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How far are mangrove ecosystems in Benin (West Africa) conserved by the Ramsar Convention?

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A B S T R A C T

Mangroves around the world provide humanity with a variety of ecosystem services. However, rising populations coupled with human activities jeopardize the sustainable management of these ecosystems. Climate change is also expected to have a severe impact on mangrove ecosystems, especially in Benin, West Africa. Since 2000, several initiatives for the conservation of mangroves have been established under the Ramsar Convention on Wetlands. Land use/land cover (LULC) changes were used at Ramsar Site 1017 in Benin for periods in 1995, 2005 and 2015 to assess the impact of the Ramsar Convention on mangrove ecosystem conservation. The observed changes during 1995–2005 and 2005–2015 were considered to predict LULC change towards 2070 using the Markov chain model. During 1995–2005, a total area of 3.43 ha of mangroves was degraded, while during the 2005–2015 period 2.65 ha were restored. Future scenarios predicted that the area of mangroves was expected to decrease by more than half between 1995 and 2070, assuming the dynamic of 1995–2005, and increase by 1.1% of the 2005 area by 2070 with the dynamic of 2005–2015. Implementation of conservation policies, projects and awareness-raising activities could contribute to the effective restoration of the mangrove ecosystems.

1. Introduction

Africa holds 3.2 million hectares of mangroves (FAO, 2007) of which 70% are located in Nigeria, Mozambique, Madagascar, Guinea and Cameroon (Fousseni et al., 2017). Mangroves play important roles by providing local people with multiple ecosystem goods and services (Ndour et al., 2012; Sinsin et al., 2018). Ecosystem services provided by mangroves include support for aquaculture and fishery activities, salt extraction, fuelwood and agriculture (Satyanarayana et al., 2013; Sinsin et al., 2018; Adanguidi et al., 2020). Mangroves play ecological, socio-economic and climate regulation roles (Ndour et al., 2012; Pramova et al., 2012; Locatelli, 2013). As such, human beings remain the main beneficiaries both in terms of direct consumption and through the improvement of their income. However, other living organisms, such as mammals, fish, insects and algae, also benefit from improved environmental conditions associated with the combination of freshwater–saltwater mangrove vegetation. Mangroves enrich the estuarine and marine environments with nutrients through the biodegradation of the organic matter they produce. These organic materials are one of the links in the food chain within the mangrove ecosystem (Ndour et al., 2012).

The surface area of West African mangroves has shrunk considerably, in the order of 30%, in the last 25 years (Fousseni et al., 2017). The degradation and deforestation of these ecosystems are related to the overexploitation of resources, conversion to pond aquaculture, coastal dumping and urbanization, as well as pollution from upstream land use (Maoulana-Abbas, 2009; Armah et al., 2010; Alexandris et al., 2013; Adanguidi et al., 2020). Timely and targeted actions are thus needed to save West African mangroves, and their associated biodiversity, from disappearance.

The mangroves in Benin are embedded in the internationally recognized wetlands of Ramsar Site 1017, also known as West Complex.

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These mangrove ecosystems are characterized by high biological productivity, which translates into significant biodiversity of benefit to many animal and plant species (Sinsin et al., 2018). It offers abundant timber and fishery resources for various agricultural, aquacultural and other activities (Sinsin et al., 2018; Adanguidi et al., 2020). In addition, it serves as a refuge for many endangered species and is an essential link for migratory birdlife (Sinsin et al., 2018). Unfortunately, the increase in human population and activities in the area—mainly demand for wood—have resulted in overexploitation of the mangrove with negative impacts on the ecosystem (Sinsin et al., 2018; Adanguidi et al., 2020). In addition to human activities, climate variation is expected to have severe impact on the ecosystem of mangroves (Sinsin et al., 2018; Teka et al., 2018).

Benin adopted the Ramsar Convention on Wetlands in 1999, which was further implemented in 2000. The convention provides a framework for national action and international cooperation on the conservation and use of wetlands and their resources. Originally focused on the conservation and use of waterbird habitats, the convention later expanded its scope by recognizing the importance of wetlands as ecosystems that contribute to biodiversity conservation and human wellbeing.

