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Reforestation, Sequestered Carbon and Ecotourism Development in the Éhotilé Islands National Park in the South-east of Côte d'Ivoire

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Abstract: Deforestation and urbanization pose serious threats to the unique coastal ecosystems of the Éhotilé Islands National Park. This study is therefore conducted to assess the potential contributions of reforestation and restoration of mangroves in the Éhotilé Islands, both in terms of carbon sequestration and ecotourism development. The study reveals a rich biodiversity with 191 plant species listed. The mangroves covering 141.73 hectares of the park have a total biomass of 12,371 tonnes, sequestering approximately 6,185 tonnes of carbon, or 22,700 tonnes of CO_2. Projections indicate an increase in biomass of 7,219 tonnes in 2.5 years, and 23,687 tonnes in five years, demonstrating the resilience of the park's ecosystems as carbon sinks. The park also features a diversity of ecosystems, ranging from mangroves to riparian and dryland forests, each of which contributes to the ecological stability of the region and to water and soil conservation. In parallel, the development of ecotourism within the Éhotilé Islands could provide economic benefits for local communities, while raising public awareness of environmental conservation. Discovery trails and observation infrastructure could enrich the visitor experience and support sustainable development initiatives. In this sense, the Éhotilé Islands National Park embodies a model of integrated conservation, combining biodiversity, carbon sequestration, and the promotion of sustainable ecotourism for the future.

Keywords: Wetlands; Carbon sequestration; Biodiversity; Ecological restoration.

INTRODUCTION

Éhotilé Islands National Park, located in southeastern Côte d'Ivoire, is a complex of island ecosystems and tropical wetlands of remarkable ecological importance. The park is home to forests and mangroves that play a key role in biodiversity conservation and provide crucial ecosystem services such as water filtration, protection against coastal erosion, and carbon sequestration (Barbier et al., 2011). Due to their particular structure, the mangroves of the Éhotilé Islands capture and store carbon in water-saturated soils, thus helping to mitigate the effects of climate change (Donato et al., 2011).

Mangrove ecosystems, such as those in the Éhotilé Islands Park, are facing accelerated degradation linked to anthropogenic pressures such as urbanization, pollution and illegal logging, compromising their capacity to provide ecosystem services (FAO, 2007). In a country like Côte d'Ivoire, where deforestation has significantly reduced forest cover, the preservation and restoration of mangroves is of strategic importance. In addition to their function as carbon sinks, these ecosystems are also refuges for rich marine and terrestrial biodiversity, essential to the health of the local food chain (Alongi, 2002).

Reforestation and ecological restoration initiatives within the Éhotilé Islands Park offer the possibility of not only regenerating ecological functions, but also of providing the potential for sustainable economic development through ecotourism. The latter constitutes an economic alternative for the surrounding communities, while raising awareness of environmental protection and contributing to the enhancement of natural heritage (Kiss, 2004). In this sense, the Éhotilé Islands Park could become a model of eco-responsible development for the region, by integrating objectives of carbon sequestration, preservation of biodiversity and enhancement of natural resources through sustainable tourism (Stem et al., 2003).

This study explores the potential of reforestation and mangrove restoration in the Éhotilé Islands, highlighting carbon storage capacity and ecotourism development. A better understanding of these ecological and economic interactions could inspire sustainable protected area management practices in Côte d'Ivoire and beyond.

MATERIALS AND METHODS

Study site

The Éhotilé Islands National Park, created in 1974, is located in the Aby-Sud lagoon, in the department of Adiaké, in the southeast of Côte d'Ivoire. It is located between 3°16'42" and 3°18'52" West longitude, and between 5°9'24" and 5°11'13" North latitude. This park is composed of an archipelago of 6 islands with a total surface area of 550 hectares (Figure 1). The islands Assokomonobaha (327.5 ha), Baloubaté (75 ha), Niamouan (47.5 ha), Méha (45 ha), Elouamin (22.5 ha) are located in the Aby-Sud lagoon and only Bosson Assoun Island (32.5 ha) is in the Tendo lagoon.

