WEST AFRICA BIODIVERSITY AND CLIMATE CHANGE (WA BiCC)

Strengthening Resilience to Climate Change in the Fresco Lagoon Landscape

Report on the Land Landcover and Land Use Mapping Mission

(September 2019)

This publication was produced for the United States Agency for International Development by Tetra Tech ARD, through a Task Order under the Prosperity, Livelihoods, and Conserving Ecosystems (PLACE) Indefinite Quantity Contract Core Task Order (USAID Contract No. AID-EPP-I-00-06-00008, Order Number AID-OAA-TO-11-00064).

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Citation: USAID/West Africa Biodiversity and Climate Change (WA BiCC). (2019). *Strengthening resilience to climate change in the Fresco Lagoon landscape: Report on the land landcover and land use mapping mission0* 2nd Labone Link, North Labone, Accra – Ghana. 36p.

Cover Photo: Coastal landscape of Fresco in Ivory Coast. Credit: WA BiCC

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SUMMARY

The land use mapping module is a study requested by Component 2 of WA BiCC Program '**Increasing coastal resilience',** implemented in the administrative area (Prefecture) of Fresco. The coastline of this prefecture forms part of the catchment area for the Bolo and Niouniourou coastal rivers and is closely associated with activities in the locality. Satellite images were used to map land cover and land use at different dates: 1990 and 2017 for the whole prefecture and 2018 for the Fresco lagoon landscape.

The results of this exercise indicate that the landscape in the prefecture of Fresco changed significantly between 1990 and 2017. Forest cover declined by 56.29% and was replaced with cultivated land, which increased by 47.46 % during this observation period.

Observations from 2018 show that 13.34% of the Fresco lagoon landscape is composed of mangrove ecosystems.

1.0 GENERAL INTRODUCTION

Globalization raises major challenges for coastlines, because the development of trade draws populations and activities towards coastal areas. The rate at which coastlines are being artificialized suggests that humans have forgotten that these are fragile environments whose balance often hangs by a thread.

These areas are mainly composed of soil runoff from watersheds and erosion from cliffs and beaches (Paskoff, 2010), but coastal sediment budgets are being disrupted by global reductions in the volume and flow of the sediments that feed these beaches (Hauhouot C., 2000).

The main causes of change in the coastal landscapes of Côte d'Ivoire and the tropical zone are agriculture and urbanization. Studies by BNETD found that 53% of the land in Côte d'Ivoire is allocated to agriculture; the country has lost 80% of its forest cover to intensive farming and now contains 3,427,963 ha of forests (http://www.commodafrica.com/27-05-2019-53-des-terres-en-cote-divoire-sont-affectees-lagriculture). Pressure on these remaining forests will be further intensified by ongoing deforestation and population growth in forest and coastal areas (N'Guessan *et al*., 2003; Oszwald, 2005, Brou *et al*., 2005; Brou, 2008; Sako, 2011; Koné *et al*., 2014).

Declining wetlands, especially in tropical environments, and the reduction of plant formations in general are causing serious concern among the scientific community and decision makers (local authorities and central governments), due to their direct repercussions on biodiversity and global changes.

International conferences prompted by growing awareness of this problem (such as those held in Stockholm in 1972 and Rio in 1992) enabled the international community to recommend that national governments commit to the sustainable use and management of fragile ecosystems. These conferences also led to the introduction of scientific programs to characterize, analyze and evaluate changes in natural environments at the global, regional and local levels. Studies such as these are essential for effective policies to protect and restore ecosystems.

This is the context in which **actions by the West Africa Biodiversity and Climate Change Program (WA BiCC),** and especially the project ***'Strengthening resilience to climate change in the Fresco lagoon landscape'***, are taking place. This project, which is part of WA BiCC Component 2, entitled '**Increasing coastal resilience'**, follows up on the vulnerability assessment conducted in the Fresco area in 2018. It aims to increase coastal resilience and adaptation to the effects of climate change in the Fresco lagoon ecosystem by working with local communities to develop a plan for the sustainable management of this zone.

To be effective, this kind of plan should be based on knowledge of how the setting works, and especially how land is occupied and used. In order to determine this, the study objectives were to:

- map land use and landcover in Fresco, using high spatial resolution satellite images;
- analyze changes in land landcover and land use over several periods in order to detect changes in land use between 1990 and 2017 or 2018;
- make recommendations for the sustainable management of forest resources, especially mangroves.

The present report is structured around the four following points:

- the geographical setting;
- the methodology;
- presentation of the findings;
- possible measures for the sustainable management of forest resources.

2.0 GEOGRAPHIC SETTING

2.1 GEOGRAPHIC LOCATION AND DESCRIPTION OF THE NATURAL ENVIRONMENT

2.1.1 GEOGRAPHIC LOCATION OF THE STUDY ZONE

The prefecture of Fresco lies in southwestern Côte d'Ivoire, 225 km west of Abidjan. Along with the prefecture of Sassandra, it constitutes the region of Gboklè, and covers the three sub-prefectures of Fresco, Dahiri and Gbagbam (Figure 1). The population of Fresco is 101,298 inhabitants (INS, 2014).

The prefecture of Fresco is located in the coastal zone of Côte d'Ivoire, at longitudes 5°24'30.37"O / 5°54'29.47"O and latitude 5° 6'10.73"N / 5°37'9.58"N.

Historically, Fresco was situated on a peninsular between the small Fresco lagoon (known as Lagune Goglè or n'gni in the literature review) and the Atlantic Ocean.

Average air temperatures in the Fresco area are similar to those in other coastal areas of Côte d'Ivoire, standing at around 28°C. They have risen by 0.5°C since the 1960s. Climate projections show an increase in average temperatures that could range from 1°C in 2050 to 1.5°C in 2100 for RCP4.5 scenario, and up to 2°C in 2050 and 4°C in 2100 for RCP8.5 scenario (WA BiCC, 2018).

Precipitation follows the subequatorial climate regime (Attiéen or Akiéen), with two rainy seasons interrupted by two unequal dry seasons each year. Annual precipitation in the Fresco area is between 1400mm and 2500mm. Over time it has diminished and become more unevenly distributed.

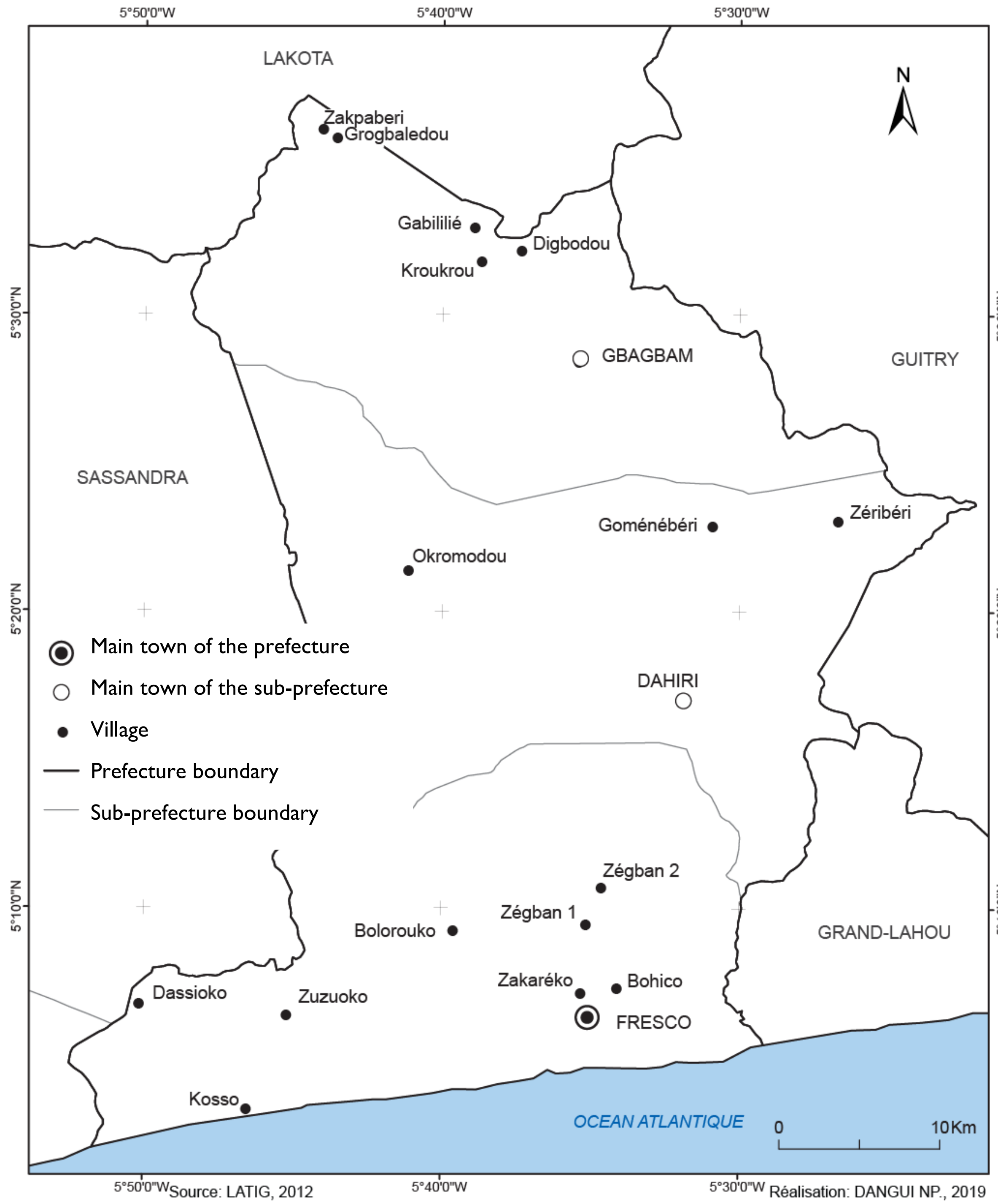

FIGURE 1: ADMINISTRATIVE MAP OF THE PREFECTURE OF FRESCO, PRODUCED BY DANGUI NP, 2019

2.1.2 DESCRIPTION OF THE NATURAL ENVIRONMENT

2.1.2.1 Relief

The relief pattern is closely related to the geological substratum. Overall, the sedimentary basin of the region has three levels of relief, with elevation gradually increasing further inland from the coast. A coastal plain 5-10m in altitude gives way to a low plateau with an average elevation of 30m, and then to a high plateau 60m above sea level. This high plateau, which is oriented north-south and heavily dissected by a dense hydrographic network, ends in a cliff overlooking the ocean west of Fresco.

