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Status and perspectives of mangrove management in Côte d'Ivoire

Egnankou Wadja Mathieu ¹ and Gnagbo Anthelme ^{2,*}

¹ *Natural Environments and Biodiversity Conservation Laboratory, Biosciences Training and Research Unit, Abidjan, Côte d'Ivoire.*

² *Agricultural Production Improvement Laboratory, Agroforestry Training and Research Unit, Daloa, Côte d'Ivoire.*

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Abstract

Mangroves are ecosystems characteristic of intertidal zones in tropical and subtropical regions. *Rhizophora racemosa*, *Avicennia germinans* and *Conocarpus erectus* are characteristic mangrove species found in Côte d'Ivoire. These mangroves could disappear without being fully studied due to the strong anthropic pressure. This study therefore proposes to establish a detailed cartography of the mangroves reported in Côte d'Ivoire and to model their potential distribution. Mangroves cover approximately 57.92 km², ie a linear coverage of 20.11% of the 540.14 km of coastline. The extent of these mangroves also decreased by 4.91 km² between 1996 and 2016. The maximum entropy model presents low-altitude coastal areas with high rainfall as well as average sunshine as favorable to mangroves. The particular ecological characteristic of mangroves as well as their particular mode of operation deserve to be taken into account in studies of flora in Côte d'Ivoire. It is therefore opportune to consider larger studies focusing specifically on the mangroves present in Ivory.

Keywords : Mangroves; Habitats; Maxent; *Rhizophora racemosa*; Côte d'Ivoire

1. Introduction

Mangroves are ecosystems characteristic of intertidal zones [1] found only in the tropics and subtropics of the Americas, Africa, Asia, Australia and New Zealand. The mangrove soil is hydromorphic, anaerobic and the submersion water is polyhaline. The salt content varies during the year inversely with the freshwater inputs [2]. In this particular environment, plants and animals must develop adaptations in order to survive. For Snedaker [3], living organisms dependent on mangroves cannot survive in any other natural environment.

The flora of a mangrove consists of species adapted to variations in salinity as well as to the absence of oxygen in the soil. The topography of the coasts, the amplitude of the tides and the quality of inland waters, condition the establishment and development of mangroves on acid soils. In an anaerobic environment, the sulphates in sea water undergo the action of sulphate-reducing bacteria and lead to the production of iron sulphides or pyrite (FeS₂), responsible for the formation of acid sulphate soils [4]. Spatial and seasonal variations in salinity impose a zonal arrangement on plant species. The halophytes that grow in this environment tolerate salt levels differently, hence the importance of a permanent supply of fresh water [2]. Schnell [5] describes viviparity as a reproductive characteristic of mangrove plants to ensure rapid establishment of seedlings.

All these ecological requirements allow a limited number of plants to survive in the mangrove. The work of Delevoy [6] counted 28 species belonging to 10 families which are subservient to mangroves. For Chapman (1970), there are 55 species distributed in 16 genera and 11 families in mangroves. Blasco [1] reports 60 tree species distributed between

* Corresponding author: Gnagbo Anthelme

Agricultural Production Improvement Laboratory, Agroforestry Training and Research Unit, Daloa, Côte d'Ivoire

25 genera and 17 families across the mangroves. African mangroves contain around 14 plant species (Egnankou, 1985). In West Africa, there are six species of which only three exist in Côte d'Ivoire. These are *Rhizophora racemosa* G. Mey. (Rhizophoraceae), *Avicennia germinans* (L.) L. (Avicenniaceae) and *Conocarpus erectus* L. (Combretaceae) (Egnankou, 1985).

Mangroves are mentioned in several scientific studies carried out in Côte d'Ivoire. According to Avenard, Eldin [7], mangroves are present on the banks of the estuaries of San-Pedro, the Bolo river near Fresco, the Sassandra river, the Comoé river as well as in the Potou and Ebrié lagoons. Kwassi, Blivi [8] described the mangroves of the Éhotilé Islands. The conservation issues as well as the socioeconomic interests of the mangroves located between Fresco and Grand-Lahou were presented in the work of Egnankou [9]. All of these authors present mangroves as a particular ecosystem threatened with extinction. Mangroves are subject to various anthropogenic pressures and disappear, thus causing enormous ecological imbalances [10]. Once stripped, the banks are subject to the harmful effects of waves and high winds. The mangroves of Côte d'Ivoire could therefore disappear without being fully studied. This study therefore proposes to list all the mangrove sites and then to build a model of potential mangrove distribution in Côte d'Ivoire. This approach will provide updated data on the distribution of mangroves in the Ivory Coast. This work is also the first in a series of studies aimed at improving knowledge of Ivorian mangroves for sustainable management of this habitat.

