



## APPLICATION OF GEOMATICS TO THE MULTICRITERIA ZONING OF THE UPPER ALIBORI FOREST RESERVE IN NORTHERN BENIN (WEST AFRICA)

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### Summary

The Forest of Upper Alibori is subject to strong agricultural and pastoral pressures from year to year despite the implementation of a forest management plan. It is therefore appropriate to conduct an integrated and spatialized analysis of the effects of these pressures on plant biodiversity from a spatial planning perspective. The research objective is to establish a multi-criteria zoning of the Upper Alibori Forest Reserve that can reconcile biodiversity conservation and sustainable agropastoral exploitation. A methodological approach based on geomatics was adopted. Hierarchical multi-criteria analysis and cross-layer analysis are the main techniques adopted. The state of plant biodiversity, one of the important criteria for multi-criteria zoning. The intersection of the scientific zoning and the zoning proposed by the riparian population shows a similarity of 54%. In the central core, the similarity between the two types of zoning is 32%. Spatially, this similarity is observed along the Alibori River. At the level of the agricultural series, the two zonings show a similarity level of 23%. The elaboration of an integrated zoning made it possible to distinguish several management series. The management series delimited are made up of the central core (32%), the protection series (11%), the production series (17%), the scientific research series (2%), the service series (2%) and the agropastoral and reforestation series (36%). The implementation of such zoning is the responsibility of the forest administration.

### Keywords

pressures • biodiversity • geomatics • management • Upper Alibori forest reserve • Benin

### 1. Introduction

In sub-Saharan Africa, deforestation rates accounted for 13% of forest cover globally between 2001 and 2015. The main driver of deforestation in tropical regions is shifting agriculture, which accounts for up to 92% of deforestation [FAO 2016].

In the north of Benin, there are most of the protected areas designed to conserve plant biodiversity. It is still this part of Benin that constitutes the economic lung of the country with the production of cotton. In northern Benin, there is a real tension between conservation and economic development objectives.

The forest reserve of Upper Alibori is located in this part of Benin which constitutes the cotton farming zone. This protected area is surrounded by the major cotton producing Districts of Banikoara, Kandi, Kérou, Gogounou, Ouassa-Péhunco and Sinendé. The forest reserve of Upper Alibori benefited from a Participatory Management Plan in 2010, developed for a period of 10 years with the support of the Forests and Riparian Lands Management Program (PGFTR). This forest management plan aimed to control anthropic pressures in this forest reserve, to restore degraded areas, to contribute to the maintenance of biodiversity while advocating for sustainable natural resource exploitation systems [DGFRN 2010]. Ten years after the implementation of this management plan, the forest reserve of Upper Alibori is increasingly threatened by agriculture, extensive cattle ranching, and illegal logging [Issiako 2021]. The protection of the forest reserve of Upper Alibori and the conservation of biodiversity is incompatible with the geographical location of this forest in the heart of the cotton farming zone of Benin. Agropastoral exploitation of this forest reserve observed in 2000 by Akindélé [2000], in 2002 by Arouna [2002], in 2010 by Danko [2014] has continued and increased [Assani Seidou et al. 2017, Issiako et al. 2018, Mama et al. 2020] despite a decade of implementation of the management plan. Deforestation and forest degradation continue in forest reserve of Upper Alibori despite the management plan developed with the participation of different stakeholders.

A fundamental issue is the spatial reorganization of this forest reserve management using a holistic geomatics-based approach after a decade of implementation of a forest management plan that has failed to conserve biodiversity.

The objective of this research is to develop a multi-criteria zoning of the forest reserve of Upper Alibori based on geomatics applications. The research hypothesis states that there is a difference between zoning based on scientific criteria and that emanating from the aspirations of local people.