2.1.2.2 Climate

The climate is equatorial with four seasons, two dry and two rainy. Rainfall is abundant, with at least 1600 mm of rain per annum (Brou, 2008). Fresco is the driest sector of the Ivorian coast but still receives more rain than central and northern regions of the country, with at least 100mm falling over the two dry seasons (which together last for eight months) (Dobé, 1980).

This high level of rainfall is due to the physical mechanisms of a moist oceanic air mass (monsoon) that crosses the coast from the southwest to the northeast, and the presence of dense forest cover that acts as a veritable reservoir of moisture.

Temperatures are moderated by ocean spray and constant humidity. They range from 23°C in the coldest month (August) to 27°C in the hottest month (February) (Dobé, 1980).

Since the mid-1970s the climate has become less humid and rainfall more irregular. This is due to the disappearance of forest cover (Brou *et al.*, 2005 a), as forests have been cleared to make way for agriculture and their water storage capacity significantly reduced by logging. Despite this, the coastline in this part of the country is still characterized as forest.

2.1.2.3 Hydrographic network

The coastal landscape of Fresco receives abundant rainfall and is drained by an extensive hydrographic network of lagoon, reservoirs, coastal rivers and streams. The two main coastal rivers in this sector, which is bounded to the south by the Atlantic Ocean, are the Niouniourou and the Bolo.

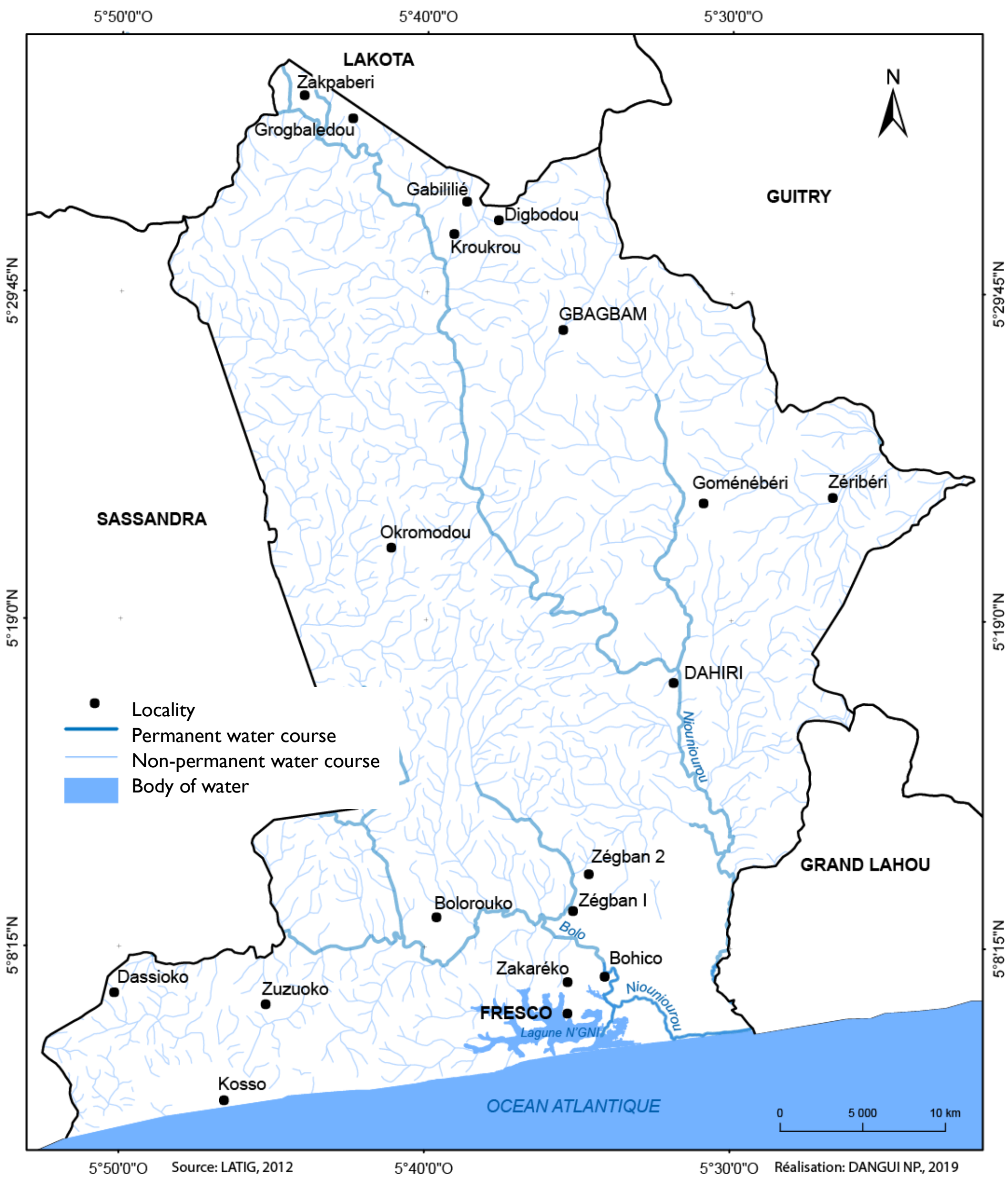

FIGURE 2: HYDROGRAPHIC NETWORK IN THE PREFECTURE OF FRESCO

2.1.2.4 Vegetation and Soils

According to the classification developed by Kouamé *et al.* (2010), vegetative cover in the study area can be described as southwestern coastal evergreen forest. This type of vegetation develops in conditions where rainfall is plentiful (between 1600mm and 2500mm) and humidity high (Guédé, 2005). Coastal evergreen forests are characterized by three not very distinct levels: an upper layer of large scattered trees 40m to 50m high, the tallest easily reaching 70 meters. Unlike the first layer, the second is hermetically sealed; while the third layer, also known as the lower layer, is composed of small, slow-growing trees no more than 10m high, with woody shrubs and herbaceous plants growing on a carpet of dead leaves.

In addition to evergreen forests, there are swamp forests, flooded grasslands, marsh meadows and mangroves. All these plant formations are closely linked to the soils, especially their water content. Mangrove grows on hydromorphic soils such as mudflats, estuaries and brackish lagoons. The two types of mangrove found in this study area are lagoon and estuarine mangroves, which include the two species *Rhizophora racemosa* (Rhizophoraceae) and *Avicennia germinans* (Avicenniaceae) (Guedé 2010).

Like other lagoons in Côte d'Ivoire, the Fresco lagoon and mangroves teem with many plant and animal species other than mangroves and their companion species. According to Sankaré and Aka (2016), there are five categories of phytoplankton: Cyanophyceae, Diatomophyceae, Pyrrhophyceae, Chlorophyceae and Euglenophyceae. There are also five classes of Microphytobenthos: phytoplankton, mobile cyanophyceae, sedentary cyanophyceae, free diatoms and sedentary diatoms. The wetlands of Fresco also contain a relatively large number of endemic plants (West African and Ivorian endemism), such as *Cissus touraensis* (Vitaceae), *Albertisinia mangenotii (*Menispermaceae)*, Mapania ivorensis* (Cyperaceae), etc. The wildlife found in mangroves is described in the following chapter (Sankaré and Aka, 2016).

In addition to the classic ecosystem services provided by mangroves in general (habitat, refuges, breeding grounds, spawning grounds, nursing areas, local climate, water exchanges between the lagoon and the sea, sediment capture and management, high CO2 storage and carbon sequestration capacity, including in the soil, benchmark area, etc.), the wetlands and mangroves of Fresco act as a buffer receptacle for fresh surface water from inland and brackish ground and surface waters. They therefore play an important role in the region's hydrological cycle by helping maintain the water balance and providing nesting, reception and transit sites for many species of migratory birds. These include *Pandion heliaetus* (osprey), *Egretta garzetta* (little egret), *Phalacrocorax africanus* (African cormorant), *Nycticorax nycticorax* (black-crowned night heron), *Butiroides striatus* (green-backed heron), *Ardea purpurea* (purple heron), *Ardea cinerea* (grey heron), *Circus aeruginosus* (marsh harrier), *Tringa ochropus* (green sandpiper), *Actilis hypoleucos* (common sandpiper), etc. It is also a transit area for many resident or partially resident avian species, such as *Ceryle rudis* (pied kingfisher), *Centropus senegalensis* (Senegal coucal), *Bulbucus ibis* (cattle egret), *Tchagra senegala* (black-crowned Tchagra), etc., and provides nesting sites for various species of marine turtle: *Dermochelys coriacea* (Leatherback turtle), *Lepidochelys olivacea* (Olive Ridley turtle), Chelonia mydas (Green turtle), Caretta caretta (Loggerhead turtle), *Testudo sulcata* (Savannah turtle) and *Trionyx triungus* (African softshell turtle). Mangroves also play a key role in the carbon and nutrient cycles of coastal environments.

The wetlands and mangroves of Fresco were classified as Ramsar sites in 2004 due to the diversity of their ecosystems and habitats, which are home to many species of flora and fauna. Some of these are endangered (Annex 1 of CITES and CMS), and others are vulnerable due to anthropogenic pressures on them and their habitats. These endangered species, which are fully protected by national legislation, include *Falco peregrinus* (peregrine falcon), *Loxodonta africana cyclotis* (African forest elephant), *Pan troglodytes* (chimpanzee) and *Cercopithecus diana* (Diana monkey).

The morphological structure and functioning of the characteristic species of mangrove ecosystems play an important role in the biological cycle of estuarine wildlife. Only three (3) of the six (6) species of mangrove found in West Africa have been recorded in Côte d'Ivoire: *Rhizophora racemosa* (red mangrove), *Avicennia germinans* (black mangrove), and *Conocarpus erectus* (button mangrove), which is an endangered species in Côte d'Ivoire. The mangroves themselves, which are biologically important ecosystems, are currently endangered by many threats (Egnankou and Sankaré 2004). In addition to the aforementioned species, which are only found in mangroves, there are many other plant species that tolerate brackish substrates and also thrive in non-saline substrates or land along the shoreline, such as

Dalbergia ecastaphyllum, *Drepanocarpus lunatus*, *Hibiscus lunatus*, *Acrostichum aureum*, *Phoenix reclinata* and *Pandanus candelabrum.*

A total of 56 plant species were observed in the mangroves and other wetland ecosystems of the Fresco lagoon landscape.

