Chapter

How Far the Mono Transboundary Biosphere Reserve Protects Biodiversity in the Dahomey-Gap Corridor, West Africa?

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Abstract

Mono Transboundary Biosphere Reserve (MTBR) is rich in biodiversity associated with different multi-functional ecosystems in the Dahomey-Gap corridor in the southern border between Benin and Togo. The reserve has been facing many anthropogenic pressures since few years including the uncontrolled exploitation of forest resources, and fragmentation of habitats and permanent search for arable land. Thus, it becomes important to develop prospective analysis approaches in order to provide specific insights for a balanced biodiversity. This study aims to provide scientific evidence to better understand and project future changes in LULC in the MTBR at different spatial and temporal scales. Changes in LULC were used to map the MTBR in 1986, 2000, and 2015 and to predict the LULC in the future up to 2070 using Markovian chain analysis. During 1986–2000, urban agglomeration/bare soil (8.79 ha/year) increased, whereas the natural vegetation cover increased during the period 2000–2015, particularly mangroves (9.81 ha/year). Assuming the dynamic observed, the mangroves will increase by 2070 (6% of its cover). However, an important increase is also expected for farmland (13% of its cover). It is, therefore, important to strengthen the actions and strategies around and within the MTBR for sustainable management of biological resources.

Keywords: Dahomey gap, future scenarios, land use/land cover, prospective analysis, protected area

1. Introduction

The land and its resources have been used to meet material, social, cultural, and spiritual needs of human beings [1]. In that process, human beings modified land uses through daily activities [2]. Conversion of natural forests and grasslands into farming and crop areas in order to meet the food demand of the ever-increasing world population is among the examples. Land use/land cover (LULC) change, as one of the main driving forces of global environmental change, is a key component in the sustainable development debate [3, 4]. LULC changes are aspects of global environmental change and affect ecosystem processes and services [2, 5, 6]. Those changes influence energy exchanges between land and atmosphere and affect climate, water and soil quality, biogeochemical cycles, biodiversity, and ecosystem services [7]. Increasing demand for agricultural, industrial, or urban areas compromises the ability of natural forests, waterbodies, and grasslands to support community's needs.

The rapid changes of LULC than ever before, particularly in developing countries, are often characterized by rampant urban sprawling, land degradation, or the transformation of forest land to farming, ensuing enormous cost to the environment [8]. In sub-Saharan Africa, several studies were conducted on mapping and valuation of ecosystem services in the context of LULC [9, 10]. Almost all studies indicate that the region is under severe pressure of degradation, with significant consequences for rural livelihoods [3–5, 11, 12]. Alterations of land cover and land use types result from human activities such as agricultural expansion, deforestation, and natural factors (drought, cyclone, etc.), and generate more or less sensitive consequences on the environment.

These observations related to changes in LULC come true in highly populated areas marked by contrasting climatic conditions and high demand for arable land and are particularly pointed out by several studies carried out in the Mono Transboundary Biosphere Reserve (MTBR) located in the Dahomey corridor on the southern border between Benin and Togo [11, 13–16]. The area is rich in biodiversity associated with different multi-functional ecosystems [16], but it has also been facing many anthropogenic pressures since few years. These include the uncontrolled exploitation of forest resources, fragmentation of habitats, and permanent search for arable land [11]. This situation puts great pressure on the dynamics and conversion of LULC. The conversion, including changes of forest and/or woodlands to agricultural lands, has negative impacts on climate, terrestrial carbon stores, loss of biodiversity [5, 6, 17], fragmentation of wildlife habitats, and disruption of ecological and hydrological processes [18].

Facing that situation and in view of the uncertainties surrounding the future of forest resources and the specific ecosystems of the MTBR, territorial prospective analysis approaches should be adopted to provide specific insights and elements for thoughts on the possible room for maneuver over a long period and at different horizons for a balanced and sustainable management of the forest resources and biodiversity of this reserve in line with the socioeconomic and environmental challenges of the region. Exploring the possible future development of land occupations and uses in the MTBR remains an effective means of identifying areas at stake for the conservation of natural resources and biodiversity and assessing the influence of management policies and strategies at different spatiotemporal scales on land use [19–21].

This study aims to provide scientific evidence to better understand and project future changes in LULC in the MTBR at different spatial and temporal scales. Based on remote sensing technologies and satellite data coupled with dynamic and spatially explicit modeling methods, this chapter aimed at: (i) analyzing the dynamics of land-use patterns in the period 1986 to 2015 for a better understanding of the trends in the evolution of the natural landscape and (ii) establishing a future scenario (2015–2070) changes in each land cover class. This research is unique as the modeling of land use dynamics in the MTBR will make it possible to follow the evolutionary trend of the landscape and to find acceptable rules for preserving natural resources, particularly forest resources and biodiversity in the reserve.