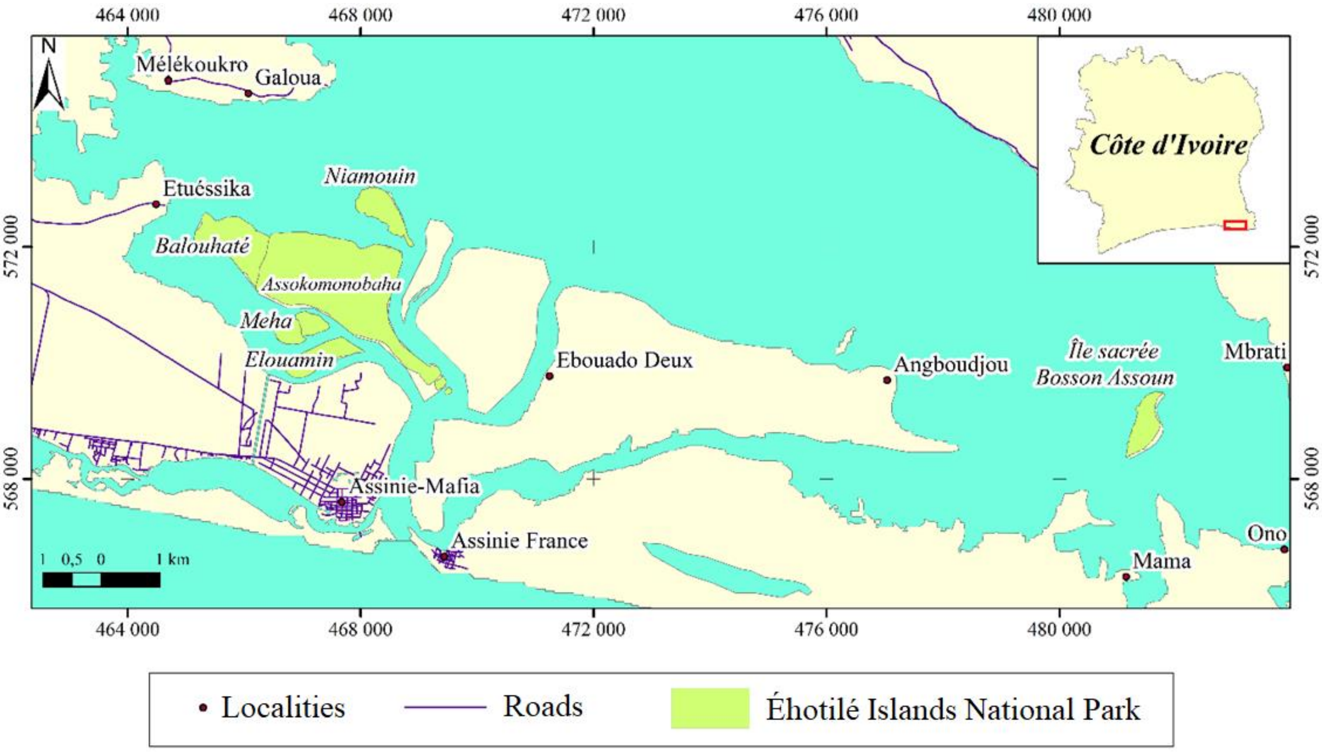

Figure 1: Presentation of all the Éhotilé Islands

This island park integrates diverse ecosystems including mangroves, island forests, floodplain savannas and intertidal wetlands. Mangroves, which form one of the main habitats of the park, play a crucial ecological role by stabilizing the coasts, sheltering marine fauna species and contributing to carbon sequestration, an essential function in the fight against climate change (Spalding et al., 2010). The Éhotilé Islands are also recognized for their great diversity of birds, fish and mammals, some of which are threatened or endemic species, giving the park a capital importance for the conservation of biodiversity in Côte d'Ivoire (Diomandé et al., 2009).