2. Methodology

2.1. Collection of data

The GBIF site (www.gbif.org consulted on 11/2/2019) was visited in order to identify the occurrences of *Rhizophora racemosa* recorded in Côte d'Ivoire. The work of Simard, Fatoyinbo [11] as well as Goldberg, Lagomasino [12] available online were consulted to extract statistics on the distribution of mangroves in Côte d'Ivoire. The bibliography on mangroves [1, 2, 8-10, 13] made it possible to complete the information on the different mangrove sites.

The physical and ecological characteristics of mangroves were also taken into account. The digital terrain model of Côte d'Ivoire available at <http://www.worldclim.org> (consulted on 2/11/2019) made it possible to extract the different altitudes. Precipitation, temperature, humidity and vegetation index (NDVI) data were obtained from <http://iridl.ldeo.columbia.edu> (accessed 11/2/2019).

2.2. Data analysis

A compilation of information collected in the bibliography as well as online data [11, 12] made it possible to assess the mangrove areas reported in Côte d'Ivoire. Conservation levels have been taken into account. Seventeen sites have been identified as harboring mangroves. The geographic coordinates of these sites were digitized in order to establish a model of the potential distribution of mangroves in Côte d'Ivoire.

To identify areas potentially favorable for the establishment of mangroves in Côte d'Ivoire, environmental variables likely to influence the presence of *Rhizophora racemosa* were taken into account through the maximum entropy program (Maxent) version 3.3.3 [14]. *Rhizophora racemosa* occurrence data were compared to environmental variables. These are altitude, NDVI, humidity, precipitation standard deviations, temperature standard deviations, maximum precipitation, minimum precipitation, average precipitation, maximum temperature, minimum temperature, and average temperature. These are raster files that have been reduced to the same extent and to a resolution of 30 meters. The ArcGis 10.6 software made it possible to convert these different files into ASCII (American Standard Code for Information Interchange). A Pearson correlation test was applied to measure the links between the different environmental variables.

The influence of these environmental variables on the prediction of mangroves was achieved using the maximum entropy model [14] via the Maxent interface [15]. A 75% subset of the presence points of *Rhizophora racemosa* was used to calibrate the model, and the remaining 25% subset of the presence points was used for the test. The "Subsample" method was used with 15 repetitions to downsample the presence data sets to assess model performance. This method allows you to randomly reselect a combination of different points each time the test is repeated. The maximum number of 5000 iterations has been defined for the model.

For the validation of the results, the performance of the models was evaluated using the ROC (Receive Operating Characteristic) curve method, which provides a measure of the power of classification of a model between real presence and real absence [16]. AUC (area under the curve) is interpreted as the probability that a randomly chosen presence point is located in a raster cell with a greater probability of species occurrence than a randomly generated point [15].

An AUC value of less than 0.5 indicates that the run model is no better than random, while a value considerably greater than 0.5 indicates better discrimination [17]. All the areas for which the AUC is greater than 0.5 were calculated using "arctools" from the ArcGis 10.6 software to determine the total area favorable to the establishment of a mangrove in Côte d'Ivoire.

3. Results

The documentary review carried out provided access to the information available on mangroves in Côte d'Ivoire. The area of mangroves in Côte d'Ivoire is estimated at 57.92 km² in 2016. This represents a linear coverage of 20.11% of the 540.14 km of coastline. This mangrove sprawls along a coastline of 108.63 kilometers out of a total of 431.51 kilometers of coastline in the Ivory Coast. The extent of these mangroves decreased by 4.91 km² between 1996 and 2016. The mangroves extend from the region of San-Pedro in the southwest to Assinie in the southeast. The most important mangrove areas are located between longitudes 2 ° 50 'and 7 ° 59' West and latitudes 4 ° 30 'and 5 ° 40' North.