2. Materials and methods

2.1 Study area

The Mono Transboundary Biosphere Reserve (MTBR) is located at the southern border between Benin and Togo (6°8′52.8″–7°3′41.8″ North latitude and 1°24′18.2″–1°30′0.0″ East longitude) and covers an area of 345.22 km^2 (**Figure 1**). The reserve is located in the Dahomey gap, a corridor characterized by mosaics of dense semi-deciduous forests, Guinean savannas, marshy meadows, marshes, mangroves, and water plans, and mosaics of crops and fallows [16]. The reserve is characterized by a tropical humid climate with a succession of four seasons per year, two dry seasons (November to March and July to September) and two rainy seasons (March to July and September to November). Rainfall varies between 850 mm and 1250 mm per year, with an average monthly rainfall of about 222.57 mm during the long rainy season and 88.30 mm during the short rainy season (October). The average maximum temperature is 31.25°C between December and April, and the minimum temperature

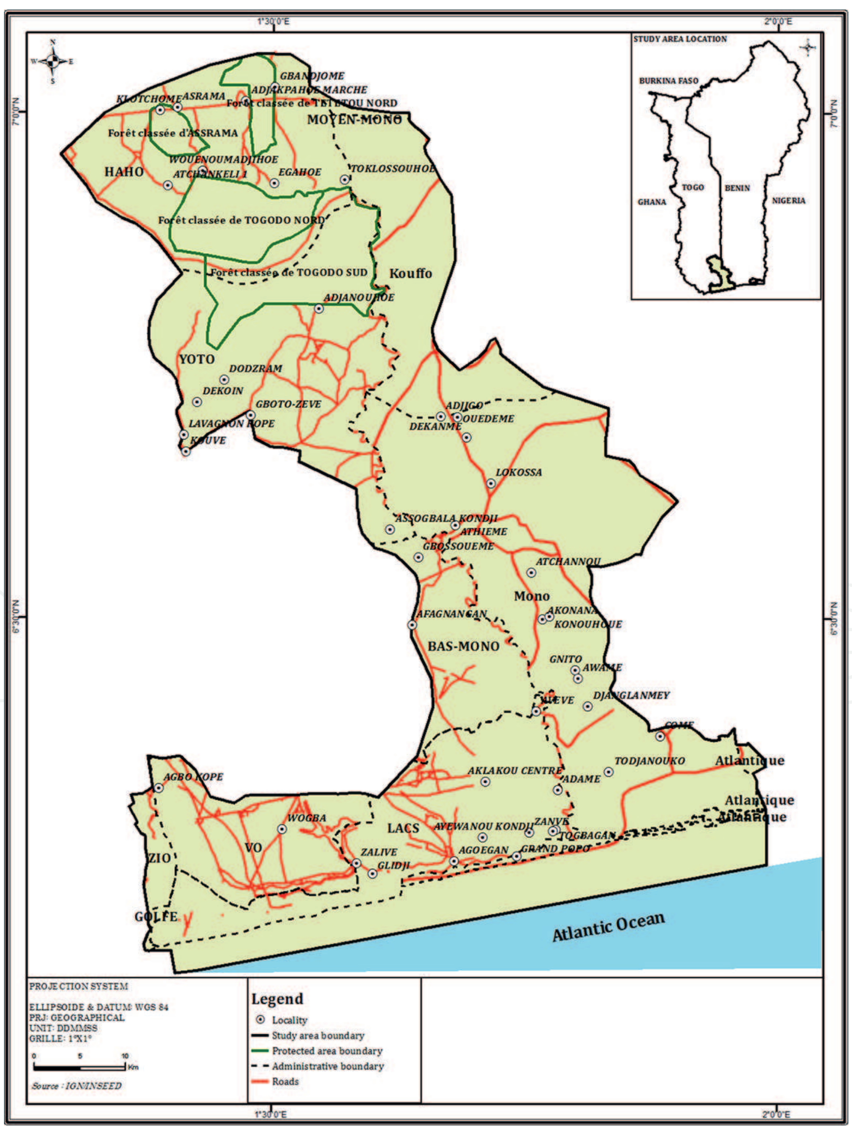

Figure 1.
Location of the Mono Transboundary Biosphere Reserve.

is 28° C between July and September. The area is home to different ecosystems (marine, terrestrial, and lagoon). The Mono River is the main river around which the reserve is built. Approximately two million people are riverine to the reserve, with 80% depending largely on the ecosystem services provided by the reserve (small-scale farming, small-scale fishing, and exploitation of wood and charcoal [22].

2.2 Land use land cover (LULC) maps

Two data sources were used to establish the baseline and the analysis of the LULC dynamics of the reserve. These include two Landsat satellite images (TM (1986) and ETM + (2000)) and a Sentinel 2A satellite image (2015 being the reference year). The scenes were chosen during the dry season with low cloud cover [23]. The interpretation was aided by additional data sources including the administrative maps of Benin and Togo, the GPS data from the field, and Google Earth Pro.

The radiometric correction of Landsat TM, ETM +, and Sentinel 2A images was used to correct for atmospheric bias and change from pixel value to digital count as a reflectance value. This operation is completed by mosaicking the two Sentinel 2A image scenes in order to obtain a single scene that can be used to extract easily the study area. The color composition of bands 4-5-7 of TM and ETM + images and bands 4-3-2 of Sentinel 2A image was chosen by selecting training sites because they present the best discrimination of LULC types [24]. About 100 plots representing all types of LULC chosen according to their spatial distribution on TM and ETM + color compositions of bands 4-5-7 and bands 4-3-2 of Sentinel 2A image were identified and delineated.

