

Is the Co-management Approach Effective for Mangrove Conservation in West Africa?

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Abstract

The conservation management literature has recently documented the increasing use of co-management approach to effectively conserve natural resources. Although most research qualify the co-management as highly effective, some authors also reported a number of uncertainties associated with the use of this conservation approach. Using the Mono Transboundary Biosphere Reserve (MTBR) as a case study, this work assessed the effectiveness of the co-management towards mangroves conservation in West Africa. Data were collected in two protected sites of the reserve (one in Togo and the other in Benin). Exploratory sequential mixed method via in-depth interviews (n=17), focus group discussions (n=14), household survey (n=274) and expert-based survey (n=10) were carried out, and subjected to the InVEST-based Habitat Risk Assessment (HRA) model, chi-square test and simple probability of likelihood. Results indicated that under the current co-management regimes, the anthropogenic stressors recorded in the reserve put the entire surface area of mangroves in Benin (100%) under low risk. Contrarily, 42% of the mangrove cover are under low risk and 58% under medium risk in Togo. Local perception also portrayed a large reduction of mangrove degradation in the study sites following the adoption of the co-management approach in the two countries. This study suggests that the implementation of the co-management approach has lowered anthropogenic stressors to mangroves in the reserve. However, there are some peculiar challenges (e.g., financial support provision, regular community engagement), which need to be thoroughly researched and addressed for a more effective conservation of mangroves in the MTBR.

Introduction

Mangrove ecosystems are coastal forests that grow in the intertidal zones of tropical and subtropical countries. They provide a set of ecosystem services (provisioning services, supporting services, regulatory services and cultural services), which support the livelihoods of millions of people worldwide (MEA, 2005). Despite their importance to mankind, mangroves are intensively being degraded around the world predominantly as a result of man-made actions. The Food and Agriculture Organization (FAO) estimated that approximately 50% of mangroves disappeared globally since 1890 (Jia *et al.*, 2018). Duke *et al.*, (2007) also reported that mangroves are being lost at a rate of one to two percent per year, and the rate of loss may increase more, up to eight percent a year, in some developing countries. The situation has taken an alarming proportion in West Africa, where mangrove cover has shown a dramatic decline over the last two decades. Indeed, the sub region has lost about 30% of its mangroves in the last 25 years (Padonou *et al.*, 2021). Given the increasing rate of mangrove degradation in West Africa, decision-makers have decided to include local communities in the management of the resource by promoting the co-management approach (d'Aquino & Bah, 2013). Widely documented, the co-management is an approach whereby government shares authority, responsibilities and functions with the resource users (Cundill, 2010). Though the approach is noted for yielding spectacular results, it can also fail to protect natural resources if not well implemented (Nunan *et al.*, 2015). Its success depends among others on the synergy among the stakeholders associated with the management of the resource and the willingness of local communities to support the process (Kepe, 2008). In West Africa, the co-management is being increasingly used to protect and promote the sustainable use of coastal resources including mangroves. But little is

known about the effectiveness of this management regime in mangrove conservation in the sub region, compared to the other parts of the continent where the subject is being increasingly researched (Hauck *et al.*, 2001, Reid *et al.*, 2004, Armitage *et al.*, 2009, O'Leary *et al.*, 2020). As such, this study assessed the impacts of co-management regime on mangrove conservation in West Africa, using the Mono Transboundary Biosphere Reserve (MTBR) as a case study. More specifically, the study sought to assess (i) the extent to which mangroves are at risk by anthropogenic stressors under the current co-management regimes, (ii) the perceived effectiveness of co-management in minimizing mangrove degradation and (iii) the constraints in implementing the approach in the reserve.

Co-management frameworks in the MTBR

The MTBR stretches over the delta, alluvial plain and coastal zone of the Mono River, a 400 km-long transboundary river, that cuts across South-eastern Togo and gets into the ocean in South-western Benin. MTBR is located between 6 ° 8 '52.8 "and 7 ° 3' 41.8" North latitude and between 1 ° 24 '18.2 "and 1 ° 30' 0.0" East longitude. The Biosphere reserve is endowed with numerous species such as diverse species of birds, fishes and monkeys among others. The MTBR is in the sub-humid tropical climate zone and is characterized by two rainy seasons from April to July and October to November, and two dry seasons, from August to September and December to March (Teka *et al.*, 2018). The annual precipitation ranges from 820 to 1300 mm and the annual average temperature is about 33°C. Mangroves represent one of the most utilized coastal ecosystems of the study sites. The reserve brings together the mosaic landscape and ecosystems of the southern Benin and Togo into a unique protected environment. It was created to contribute to the conservation of the coastal and inland ecosystems located within the Mono Delta shared between the two countries (UNESCO, 2017). The process of its designation was financed by the Federal Ministry for the Environment, Nature Conservation, Construction and Nuclear Safety of the Federal Republic of Germany. It was started in 2014 and completed in 2017 with the delineation and recognition of the reserve as UNESCO-MAB Reserve (Ecobenin, 2018). Overall, the size of the reserve is approximately 346,285 ha (Adjonou *et al.*, 2021). A total of thirteen protected inland and coastal protected sites came together to form the MTBR (see supplementary data, Figure S4). However, mangroves in the reserve are concentrated in three protected sites, which represent the coastal sites of the reserve. They include "*La bouche du Roy*" in Benin, "*Le chenal de Gbaga*" and "*La forêt sacrée d'Akissa*" in Togo. Prior to the creation of the reserve in 2017, mangroves located within these three sites were managed by the Authority of Mono Delta represented by the governments of Benin and Togo. In the aftermath of the creation of the reserve in 2017, decision-makers agreed on the implementation of the co-management approach. Therefore, the management of all the natural resources of the reserve was decentralized, with the active participation of the local communities (Adjonou *et al.*, 2021). Prior to the establishment of the reserve, each community in the area was having some local associations which regulated the use of resources at community level, however their operations were subjected to central governments decisions. With the creation of the reserve, it became necessary for all community-based organizations to be merged into one broad organization in each country. For example, all the community-based organizations located within the coastal site "*La bouche du Roy*" in Benin came together to form the association of conservation and promotion of the site "*La bouche du Roy*", called ACP-Doukpo. In the other part of the reserve, the

community-based organizations located within the site “*Le chenal de Gbaga*” in Togo created the federation of the associations of mangrove planters of the Channel Gbaga, called *FAH-Gbaga*. The two newly created associations received later in 2017, the legal authorization from the governments of the two countries to manage the resources under their territories, including mangroves. Apart from these associations, power was also devolved to other stakeholders including technical and financial partners, research institutions and civil society organizations among others, to actively participate in mangrove management in the reserve (see Figure 1). They are expected to help the local associations with financial and technical supports as well as capacity building in order to attain effective mangrove and coastal resources conservation in the area. The roles of each stakeholder are presented in the Table 1. At community level, the two associations are represented by their focal points which have the mandate to ensure the sustainable use of coastal resources including mangrove ecosystems, and escalate any case of the resource degradation to the members of the associations for subsequent actions. The associations also receive support at community level from the head of villages, traditional authorities and other local associations existing in the villages (associations of youth, fishermen, fishmongers for examples) for mangrove conservation. This study therefore assessed the effectiveness of this co-management approach in the MTBR, with the assumption that this new management regime is helping to curtail the high anthropogenic pressures on mangroves that prevailed in the area prior to the establishment of the reserve.

