses per activity does not necessarily correspond to the number of people surveyed. The same person could therefore be counted in several activity categories when they reported actually engaging in them. The percentages relating to factors of deterioration should therefore be interpreted as multiple responses and not as a distribution exclusive to the 40 respondents.

This approach allows us to take into account the versatility of the livelihoods of local populations, but it does not allow us to estimate an independent prevalence for each occupational category.

2.2.2. Research Documentary

A literature review was conducted to assess the existing literature on similar studies. This involved compiling available data on the ecosystem goods and services

of wetlands in general, and mangroves in particular. This exercise also yielded a number of documents describing human activities that influence the integrity of the mangrove in Tristão, which formed the basis of our analysis.

2.2.3. Identify the Activities Contributing to the Degradation of the Mangroves of the Tristao Islands

To identify the activities causing impacts related to mangrove logging, we conducted a survey using semi-structured interview forms with four (4) activity groups distributed across the four (4) districts of the Tristao MPC (Mediterranean Protected Area) and agents of the Guinean Office of Parks and National Reserves (OGPRN), as well as direct field observations to establish a list of sensitive environmental elements likely to be affected by these activities. This allowed us to locate logging areas, salt production sites, agricultural sites (reinforcement of dikes and new fish traps), and fish smoking camps, to gain an overview of the activities carried out by the population of the Tristao islands, and to understand their perspective on mangrove logging. The identified impacts are summarized in **Table 1**. This table was developed based on the Leopold identification matrix used for environmental impact assessments. This matrix allowed us to link impact-generating activities with the affected environmental components. We also compiled a list, with the help of the Maritime Navigation Agency (ANAM), of the boats affiliated with the landing stages included in the survey and categorized them according to their type and capacity.

2.2.4. Estimate the Woody Biomass Consumed in the Tristao Islands

i) Quantity of mangrove timber landed at the two main landing stages of the Tristao Islands

We conducted temporal sampling of landings, randomly selecting several observation days per week to represent the frequency and variability of landings and to estimate the total quantity of mangrove timber landed at the landing sites (camps). To estimate the quantity of mangrove timber landed, the Newton-Simpson method was used to estimate the volume of logs, tree trunks, or other pieces of wood as their cross-section varies along their length.

Newton-Simpson formula

$$V = L/6(S_1 + 4S_m + S_2)$$

Or:

- V = volume of wood (m^3)
- L = length of the log (m)
- S_1 = area of the section at the small end (m^2)
- S_m = area of the cross-section at the midpoint of the length (m^2)
- S_2 = area of the section at the larger end (m^2)

Calculating the area of a cross-section

If the cross-section is approximately circular:

$$S = \pi D^2/4$$

where D is the diameter (m).

ii) Estimated monthly quantity of mangrove wood harvested for salt extraction

Estimating monthly wood consumption in the context of fire-based salt production involved quantifying the total amount of mangrove wood consumed in a month by the eight (8) production units distributed across the four (4) districts of the Tristão Islands. The amount of wood consumed was first determined in kilograms (kg), then converted to volume (m^3) based on the wood density of the harvested species. The corresponding monthly wood quantity was calculated using the following formulas:

$$Q_{\text{BM/month}} = Q_{\text{BC}} \times N_{\text{C/J}} \times N_{\text{J/M}} \times N_{\text{UP}}$$

Or:

- $Q_{\text{BM/month}}$: Quantity of wood consumed per month (kg, /month);
- Q_{BC} : Average quantity of wood consumed per cooking (kg);
- $N_{\text{C/J}}$: Average number of operations (cookings) per day;
- $N_{\text{J/M}}$: Number of production days in the month;
- N_{UP} : Number of production sites (salt works).

iii) Clearing of the mangrove for the creation of new rice paddies

The total area affected by mangrove logging in one year is calculated based on the relationship.

$$S_t = 1/5 (S_{\text{m/cp}} \times N_{\text{cp}} \times N_{\text{ug}}) (\text{ha})$$

with:

S_t : Cumulative area affected by mangrove wood cutting over five (5) years (ha);

$S_{\text{m/cp}}$: average area cut per unit of groupings and per operation (ha);

N_{cp} : average number of cutting operations per grouping unit over five (5) years;

N_{ug} : total number of units of groups practicing cutting.

iv) Estimated monthly quantity of mangrove wood harvested for fish smoking

$$Q_{\text{tb/month}} = Q_{\text{mb/op}} \times N_{\text{op/week}} \times N_{\text{week/month}} \times N_{\text{ug}}$$

$Q_{\text{tb/month}}$: Total quantity of wood used per month.

$Q_{\text{mb/op}}$: Average quantity of wood used per operation.

$N_{\text{op/week}}$: Number of smoking operations per week.

$N_{\text{week/month}}$: Number of weeks per month (4).

N_{ug} : Total number of fish smoking grouping units (4).

3. Results

3.1. Presentation and Interpretation of Results

3.1.1. Identify the Activities Contributing to the Degradation of the Mangroves of the Tristao Islands

Identifying activities linked to mangrove degradation has highlighted the main anthropogenic pressures exerted on this ecosystem in the study area. The results

show that mangrove degradation is associated with several socioeconomic activities carried out by local communities. These activities meet essential needs for income, food, energy, and livelihoods, but their intensification can compromise the mangrove's regeneration capacity and ecological functions.

According to the qualitative assessment carried out using the impact matrix, logging was associated with the highest level of impact on the mangrove forest.

Table 1 presents a qualitative assessment of the impacts of the main human activities on the biophysical and human components of the environment, namely wildlife, mangrove forest, soil, water, and the human environment. The results highlight a heterogeneity in impact levels depending on the activities and environmental components considered. They also show that local economic activities can simultaneously generate negative environmental effects and positive effects on the socioeconomic conditions of the population.