The spectral properties were used to classify the different LULCs of the image into thematic classes based on the supervised classification (due to a good knowledge of the study area) using the maximum-likelihood algorithm. The accuracy of the classifications was evaluated using a confusion matrix or contingency table obtained from field truth data and a representative of each LULC class. The validation of the classification was based on the calculation of two indices: the overall accuracy (the proportion of well-ranked pixels in percentage) and the Kappa index (the ratio between the well-ranked pixels and the total pixels surveyed) [25]. In addition, the field truth data were used for validation.

2.3 Land use/land cover dynamic analysis

Quantitative analysis of changes over the entire study period was carried out in order to identify the different changes in LULC classes based on change detection matrix resulting from the comparison between the pixels of the classifications of two dates [26]. This analysis was done by calculating the rate of change (Rc) used in LULC studies [27, 28] as follows:

$$Rc = \left[(\mathrm{S2} / \mathrm{S1}) 1 / \mathrm{d} - 1 \right] \times 100 \tag{1}$$

(where: Rc = rate of change (%); S1 = area of the LULC class of the date d1; S2 = area of the class of the date d2 (d2 > d1) et d = number of years between the two dates). Positive values indicate a “progression,” whereas negative values indicate a “regression.” Values close to zero indicate a relative “stability” of the class.

The average annual rate of forest degradation [29] was evaluated using the following formula:

$$ARD = (S2 / S1) / d \times 100 \tag{2}$$

(where ARD = average annual rate of degradation (%); S2 = Total area of forest lost; S1 = Initial area of forest and d = number of years between the two dates).

The transition matrix was elaborated by superposing the LULC maps of 1986, 2000, and 2015 with the "Intersect polygons" algorithm of the Geoprocessing extension using ArcGIS 10.0. The transition matrix was used to highlight the different changes in LULC between two dates [30]. The matrix values were standardized to obtain annualized changes and to make comparisons. To annualize the matrix values, each probability matrix was used separately to compute the matrix's eigenvectors and eigenvalues using the diagonalization method [31].

2.4 Futures scenarios

The standard annualized transition matrices were used to further predict the proportion of each land cover class at any one time based on a Markovian chain model. Two different scenarios were assumed corresponding to each of the two Markovian matrices (1986–2000 and 2000–2015). The area expected for 2015 scenarios based on the 1986–2000 period was compared with the area of 2015 from the 2015 map using a chi-square (χ^2) test for the model validation.

3. Results

3.1 Land cover maps

The results of the processing images of the year 2015 indicated an overall good accuracy (89.84%) and an estimated Kappa index of 0.88 with nine LULC units (**Table 1**; **Figure 2**) including forest, savannas, mosaic of crops and fallows, wetlands, plantations, urban agglomerations, and bare soil. Forests were composed of dense semi-deciduous forests, woodland, and gallery forests with an area of 15,740.91 ha

Land cover/land use classes		**Area (ha)**	**Percentage (%)**
Forests (dense, semi-deciduous, woodlands, and gallery forest)		15,740.91	4.55
Savannas on drained soil		88,917.48	25.71
Wetlands	Floodplain savannas of *Mitragyna inermis*	41,125.77	11.89
	Marshy meadows	15,092.73	4.36
	Mangroves	25,941.87	7.50
	Water body	41,979.51	12.14
Plantations		27,113.13	7.84
Mosaic of crops/fallows		80,599.05	23.31
Urban agglomeration/bare soil		9249.03	2.67

Table 1.
Land use land cover classes in the Mono Transboundary Biosphere Reserve in 2015.