Table 1. Stakeholders of mangrove co-management in the MTBR and their roles

Stakeholder	Nature	Roles
Research institutions (INRAB, ITRA, UAC, UL among others)	Academia	Their main role is to conduct research to facilitate decision-making. They are also involved in the dissemination of technical and scientific knowledge such as training for nursery and the planting of mangrove trees for sustainable mangrove conservation
Governmental agencies (CENAGREF, DGEFC, ABE, DRF among others)	Government institutions	They set and enforce laws and legal instruments partnering stakeholders to conserve mangroves in the reserve.
Local associations (ACP-DOUKPO, FAH-GBAGA)	Representatives of the local communities of each site	They are delegated authority that represent local communities during decision-making involving all the stakeholders, conduct all the mangrove restoration activities, and assure the surveillance of the mangroves and enforcement of local rules and norms on mangroves conservation
Non-governmental organizations (Ecobenin, CoRDE, COSOL PG, AHD, AVOTODE among others)	Civil society organizations	They are strongly involved in capacity building of the local associations, sensitization activities, grants and projects development for mangrove restoration.
Financial and Technical partners (World Bank, FEM, GIZ among others)	International institutions	Development organizations that provide financial resources through projects. Technical assistance and small grants for an effective mangrove conservation.
Management support groups (Local and traditional authorities, focal points of the associations at community level, other local associations among others)		They support mangrove sustainable use at community level, conduct surveillance activities, participate in mangrove-oriented awareness raising and educate their peers for mangrove conservation in their communities

Mangrove degradation in West Africa and Significance of the study

The widespread collection of wood and timber from mangrove forests in West Africa has led to their rapid degradation and the depletion. (Adanguidi *et al.*, 2021). Apart from the wood collection, *Acadja* system also contribute significantly to mangrove degradation in the sub region (Zanvo *et al.*, 2021). The technique which originated from Benin, consists of the use of mangrove branches and leaves in a demarcated area of the water body (12-16 m²) to artificially mimic fish habitats and capture them (Adite *et al.*, 2013). Salt extraction also cause severe changes to mangrove ecosystems in West Africa. Dainou *et al.*,

(2008) specified that about 47,613 m³ of wood is annually needed to produce 30,000 tons of salt. This wood is mostly extracted from mangroves in the coastal zones of West-Africa, resulting in the large degradation of the ecosystem (Feka et Ajonina, 2011). Coastal agriculture is another widely documented contributing factor to mangrove degradation in West Africa (Nortey *et al.*, 2016). The area is noted for the farming of cash crops such as rice, coconuts or sugar cane. However, the increase in the number of local populations in the sub region has resulted in an increase in demand for land to support farming purposes, leading to the encroachment and the degradation of mangrove ecosystems (Padonou et al. 2021). Coastal development and uncontrolled urbanization also contribute largely to mangrove degradation in West-Africa. Most cities in the sub region owe their development to favorable economic factors such as cheap labour, transportation, and available natural resources (Feka & Ajonina 2011). This high industrialization has resulted in massive pollution and biodiversity loss in coastal ecosystems, including mangroves (Jiang *et al.*, 2017).

In the study area, the top-down approach to resource management implemented prior to the creation of the MTBR has failed to effectively conserve mangroves in the area. This is reported by Adjonou *et al.*, (2020) who observed that over 93% of mangroves and wetlands in the area were lost from 1980 to 2015. The co-management adopted following the creation of the reserve is expected to promote mangrove reforestation, curb human-induced mangrove degradation and promote mangrove sustainable use in the reserve (Ecobenin, 2017). Information on the effectiveness of co-management towards mangrove conservation and sustainable use is therefore essential for informed decision-making regarding the protection of the mangroves for coastal dwellers and coastal environment.

Methodology

Study Area

Two of the three coastal sites of the reserve were considered for data collection. They included the site "*La bouche du Roy*" in Benin and the site "*Le Chenal de Gbaga*" in Togo (see Figure 2). The former extends from 6°12' and 6°15' North to 1°52' and 1°59' East with a surface area of approximately 9,678 hectares whereas the latter lies between 6°17' and 6°18' North and 1°39' and 1°48' and covers surface area of 4,575 hectares. The site "*Chenal de Gbaga*" is a transboundary site with the *Gbaga lagoon* serving as a natural border between Benin and Togo. It extends from Agbanakin to Agokpame, lying between 6°17' and 6°18' North and 1°39' and 1°48' East and covering a surface area of 4,575 hectares. Mangroves and the *Gbaga lagoon* represent its major coastal ecosystems with a population dominated by the ethnic group of *Mina*. The site is locally managed by the Association "FAH-Gbaga".

Study design and data collection procedure

This study used the exploratory sequential mixed method, including focus group discussion, In-depth Interviews, household and expert-based surveys. Two rounds of data collection were conducted. A

qualitative phase was firstly carried out to have a better understanding of the research topic before a quantitative phase was applied to statistically measure the relationships between the study area and the variables discussed in the qualitative phase (Cabrera, 2011; Nikpour, 2018).

Identification of the stressors

Anthropogenic stressors responsible for mangrove degradation in the study sites were identified through extensive literature review, field interactions and direct observations. Firstly, a broad range of articles were consulted to identify the documented threats responsible for mangrove degradation worldwide. The list of the identified threats was brought to the field and the research team stayed in the study communities for the period of eight months with regular visits to mangrove sites in order to check which of the identified stressors were degrading mangrove ecosystems in the area. This was through direct observations and informal field interactions. In addition to this, fourteen focus group discussions involving ten participants per group (140 participants in total) were organized in the two sites to crosscheck and validate the collected information and also to record the possible stressors unidentified by the literature review and the direct observations. The FGDs were separated along gender lines to avoid the influence of men over women. Participants of the focus groups were purposively (Sagoe *et al.*, 2021). They include matured residents (30 years and above) who have resided in the reserve for at least ten years and who are knowledgeable about the situation of mangroves in the reserve (threats, services, and functions). Information collected from the focus group participants was further complemented by the In-depth interviews. Key informants considered for the study were selected based on snowball and purposive sampling techniques (Sagoe *et al.*, 2021). In total, twenty key informants including ten resource persons, four NGOs, one state agency and five members of the two associations mandated to manage the sites were consulted (see supplementary data, Tables S5 & S6).