The mangroves of Côte d'Ivoire come in three types of plant associations. There are monospecific mangroves with *Rhizophora racemosa*. Then, degraded mangroves with *Avicennia germinans* alone, with companion species *Paspalum vaginatum* Sw. (Poaceae). Finally, there are mangroves with two species of mangrove trees, *Avicennia germinans*, succeeding *Rhizophora racemosa* towards the mainland. All these mangroves are generally accompanied by characteristic species. We observe in the mangroves around the lagoons of Fresco and Grand-Lahou a herbaceous formation where *Paspalum vaginatum* represents, according to the site, between 95 and 100% of the vegetation cover. *Drepanocarpus lunatus* (L. f.) G. Mey formations are also observed there. (Fabaceae) and *Dalbergia ecastaphyllum* (L.) Taub. (Fabaceae) contiguous to mangroves. These environments contain shrub and tree species which are among others, *Hibiscus tiliaceus* L. (Malvaceae), *Acrostichum aureum* L. (Pteridaceae), *Caesalpinia bonduc* (L.) Roxb. (Caesalpiniaceae), *Nauclea latifolia* Sm. (Rubiaceae). In the Éhotilé Islands in Assinie, the species *Mariscus ligularis* (L.) Urb. (Cyperaceae), *Cyperus articulatus* L. (Cyperaceae) and *Pycreus polystachyos* (Rottb.) P. Beauv. (Cyperaceae) to which must be added *Ethulia conyzoides* L. f. (Asteraceae), *Echinochloa pyramidalis* (Lam.) Hitchc. & Chase (Poaceae), *Sporobolus virginicus* (L.) Kunth (Poaceae), *Fimbristylis thonningiana* Boeckeler (Cyperaceae) and *Fuirena umbellata* Rottb. (Cyperaceae) are very common in mangroves.

The areas favorable to the establishment of mangroves is obtained after comparing the environmental parameters with the points of presence observed (Figure 1). These cover a total area of 1333.68 km². Sites reported favorable to the presence of mangroves are the mouth of the Cavally River on the border with Liberia, the San-Pedro region, the mouth of the Sassandra River and the coastal strip from Fresco to the border with Ghana.