Swamp forests are recognizable by their main plant types, such as *Xylopia rubescens*, *Crudia Klainei, Carapa procera* and *Carapa raphia*, which are found in constantly hydromorphic areas (Dobé, 1980). Finally, forests containing *Eremosptha macrocarpa* and *Diospyros manii* grow on highly desaturated and impoverished sandy soils with poor water-holding capacity.

2.2 HUMAN AND ECONOMIC CHARACTERISTICS OF THE STUDY AREA

The population in the study area shares the main characteristics of the coastal population in general, and the southwestern population in particular. It changed rapidly in less than four decades, as the region's potential for agricultural and economic development drew large numbers of incomers into the area in a very short time. While the population continues to change, it remains rural and is still heavily geared towards primary activities such as fishing and agriculture.

2.2.1 A RURAL, CONSTANTLY CHANGING POPULATION MAINLY ENGAGED IN AGRICULTURE

2.2.1.1 An almost rural area

The prefecture of Fresco contains a total of 19 localities (16 villages, 2 main sub-prefectural towns and 1 main prefectural town), 9 of which are in the sub-prefecture of Fresco, 4 in the sub-prefecture of Dahiri, and 6 in the sub-prefecture of Gbagbam (Figure 3).

The population of this prefecture stands at 101,298 inhabitants, with 53,579 men and 47,719 women, giving a male to female ratio of 112.3 % (RGPH 2014). Analysis of statistical data from the General Population and Housing Census shows that the population lives almost entirely in rural areas.

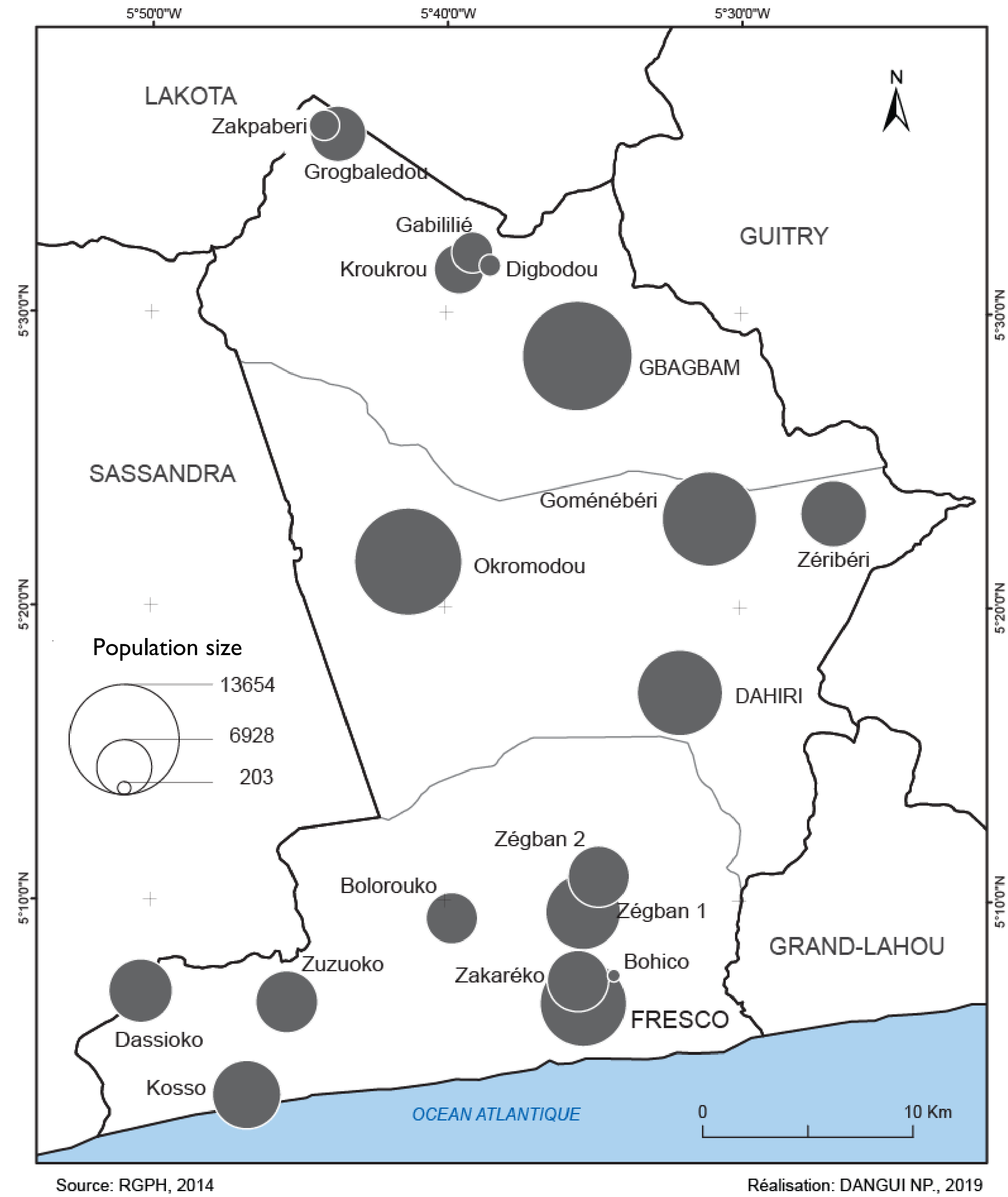

FIGURE 3: POPULATION DISTRIBUTION IN THE DEPARTMENT OF FRESCO IN 2014, PRODUCED BY DANGUI NP, 2019

Until 1988 the administrative district of Fresco was entirely rural, and most localities in the area had fewer than 4,000 inhabitants. The town of Fresco, which looked more like a large village than a town, was the main human settlement in the area and main town in the department from the colonial period until 1988 (Dobé, 1980). Fresco remains one of the most rural administrative districts on the Ivorian coast, despite the influx of people into the area and various development programs implemented throughout the southwest region.

2.2.1.2 Strong demographic growth

Like the coastal population, the population in the study area has grown rapidly. Between 1965 and 1998 it increased by 92.21%, rising from 6,500 to 83,462 inhabitants. This represents a much higher annual growth rate than the national average, with growth estimated at 5.96% between 1965 and 1975, compared with the national average of 4.8% (Dobé, 1980), and 12% between 1988 and 1998, when the national average was 6% (National Institute of Statistics (INS), RGPH, 1988 and 1998).

This speedy population growth increased significantly between 1965 and 1975, when it nearly doubled, and then rose even more rapidly between 1975 and 1988. It further increased after 1988 when the town of Fresco became a sub-prefecture with amenities and infrastructures for civil servants, and the economic situation triggered an exodus of city dwellers.

The population in the prefecture of Fresco grew by 48.37% in the decade 1988-1998 , and then rose from 83,462 inhabitants in 1998 to 101,298 inhabitants in 2014.

This rapid growth is due to continuous immigration from the sub-region and the exodus of Ivorian nationals to forested areas. Human settlements in the prefecture of Fresco are composed of people from the local Godié ethnic group, the Akan, Mandé, Gurs or Voltaique (Senufo, Lobi, Koulango) and the Krou, who originally came from other parts of Côte d'Ivoire. There are also many peoples from the West African sub-region (Burkina Faso, Ghana, Togo, Benin, Guinea) and the Lebanon. The main faiths are Christianity, Islam and animism.

The significant demographic changes in our study area also include fairly major increases in population density, which stand at an estimated 65.9 people/km^2, compared with a national average of 47 people/km^2, and 137 people/km^2 along the coastline as a whole (Figure 4).