Habitat Risk Assessment (HRA)

After the identification of the stressors, the study assessed the magnitude of risk that they posed to mangroves at the study sites, under the current co-management regime. As such, the HRA model was run using the InVEST software version 3.9.0. The HRA model allows the assessment of the cumulative risk posed by anthropogenic activities to habitats and/or species as well as the consequences for the provision of ecosystem services and biodiversity (Cabral *et al.*, 2014; Caro *et al.*, 2020; Ghehi *et al.*, 2020; Studwell *et al.*, 2021). Table 2 presents the data requirements of the model and how they were generated and used. It incorporates information from exposure and consequence to calculate the risk to ecosystems and species with the assumption that habitats or species with high exposure to human activities and high consequence of the exposure are at high risk (Arkema *et al.*, 2015). The InVEST HRA model firstly determines the degree of exposure of the habitats or species under study to the stressors and the consequence of this exposure (Arkema *et al.*, 2015). Exposure (E) and consequence (C) are rated on a scale of 1 (the lowest) to 3 (the highest) using a set of criteria for each attribute (see Table 3). If there is no score for any of the criteria, the model allows the use of 0. For this study, scores were assigned based on literature, direct observations from the field and expert-based survey (see supplementary data, Tables 8 & 9). Experts engaged for this study included mangrove-oriented researchers and NGOs officials working in

the area. The overall exposure and consequence were determined as weighted average of the consequence values C_i and exposure values E_i for each criterion i from the habitat j and the stressor k (see Eq.1 &2).

$$E = \frac{\sum_{i=1}^n \frac{E_i}{d_i \cdot w_i}}{\sum_{i=1}^n \frac{1}{d_i \cdot w_i}} \quad \text{Eq.1}$$

$$C = \frac{\sum_{i=1}^n \frac{C_i}{d_i \cdot w_i}}{\sum_{i=1}^n \frac{1}{d_i \cdot w_i}} \quad \text{Eq.2}$$

In the formulars, d_i is the data quality rating for criterion i , w_i is the importance weighting for criterion i and n represents the number of criteria considered for each habitat (Moreira *et al.* 2018). For this study, the Euclidean risk equation with linear decay was used (see Eq.3). This approach combines the exposure and the response values to generate a risk value for each stressor-habitat combination in each grid cell (Ghehi *et al.*, 2020). Euclidean risk calculation considers the risk to habitat j caused by stressor k in each location (cell precisely) and calculates it as the Euclidean distance from the origin in the exposure-consequence. Here, average exposure (Eq.1) represents the first axis and the average consequence (Eq.2) represents the second axis (Ghehi *et al.*, 2020).

$$R_{ij} = \sqrt{(E - 1)^2 + (C - 1)^2} \quad \text{Eq.3}$$

The model then estimates the risk posed by multiple stressors to habitats or species where risk i caused by stressor j is calculated by multiplying the exposure and the consequence (Eq.4) (Arkema *et al.*, 2015)

$$R_{ij} = E \times C \quad \text{Eq.4}$$

Table 2. Data used to run the InVEST HRA model and their sources

Model	Required inputs	Data used	sources
HRA model	Habitats maps	The shapefiles of the mangroves cover of each site in projected coordinate system (WGS 1984 UTM Zone 31 N)	Retrieved from ECOBENIN (2018) for the site of Benin and Guelly <i>et al.</i> , (2020) from the site of Togo
	Stressors maps	The shapefiles of the stressors of each site in projected coordinate system (WGS 1984 UTM Zone 31 N)	All the stressors recorded during the qualitative phase were mapped out for each study site using the participatory mapping approach (see supplementary data, Figure 5).
	The habitat stressor file	It is a CSV table which contains information about each habitat and stressor input layer as well as buffer distance for the input layer	Design by the authors based on the information collected during the qualitative phase (direct observation). See figure 5 in the supplementary data for more understanding
	The criteria scores file	It is a CSV table which contains the criteria scores for all the habitats and stressors	Scores were assigned to each criterion using the expert-based survey, direct observation and literature. Ten experts including NGOs officials, people in academia and working on mangroves represented the experts used for this study (see supplementary data, tables 8 & 9)
	Resolution of Analysis	500	Arkema <i>et al.</i> , (2015)
	Maximum criteria score	3	Arkema <i>et al.</i> , (2015)
	Risk Equation	Euclidean	Arkema <i>et al.</i> , (2015)
	Decay Equation	Linear	Arkema <i>et al.</i> , (2015)

Table 3. Criteria for attributes rating

Criteria	Low risk (1)	Medium risk (2)	High risk (3)	Criteria description
Exposure criteria				
Spatial overlap	<10% of the habitat overlaps with the stressor	10 to 30% of the habitat overlaps with the stressor	>30% of the habitat overlaps with the stressor	The model uses the maps of the habitats (mangroves in this case) and the human-led stressors to calculate the percentage of the area of the habitat which overlaps with each stressor and its zone of influence
Temporal overlap	Habitat and stressor co-occur for 0 to 4 months a year	Habitat and stressor co-occur for 4 to 8 months a year	Habitat and stressor co-occur for 8 to 12 months a year	It refers to the duration of time that the habitat and the stressor experience spatial overlap
Intensity	Low intensity	Medium intensity	High intensity	It portrays how destructive the stressor can be for the habitat.
Management effectiveness	Very effective	Somewhat effective	Not effective	It indicates that an effective management is essential in limiting the negative impacts of human activities on habitats or species
Consequence criteria (sensitivity)				
Change in area	Low loss in area (<20%)	Medium loss in area (20 to 50%)	High loss in area (50 to 100%)	This criterion measures the percent change in extent of a habitat or species when exposed to a particular stressor
Change in structure	Low loss in structure (<20% loss in density)	Medium loss in structure (20 to 50% loss in density)	Medium loss in structure (50 to 100% loss in density)	It is the percentage change in structural density of the habitat as a result of a given stressor.
Frequency of disturbance	Daily to weekly	Several times a year	Less often	It measures the frequency at which the habitat is perturbed by the stressor.
Consequence criteria (Resilience)				
Natural mortality	High mortality (<80% or above)	Moderate mortality (20 to 50%)	Low mortality (<20%)	It measures the natural mortality rates of the habitat or species.

Recruitment	Annual or more often	Every 1-2 year	Every 2+ years	It assesses the rate of recruitment of the habitat or the species.
Connectivity	High dispersal (>100km)	Medium dispersal (10-100km)	Low dispersal (<10km)	This indicates that close spacing of the habitat patches and seed dispersal enhance the recovery potential of a habitat
Recovery time	Less than 1 year	1-10 years	More than 10 years	It measures how long it will take for the habitat or the species to recover from a shock caused by a stressor

Source: Arkema *et al.*, (2015)

Effectiveness of the co-management in mangrove conservation

To ascertain whether the management regime put in place is effective in reducing anthropogenic threats to mangrove, a household survey was conducted in the two study sites. Households which partook in the survey were selected based on simple random sampling technique (Sagoe *et al.*, 2021). The sample size was calculated for each site in a separate manner using the formula (Köhl *et al.*, 2006):

$$n = \frac{1}{e^2} p(1 - p) U_{1-\frac{\alpha}{2}}^2$$

where, n represents the total sample size, U is the value of the normal random variable ($U=1.96$ for $\alpha = 0.05$) and e represents the authorized margin error held to be 9% in this survey (Köhl *et al.*, 2006). The pilot survey conducted during the field reconnaissance with fifty households selected in each site helped to identify the proportion of households who are knowledgeable about the history of mangroves (evolution, degradation, threats, among others) at each site. After calculation, 184 respondents were investigated in Benin ($p=0.7$) whereas 90 respondents were surveyed in Togo ($p=0.9$). Respondents were engaged in a face-to-face interview with paper-based interview guide. Their perception was sought on how effective is the co-management towards mangrove conservation.