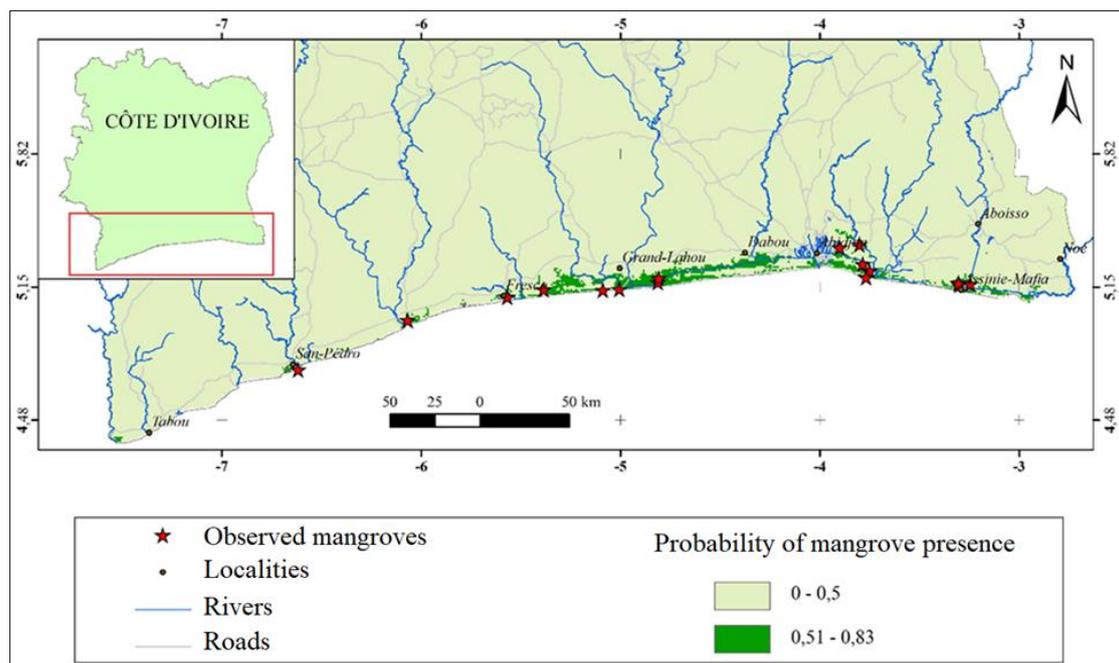


Figure 1 Mangroves location and favorable areas in Côte d'Ivoire

The mean value of AUC obtained by the maximum entropy model is 0.995 with a standard deviation of 0.002. The variables that best contribute to the construction of the model are altitude (82.1%), mean temperatures (6.4%) and minimum precipitation (5.2%). Each of the other environmental variables has a contribution value of less than 3%.

Figure 2 presents the different influences of environmental variables on the presence of mangroves. For a minimum rise in altitude, the probability of the presence of a mangrove becomes zero. We deduce that altitude has a limiting effect on the establishment of a mangrove. The probability of the presence of a mangrove changes inversely with the rise in average temperatures. The high average temperatures are also becoming a factor limiting the presence of mangroves. Regarding minimum rainfall, we observe that an increase in values, and therefore an increase in rainfall, favors the establishment of mangroves.

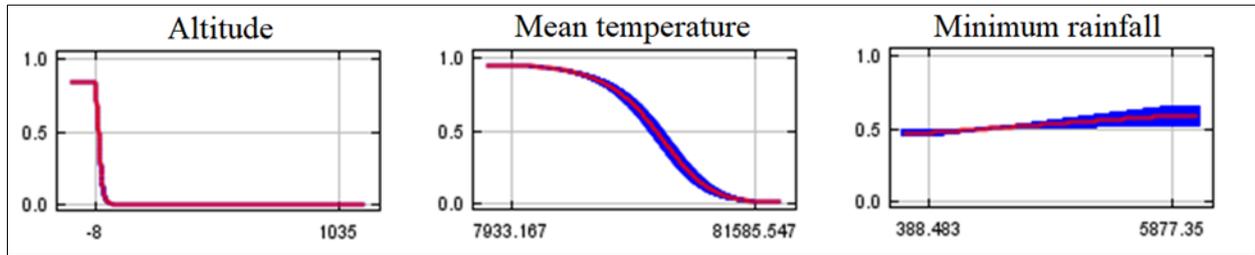


Figure 2 Influences of environmental variables on the mangrove’s presence

Figure 3 presents the influence values of the variables in the Jackknife test in the prediction of favorable areas for mangroves. We can see that the variable that increases the AUC gain when used alone is altitude. It is also this same altitude variable that decreases the AUC gain the most when omitted. It is therefore the altitude that provides the most information to the model compared to all the other environmental variables.