The particularity of this park lies in its integration of different types of wetlands, which shelter diverse ecological communities and play an important socio-economic role for local populations. Indeed, the wetlands of the Éhotilé Islands provide essential resources, such as fish and wood, and serve as a basis for cultural and spiritual practices, thus reinforcing their heritage and cultural value (Koffi et al., 2011). However, these resources are subject to increasing anthropogenic pressures, particularly due to overfishing, illegal logging and the expansion of agriculture in the surrounding area, threatening the ecological balance of the park (Koné et al., 2008).

To address these threats, conservation and reforestation initiatives, including mangroves, are being implemented in the Éhotilé Islands National Park. These efforts aim to restore degraded ecosystems, strengthen the islands' resilience to climate impacts, and promote sustainable ecotourism activities. This park thus represents a model of integrated conservation that combines biodiversity protection, the enhancement of ecosystem services, and community development (Barbier et al., 2011).

To limit the overexploitation of the park's resources, ecotourism activities have been proposed. To establish an ecotourism circuit in the space of the Éhotilé Islands National Park including the lagoon plan and the historic city of Assinie, a methodology structured around

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biodiversity, cultural resources, and the needs of local communities was followed. The site visit and interviews with local populations made it possible to carry out an analysis of the site as well as an evaluation of resources. Stakeholder engagement, the development of tourism products and monitoring and evaluation were also taken into account.

Data collection

The data collection proposed for this study on reforestation, ecotourism value and carbon sequestration in the Éhotilé Islands National Park is based on a multidisciplinary approach combining ecological analyses, biomass estimations and socio-economic surveys.

Surface surveying was used to characterize mangrove vegetation. Trees, shrubs, and vines with diameters at breast height exceeding 5 cm were inventoried. During this study, 20 survey plots were demarcated at each site, each covering an area of 500 m² (25 meters long by 20 meters wide), in order to collect accurate and representative data on the structure and composition of the mangroves. The ecotourism dimension of restoration will be explored through surveys and interviews with local stakeholders, including surrounding communities, park managers and visitors. Questions will focus on the perception of the benefits of restoration, willingness to pay for ecotourism services and the perceived impact of tourism on environmental conservation (Stem et al., 2003). An analysis of visitor flows and ecotourism practices will be conducted to assess the potential for sustainable development in this area and identify opportunities for improvement to maximize economic and environmental benefits (TIES, 2015).

Data analysis

Biomass data are calculated from forest inventories conducted in different areas of the park. Each measured tree is characterized by its diameter at breast height (DBH) and height, allowing individual biomass to be calculated using allometric equations adapted to tropical species (Chave et al., 2014). Aboveground and belowground biomass are then added to obtain an estimate of total biomass. The equation of Chave et al. (2014) used in this study is: $AGB=0.0673\times(\rho D^2H)^{0.976}$

AGB, ρ, D, and H represent, respectively, aboveground biomass (in kg), specific wood density (in $g.cm^{-3}$), tree diameter (in cm), and total tree height (in m).

Carbon stock refers to the amount of carbon contained in a reservoir or system capable of accumulating or releasing it (IPCC, 2007). In forests, it corresponds to the carbon stored mainly in biomass and soil, with a lesser contribution from dead wood and litter. Expressed in tonnes of carbon per hectare (tC/ha), it is calculated by multiplying the biomass by its carbon content.

The carbon content of biomass varies according to the species, organ, and growth conditions (Chave et al., 2005). In the absence of a specific value, climate change studies use the standard values of 50% and 47%, recommended by the IPCC (2007). Thus, the carbon stock represents approximately half of the total biomass. From this stock, the carbon equivalent can be deduced.