Ethical considerations

Prior to data collection, ethical approval reference UCCIRB/CANS/2021/20 was obtained from the University of Cape Coast Institutional Review Board (UCCIRB). Within the study communities, the purpose of the work was thoroughly explained to each interviewee as well as the possible risks associated with their participation. Oral consent was also sought from participants before engaging them in the study.

Data analysis

Information from the focus group discussions and in-depth interviews was transcribed for understanding and content validity. For each site, the percentages of mangrove surface area under low, medium and high risk under the current co-management system were generated through HRA model using InVEST 3.9.0.

This was done for the cumulative risk for all the recorded stressors per sites as well as for each stressor taken individually. Respondents of the household survey were grouped based on their age young householders: < 30 years, adult householders: 30-60 years, and old householders > 60 years in the+ two countries), activities (artisanal activities, fishing activities, mat weaving, petty trading and salt production in Benin; artisanal activities, fishing activities, farming and petty trading in Togo), gender (Male versus Female in the two countries), ethnic groups (Fon, Mina, Xwlah and Xwedah in Benin; Mina, Ewe and Ouatchi in Togo) and level of education attainment (no education, primary and secondary in the two countries). Then, differences in their perception on the effectiveness of the co-management system across gender, age categories, activities, ethnical groups and educational background were tested using Chi-square test with the software R version 4.0.1 (R Core Team 2020).

Results

Dynamic of the manmade stressors responsible for mangrove degradation in the MTBR: insights from the Focus group discussions, direct observations and in-depth interviews

A total of six stressors including IUU, pollution, mangrove over-harvesting, fire, mangrove clearing and change in salinity of water were recorded in Benin. In Togo, seven stressors were recorded, which included IUU, mangrove clearing, over-harvesting, change in salinity of water, pollution, livestock and invasive species. IUU here refers to any prohibited fishing activity which takes place within mangroves. It was recorded in both the two study sites. Chief fishermen and resource persons consulted in the two sites acknowledged the use of prohibited fishing gears within mangroves in their communities. They narrated that fine mesh nets were still being used in mangroves in Benin. They also reported the use of destructive fishing techniques such as the cutting of mangroves' prop roots for fish collection purposes.

In the context of this study, mangrove overharvesting indicates the overexploitation of mangrove wood for different purposes. Mangroves were being increasingly harvested in the study sites for two major uses: commercial purposes and domestic uses for cooking and construction. Information collected from the field showed that salt producers prefer to use mangrove wood during the salt preparation process, particularly *R. racemosa*. The same species is said to be of paramount importance for house construction as a result of its hardness and resistance against insects. Mangrove species were also being increasingly harvested as firewood in both sites. Given the large preference of mangrove species for diverse uses in the area, many residents have shown keen interest in the commercialization of mangrove woods, in violation of the legal instruments that protect the ecosystem in the two countries. Informants who have ventured into mangrove exploitation explained that they harvested mangrove species either from their own farm or far away from the banks of the coastal lagoon. They indicated that mangroves located within their plots of land belong *de facto* to them and can be harvested without official approval. They also explained that mangroves situated far away from the banks of the lagoon are allowed to be utilized.

Mangrove clearing as portrayed in this study refers to the conversion of mangrove ecosystems to other land use types, following complete or partial removal of mangrove species. The issue of mangrove clearing was recorded in the two study sites. In Benin, mangroves were being cleared mainly for

aquaculture development, farming activities or salt ponds installation. Indeed, participants of the focus group discussions acknowledged that mangroves were being cleared for agricultural purposes, particularly to grow sugar cane or to produce salt. In Togo, informants explained that they systematically removed mangroves closer to habitations to protect their family against the wild animals such as snakes and crocodiles, among others.

Fire is another stressor which caused a lot of damages to mangrove ecosystems in the study area. It was recorded only in site of Benin, and occurs predominantly during the dry season. According to the participants of the focus group discussions, fire was mainly set around mangroves during the dry season for hunting purposes. Other informants reported that fire was used to prepare the land for vegetable growing or coastal cultivation, or when the vegetation around mangroves was bushy enough to endanger local population. Fire set in the adjacent environment of mangroves most of the time ends up burning the ecosystem leading to habitat destruction.

Mangrove pollution and change in water salinity were also cited as one of the stressors which impeded mangrove development in the area. They were mostly reported by key informants in both sites and were attributed to manmade actions. In addition to these stressors, livestock and invasive species were also recorded but uniquely in the site of Togo. Informants further made mention of herb of beefs which occasionally destroyed mangroves, particularly after restoration exercises.

When asked to explain the dynamic of the stressors in the area, informants unanimously indicated that all the stressors listed above have been degrading mangroves for ages, long before the creation of the reserve in 2017. However, they acknowledged that the establishment of the MTBR and its associated management system has helped to drastically lessen the intensity and the frequency of occurrence of the stressors.

Risks posed by the identified stressors to mangroves in the MTBR under the co-management regime

Cumulative risk from all stressors

A detailed analysis of the output of the HRA model showed that the highest values of the cumulative risk scores of the two study sites did not exceed the upper medium score limit which is 1.86 for all habitat-stressor combinations. The cumulative risk score recorded in Benin was 0.48 indicating that the combination of all the stressors recorded in Benin pose low risk to mangroves. In Togo, the model depicted a cumulative risk score of 0.89, revealing that the combination of all the stressors recorded in Togo pose low to medium risk to mangroves. This is better explained by the Figure 2 and the Table 4, which show the maps of habitat-specific cumulative risks from all stressors in grid cell for the two study sites. It indicates that all the mangroves (100%) in the site of Benin are under low risks (Figure 3a), whereas those in Togo are under low and medium risks (42% under low risk and 58% under medium risk).

Individual risk from each stressor

The Table 4 gives an overview of the risk posed by each stressor on the mangroves in the study sites, assessed individually. It indicates that in Benin, change in salinity of water and mangrove pollution put the

total surface area of mangroves (100%) under low risk, with an average risk of 0.33 and 0.06 respectively. Regarding IUU, mangrove clearing and fire, they put 19.37%, 6.20% and 41.86% of the mangrove cover under medium risk whereas 80.62%, 93.79% and 58.13% were under low risk respectively, with an average risk of 0.43, 0.17 and 0.8. Regarding the overharvesting, it has led to low risk for 58.13% of the mangrove coverage and high risk for 41.86% of the mangrove surface area, with an average risk of 1.06. Taken individually, stressors recorded in Togo appeared more detrimental to mangroves than Benin. The model showed that change in salinity of water, mangrove pollution, invasive species and livestock put 82%, 30%, 34% and 24% of the mangrove coverage under medium risk and 18%, 70%, 66% and 76% under low risk respectively, with an average risk of 1.28, 0.58, 0.85 and 0.52. Regarding IUU, mangrove clearing and mangrove overharvesting, presented an average risk of 0.30, 0.67 and 2.05 respectively. IUU and mangrove clearing pose high risk to 12 and 20% of the total mangrove cover of the site but represented low risk to 88 and 80% respectively. Likewise, over-harvesting put 82% of mangroves under high risk, but poses low risk to 18% of the mangrove cover of the area.

