

ECOLOGICAL AND SOCIO-ECONOMIC ASSESSMENT OF THE MAHAVAVY-KINKONY COMPLEX PROTECTED AREA COASTLINE IN MADAGASCAR IN RESPONSE TO CLIMATE CHANGE IMPACTS

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ABSTRACT

This study, focusing on marine and coastal areas, was conducted in the western region of Madagascar with the objective of assessing the impact of climate change on conservation efforts in coastal areas. The methodology involved surveys, inventories, and monitoring activities, with a particular focus on analyzing climatic parameters such as atmospheric air temperature, rainfall, winds, and cyclones. A baseline climate analysis was conducted, followed by projections according to the RCP4.5 scenario, providing insights into climate trends from 2020 to 2099. The findings reveal that a significant number of villagers have observed and adapted to climate change through their daily activities. Observable changes include a shortened rainy period with intense rainfall and an extended dry period, erosion of the Mahavavy River bed due to the degradation of the galleries forest and siltation of the mangrove mudflats, after heavy rains or cyclones. Observations also indicate stresses on coastal and marine ecosystems due to fluctuations in physicochemical parameters in coastal areas. Consequently, the behaviors, reproduction, and survival of birds, crabs, and fish are adversely affected. In light of these findings, recommendations are put forth for the manager to enhance resilience, emphasizing the importance of continuing ecological restoration efforts, particularly in mangroves, gallery forests, and coral reefs within the CMK.

Keywords: Madagascar, marine and coastal areas, Climate change, conservation.

RESUME

Cette étude, centrée sur les zones marines et côtières, a été menée dans la région ouest de Madagascar dans le but d'évaluer l'impact du changement climatique sur les efforts de conservation dans les zones côtières. La méthodologie impliquait des enquêtes, des inventaires et des activités de surveillance, avec un accent particulier sur l'analyse des paramètres climatiques tels que la température de l'air atmosphérique, les précipitations, les vents et les cyclones. Une analyse climatique de référence a été réalisée, suivie de projections selon le scénario RCP4.5, fournissant un aperçu des tendances climatiques de 2020 à 2099. Les résultats révèlent qu'un nombre important de villageois ont observé et adapté au changement climatique à travers leurs activités quotidiennes. Les changements observables comprennent une période pluvieuse raccourcie avec des précipitations intenses et une période sèche prolongée, l'érosion du lit de la rivière Mahavavy due à la dégradation de la forêt galerie et l'envasement des vasières de mangrove, après de fortes pluies ou des cyclones. Les observations indiquent également des stress sur les écosystèmes côtiers et marins dus aux fluctuations des paramètres physico-chimiques dans les zones côtières. Par conséquent, les comportements, la reproduction et la survie des oiseaux, des crabes et des poissons sont affectés. À la lumière de ces résultats, des recommandations sont proposées au gestionnaire pour renforcer la résilience, en soulignant l'importance de poursuivre les efforts de restauration écologique, en particulier dans les mangroves, les galeries forestières et les récifs coralliens au sein de la CMK.

Mots clés : Madagascar, zones marines et côtières, Changement climatique, conservation.

1. INTRODUCTION

Madagascar, as an island nation, faces heightened exposure to natural disasters in Africa due to its strategic location. Positioned in the far west of the Indian Ocean, the country is particularly susceptible to cyclones and floods. Climate change in Madagascar epitomizes the concrete consequences of environmental degradation, posing a dual threat to biodiversity conservation and economic development. In the Boeny Region, located in the northwestern part of the island, the Mahavavy-Kinkony Wetlands Complex holds significant ecological and socio-economic importance. However, the escalating impact of climate change, coupled with expanding anthropogenic activities, detrimentally affects the successful management of these areas. This study aims to elucidate the impact of climate change on conservation efforts in coastal regions, encompassing the perceptions and adaptations of villagers to climatic fluctuations, subsequent alterations in natural habitats, and the bioecological vulnerability of the sheltered faunal community.

2. MATERIALS AND METHODS

2.1. Presentation of the study area

Located in the District of Mitsinjo, Region of Boeny, in the North West part of Madagascar, the Mahavavy-Kinkony is located between 45° 28' and 45° 56' East longitude and between 15° 46' and 16° 12' South latitude (figure 1). The altitude varies between 7 m and 140 m and the total area is 351,300 ha [1]. It is the one and only area labeled Malagasy Ramsar City after its importance was assessed during the meeting on Ramsar sites (Wetlands) or Cop-13 in October 2018 in Dubai.