Table 1. Identification of activities causing mangrove degradation.

No.	Sources of impact	Level of impact on environmental elements				
		Wildlife	Mangrove forest	Ground	Human environment	Water
1	Rice cultivation (creation of new paddies)	Moderate	Moderate	Moderate	Moderate	Moderate to high
2	Salt production	Strong	Strong	Strong	Positive/Moderate	Strong
3	Fish smoking	Moderate	Strong	Low to moderate	Positive	Low to moderate
4	Logging	Strong	Very strong	Moderate to high	Positive/Moderate	Moderate to high

Table 2 presents a five-level qualitative scale for assessing the intensity of environmental and socio-economic impacts. It thus enables the characterization and prioritization of impacts in order to guide appropriate management measures.

Table 2. Legend-evaluation criteria.

Level	Evaluation criteria
Weak	Localized effect, low intensity, easily reversible and limited in time
Moderate	A noticeable, relatively localized effect that can be controlled by appropriate measures
Strong	A significant effect directly affecting a component of the environment and requiring management measures
Very strong	A major, widespread, or potentially lasting effect that significantly affects the structure or functioning of the component concerned.
Positive	Positive effect on socioeconomic or environmental conditions

3.1.2. Respondents' Perceptions

i) Factors contributing to mangrove degradation

The perceptions of stakeholders regarding the factors contributing to mangrove degradation highlight the significant human pressures exerted on this ecosystem.

The responses collected show that mangrove degradation is perceived as the consequence of several socioeconomic activities, the intensity and effects of which vary according to local practices. This perception provides a relevant indicator of how local communities understand the changes affecting their environment and the resources on which they depend. The results are presented in **Figure 1** below.

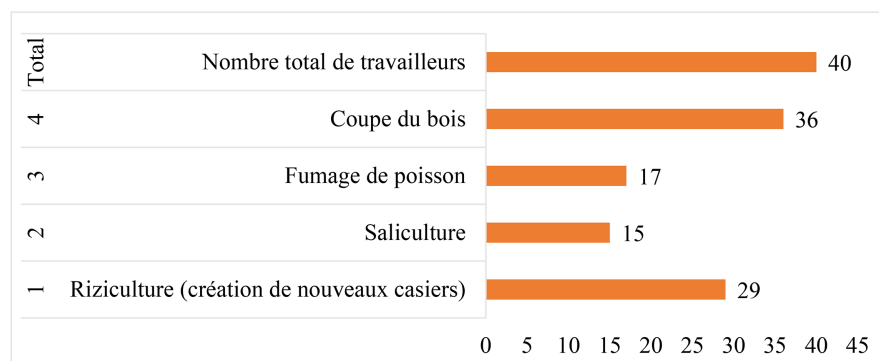


Figure 1. Factors contributing to the degradation of mangroves in the Tristao Islands.

These results shown in **Figure 1** highlight a differentiated perception of the factors contributing to mangrove degradation. The predominance of logging (90%) shows that this activity is clearly identified by local populations as a major pressure on mangrove stands. The high proportion attributed to the creation of new rice paddies (72.5%) also reveals the importance of converting mangrove areas for agricultural purposes. Fish smoking (42.5%) appears to be a primarily indirect pressure linked to fuelwood consumption, while salt production (37.5%) is less frequently perceived as a cause of degradation, although it can lead to significant habitat transformation when it involves converting mangrove areas. These results confirm that mangrove degradation is perceived as the result of several interdependent human activities, with logging and the conversion of mangrove areas for agricultural purposes being the most prominent.

ii) Origin and end use of wood

The wood studied in this research comes primarily from mangrove stands harvested on the Tristão Islands. Observations made at the main landing sites of Kachek and Katountoun allowed researchers to estimate the volumetric capacity of the wood and the frequency of landings. After landing, the wood is used for various local purposes. Surveys conducted in the studied communities show, in particular, its use as fuelwood for traditional salt production and for smoking fish. Some of the wood may also be used for other domestic or socioeconomic purposes, as utility wood, and as construction timber.

The estimates of 1612.375 kg of wood for salt production and 1881.25 kg for fish smoking correspond to the quantities used during the observed operations. The available data do not allow us to determine with certainty what fraction of these quantities originated from the wood shipments recorded at Kachek and Katountoun. Consequently, the volumes estimated at the landing sites and the

wood consumption associated with salt production and fish smoking are considered complementary indicators of the pressure exerted on the timber resource, and not independent harvest volumes that can be added together. This precaution avoids double counting of harvested wood.

3.1.3. Particular Pressure on *Rhizophora* Species

The woody species of the mangrove constitute an important resource for local communities, particularly for fuelwood, smoking fish products, and certain domestic uses. However, the pressure exerted by logging varies depending on the species.

Analysis of **Table 3** reveals a differentiated exploitation of mangrove species. The three *Rhizophora* species appear to be the most heavily exploited, while the other identified species are subject to less pressure. This situation suggests that harvesting practices are not uniform and likely depend on the use value, accessibility, and wood characteristics of the different species. For our study, which focuses on the effects of logging on mangroves, this finding is particularly important: the preferential pressure exerted on *Rhizophora* can lead to a gradual change in the species composition of the stands and, ultimately, affect their regeneration capacity and ecological functions.

Table 3. Exploitation status of the main exploited species.

