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MAPPING THE LAND COVER DYNAMICS OF THE MOANDA MANGROVE MARINE PARK IN CENTRAL KONGO PROVINCE, DRC FROM 2002 TO 2020

Cartografía de la dinámica del cubierta terrestre del Parque Marino de los Manglares de Moanda, en la provincia de Kongo Central (RDC), de 2002 a 2020

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ABSTRACT: The mangrove land cover is undergoing unprecedented anthropization. The main objective of this study is to map and quantify the dynamics of land cover in the Moanda Mangrove Marine Park between 2002 and 2020. Specifically, it aims to: (i) assess the annual rate of change in the mangrove land cover; (ii) estimate the influence of wood energy on the decline in mangrove forest area; and (iii) propose measures for the sustainable management of the

Mangrove Marine Park forest. The study method is a combination of field survey, diachronic analysis of Landsat images and statistical analysis. The very good correspondence between the classification results and field reality was justified by the Kappa value (0.81) and overall accuracy (82.4 %). The diachronic analysis of satellite images showed the regression of areas covered by forest classes in favor of the anthropogenic activities, herbaceous mangroves and the savannah. The annual deforestation rate in the Moanda Mangrove Marine Park is estimated at around 0.07 %. The result points to the heavy dependence of coastal households in Moanda on fishing (31 %), agriculture (26 %) and charcoal production (22 %), all of which put pressure on the natural resources of the Mangrove Marine Park. Promoting an integrated approach and techniques for the sustainable use of natural resources is an effective way of combating deforestation in the Moanda Mangrove Marine Park.

KEYWORDS: Classification; forest; deforestation; image; change.

RESUMEN: La cubierta terrestre de los manglares está sufriendo una antropización sin precedentes. El principal objetivo de este estudio es cartografiar y cuantificar la dinámica de la cubierta en el Parque Marino de Manglares de Moanda entre 2002 y 2020. En concreto, se pretende: (i) evaluar la tasa anual de cambio de la cubierta terrestre de los manglares; (ii) estimar la influencia de la madera energética en la disminución de la superficie del bosque de manglares; y (iii) proponer una serie de medidas encaminadas a la gestión sostenible del bosque del Parque Marino de Manglares. El método de estudio es una combinación de encuesta sobre el terreno, análisis diacrónico de imágenes Landsat y análisis estadístico. El valor Kappa (0,81) y la precisión global (82,4 %) justifican la muy buena adecuación entre los resultados de la clasificación y la realidad sobre el terreno. El análisis diacrónico de las imágenes de satélite mostró una disminución de la superficie cubierta por las clases forestales a favor de las actividades antropogénica, los manglares herbáceos y la sabana. La tasa de deforestación anual en el Parque Marino de Manglares de Moanda se estima en torno al 0,07 %. Los resultados muestran que los hogares costeros de Moanda dependen en gran medida de la pesca (31 %), la agricultura (26 %) y la producción de carbón vegetal (22 %), todo lo cual ejerce presión sobre los recursos naturales del Parque Marino de Manglares de Moanda. Promover un enfoque integrado y técnicas para el uso sostenible de los recursos naturales es una forma eficaz de luchar contra la deforestación en el Parque Marino de Manglares de Moanda

PALABRAS CLAVE: Clasificación; bosque; deforestación; imagen; cambio.

1. Introduction

Mangroves are forests that grow in the tidal area of intertropical regions. They are an association of halophytic woody species, generally dominated by mangroves, which are more resistant to salinity and can live on anaerobic soils characterized by maximum humidity (Folega *et al*., 2017). Mangroves are found along shorelines, estuaries, and deltas (White & Edwards, 2001). Mangroves play crucial biological, ecological and social roles for the benefit of humanity. Proisy (1999) found that mangroves produce an estimated 10 tons per hectare per year of excess dry plant matter.

Mangrove forests form an important barrier against natural disasters. They protect surrounding populations from damage caused by cyclones, hurricanes, and tsunamis (Murdiyarso *et al*., 2015; Nfotabong, 2011). Mangroves limit coastal erosion and help land advance towards the ocean, while providing a buffer area in regions prone to storms and cyclones (Hervieu, 1969). Mangroves play an important role in controlling water pollution. The tangled roots of mangroves help filter estuarine water, trapping coarse debris and sediments (Folega *et al*., 2017; Fromard, 2002).

Like all forest ecosystems, mangroves sequester atmospheric CO_2 and thus help reduce global warming. They are an ecosystem of great importance in the global carbon cycle, due to their high productivity, global distribution, and position at the interface between land and ocean. Mangroves have a dual role as a sink for atmospheric CO_2 and as a source of organic and inorganic carbon for coastal zones (Sharma *et al*., 2020; Ajonina, 2013; Nfotabong, 2011). Mangroves play a significant role in climate stability: according to recent estimates, around 11% of the total mass of organic carbon at the land-ocean interface is stored by mangroves (Nfotabong, 2011).

Mangrove forests are home to a variety of vertebrates (monkeys, snakes, birds, etc.) and invertebrates (crabs, gastropods, insects, etc.). Mangroves are an important habitat for maintaining aquatic biodiversity; they are the breeding, spawning, egg-hatching, and nursery grounds for young fish and crustaceans. (Folega *et al*., 2017). On the one hand, these intertidal forests are a potential recreational environment for the development of ecotourism activities. On the other hand, they constitute a reserve of goods and services for the population living in and around them (Cormier-Sale, 1994).

However, recent studies on mangrove dynamics point to an increasing regression in the areas occupied by woody mangrove vegetation due to anthropogenic pressure: urbanization, energy wood extraction, land conversion for aquaculture and agriculture, dyke construction, etc. (Marjolaine *et al*., 2022; Bhomia *et al*., 2016; Webber *et al*., 2016; Mpoyi *et al*., 2013; Cormier-Sale, 1994).

Most coastal villagers (81 %) use resources from mangroves. The main driver of mangrove deforestation is timber extraction (32 %). Mangrove wood is mainly used to fuel woodburning ovens for cooking. In fact, it is the most widely used fuel (Folega *et al*., 2017; Schure *et al*., 2012; Trefon *et al*., 2010; CIFOR *et al*., 2007; MECNT, 2012 Rajoharison, 1990; MAFET, 2002). However, a tone of wood contains 500 kg of carbon, so 365 kg of carbon are released into the atmosphere after each carbonization of a tone of wood, with a low-performance technique. Conversely, with an improved carbonization technique, these emissions can be reduced to 275 kg (Trefon *et al*., 2010; Mangion, 2010).