2.2. Data collection methods

Methods adopted for climatic data in the study area and ecological data on mangroves, waterfowl, fish and coral reefs are described in this section.

2.2.1. Collection and analysis of climate data

Atmospheric air temperature and precipitation are analyzed using data from the World Bank Group – Climate Change Knowledge Portal [2] website. The climate history from 1986 to 2020 was used as a reference for a climate projection from 2020 to 2099 according to the RCP4.5 scenario, with the value of temperature (T°) and precipitation (P°) anomalies. The RCP4.5 Scenario was taken because it is based on a fairly reasonable constant CO₂ emission [3]. Cyclonic disturbances are analyzed based on their frequency, their speed and, if applicable, the rain brought in 24 hours. Sea level variation is also assessed. Historical temperature and precipitation data have essentially been used to analyze the variability of climatic parameters, T° and P°, over the past 20 years. The medians of the monthly T° and P° for all the 16 models considered between the period from 2020 to 2099 were taken in order to have maximum reliability of the simulation. The physico-chemical parameters for the two seasons (wet and dry) were recorded in the field using soil and salinity testers (brand lipeng tester, smart sensor salinometer, acidity with pH meter as well as quality testers of water and thermometer).

2.2.2. Collection of socio-economic and ecological data

Socio-economic surveys were conducted among farmers residing in proximity to coastal ecosystems, assessing their perception of climate change and its impact on daily activities. Simultaneously, faunal inventories and ongoing monitoring of coral reefs, fish, aquatic birds,

and mangroves were undertaken to analyze the ecological richness of coastal regions. Ecological data was further derived from field studies investigating the dynamics of natural habitats in the face of seasonal imbalances, flooding, and drought.

3. RESULTS

3.1. Biological wealth of the coastal sectors of the Mahavavy-Kinkony Complex

The coastal areas of the Mahavavy-Kinkony Complex protected area had 08 species distributed in 5 families of mangroves, including *Avicennia marina* (Forsk.) Vierh, *Bruguiera gymnorhiza* (L.) Savigny, *Ceriops tagal* (Perr.) C.B.Rob., *Rhizophora mucronata* Lam. , *Sonneratia alba* Smith, *Heritiera littoralis* Aiton and *Xylocarpus granatum* J. Koenig. Marine and coastal birds include 64 species, 37 of which are migratory birds (Tsiavahananahary, 2018) and 8 endangered endemic species, including *Ardeola idae* (En), *Anas bernieri* (En) and *Haliaeetus vociferoides* (Cr). Marine fish recorded include at least 46 species. Thus, the coral reefs of Ambatomazava have been detected between Boeny Bay and the Mahavavy Delta, whose living coral recovery rate is quite high, around 62%. Dead corals showed only 1% cover. Living corals are composed of 15.67% of massive corals including very varied genera including *Goniopora*, *Favia*, *Favites*, *Platygyra*, *Porites*, *Astreopora*, *Galaxea*, etc., 13.69% of tabular *Acropora*, *Acropora hyacinthus* and 8.6% branching *Acropora*, 5.71% digitate *Acropora*, *Acropora digitifera* and *A. humilus*, 3% foliose corals (*Pavona cactus*), 1.23% encrusting corals and 6, 27% sub-massive corals (dominated by the *Seriatopora* genus). The rest of the benthos is composed of 4.38% sponges and 14.13% soft corals.

3.2. Physico-chemical parameters of coastal areas of CMK

The coastal zones within the Mahavavy-Kinkony Complex are composed of the mangrove habitats of Boeny Bay, Mahavavy Delta, and Marambitsy Bay. Table 1 provides data on physico-chemical parameters influencing the environmental conditions of these coastal habitats, recorded in the field during October 2022 (Dry season) and February 2023 (Wet season) (Table 1).

Soil pH exhibits variation based on the zonation of the mangrove forest. The ribs display a strongly acidic pH ranging from 5 to 5.4, while the inner zone maintains a relatively neutral pH. Seasonal fluctuations are observed in both soil and surface water temperatures, as well as salinity. Temperatures rise during the rainy season, concurrent with a decrease in salinity

Compared to the physicochemical parameters of the coastal areas of Mahavavy-Kinkony, the influence of climate change is noted by the variation in temperature and salinity. Concerning the soil temperature of the mangrove coasts, it varies from 27°C to 34.2°C while the surface water showed a maximum value of 33.2°C. However, during the rainy period. The salinity of seawater varies from 12.22 ppt (parts per tonne) to 27.30 ppt depending on the distance to tributaries. In the dry season, the average salinity rate is 36.20 ppt. In short, it is found that the salinity of seawater is inversely proportional to precipitation.