Since then, several projects have been implemented in Ramsar Site 1017 for the sustainable use and conservation of the wetlands, including the mangrove ecosystems. However, little is known about the impact of this convention and the associated projects on mangrove conservation. The aim of this study is to assess the impact of changes in land use/land cover (LULC) on the dynamics of mangrove ecosystems in order to act appropriately for the conservation of these systems.

2. Methods

2.1. Study area

Ramsar Site 1017 (1°37'45''–2°20'05'' and 6°12'37''–7°1'N) covers an area of 4147 km^2 (Fig. 1). It is located in the southwestern part of Benin, in the coastal zone characterized by the Guineo–Congolian climate, with two rainy seasons (March–July and September–November) of 900–1300 mm. Major soil types are sandy, hydromorphic, halomorphic vertisols, ferruginous and ferralitic soils. Dominant vegetation types are coastal forests, thickets and mangroves (Adomou et al., 2006). The study was conducted between the parallel 1°20′–1°25′E and 6°14′–6°20′N of Ramsar Site 1017 (Fig. 1).

2.2. LULC maps

2.2.1. Changes in LULC

Three Landsat images taken in the dry season—February 1995, December 2005 and December 2015—were interpreted (Fig. 2). We used color composition for bands (RGB 4, 7, 5) to differentiate the different types of LULC. The satellite images were classified following supervised classification techniques based on the tones of the different units and field knowledge. The resulting maps were edited by giving them appropriate colors or symbols. ArcMap 10 (ESRI) software was used to perform overlay analysis elaborating the maps. Error matrix was used to assess the classification accuracy (Padonou et al., 2017). A total of 300 reference points (50–60 per class) were distributed in the area with a stratified sampling scheme (Padonou et al., 2017).

2.2.2. LULC transition matrices

Probability of transition matrices elaborated for 1995–2005 and 2005–2015 were used to analyze each class of LULC. The matrix represented either the transition of each class of LULC to another class, or each class's persistence from the initial to the final year in the period. Standardization was used to annualize the probability matrix values for comparison using the method of diagonalization (Çinlar, 1975).

2.3. Future scenarios

Each LULC was predicted using the annualized probability matrices with the Markov chain model. We assumed two scenarios corresponding to the probability matrices of 1995–2005 and 2005–2015. A chi-square test (χ^2) was used to test the model validation by comparing the area