Carbon equivalent = Carbon stock (tonnes) × 3.67

The biomass recovery trajectory (AGB) was modeled using a model written in the Stan language (Carpenter et al., 2017), a probabilistic programming language designed for specifying statistical models. Stan provides full Bayesian inference for continuous variable models. Bayesian inference is a method used to determine the probability of an event based on the probabilities of other already evaluated events (McKay, 2005). Applying this method, the maximum likelihood for AGB recovery is described by the following equation:

$$AGB_t = AGB_{max}(1-e^{-0.089(t/15.29)^{\wedge}1.72})$$

AGB_t represents the above biomass at age t, while AGB_{max} is the maximum asymptotic biomass, estimated from the densest plot observed across all surveys conducted during this study. The value -0.089 corresponds to the observed recovery rate (λ_{obs}) derived through inference. The parameter 15.29 represents the inflection point (θ) obtained after inference, and 1.72 is the parameter β, which adjusts the flexibility of the relationship between the recovery rate (λ) and time (t). The observed biomass recovery rates were determined using the maximum likelihood parameterized model and the biomass values ($AGB_{p,t}$) for each inventoried plot. The biomass flux, expressed in tonnes per hectare per year (t/ha/year), was then calculated using the formula:

Biomass flux = $AGB_{t2} - AGB_{t1}$

where AGB_{t2} is the predicted biomass at time t2, and AGB_{t1} is the predicted biomass at time $t1$.

RESULTS

During the botanical data collection, 191 species of vascular plants were observed on all the islands inventoried. In Éhotilé Islands National Park, the mangrove is well developed on Balouhaté Island where it represents the majority of the vegetation (Figure 2). It is also found in the southwest and west of Assokomonobaha. The mangrove also occupies 60% of the surface area of the Meha and Elouamin Islands. At Niamouin Island, it is reduced to a few feet of very scattered mangrove trees along the banks.

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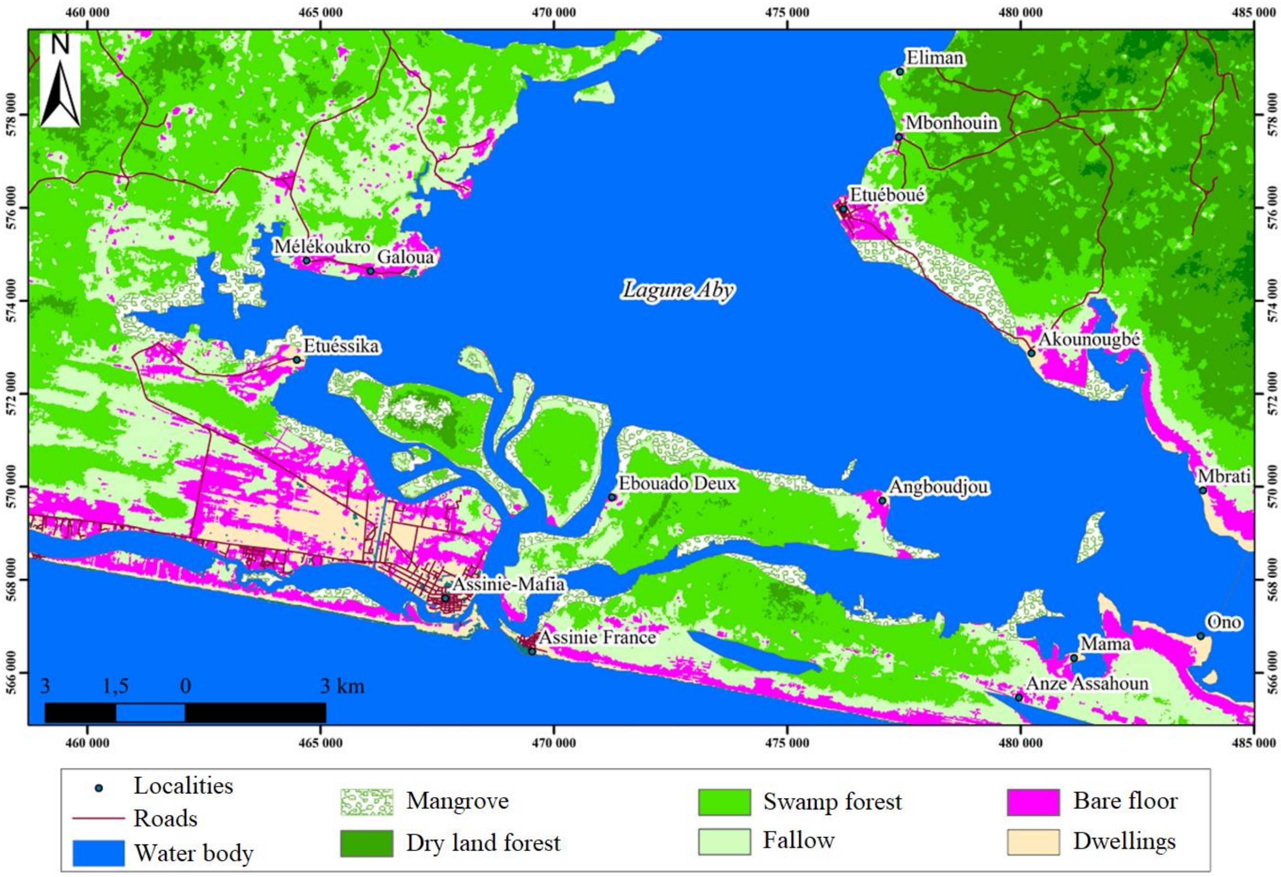