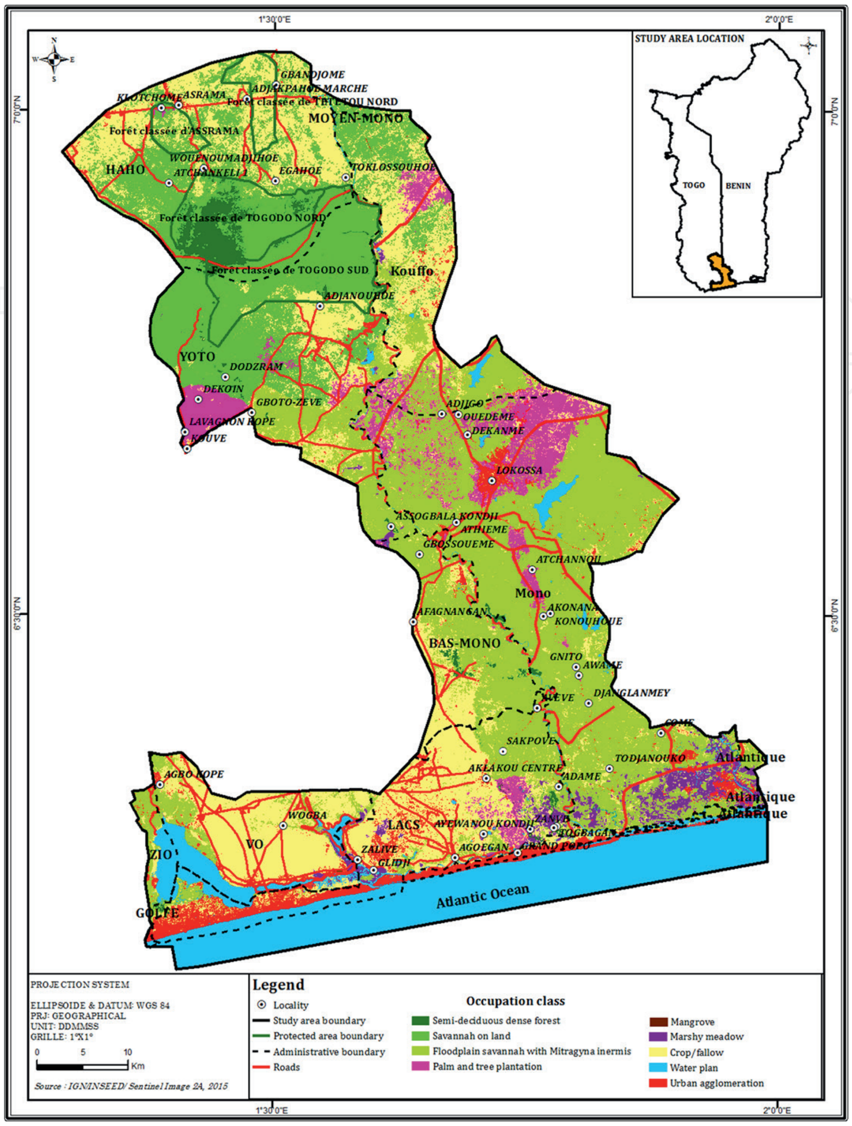

Figure 2.
Reference situation map of LULC in the Mono Transboundary Biosphere Reserve in 2015.

(4.55% of the reserve); these ecosystems were in the form of fragmented islands dispersed within the reserve.

Savannas on drained soil had an area of 88,917.48 ha (25.71% of the reserve), holding tree and shrub savannas. Wetlands covered an area of 124,139.88 ha (35.90% of the reserve) and included mangroves, floodplain savannas dominated by *Mitragyna inermis*, marshy meadows, and water. The majority of wetlands and their associated plant communities were mostly located in the southern half of the reserve. Within these wetlands, mangroves that constitute particular ecosystems occupied an area of 25,941.87 ha (7.50% of the reserve area).

Plantations with an area of 27,113.13 ha (7.84% of the reserve) were composed of *Tectona grandis, Khaya senegalensis, Eucalyptus* sp., *Elaeis guineensis,* and *Cocos nucifera*. Mosaic of crops and fallows with a total area of 80,599.05 ha (23.31% of the reserve) consisted of areas of crops and areas previously cultivated and abandoned (fallows) or invaded by exotic species.

Urban agglomerations and bare soil with an area of 9249.03 ha (2.67% of the reserve) included towns and villages and areas with very low vegetation cover, including quarries (sand and gravel) and rocky outcrops.

3.2 Changes in land use/land cover

The proportions of the nine LULC types changed considerably from 1986 to 2015 (**Table 2**). In 1986, floodplain savanna of *Mitragyna inermis*, savannas on drained soil and mosaic of crops, and fallows were the dominant land cover types (**Table 2**; **Figure 3**). In 2000, the land cover types were dominated by agglomeration and dry savannas, whereas in 2015, savannas on drained soil and farmland were the dominant land cover types. The cover of forests and floodplain savannas of *Mitragyna inermis* decreased in the periods 1986–2000, whereas other land uses increased except farmland, which remained stable. In the period 2000–2015, the cover of floodplain

Land cover class		Year 1986		Year 2000		Year 2015	
		Area (ha)	%	Area (ha)	%	Area (ha)	%
Forests		18,346.95	5.31	11,384.73	3.29	15,740.91	4.55
Savannas on drained soil		53,481.15	15.47	65,298.96	18.89	88,917.48	25.71
Mosaic of crops and fallows		55,029.69	15.91	51,973.65	15.03	80,599.05	23.31
Wetlands	Floodplain savannas of *Mitragyna inermis*	117,954.27	34.11	55,974.87	16.18	41,125.77	11.89
	Swamp grasslands/ Marshy meadows	18,021.51	5.21	23,800.05	6.88	15,092.73	4.36
	Mangroves	4721.4	1.36	6369.03	1.84	25,941.87	7.50
	Water body	40,721.04	11.77	41,912.37	12.12	41,979.51	12.14
Plantations		16,650.45	4.82	21,235.41	6.14	27,113.13	7.84
Urban agglomeration/bare soil		20,833.02	6.03	67,810.41	19.61	9249.03	2.67
Total		**345,759.48**	**100**	**345,759.48**	**100**	**345,759.48**	**100**

Table 2.
Land use/land cover classes used in the analysis of change (area in ha).