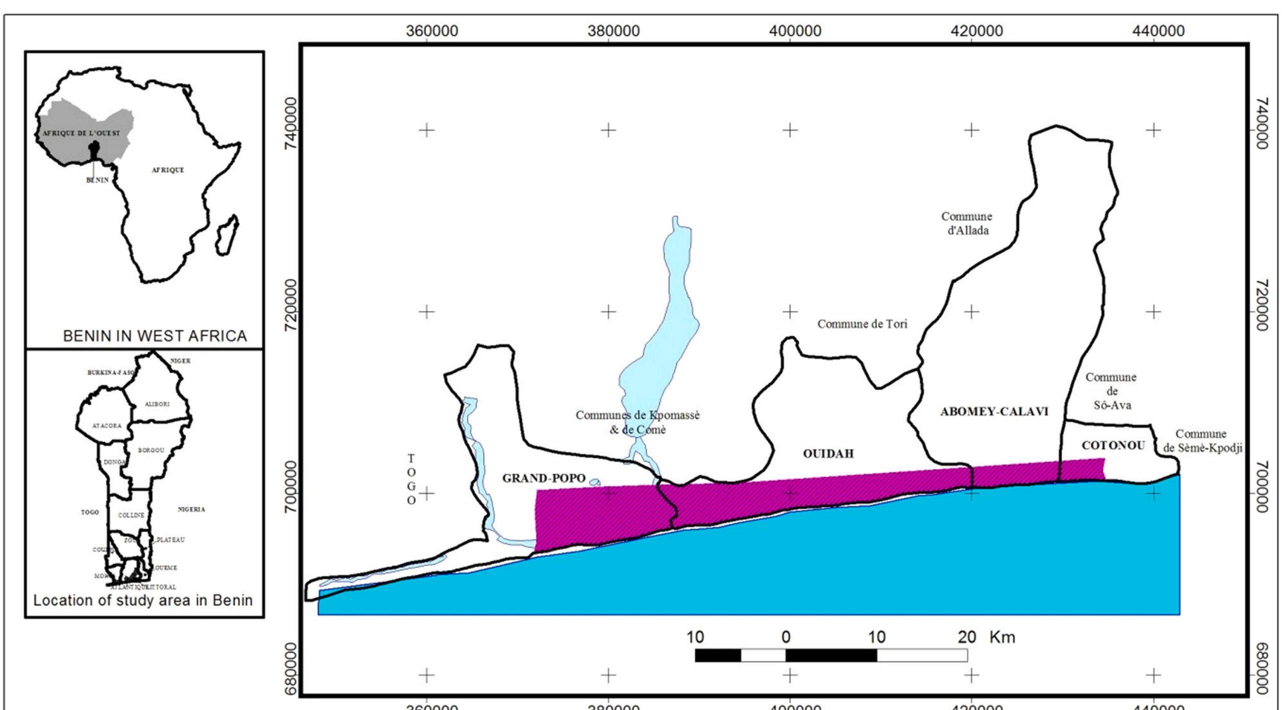

Fig. 1. Maps showing the location of Ramsar Site 1017 with the study area section in pink. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