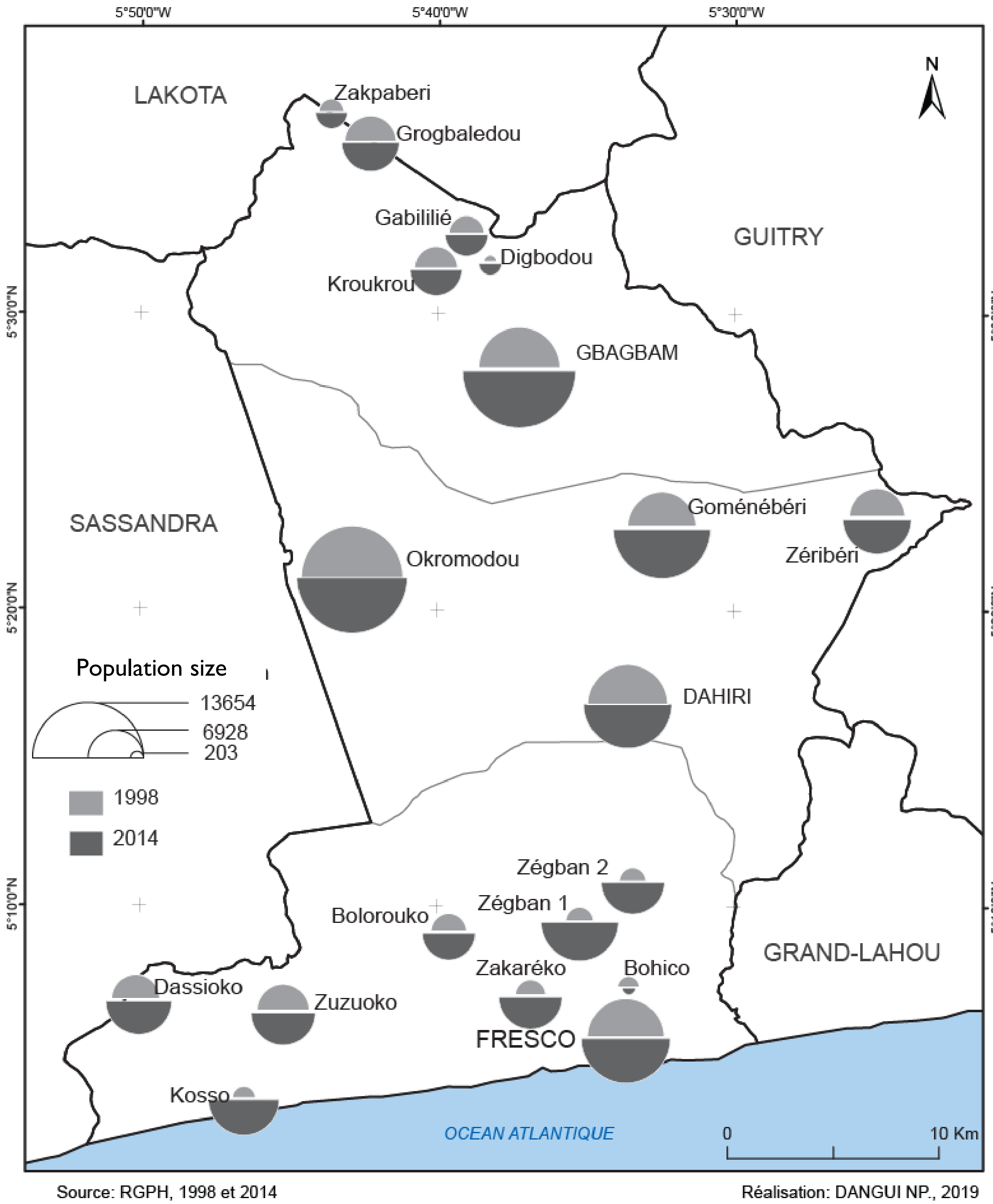

FIGURE 4: POPULATION DISTRIBUTION IN THE PREFECTURE OF FRESCO BETWEEN 1998 AND 2014 (PRODUCED BY DANGUI NP, 2019)

2.2.2 ECONOMIC ACTIVITIES DOMINATED BY THE PRIMARY SECTOR

The sub-prefecture of Fresco as a whole remains very rural, with large numbers of people living in villages and other agricultural settlements, and many active in the agricultural and related sectors.

Fishing was the main activity for coastal populations for many years, until the authorities encouraged them to abandon it in favor of cash and food crops. These plantations have had a significant impact on the evolution of rainforest ecosystems, which have shrunk as more land is given over to fields (Balac, 1999; Brou, 2008; etc.). Mangroves are also disappearing at an increasing rate as their wood is used for fishing activities (Egnankou, 2008).

3.0 METHODOLOGY

3.1 DESCRIPTION OF STUDY DATA

The data for this study on landcover and land use and their dynamics was obtained from a growing number and range of available sources. We mostly used geographic data and socio-economic statistics obtained from the pictorial, cartographic and textual materials described below.

3.1.1 SOURCES OF SPATIAL DATA

This category includes satellite images and archival maps, i.e. land use maps of the study area.

3.1.1.1 Satellite images

Remote sensing is an invaluable tool for mapping land use and planning and managing natural resources. According to Pouchin (2001), satellite images can provide a broader description of environments and much more spatial and spectral information than aerial photographs, helping us better characterize objects across a wide range of the electromagnetic spectrum.

In this study we used images from Landsat satellite sensors for diachronic mapping of land use in the prefecture, and SPOT images for the mangroves.

SPOT images. According to the SPOT image positioning grid for Côte d'Ivoire, scenes K 340, J 049 or K 339 and J 049 cover the study area. SPOT images were mainly used to characterize the mangroves in Fresco and analyze their evolution. The SPOT image scene was provided by the specialist American structure HARRIS (www.harrisgeospatial.com), which sells images (Table1).

TABLE 1: FEATURES OF SPOT IMAGES

Images	Wavelength	Resolution	Footprint	Date	Cloud Cover	Coordinate System
SPOT 6 and 7	Blue band (0.455–0.525 µm)	1.5	60 km by 60 km	27/12/2018	0%	WGS/UTM30 N
	Green band 0.530 – 0.590 µm)					
	Red band0.625– 0.695 µm)					
	Near infra-red band (0.760 – 0.890 µm)					

The image was recorded in December, which is the main dry season in the study area and therefore the best time to avoid the effects that cloud cover usually has on images taken in tropical areas during the rainy season. SPOT data are suitable for close surface monitoring as they have good spectral and spatial resolution, and this sensor has spectral bands that can help distinguish between very close spectral channels when images are processed automatically. The pixel size of the image evaluated at 20m also makes it possible to identify small landscape units covering 0.04 hectares (Brou, 2005).

Landsat images. Four images from Landsat TM, ETM+ and OLI sensors were acquired between 1990 and 2017 according to their availability in the National Aeronautics and Space Administration (NASA) archives and their qualities (Table 1). They allowed us to analyze the space-time dynamics of land use in the prefecture over a period of 29 years.

Satellite imagery from Landsat sensors have spectral and spatial advantages similar to those of the SPOT sensor. They provide multispectral data, with 6 bands for the TM sensor, 8 bands for the ETM+, and 12 bands for OLI; and spatial resolution of 30m in multispectral mode and 15m in panchromatic mode. They are suitable for local studies as they can be used to map small landscape features (0.09 ha) on the ground.

The spectral bands of Landsat images are used to study vegetative cover. Band 3 (0.630 to 0.69 µm), which is in the red band of the visible spectrum, has the capacity to absorb the chlorophyll in healthy (green) vegetation; while band 4 (0.76 to 0.9 µm) of the near infra-red (NIR) band is ideal for measuring the amount of biomass in a plant surface. It is therefore very useful for distinguishing different types of vegetation, and for radiometrically separating bare soil from agricultural land, and areas of land from water (Girard and Girard, 1999). Finally, band 5 of the Middle Infrared (MIR) band allows us to determine the water content of plants. Chaletain (1996) maintains that this capacity enables us to differentiate between different types of vegetation. The different spectral bands described above were used when processing different Landsat images for multi-date mapping of land cover in classified forests in the Fresco area.

3.1.2 LAND USE MAPS

We used the Grand Lahou land use maps of the land management agencies as ancillary data. These maps, which cover the study area and are available at a scale of 1/50 000, enabled us to extract information on the administrative boundaries and localities in the area, and served as a reference point for determining and locating the different land use units. They also provided other useful information for our study, such as the contour lines used to estimate landscape elevation, and the location of human settlements shown in our maps of population distribution in the area in 1998 and 2014.

3.1.3 BIOGEOGRAPHIC FIELD DATA

This is biogeographic information from field surveys conducted during missions in the different classified forests, mangroves along the Fresco lagoon, and the lagoon catchment area, water courses, agricultural lands and built-up/bare ground upstream from the lagoon. We made 126 spot observations using GPS (Global Positioning System) over the course of several week-long missions in June 2019. These surveys correspond to monospecific zones of land use units that were used to guide automatic classification in the laboratory. Some of these data were used to create vector layers to validate and assess the accuracy of the multi-date classifications made during this study. Field data were collected well before supervised classification of the images, which were processed by the type of land use taken homogenously across all images, at a rate of 10 to 20 points. A final round of field surveys was used to validate the different classifications.

3.1.4 SOCIO-ECONOMIC DATA

This category includes all socio-economic data that could be useful in analyzing land use dynamics in the portion of the coast covered by the study – such as demographic data, agricultural statistics and available climate data. Most of these data were obtained from reports produced by government structures responsible for such matters, and from scientific articles, dissertations and theses.

Data on population size in 1998 and 2014 were collected by the National Institute of Statistics (INS).

3.2 DESCRIPTION OF PROCESSING METHODS

3.2.1 PRE-PROCESSING

Pre-processing of the images includes radiometric and atmospheric calibrations, which are necessary because of the processes used to acquire information in remote sensing. Electromagnetic radiation emitted by the energy source (the sun in optical remote sensing) is doubly disrupted by dust and gases present in the atmosphere (first from the source to the ground targets, and secondly from the ground targets to the sensor). Various formulas have been developed to reduce the effect of these disruptions. Using the header file containing all the variables needed to apply these formulas, we started with a radiometric calibration to obtain radiance information and then switched from radiances to exo-atmospheric reflectance. The next step was atmospheric calibration to switch from exo-atmospheric reflectance to the true reflectance of objects on the ground. Once the processed file was completed, it was exported in the format in which we intended to work.