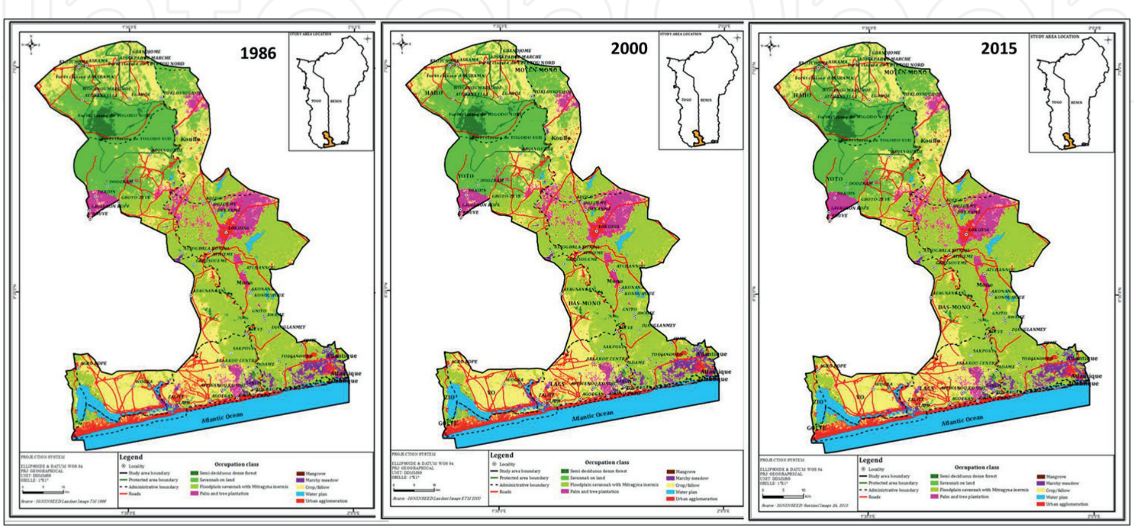

Figure 3.
Dynamic of land use/land cover in the Mono Transboundary Biosphere Reserve from 1986 to 2015.

savannas of *Mitragyna inermis*, swamp grassland/marshy meadow, and urban agglomeration/bare soil decreased, while the others increased except for water body that remained stable. In both periods, the cover of floodplain savannas of *Mitragyna inermis* decreased, while the cover of savannas on drained soil, mangroves, and plantations increased.

The transition matrices of the observed time periods 1986–2000 and 2000–2015 (**Table 3**) helped to derive the probability of change (**Table 4**). During the period 1986–2000, water body and savannas on drained soil showed large persistence (99.9% and 97.8% per year, respectively) as well as farmland and urban agglomeration/bare soil (96.5% and 96.0%, respectively) (**Table 3**). The forest cover converted to mangroves (0.1%), floodplain savannas of *Mitragyna inermis* (1.4%), savanna on drained soil (1.2%), swamp grassland (0.3%), plantations (0.6%), farmland (0.7%), and urban agglomeration/bare soil (1.1%). The floodplain savannas of *Mitragyna inermis* mainly regressed into savannas on drained soil (0.5%), swamp grassland (0.6%), plantations (0.6%), farmland (0.5%), urban agglomeration/bare soil (2%), and water body (0.1%). However, it progressed in forests (0.3%) and mangroves (0.2). The mangroves also regressed into floodplain savannas of *Mitragyna inermis* (1.8%), savannas on drained soil (0.3%), swamp grassland (1.8%), plantations (0.5%), farmland (0.1%), and urban agglomeration/bare soil (0.6%). However, it progressed into forest (0.9%).

In the period 2000–2015, water body had a large annual persistence (99.8%) followed by farmland (97.9%). Forest cover was regressed into mangroves (0.6%), savanna on drained soil (2.2%), floodplain savannas of *Mitragyna inermis* (1.1%), swamp grassland (0.2%), plantations (0.5%), and farmland (0.3%). Floodplain savannas of *Mitragyna inermis* were mainly regressed in savannas on drained soil (2.5%), swamp grassland (0.1%), plantations (1.7%), farmland (0.7%), and water (0.1%). However, it progressed into mangroves (0.4%) and forests (0.3%). Mangroves were regressed into savannas on drained soil (2.1%), floodplain savannas of *Mitragyna inermis* (1.5%), swamp grassland (0.2%), plantations (0.4%), farmland (1%), and urban and agglomeration/bare soil (0.2%). However, it progressed into forests (0.3%).

3.3 Land use/land cover degradation or conservation rates

During the first period, 1986–2000, the highest rate of degradation (**Table 5**) was observed for floodplain savannas of Mitragyna inermis (61,979.4 ha lost) and forests (6962.22 ha). The other LULC had increased with the highest increase for urban agglomeration/bare soil (46,977.39 ha). In the second period, 2000–2015, urban agglomeration/bare soil had a high annual rate of degradation (58,561.38 ha) in addition to floodplain savannas of Mitragyna inermis (14,849.10 ha). The other LULC had increased with the highest increase for mangroves (19,572.84 ha).

3.4 Future LULC changes forecasting

Future land cover changes will depend upon the previously observed dynamics for the time period considered (1986–2000 and 2000–2015). Based on the observed dynamics in the first period (1986–2000), the area of forest and floodplain savannas of *Mitragyna inermis* is expected to decrease by 3.5% and 25.5% of the area recorded in 1986 by 2070 (**Figure 4**). The area of savannas on drained soil, mosaic of crops and fallows, swamp grasslands, mangroves, water, and urban agglomeration/bare soil will increase respectively by 8.4%, 3%, 1.3%, 0.1%, 2.4%, and 13.8% of the areas recorded in 1986 by 2070.