No.	Species names	Families	Operating status
1	<i>Rhizophora racemosa</i>		
2	<i>Rhizophora mangle</i>	Rhizophoraceae	More exploited
3	<i>Rhizophora harrisonii</i>		
4	<i>Avicennania germinans</i>	Avicennaceae	
5	<i>Laguncularia racemosa</i>		
6	<i>Conocarpus erectus</i>	Combretaceae	Little exploited
7	<i>Drepanocarpus lunatus</i>	Fabaceae	

3.1.4. Capacity and Frequencies of Boats

i) Boat capacity

The capacity of the boats varies according to their type and directly determines the volume of mangrove wood transported per operation. Larger capacity boats can carry greater volumes than smaller canoes and dugout canoes. This difference, combined with the frequency of landings, is an indicator of the intensity of mangrove wood harvesting. Thus, analyzing boat capacity allows us to estimate the volumes of wood extracted and assess the pressure exerted on timber resources.

Table 4 shows that the 34 boats surveyed are numerically dominated by dugout canoes (16), followed by small (12) and large (6) plank canoes. However, the

large plank canoes, although fewer in number, transported the largest volume (7.198 m³), compared to 1.931 m³ for the small canoes and 1.077 m³ for the dug-out canoes. Thus, the volume of wood transported depends more on the loading capacity of the boats than on their number. These results highlight the predominant role of large canoes in the removal of mangrove wood. The large canoes demonstrate their importance in transporting significant quantities of wood and may be a factor contributing to the intensification of mangrove resource exploitation.

Table 4. Estimated volumetric capacity of the vessel (m³).

No.	Types of boats	Volume m ³	Number of boats
1	Plank canoe (large model)	7.198	6
2	Plank canoe (small model)	1.931	12
3	Monoxyle	1.077	16
Total			34

ii) Frequency of weekly mangrove wood landings

The frequency of landings is an indicator of the intensity of mangrove timber harvesting and trade. Frequent landings reflect regular supply activity at the ports of Kachek and Katountoun and imply increased pressure on the harvested stands. Combined with the number of boats and the average volume transported per boat, this frequency allows us to estimate the quantities of timber landed per week, and then extrapolate harvests to monthly and annual scales.

Figure 2 highlights the predominance of dugout canoes in both ports, with 9 boats in Kachek and 7 in Katountoun. Small plank canoes are the second most common, with 7 and 5 boats respectively, while large canoes are found only in Kachek (6 boats). Regarding landing frequency, Kachek has slightly higher activity, with 5 landings per week for large canoes, 6 for small canoes, and 7 for dugout canoes. In Katountoun, there are 6 landings per week for small canoes and 7 for dugout canoes, while no landings of large canoes are recorded. Kachek is the main

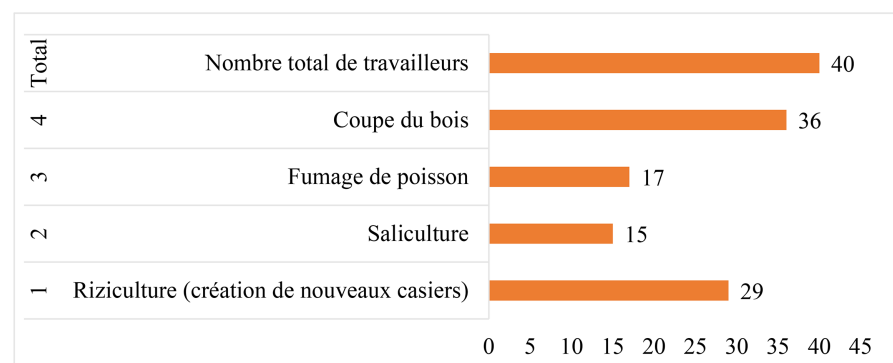


Figure 2. Frequency of landings.

landing site and has a greater diversity of boats, whereas Katountoun is primarily characterized by small plank canoes and dugout canoes. The high frequency of dugout canoes in both ports reflects their importance in mangrove timber transport activities, despite their lower individual loading capacity.

3.1.5. Estimating the Woody Biomass Consumed in the Tristao Islands

Landed mangrove timber is a direct indicator of the intensity of timber resource exploitation in the study area. Landed quantities reflect the volume of timber extracted from mangrove stands and transported to landing sites for various uses, including firewood, salt production, fish smoking, and domestic needs. An increase in landed quantities can therefore reflect increased pressure on mangrove stands. This repeated exploitation can lead to a reduction in timber biomass, a decrease in stand density, changes in forest structure, and progressive habitat degradation. When harvesting exceeds natural regeneration capacity, it can compromise the long-term viability of the stands and the ecological functions of the mangrove, including coastal protection, carbon sequestration, and the maintenance of aquatic habitats. Thus, landed mangrove timber is a relevant parameter for assessing the anthropogenic pressure exerted on mangroves. His analysis, based on the types of canoes, the frequency of landings, and the volumes transported, allows for a more precise estimation of the significance of the feat.

i) Importance of mangrove wood harvesting in the Tristão Islands

Table 5 highlights the strong predominance of large plank canoes in the weekly volume of timber transported. Although they represent only 6 out of 22 boats, they account for 215.94 m³/week, or approximately 59.2% of the total weekly volume. Smaller canoes contribute 81.102 m³/week (22.2%), while dugout canoes represent 67.851 m³/week (18.6%). On a monthly basis, the total estimated volume reaches 1459.572 m³/month, of which 863.76 m³/month is for large canoes, 324.408 m³/month for small canoes, and 271.404 m³/month for dugout canoes. These results show that the loading capacity of the boats is a determining factor in the volume of timber transported, more so than their number. Thus, large canoes, although in the minority, appear to be the main means of transporting mangrove wood and could contribute significantly to the pressure exerted on the resource.

Table 5. Quantity of timber landed at Kachek.