3.3 Climate analysis

3.3.1 Historical fact and climate projection

Analysis of climate data; Atmospheric air temperature and rainfall in District of Mitsinjo showed two distinct seasons: the dry and cool season is from April to October and the rainy and hot season from November to March. Average

temperatures and rainfall vary seasonally, decreasing to 24.2°C (June) and 0.9 mm (May) in the dry and cool seasons respectively. The average values of these climatic indices increase to 28.1°C and 385.4 mm in February, corresponding to the hot and humid season. The results of the climate simulation according to the RCP4.5 scenario on precipitation from 2020 to 2099 predicts that the months of December and November will see a drop in precipitation, respectively of the order of - 10 mm and - 7 mm, while an increase of +6 mm is expected towards the end of the rainy season in April (figure 2). For temperature, the simulation results showed an upward trend of around +1.2°C to 1.4°C.

3.3.2 Climate risks for coastal areas

In the western part of Madagascar, more intense cyclones, longer droughts, irregular and more violent rainfall, rising sea levels, intensification of periods of high heat, changing seasons favor the main climatic risks. For the frequency of cyclones, 26 cyclonic disturbances are recorded around the Mahavavy-Kinkony Complex Protected Area, particularly in the Boeny region over the past 45 years [4],[5]. The passage of these disturbances causes torrential rains causing alarming floods, often aggravated by a rising tide particularly affecting the mangroves and the coasts by the increase in the sea level accompanied by erosion and submersion (Table 2). An average rate of coastal retreat of 2 to 3 m per year is recorded in the sites of the Region [5].

3.4. Analysis of socio-economic and ecological impacts

3.4.1. Socio-economic impacts

More than 68% of villagers in coastal areas have felt the change in climate and have adapted their daily activities, especially fishing. As a result, a reduction of around 40% was seen in the products usually collected, as well as for crab collectors. Climate change is manifested by the shortening of the rainy period with heavy rains and the long dry period. The drying up of croplands and the reduction of arable land for farmers were noted by 22% of the grassroots communities (COBA) surveyed. This decrease in the profitability of activities risks reversing the lives of several households and harming coastal resources, including mangrove wood, fish and small crabs. On the other hand, within the framework of socio-economic development, actions for adaptation and mitigation of climate change have been put in place by the managers of the Protected area such as the improvement of cultivation techniques, the development of craft and honey sectors. as well as fish farming. This makes it possible to improve the income-generating activities of farmers in coastal areas in order to discourage their behavior depending on natural resources.

3.4.2. Ecological issues

The degradation of gallery forests has led to observed erosion in the Mahavavy River bed, with mangrove mudflats experiencing increased silting, particularly following heavy rains or cyclones causing flooding. Additionally, coastal mangrove areas have expanded towards the sea due to sediment contributions from the Mahavavy River, impacting migration surfaces. Tidal influences and river dynamics reshape coastlines through alternating siltation and de-siltation processes. Nevertheless, excessive sedimentation results in the desiccation of back-mangrove areas due to substrate

elevation. The impact of intense cyclones on the Mahavavy-Kinkony Wetlands Complex's coastal regions manifests in leaf fall, mangrove tree felling, and even uprooting. Consequently, mangroves are silted due to cyclone-induced wind effects, altering substrate physical characteristics and the respiratory function of mangrove root systems. Additionally, rising sea levels contribute to increased salinity in areas behind mangroves. These combined pressures contribute to mangrove mortality and overall degradation. In addition, birds in coastal areas including endemic and threatened species such as *Anas bernieri* (En), *Threskiornis bernieri* (En) and *Ardea humblotii* (En) suffered from the effect of heavy flooding and cyclones, especially during the *breeding season*.

IV. DISCUSSION

The northwestern part of Madagascar, in particular the Boeny Region, and its surroundings, have a significant specific richness, but is highly susceptible to climate change and alterations in physicochemical parameters. Climate change poses socio-economic challenges for farmers in coastal areas, emphasizing the need for development support to concurrently safeguard coastal biodiversity and enhance income-generating activities for the local population.