The rate of mangrove area loss in Africa is estimated at around 13.8 % (Polidoro *et al*., 2010). The same authors (Polidoro *et al*., 2010) report that 16% of species exclusive to mangroves are at high risk of extinction. The destruction of these forests not only leads to changes in their structure, but also to the loss of ecological, biological and economic functions (Folega *et al*., 2017). Population growth in rural areas plays an important role in the loss of forest cover (Tungi-Tungi *et al*., 2022; Tungi-Tungi *et al*., 2021; Defourny and Kibambe, 2012; Defourny *et al*., 2011).

The immediate consequence of mangrove overexploitation is highlighted in several studies addressing the loss of the original mangrove area (Marjolaine *et al*., 2022; Sharma *et al*., 2020; Bahamondez and Thompson, 2016; Roche and Van Cu, 2015). Rajoharison (1990) points out that the disappearance of mangrove plant cover exposes the area to various natural disasters such as coastal erosion, flooding and the multiplication of flash and flash floods; this is the case of the river disasters that caused the gradual accumulation of alluvial deposits in lagoons, mangroves and coral reefs as a whole in the 1990s in Madagascar (Guillet *et al*., 2008).

In addition to human activities, natural factors also contribute to mangrove disturbance, such as successive deposits of sand on ocean shores, which cover the lenticels of *Avicennia* pneumatophores, leading to the physiological death of mangroves; violent waves, which cause mangroves to fall, etc. However, they are less disruptive to those coastal ecosystems than manmade cuttings. And they are less disruptive to coastal ecosystems than man-made logging (Nfotabong, 2011; Rajoharison, 1990).

The Moanda Mangrove Marine Park in the Democratic Republic of the Congo (DRC) is no exception to the degradation and deforestation that mangroves are experiencing worldwide. Despite its status as a protected area, farmers are clearing fields and cutting mangroves for carbonization. Indeed, the absence of a permanent culinary energy source other than wood is one of the causes of the use of mangrove wood as an energy source by coastal households (MECNEF, 2007). OSFAC (2014) estimated the annual deforestation rate of this Mangrove Marine Park at 0.04% for the period 2000-2010. This situation is becoming problematic due to the lack of incentives to restore the natural landscape of this Mangrove Marine Park.

The aim of this study is to map and quantify the dynamics of land cover in the Moanda Mangrove Marine Park between 2002 and 2020; in particular: (i) to assess the annual rate of change in the mangrove land cover; (ii) to estimate the influence of wood energy on the decline in mangrove forest area; and (iii) to propose a number of measures for the sustainable management of the park's wood resources.

2. Material and method

2.1. Study area

This research is being carried out in the Moanda Mangrove Marine Park in DRC. The park is located in the extreme south-west of the DRC, just at the Congo River mouth, in the Mer sector, Moanda territory in the province of Central Kongo.

The Moanda Mangrove Marine Park is covered by a vast vegetation characterized by savannah, degraded forest land, high or old mangrove dominated by the species *Rhizophora racemos* and *Rhizophora mangle,* low or young mangrove dominated by the species *Avicenia germinans*, and herbaceous mangrove. Mangrove vegetation covers the banks of the Congo River (Figure 2). The mangroves of Moanda are declared a protected area under ministerial decree n°044/CM/ECN/92 of 02.V.1992, known as Nature Reserve or Mangrove Marine Park (MECN, 1992). This Marine Park covers an administrative area of 76,000 ha, of which the Atlantic Ocean occupies around 20% (MECNT and WRI, 2009).

Moanda's soil is of the Guinean-Congolese type, specifically sandy-clay, which is favorable for growing cassava, groundnuts, and perennial crops. Its northwestern part is dominated by a vast swampy area, suitable for lowland crops (Moanda Territory Office, 2015).