Figure 2: Vegetation of the Assinie region

In contrast to forests on permanently hydromorphic or periodically flooded soils, dryland forests have developed on relatively well-drained, sandy to sandy-clayey soils. This type of formation is found on the islands of Assokomonobaha and Niamouin. It is characterized by species such as *Heisteria parvifolia*, *Strychnos dinklagei*, *Drypetes aframensis*. The most common species are *Homalium letestui*, *Baissea axillaris*, *Baphia nitida*, *Hymenostegia afzelii*, *Lophira alata*, *Tabernaemontana crassa*.

The riparian forest has developed on the banks of the islands in the elevated areas and only suffers from short-term flooding. It forms a narrow strip rarely exceeding ten meters in width, well closed towards its lagoon front by a curtain of lianas such as *Paullinia pinnata*, *Laccosperma secundiflora*, *Baissea axillaris*, *Adenia spp*., *Combretum spp*. The riparian forest contains in places large trees, some of which can reach thirty meters in height. These are *Pterocarpus santalinoides*, *Crudia Klainei*, *Cathormion altissimum*, *Lonchocarpus sericeus*, *Uapaca heudoelotii*, *Xylopia aethiopica*, *Trichilia monadelpha*.

There are also old coconut plantations. They occupy large areas on the islands of Meha, Elouamin and the northern part of Assokomonobaha. The state and extent of these plantations show the intensity of the agricultural activities that were practiced there. On the sampled islands, Niamouin, Bosson Assoun and Balouhaté, are spared traces of agricultural activities.

Swamp forests are observed in the park. They are located on poorly drained, hydromorphic flat soils where the accumulation of organic matter forms real peats. This form of forest is characterized by *Hallea ledermannii*, *Symphonia globulifera* and *Raphia hookeri*. The companion species observed are *Calamus deerratus*, *Crudia klainei*, *Xylopia aethiopica* and *Xylopia quintasii*, *Cyrtosperma senegalense*, *Cynometra ananta*.

The marshy thickets are located in the back of the mangrove. On Balouhaté Island, these marshy thickets are well developed. They are closed formations with a layer of five to six meters. At the level of the Assokomonobaha, Elouamin and Meha islands, the marshy thicket makes the transition between the mangrove ecosystem and the dry land vegetation. Floristically, it is composed of *Drepanocarpus lunatus*, *Acrostichum aureum*, *Dalbergia ecastaphyllum*, *Hibiscus tiliaceus*, *Phoenix reclinata*, *Calamus deerratus* and *Pandanus candelabrum*.