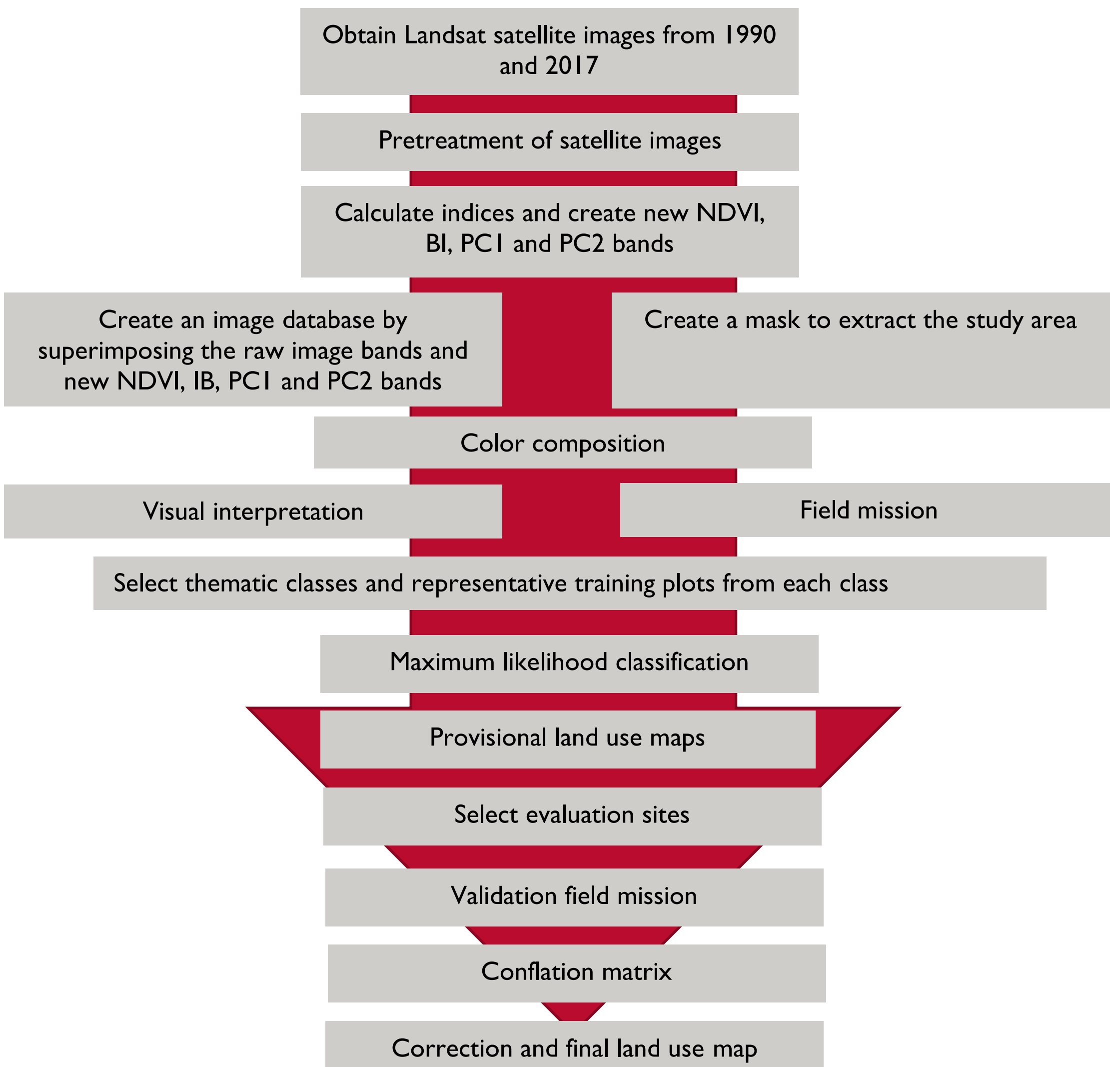

FIGURE 5: IMAGE PROCESSING FLOW CHART

3.2.2 CALCULATING INDICES AND CREATING NEW BANDS

Some indices can help improve the results of satellite image classification. The most commonly used indices are:

- Normalized difference vegetation index (NDVI), which is sensitive to the vigor and quantity of vegetation, and is based on the red (R) and near-infrared (NIR) bands of the satellite image. The NDVI is obtained from the difference between the visible red band and the near-infrared band, using the following equation:

$$NDVI= (NIR-R)/NIR+R)$$

- The brightness index is the average of the image brightnesses. It is sensitive to the brightness of the ground according to its humidity and the presence of salts on its surface, and mainly characterizes the albedo. The brightness index is constructed from the red (R) and near-infrared (NIR) bands, using the following equation:

$$BI = (R^2+NIR^2)^{0,5}$$

Brightening is caused by different phenomena such as surface moisture (caused by rain or irrigation), rougher surfaces (due to tillage) and/or increased vegetative cover. It may of course also be due to a decline in vegetative cover, and often leads to a diagnosis of environmental degradation.

Combining these two indices helps better discriminate between vegetation and bare soil, so both were used on the two Landsat images used in the study.

Principle component analysis (PCA) is used to create new images from raw image bands. As noted above, optical remote sensing images are subject to distortions and disturbances caused by atmospheric effects, sensor vibration and other factors, which create additive noise that is added to the pixel content. This can cause problems with redundant information or duplicate data when images are correlated, so PCA is used to combine original variables and reduce them to their most important and descriptive components. …) Here, principle components 1 and 2 were used as they contained most of the information.

3.2.3 CREATING A MASK TO EXTRACT THE STUDY AREA

This step consists of reducing the final classification processes to a small area called a subset. To do this, a mask is applied to the part of the satellite image we are interested in so that it can be extracted in order to create a new image.

To simplify this task, users are advised to extract 'useful' information in the image resulting from the different indices (NDVI-IB ACP) and break down the data according to the boundaries of the study area.

3.2.4 COLOR COMPOSITION

The color composition of an image allows us to visually analyze it with a direct reading of the information in the image (photo interpretation). This is done by applying interpretation keys to elicit different types of information.

However, this method has its limitations in very heterogeneous environments, as it is very hard to recognize objects that are not easily differentiated from others with the naked eye. The boundaries of most of these features are too blurred to be visually determined.

3.2.5 FIELD MISSION

Between 25 and 30 June 2019, water and forestry agents from Okromodou and Port Gauthier classified forest management units participated in a mission to collect field data to sample the main categories of land cover and land use in the Fresco landscape (Photo 1).

PHOTO 1: WATER AND FORESTRY AGENTS WORKING IN THE FIELD, 27 JUNE 2019

This entailed identifying and describing polygons of the types of land cover studied, along with their GPS coordinates (731 points) and, where possible, photographs recording the characteristics of the site (see Photo 2). The borders of the different types of cover were deliberately avoided to reduce the possibility of mislabeling categories of landcover and land use, and to improve the reliability of the data. A drone was used to take aerial views of inaccessible areas (Photo 3).

PHOTO 2: MANGROVE POLYGON COORDINATES SURVEY WITH GAMIN GPS IN FRESCO, JUNE 2019 (PHOTO CREDIT: DR. NADI PAUL DANGUI)

PHOTO 3: USING THE DRONE TO COLLECT SAMPLES FOR THE FRESCO LAGOON LANDSCAPE (MANGROVE AND OTHERS) 27 JUNE 2019 (PHOTO CREDIT: DR. NADI PAUL DANGUI)

3.2.6 MAXIMUM LIKELIHOOD CLASSIFICATION

A well-defined classification scheme is fundamental to the success of any attempt to identify and categorize land use and land cover. One of the golden rules for setting up a good system is to have mutually exclusive categories of information. For this study, the main types of land cover in the Fresco lagoon landscape were identified and grouped into nine clearly defined mapping classes. Certain choices were guided by the study objectives, the spatial resolution of the images (30 m) used, and previous studies in the area (Table 2).

Image classification plays an important role in detecting changes in a landscape. In this process image pixels are grouped according to similarities in the main predefined classes of land cover. The Fresco landscape, which can be categorized as tropical, is still very fragmented; composed of overlapping heterogeneous types of land cover whose complexity makes it difficult to use a traditional algorithm to obtain a representative classification. The images were subjected to unsupervised and supervised hybrid classification (Wondrade, 2014).

TABLE 2: SUMMARY OF LAND USE AND LAND COVER CLASSES

Class of Land Use and Land Cover	Classes Mapped	Description of the Class in the Landscape
Continuous forest cover	*Forest*	*Wooded areas with dense tree cover occupying more than 0.5 hectares, with trees over 5 meters tall. This includes forests inside and outside conservation areas but excludes plantations that meet these criteria.*
	Open forest	*Degraded wooded areas with dense tree cover occupying more than 0.5 hectares, with trees over 5 meters tall.*
	Mangroves	*Area of forest and other wooded land with mangrove vegetation (Rhizophora spp. and Avicennia spp.) found along watercourses.*
Annual and biennial crops, market gardens fallow land	*Food crops*	*Portions of the landscape that are arable and planted with temporary annual or biennial crops, with no permanent cash crops. This class includes areas left fallow according to the growing seasons.*
Shrubs and grasses	*Grasslands*	*The main characteristic of grasslands is that they are places where lots of grass grows, but they may also contain low shrubs and other plants.*
Rivers, creeks, lagoons, lakes, stagnant water	*Water*	*Refers to all types of water bodies in the study area. i.e., streams, lagoons, bodies of standing water, etc.*
Bushes, grasses, waterlogged land (marshland)	*Wetlands*	*Areas of land that are flooded during a certain period of the year. i.e. marshlands, which may sometimes contain other bushes*
Cocoa, coffee, rubber, citrus, oil palms, coconut	*Plantation*	*Refers to areas with longstanding plantations that produce crops over many harvests. Usually planted for commercial purposes.*
Built-up areas		

Class of Land Use and Land Cover	Classes Mapped	Description of the Class in the Landscape
Bare ground, rocky outcrops, sandy beaches	*Built-up/Bare ground*	*Small, isolated, unvegetated parts of the landscape, including built-up, bare, rocky areas, beaches and operational mining areas*

Source: Fresco vulnerability assessment, 2018

4.0 RESULTS

4.1 ASSESSMENT OF LAND USE IN THE PREFECTURE OF FRESCO IN 1990

In order to better understand the environment and its evolution, it needs to be described in detail. This assessment therefore aims to identify both the different types of land use, and their extent and prevalence (proportion).

The various plant formations in the prefecture of Fresco were identified during field reconnaissance missions and by consulting all the relevant documentation. They are listed in Table 2 above.

In the interests of simplicity and clarity, the land uses listed above were divided into the following types of cover: forest, crops, marshland, water, and built-up areas/bare ground.

4.1.1 STATUS OF LAND USE IN THE PREFECTURE OF FRESCO IN 1990

Observations made in the prefecture of Fresco in 1990 show that cultivated areas occupied more ground than other types of land use in the study area. Statistics on the different types of land use taken from the map made at that date show that crops (annual food crops and perennial crops) occupied 53.50% of the study area (94,194.18 ha); forests occupied 36.23% of the study area (63,786.34 ha); and built-up/bare land, marshlands and water respectively occupied 2.20% (3873.78 ha), 7.40% (13,031.22 ha) and 0.67% (1,173.67 ha) of the study area (see Figure 5). There were large areas of forest in the classified forests of Okromoudou and Port Gauthier, and in Dassioko and Kosso in the south-west of the prefecture. Cultivated land existed almost everywhere in the study site, not only in isolated areas but also in Okromodou classified forest to the west of the prefecture , and in the northern part of the classified forest of Port Gauthier in the east of the prefecture. There was also intensive cultivation between Okromodou classified forest and Gbagbam to the north of the prefecture (Figure 6).

In 1990, most of the marshland (7.40%) was located in the southeast and center of the prefecture, and to a lesser extent in the northwest and southwest, towards Dassioko and Kosso.