Table 4. Risk to mangroves in the study sites

Stressors	Benin				Togo			
	R_mean	R_High	R_medium	R_Low	R_mean	R_High	R_medium	R_Low
Change in salinity of water	0.33	0	0	100	1.28	0	82	18
IUU	0.43	0	19.37	80.62	0.30	12	0	88
Mangrove clearing	0.17	0	6.20	93.79	0.67	20	-	80
Over-harvesting	1.06	41.86	0	58.13	2.05	82	0	18
Pollution	0.06	0	0	100	0.58	0	30	70
Fire	0.80	0	41.86	58.13	-	-	-	-
Invasive species	-	-	-	-	0.85	0	34	66
Livestock	-	-	-	-	0.52	0	24	76
All stressors	0.48	0	0	100	0.89	0	42	58

Source: Output of the InVEST HRA model

Perceived impact of the co-management on mangrove protection in the reserves

The perception of local residents about the effectiveness of the co-management system in protecting mangrove protection in the reserve is summarized by the Figure 4. In Benin, 32.6% of the respondents

reported a drastic reduction of human-led pressures on mangroves following the adoption of the co-management while 45.6% asserted that these pressures have somewhat reduced. On the other hand, 21.7% of the respondents indicated that the adoption of the co-management system has not yet produced any result in terms of mangrove conservation (see figure 4 a). Peoples' perception in Benin varied significantly across to ethnical groups ($\chi^2 = 21.09$, $p < 0.001$) but not among age categories ($\chi^2 = 6.17$, $p=0.18$), sex ($\chi^2 = 1.36$, $p=0.5$), activities ($\chi^2 = 10.66$, $p=0.22$). and educational background ($\chi^2 = 2.68$, $p=0.61$). Indeed, most *Xwlahs* and *Xwedahs* reported the reduction of manmade pressures to mangroves following the advent of the co-management regime. In Togo, 49.7% of the interviewees informed that manmade pressures to mangroves have drastically reduced since the advent of the co-management, 36.2% indicated that the situation has somewhat changed and 14.1% reported that it has remained the same (see figure 4b). Here, respondents' perception is significantly influenced by the ethnical groups ($\chi^2 = 12.29$, $p=0.01$) and activities ($\chi^2 = 6.46$, $p < 0.001$) did not vary according to sex ($\chi^2 = 1.01$, $p= 0.6$), educational background ($\chi^2 = 5.01$, $p= 0.28$), and age categories ($\chi^2 = 3.88$, $p= 0.42$). As in Benin, respondents belonging to *Mina* ethnic group mostly reported that the situation of mangrove degradation in Togo has reduced as a result of the new management approach as compared to the *Ouatchi* and the *Ewes*. However, in the two study sites, no respondent indicated the situation whereby mangrove degradation has increased ever since the co-management has become effective.

Constraints associated with mangrove management in the study sites

Meetings held with the members of the local associations, NGO officials and state agencies helped to understand some of the challenges associated with the local management of mangroves in the study sites. NGOs and local associations lamented the lack of financial support to efficiently protect mangroves. They also raised issues of inadequate canoes, outboard motors and fuel to conduct patrol exercises. They also indicated that they heavily resort to international organizations for funding. They further explained that supports from the government are rare and limited to sensitization activities on special occasions (National Tree Planting Day for example). Although the members of the associations acknowledged the assistance of civil society organizations (NGOs) in awareness raising and capacity building, they deplored the inadequate sensitization exercises. They also lamented the lack of commitment of some local dwellers to participate in key activities such as decision-making-oriented meetings, mangrove restoration campaigns, sensitization and awareness raising.

Discussion

Co-management approach and its implications in mangrove conservation in the study sites

The contribution of the co-management regime in reducing anthropogenic threats to mangroves in the MTBR depicted a strong geographical variation. This is evidenced by the Figure 3, which showed the cumulative risk of all stressors to mangroves in the study sites. The success of the co-management in mangrove conservation has already been demonstrated by a large body of research worldwide (Yandle, 2003; Chuenpagdee et al., 2004; Gelcich et al., 2008; Levine & Richmond, 2014). Figure 3 showed that

mangroves located in the site of Benin were all under low risk of human-led degradation under the newly implemented co-management regime. Indeed, the local association mandated to manage the site of Benin has put in place some participatory measures, which fostered mangrove management and local governance. The strong involvement of the customary laws that governed the area coupled with the use of traditional means to protect mangroves within the site yielded tremendous results, and fostered mangroves conservation in the area. Firstly, the customary laws known for *Xwlahs*, which represented over 50% of the local population within the site (Gnansounou et al., 2021) have been set as general rules in order to fight against mangrove pollution in the reserve. These laws, which include the ban on open defecation as well as sewage and waste dumping into the water bodies of the area have helped to considerably limit mangrove pollution which was not a major threat to mangrove, since it put the ecosystem under low risk (see Table 4). Just a small portion of the Benin site still lacked behind concerning mangrove pollution (see supplementary data, Figure S5). This aligns with Aheto et al., (2016) and Sagoe et al., (2021) who pinpointed the roles of customary laws in management of coastal resources in West Africa. The authors explained that traditional rules and regulations are easy to enforce and simple to comply with and therefore, contribute more to mangroves management. Communities who are yet to manage their protected areas through bottom-up approaches should consider the customary laws and traditional rules of their communities in order to meet their conservation objectives. To curb the ongoing degradation of mangroves, stakeholders in Benin have also sought contribution from the local deities, especially the *Zangbeto*. This has resulted in the identification of many mangrove ecosystems as sanctums, which people were prohibited from accessing, using or clearing. These sanctum ecosystems have over the years promoted ecotourism in the areas and serve as habitats for variety of species including migratory birds. Research conducted by Zanzo et al., (2021) in the area demonstrated that the creation of sanctums from mangrove forests highly contributed to mangrove conservation in Benin. The authors compared tree taxonomic diversity, structural diversity and dominance patterns in mangroves subjected to low and high wood harvesting intensity and observed that mangroves that showed higher tree density, structural diversity and growth characteristic were those protected with the local divinity *Zangbeto*. The non-implementation of these traditional and customary means in Togo could account for the medium risks recorded in this site as shown in Figure 2. It could also be due to some internal factors including the governance of mangroves, conflicts among stakeholders or the institutional arrangements-oriented biases that may be revealed by further studies.