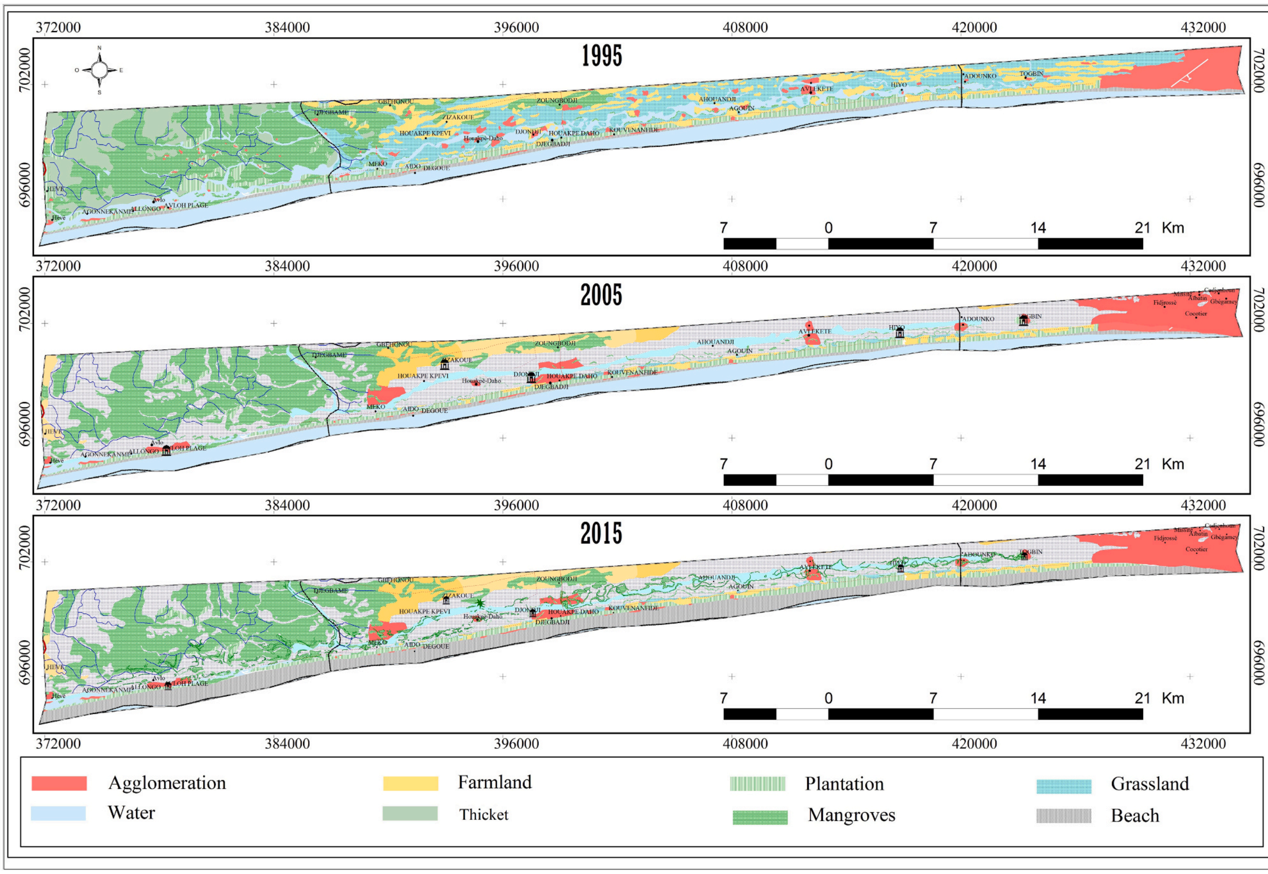

Fig. 2. Distribution of LULC classes in 1995, 2005 and 2015.

expected for 2015 from simulation using the period 1995–2005 with the area of 2015 from the map of that year.

2.4. Degradation or conservation rate

The degradation or conservation rate for each period (1995–2005 and 2005–2015) was calculated using the proposed formula of FAO (1996). The degradation rate, D (% lost area/year), was calculated as follows:

$$D = \left[1-\left(1-\frac{(A_1-A_2)}{A_1}\right)^{1/t}\right] \times 100$$

A_1 (initial year) and A_2 (final year) represent the cover of each LULC class and t is the number of year within each period.

Table 1
Cover in hectares of LULC classes in 1995, 2005 and 2015.

LULC class	Area 1995	%	Area 2005	%	Area 2015	%
Mangroves	14.59	0.62	11.16	0.47	13.81	0.59
Grassland	301.40	12.81	310.93	13.21	358.55	15.24
Thicket	45.59	1.94	10.04	0.43	18.29	0.78
Plantation	120.66	5.13	146.81	6.24	174	7.39
Farmland	1670.67	70.99	1659.99	70.53	1555.86	66.11
Water	110.70	4.70	109.80	4.67	110.17	4.68
Beach	18.68	0.79	1.39	0.06	7.80	0.33
Agglomeration	71.11	3.02	95.27	4.05	114.89	4.88
Total	2353.40	100	2353.4	100	2353.4	100

3. Results

3.1. LULC classes

A total of eight LULC classes were obtained from the maps (Table 1, Fig. 2). The proportions of these eight classes showed important shifts between 1995 and 2015 (Table 1, Fig. 2). In 1995, farmland and grassland were the predominant LULC classes, whereas mangrove forests covered only 0.62% (Table 1). In 2005 and 2015, farmland and grassland remained the predominant LULC classes. From 1995–2005, the areas of beach, water, thicket and mangrove forests had decreased, whereas the areas of the other LULC classes increased. During the second period (2005–2015), all LULC classes increased except farmland. Mangroves were lost during 1995–2005 (0.15% decrease from 1995) and restored during 2005–2015 (12% increase in 2005).

3.2. Changes in LULC

During the period 1995–2005, water, farmland and grassland showed strong persistence compared with the other LULC categories (Table 2). Mangrove was converted to grassland and farmland; thicket was transformed to grassland and farmland; plantation converted to farmland, beach and agglomeration; beach converted to water; and agglomeration to thicket (Table 2).

During the period 2005–2015, beach, water and farmland largely showed persistence (Table 2). Mangrove was converted to grassland; grassland was transformed to farmland and agglomeration; thicket was transformed to farmland and grassland; plantation was transformed to farmland and agglomeration; and agglomeration converted mainly to farmland (Table 2).

Table 2
Annual probability matrices (1995–2005–2015).