In the Éhotilé Islands, the aboveground biomass is estimated at 58.19 tonnes per hectare, with an underground biomass of 29.10 tonnes per hectare. This brings the total biomass of the mangroves in the region to 9.224 tonnes per hectare. Covering a total area of 141.73 hectares, the mangroves of the Éhotilé Islands National Park hold an estimated total biomass of 12,371.05 tonnes.

From the sampled areas, the carbon stock was estimated at 43.64 tonnes of carbon per hectare, equating to a total

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carbon storage capacity of 6,185.53 tonnes across all the mangroves. This corresponds to 22,700.87 tonnes of stored CO_2.

The biomass gain across the park over a 2.5-year period is estimated at 7,219 tonnes. When projected over a 5-year interval, this gain increases to 23,687 tonnes. Over the same 2.5-year interval, the total biomass gain reaches 16,456 tonnes. The calculated biomass flux for the mangroves of the Éhotilé Islands National Park is 3.36 tonnes per hectare per year. Potential reforestation areas were identified taking into account ecological characteristics, soil topography, marsh movements of the sites, sites exposed to coastal erosion. The coastal area of Assinie Mafia has areas of high erosion that can lead to ecological problems. Sites were therefore identified to implement a reforestation strategy to contain the erosion process. Seven sites were identified for reforestation. The beach lengths covered by the selected sites vary between 217.63 meters and 2034.83 meters. All the sites that can be reforested between Assinie-Mafia and Assinie-France cover a distance of approximately 7.24 kilometers (Figure 3). The ecotourism assets of the Éhotilé Islands area are rich and diverse. The park is home to a variety of wildlife, including about 128 species of birds, primates, bush pigs, and reptiles. Endangered species such as the manatee and bats on Balouaté Island are also observed. The park's six islands contain archaeological sites, such as 17th-century cannons and ancestral cemeteries that are sacred places for the Éhotilé people. A tourist circuit in the Éhotilé Islands National Park and the historic town of Assinie is proposed. It highlights the natural and cultural assets of the region. To explore the Éhotilé Islands, a boat from the village of Etuessika allows you to reach Balouaté Island in the park. This island allows the observation of colonies of bats and historic cannons dating from the 17th century, migratory birds and a landscape of mangroves. A Botanical trail on Assokomonobaha Island will allow you to discover the local flora with endemic species. These different trips on the lagoon plan allow the practice of a nautical activity while observing the animal and plant biodiversity.

Nyamouan Island allows the discovery of the cultural and spiritual importance of the site for the local populations. On Elouamin Island, old coconut fields and local agricultural traditions furnish the landscape. The surrounding villages offer local culinary specialties. Mid- and high-end hotel complexes on the edges of the lagoon plans offer varied reception settings.

Finally, the site is easily accessible from Abidjan, the economic capital of the country, with a regular connection to Assinie. Local guides will enrich the experience with their knowledge of biodiversity and cultural history. This tour not only allows you to discover the natural beauty of the Éhotilé Islands National Park but also to appreciate the cultural heritage of Assinie, while promoting sustainable tourism that benefits local communities.