	Forest	Savannas on drained sol	Floodplain savannas of Mitragyna inermis	Swamp grasslands	Mangroves	Plantations	Water	Mosaic of crops and fallows	Urban agglomeration/bare soil
1986–2000									
Forests	4351.41	3099.33	3680.46	809.01	375.3	1450.08	67.86	1767.69	2745.81
Savannas on drained sol	762.21	37075.95	1384.11	3370.32	320.04	516.87	0.45	4108.59	5942.61
Floodplain savannas of *Mitragyna inermis*	4416.21	9052.02	39273.93	10028.07	3205.62	9458.55	979.38	7802.28	33738.21
Swamp grasslands	378.18	5544.54	1464.66	6321.15	503.37	358.92	301.41	908.1	2241.18
Mangroves	598.95	210.42	1201.86	1179.54	656.64	339.48	24.57	95.76	414.18
Plantations	463.14	1132.29	4792.41	16.29	230.85	4801.14	4.14	3307.32	1902.87
Water body	1.53	8.64	305.64	36.27	5.94	0.09	40121.64	2.07	239.22
Mosaic of crops and fallows	293.13	7333.92	2790.45	851.49	643.14	3431.34	11.25	28390.32	11284.65
Urban agglomeration/bare soil	119.97	1841.85	1081.35	1187.91	428.13	878.94	401.67	5591.52	9301.68
2000–2015									
Forests	3131.01	3686.13	1799.28	393.84	1074.42	769.5	17.73	457.02	55.8
Savannas on drained sol	2940.39	20812.59	11491.65	9608.04	8335.53	584.37	47.79	10969.29	509.31
Floodplain savannas of *Mitragyna inermis*	3745.8	21,321	5903.19	1210.68	3187.17	14104.17	668.61	5465.16	369.09
Swamp grasslands	775.71	6690.06	7322.22	2486.88	3788.37	46.71	165.96	1989	535.14
Mangrove	300.96	2027.07	1457.01	162.18	886.14	403.29	27	928.62	176.76

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	Forest	Savannas on drained sol	Floodplain savannas of Mitragyna inermis	Swamp grasslands	Mangroves	Plantations	Water	Mosaic of crops and fallows	Urban agglomeration/bare soil
Plantations	543.69	6010.11	1240.92	31.23	671.22	5567.94	3.06	6847.74	319.5
Water body	83.16	174.69	457.47	248.13	288.99	6.93	40447.8	25.11	180.09
Mosaic of crops and fallows	228.15	7298.28	3402.9	256.68	2795.13	1197.63	20.07	35503.2	1271.61
Urban agglomeration/bare soil	3992.04	20897.55	8051.13	695.07	4914.9	4432.59	581.49	18413.91	5831.73

Table 3.
Land use/land cover transition matrix (area in ha) for the considered time period (1986–2000–2015).

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	Forests	**Savannas on drained sol**	**Floodplain savannas of Mitragyna inermis**	**Swamp grasslands**	**Mangroves**	**Plantations**	**Water body**	**Mosaic of crops and fallows**	**Urban agglomeration/bare soil**
1986–2000									
Forests	0.946	0.012	0.014	0.003	0.001	0.006	0.000	0.007	0.011
Savannas on drained sol	0.001	0.978	0.002	0.005	0.000	0.001	0.000	0.005	0.008
Floodplain savannas of *Mitragyna inermis*	0.003	0.005	0.952	0.006	0.002	0.006	0.001	0.005	0.020
Swamp grasslands	0.001	0.022	0.006	0.954	0.002	0.001	0.001	0.004	0.009
Mangroves	0.009	0.003	0.018	0.018	0.939	0.005	0.000	0.001	0.006
Plantations	0.002	0.005	0.021	0.000	0.001	0.949	0.000	0.014	0.008
Water body	0.000	0.000	0.001	0.000	0.000	0.000	0.999	0.000	0.000
Mosaic of crops and fallows	0.000	0.010	0.004	0.001	0.001	0.004	0.000	0.965	0.015
Urban agglomeration/bare soil	0.000	0.006	0.004	0.004	0.001	0.003	0.001	0.019	0.960
2000–2015									
Forests	0.952	0.022	0.011	0.002	0.006	0.005	0.000	0.003	0.000
Savannas on drained soil	0.003	0.955	0.012	0.010	0.009	0.001	0.000	0.011	0.001
Floodplain savannas of *Mitragyna inermis*	0.004	0.025	0.940	0.001	0.004	0.017	0.001	0.007	0.000
Swamp grasslands	0.002	0.019	0.021	0.940	0.011	0.000	0.000	0.006	0.001
Mangroves	0.003	0.021	0.015	0.002	0.943	0.004	0.000	0.010	0.002
Plantations	0.002	0.019	0.004	0.000	0.002	0.951	0.000	0.021	0.001
Water body	0.000	0.000	0.001	0.000	0.000	0.000	0.998	0.000	0.000

	Forests	Savannas on drained sol	Floodplain savannas of Mitragyna inermis	Swamp grasslands	Mangroves	Plantations	Water body	Mosaic of crops and fallows	Urban agglomeration/bare soil
Mosaic of crops and fallows	0.000	0.009	0.004	0.000	0.004	0.002	0.000	0.979	0.002
Urban agglomeration/ bare soil	0.004	0.021	0.008	0.001	0.005	0.004	0.001	0.018	0.939

Table 4.
Annual probability matrices for the considered time period (1986–2000–2015).

