Caribbean Marine Biodiversity Program (CMBP)

Assessment of Mangroves in the Protected Area of Three Bays, Northeast Haiti

Technical Report Submitted by Landy Sabrina Cyprien and Francoise Benjamin, August 31, 2017.

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Executive Summary

The Caribbean Marine Biodiversity Program (CMBP), funded by USAID, aims to reduce threats to marine and coastal biodiversity in priority areas in the Caribbean, such as coral reefs, mangroves, and seagrass beds. The goals of this work are to achieve sustained biodiversity conservation, maintain critical ecosystem services, and realize tangible improvements in human wellbeing in communities adjacent to marine protected areas (MPAs) and marine managed areas (MMAs). To achieve these goals, four steps must be completed:

1. Create an environment that will enable long-term MPA success.
2. Develop effective marine spatial plans (MSPs) and seascape governance mechanisms.
3. Create a more sustainable fisheries sector by maximizing the fishery benefits of MPAs/MMAs, promoting innovative fishery management actions, and promoting sustainable livelihoods.
4. Maintain effective management and governance of MPAs/MMAs.

To help achieve the goals of the CMBP, mangrove restoration, monitoring, and assessments are being done in targeted CMBP seascapes to sustain and restore marine and coastal biodiversity. Mangroves are very valuable ecologically, as they play a critical role in protecting coastal shorelines and provide nursery and feeding grounds for commercially important marine species that contribute to local economies. Regular mangrove assessments can reveal the health status of mangrove populations and their surrounding ecosystem. Assessments should cover threats impacting mangroves as well as changes (i.e., loss or increase) in mangrove biomass and growth. Depending on the type and level of threats detected, suitable conservation methods can then be applied.

The CMBP team developed a performance monitoring plan to guide monitoring of the program, using a core set of performance indicators for project targets, data collection, and analysis.

One indicator was selected to track changes in the biophysical conditions of marine and coastal environments in each of the seascapes: the number of hectares (ha) of natural resources (represented by coral reefs and mangroves) that showed improved biophysical conditions as a result of United States government assistance.

This study aimed to conduct ground-truthing of 30 mangrove sites throughout the Protected Area of Three Bays (PA3B), Haiti, to determine the health status of the mangroves there and identify suitable conservation actions to preserve this ecosystem. The consultants analyzed changes in the biophysical conditions of the different mangrove species in the PA3B, relative to conditions reported from previous field work, and provided data to improve the classification accuracy of mangroves for satellite imagery representation. Four species of mangroves were identified: black mangrove (*Avicennia germinans*), white mangrove (*Laguncularia racemosa*), buttonwood mangrove (*Conocarpus erectus*), and red mangrove (*Rhizophora mangle*). *R. mangle* was the most abundant species (4,681 trees/ha), followed by *L. racemosa* (854 trees/ha) and *A. germinans* (785 trees/ha). The buttonwood mangrove (*C. erectus*) had the lowest density of all the species and was observed at only 11 of the 30 sites, with an average density of 185 trees per hectare.

The average diameter at breast height (DBH) and height of the red mangroves in Caracol/Limonade were 1.49 m and 2.96 m, respectively, lower than those found in Fort Liberté, where average DBH was 1.86 m and average height was 4.97 m, and Lagon aux Boeufs, where average DBH was 2.66 m and average height was 7.47 m. Anthropogenic activities are concentrated around Caracol and solid waste pollution was present at several sites. Thus, the overall health of the plots based on disturbance level was 3 out of 5. While the mangroves of Lagon aux Bœufs showed the highest average DBH and height, there is evidence of degradation in some areas of this site. Researchers noted signs of pollution (plastic bags, excrement, and other forms of solid waste), cut trees and branches, and charcoal dumping, among other things. Fort Liberté had the highest number of buttonwood mangroves; this species was present in five of the 11 sites in Fort Liberté. The overall condition of the mangrove ecosystem in the PA3B seems relatively healthy. There was one exceptional site in this area with absolutely no signs of pollution or disturbance.

The field team identified six associated coastal plants, 27 species of birds (including two endemic species, *Phaenicophilus palmarum* and *Coccyzus longirostris*), two species of crustaceans, and three species of mollusks within the sampling area. The average salinity in Caracol and Fort Liberté was between 33 and 36 ppt, corresponding to the modal salinity of open water, while the salinity in Lagon aux Bœufs was much lower, around 7 ppt. The significantly lower salinity in this area was likely due to the nearby presence of the Massacre (Dajabón) River. The pH in Caracol and Fort-Liberté were similar, around 6.7 to 7.2, while the pH of Lagon aux Bœufs was higher, at 7.4.

All sites visited within the PA3B boundaries are heavily influenced by past and present human extractive activities, primarily the illegal harvest of trees for charcoal and firewood production. In some places, local fishers and organizations have protected mangrove nurseries. However, in other places, mangroves have been used as a waste disposal site for plastics and other types of garbage, which increases pollution levels. The local communities need support to protect the remaining mangroves by sensitizing the residents to the value of mangroves and encouraging them to actively participate in protecting this ecosystem, while reducing anthropogenic pressures.

The team also observed poor water quality at the PA3B due to pollution. To improve water quality, restoration and solid waste management activities should be continued in the PA3B. The social and economic situation of the local population should be considered during regularly monitoring the biophysical conditions of the ecosystem. To encourage decreased dependence on mangroves in the PA3B, management authorities for the park could offer local people alternatives to charcoal use, such as by phasing in use of solar stoves.

Background

This ecological assessment evaluated mangrove ecosystems using a combination of remote sensing technology and field surveys to provide in-depth information on the spatial extent and biophysical conditions of the forest. The mangrove forest in the PA3B, northeast Haiti (Figure 1), includes approximately 18% of the country's remaining mangroves. The system is

highly productive and is home to a rich diversity of flora and fauna, including a site designated an Important Bird Area in Lagon aux Boeufs. Despite the ecological importance of the mangrove system, it remains under major threat from the local charcoal production industry. There are ongoing reforestation initiatives that involve sowing mangrove plantlets in areas of die-off, which directly engage members from communities located within the PA3B. Several mangrove nurseries have also been constructed throughout the PA3B, and community members have been educated on the importance of the ecosystem and on environmental stewardship.

The baseline assessments, performed in 2015–2016, showed that the core mangrove area in PA3B covered 4,305 ha. It is imperative to execute follow-up monitoring activities to assess any changes in the cover of the mangrove forest and its biophysical conditions, compared with data from the previous assessment, as well as to strategically guide mangrove reforestation efforts by the local CMBP partner Foundation pour la Protéction de le Biodiversité Marin (FoProBiM).

Figure 1: Terrestrial and marine boundaries of the Protected Area of Three Bays (PA3B)

Materials and Methods

A vegetation field guide was created to facilitate the identification of species in the field. For each taxon, a checklist of expected species was compiled according to the *World Atlas of Mangroves* (Spalding et al., 2010), and the *Rapid Assessment of Haiti's Mangroves* (Wiener et al., 2014). Other books were consulted, particularly the "*Guide Méthodologique pour la Cartographie des Mangroves de l'Outre-Mer Français*" (Taureau et al., 2015). In addition, we prepared a digital field guide to identify mollusks and crustaceans by using information from the Internet (IUCN website) and *The Manuel de Zoologie* (Blaise, 2005).

The field work was conducted from July 21 to July 29 at the PA3B, in the northeastern coast of Haiti. The two consultants (Landy Sabrina Cyprien and Francoise Benjamin) sampled 30 sites within the Park and gathered anecdotal information (common use, activities related to mangroves, and so on) from community members. Data collection at each site took an average of three hours. Three to four sites per day were sampled, depending on the accessibility of areas. Figure 2 shows the distribution of sample sites visited throughout the park.

Figure 2: Distribution of the sites in the PA3B

At the beginning of the project, a preliminary field assessment was performed using WorldView-2 (2 m) satellite imagery acquired in April 2014 by The Nature Conservancy to study the spatial distribution of the predetermined sites. At the same time, we implemented the fieldwork strategy, selected the sites, and collected data.