Effectiveness of the co-management in mangrove protection and constraints associated with the approach

Although a lot of conservation efforts need to be made particularly in the site of Togo, information collected from the field showed a satisfactory trend regarding the contribution of the co-management approach in conserving mangroves within the reserve. Indeed, no interviewee in the two study sites reported the escalation of mangrove degradation following the establishment of the reserve. This meets the main objective of the establishment of the reserve, which was to create a conducive environment for a successful conservation of coastal resources located within the Mono Delta (Ecobenin, 2018). While majority of the respondents in the two study sites described a situation of large reduction of manmade

threats to mangroves following the implementation of the co-management approach, a handful of interviewees (21.7% in Benin and 14.1% in Togo) asserted that the situation remained unchanged even with the new management regime (see Figure 4). They further buttressed their point of view by the surface area of mangroves, which has not shown significant change in the reserve ever since the co-management is being implemented. This may be due to the inadequate awareness raising activities within the reserve. Indeed, it takes decades for mangrove ecosystems to bounce back to normal if they undergo serious disturbances. This was the case in the area prior to the establishment of the reserve in 2017 (Adjonou et al., 2020; Teka et al., 2018). This necessitates a lot of restoration and conservation efforts currently underway within the reserve with the support of many international institutions (Guelly et al., 2020). It is therefore important to carry out quantitative and qualitative research to understand the various misconceptions of mangroves functioning, phenology and ecosystem services in order to restructure sensitization activities based on local communities' perception. The results of the chi-square test showed a significant influence of the ethnicity on the perceived impacts of the co-management on mangroves protection in the reserve. Most *Xwlahs* and *Xwedahs* in Benin, and most Minas in Togo reported the reduction of manmade pressures to mangroves as a result of the co-management. These ethnic groups represent the indigenous sociocultural groups of the area (Gnansounou et al., 2021), and therefore are more knowledgeable about the degradation of mangroves in the reserve. This concurs with Nyangoko et al., (2021) who found difference in perception in the local use of mangroves in Tanzania with a significant variation across ethnic groups.

Persistent anthropogenic threats to mangroves under the co-management regime.

The anthropogenic stressors recorded in the two study sites are similar to those listed by Feka & Ajonina (2011) who documented the anthropogenic threats to mangroves within the subregion. Informants indicated their large contribution to mangrove degradation and biodiversity loss in the area before the establishment of the reserve. Notwithstanding stakeholders' efforts, some anthropogenic stressors seemed to undermine the journey towards the effective conservation of mangroves in the study sites. Indeed, the Table 4 showed that IUU, fire and overharvesting represent respectively medium and high risk to mangroves in Benin. The situation is compounded in Togo where IUU, mangrove clearing and overharvesting put respectively 12%, 20% and 82% of mangrove surface area under high risk. This calls for urgent actions in order to deal with these threats, which could cause severe harm to mangrove ecosystems going forward. Direct observation from the field showed that mangroves overharvesting is taking an alarming proportion in the study sites, particularly in Togo (see supplementary data, Figure 5). Mangroves' woods are harvested in the study mainly for domestic uses. This concurs with the findings of previous works carried out in the reserve (Gnansounou *et al.*, 2021, Adanguidi *et al.*, 2020, Zanzo *et al.*, 2021). The growing interest on mangroves' woods for domestic uses in the study sites may be due to the demographic growth currently prevailing in the reserve (Teka *et al.*, 2018). Research on the cooking fuels within the reserve will undoubtedly help to propose alternative and affordable fuel sources in order to curb the increasing domestic use of mangroves for cooking purposes. Furthermore, awareness raising must be increased in the reserve in order to advert the growing clearing of mangroves. Fire is also being detrimental to mangrove species in the MTBR. It happens predominantly in Benin in the breach of the legal

instruments which protect mangroves in the country. An analysis of the Table 4 indicated that IUU poses also a serious threat to mangroves under the current co-management regime. Though the use of mangrove species to establish the *acadja* has drastically declined in the two study sites following the creation of the reserve and the subsequent implementation of the co-management approach, other illegal fishing techniques continue to degrade mangroves in the study sites. This may be due to the dwindle in fish stock in the marine and coastal waters of the subregion (Asiedu et al., 2021; Nunoo et al., 2014). A study of livelihood need assessment is therefore important in order to ascertain the preferred livelihood options of the fishermen and farmers operating within the study sites of subsequent actions in order to limit fire and IUU-induced mangrove degradation in the reserve. There are many challenges associated with the implementation of the co-management in the MTBR. Constraints raised by the informants in this study were also reported by other authors (Nunan, 2020; Buck et al., 2004). Linke & Bruckmeier also (2015) also highlighted the lack of commitment of the local population towards the co-management can lead to dire implications to resource conservation in the area. There is therefore crucial to document the causes of the current and possible future challenges that may undermine the successful implementation of the co-management in the reserve for informed policy making.

Conclusion

This work investigated the significance of the contribution of the co-management in mangrove conservation in West Africa, using the MTBR as case study. There is a drastic reduction of the frequency and the intensity of anthropogenic stressors to mangroves in the reserve following the adoption and the implementation of the co-management approach. However, there are some peculiar challenges, which need to be thoroughly researched and addressed for an effective conservation of mangroves in the MTBR.

Limitation of the study

The model used for this study does not count for the effects of historical human activities on the current risks. As a result, it was not possible to develop the habitat risk maps of the reserve before the creation of the reserve. However, interactions with the community members during the quantitative survey helped to know the importance of the co-management system in curbing mangroves-oriented anthropogenic pressures in the reserve.

Declarations

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Competing interests

The authors have no relevant financial or non-financial interests to disclose

Author Contributions: Conceptualization: GSC; Methodology: GSC, VKS, AAS, and DWA; Data analysis: GSC and VKS; Original draft preparation: GSC, Manuscript editing: VKS, AAS, PADM, DWA and RGK; Supervision: DWA and RGK.

Data availability

The datasets generated during and/or analysed during the current study are available from the corresponding author on reasonable request