Land cover class	1986–2000	2000–2015
Forests	3.35	−2.18
Savannas on drained soil	−1.44	−2.08
Mosaic of crops and fallows	0.41	−2.96
Floodplain savannas of *Mitragyna inermis*	5.18	2.03
Swamp grasslands	−2.01	2.99
Mangroves	−2.16	−9.81
Water	−0.21	−0.02
Plantations	−1.75	−1.64
Urban agglomeration/bare soil	−8.79	12.43

Table 5.
Annual rate of degradation and conservation of land use/land cover (% lost ha/year).

Assuming the dynamics recorded in the second period (2000–2015), the area of land covered by floodplain savannas of *Mitragyna inermis*, swamp grassland, water, and urban agglomeration/bare soil will decrease by 4.3%, 2.1%, 0.5%, and 17.8% considering their cover in 2000, respectively, while the areas covered by forests, savannas on drained soil, mosaic of crops and fallows, mangroves, and plantations will increase by 0.6%, 4.8%, 13%, 6%, and 0.4% of their cover in 2000, respectively.

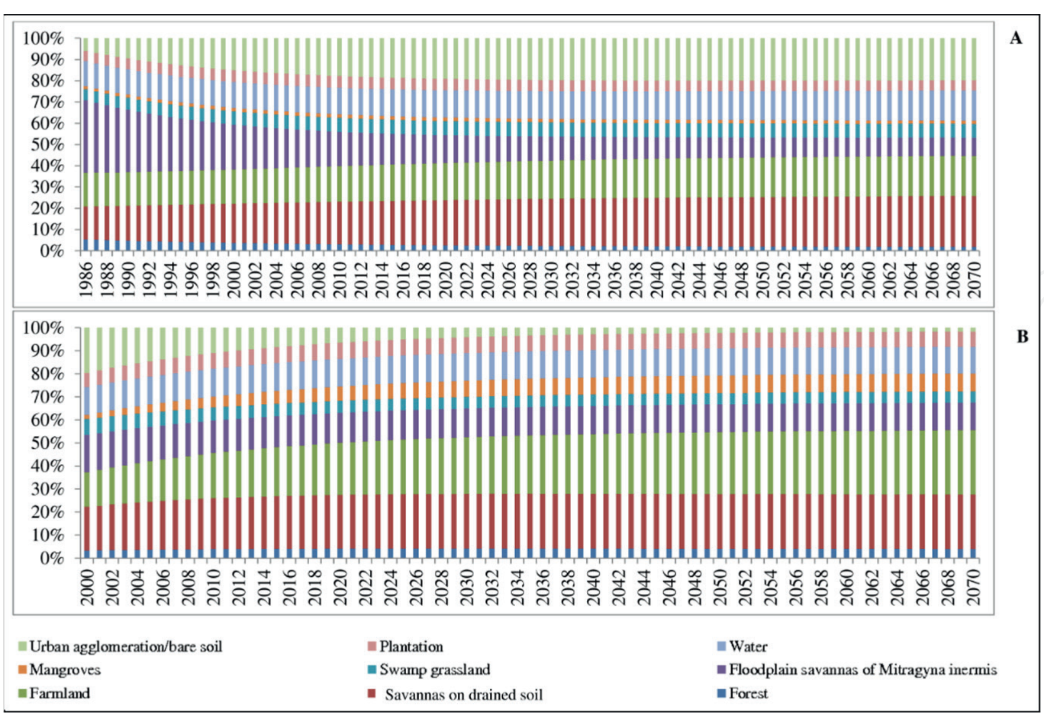

Figure 4.
Simulation of the evolution of the nine land cover classes under two future scenarios (dynamics observed during the periods 1986–2000 and 2000–2015).

4. Discussion

Main findings from this study were that natural vegetation (closed forest formation, mangrove forest, flooded savanna of Mitragyna, savannas on drained soil, swamp grassland) converted into agricultural and nonvegetated areas (mosaic of crops and fallows, urban agglomeration/bare soil, and plantations). These changes in LULC confirmed the dynamic of Mono Transboundary Biosphere Reserve [11, 32, 33].

The Mono Transboundary Biosphere Reserve (MTBR) holds an important wetland protected by the Ramsar convention. Before the year 2000, only natural vegetation (forest and floodplain savannas of *Mitragyna inermis*) was observed to be degraded, while after the year 2000, urban agglomeration/bare soil was mainly degraded, when important reconstitution was observed for natural vegetation (forests, savannas on drained soil, and mangroves). The year 2000 was marked by the ratification of the Ramsar convention by Benin. In the case of Togo, the Ramsar convention was ratified since 1995. Prior to this period, there was no restriction on the use of the reserve resources that were subject to important overexploitation, as confirmed by the exceptional increase of urban agglomeration/bare soil in the period 1986–2000. Later in 2000, several project activities followed the ratification of the Ramsar convention that contributed to the restoration of the natural vegetation, mainly the mangroves.