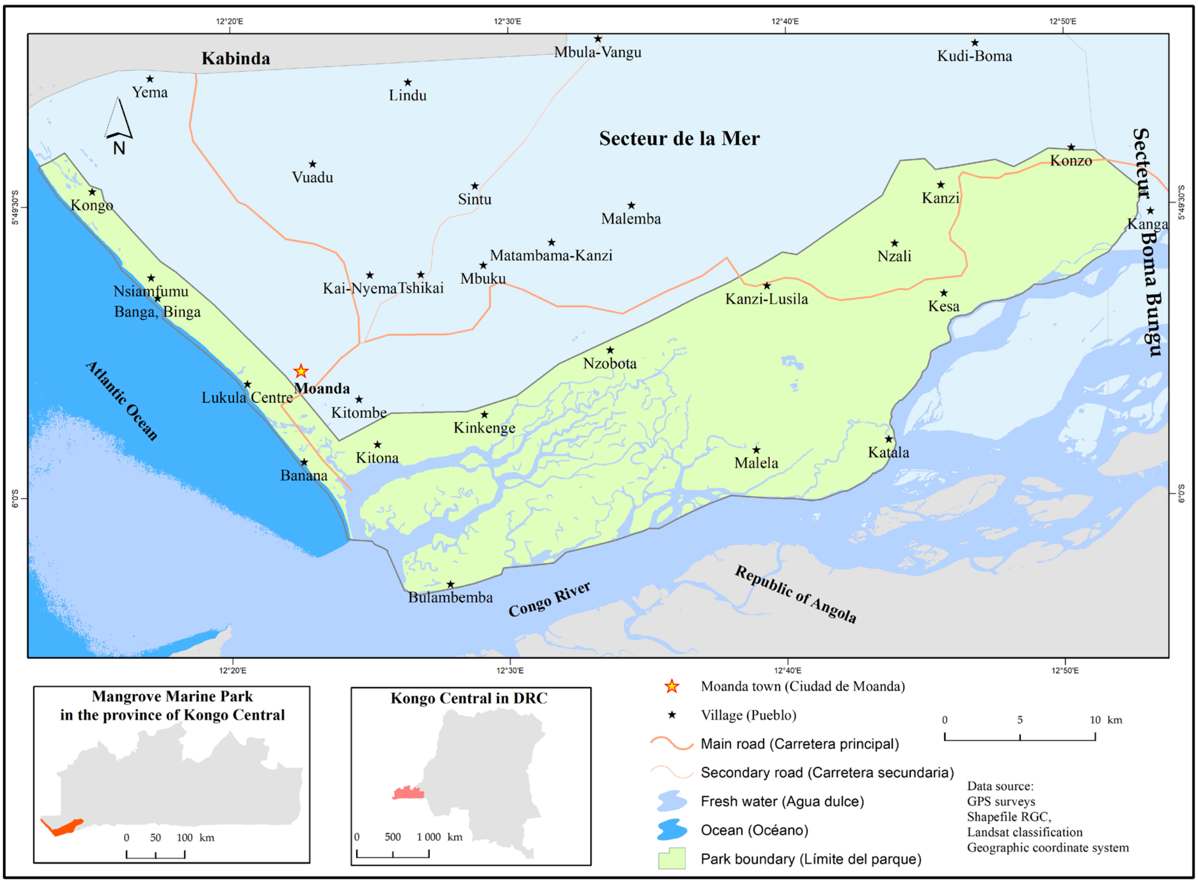

Figure 1. Location of the Moanda Mangroves Marine Park.
Figura 1. Ubicación del Parque Marino de Manglares de Moanda.

Nearly 45 villages are settled in or close to Mangrove Marine Park, depending largely on the resources of the said park (Moanda Territory Office, 2015). Most of the population of these villages lives mainly from slash-and-burn agriculture, artisanal fishing, small livestock and poultry rearing, as well as partially from small game hunting. Moanda is home to two oil companies. These are the French company PERENCO-REP for oil exploration and exploitation both offshore and onshore, and the Congolese company for refining industries (COCIR) (ULB-coopération, 2021; Vambi *et al.*, 2018; Moanda Territory Office, 2015).

2.2. Methods

2.2.1. Data

Field data were collected in two ways: (1) in the form of geospatial data, using a Global Positioning System (GPS) receiver, (2) in the form of socio-economic survey data, using a pre-established questionnaire validated by the research team. Through this questionnaire, the rural population was interviewed about their various activities having a positive or negative impact on the forest cover of the Mangrove Marine Park. The survey was carried out in 22 villages in and around the Moanda Mangrove Marine Park. Nearly 250 rural households were surveyed, with ±11 households per locality.

To complete the data, we used raster data. This included Landsat 7 satellite imagery acquired on April 08, 2002, and Landsat 8 on May 3, 2020, and forest cover evolution data from intervening years acquired on the Global Forest Watch (GFW) platform. The GFW dataset has a spatial resolution of 30 m (Hansen *et al.,* 2013).

Satellite data underwent radiometric correction to eliminate contamination introduced by the atmosphere. To improve localization accuracy, geometric correction involving esampling and ortho-rectification was applied. These images were then normalized to take account of the effect of anisotropy, to reduce highlighting in the east of the image compared with the west.

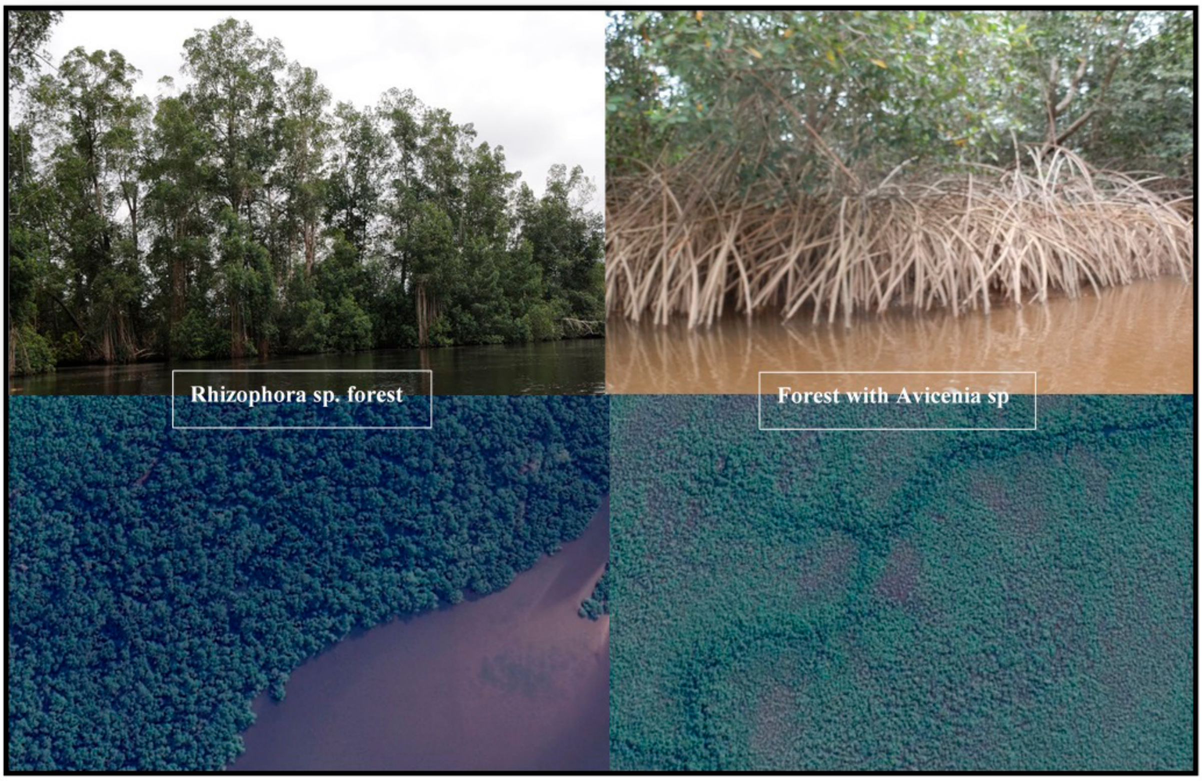

Figure 2. Landscape of the Moanda mangroves seen on satellite image and on the ground.
Figura 2. Paisaje de los manglares de Moanda visto en imagen satelital y en el terreno.