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Figures

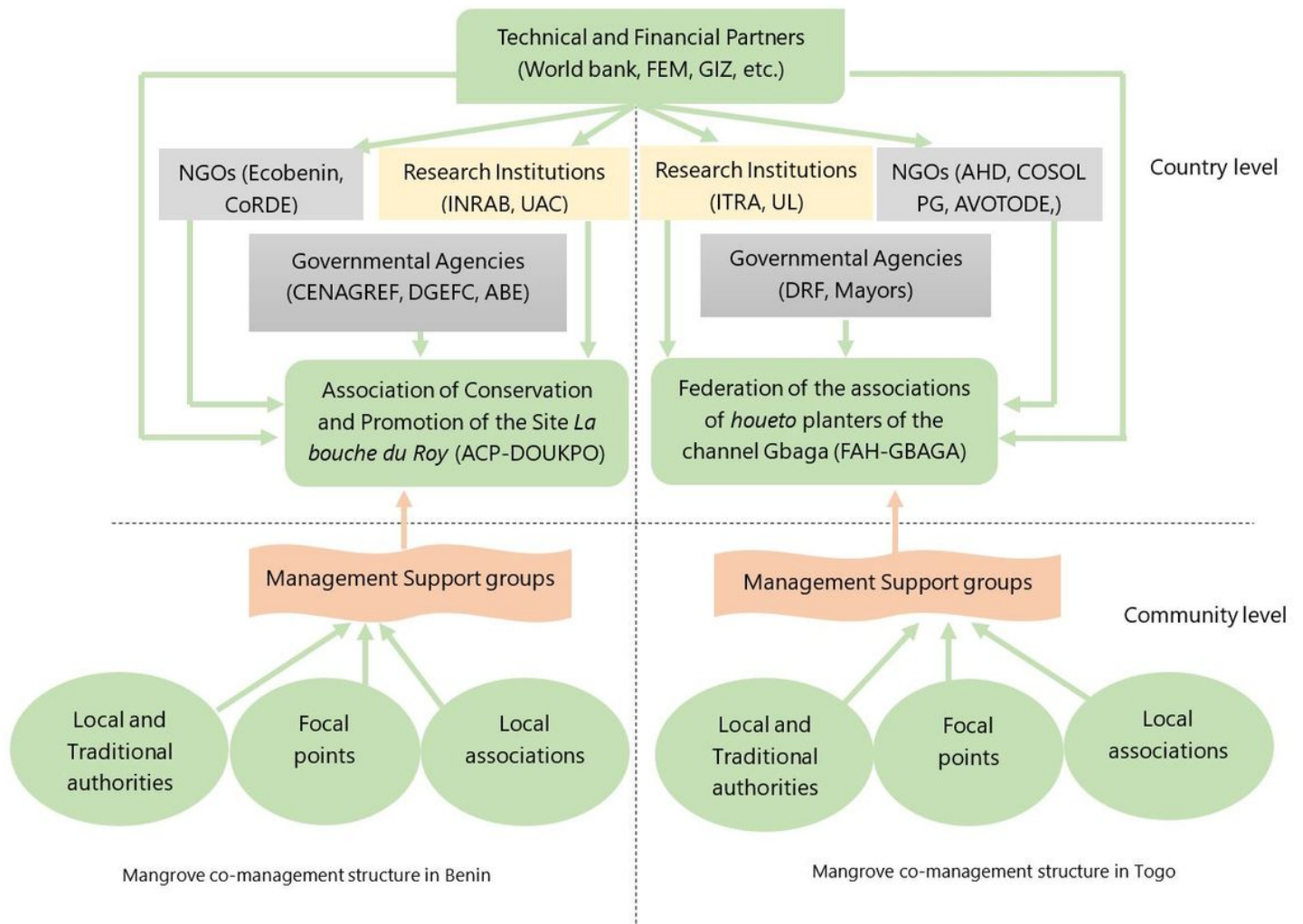


Figure 1

Mangrove Co-management Frameworks in the two countries which share the MTBR

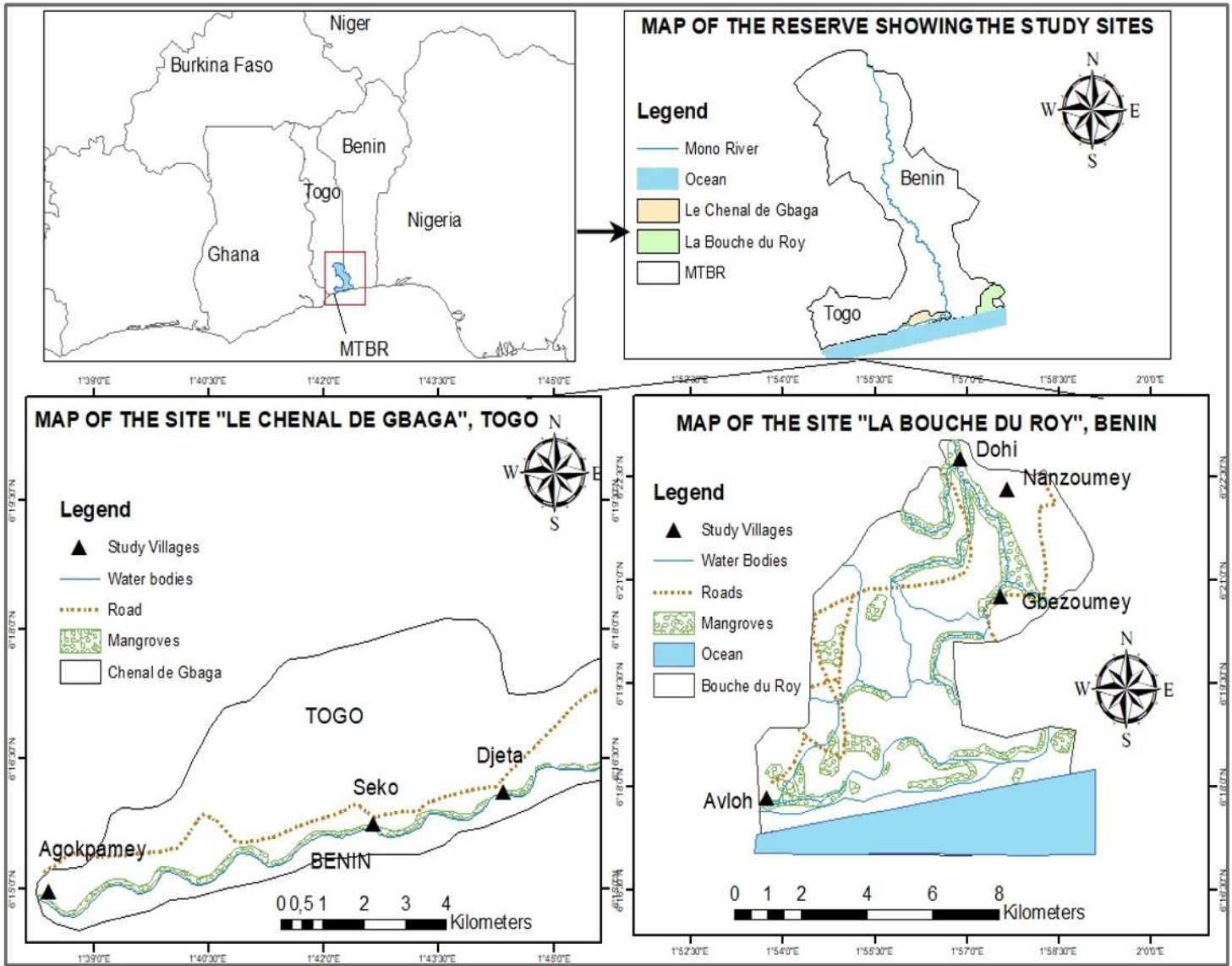


Figure 2

Maps of the study area

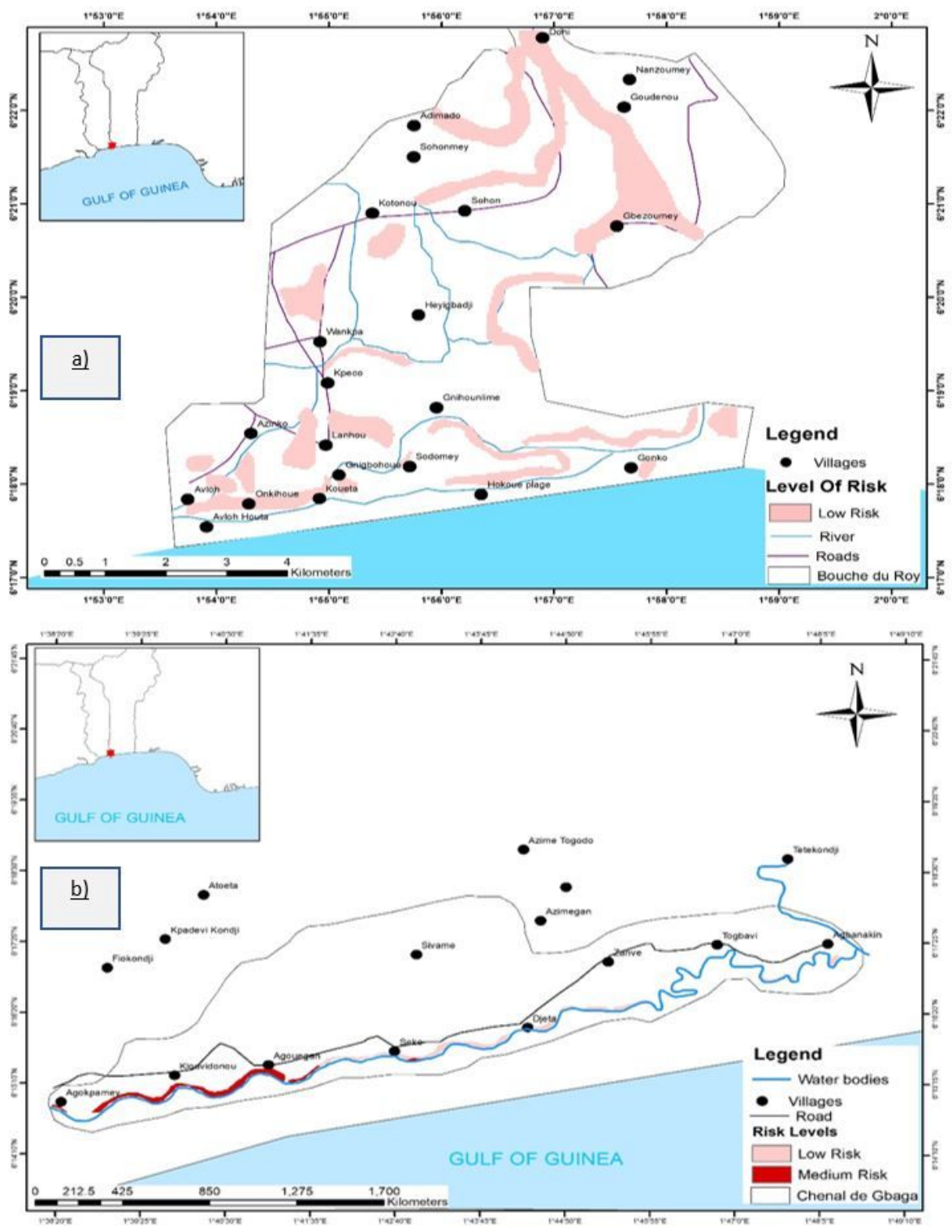