Mangroves were surveyed in 30 sites within quadrats of 250 m² (25 x 10) per site. In some areas, where the quadrats were difficult to lay mainly because of the density of the vegetation, we used a 100-m transect along the mangroves. This method has been used for sites located closer to the sea, where the roots of the mangroves, mostly *R. mangle*, were immersed in water more than 80 cm deep. In those cases, we used a boat to perform the survey. Several parameters were identified and measured, such as species of mangrove and the estimated canopy cover.

The number of plants per species in each quadrat was counted, using the field guide. Several pictures of associated flora (leaf, flower, seed, root, and fruit) and samples were taken to put together a herbarium, which allowed for further identification after the field work. The phenology (flowering, fructification, and seedling) of the plants was also recorded.

The canopy cover was estimated as a percentage from 0% to 25% for areas where the canopy cover was less significant and from 25 to 50% in areas when the canopy formed a partial cover. In sections where vegetation was very dense and the size of the tree crown within the quadrat was significant, the canopy cover was estimated to be between 50% and 75%. In areas where the tree crowns were consistently overlapping, canopy cover was estimated between 75% and 100%. However, information from drones will improve the accuracy of the overall canopy cover estimates.

The heights of the mangroves were measured from the ground to the crown. For each species, we calculated the average height of the trees and for individuals growing higher than 2 meters; we also calculated the average DBH at 1.35 m from the ground for each species.

In addition to the mangrove identification and measurement, information about the overall habitat was recorded, such as the type of substratum, associated species, and water quality. Where tree roots were immersed, pH, salinity, and temperature of the water were measured using a multi-parameter tester. Flora of the mangrove ecosystem were identified by examining their morphological characteristics, while fauna (i.e., birds, mollusks, and crustaceans) were listed based on sighting, referencing documents on wildlife that frequent the area, and consulting local individuals.

To estimate plot health, we used a quantitative scale from 1 to 5, described in Moore (2014), in which a score of 1 = poor and 5 = exceptional, as explained in the Baseline Ecological Inventory for Three Bays National Park, Haiti (2015). To evaluate disturbance levels, we ranked plots according to the following scale. A ranking of “Good” implies little to no evidence of disturbance (e.g., cutting/harvest) or die-back; forest cover is > 50%, trees and shrubs are reproducing and exhibit strong evidence of stand seedling recruitment; and there is an opportunity for stand

expansion or migration. A ranking of “Fair” indicates some evidence of disturbance; forest cover is < 50% but >25%; there is some evidence of seedling recruitment, but stand expansion or migration is likely limited. Finally, a ranking of “Poor” means that there is abundant evidence of disturbance, forest cover is < 25%, there is no evidence of seedling recruitment, and stand expansion or migration appears impossible. In contrast with Moore, authors like Ellison and Farnsworth (1996) considered four classes of anthropogenic disturbance: 1) extractive uses of mangrove trees and fauna, 2) reclamation of mangrove habitat for non-extractive uses; 3) pollution of the mangrove area; and 4) damage to mangroves due to climate change. It is clear from the literature that many factors affect the level of disturbance (Table 1). Therefore, we scored areas out of a possible five points, with five indicating a healthy and undamaged area, and lower numbers indicating more disturbance.

Table 1: Description of disturbance factors identified in the PA3B

Disturbance factor	**Comments**
Pollution	Soil and water pollution
Solid waste (such as plastic bottles)	Need low-cost disposal options for local community
Withering	
Mortality	
Deforestation/mangrove cutting	Visible sign of cutting: piles of wood, charcoal placement, sectioned trunks
Regeneration	Presence of plantlets or young trees
Agriculture	Nearby agriculture area
Barrier	Presence of mangrove-made barrier for fishing activities
Land conversion	Mostly for salt mining and agriculture
Settlement proximity	Houses nearby
Livestock proximity	Cattle nearby
Fishing	Boats, nets, fish vendors, crab traps, and so on nearby

The spatial distribution of plants (density per hectare), average DBH, and average tree height were analyzed using ArcGis, a mapping software that uses graduated symbols or diagrams at each site to compare the biophysical parameters. Each parameter is added to a single map for the four species of mangroves, using different colors to code for the different species, and they are compared.

Results

Mangrove Inventory

Of the four mangrove species identified, the red mangrove was the most abundant species in the area, followed by the black mangrove, with both species demonstrating high values for DBH and height. The average measurements of the species are listed in Table 2.

Table 2: Average size of the four mangrove species sampled in the PA3B

Species	Scientific Name	Average DBH (cm)	Average Height (m)
Black mangrove	*Avicennia germinans*	4.13	3.41
White mangrove	*Laguncularia racemosa*	2.44	2.31
Red mangrove	*Rhizophora mangle*	4.64	4.95
Buttonwood mangrove	*Conocarpus erectus*	2.07	2.12

Several areas entirely covered with water were surveyed, where the only species identified was the red mangrove. The trees had their roots, which were up to 70 cm long, partially immersed. These plots were the ones located closest to the sea. They were considered to be in good health and disturbance was minimal, with no visual signs of pollution or deforestation. These mangrove trees are young and should grow normally if external disturbances are kept at bay. At most other sites, the mangroves were threatened by human activities; we observed several charcoal disposal sites nearby and piles of newly cut mangrove wood.

The area surveyed was subdivided into three main sectors: Caracol/Limonade, Fort Liberté, and Lagon aux Bœufs. A number of parameters were assessed at each site, including the site's overall health, mangrove species present, and their measurements.

Sector I: Caracol/Limonade Bay

Caracol/Limonade Bay is the largest area of the study, containing 11 sites (Figure 3).

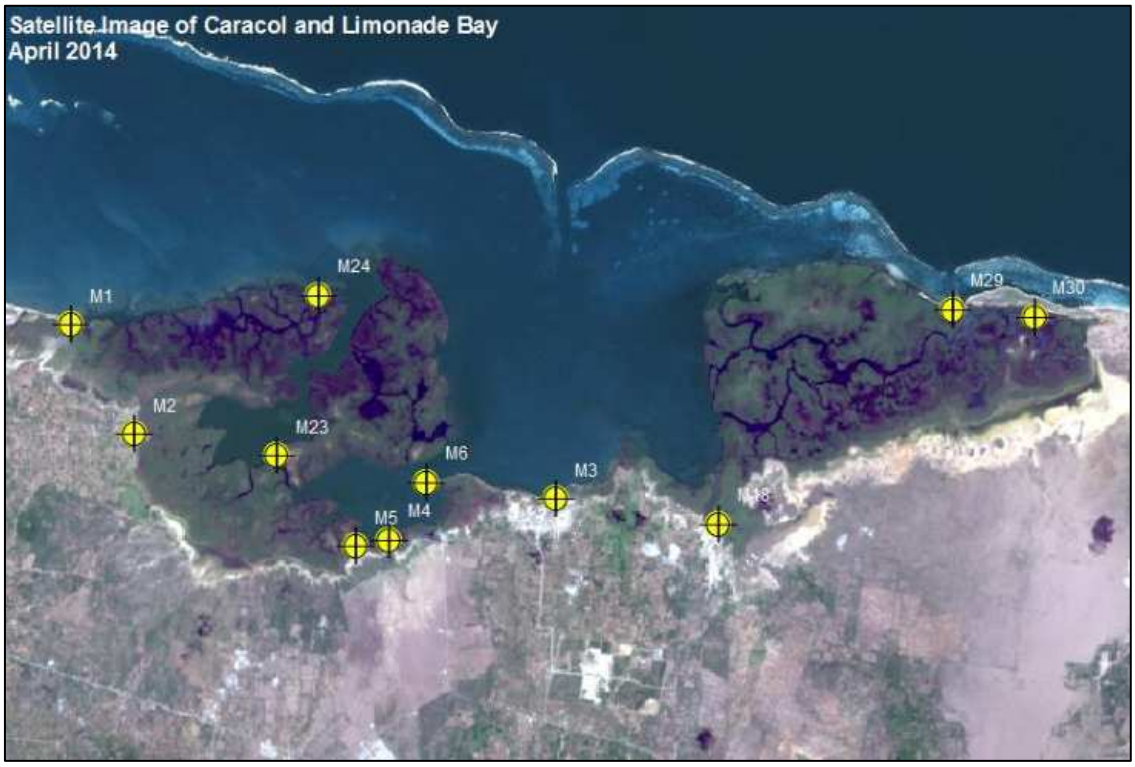

Figure 3: Satellite image of sector I, Caracol/Limonade Bay

Table 3: Data on mangroves in plot #1, sector I, Caracol/Limonade

Species	Number of Plants	Height (m)	Average DBH (cm)	Density (trees/ha)	% of Total, by Species
Avicennia germinans	46	1.5	2.2	1,840	52
Rhizophora mangle	41	1.5	< 2	1,640	46
Laguncularia racemosa	2	2	2.3	80	2
Conocarpus erectus	0	0	0	0	0
Total	**89**	-	-	**3,560**	**100**