	Mangroves	Grassland	Thicket	Plantation	Farmland	Water	Beach	Agglomeration
1995				**2005**				
Mangroves	**0.77**	0.00	0.00	0.04	0.00	0.00	0.00	0.00
Grassland	0.22	**0.96**	0.12	0.00	0.00	0.00	0.00	0.00
Thicket	0.00	0.00	**0.56**	0.00	0.00	0.00	0.00	0.42
Plantation	0.00	0.00	0.00	**0.75**	0.01	0.00	0.00	0.00
Farmland	0.01	0.03	0.33	0.14	**0.98**	0.00	0.00	0.00
Water	0.00	0.00	0.00	0.00	0.00	**1.00**	0.85	0.00
Beach	0.00	0.00	0.00	0.05	0.01	0.00	**0.15**	0.00
Agglomeration	0.00	0.01	0.00	0.02	0.01	0.00	0.00	**0.58**
2005				**2015**				
Mangroves	**0.81**	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Grassland	0.19	**0.86**	0.07	0.00	0.00	0.00	0.00	0.00
Thicket	0.00	0.00	**0.55**	0.00	0.00	0.00	0.00	0.00
Plantation	0.00	0.00	0.00	**0.76**	0.01	0.00	0.00	0.00

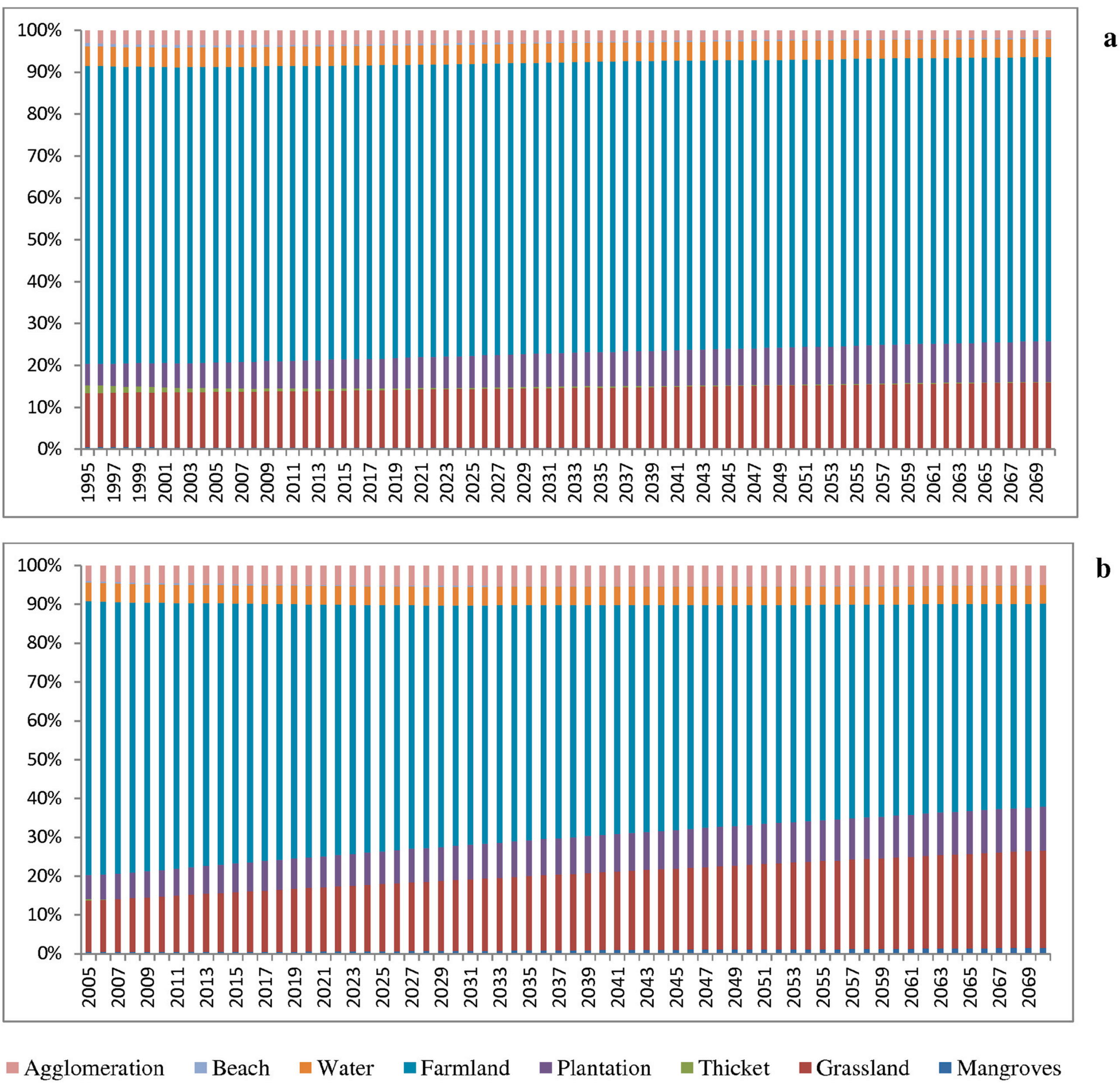

Fig. 3. Simulation of the eight LULC classes with two scenarios using the dynamics of the periods 1995–2005 (a) and 2005–2015 (b).