Data relating to the road network, hydrographic network and administrative boundaries were downloaded from various databases (RGC, WRI and OSM RDC). Given the size of the study area and the inaccessibility of certain zones, the geolocalized data collected in the field were completed using Google Earth, to validate the results of the land cover classification carried out using satellite images.

2.2.2. Data Geospatial data processing and analysis

Land cover classes in the Moanda Mangrove Marine Park were discriminated using supervised classification of Landsat satellite images (Kharki *et al*., 2021; Pony *et al*., 2000). Supervised classification requires a priori knowledge of the area under study, to create training area. This classification was carried out using the Maximum Likelihood algorithm in ENVI 5.0 software. This algorithm classifies pixels using a probabilistic approach. For each pixel in the image, it calculates the probability of being assigned to each class. These calculations are based on the mean of the training area, the spectral signature of the pixel and the standard error margin of the covariance matrix of the pixels in the training area. The pixel is then assigned to the class with the highest probability (Kharki *et al*., 2021; Pony *et al*., 2000).

Land cover classes were separated and then cross-referenced to discriminate forest evolution in the Moanda Mangrove Marine Park. Deforestation in the Moanda Mangrove Marine Park was monitored for the intervening years (between 2002 and 2020) using Global Forest Change data.

2.2.3. Evaluation of classification results

The concordance between ground reality and the land cover classes produced from satellite image classification was assessed using the confusion matrix (Tungi tungi *et al*, 2021). The confusion matrix is a contingency table that compares the results of interpretation with field data recognized as “the truth”, after which accuracy indicators are produced.

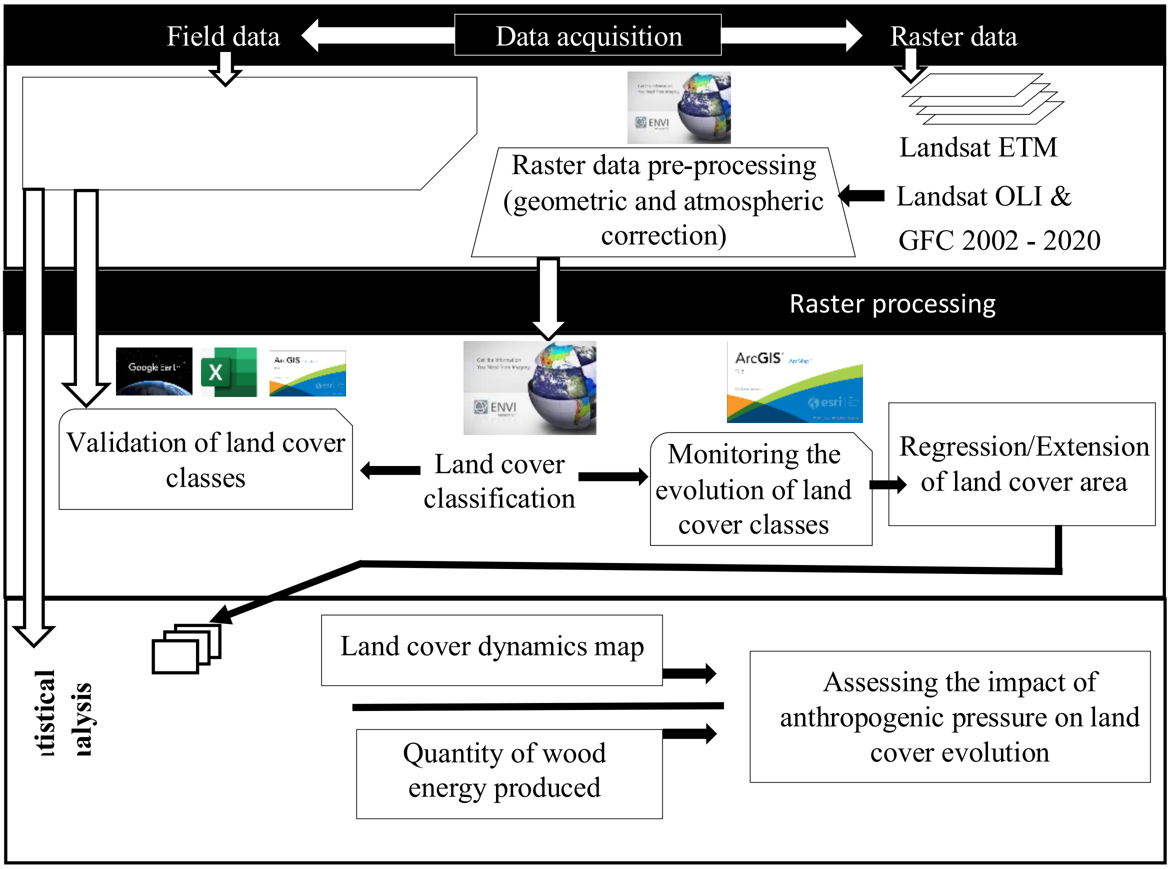

Figure 3. Illustrative diagram of the method used.
Figura 3. Diagrama ilustrativo del método utilizado.

2.2.3. Statistical analysis

Statistical analyses of land cover data and survey data were carried out based on the following formulas:

$$\bar{x} = \frac{\sum f_i M_i}{n} \; ; \; \sigma^2 = \frac{\sum fi(Mi - \bar{x})^2}{n-1} \; ; \; \sigma = \sqrt{s^2}$$

Where σ^2: variance; Mi: middle of class; $\bar{x}$: mean of observations; fi: frequency of observations; $\sum$: sum ; σ: standard deviation; n: sample size

Bernier's formula (1992) was used to highlight the rate of annual change in land cover classes:

$$T = \frac{(lnS2 - lnS1)}{(t \times lne)} \times 100$$

T: Annual rate of spatial expansion in %;
ln: Neperian logarithm;
e: The base of the neperian logarithm (e = 2.71828);
S1: Area of first-year land cover;
S2: Area of recent year's land cover;
t: Number of years in the period concerned.

Survey data were analyzed using Epidata and SPSS 28.0.1 statistical software and Microsoft Excel.