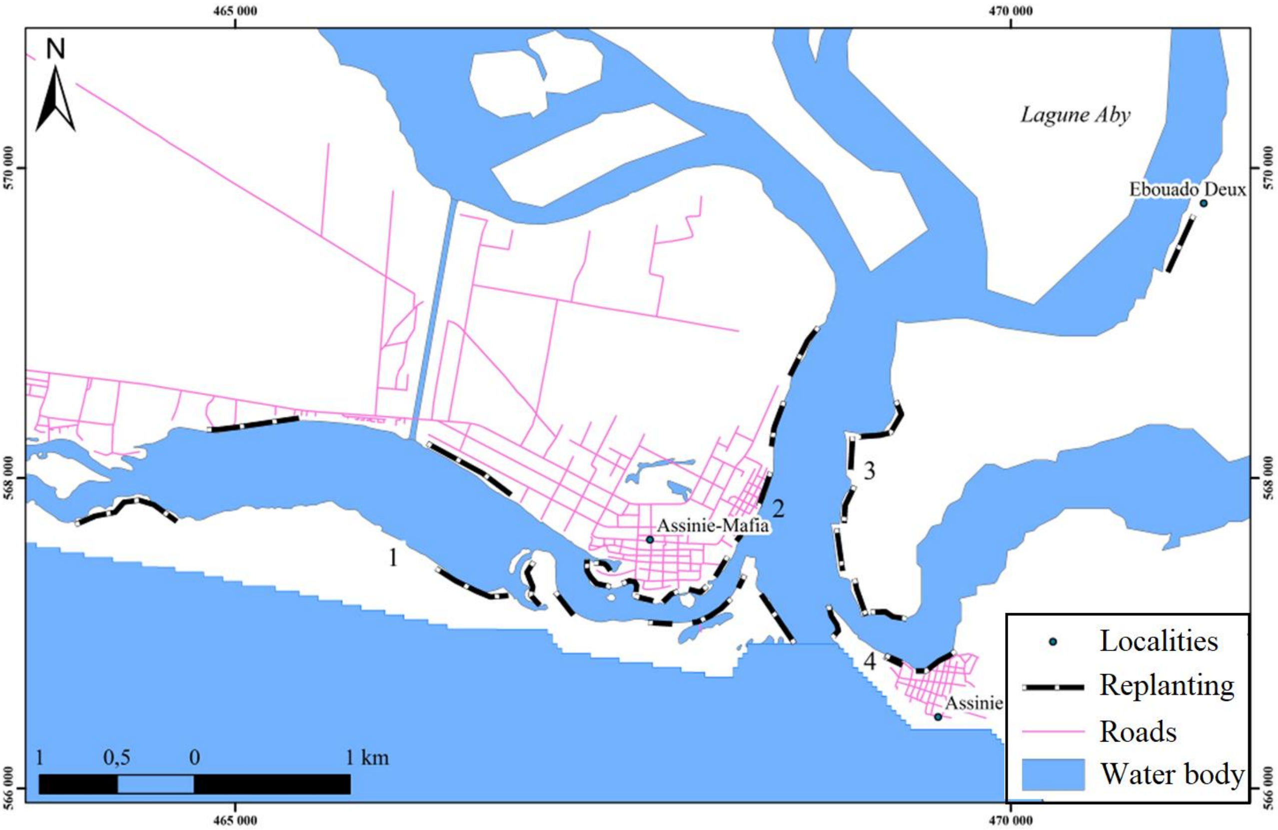

Figure 3: Location of sites to be reforested south of the Éhotilé Islands Park

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Discussion

With 191 species of vascular plants recorded, these islands are home to a diverse plant biodiversity. This highlights the importance of protecting and enhancing this area for its crucial role in carbon sequestration. The mangroves covering 141.73 hectares of the Éhotilé Islands National Park have a total biomass estimated at 12,371.05 tonnes, allowing for the sequestration of 6,185.53 tonnes of carbon, or 22,700.87 tonnes of CO_2. These mangroves have a greater carbon storage capacity than many other types of forests (Alongi, 2014). With an annual biomass gain capacity of 3.36 tonnes per hectare, these mangroves play a vital role in the absorption of atmospheric carbon, thus helping to mitigate the effects of climate change (Donato et al., 2011). Projections of total biomass also show an expected gain of 7,219 tonnes in the next 2.5 years and 23,687 tonnes in five years, highlighting the resilience and dynamics of these ecosystems in their role as carbon sinks.

The different types of forests and vegetation zones present in the park support an exceptional plant diversity. The mangrove, predominant on the Balouhaté and Assokomonobaha islands, is essential for stabilizing soils against coastal erosion and for preserving water quality, as well as for protecting local biodiversity (Kathiresan & Bingham, 2001). In addition, the dryland forest, characterized by species such as *Heisteria parvifolia* and *Strychnos dinklagei*, and the riparian forest sheltering *Pterocarpus santalinoides* and *Crudia klainei*, contribute to the ecological richness of the park. This type of diversity also increases the attractiveness of the Éhotilé Islands for ecotourism, by allowing the observation of different types of ecosystems in the same geographical space (Tomlinson, 2016).