3.3. Future scenarios

There was no significant difference ($\chi^2 < 14.07$; $P > 0.05$) between the probabilities observed in the LULC map of 2015 and the probabilities simulated for 2015 using the period 1995–2005. The model therefore can simulate the change in LULC. Future LULC changes (Fig. 3) will depend upon the previously observed dynamics for the time period considered (1995–2005 and 2005–2015).

With the dynamics observed in 1995–2005, the area of mangroves will decrease by more than half of the 1995 area by 2070. Moreover, farmland, water, thicket, beach and agglomeration areas will decrease by 3.4%, 0.3%, 1.7%, 0.5% and 1.3%, respectively, by 2070. However, by 2070, grassland will increase by 2.8% of its 1995 area, and plantation by 4.5%.

With the dynamics observed in 2005–2015, farmland, water, beach and thicket areas will decrease by 19.6%, 0.1%, 0.3% and 0.4%, respectively, of their 2005 area, while mangroves, grassland, plantation and agglomeration areas will increase by 1%, 11.2%, 4.8% and 0.8%, respectively.

3.4. Degradation or conservation rate

The degradation or conservation rate changed during the two periods (Table 3). In the period 1995–2005, beach, thicket and mangroves were most degraded, while agglomeration and plantation increased the most. In the period 2005–2015, only the farmland cover was degraded. Mangroves were degraded in the period 1995–2005 and increased in the period 2005–2015.

4. Discussion

A total area of 3.43 ha of mangroves was degraded between 1995 and 2005. This was mainly due to the overexploitation of the mangroves (Zannou et al., 2017; Adanguidi et al., 2020) as well as the demands of a growing local population. The population living in the mangrove areas of Ramsar Site 1017 has high fuelwood needs with more than 36% of these not covered by local supplies. The most important activities that consume wood energy around mangrove areas are salt production, fish smoking and household food cooking. In 2018, an average 8.21 m^3 of firewood and 23.19 kg of charcoal were consumed per capita in the mangrove areas in Benin (Adanguidi et al., 2020). However, annual firewood and charcoal needs per capita were 12.83 m^3 and 36.25 kg, respectively. This non-satisfaction gap of fuelwood needs puts pressure on the mangroves (Adanguidi et al., 2020). The population growth in the mangrove areas is estimated at rising from 1,347,618 inhabitants in 1992 to 2,351,406 in 2002 and 3,319,812 in 2013, with an annual growth rate of 3.25% in the period 1992–2002 and 3.51% in the period 2002–2005 (INSAE, 2016). This population growth puts further pressure on the natural resources in the wetlands of Ramsar Site 1017 and jeopardizes the conservation of the mangrove ecosystems.

From 2005–2015, 2.65 ha of the mangroves were restored. This was mainly due to the number of projects to implement the Ramsar Convention on Ramsar Site 1017, including the World Wetlands Day organized every February 2 since 2000, with the support of technical and financial partners. These projects aimed to raise awareness among local populations about the value of wetlands for humanity and the planet and emphasize the importance of mangrove ecosystems. The wetlands are managed by the Beninese Environment Agency, created in 1994, before the implementation of the Ramsar Convention in 2000. This agency has supported several initiatives of mangrove conservation, including the Community Management Project for Marine and Coastal Biodiversity in the period 2011–2014. Several NGOs, including ECO-Benin, Action Plus and CAPES, have been actively engaged in mangrove conservation since 2000. The Benin government has now forbidden the exploitation of mangroves following a meeting of the Council of Ministers on October 26, 2016.

Table 3
Annual rate of degradation (% lost ha/year).