No.	Boat category	Volume (m ³) of wood/boat	Number of boats	Landing/ Week	Volume (m ³) of wood/week	Volume (m ³) of wood /month
1	Plank canoe (large model)	7.198	6	5	215.94	863.76
2	Plank canoe (small model)	1.931	7	6	81.102	324.408
3	Monoxyle	1.077	9	7	67.851	271.404
4	Total	10.206	22		364.893	1459.572

These results, shown in **Table 6**, indicate that the total volume of mangrove timber landed is estimated at 110,703 m³ per week, or 442,812 m³ per month. Small plank canoes contribute slightly more to this volume with 57.93 m³/week (52.3%), compared to 52,773 m³/week (47.7%) for dugout canoes. This difference is mainly explained by the unit volume and frequency of landings. These results demonstrate regular and relatively significant exploitation of mangrove timber, which could exert significant pressure on mangrove stands if this intensity continues over time.

Table 6. Quantity of wood landed at Katountun.

No.	Boat category	Volume (m ³) of wood/boat	Number of boats	Landing/ Week	Volume (m ³) of wood/week	Volume (m ³) of wood /month
1	Plank canoe (small model)	1.931	5	6	57.93	231.72
2	Monoxyle	1.077	7	7	52.773	211.092
Total		3.008	12		110.703	442.812

Table 7 indicates a total monthly volume of 1902.384 m³ of mangrove timber landed at the two main landing sites studied. Port Kachek is the primary landing point with 1459.572 m³/month, representing approximately 76.7% of the total volume. Port Katountoun accounts for 442.812 m³/month, or 23.3%. This significant difference demonstrates that Port Kachek concentrates the majority of mangrove timber landings and is therefore a particularly important site for monitoring resource exploitation. Together, the two landing sites record 1902.384 m³/month of timber, reflecting a relatively high intensity of mangrove timber harvesting and movement in the study area.

Table 7. Estimated monthly mangrove wood volume.

No.	Landing stages	Volume (m ³) of wood/month
1	Port Kachek	1459.572
2	Port Katountun	442.812
Total		1902.384

ii) Volume of mangrove wood consumed for fire-based salt production per month

Fire-based salt production, which relies on fire or thermal energy to evaporate salt water, is a significant source of pressure on mangrove timber resources. This activity typically requires substantial quantities of wood as fuel, which can lead to regular vegetation cutting, biomass reduction, and progressive degradation of mangrove stands. The intensity of the impact depends on factors such as the frequency of operations, the duration of production, and the amount of wood consumed. In the long term, the practice can contribute to reduced forest cover, hab-

itat fragmentation, and a decrease in the ecological functions of mangroves. Thus, in areas where mangrove wood is the primary energy source, fire-based salt production can be considered a significant to very significant source of pressure on mangroves.

Figure 3 highlights a significantly higher wood consumption than average salt production across all the studied groups. Average wood consumption ranges from approximately 1430 kg/month in Kapkin to 1710 kg/month in Katfoura, while average salt production remains relatively consistent, between 560 and 600 kg/month. Overall average consumption is estimated at approximately 1610 kg of wood/month for 580 kg of salt/month, representing a ratio of approximately 2.8 kg of wood per kilogram of salt. This situation reflects a strong dependence of salt production on the use of wood as an energy source, with greater pressure observed in the groups exhibiting the highest wood consumption.

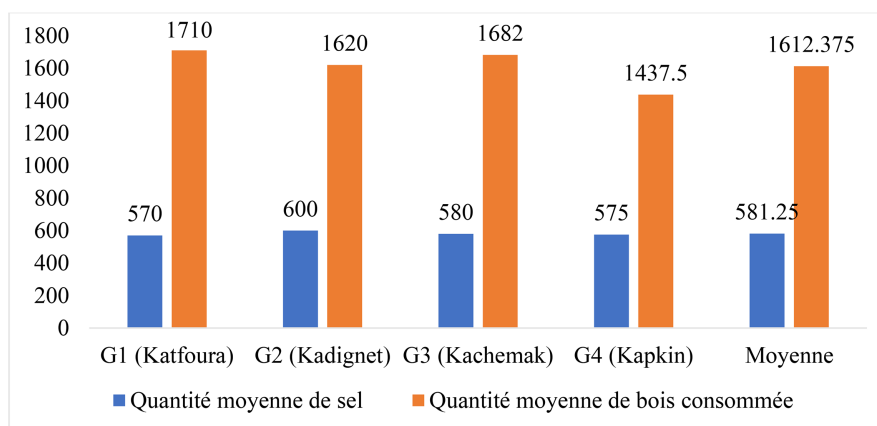


Figure 3. Volume of wood consumed by salt production/month.

iii) Estimation of the area cleared for the creation of new rice paddies

The creation of new rice paddies places significant pressure on mangrove ecosystems. It generally involves clearing vegetation, converting mangrove areas into agricultural land, and constructing dikes and canals. These developments can alter natural hydrological flows, disrupt the exchange between fresh and salt water, and locally promote salinization or water stagnation. The destruction of vegetation cover also reduces available habitats for wildlife and can contribute to soil degradation and riverbank erosion. Therefore, the expansion of rice paddies represents a direct factor in the transformation of mangroves, with potentially moderate to severe effects depending on the size and location of the converted areas.

In **Figure 4**, the estimate is based on land clearing operations recorded over a five-year period. The calculated areas for the different groups are 3 ha in Katfoura, 2 ha in Kadignet, 4 ha in Kapkin, and 0 ha in Kachemak, for a cumulative area of 9 ha over five years. This value therefore represents a cumulative area, not an annual area. When this value is annualized over the reference period, it corresponds to a theoretical average of 1.8 ha/year, calculated as follows: $9 \text{ ha} / 5 \text{ years} = 1.8 \text{ ha/year}$.