Addressing the ecological implications of climate change, stress on coastal and marine ecosystems is evident through fluctuations in physicochemical parameters in these regions. Coral reefs, in this context, face the risk of bleaching. Despite the impact of elevated salinity and decreased pH in mangrove soil, natural regeneration of mangroves is notably advanced, particularly within the Mahavavy Delta, characterized by its seaward expansion. According to Tsiavahananahary [6], mangrove cutting and exploitation existed, but their significant impact was minimal until recently when the mass and illegal exploitation of mangrove products by urban operators exacerbated the situation.

Consequently, the direct effects of climatic hazards adversely impact crab and fish communities, rendering their habitats less conducive to reproductive systems and potentially reducing the production capacity of fishery sites. Nevertheless, coastal siltation proves beneficial as feeding grounds for seabirds. The increased numbers of migrating birds, including a sizable colony of flamingos becoming resident in the coastal areas of the Mahavavy-Kinkony Complex, present valuable tourist potential. This observation has already been acknowledged and initiated by site manager through the "Mahajanga Bird Safari" due to the presence of numerous migratory bird species along the west coast of the island [6].

CONCLUSION

The study reveals that in the absence of proactive measures from all stakeholders, climate change inflicts devastating consequences on both the environment and the local communities reliant upon it. Sectors highly sensitive to climate variations, such as agriculture, tourism, fishing, and forestry, face the imminent risk of severe negative impacts. Notably, the managers of the CMK Protected Area have undertaken commendable efforts with demonstrable results to counteract this adverse trend. Various local and regional partners are also aligning with this crucial cause. Consequently, recommendations for enhancing resilience will center on sustaining ecological restoration, particularly focusing on the mangroves and gallery forests of the Mahavavy-Kinkony Complex.

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FIGURES AND TABLES

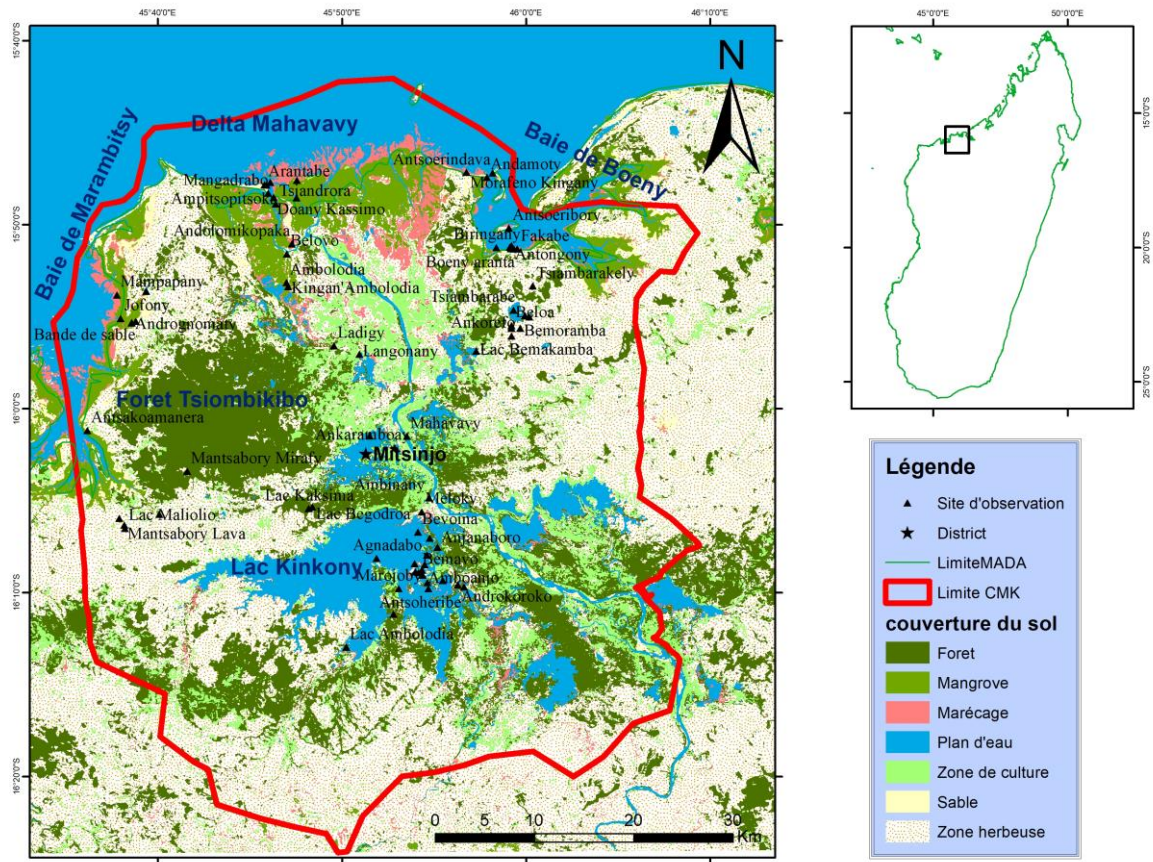


Figure 1: Location map of the Mahavavy-Kinkony Complex Protected Area (Tsiavahananahary 2023)