LULC class	1995–2005	2005–2015
Mangroves	2.64	−2.15
Grassland	−0.31	−1.43
Thicket	14.04	−6.18
Plantation	−1.98	−1.71
Farmland	0.06	0.64
Water	0.08	−0.03
Beach	22.88	−18.83
Agglomeration	−2.97	−1.89
Total	34.45	−31.59

(–) restoration or increase (+) degradation or decrease.

Some activities now being conducted in the mangrove areas include the plantation of mangrove trees and the elaboration of a sustainable management plan of the mangrove ecosystems with the project “Restoration of mangrove ecosystems at the Ramsar Site 1017 (TCP/BEN/3502).” Others projects have provided sustainable alternatives to fuelwood for women involved in salt production and fish smoking to continue their business. This is the aim of the project “Solar energy and biotechnologies for women entrepreneurs in the mangroves of Ramsar Site 1017 in Benin (SEWomen),” which promotes the use of solar energy cookers to counter fuelwood demand in the mangrove areas. These strategies have proved very effective for mangrove ecosystem restoration (Borrini-Feyerabend and Hill, 2015; Mannigel, 2008) using a combination of traditional and interventionist approaches (Teka et al., 2018).

Future scenarios showed that the area of mangroves is expected to decrease by more than half of the 1995 area by 2070, assuming the dynamic of 1995–2005, and increase by 1% of the 2005 area by 2070 with the dynamic of 2005–2015. It is important to continue raising awareness among the local populations and to monitor the management plan of the mangrove ecosystems in order to sustain the restoration and conservation of the mangrove ecosystems. It is therefore urgent to focus targeted research in the management of Ramsar Site 1017 by helping the government to have a scientifically proven database that can help guide the actions of the stakeholders.

Farmland will decrease whatever the dynamic considered. Thus, it is important to support the local communities with sustainable alternative activities, including ecotourism. The mangrove area is an important site for ecotourism that can benefit the local population who can serve as ecotourism guides. Moreover, the Benin government is promoting ecotourism in the mangrove areas with infrastructures (road, hotels and touristic sites) that will create income-generating activities for the local population. It is also important to highlight that the farmland that will decrease is in the wetlands (Fig. 2), while the farmland that remains in the dry land near the mangrove areas can be managed sustainably to secure the livelihoods of the local population.

5. Conclusion

The mangrove ecosystem of Ramsar Site 1017 experienced a sharp decline in area over the period of 1995–2005. Human pressures are the major cause of this regression and therefore have a negative impact on the ecosystem services provided by mangroves. However, from 2005 to 2015, the mangrove ecosystem was restored due to the implementation of the Ramsar Convention with several projects on the conservation of biodiversity and sustainable use of mangrove ecosystems resources. The future scenarios predict a progression of the mangrove area recorded in 2005 by 2070. It is thus important to continue the biodiversity conservation and sustainable use of mangrove ecosystems in order to restore these ecosystems and limit the impact of land use change on Ramsar Site 1017.

CRediT authorship contribution statement

Category 1 **E.A. Padonou, N.I. Gbaï:** Conception and design of study. **N.I. Gbaï, E.A. Padonou, M.A. Kolawolé:** acquisition of data. **E. A. Padonou, M.A. Kolawolé, R. Idohou, M. Toyi:** analysis and/or interpretation of data. Category 2 **E.A. Padonou, M.A. Kolawolé, N.I. Gbaï, R. Idohou:** Drafting the manuscript. **E.A. Padonou, M.A. Kolawolé, N.I. Gbaï, R. Idohou, M. Toyi:** revising the manuscript critically for important intellectual content. Category 3 **E.A. Padonou, N.I. Gbaï, M.A. Kolawolé, R. Idohou, M. Toyi:** Approval of the version of the manuscript to be published.

Data availability

The data that support the findings of this study are available from the corresponding author upon reasonable request.

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.landusepol.2021.105583.

References

Adanguidi, J., Padonou, E.A., Zannou, A., Houngbo, S.B., Saliou, I.O., Agbahoungba, S., 2020. Fuelwood consumption and supply strategies in mangrove forests-Insights from RAMSAR sites in Benin. For. Policy Econ. 116, 102192.