As shown in Table 3, plot #1 contained 89 trees, 52% of which were black mangrove and 46% of which were red mangrove. The trees' average height was approximately 1.5 m. The density was calculated at 3,560 trees/ha (including only 80 white mangrove trees/ha and more than 1,500 red and black mangrove trees/ha), and the overall canopy cover was estimated to be between 0 and 25%. Around this site, we observed much evidence of charcoal production and a pile of cut wood from trees in the immediate area. We also observed solid waste, plastic bags, and bottles in the area. The overall health of the site was estimated at 3/5. About 50 m from the site, we observed a seedling nursery for red mangrove. Farther away, around 100 m from the site, we identified buttonwood mangroves; however, these trees were not included in the data for the plot, as they did not fall within its physical boundaries.

Table 4: Data on mangroves in plot #2, sector I

Species	**Number of Plants**	**Height (m)**	**Average DBH (cm)**	**Density (trees/ha)**	**% of Total, by Species**
Avicennia germinans	93	2.35	2.7	1,840	100
Rhizophora mangle	0	0	0	0	0
Laguncularia racemosa	0	0	0	0	0
Conocarpus erectus	0	0	0	0	0
Total	**93**	-	-	**1,840**	**100**

Table 4 shows that plot #2 contained 93 trees, all black mangroves, with an average DBH above 2 cm. The average tree height was 2.35 m, although some trees grew higher than 3 m. The density was 1,840 trees/ha and the canopy cover was estimated to be between 25% and 50%. The health of the plot was estimated to be excellent (5/5), as there was no waste or charcoal disposal observed. The mangroves were growing in marshy soil, ideal for this species.

Table 5: Data on mangroves in plot #3, sector I

Species	Number of Plants	Height (m)	Average DBH (cm)	Density (trees/ha)	% of Total, by Species
Avicennia germinans	50	2.43	6.6	2,000	89
Rhizophora mangle	0	0	0	0	0
Laguncularia racemosa	6	1.95	2.5	240	11
Conocarpus erectus	0	0	0	0	0
Total	**56**	**-**	**-**	**2,240**	**100**

As shown in Table 5, plot #3 contained 56 trees, including 89% black mangroves and 11% white mangroves. The average DBH was 6.6 cm for black mangroves and 2.5 cm for white mangroves. The average tree height for this plot was approximately 2.19 m. The density was 2,240 trees/ha, including 2,000 black mangroves and 240 white mangroves. This site was heavily affected by humans, with campfire sites, fishing boats, nets and a lot of garbage (See annexes). The health of the plot was estimated to be poor (1/5).

Table 6: Data on mangroves in plot #4, sector I

Species	Number of Plants	Height (m)	Average DBH (cm)	Density (trees/ha)	% of Total, by Species
Avicennia germinans	17	2.8	2.3	680	20
Rhizophora mangle	61	3.8	2.65	2,440	74
Laguncularia racemosa	5	1.9	1.6	200	6
Conocarpus erectus	0	0	0	0	0
Total	**83**	**-**	**-**	**3,320**	**100**

Plot #4 had a total of 83 trees: 20% black mangroves, 74% red mangroves, and 6% white mangroves. The average DBH of the three species was approximately 2 cm. The average height of the trees in this plot was about 1.5 m and the canopy cover was estimated to be between 50% and 75%. The density was 3,320 trees/ha with white mangroves having lowest density, 200 trees/ha. This site is generally in good health, but there is an agriculture plot nearby, giving it a rating of 4/5.

Table 7: Data on mangroves in plot #5, sector I

Species	**Number of Plants**	**Height (m)**	**Average DBH (cm)**	**Density (trees/ha)**	**% of Total, by Species**
Avicennia germinans	11	2.7	2.8	440	9
Rhizophora mangle	102	3.2	3	4,080	84
Laguncularia racemosa	0	0	0	0	0
Conocarpus erectus	8	2	1.1	320	7
Total	**121**	**-**	**-**	**4,840**	**100**

As shown in Table 7, plot #5 had a total of 121 trees with an average DBH of 2.3 cm. The trees were 9% black mangrove, 84% red mangrove, and 7% white mangrove. The trees in this plot were approximately 2.6 m high. The density was 4,840 trees/ha. This site has suffered few disturbances and is surrounded by water. The health of the plot was classified as 4 out of 5.

Table 8: Data on mangroves in plot #6, sector I

Species	Number of Plants	Height (m)	Average DBH (cm)	Density (trees/ha)	% of Total, by Species
Avicennia germinans	24	3,1	3,6	960	8
Rhizophora mangle	217	3,6	3,3	8,680	74
Laguncularia racemosa	43	3,1	2,4	1,720	15
Conocarpus erectus	8	2,6	2	320	3
Total	**292**	**-**	**-**	**11,680**	**100**

As shown in Table 8, plot #6 contained 292 trees with an average DBH of 2.8 cm. The trees were 8% black mangroves, 74% red mangroves, 15% white mangroves, and 3% buttonwood mangroves. The trees in this plot were on average 3.1 m high, with red mangrove being the tallest of the species. The canopy cover was estimated to be between 50% and 75%. The density was 11,680 trees/ha. Solid waste was observed around the site, making the estimated health of the plot 3/5.

Table 9: Data on mangroves in plot #18, sector I

Species	Number of Plants	Height (m)	Average DBH (cm)	Density (trees/ha)	% of Total, by Species
Avicennia germinans	43	2.1	3.1	1,720	29
Rhizophora mangle	5	2.1	2.1	200	3
Laguncularia racemosa	102	3.2	7.6	4,080	68
Conocarpus erectus	0	0	0	0	0
Total	**150**	**-**	**-**	**6,000**	**100**

Table 9 shows that plot #18 contained 150 trees, of which 68% were white mangroves, 29% were black mangroves, and 3% were red mangrove. The white mangroves had the highest average DBH, 7.6 cm. The average tree height was about 2.46 m and the canopy cover estimated to be between 0% and 25%. The density (number of trees per hectare) was 6,000. The mangrove area was young, as indicated by the presence of many growing plantlets, and significant tree cutting had occurred in the area. The health of the plot was estimated at 4 out of 5.

Table 10: Data on mangroves in plot #23, sector I

Species	**Number of Plants**	**Height (m)**	**Average DBH (cm)**	**Density (trees/ha)**	**% of Total, by Species**
Avicennia germinans	0	0	0	0	0
Rhizophora mangle	126	4	3	5,040	99
Laguncularia racemosa	1	2	2	40	1
Conocarpus erectus	0	0	0	0	0
Total	**127**	**-**	**-**	**5,080**	**100**

As shown in Table 10, plot #23 contained 127 trees with an average DBH of 2.5 cm. Of the trees, 99% were red mangroves and only one specimen of white mangrove was present. The canopy cover was estimated to be between 0% and 25%. The density was 5,080 trees/ha. The plot for this site was designated about 60 m from the original location because of accessibility problems. The site was surrounded by water, and there were signs of mangrove cutting, such as piles of wood, cut branches, and freshly damaged trunks. The health of this plot was 3/5.

Table 11: Data on mangroves in plot #24, sector I

Species	Number of Plants	Height (m)	Average DBH (cm)	Density (trees/ha)	% of Total, by Species
Avicennia germinans	0	0	0	0	0
Rhizophora mangle	25	4	4	1000	100
Laguncularia racemosa	0	0	0	0	0
Conocarpus erectus	0	0	0	0	0
Total	**25**	**-**	**-**	**1000**	**100**

Table 11 shows that plot #24 contained a total of 25 trees, all black mangroves, with an average DBH of 4 cm and an average height of 4 m. The canopy cover was estimated to be between 0% and 25%. The density was 1,000 trees/ha. This site was surrounded by water, and its health was categorized as 3/5.