3. Results

3.1. Riparian forest characteristics: tree species, sizes, and ages

In the initial year (2002), the landscape of the Moanda Mangrove Marine Park was mainly savannah (25%), *Rhizophora* sp. forest (17.5%), young secondary forest (15.6%), *Avicenia* sp. forest (11.8%) and water (11%). Anthropogenic area (8.7%), herbaceous mangroves (7.4%) and mature secondary forest (2.6%) occupied very small areas. In 2002, this landscape was less disturbed, but over the years it has undergone significant changes, generally of anthropogenic origin (Table 1 and Figure 4).

Table 1. Land cover statistics of the Mangrove Marine Park from 2002 to 2020.
Tabla 1. Estadísticas de la cobertura del suelo del Parque Marino de Manglares desde 2002 hasta 2020.

Land use	Area (ha)			
	Year 2002	**%**	**Year 2020**	**%**
Rhizophora sp. Forest	12633.48	17.51	12458.97	17.26
Forest with *Avicenia* sp.	8559.36	11.86	8478.27	11.75
Herbaceous mangroves	5352.57	7.42	5617.98	7.78
Mature secondary forest	1895.58	2.63	1506.96	2.09
Young secondary forest	11311.92	15.68	9968.85	13.81
Savannah	18145,8	25.15	18542.43	25.69
Anthropogenic zone	6290.91	8.72	7616.16	10.55
Water	7975	11.05	7975	11.05
Total	72164.62	100	72164.62	100

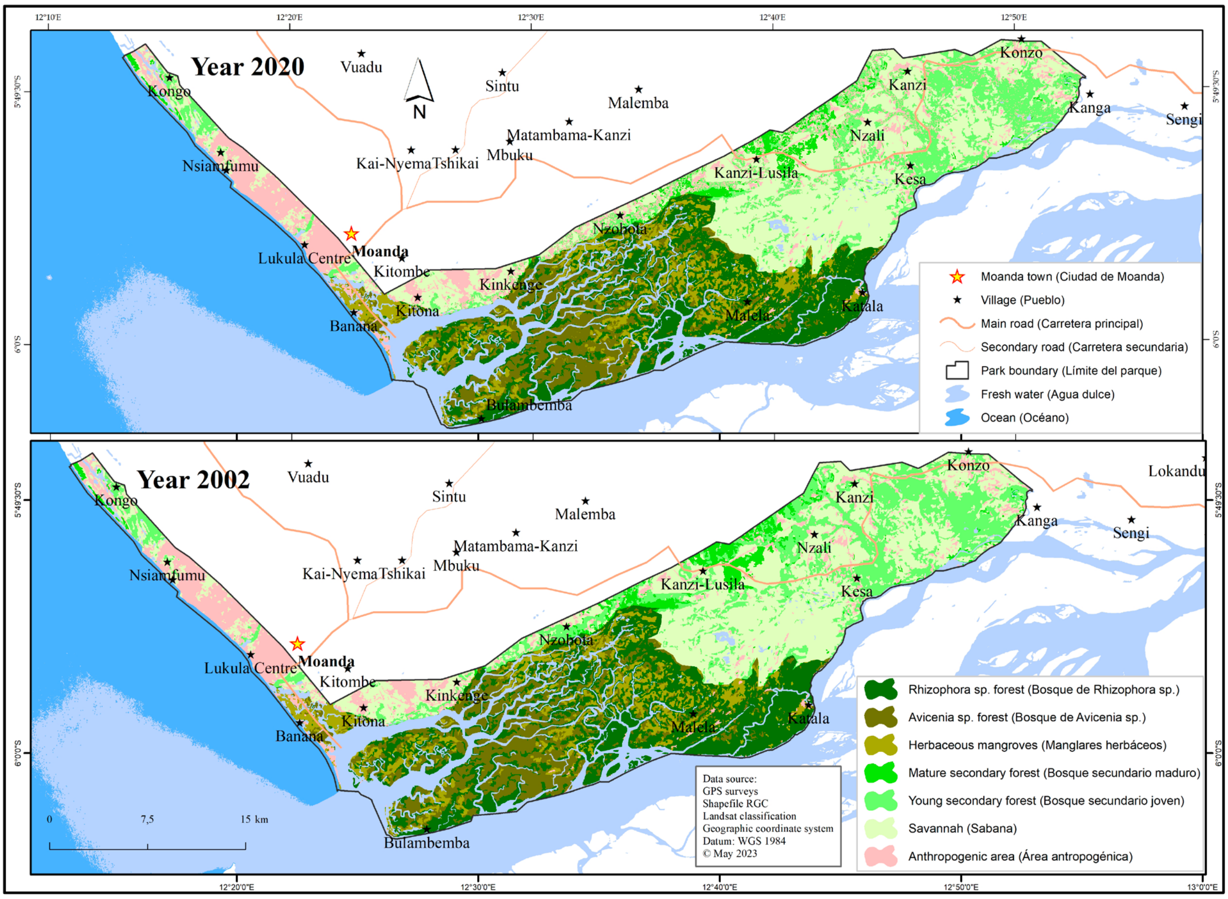

Figure 4. Land cover of the Mangrove Marine Park from 2002 to 2020.
Figura 4. Cobertura del suelo del Parque Marino de Manglares desde 2002 hasta 2020.

The result of the land cover classification shows a very good match with the data collected in the field. This agreement is justified by the accuracy indicators, overall accuracy, and Kappa index of 82.4% and 0.81 respectively.

3.2 Dynamics of land cover in the Mangrove Marine Park between 2002 - 2020

The *Rhizophora* sp. forest (high mangroves) has decreased from around 12633 ha in 2002 to around 12459 ha in 2020, representing a loss of 1.38% of its initial area (174.5 ha). The *Avicenia* sp. forest (low mangroves) covered around 8559 ha in the initial year (2002), and by the year 2022 it covers 8478 ha, representing a 0.95% reduction in its initial area. The greatest losses are observed in the mature secondary forest class, with 388.6 ha representing 20.5% of its initial area, and the young secondary forest class, with 1343 ha, or 11.8% of its initial area. Unlike the forest classes, which saw a reduction in their initial areas, the savannah, herbaceous mangrove and anthropogenic area classes expanded by 265 ha (4.96%), 396.63 ha (2.19%) and 1325.25 ha (21%) respectively (Figure 5).