Adomou, A.C., Sinsin, B., Van der Maesen, L.J.G., 2006. Phytosociological and chorological approaches to phytogeography: a meso-scale study in Benin. Syst. Geogr. Plants 76 (2), 155–178.

Alexandris, N., Chatenoux, B., Harriman, L., Lopez Torres,L., & Peduzzi, P. 2013. Monitoring Mangroves Restoration from Space.

Armah, A.K., Diame, A., Ajonina, G., Kairo, J., 2010. Protection des mangroves: Le rôle du Réseau africain des mangroves. In: Bojang, F., Ndeso-Atanga, A. (Eds.), L'importance des forêts de mangrove pour la pêche, la faune sauvage et les ressources en eau en Afrique. Nature et Faune, Accra, pp. 27–30.

Borrini-Feyerabend, G., Hill, R., 2015. Governance for the conservation of nature. Protected Area Governance and Management. ANU Press, pp. 169–206.

Çinlar, E., 1975. Exceptional paper—Markov renewal theory: a survey. Manag. Sci. 21 (7), 727–752.

FAO, 2007. The world's mangroves 1980–2005. Forestery Paper, No. 153, Rome-Italy, 55.

Fousseni, F., Andrianamenoso, R., Kperkouma, W., Agbelessessi, W., Madjouma, K., Hodabalo, P., Aniko, P.-A., Komlan, B., Koffi, A., 2017. Écologie et dynamique spatio-temporelle des mangroves au Togo. VertigO La Revue Électron. Ensci. de l'environn. 17 (3) https://doi.org/10.4000/vertigo.18791.

INSAE, 2016. Effectif de la Population des Villages et Quartiers de Villes du Bénin. RGPH 4, République du Bénin.

Locatelli, B., 2013. Services Écosystémiques et Changement Climatique (Doctoral dissertation). Université Grenoble, p. 1.

Mannigel, E., 2008. Integrating parks and people: how does participation work in protected area management? Soc. Nat. Resour. 21 (6), 498–511.

Maoulana-Abbas, S., 2009. Diagnostic Géobotanique et Impacts Anthropiques sur le Paysage de la Mangrove Dans la Baie de Toliara (Doctoral dissertation). Université de Tuléar, Madagascar.

Ndour, N., Dieng, S., Fall, M., 2012. Rôles des mangroves, modes et perspectives de gestion au Delta du Saloum (Sénégal). VertigO La Revue Électron. en Sci. de l'environ. 11 (3) https://doi.org/10.4000/vertigo.11515.

Padonou, E.A., Lykke, A.M., Bachmann, Y., Idohou, R., Sinsin, B., 2017. Mapping changes in land use/land cover and prediction of future extension of bowé in Benin, West Africa. Land Use Policy 69, 85–92.

Pramova, E., Locatelli, B., Djoudi, H., Somorin, O., 2012. Le rôle des forêts et des arbres dans l'adaptation sociale à la variabilité et au changement climatiques.

Satyanarayana, B., Mulder, S., Jayatissa, L.P., Dahdouh-Guebas, F., 2013. Are the mangroves inthe Galle-Unawatuna area (Sri Lanka) at risk? A social-ecological approach involving local stakeholders for a better conservation policy. Ocean Coast. Manag. 71, 225–237.

Sinsin, B., Assogbadjo, A.E., Tente, B., Yo, T., Adanguidi, J., Lougbegnon, T., Ahouansou, S., Sogbohossou, É., Padonou, E., Agbani, P., 2018. Inventairefloristique et faunique des écosystèmes de mangroves et des zones humidescôtières du Bénin. FAO & Laboratoire d'Écologie Appliquée, Bénin.

Teka, O., Houessou, L.G., Djossa, B.A., Bachmann, Y., Oumorou, M., Sinsin, B., 2018. Mangroves in Benin, West Africa: threats, uses and conservation opportunities. Environ. Dev. Sustain. 21 (3), 1153–1169. https://doi.org/10.1007/s10668-017-0075-x.

Zannou, A., Allou, N.Z., Biaou, G., 2017. Déterminants terminants sociotechniques et économiques de la dégradation des forêts de mangrove dans la lagune cotière du Bénin. Ann. Des. Sci. Agron. 21 (1), 77–88.