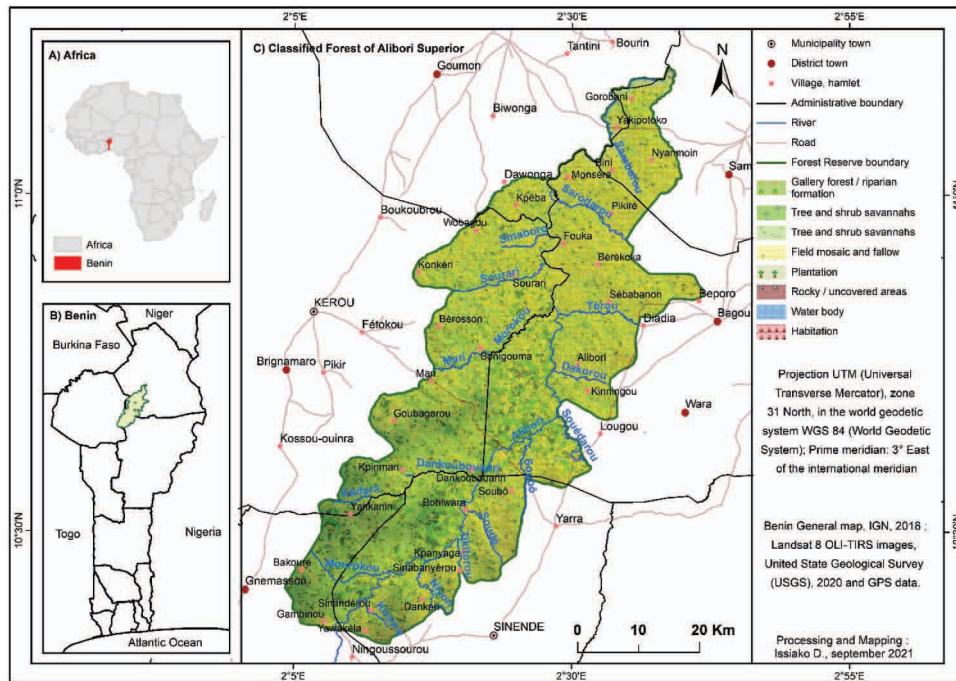
## 2. Materials and methods

### 2.1. Study site

The forest reserve of Upper Alibori straddles the Provinces of Atacora, Borgou and Alibori. It is located 10°14' and 11°40' north latitude and 1°54' and 2°55' east longitude. It extends over six districts, namely: Banikoara, Gogounou, Kandi, Kérou, Ouassa-Péhunco and Sinendé, with an area of 256 ha (DGFRN, 2010). Figure 1 shows the geographical location of the Upper Alibori forest reserve.

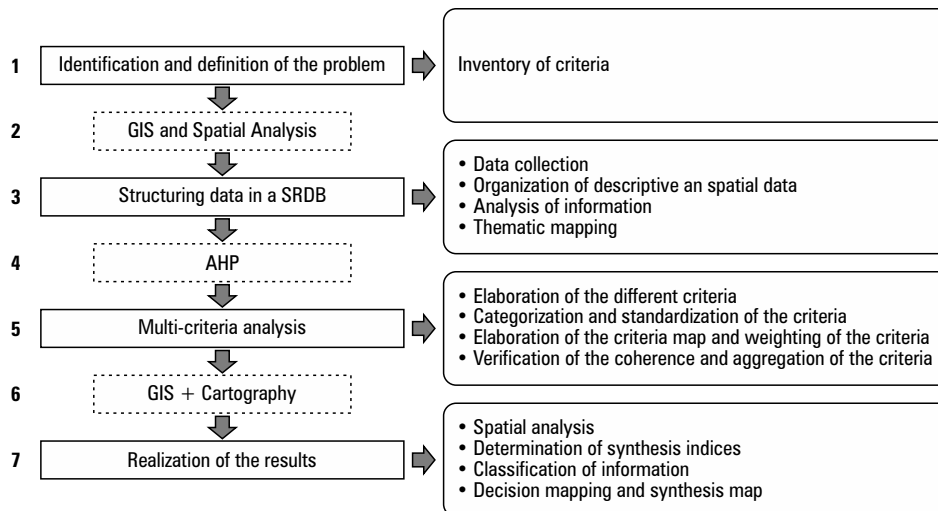
### 2.2. GIS integration and hierarchical multi-criteria analysis process

Mapping combined with the Hierarchical Multi-criteria Analysis (HMA) approach is the methodological approach adopted to conduct this research (Fig. 2).



Source: Authors' own study

Fig. 1. Geographic location of the Upper Alibori forest reserve



Source: Own elaboration following the decision-making process with the analytical hierarchical process of Saaty [1984]

Fig. 2. GIS and HMA integration process for spatial decision support

### 2.3. Criteria weighting

Table I below presents the summary of the weightings and their meaning. Note that the criterion stream distribution was not weighted because the water resource is distributed almost uniformly throughout the Forest Reserve of Upper Alibori.

**Table 1.** Weighting of selected criteria

Criterion	Level of importance	Definition	Explanation
Specific diversity	1	Not very diversified	Vegetation formations with little diversity. These are fields, fallows, and plantations.
	2	Moderately diversified	Abundant formations. These are gallery forests.
	3	Diversified	Diversified vegetation formations. These are open forests and wooded savannahs and tree and shrub savannahs.
Density of woody plants	1	Low density	Low densities (1 to 55 trees/ha) are obtained in tree and shrub savannahs, plantations, fields, and fallows, settlements, and rocky surfaces.
	2	Medium density	The values from 55 to 126 trees/ha are characterized as medium and obtained in the class of dense dry forests, open forests, and wooded savannahs.
	3	High density	The high densities are obtained in the class of gallery forests with values from 126 to 153 trees/ha.