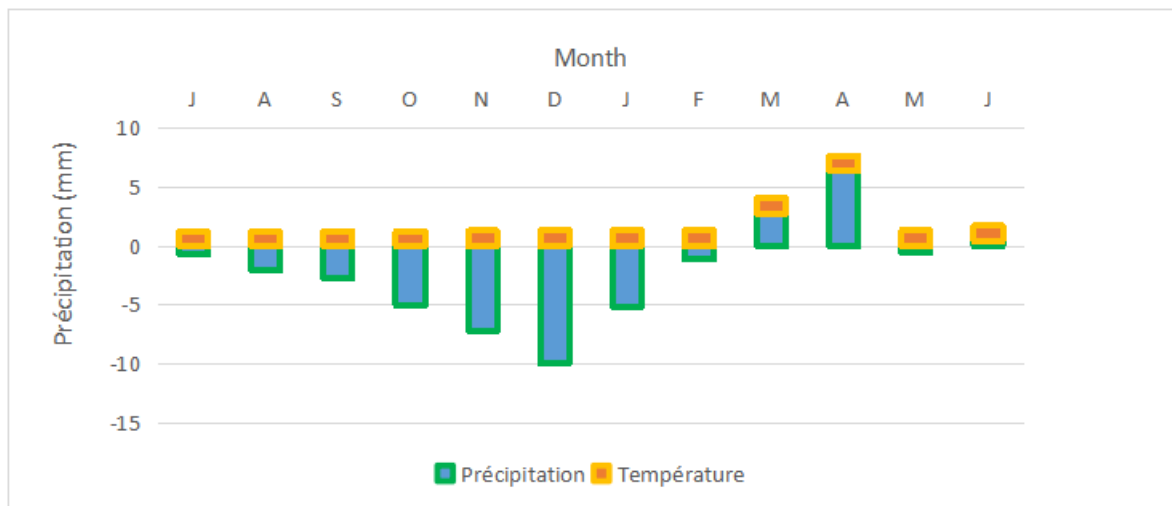


Figure 2. Projection of temperature variation and precipitation of Mitsinjo (2020 - 2099) (World Bank Group – Climate Change Knowledge Portal, 2022)

Table 1. Physico-chemical parameters of soil and surface water

Ground surface of MKC coasts				Surface water			
Temperature (°C)		pH		Temperature (°C)		Salinity (ppt)	
DS	WS	Min	Max	DS	WS	DS	WS
28,8 ± 3,4	30.2 ± 5,6	< 5,4	≥ 7.2	28,1 ± 8,6	29,3 ± 4,8	26,9 ± 9,1	11,2 ± 4,4

DS : Dry season, WS : Wet season, ppt : part per thousand

Table 2. Cyclones causing the most flooding in the study sites over the past 15 years (DGM. 2020; Firinga. 2023)

Years	Name	Type	Wind speed	Bilan
2020, 23 th /01	DIANE	Tropical disturbance	130 km/h	31 deaths. 7 districts in the North were the most impacted. 107,000 people affected. 10,600 houses flooded, 146 of them destroyed.
2019, 09 th /12	BELNA	Tropical cyclone	180 km/h	4 deaths and 2900 displaced persons
2019, 24 th /01	EKETSA NG	Moderate tropical storm	92 km/h	27 dead and 1 missing. More than 9,000 victims and more than 2,000 people who have been displaced. 1778 houses were flooded and 187 destroyed.
2018, 17 th /03	ELIAKIM	Tropical storm	150km/h	17 deaths, 15,772 victims 6,282 displaced persons
2014, 31 th /03	HELLEN	Very intense tropical cyclone	205km/h	237 people affected and 51 dwellings flooded
2004, 07 th /03	GAFILO	Very intense tropical cyclone	278km/h	300 deaths and 700,000 people affected