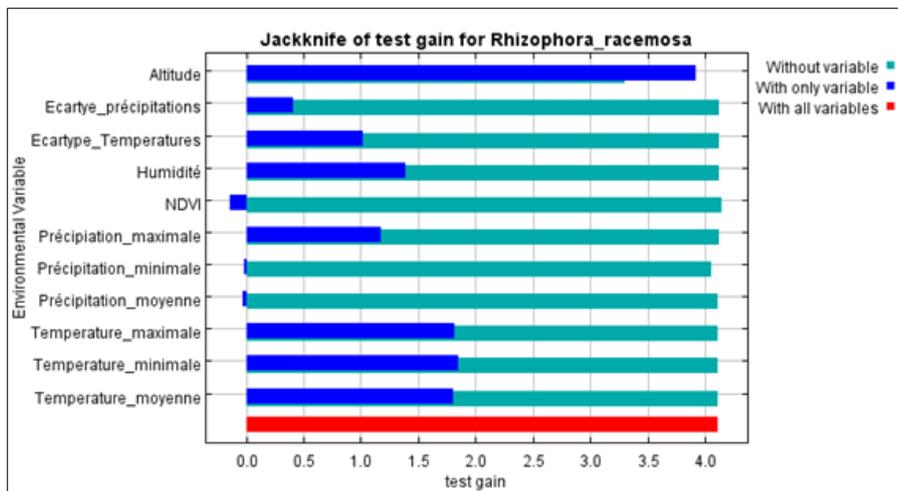


Figure 3 Contribution of variables to the Jackknife test

4. Discussion

Hydromorphic forests and mainly mangroves have been the subject of study in Côte d'Ivoire for several decades [6, 7, 18]. These various works have highlighted the importance of mangroves in the interactions between water, soils, topography, micro-organisms, plants and animals. These wetlands constitute, thanks to their hydrological functions, one of the important elements of water resources management [13]. In these mangroves, hydrophytes participate in the oxygenation of water through photosynthesis, and contribute to the purification of the environment by absorption or fixation of dissolved mineral elements. Mangroves therefore play an important role in water pollution control. Mangroves also serve as spawning grounds for many species of fish [2]. Despite this great ecological importance, the mangrove is a fragile ecosystem that is subject to many anthropogenic pressures.

The Ivorian mangroves in general and those between Fresco and Grand-Lahou, are threatened with disappearance [9]. According to this author, entire stations have already disappeared and then replaced by meadows with *Paspalum*

vaginatum. The mangroves located between Grand-Lahou and Assinie are also subject to overexploitation which also leads to the disappearance of several stations, especially in the region of Grand-Bassam [2, 10]. The Azuretti mangrove, which contained a large fringe of *Conocarpus erectus* in back-mangrove swamps with populations of *Avicennia germinans*, has disappeared [19]. The gray mangrove (*Conocarpus erectus*) is no longer found in these regions where coconut groves and other subdivisions have significantly encroached on the mangrove ecosystem. In the regions of Fresco and Grand-Lahou, the reduction in the area of the mangrove ecosystem has led to a reduction in fishery resources [20]. The loss of mangrove areas continues to continue for Goldberg, Lagomasino [12] who estimate that the extent of mangroves in Côte d'Ivoire decreased by 4.91 km² between 1996 and 2016.

In this study, AUC was chosen to assess the robustness of the model because it measures the quality of the prediction and the accuracy of the model regardless of the classification threshold selected [14]. The high value of AUC therefore shows a good prediction of the model. Despite anthropogenic pressure on mangroves, the prediction model established shows that habitats favorable to the establishment of mangroves cover large areas. We can therefore say that a recovery of mangroves on deforested sites remains possible. It is observed that the mouth of the Cavally River at the border with Liberia is reported as a potentially favorable area for the establishment of a mangrove. However, the literature consulted did not allow us to report the actual presence of mangroves in this area. It is therefore possible in future work to verify the effectiveness of the presence of mangroves in this area.

The maximum entropy model presents mangroves as favorable to low-altitude coastal areas with high rainfall as well as average sunshine. These ecological characteristics have already been defined in several scientific works. Egnankou [2] presents mangroves as ecosystems subservient to the intertidal zone. Low and high tide movements therefore determine the natural habitat of a mangrove. Mangroves are also fragile ecosystems which are easily influenced by variations in the ecological environment [21, 22]. The particular ecological characteristics of mangroves as well as the functioning of this type of ecosystem deserve to be taken into account in studies of flora in Côte d'Ivoire. It is therefore opportune to consider larger studies focusing specifically on the mangroves present in Ivory.

5. Conclusion

Mangroves are present on the coast in Côte d'Ivoire. These habitats play a critical ecological role in coastal areas. Mangroves also provide ecosystem services to local people. These are favorable areas for the reproduction of several marine and continental aquatic animal species. Despite their importance, these mangrove ecosystems are adversely affected by human activities which ended up destroying approximately 4.91 km² of their area between 1996 and 2016. Despite these losses, the area of mangroves in Côte d'Ivoire remains estimated at 57.92 km² in 2016. These mangroves appear in three types of plant associations with the characteristic species *Rhizophora racemosa* and *Avicennia germinans*.

The areas favorable to the establishment of mangroves cover a total area of 1,333.68 km² on the entire Ivorian coast. Mangroves are found in the intertidal zones of low altitudes. The altitude is presented as the major environmental factor that determines and limits the establishment of a mangrove. Rainfall and sunshine are secondary factors that are also involved in the characterization of mangroves. The maximum entropy model produced presents altitude as the environmental variable that provides the most information for the prediction of areas favorable to mangroves.

Compliance with ethical standards

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Disclosure of conflict of interest

The research team emphasizes that there is no conflict of interest for this study.

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