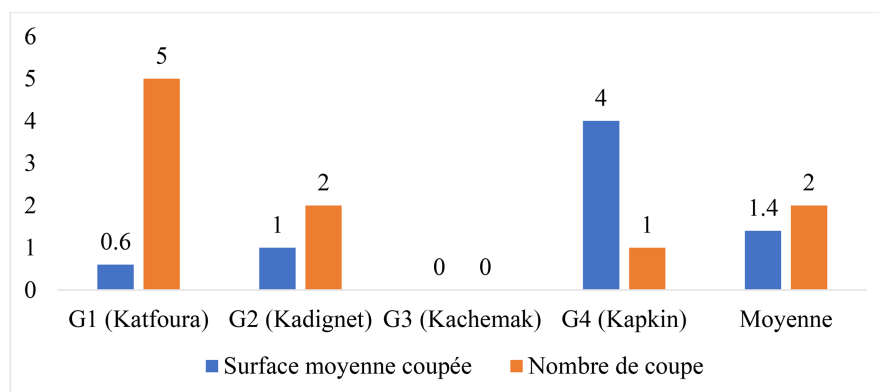


Figure 4. Area cleared for rice cultivation.

iv) Volume of mangrove wood consumed for smoking fish/month

Fish smoking is an activity that puts pressure on mangrove stands, primarily due to its high demand for fuelwood. Mangrove wood is commonly used as fuel for burning and drying fish products. This practice leads to regular harvesting of woody biomass and can contribute to a reduction in forest density and cover when harvesting is significant or exceeds natural regeneration capacity. Beyond the vegetation, repeated wood harvesting can lead to habitat degradation, a decrease in forest biomass, and disruption of mangrove ecological functions, including carbon sequestration and coastal protection. Thus, fish smoking appears as a significant source of pressure on mangroves, particularly in areas where no alternative energy sources are available.

Data analysis in **Figure 5** reveals high wood consumption associated with fish smoking in the four groups studied. On average, 687.5 kg of fish are smoked per operation, consuming 1,881.25 kg of wood, resulting in an average ratio of approximately 2.74 kg of wood per kilogram of fish smoked. Group G2 (Kadignet) exhibits the highest specific consumption, at 3 kg of wood/kg of fish, while groups G3 (Kachemak) and G4 (Kapkin) show the lowest ratios (2.5 kg/kg). These results indicate a strong dependence of fish smoking on wood fuel and suggest that this activity constitutes a potential source of pressure on mangrove wood resources.

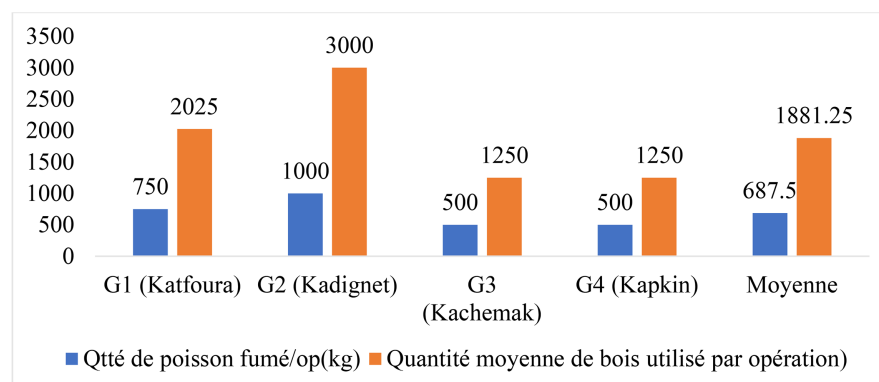


Figure 5. Quantity of wood for smoking fish/month.

3.1.6. Analyze the Main Effects of These Withdrawals on the Biophysical and Socioeconomic Components of the Environment

i) Effects of rice cultivation on the environment

Rice cultivation, particularly the creation of new paddies, has moderate negative impacts on wildlife, mangrove forests, and soil. Paddle creation may require clearing vegetation, altering soil structure, and disrupting habitats used by wildlife, especially fish associated with channels and intertidal zones. The impact on water, however, is assessed as moderate to severe. This can be explained by the alteration of natural flows, the construction of dikes and canals, and changes in the hydrological regime of the developed areas. These transformations can locally promote water stagnation, increase turbidity, or alter the exchange between fresh and brackish water. The impact on the human environment is also considered moderate to negative in the matrix. This assessment can be attributed to disruptions in traditional land uses, potential conflicts between activities, and the transformation of production areas. However, rice cultivation also offers significant socioeconomic benefits, particularly in terms of food security and income. Therefore, in discussing this thesis, it would be relevant to distinguish between the positive socioeconomic impacts and the environmental and social risks associated with expanding rice paddies.

ii) Effects of salt production

Salt production appears to be one of the activities with the most significant negative impacts on biophysical components. The impacts are assessed as severe on wildlife, mangrove forests, soil, and water. In mangroves, the creation of salt pans can lead to the direct conversion of wooded areas, the fragmentation of stands, and alterations to their regeneration capacity. The impact on the soil is also significant due to the potential increase in salinity and changes in soil structure and hydrological functioning. The strong impact on water is primarily explained by the alteration of circulation and hydrological exchanges associated with salt production facilities. These changes can affect the physicochemical conditions of the water and, indirectly, the habitats of certain aquatic species. In contrast, the impact on the human environment is assessed as positive to moderate. Salt production is, in fact, an income-generating activity and contributes to the livelihoods of communities. This opposition between socioeconomic benefits and environmental costs clearly illustrates the dilemma between economic exploitation of resources and conservation of mangrove ecosystems.

iii) Effects of smoking fish

Fish smoking has relatively low to moderate impacts on some components, but its effect on mangrove forests is assessed as significant. The impact on mangroves is primarily indirect, resulting from the demand for wood used as fuel in smoking facilities. When mangrove wood is the main energy source, increased smoking activity can stimulate the exploitation of woody stands. Effects on soil and water are relatively limited to moderate and mainly concern the accumulation of ash, residues, and waste around processing sites. Conversely, smoking has a positive impact on the human environment, as it allows for the preservation of fish prod-

ucts, facilitates their marketing, and contributes to income and job creation.