Table 12: Data on mangroves in plot #29, sector I

Species	Number of Plants	Height (m)	Average DBH (cm)	Density (trees/ha)	% of Total, by Species
Avicennia germinans	20	3	6.21	800	6
Rhizophora mangle	120	3	4.14	4,800	34
Laguncularia racemosa	210	1	< 2	8,400	60
Conocarpus erectus	0	0	0	0	0
Total	**350**	**-**	**-**	**14,000**	**100**

As shown in Table 12, plot #29 contained 350 trees, 6% of which were black mangroves, 34% red mangroves, and 60% white mangroves. The average height for this plot was 2.3 m. The density was 14,000 trees/ha. The mangroves in this site were growing in a marshy soil. A few signs of human activities, such as trunks damaged by cutting, were observed, but there was no solid waste in the immediate vicinity of the plot. The health was categorized as a 4/5.

Table 13: Data on mangroves in plot #30, sector I

Species	**Number of Plants**	**Height (m)**	**Average DBH (cm)**	**Density (trees/ha)**	**% of Total, by Species**
Avicennia germinans	0	0	0	0	0
Rhizophora mangle	1,000	1.5	6.3	40,000	100
Laguncularia racemosa	0	0	0	0	0
Conocarpus erectus	0	0	0	0	0
Total	**1000**	**-**	**-**	**40,000**	**100**

Table 13 shows that plot #30 contained 1,000 trees, all black mangroves, with an average DBH of 6.3 cm. The density was 40,000 trees/ha. The health of the plot was categorized as 4/5, as no pollution or human activities were observed. However, this site is located by a highly frequented open-access area, close to the core mangrove zone, which makes it vulnerable to potential threats, such as mangrove harvesting.

Sector II: Fort Liberté

In the Fort Liberté area, mangroves were surveyed in 11 sites (Figure 4). This sector contained the highest mangrove densities, but it also included a higher number of threatened sites. There were many places where mangroves had been cut, and charcoal sites were observed throughout the

sector. There were also positive signs of regeneration where replanting activities were taking place.

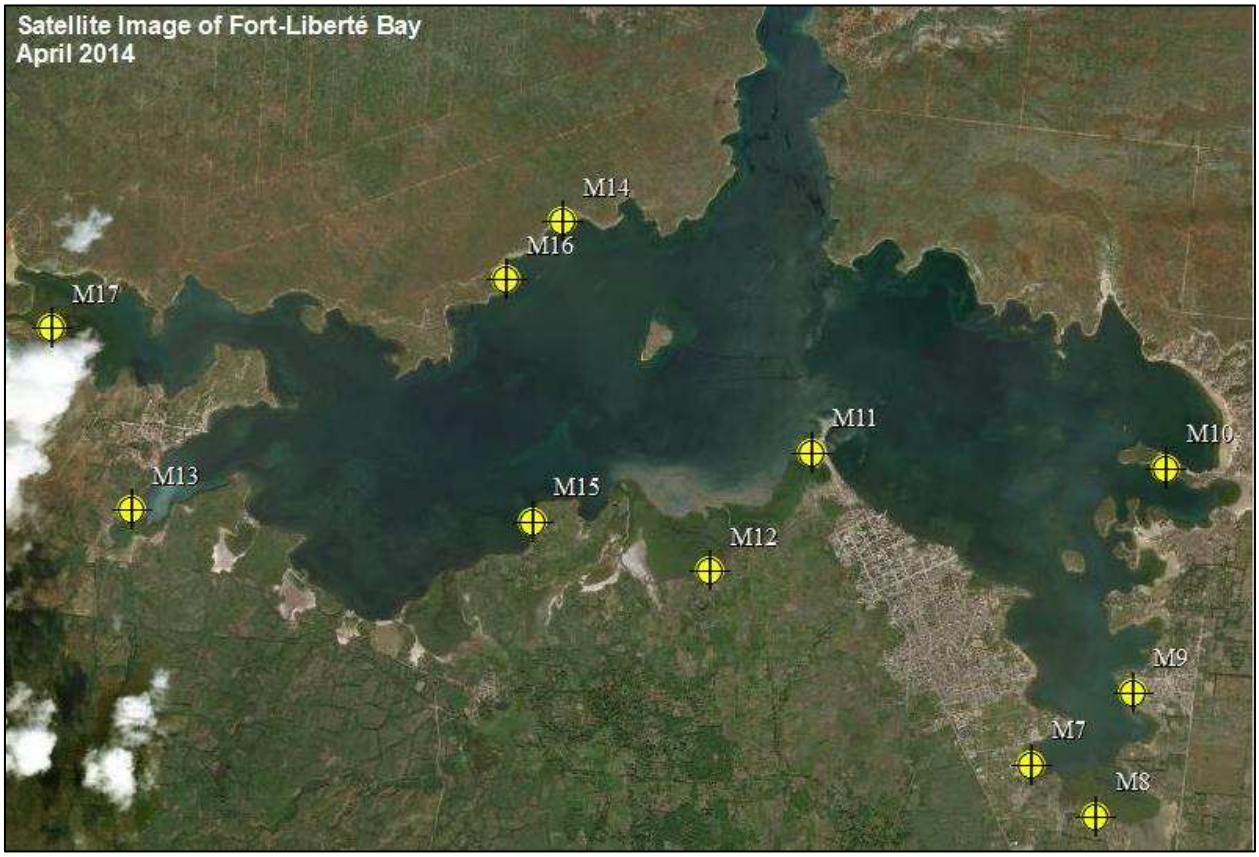

Figure 4: Satellite image of sector II, Fort Liberté Bay

Table 14: Data on mangroves in plot #14, sector II, Fort Liberté

Species	Number of Plants	Height (m)	Average DBH (cm)	Density (trees/ha)	% of Total, by Species
Avicennia germinans	10	3.5	2.9	400	7
Rhizophora mangle	117	8	6.7	4,680	79
Laguncularia racemosa	7	2,1	1,1	280	5
Conocarpus erectus	13	1,2	0,2	520	9
Total	**147**	**-**	**-**	**5880**	**100**

Plot #14 contained 147 trees, composed of 7% black mangroves, 79% red mangroves, 5% white mangroves, and 9% buttonwood mangroves. The average tree size for this plot was low, except for the red mangrove, whose average height was estimated to be 6.7 m. The canopy cover was estimated to be between 0% and 25%. The density was 5,880 trees/ha. This site was located close to a dry forest, and its health was categorized as 3/5.

Table 15: Data on mangroves in plot #16, sector II

Species	**Number of Plants**	**Height (m)**	**Average DBH (cm)**	**Density (trees/ha)**	**% of Total, by Species**
Avicennia germinans	0	0	0	0	0
Rhizophora mangle	22	4.2	3.18	880	47
Laguncularia racemosa	25	0.5	1.1	1,000	53
Conocarpus erectus	0	0	0	0	0
Total	**47**	**-**	**-**	**1,880**	**100**

As shown in Table 15, plot #16 had a total of 47 trees, 47% of which were red mangroves and 53% of which were white mangroves. The red mangroves' average DBH was approximately 3.18 cm and their average height was 4.2 m. The overall canopy cover was estimated to be between 0% and 25%. The density was 1,880 trees/ha. Anthropogenic interference was observed at this site, with a large amount of garbage present and recently cut trees observed. Therefore, the level of health was categorized as a 2/5.

Table 16: Data on mangroves in plot #17, sector II

Species	Number of Plants	Height (m)	Average DBH (cm)	Density (trees/ha)	% of Total, by Species
Avicennia germinans	0	0	0	0	0
Rhizophora mangle	25	3	1.6	1,000	68
Laguncularia racemosa	5	2.2	5	200	13
Conocarpus erectus	7	1.7	2.2	280	19
Total	**37**	**-**	**-**	**1,480**	**100**

Table 16 shows that plot #17 contained 37 trees, 68% of which were red mangroves, 13% white mangroves, and 19% buttonwood mangroves. The average DBH was 2.86 cm. The density was 1,480 trees/ha and the canopy cover was estimated to be between 0% and 25%. Trees at this site were relatively short and only the red mangroves grew higher than 3 m. The health of this site was categorized as 3/5.