Spatial analysis of satellite images providing information on GFW forest cover for the study area from 2002 to 2020 revealed average annual deforestation of around 79.62 ± 86.19 ha, a rate of around 0.07%. Annual trends in the loss of forest cover show a progression in terms of total number of occurrences, although there were years of inflexion in 2014 (369.5 ha), 2011 (141.9 ha) and 2010 (167 ha) in terms of the severity of this phenomenon. On the other hand, deforestation was low in 2003 (7.9 ha) and 2004 (21.5 ha) (Figure 6).

Analysis of land cover dynamics revealed an exceptional rate of change in land cover classes in the Moanda Mangrove Marine Park. The analysis revealed a more accelerated annual rate of regressive change for the mature secondary forest (-1.27%) and young secondary forest (-0.7%) classes. The annual rate of deforestation of *Rhizophora* sp. forest and *Avicenia* sp. forest is very low compared with that of young secondary forest and adult secondary forest. The most pronounced annual rate of expansion is observed in anthropogenic area (1.06%), herbaceous mangroves (0.27%) and savannah (0.12%) (Table 2).

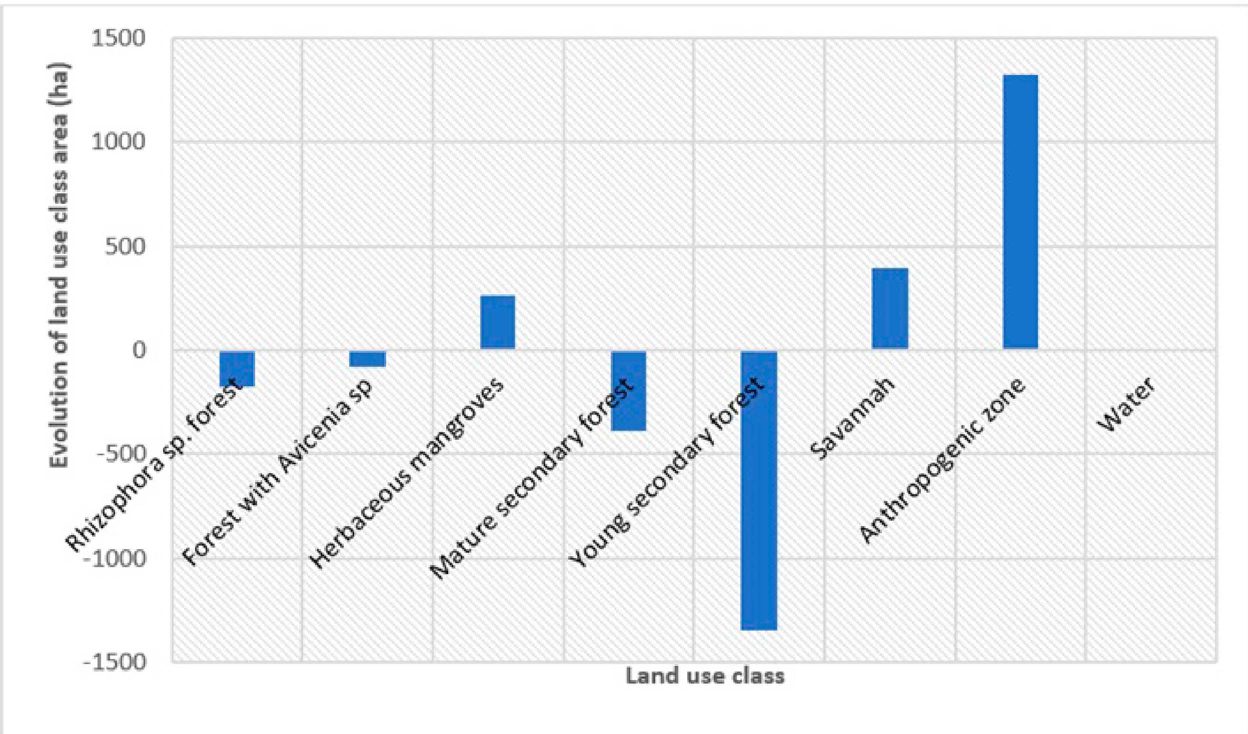

Figure 5. Expansion and regression of land cover class areas over time.
Figura 5. Expansión y regresión de las clases de cobertura del suelo a lo largo del tiempo.

Table 2. Annual change rate of land cover classes between the years 2002 to 2020.
Tabla 2. Tasa de cambio anual de las clases de cobertura del suelo entre los años 2002 y 2020.

Land use	Annual change (%)
Rhizophora sp. Forest	-0.08
Forest with *Avicenia* sp.	-0.05
Herbaceous mangroves	0.27
Mature secondary forest	-1.27
Young secondary forest	-0.70
Savannah	0.12
Anthropogenic zone	1.06
Water	0

3.3 Survey results

Fishing is the main income-generating activity for most of the households surveyed (31%); government employment and sales account for 3% and 17% respectively. 26% of households depend mainly on agriculture, and 22% of households surveyed identified charcoal production as their main income-generating activity (Figure 7). According to field data, mangrove charcoal is in greater demand on the Moanda market, due to its high calorific value. Charcoal is generally produced by groups of charcoal-makers, although some charcoal-makers remain solitary. There are also a few reluctant charcoal burners, even in the fully protected area. The exploitation of wood energy, mainly charcoal, is most intense in and around the Mangrove Marine Park, with monthly production reaching around 252 ± 160 bags.

Slash-and-burn agriculture is one of the activities adversely affecting forest cover in and around