This situation shows that fish smoking is an important socioeconomic factor but also an indirect vector of pressure on woody resources.

iv) Effects of wood cutting

Logging is the activity with the most significant environmental impacts in the ecosystem. It is associated with a strong impact on wildlife, a very strong impact on mangrove forests, a moderate to strong impact on soil, and a moderate to strong impact on water. The very strong impact on mangrove forests is directly attributable to the harvesting of woody biomass. Repeated harvesting can lead to a decrease in stand density, a reduction in biomass, and disruption of natural regeneration. It can also gradually alter the floristic composition when certain species are preferentially harvested. Regarding wildlife, the disappearance of vegetation cover leads to habitat loss and fragmentation, which can affect terrestrial and aquatic species associated with mangroves. The degradation of root systems can also reduce refuge and breeding grounds for several fish and invertebrate species. The impact on soil is linked to the disappearance of vegetation cover and the reduction of the stabilizing effect of root systems. This situation can promote erosion, sediment resuspension, and progressive soil degradation. The impact on water is also significant, particularly due to the potential increase in turbidity and sediment transport resulting from the degradation of the vegetation cover. Despite these significant environmental effects, logging has a moderate to positive impact on the local community, as it provides a source of income and wood used primarily as fuel. This situation confirms the strong socioeconomic dependence of local populations on mangrove resources.

v) Comparison of activities

Comparing the four activities shows that logging constitutes the most significant environmental pressure, particularly on mangrove forests. Salt production follows, with strong impacts on several components, notably soil and water. Rice cultivation has generally moderate impacts, but its expansion can become a concern when new paddies are created directly within natural stands. Finally, fish smoking primarily has an indirect impact on mangroves, through the consumption of fuelwood.

Table 8 highlights varying levels of environmental pressure depending on the

Table 8. Summary of the level of impact of the main human activities on the environmental components of mangrove ecosystems.

Activity	Main component affected	Dominant level
Rice cultivation	Water and habitats	Moderate to high
Salt production	Mangrove, soil and water	Strong
Smoking the fish	Mangrove forest	Strong
Logging	Mangrove forest	Very strong

activity. Wood harvesting has the highest impact level (very high), primarily affecting the mangrove forest, followed by fish smoking and salt production, which have high impacts. Rice farming exerts moderate to high pressure, particularly on water resources and habitats. Overall, these activities contribute to the gradual degradation of the mangrove and its ecological functions, with the forest cover being particularly vulnerable.

vi) General Interpretation

Overall, this matrix highlights a close relationship between local livelihoods and mangrove ecosystem degradation. Activities that provide economic benefits to communities are also those that can exert the greatest pressure on natural resources. Logging appears to be the main direct driver of mangrove degradation, while rice cultivation and salt production contribute more to habitat transformation and conversion. Fish smoking, for its part, constitutes a primarily indirect but significant pressure due to its reliance on fuelwood. These results should, however, be interpreted as a qualitative assessment of impact levels and not as a quantitative measure of each activity's contribution to degradation. To strengthen the scientific argument in this thesis, this analysis can be correlated with forest inventory data, including stem density, basal area, biomass, regeneration rate, floristic composition, and harvested timber volume. This would allow for a comparison of perceptions and the qualitative impact assessment with biophysical indicators measured in the field.

4. Interpretation and Discussion of the Results

4.1. Mangrove Wood Samples from the Tristão Islands

The results obtained in the Tristão Islands highlight the significant pressure exerted by logging on mangrove stands. Observations made at the two main landing sites, Kachek and Katountoun, allowed for an estimated monthly volume of mangrove timber landed at 1902.384 m³. If this rate continues for twelve months, this volume would correspond to approximately 22828.608 m³/year. This estimate reflects a substantial mobilization of woody biomass and serves as an indicator of the pressure exerted on the forest resources of the study area.

The spatial distribution of landings, however, shows a strong concentration of activity at Kachek. This landing site accounts for 1459.572 m³/month, or 76.7% of the total estimated volume, compared to 442.812 m³/month (23.3%) for Katountoun. This difference appears to be primarily linked to the capacity of the boats and their landing frequency. At Kachek, the six large plank canoes, although a minority among the 22 boats recorded, alone account for 215.94 m³/week, or approximately 59.2% of the weekly volume landed. Smaller canoes and dugout canoes represent 22.2% and 18.6%, respectively. These results thus show that the intensity of harvesting depends not only on the number of boats, but also on their loading capacity and the frequency of trips.

This situation aligns with observations made in other West African mangrove ecosystems. In the Saloum Delta, Ndour (2005) reports that cutting intensities of

1500 to 5700 trees/ha are associated with low cover rates of 45 to 56% in some heavily exploited areas. The results of Yo *et al.* (2018) in Benin also provide an interesting point of comparison. In two Ramsar sites, these authors estimated the average consumption of service wood at 1.55 m³/capita/year, with values ranging from 1.11 to 2.52 m³/capita/year depending on the site. They also report an average consumption of 8.21 m³ of firewood per capita per year and 23.19 kg of charcoal per capita per year. The annual needs of the populations of the two Ramsar sites were estimated at 12,266,748 m³ of firewood and 34648.706 kg of charcoal in 2017, with respective projections of 18859.806 m³ and 53271.485 kg by 2027 (YO *et al.*, 2018).

These observations are consistent with the work of Feka and Ajonina (2011), who emphasize that logging is a major factor in the degradation of mangroves in West and Central Africa. These authors indicate, in particular, that mangrove wood is heavily used for domestic energy, fish smoking, construction, and various economic activities. More generally, Alongi (2002) highlights that logging is among the main anthropogenic pressures likely to alter the structure and productivity of mangroves. The results obtained in Tristão thus reflect a regional trend where the demand for woody biomass is a significant driver of transformation in coastal ecosystems.