Table 17: Data on mangroves in plot #13, sector II

Species	Number of Plants	Height (m)	Average DBH (cm)	Density (trees/ha)	% of Total, by Species
Avicennia germinans	104	3.68	8.75	4,160	61
Rhizophora mangle	61	6.5	5.25	2,440	36
Laguncularia racemosa	5	1.5	1	200	3
Conocarpus erectus	0	0	0	0	0
Total	**170**	**-**	**-**	**6,800**	**100**

Table 17 shows that plot #13 contained 170 trees, including three species: 61% of the trees were black mangroves, 36% were red mangroves, and 3% were buttonwood mangroves. The average DBH of the black mangroves was 8.75 cm. The density was 6,800 trees/ha and the canopy cover was estimated to be between 50% and 75%. The red mangroves grew to a maximum height of 6.5 m. The site was located in a marshy area, and its health was 3/5.

Table 18: Data on mangroves in plot #15, sector II

Species	**Number of Plants**	**Height (m)**	**Average DBH (cm)**	**Density (trees/ha)**	**% of Total, by Species**
Avicennia germinans	0	0	0	0	0
Rhizophora mangle	52	4.8	8.7	2,080	100
Laguncularia racemose	0	0	0	0	0
Conocarpus erectus	0	0	0	0	0
Total	**52**	**-**	**-**	**2,080**	**100**

As shown in Table 18, plot #15 contained a total of 52 trees, all red mangroves. The mangroves' average DBH was about 8.7 cm and some trees reached 5 m in height. The average tree height was 4.8 m and the canopy cover was 25%–50%. The density was 2,080 trees/ha and the plot's health was rated 4/5. No visible signs of pollution or other human activities were observed.

Table 19: Data on mangroves in plot #11, sector II

Species	**Number of Plants**	**Height (m)**	**Average DBH (cm)**	**Density (trees/ha)**	**% of Total, by Species**
Avicennia germinans	23	7.2	6.36	920	14
Rhizophora mangle	140	7.5	4.98	5,600	82

Laguncularia racemose	7	3.5	2.5	280	4
Conocarpus erectus	0	0	0	0	0
Total	**170**	**-**	**-**	**6,800**	**100**

Table 19 shows that plot #11 contained 170 trees: 14% of the trees were black mangroves, 82% were red mangroves, and only 4% were white mangroves. The average height of trees at this site was one of the highest, 7.2 m for black mangroves and 7.5 m for red mangroves. Canopy cover was estimated to be between 75% and 100%. The average DBH values for this site were 6.36 cm and 4.98 cm for the black and red mangroves, respectively. The density was 6,800 trees/ha and the health of the plot was categorized as a 4/5, with no pollution or visible signs of human activities.

Table 20: Data on mangroves in plot #7, sector II

Species	**Number of Plants**	**Height (m)**	**Average DBH (cm)**	**Density (trees/ha)**	**% of Total, by Species**
Avicennia germinans	50	3	2.8	2,000	58
Rhizophora mangle	35	3.1	2.5	1,400	40
Laguncularia racemosa	0	0	0	0	0
Conocarpus erectus	2	2	3	80	2
Total	**87**	**-**	**-**	**3,480**	**100**

As shown in Table 20, plot #7 had a total of 87 trees, including 58% black mangroves, 40% red mangroves, and 2% buttonwood mangroves. The red mangrove grew the tallest, with an average height of 3.1 m, although the average height of the other two species was > 3m. The DBH for all

three species was less than or equal to 3 cm. The canopy cover was between 50% and 75%. The density was 3,480 trees/ha. The health of this plot was a 3/5.

Table 21: Data on mangroves in plot #8, sector II

Species	**Number of Plants**	**Height (m)**	**Average DBH (cm)**	**Density (trees/ha)**	**% of Total, by Species**
Avicennia germinans	5	3.2	2,5	200	4
Rhizophora mangle	0	0	0	0	0
Laguncularia racemosa	71	2.6	2.8	2,840	53
Conocarpus erectus	58	1.7	1.6	2,320	43
Total	**134**	**-**	**-**	**5,360**	**100**

Table 21 shows that plot #8 had a total of 134 trees, of which 4% were black mangroves, 53% were white mangroves, and 43% were buttonwood mangroves. The average height of the trees was around 2.5 m and the average DBH was less than 3 cm for all three species. The density was 5,360 trees/ha, and the canopy cover was estimated to be between 50% and 75%. This site was surrounded by water and was observed to be in exceptional health. No visible sign of pollution or any other types of disturbances were identified; the health level was categorized at 5/5.

Table 22: Data on mangroves in plot #9, sector II

Species	**Number of Plants**	**Height (m)**	**Average DBH (cm)**	**Density (trees/ha)**	**% of Total, by Species**
Avicennia germinans	20	4	5	800	22
Rhizophora mangle	73	5.2	4.5	2,920	78
Laguncularia racemosa	0	0	0	0	0

Conocarpus erectus	0	0	0	0	0
Total	**93**	**-**	**-**	**3,720**	**100**

Table 22 shows that plot #9 had a total of 93 trees, represented by two species: 22% of the trees were black mangroves and 78% were white mangroves. The average height was above 4.6 m, while the average DBH was less than 5 cm for the two species. The density was calculated at 3,720 trees/ha. Pollution was observed throughout this site, with a central waste disposal area 50 m from the site and fecal matter found all around the sample site. This site's disturbance level was categorized at 2/5.

Table 23: Data on mangroves in plot #10, sector II

Species	**Number of Plants**	**Height (m)**	**Average DBH (cm)**	**Density (trees/ha)**	**% of Total, by Species**
Avicennia germinans	26	5.93	2.2	1,040	12
Rhizophora mangle	153	3.1	1.87	6,120	69
Laguncularia racemosa	22	2.46	1.7	880	10
Conocarpus erectus	21	2.1	2.1	840	9
Total	**222**	**-**	**-**	**8,880**	**100**

Table 23 shows that plot #10 contained 222 trees, representing all four species of mangroves: 12% of the trees were black mangroves, 69% were red mangroves, 10% were white mangroves, and 9% were buttonwood mangroves. The average height of the trees was less than 4 m, and the average DBH was less than 2 cm. The canopy cover was estimated to be between 0% and 25%. The density was 8,880 trees/ha and the health of the plot was recorded at 3/5.

Table 24: Data on mangroves in plot #12, sector II

Species	Number of Plants	Height (m)	Average DBH (cm)	Density (trees/ha)	% of Total, by Species
Avicennia germinans	47	4.2	6.1	1,880	41
Rhizophora mangle	34	4.3	7.8	1,360	29
Laguncularia racemosa	35	3	2.6	1,400	30
Conocarpus erectus	0	0	0	0	0
Total	**116**	**-**	**-**	**4,640**	**100**

Table 24 shows that plot #12 contained 116 trees, including 41% black mangroves, 29% red mangroves, and 30% white mangroves. The average height was 3.83 m and the overall average DBH was 5.5 cm. The canopy cover was estimated to be between 0% and 25%, and the density was 4,640 trees/ha. The health of the plot was categorized as a 2, due to a nearby agricultural area and the presence of cut trunks and branches.

Sector III: Lagon aux Boeufs

Sector III included seven sites in the area around Lagon aux Bœufs (Figure 5).