Figure 3

Habitat-specific cumulative risks from all stressors in Benin (a) and Togo (b)

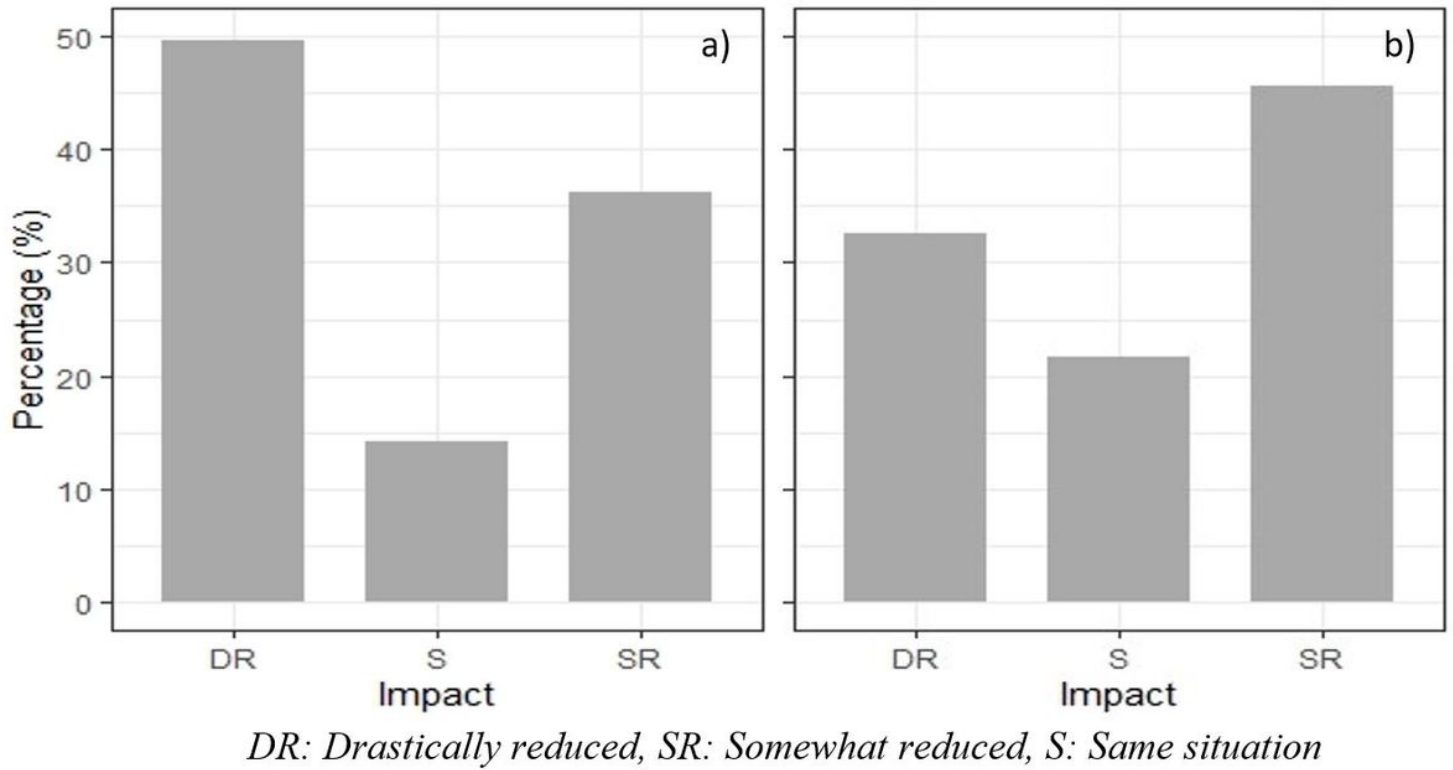


Figure 4

Perceived impact of the co-management on mangroves conservation

Supplementary Files

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