4.2. Particular Pressure on *Rhizophora* Species

The survey results highlight a preferential exploitation of species of the genus *Rhizophora*, particularly *R. racemosa*, *R. mangle*, and *R. harrisonii*. This selectivity can be explained by their accessibility, availability, the mechanical and energetic properties of their wood, and user preferences. Repeated and selective exploitation of *Rhizophora*, especially individuals of certain diameter classes, is likely to progressively alter the structure and floristic composition of mangrove stands. These results are consistent with the observations of Ndour *et al.* (2011) in the Saloum Delta, where the main mangrove species include *R. mangle*, *R. racemosa*, *R. harrisonii*, and *Laguncularia. racemosa*, *Avicennia germinans* and *Conocarpus erectus*. The authors particularly emphasize the importance of the genus *Rhizophora* as a source of wood energy, especially for smoking fish, due to its high calorific value and slow combustion.

Similarly, Fousseni *et al.* (2017) demonstrate a high level of resource use in mangroves: 88.88% of respondents reported periodically harvesting mangrove wood, and 91% harvested the two main species studied. The utilization index reached 0.91 for *R. racemosa* compared to 0.69 for *A. germinans*, confirming the dominant role of *R. racemosa* in local practices. This preference is also linked to the accessibility and availability of the species in the river-lagoon ecosystems. Furthermore, Feka and Ajonina (2011) show that human harvesting can lead to changes in the structure, composition, and regeneration of mangroves in West and Central Africa. Thus, in the Tristão Islands, timber harvesting should not be assessed solely by the total volume harvested, but also according to the species

targeted and the diameter classes exploited. The selective pressure exerted on *Rhizophora*, particularly on individuals exhibiting characteristics sought by users, could eventually reduce their abundance and alter the structure of the stands.

4.3. Pressure from Fire-Based Salt Production on Mangrove Wood Resources

The results show that fire-based salt production places significant pressure on the wood resources of the Tristão Islands due to its heavy reliance on mangrove wood as an energy source. The estimated average consumption is 1612.375 kg of wood for 581.25 kg of salt, or approximately 2.77 kg of wood per kilogram of salt produced. This consumption varies among the communities, from 1437.5 kg in Kapkin to 1.710 kg in Katfoura, while salt production remains relatively consistent (570 to 600 kg). These variations may be related to the efficiency of the hearths, production techniques, wood moisture content, and the characteristics of the species used. These results are consistent with those of Togbodouno JT (2009), who demonstrated, in seven salt-producing sites in Sangaréyah Bay, a strong dependence of traditional salt production on mangrove wood.

His study estimated the harvest at approximately 9672.86 tonnes of wood per year, corresponding to a degraded mangrove area of about 255 hectares. It also indicated a preferential exploitation of *Rhizophora* (70%), *Avicennia* (25%), and *Laguncularia* (5%). The predominance of *Rhizophora* in the harvests thus aligns with observations made in the Tristão Islands.

On a larger scale, Yo *et al.* (2018) also highlighted a strong dependence of the populations of Ramsar sites in Benin on wood resources. Fuelwood requirements there averaged 8.21 m³/inhabitant/year, while the total fuelwood requirements of the two sites studied were estimated at over 12.26 million m³ in 2017. These data confirm that traditional activities based on fuelwood can exert considerable pressure on wetland ecosystems when practiced on a large scale. The results obtained at the Tristão Islands confirm observations made in other West African mangroves: salt production using firewood represents a direct energy pressure on the mangrove, particularly when fresh wood is the primary fuel.

4.4. Pressure from Fish Smoking on Mangrove Wood Resources

Fish smoking is an activity heavily dependent on woody biomass and, therefore, represents an indirect source of pressure on the mangroves of the Tristão Islands. The results obtained in the four groups indicate an average production of 687.5 kg of smoked fish per operation, with an average consumption of 1881.25 kg of wood, representing a ratio of 2.74 kg of wood per kilogram of smoked fish. Specific consumption varies from 2.5 kg/kg in Kachemak and Kapkin to 3 kg/kg in Kadignet, reflecting differences in efficiency between smoking practices and equipment.

This level of consumption highlights the strong energy dependence of fish smoking on wood, although comparisons with other studies must take into account differences in smoking techniques, combustion time, wood moisture con-

tent, and the water content of fish products. In Cameroon, for example, data reported for Manoka indicate that approximately 370 fish smokers harvest nearly 18,000 m³ of mangrove wood per year, or about 48 m³ per smoker per year. In Kribi, fish smoking accounts for about 60% of firewood use, with an average consumption of 6.8 m³ per traditional smokehouse, compared to 3.4 m³ for improved smokehouses (Hyacinthe A. 2015). These observations align with the work of Feka and Ajonina (2011), who identified the smoking of fish products as one of the important uses of mangrove wood in West and Central Africa. Thus, in the Tristão Islands, the impact of smoking on the mangrove is primarily indirect, as it stems from the demand for wood fuel needed to process fish. Reducing this pressure therefore requires, in particular, improving the energy efficiency of smokehouses, diversifying energy sources, and promoting wood-saving smoking techniques.

4.5. Effects of Rice Cultivation on the Mangrove

Direct pressure on the mangrove, unlike fish smoking and salt production using firewood, whose effects are mainly mediated by fuelwood consumption. Significant spatial variability was observed among the studied groups. Katfoura recorded five clearing operations, averaging 0.60 ha per operation, totaling approximately 3 ha, compared to two operations in Kadignet covering about 2 ha and a single operation in Kapkin covering approximately 4 ha. No operations were recorded in Kachemak. These results demonstrate that the number of operations does not necessarily reflect the spatial extent of the pressure: a low frequency of clearing can correspond to a heavily impacted area.