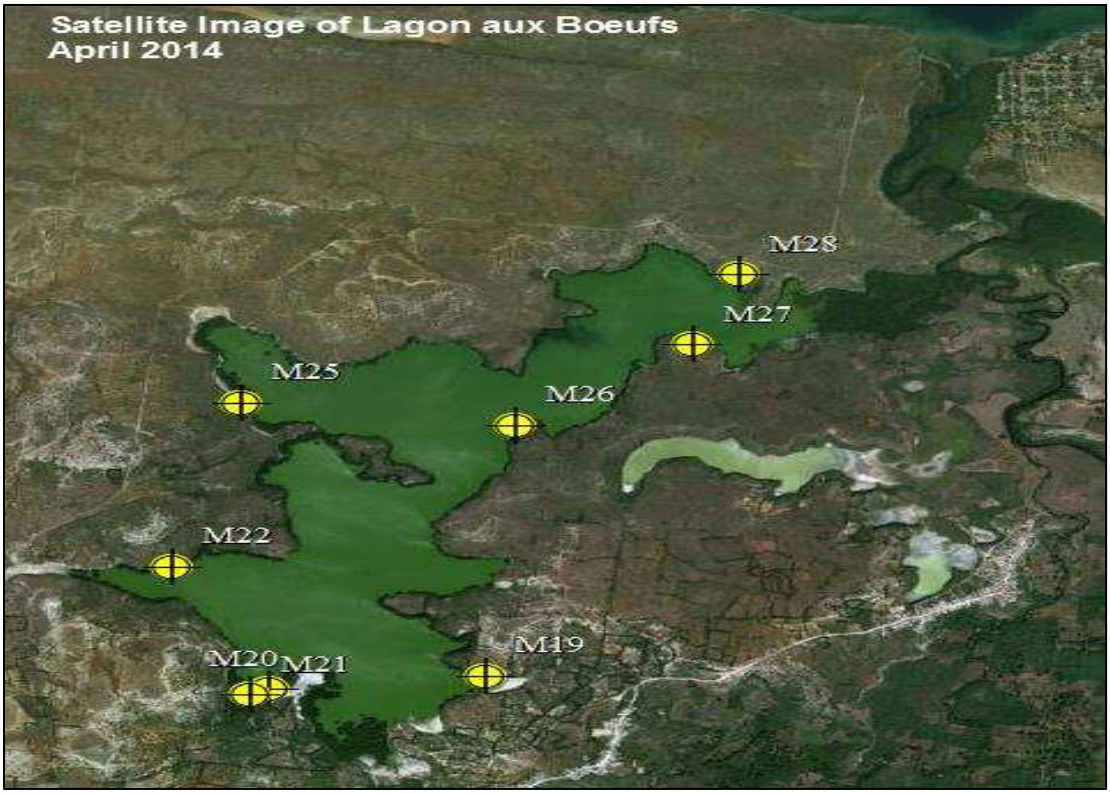

Figure 5: Satellite image of sector III, Lagon aux Bœufs

Table 25: Data on mangroves in plot #25, sector III, Lagon aux Boeufs

Species	**Number of Plants**	**Height (m)**	**Average DBH (cm)**	**Density (trees/ha)**	**% of Total, by Species**
Avicennia germinans	0	0	0	0	0
Rhizophora mangle	0	0	0	0	0
Laguncularia racemosa	7	2.83	3.46	280	37
Conocarpus erectus	12	1.7	1.33	480	63
Total	**19**	-	-	**760**	**100**

Table 25 shows that plot #25 had a total of 19 trees, of which 37% were white mangroves and 63% were buttonwood mangroves. The average height of the trees was 2.26 m, with canopy

coverage of 0% to 25%. The average DBH was less than 3 cm. The density was 760 trees/ha. Though there were no visible signs of pollution, some damaged trees were observed, so the health of the plot was designated as a 3/5.

Table 26: Data on mangroves in plot #22, sector III

Species	**Number of Plants**	**Height (m)**	**Average DBH (cm)**	**Density (trees/ha)**	**% of Total, by Species**
Avicennia germinans	0	0	0	0	0
Rhizophora mangle	107	10	6.36	4,280	94
Laguncularia racemosa	4	2.45	0.3	160	3
Conocarpus erectus	3	2.34	0.3	120	3
Total	**114**	**-**	**-**	**4,560**	**100**

As shown in Table 26, plot #22 had a total of 114 trees, including 94% red mangroves, 3% white mangroves, and 3% buttonwood mangroves. The average height was 4.93 m, but some red mangrove trees had a maximum height of approximately 10 m. The canopy cover was between 50% and 75%, and the overall average DBH was less than 3 cm. The density was 4,560 trees/ha. Much evidence of disturbance was observed at this site, including cut trunks and damaged trees. Several charcoal production sites and other campfire sites were present. The level of pollution was very high, so the health of the site was categorized as a 1/5.

Table 27: Data on mangroves in plot #19, sector III

Species	Number of Plants	Height (m)	Average DBH (cm)	Density (trees/ha)	% of Total, by Species
Avicennia germinans	0	0	0	0	0
Rhizophora mangle	107	7	10.3	4,280	100
Laguncularia racemosa	0	0	0	0	0
Conocarpus erectus	0	0	0	0	0
Total	**107**	**-**	**-**	**4,280**	**100**

Table 27 shows that plot #19 contained 107 red mangroves, with an average DBH of 10.3 cm and an average height of 7 m. Tree density was high at this site (4,280 trees/ ha), and the canopy cover was estimated to be between 75% and 100%. This site was in a marshy area and considered to be in excellent condition; therefore, the plot health was categorized as a 4/5.

Table 28: Data on mangroves in plot #21, sector III

Species	Number of Plants	Height (m)	Average DBH (cm)	Density (trees/ha)	% of Total, by Species
Avicennia germinans	0	0	0	0	0
Rhizophora mangle	312	14	7.5	12,480	100
Laguncularia racemosa	0	0	0	0	0
Conocarpus erectus	0	0	0	0	0
Total	**312**	**-**	**-**	**12,480**	**100**

Table 28 shows that plot #21 had a total of 312 trees, all red mangroves, with an average height of 14 m. This was one of the sites with the highest mangrove density (12,480 trees/ha); the canopy cover was between 50% and 75%. The average DBH of the trees was about 7.5 cm. This site was located at a fish landing area, and active crab traps were seen around the site. The plot health was categorized as a 2/5 due to the presence of livestock, intensive fishing activities, and a wooden dam nearby.

Table 29: Data on mangroves in plot #20, sector III

Species	**Number of Plants**	**Height (m)**	**Average DBH (cm)**	**Density (trees/ha)**	**% of Total, by Species**
Avicennia germinans	0	0	0	0	0
Rhizophora mangle	130	7.6	3.28	5,200	100
Laguncularia racemosa	0	0	0	0	0
Conocarpus erectus	0	0	0	0	0
Total	**130**	**-**	**-**	**5,200**	**100**

Table 29 shows that plot #20 contained 130 trees, all red mangroves, with an average height of 7.6 m. The canopy cover was between 50% and 75%. The density was 5,200 trees/ha, and the average DBH of the trees was about 3.28 cm. This site showed very few signs of disturbance or pollution; it was surrounded by water and its health was ascribed a 5/5.

Table 30: Data on mangroves in plot #26, sector III

Species	**Number of Plants**	**Height (m)**	**Average DBH (cm)**	**Density (trees/ha)**	**% of Total, by Species**
Avicennia germinans	0	0	0	0	0

Rhizophora mangle	102	6	4.5	4,080	55
Laguncularia racemosa	77	5	2.7	3,080	42
Conocarpus erectus	5	5.5	3	200	3
Total	**184**	-	_	**7,360**	**100**

As shown in Table 30, plot #26 had a total of 184 trees: 55% red mangroves, 42% white mangroves, and 3% buttonwood mangroves. The density was 7,360 trees/ha, while the average DBH of the trees was 3.4 cm. Mangroves in this plot grew to an average height of more than 5 m. Due to mangrove cutting in the area, the plot health was categorized as a 2/5.

Table 31: Data on mangroves in plot #27, sector III

Species	**Number of Plants**	**Height (m)**	**Average DBH (cm)**	**Density (trees/ha)**	**% of Total, by Species**
Avicennia germinans	0	0	0	0	0
Rhizophora mangle	37	3.7	2.2	1,480	92.5
Laguncularia racemosa	3	2.5	1.18	120	7.5
Conocarpus erectus	0	0	0	0	0
Total	**40**	-	-	**1,600**	**100**

Table 31 shows that plot #27 contained 40 trees, 92.5% red mangroves and 7.5% white mangroves. The density was 1,600 trees/ha and the average height was around 3.1 m. The plot health was categorized as a 3/5. Mangroves were harvested to build several wooden dams to enable fishing activities (see Annex 16).

Table 32: Data on mangroves in plot #28, sector III

Species	Number of Plants	Height (m)	Average DBH (cm)	Density (trees/ha)	% of Total, by Species
Avicennia germinans	0	0	0	0	0
Rhizophora mangle	307	4	3.62	12,280	99
Laguncularia racemosa	4	0.45	0.4	160	1
Conocarpus erectus	0	0	0	0	0
Total	**311**	**-**	**-**	**12,440**	**100**

Table 32 shows that plot #28 had a total of 311 trees, of which 99% were red mangroves and 1% were white mangroves. The density was 12,440 trees/ha. The average DBH of the red mangroves was 3.62 cm and the average height was 4 m. The level of disturbance and plot health was categorized as a 3/5, as many cut mangroves were observed in this area.