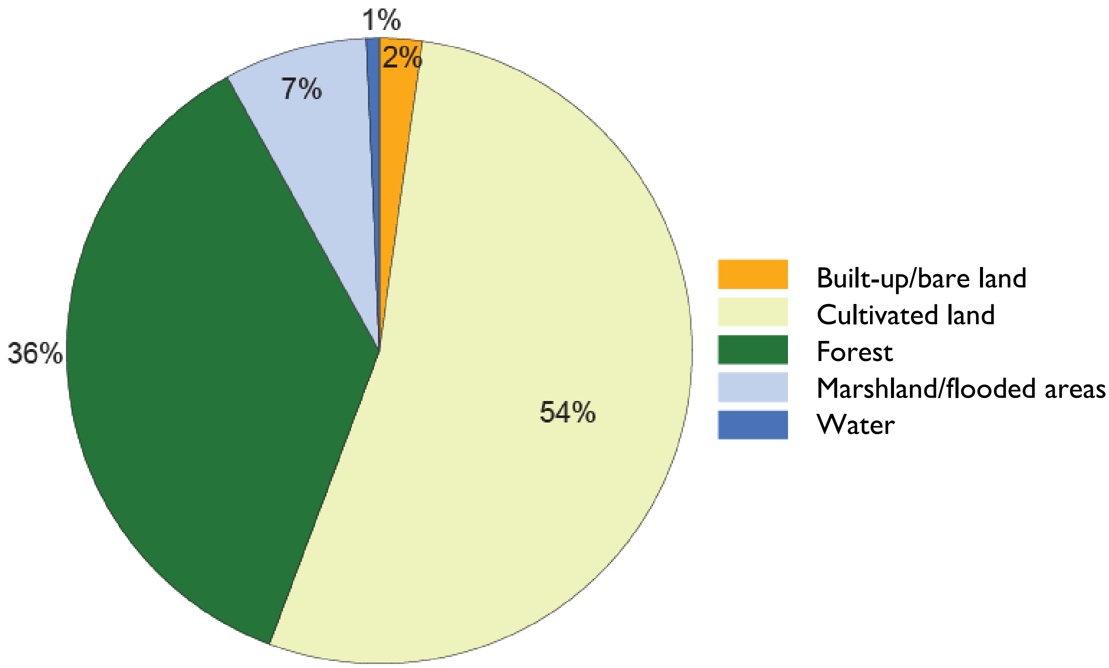

FIGURE 6: PROPORTION OF DIFFERENT TYPES OF LAND USE IN THE PREFECTUREOF FRESCO IN 1990

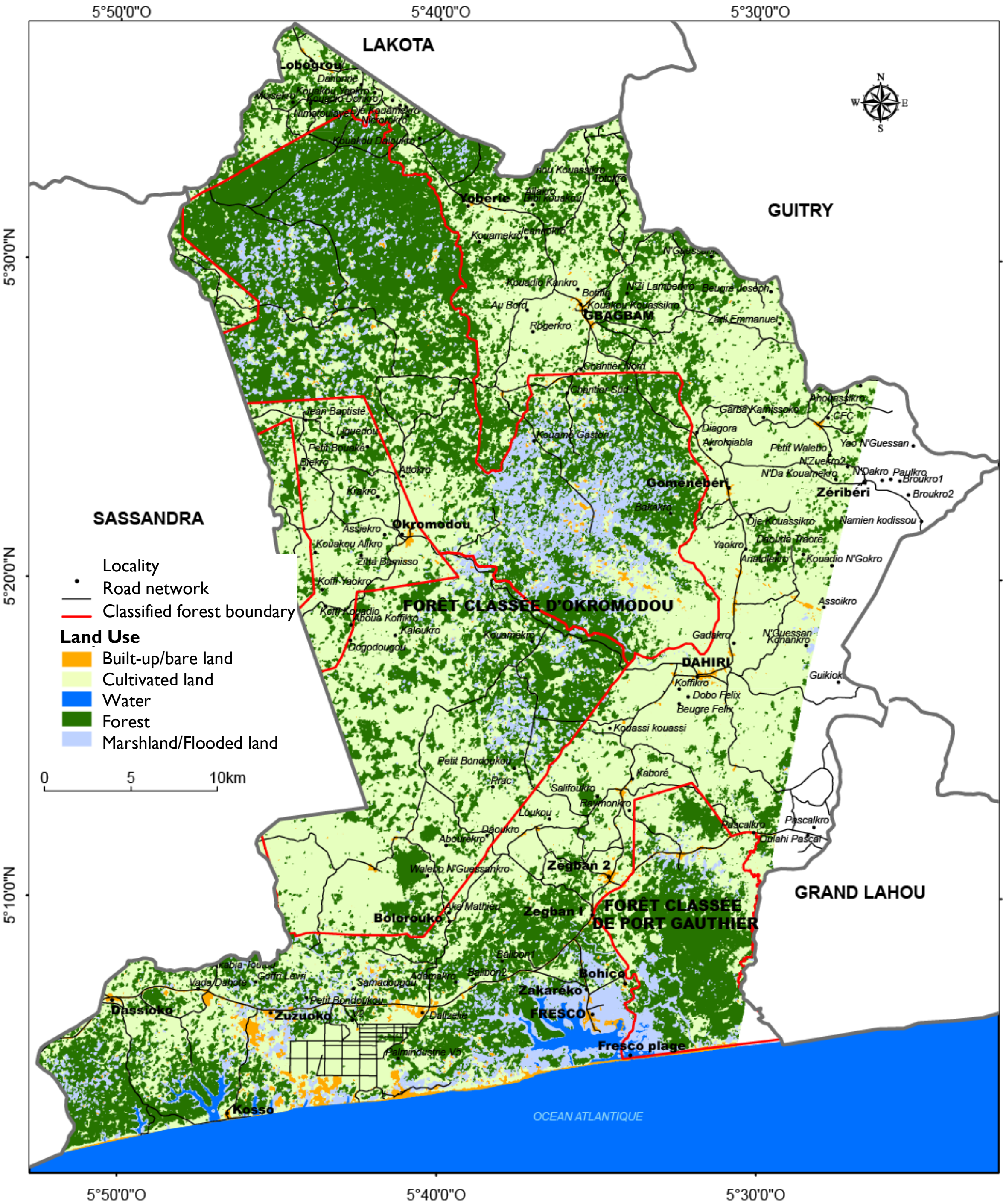

FIGURE 7. MAP OF LAND OCCUPANCY AND LAND USE IN THE FRESCO STUDY AREA IN 1990

Key: Locality, Road network, Classified forest boundary
Land use: Built-up/bare land, Cultivated land, Water, Forest, Marshland/flooded land

4.1.3 LAND USE IN THE PREFECTURE OF FRESCO IN 2017

In 2017, 78.89% of the study area was taken up by cultivated land (138,900 ha) and 15.84% by forests (27,882.40 ha). Less than 6% of the total area was available for other types of land use, with built-up or bare land, marshland and water respectively occupying 1.89% (3,313.11 ha), 2.26% (3,977.09 ha) and 1.13% (1,986.59 ha) of the study area (see Figure 7 above).

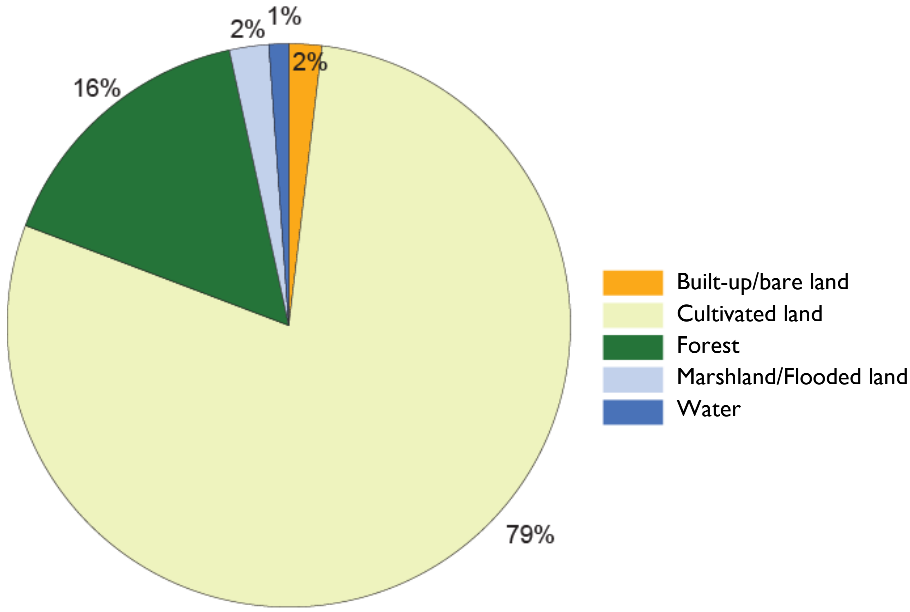

FIGURE 8: PROPORTION OF DIFFERENT TYPES OF LAND USE IN THE PREFECTURE OF FRESCO IN 2017

The proportions of different types of landcover and use presented in Figure 8 show that the amount of land under cultivation in the prefecture of Fresco rose from 94,194.18 ha in 1990 to 138,900 ha in 2017, representing an increase of 44,705.82 ha. The amount of land under forest fell by 35,903.94 ha, meaning that 56.29% of the total forest area was lost during this period.