The conversion of mangroves into rice paddies leads to the direct removal of vegetation cover and the transformation of land use. It can also alter runoff, hydrological exchanges, and salinity conditions, thus compromising several ecological functions of the mangrove, including coastal protection, habitat maintenance, and nutrient cycling (Lee *et al.*, 2014). This dynamic aligns with the observations of Geist and Lambin (2002), who identify agricultural expansion as one of the main direct drivers of deforestation. The FAO (2003) also highlights the frequently observed relationship between the expansion of cultivated land and the reduction of forest areas. Thus, in the context of the Tristão Islands, rice cultivation appears as a factor in the spatial conversion of mangroves, likely to lead to a lasting loss of vegetation cover and ecosystem functions. However, unlike the situations of continental deforestation described in the Amazon by Fearnside (2005) and Morton *et al.* (2006), the dynamics observed at Tristão must be interpreted taking into account the ecological particularities of the intertidal environments and the interactions between deforestation, hydrology and salinity.

4.6. Public Perceptions and Comparison with Quantitative Results

The perceptions of the surveyed populations reinforce the results obtained from quantitative observations. Of the 40 people interviewed, 36 (90%) consider logging to be a factor in mangrove degradation. The creation of new rice paddies is

cited by 29 people (72.5%), fish smoking by 17 (42.5%), and salt production by 15 (37.5%). The resulting hierarchy is: Logging (90%) > Rice cultivation (72.5%) > Fish smoking (42.5%) > Salt production (37.5%). This perception is particularly interesting as it generally aligns with the results of the impact matrix, in which logging has a very strong impact on the mangrove forest, while salt production has strong impacts on several components. However, it should be noted that these percentages correspond to multiple responses: their sum reaches 242.5% and should therefore not be interpreted as an exclusive distribution of the causes of degradation. The concordance between local perception and quantitative observations reinforces the relevance of the results, while showing that the populations have significant empirical knowledge of the processes of degradation of their environment.

5. Conclusion and Recommendations

5.1. Conclusion

The study highlights significant anthropogenic pressure on the mangrove forests of the Tristão Islands, resulting primarily from logging, salt production using natural gas, fish smoking, and the creation of new rice paddies. These activities, however, exert different forms of pressure. Logging constitutes the main direct pressure on mangrove stands, while salt production and fish smoking contribute to degradation primarily through the demand for fuelwood. Rice cultivation, on the other hand, acts by directly converting mangrove areas into agricultural land. Log landings recorded at the ports of Kachek and Katountoun are estimated at 1902.384 m³/month, or approximately 22828.608 m³/year by extrapolation. This quantity reflects a high level of mobilization of the timber resource and suggests potentially significant pressure on the available timber stock, particularly when harvesting preferentially targets *Rhizophora* species.

Salt production consumes an average of 1612.375 kg of wood for every 581.25 kg of salt, or approximately 2.77 kg of wood per kg of salt. Fish smoking requires an average of 1881.25 kg of wood for every 687.5 kg of fish, corresponding to approximately 2.74 kg of wood per kg of fish. These results demonstrate the strong dependence of these two activities on fuelwood and their indirect contribution to the pressure exerted on the mangrove. The creation of new rice paddies represents, for the operations surveyed, a theoretical area of approximately 9 hectares. This conversion constitutes a direct spatial pressure likely to lead to a loss of vegetation cover, biomass, and habitats, as well as a modification of hydrological and salinity conditions.

Overall, the results indicate that mangrove degradation stems from the combined effect of several human activities, the impacts of which can accumulate over time and space. The sustainable conservation of the Tristão Islands mangroves therefore requires a reduction in pressure on timber resources, a limitation of stand conversion, and increased involvement of local communities in resource management.

5.2. Priority Recommendations

i) Reduce pressure on mangrove wood.

Strengthen control of logging and monitoring of timber volumes landed in order to better control harvesting and limit overexploitation of stands.

ii) Reduce wood energy consumption.

Promote improved smokehouses and more efficient salt kilns to reduce the amount of wood needed for fish processing and salt production.

iii) Limit the conversion of mangroves into rice paddies.

Prohibit or control the opening of new cells in natural stands and prioritize the restoration and enhancement of former agricultural areas.

iv) Restore degraded mangrove areas.

Prioritize natural regeneration and, when this is insufficient, implement restoration actions with local species adapted to the ecological conditions of the site.

v) Strengthen community management and ecological monitoring.

Involve local communities in management decisions and implement periodic monitoring of density, diameter structure, basal area, volume, biomass and mangrove regeneration in order to assess changes in the state of the stands.

Declaration of Generative AI and AI-Assisted Technologies in Manuscript Preparation

During manuscript preparation, the authors used Claude (Anthropics) solely for limited language editing of selected sentences in order to revise in order to improve clarity. No AI tool was used to generate research content, analyze data, interpret results, or prepare references, the ideas, argument, and intellectual contribution of the paper are entirely original. All AI-assisted suggestions were reviewed, revised where necessary, and approved by the authors, who take full responsibility for the final manuscript.

Author Contributions

Mohamed Youssef Fofana was responsible for the study design, literature search, data collection and analysis, interpretation of results, and drafting of the initial manuscript. Nounténin Sidimé contributed to the scientific analysis, interpretation of results, and critical revision of the manuscript. Kandè Bangoura participated in data analysis, discussion of the results, and revision of the scientific content. Adama Moussa Sakho contributed to scientific supervision, validation of the methodological approach, and critical revision of the manuscript. All authors have reviewed the final version and approved the manuscript for publication.

Conflicts of Interest

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

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