Mapping the Mangroves

A spatial analysis was conducted for each species of mangrove, considering density (trees/ha), height, and DBH.

Figure 6: Density of the four mangrove species

Figure 6 shows the density of the four mangrove species in the PA3B. The mangrove forest was densest in Caracol (average density: 8,505 trees/ha), followed by Lagon aux Boeufs (6,085 trees/ha) and Fort Liberté (4,636 trees/ha). *R. mangle* showed the most significant differences in highest density across the three sectors, with an average of 6,170 trees/ha in Caracol, 2,589 trees/ha in Fort Liberté, and 5,510 trees/ha in Lagon aux Boeufs. There was very little difference in the average density for the three other species across sectors.

Figure 7: Distribution of the diameter at breast height for the four mangrove species

Figure 7 shows the distribution of mangrove DBH values within the PA3B. Even though the highest tree densities were observed in Caracol, the DBH (and by extension biomass) values were higher in Fort Liberté and Lagon aux Boeufs. The mean DBH of *R. mangle* was much higher in Lagon aux Boeufs (2.66 cm ± 0.47 cm) than in Caracol (1.49 cm ± 0.59 cm) and Fort Liberté (1.87 cm ± 0.43 cm). Plot #17, located in sector I, and plot #18, in sector II, presented the highest DBH values. Trees in Caracol, which were mostly in the more inundated sections, had higher density but tended to be smaller, presenting lower overall biomass. Many threats to the mangrove habitat were observed in that area, particularly solid waste disposal.

No *A. germinans* (black mangrove) were located in our sample sites in Lagon aux Boeufs. A facultative halophyte, *A. germinans* thrives in the waterlogged saline soils of the lagoons along the PA3B coastline. However, as recorded salinity levels were much lower at Lagon aux Boeufs (7 ppt compared with 35 ppt in Caracol Bay and Fort Liberté), growth of the black mangroves in

Lagon aux Boeufs may have been limited. Other biological reasons behind the absence of black mangroves from Lagon aux Boeufs should be explored to understand the nuances of the ecosystem. The tallest specimens were concentrated in the areas where the highest salinity levels were recorded (Phaéton, in Fort Liberté Bay, sector II).

C. erectus (buttonwood mangrove) was the least common species among the three sectors. This species was identified in places closest to the dry forest. Historically, it has been used in the charcoal industry. It is the most inland mangrove species; thus, it is more accessible for harvesting than other mangrove species. Its sparse distribution is perhaps attributable to a long history of mangrove cutting and harvesting for human use.

Figure 8: Distribution of the average height of the four mangrove species

Figure 8 shows the distribution of mangrove heights within the PA3B. The average height of *R. mangle* was much lower in Caracol (2.96 cm ± 0.3 cm) than in Fort Liberté (4.97 cm ± 0.55 cm) or

Lagon aux Boeufs (7.47 cm ± 1.27 cm). Lagon aux Boeufs had the tallest observed mangroves, measuring around 15 m.

The average height of white mangroves was higher in Lagon aux Boeufs (2.64 cm ± 0.57 cm) than in Caracol (2.23 cm ± 0.27 cm) and Fort Liberté (2.16 cm ± 0.23 cm). The highest specimen recorded was found in plot #26, where tree crowns reached approximately 5 m.

A. germinans were taller, on average, in Fort Liberté (4.97 cm ± 0.44 cm) than in Caracol. *C. erectus* was the least common species represented across the three sectors. This species has been identified in places close to a dry forest.

The sparse distribution of buttonwood mangroves is perhaps attributable to the long history of mangrove cutting and harvesting for human use. Average buttonwood mangrove heights in Caracol and Fort Liberté were quite similar except for plot #29. The tallest trees of this species were observed in Lagon aux Boeufs, as was the case with *R. mangle* and *L. racemosa*.

Species Identification and Habitat Description

Several seagrass species were observed in the area, though not identified. According to the literature, there are three species of seagrass in the area: turtlegrass (*Thalassia testudinum*), manatee-grass (*Syringodium filiforme*), and shoal grass (*Halodule wrightii*). These species are important in the production of organic matter in the ecosystem. They are major habitat-forming species and constitute a vegetation belt that plays a key role in the filtering of river and runoff water.

The PA3B system contains mangrove types classified as fringe and basin habitats. Fringe mangroves are characterized by the dominance of red mangroves along the exposed coastal edge, as seen in Caracol and Limonade Bay. This area is covered by seagrass beds containing turtle grass (*T. testudinum*) and manatee grass (*Syringodium* sp.). These plants provide cover during the day for a host of marine species. Fringe habitats also host mangrove and pearl oysters (*Crassostrea rhizophorae* and *Pinctada* sp. (see Annex 10). The basin mangrove habitat occurs within the

interior of the mangrove forest, where the four species of mangrove listed in the study are associated with saltwort (*Batis maritima*) and other plants, mostly *Prosopis juliflora*, *Rhabdadenia biflora*, and *Leucaena leucocephala* located at the upper edge of the system. The basin system provides habitats for abundant fiddler crabs (*Uca* sp.) and mangrove crabs (*Aratus pisonii*). It is also an important bird area, where species like green heron, white ibis, black-crowned night heron, little blue heron, tricolored heron, and snowy egret have been observed (Table 34).

Table 33: Common and scientific names of plants in the PA3B

Common Name	**Scientific/Botanical Name**
black mangrove	*Avicennia germinans*
white mangrove	*Laguncularia racemosa*
buttonwood mangrove	*Conocarpus erectus*
red mangrove	*Rhizophora mangle*
bayahonda	*Prosopis juliflora*
leucaena	*Leucaena leucocephala*
saltwort	*Batis maritime*
sweet acacia	*Vachellia farnesiana*
acacia	*Acacia farnesiana*
mangrove vine	*Rhabdadenia biflora*

Table 34: List of birds and their conservation status (IUCN)

Common Name	**Scientific Name**	**Status**
green heron	*Butorides virescens*	breeding resident
white ibis	*Eudocimus albus*	breeding resident
black-crowned night heron	*Nycticorax*	breeding resident

little blue heron	*Egretta caerulea*	breeding resident
tricolored heron	*Egretta tricolor*	breeding resident
snowy egret	*Egretta thula*	breeding resident
great blue heron	*Ardea herodias*	breeding resident
great egret	*Ardea alba*	breeding resident
clapper rail	*Rallus longirostris*	breeding resident
Caribbean coot	*Fulica caribaea*	breeding resident
common moorhen	*Gallinula chloropus*	breeding resident
Wilson's plover	*Charadrius wilsonia*	breeding resident
spotted sandpiper	*Actitis macularius*	non-breeding visitor
black-necked stilt	*Himantopus mexicanus*	breeding resident
sandwich tern	*Sterna sandvicensis*	breeding resident
white-winged dove	*Zenaida asiatica*	breeding resident
zenaida dove	*Zenaida aurita*	breeding resident
common ground dove	*Columbina passerina*	breeding resident
white-crowned pigeon	*Patagioenas leucocephala*	breeding resident
mangrove cuckoo	*Coccyzus minor*	breeding resident
smooth-billed ani	*Crotophaga ani*	breeding resident
gray kingbird	*Tyrannus dominicensis*	breeding resident
northern mockingbird	*Mimus polyglottos*	breeding resident
Hispaniolan lizard-cuckoo	*Coccyzus longirostris*	endemic
black-crowned palm-tanager	*Phaenicophilus palmarum*	endemic
greater Antillan grackle	*Quiscalus niger*	breeding resident
village weaver	*Ploceus cucullatus*	breeding resident

Tables 33 and 34 identify species found within quadrats. However, other species associated with mangroves have been observed inside the Park, such as ghost crabs (*Ocypode* sp.) and fiddler crabs, which are also bioindicators of the overall quality of the mangrove habitat. Indeed, many recent studies have suggested there are population trends and animal behaviors that can be used to accurately determine the health status of benthic communities (Giblock et al., 2013). Fiddler crabs, as well as several other mangrove crabs, are well known to play a key role in the ecological processes of mangrove ecosystems, by means of their continuous soil processing and reworking, during foraging and burrow excavation (Bartolini et al., 2008).