The diverse ecosystems of the Éhotilé Islands provide an ideal setting for developing ecotourism. By allowing visitors to discover mangroves, riparian forests and unique plant species, the park could attract an audience aware of environmental issues and sustainable tourism (Honey, 2008). The development of trails and observation towers would not only enhance the tourist experience, but also raise awareness of the ecological services provided by these ecosystems. These ecotourism activities can also create economic opportunities for local communities while strengthening environmental conservation (Ross & Wall, 1999). Educational programs based on the biodiversity of the Éhotilé Islands and the importance of carbon sequestration could be implemented to explain the benefits of mangroves in climate regulation (Spalding, 2014).

Areas identified for reforestation, such as those in Assinie Mafia affected by erosion, are strategic spaces for the conservation and restoration of coastal ecosystems (Lewis, 2005). Reforestation of mangroves over a distance of approximately 7.24 kilometers would stabilize soils and strengthen the park's carbon sequestration capacities. Mangroves play a crucial role as natural bulwarks against storms and erosion, in addition to supporting essential marine biodiversity. By supporting local communities in reforestation projects and raising awareness of the importance of mangrove ecosystems, park managers can improve environmental resilience while increasing the ecotourism potential of the Éhotilé Islands.

The Éhotilé Islands National Park and the historic town of Assinie constitute an exceptional ecotourism area where ecological wealth meets a unique cultural heritage. The presence of endangered species, then the observation of colonies of bats, migratory birds, the exploration of mangroves, offer opportunities for environmental education and awareness of conservation (Buckley, 2010). The presence of sacred and archaeological sites illustrates the importance of natural sites in intangible heritage. A respectful development could include thematic circuits or stories guided by locals. The protection of the habitats of endangered species is crucial to maintain this fragile balance, particularly in the face of anthropogenic pressures such as illegal fishing and deforestation. Initiatives such as the establishment of marked trails or restricted areas can minimize the impact of visitors (Goodwin, 2011). This implies a balance between development and sustainability to avoid overcrowding (Weaver, 2001). The introduction of ecological means of transport on the lagoon, such as non-motorized boats, could reduce the environmental impact while enriching the visitor experience. The training of guides, the production of handicrafts, and local catering will also allow for equitable economic redistribution (Dehoorne O., 2013).

Conclusion

The results of this study clearly show the ecological and economic importance of the ecosystems of the Éhotilé Islands National Park, where mangroves play a central role. Not only do the 141.73 hectares of mangroves capture 6,185.53 tons of carbon, which is equivalent to approximately 22,700.87 tons of stored CO_2, but they also demonstrate significant carbon sequestration potential, thus actively contributing to the fight against climate change. This storage capacity, reinforced by a dynamic of annual biomass gain, underlines the strategic role of these ecosystems for climate regulation and mitigation of environmental impacts.

The diversity of habitats in the park, with varied ecosystems such as riparian forests, mangroves and dryland forests, constitutes an ecological wealth that can also be valued in an ecotourism development perspective. These areas provide a space for environmental awareness for visitors and generate economic opportunities for local communities. The development of ecotourism activities, such as observation trails and educational programs, could strengthen the conservation of these habitats while supporting sustainable initiatives.

Finally, reforestation strategies, particularly in areas affected by coastal erosion, are essential to strengthen the resilience of the park's ecosystems and protect local biodiversity. Mangrove conservation and restoration efforts, combined with community awareness-raising actions, can strengthen the ecological integrity of the Éhotilé Islands National Park, while maximizing its positive impacts on the climate and the local economy. The National Park of the Éhotilé and Assinie Islands offers a

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unique opportunity to promote sustainable tourism combining ecological conservation and cultural valorization. By implementing environmentally friendly practices and actively involving local communities, this circuit can become a model for other destinations.

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Conflict of Interest

There are no conflicts of interest declared by the authors.

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