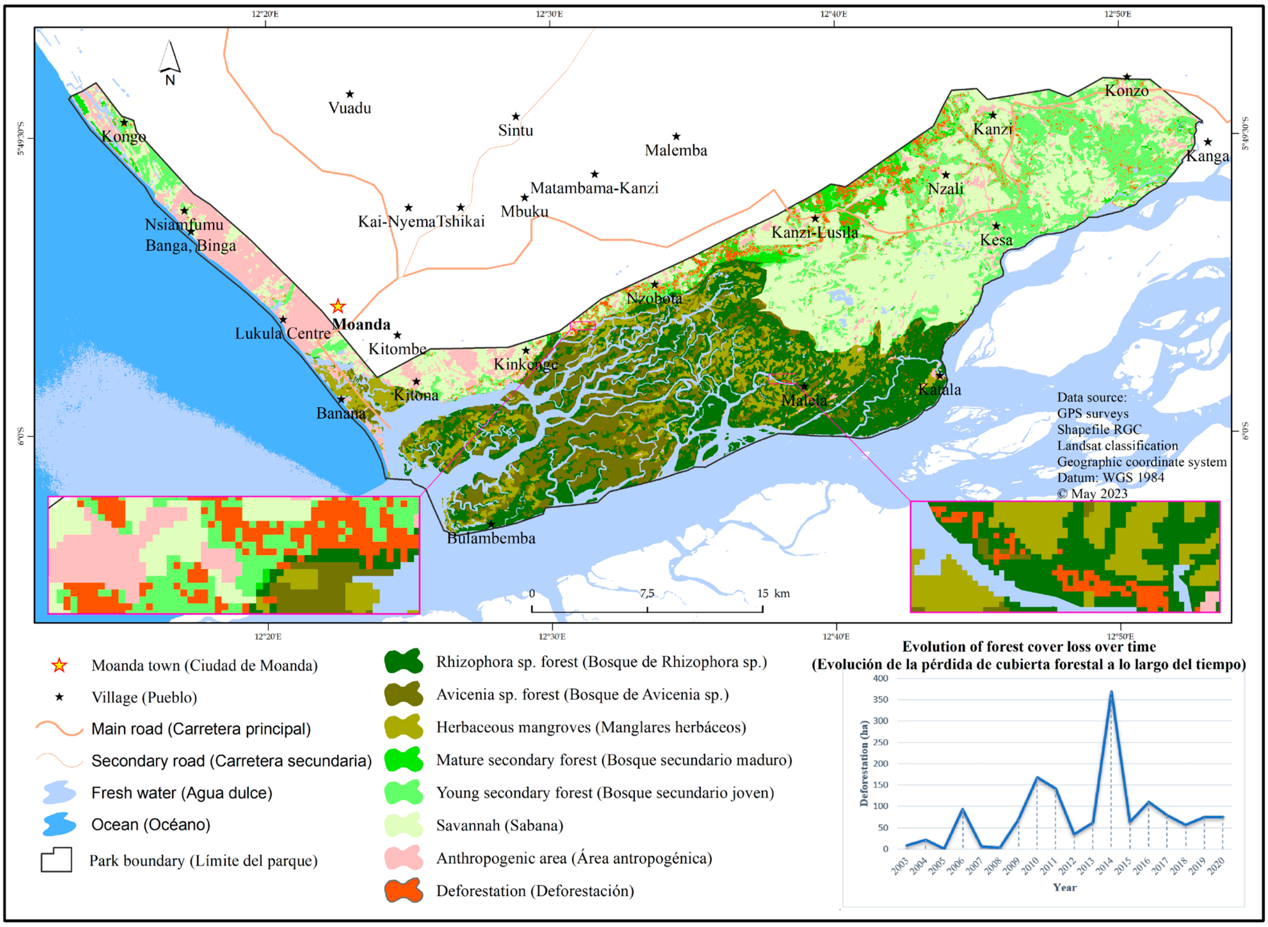

Figure 6. Evolution of land cover in the Mangrove Marine Park between the years 2002 and 2020.
Figura 6. Evolución de la cobertura del suelo en el Parque Marino de Manglares entre los años 2002 y 2020.

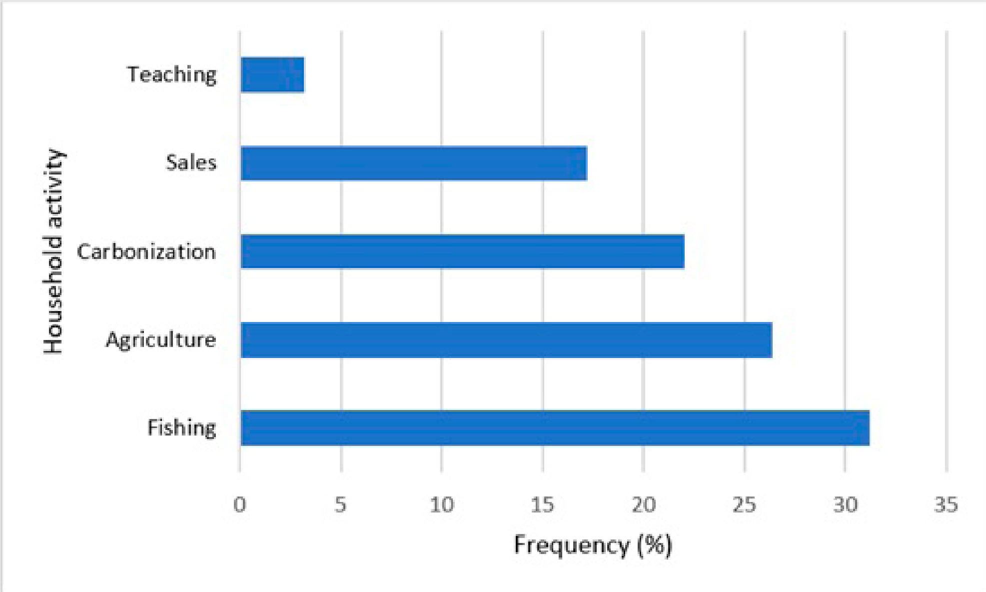

Figure 7. Main activities of surveyed coastal households.

Figura 7. Principales actividades de los hogares costeros encuestados.

the Moanda Mangrove Marine Park. Farmers grow more cassava, maize, groundnuts, beans, eggplants, and tomatoes. A coastal household clears an average of 2 ± 0.872 fields per year, each covering an area valued at around 0.375 ± 0.218 ha.

4. Discussion

The results of the satellite data analysis revealed strong landscape dynamics in the Moanda Mangrove Marine Park between the years 2002 and 2020. Major changes were observed in the adult secondary forest (-20%), young secondary forest (-11.8%), anthropogenic area (21%) and herbaceous mangroves (4%) classes. As for mangrove forest, the loss amounts to 1.38%, i.e. 174.5 ha for *Rhizophora* sp. forest, and 0.95%, i.e. 81.09 ha for *Avicenia* sp. forest. The negative change is recorded only in the forest classes, while non-forest areas have all seen an extension of their initial areas.