Table 35: Common and scientific names of crustaceans and mollusks identified

Common Name	**Scientific Name**
Crabs	
Fiddler crab	*Uca* sp.
Mangrove crab	*Aratus pisonii*
Mollusks	
Mangrove oyster	*Crassostrea rhizophorae*
Pearl oyster	*Pinctada* sp.
Queen conch	*Lobatus gigas* (previously called *Strombus gigas)*

Water Quality Assessment

Water quality assessments in the three sectors were completed by measuring pH, salinity, and temperature. Temperature data were difficult to compare, as surveys were done at different times of the day. Temperature readings fluctuated from 28°C in the morning to 35°C at noon.

In Caracol and Fort Liberté, the average salinity ranged between 33 and 36 ppt, similar to that of open water. The salinity in Lagon aux Bœufs was much lower, around 7 ppt; this may be the result of riverine input from the nearby Massacre River and subterranean water. The pH in Caracol and Fort Liberté ranged from 6.7 to 7.2 while the average pH of Lagon aux Bœufs was higher, 7.4.

Discussion and Recommendations

Overall, the mangrove habitats in the PA3B are threatened by anthropogenic activities and require biodiversity conservation efforts to improve their health. Mangroves in the PA3B offer a large range of ecosystem services; they serve as a fish nursery and habitat, aid in coastal protection, and filter water to improve the quality of water flowing from the land to the ocean. Mangroves also play a vital role in the interconnected nature of coastal ecosystems (coral reefs, mangrove forests, and seagrasses), which provide joint benefits to human populations. They are threatened mainly by:

- Cutting for charcoal production and firewood
- Solid waste pollution (local residents dump garbage in the mangroves)
- Water pollution, from excrement and chemicals from agricultural and livestock farms
- Land conversion, mainly for salt mining and agriculture

Mangroves in Caracol/Limonade Bay

Caracol is used by a large community of fishers and is the largest mangrove area in the study. All four species of mangroves were identified in this area; however, the red mangroves were the most dominant, with a density in some areas of up to 40,000 trees/ha, which translates to an average of 4 plants/m². Despite its relative abundance, R*. mangle* is under the highest level of pressure, as it is the main tree harvested for charcoal production and export. Other species associated with the mangroves, such as *P. juliflora* and *L. leucocephala*, face similar threat levels, as they are affected by solid waste disposal in the area. Crabs, such as *A. pisonii* and *Uca* sp., were observed in all the inundated areas where red mangroves were present. Mangrove crabs are also useful bioindicators of healthy mangrove habitats, as they are ecologically important organisms

in mangrove environments. They are an important food source for many fish and birds in the mangroves and play a role in reworking the sediment in the mangrove system. The partially immersed roots of the red mangrove provide habitat for abundant mangrove and pearl oysters, as well as many sponges and tunicates.

The mangroves throughout the bay need protection through strategic plans on restoration and conservation. Visible signs of cutting were present in many sites, mainly on black mangroves and *P. juliflora.* Wood harvesting seemed to be concentrated around Caracol and Fort Liberté, where there were several cutting sites. Local residents of these areas should be helped to find alternative sources of energy, such as gas or solar, to reduce their dependence on mangroves and reduce harvest pressure on limited resources.

Environmental issues in the PA3B are a consequence of economic and social problems. The lack of environmental awareness and knowledge on the part of local stakeholders regarding the ecological importance of the mangrove ecosystem ultimately causes the dominant issues affecting the system. However, some efforts are being made to improve awareness. For example, the fishers are aware that mangroves support their livelihoods, but they blame people from other villages for wood harvesting. For them, those people are the major threat to the mangroves and always have been. For many years, humans have carried out extractive activities within the mangrove forests of northeast Haiti, limiting plant growth and potentially changing the biological characteristics of the ecosystem.

The local organization FoProBiM (Fundaciyon por la Protection de la Biodiversité Marine) is working in this area to help conserve coastal and marine natural resources through community sensitization, mangrove nursery creation and planting, and general monitoring within the mangrove area. Monitoring activities are ineffective due to the lack of resources and capacity. The presence of mangrove nurseries in some localities is a sign that nonprofits and community-based organizations have been taking action to support mangrove restoration. It is imperative to reinforce patrols and community policing within the Park to prioritize overall conservation of the ecosystem.

Mangroves in Fort Liberté

Mangroves in Fort Liberté face similar threat levels as those in Caracol/Limonade. They are affected by human activities, such as logging for charcoal production and export and firewood harvesting for domestic use. Evidence of recent and continued logging was observed throughout the Bay. The mangroves in Fort Liberté are ecologically significant, and any acceleration of deforestation rates potentially impacts the different ontogenetic stages of associated species living in this ecosystem. Fort Liberté Bay is dominated by red mangroves, but buttonwood mangrove densities were highest in this area compared with the other sectors. All species of mangrove trees in this area had relatively low heights, possibly indicating that they were younger trees than the mangroves observed in Lagon aux Bœufs and in some areas of Caracol (Bord de Mer de Limonade). Many stumps as a result of past logging activities were also observed.

To ensure the protection of the remaining mangroves, the area needs a monitoring plan to facilitate and control levels of natural resource use. As a protected area, the PA3B has is governed by certain regulations. Therefore, a proper partnership among the different local stakeholders, such as the Agence Nationale Des Aires Protegees / National Protected Areas Agency (ANAP), local nonprofits, and community-based organizations working within the area, should allow for the implementation of a monitoring and co-management program.

Mangroves in Lagon aux Bœufs

As in the other two sectors, the mangrove forest in Lagon aux Bœufs is dominated by *R. mangle.* Of the three sectors, this one had the tallest trees, including some that were taller than 15 m. Of note, no black mangroves were observed within the sample areas.

Many fishing-related activities are carried out within the lagoon, including a crustacean fishery. Set traps were observed throughout the area. Many birds were also observed in the lagoon; however, in some places the water seemed to be heavily polluted and eutrophication was evident, possibly caused by occasional flooding from the Massacre River, along with wastewater and runoff from nearby agricultural and pasture activities. This runoff also affects the salinity readings recorded at the site, which were markedly low.

Conclusion

Although some areas of the park seem relatively healthy, the mangrove forest of the PA3B faces significant anthropogenic threats from local communities and a thriving charcoal industry. The Park has potential for successful conservation and/or restoration programs, while supporting ecotourism opportunities. However, any ecotourism will have to be in line with the conservation objectives of the various stakeholders. As the Park is a protected area, it is important to control the activities within its borders, and a monitoring program to manage the area is vital.

Mangroves in Caracol and Limonade appeared to be most affected by human activities, and immediate action to protect them is required. The conditions at Fort Liberté and Lagon aux Bœufs were somewhat similar, though the habitat was generally less damaged there. The tallest trees and those with the highest biomass values (inferred by DBH readings) were observed for each of the species at Fort Liberté and Lagon aux Bœufs. Immediate action should be taken by local stakeholders to preserve and restore the mangrove ecosystem here. The active participation of the local residents and government enforcement are crucial for the success of any protection program throughout the PA3B. It is recommended that on-the-ground conservation and restorative activities involving the mangrove ecosystem should be initiated or ramped up in the Caracol/Limonade area, which is currently the most vulnerable subsection of the park.

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Annexes

Annex 1: Crabs in the PA3B (*Uca* sp.)

Annex 2: Crab in the PA3B (*Aratus pisonii*)

Annex 3: Soil sampling around a red mangrove

Annex 4: Birds: *Tyrannus dominicensis*

Annex 5: Mangrove nursery (Bord de Mer de Limonade)

Annex 6: Quadrat delimitation

Annex 7: Waste disposal near the mangroves

Annex 8: Pile of wood cut from mangroves and bayahona

Annex 9: *Rhabdadenia biflora*

Annex 10: Mangrove oyster

Annex 11: Charcoal production near the mangroves

Annex 12: Campfire site next to a large pile of juvenile conch shells which is an indication of intense juvenile harvesting of conch in the area.

Annex 13: Boats stationed near mangrove habitat

Annex 14: Livestock near mangrove habitat

Annex 15: Mangrove harvesting

Annex 16: Wooden dam in Lagon aux Boeufs

Annex 17: Crustacean traps