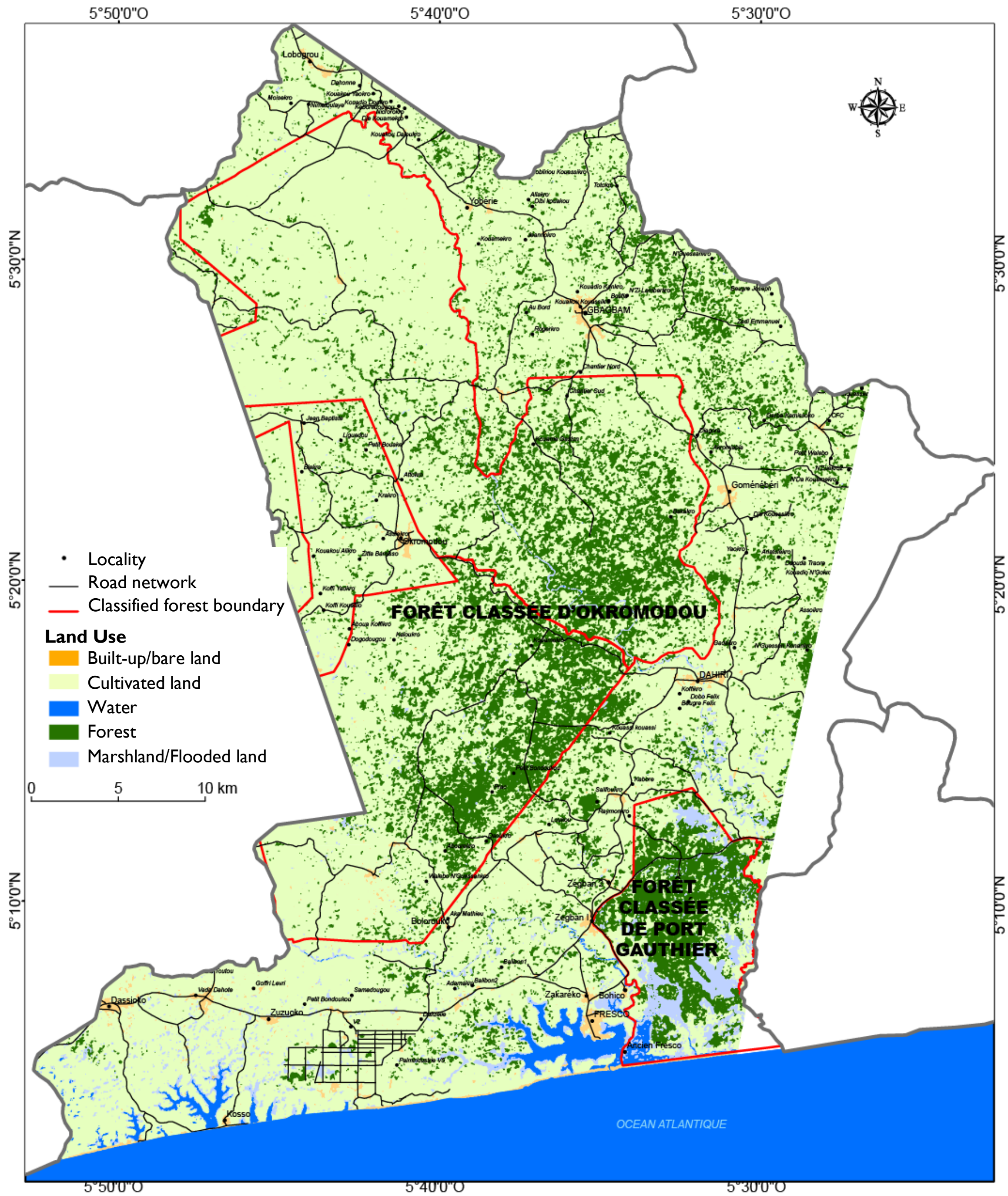

FIGURE 9. MAP OF LAND COVER AND LAND USE IN THE FRESCO STUDY AREA IN 2017

Over the 27 years of observation, forest cover decreased by 3.02% per year, while built-up/bare land and marshlands respectively shrank by 14.47% (560.67 ha) and 69.48% (9,054.13 ha) in comparison with their initial surface areas in 1990 (see Figure 9 and Table 3).

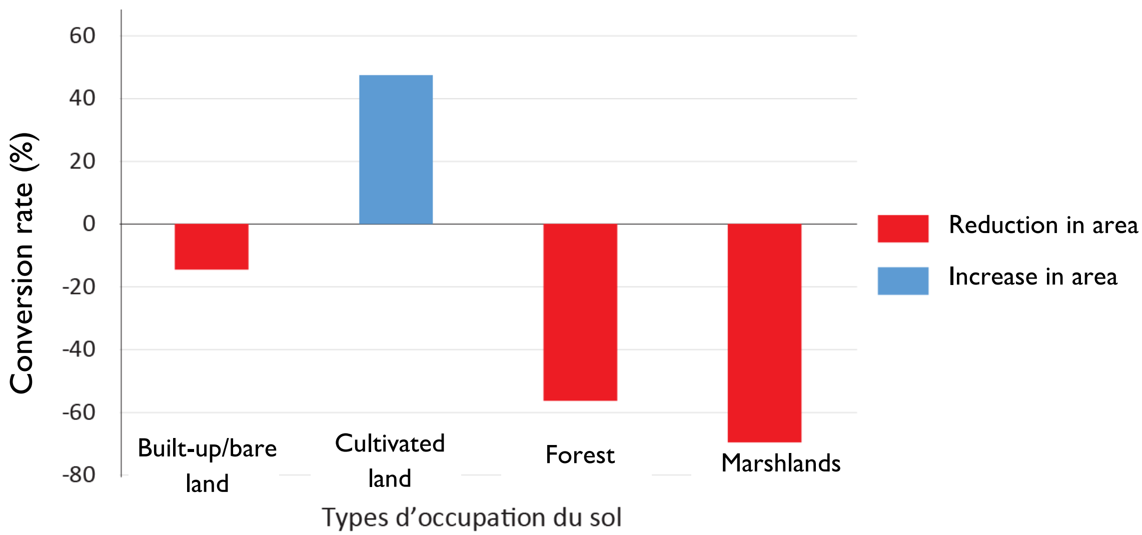

FIGURE 10. CHANGES IN VEGETATIVE COVER IN THE PREFECTURE OF FRESCO BETWEEN 1990 AND 2017

TABLE 3: AREA COVERED BY DIFFERENT TYPES OF LAND USE AND RATES OF CHANGE IN 27 YEARS

Types of land use	Area (ha) in 1990	Percentage (%) in 1990	Area (ha) in 2017	Percentage (%) in 2017	Rate of change	Mean annual growth rate
Built-up/bare land	3,873.78	2.20	3,313.11	1.88	-14.17	-0.58
Cultivated land	94,194.,18	53.50	138,900.00	78.89	47.46	1.45
Forest	63,786.,34	36.23	27,882.,40	15.84	-56.29	-3.02
Marshland	13,031.22	7.40	3,977.09	2.26	-69.48	-4.30
Water	1,173.67	0.67	1,986.59	1.13	69.26	1.97

Almost all the land in Fresco Prefecture had been turned over to cash crops (cocoa, oil palm, rubber plantations, etc.) and food crops (rice, cassava) by the end of the study period (see Photo 4). This kind of intensive agriculture is probably one of the main reasons why forests have declined to just 15.84% of land cover, found in the two classified forests of Okromodou and Port Gauthier. The forest in Okromoudou is a composite of forest-crops such as cocoa plantations. According to the General Census of Population and Housing (RGPH), the predominantly rural human population, which is partly responsible for the decline in forested land, rose from 83,462 to 101,298 inhabitants between 1998 and 2014.

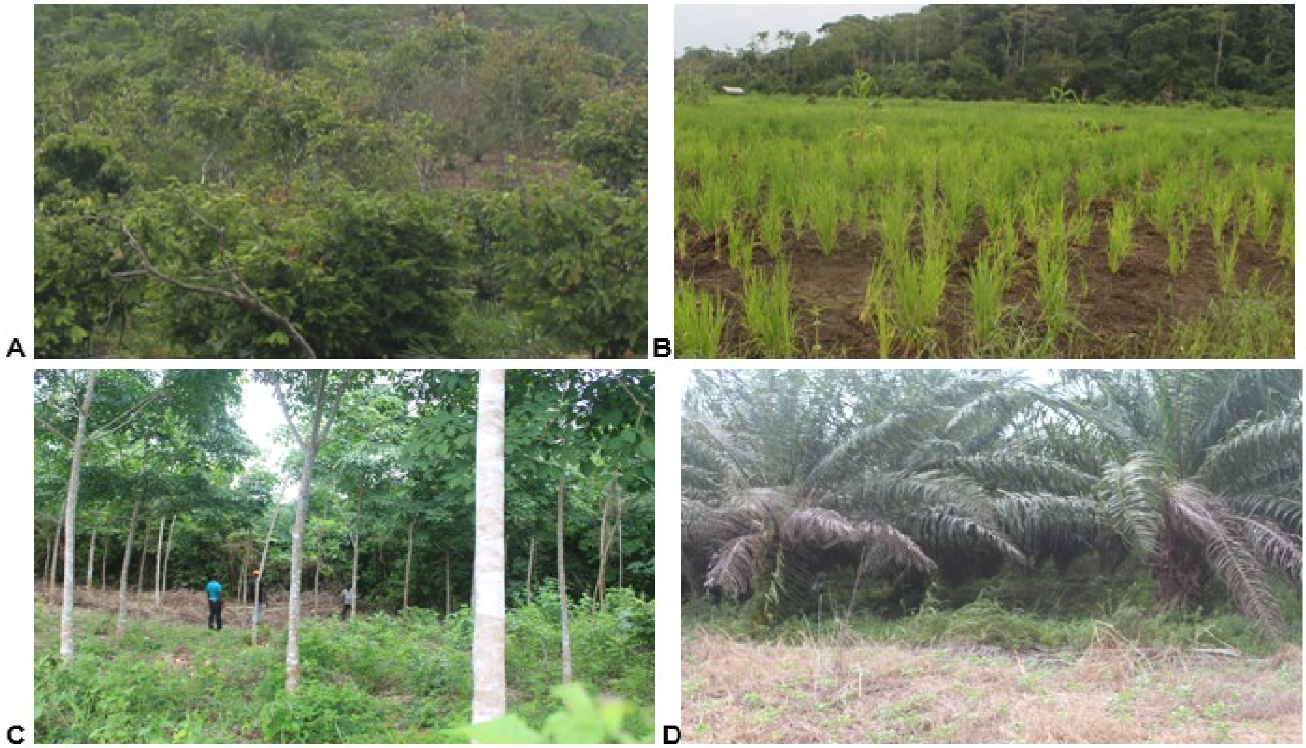

PHOTO 4: PHOTOGRAPHS OF CROPS IN THE FRESCO AREA (PHOTO CREDIT: DR. NADI PAUL DANGUI, 2019)

A: Cocoa plantation in Okromodo classified forest, 2019
B: Rice fields in Port Gauthier classified forest, 2019
C: Rubber plantation near Dassioko, 2019
D: Palm plantation in Dassioko, 2019

Most of the remaining forest exists in the classified forests of Port Gauthier and, to a lesser extent, Okromoudou to the east of the study area. Vigorous action by SODEFOR's Forest Management Unit (FMU) agents has protected most of Port Gauthier classified forest, which contains large trees with well-developed canopies, shelter and large creepers (see Photos 5 and 6).