Overall, deforestation dynamics in the Moanda Mangrove Marine Park are estimated at an annual average of around 79.62 ± 86.19 ha, or a rate of 0.07%. The park lost large tracts of forest in 2014 (369.5 ha), 2011 (141.9 ha) and 2010 (167 ha). This high level of deforestation is thought to be due to the intensification of anthropogenic activities within the Mangrove Marine Park, such as unsustainable agriculture and the cutting of wood for various uses (construction, firewood, charcoal, etc.).

The analysis revealed a more accelerated annual rate of regressive change for the adult secondary forest (-1.27%) and young secondary forest (-0.7%) classes. The annual rate of deforestation of *Rhizophora* sp. forest and *Avicenia* sp. forest is very low compared with that of young secondary forest and adult secondary forest. The most pronounced annual rate of expansion is observed in anthropogenic area (1.06%), herbaceous mangroves (0.27%) and savannah (0.12%).

The annual deforestation rate found by our analyses (0.07%) is higher than that (0.04%) found by OSFAC (2014), as the latter's analyses were based on the period 2000-2010, while our analyses considered the broader period 2002-2020. In addition, our results on the evolution of land-use classes confirm the high production of fuelwood and the activity of shifting cultivation in the park, as reported during field surveys. In addition, our analyses revealed very high deforestation values in years not considered by the study conducted by OSFAC (2014), namely 2014 and 2011.

Analysis of the survey data revealed that Moanda's coastal population earns its living from fishing (31%), state civil service (3%), sales (17%), agriculture (26%) and charcoal production (22%). Fishing is the most important activity for the coastal population. It is most intense around the villages of Nsiamfumu/Vista, Banana, Ile Mateba, Tompo, Kimuabi, Tshonda and Inga. This fishing is generally traditional and artisanal in Moanda, using large-mesh and sometimes small mesh nets. Nevertheless, the local population has reported the presence of foreign fishing boats on the Congolese coast. The use of small mesh nets does not guarantee the sustainability of Moanda's coastal fishery; the presence of foreign boats on Congolese territory is due to the absence of a good number of Ecoguards serving this Marine Park.

According to the local population, mangroves are more in demand for charcoal, due to their high calorific value. The analysis shows a monthly production of around 252 ± 160 bags of charcoal per village. Charcoal production in the Moanda Mangrove Marine Park corroborates the findings of MECNEF (2007). The high consumption of wood energy by Congolese urban centers has already been reported by Schure *et al* (2012), Trefon *et al* (2010) and CIFOR *et al* (2007).

Slash-and-burn agriculture is gaining ground in the landscape of the Moanda mangrove marine park. It is one of the driving forces behind the anthropization of the park's landscape. A coastal household's field covers an average of 0.375 ± 0.218 ha; a household can clear 2 ± 0.872 fields per year. This result confirms those of Marjolaine *et al.* (2022), Bhomia *et al*. (2016), Webber *et al.* (2016) and Mpoyi *et al.* (2013), who refer to the regression of mangrove woody spaces due to the expansion of agricultural land.

Wood contains 50% carbon, and a low-performance carbonization technique yields around 63.5% charcoal and 36.5% carbon dioxide emissions (Mangion, 2010). Considering that a bag of charcoal weighs on average 65 kg (Trefon *et al*., 2010), the carbon dioxide emissions of a coastal village in Moanda amount to almost 9415 ± 5978 kg for its monthly charcoal production. With an improved carbonization technique, carbon dioxide emissions are reduced by up to 27.5% (Mangion, 2010); with this technique, carbonization emissions are estimated at 6213 ± 3945 per village.

This result illustrates the role of anthropization of the Mangrove Marine Park land cover on climate degradation. Activities such as slash-and-burn agriculture and carbonization make a significant contribution to greenhouse gas emissions.

5. Conclusions

The main aim of this study was to map and quantify the dynamics of land cover in the Moanda Mangrove Marine Park between 2002 and 2020. It reveals that the landscape of the Moanda Mangrove Marine Park is undergoing increasing changes over the years, because of anthropization, despite its protected status. Forests are mainly disappearing to make way for crops, savannah, and other anthropogenic occupations. Through diachronic analysis of Landsat images, and analysis of field survey data. Accuracy analysis showed very good agreement between land cover classes and the corresponding field data, with a Kappa value of 0.81 and overall accuracy of 82.4%.

The study showed the high dependence of the coastal population of Moanda on the natural resources of the Mangrove Marine Park via fishing (31%), agriculture (26%) and charcoal production (22%). Average village production is around 252 ± 160 bags of charcoal per month. As for slash-and-burn agriculture, an average field covers an area of 0.375±0.218 ha. A coastal household can clear an average of 2 ± 0.872 fields per year.

Average deforestation in the Moanda Mangrove Marine Park is estimated at around 79.62 ± 86.19 ha per year, or a rate of 0.07%. The years 2014, 2011 and 2010 are characterized by high deforestation in the Moanda Mangrove Marine Park, with loss values of 369.5 ha, 141.9 ha and 167 ha respectively. Low levels of deforestation were recorded in 2003 (7.9 ha) and 2004 (21.5 ha) (Figure 7). The study highlighted the influence of population growth on the loss of forest cover in the Marine Park.

Although mangrove deforestation is a consequence of satisfying certain human needs, it also has far-reaching and sometimes devastating consequences, such as social conflict, extinction of plants and animals, and climate disruption.

Restoring mangrove stands (*Rhizophora* sp. and *Avicenia* sp.) by reforesting deforested areas would improve the ecological conditions of species at risk of extinction and provide a response to natural disasters. In addition, redevelopment of the Moanda Mangrove Marine Park using an integrated approach would reduce pressure on the park. The promotion of renewable energy, as an alternative to wood energy; the promotion of improved stoves; and the promotion of sustainable agriculture are effective ways of countering deforestation in the Moanda Mangrove Marine Park.

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Data availability

Field data were collected in two ways: (1) in the form of geospatial data, using a Global Positioning System (GPS) receiver, (2) in the form of socio-economic survey data, using a pre-established questionnaire validated by the research team. Satellite imagery Landsat 7 and Landsat 8, and forest cover evolution were downloaded to the Global Forest Watch (GFW) platform.

Data relating to the road network, hydrographic network and administrative boundaries were downloaded from various databases (RGC, WRI and OSM RDC). Other geolocalized data were collected on Google Earth platform.

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Authorship contribution statement

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