The MTBR is the only place in Dahomey Gap where mangroves remain natural. The mangroves provided ecosystem services including support for aquaculture and fishery activities, salt extraction, fuelwood, and agriculture [34–36]. Mangroves also provide ecological, socioeconomic, and climate regulation roles [37–39]. Thus, human beings remain the main beneficiaries in terms of self-consumption and the improvement of their income. The multiple ecosystem goods and services provided by the mangroves are among the main reason for the designation of the MTBR in 2017. This reserve is sustaining the conservation of mangroves as its cover had significantly increased in the period 2000–2015.

The future scenarios predict an important loss of natural vegetation (forests and floodplain savannas of *Mitragyna inermis*) and a significant increase in urban agglomeration/bare soil, assuming the dynamic recorded in the first period (1986–2000). In the second period, natural vegetation, mainly mangroves, will increase, while important loss will be observed for urban agglomeration/bare soil. Based on the progress observed after the year 2000 in the restoration of the natural vegetation, it is hopefully expected that the dynamic observed in the period 2000–2015 will prevail in the future. Moreover, the recent designation of MTBR as UNESCO biodiversity reserve confirms the need to sustain the conservation of this important biodiversity.

More actions including awareness-raising and sustainable management are needed to reduce the cover of farmland that will progress by 2070, assuming the dynamic of the period 2000–2015. The management of the reserve must be participatory based on gender approach in order to prevent the population from illegally re-introduction in the reserve. The successful management of the reserve also requires local interventions coordinated across ecologically appropriate spatial scales, and best guided by frequent and synoptic sampling and monitoring through the results of multidisciplinary research [40, 41].

The Markovian model used to predict the dynamic of LULC is useful for exploratory analysis and for depicting contrasting scenarios [41]. The model is not spatially explicit and assumes homogeneity of the transition probabilities over time

[41, 42]. Thus, spatially explicit model should be used in future on changes in LULC analysis to understand the LULC dynamics locations and pathways in the MTBR. Future similar studies should take into account the limits observed in the model used in this study.

5. Conclusion

The Mono Transboundary Biosphere Reserve (MTBR) has contributed to the restoration of natural vegetation since the year 2000, that is, characterized by the ratification of Ramsar convention by Benin and Togo with the aims of the conservation and sustainable use of wetlands. The current study was designed to assess LULC dynamics from 1986 to 2015 and to predict future scenarios in the Mono Transboundary Biosphere Reserve (MTBR). The analysis of the dynamics of change in LULC revealed the different processes of evolution within the landscape during the period 1986–2015. These changes mainly concern the regression of natural ecosystems such as forests and wooded savannas, whereas low-cover land occupancies (mosaics of crops/fallows and urban agglomerations/bare soil) have been gradually increasing.

Despite the changes and conversions observed during the period of this study (1986 to 2015), the area remained largely covered by natural vegetation and still has good potential for biodiversity conservation. The MTBR is the only place in Dahomey Gap where mangroves remain natural. These mangroves provided ecosystem services including support for aquaculture and fishery activities, salt extraction, fuelwood, and agriculture. These mangrove ecosystems also provide ecological, socioeconomic, and climate regulation roles, and the multiple ecosystem goods and services provided by the mangroves are among the main reason for the designation of the MTBR in 2017.

The simulation of future land use dynamics in this study is part of the need to understand the functioning of LULC in the area of the reserve. Based on the observed dynamics in the first period (1986–2000), the area of forest and floodplain savannas of *Mitragyna inermis* is expected to decrease by 3.5% and 25.5% of the area recorded in 1986 by 2070. The area of savannas on drained soil, mosaic of crops and fallows, swamp grasslands, mangroves, water, and urban agglomeration/bare soil will increase, respectively, by 8.4%, 3%, 1.3%, 0.1%, 2.4%, and 13.8% of the areas recorded in 1986 by 2070.

The future scenario predicts the conservation of the natural vegetation mainly mangroves assuming the dynamic recorded in the period 2000–2015. By describing the possible evolutions of the LULC on the basis of prospective scenarios, it becomes possible to initiate a reflection on possible adaptation strategies to adjust natural and human systems to a new environment. It is very important to strengthen the conservation of the reserve with activities that support the Ramsar convention on wetlands and monitor the implementation of the management plan of the reserve in order to reduce the cover of farmlands that are expected to increase by 2070. Thus, the MTBR will be the potentially good for the conservation of biodiversity for the future generation. Thus, more actions including awareness-raising and sustainable management are needed to reduce the cover of farmland that will progress by 2070, assuming the dynamic of the period 2000–2015. The management of the reserve must be participatory and based on a gender approach in order to prevent the population from illegally re-introduction in the reserve.

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Conflict of interest

The authors declare no conflicts of interest.

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