PHOTO 5: UNDERGROWTH WITH CREEPERS IN PORT GAUTHIER CLASSIFIED FOREST, 2019 (PHOTO CREDIT: DR. NADI PAUL DANGUI)

PHOTO 6: CANOPY OF PORT GAUTHIER CLASSIFIED FOREST SEEN THROUGH THE TOPS OF LARGE TREES, 2019 (PHOTO CREDIT: DR. NADI PAUL DANGUI)

4.2 MANGROVES

As we were unable to obtain a good quality historical image that could be used for a diachronic study of the Fresco lagoon landscape area, we used historical data on mangroves from the 2018 vulnerability assessments. After shrinking continuously for nearly 30 years, there is now very little mangrove left in the Fresco lagoon landscape. Using the baseline situation for ecosystems in this landscape shown in the land-use map below (Figure 11), we estimate that vegetation has degraded by about 10%. Egnankou's 1991 study of the color composite image of SPOT satellite scenes 48/340 and 49/340 taken in the Fresco lagoon landscape in March and December 1988 (1:83 000 scale) provided the information shown on the map, giving estimated levels of vegetation degradation at about 40% east of N'Gni lagoon, 30% south of the lagoon and 20% in the southwest and west (2018 vulnerability assessment).

4.2.1 LAND USE AND LANDCOVER IN 2018

The main type of land use in 2018 was cultivation: just over half of the total study area (50.69%, or 4,295.26 ha) was under crops, and only 12.16% under forest (1,030.14 ha). Other types of land use accounted for less than 40%, with built-up/bare land, marshland and water respectively occupying 6.44% (545.57ha), 13.34% (1,130.50 ha) and 17.36% (1,471.25 ha) of the study area (Figure 10).

The map in Figure 11 below shows that the main concentrations of mangrove in the Fresco lagoon landscape are found along the banks of the Niouniourou river to the east, with scattered clumps in Fanti village in the center and, to a lesser extent, in bays to the west of N'gni lagoon. The mangroves to the east on the banks of the Niouniourou are very tall, with sizeable trunks; while those in the center and west of N'gni lagoon are younger with small trunks, mainly growing in clumps or strips in the bays of the lagoon (Photos 7, 8 and 9).

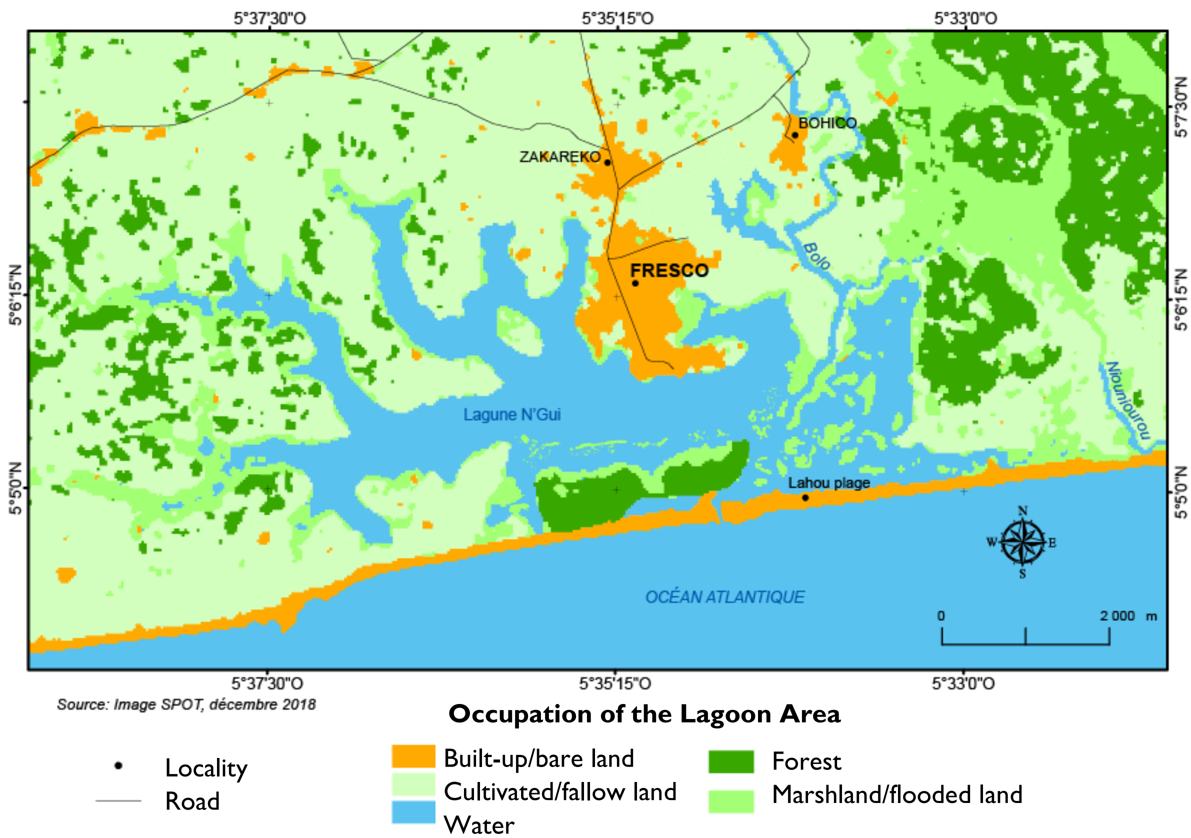

FIGURE 11: MAP OF LAND USE AND LANDCOVER IN THE FRESCO LAGOON LANDSCAPE IN 2018

PHOTO 7: CLUMPS OF MANGROVE IN THE MIDDLE OF NGNI LAGOON (BAHIKORO, UAV TAKEN 28 JUNE 2019)

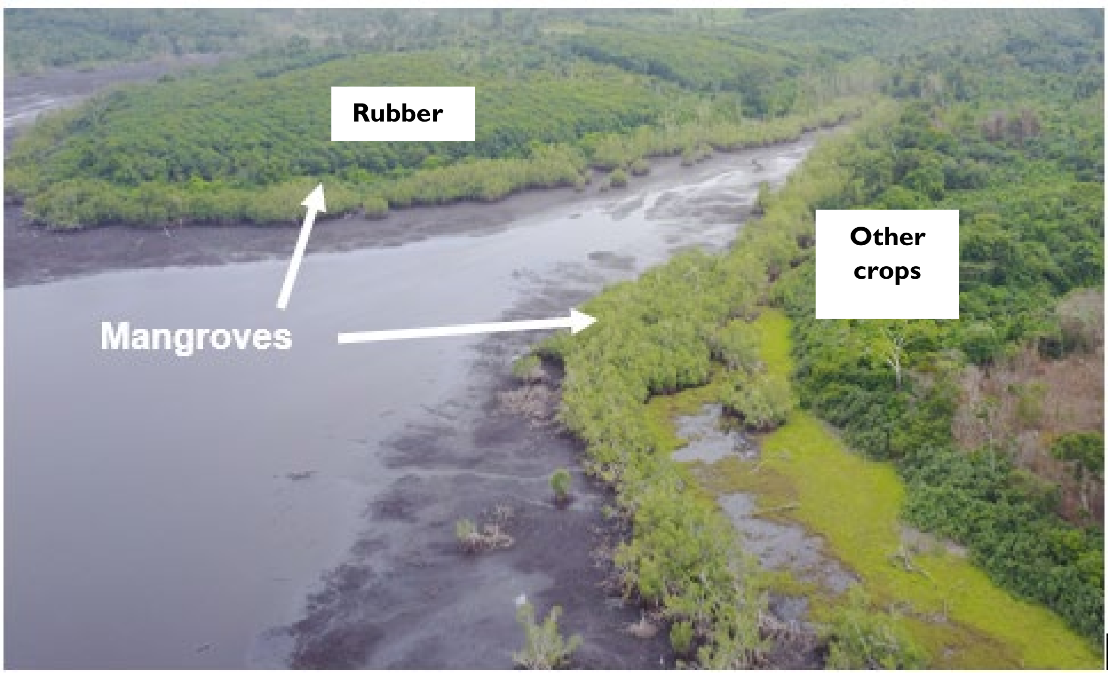

PHOTO 8: BANDS OF MANGROVE ON THE WESTERN BANKS OF NGNI LAGOON (BAHIKORO, UAV TAKEN 28 JUNE 2019)

PHOTO 9: TALL MANGROVE TREES ON THE BANKS OF NIOUNIOUROU RIVER IN THE EASTERN SECTOR OF THE FRESCO LAGOON LANDSCAPE (PHOTO CREDIT: DR. NADI PAUL DANGUI, 2019)

The degradation of mangroves in the lagoon landscape is partly due to harmful anthropogenic actions and partly to the sea, whose impacts can be seen along the shoreline. Mangroves on the beach a few kilometers east of Kpandèdou (Photo 9) are suffering from the impacts of coastal erosion and submersion in seawater (Photo10), as are those in the bays and banks of N'gni lagoon to the west of the lagoon landscape (Photo 11).

PHOTO 10: MANGROVES STANDING IN SEAWATER NEAR KPANDÈDOU TO THE EAST OF THE STUDY AREA (PHOTO CREDIT: DR. NADI PAUL DANGUI, 2019)

PHOTO 11: MANGROVES RETREATING FROM A BAY WEST OF NGNI LAGOON IN FRESCO (PHOTO CREDIT: DR. NADI PAUL DANGUI, 2019)

5.0 CONCLUSION

In order to assess the landscape in the prefecture of Fresco we needed to map land use and occupation in the study area. This was done using remote sensing methods and Geographic Information Systems (GIS), which enabled us to show the dynamics of different types of land use. We needed different types of data to study the dynamics of vegetative cover and make an inventory of mangroves across the prefecture and in the lagoon landscape. Combining existing data with field data gathered during various missions in the field enabled us to better characterize the different types of land cover and land use in the prefecture of Fresco.

The results of this study show that the degradation of forest areas in the study area accelerated between 1990 and 2017, as converting forests to cultivated land resulted in a 56.29% reduction in forest cover.

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