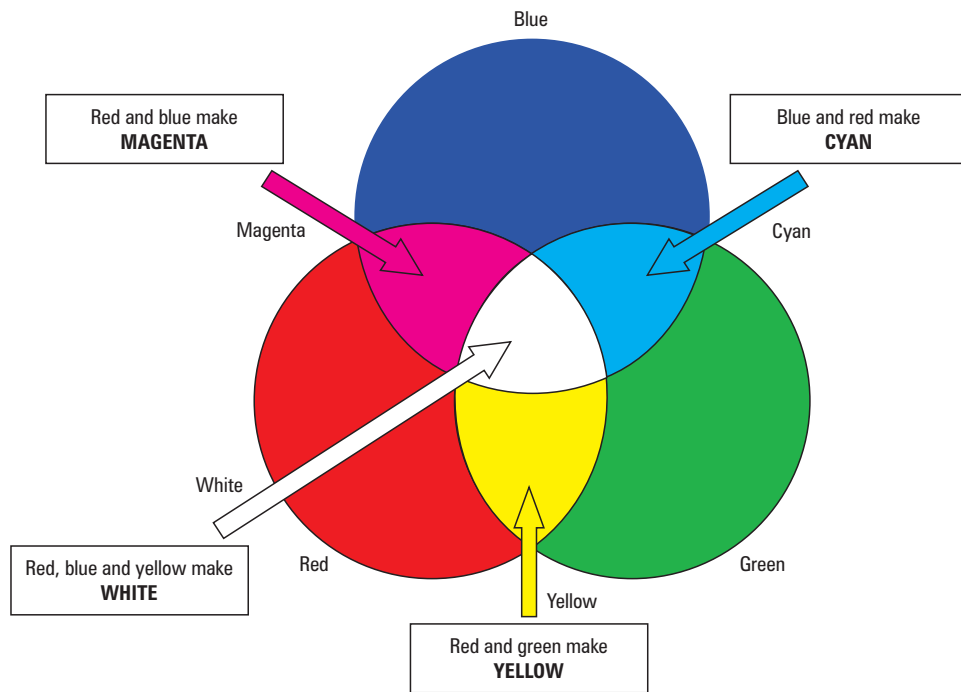
### 2.4. Color theory and criteria weighting

The color theory was used in the framework of the card crossing. The colors located halfway between the primary colors and obtained by mixing the adjacent colors correspond to the secondary colors by additive synthesis (Fig. 3).

The additive synthesis by superposition of the red, the green and the blue to obtain the white color. Their addition two by two makes it possible to obtain the secondary colors, namely: blue, green, cyan, magenta, yellow and red. Table 2 shows the combination of colors and the different weighted values.

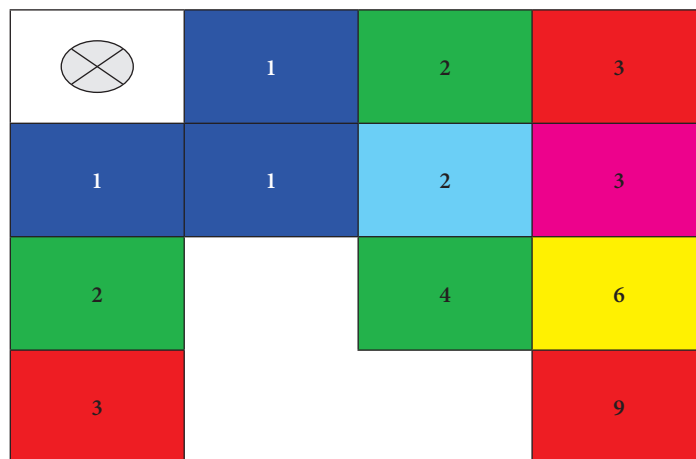
The weighting scale of the criteria was made the extension spatial analyst tool > Map algebra > raster Calculator. The matrix of combination of colors and scale of raster Calculator (Spatial Analyst) is presented by Figure 4.

Figure 3 shows the crossing of the primitive colors (blue (1), green (2) and red (3) to obtain the secondary colors. These colors are blue (1), cyan (2), magenta (3), green (4), yellow (6) and red (9). The explanation of the scales proposed by the raster Calculator (Spatial Analyst) according to Thomas SAATY (1984) is in Table 2.



Source: Authors' own study

Fig. 3. Combination of the colors



Source: Authors' own study

Fig. 4. Color combination matrix and raster calculator scale

**Table 2.** Scale proposed by raster Calculator (Spatial Analyst)

Levels of importance	Explanation
1	Low importance: two characteristics contribute equally
2	Low importance: personal experience and appreciation slightly favor one characteristic over another.
3	Strong or decisive importance: experience and appreciation strongly favor one characteristic over another.
4	Moderate importance: two characteristics contribute equally.
6	Strong or proven importance: one characteristic is strongly favoured, and its dominance is proven in practice.
9	Absolute importance: the evidence favouring one characteristic over another is as convincing as possible.

Source: inspired by Thomas Saaty (1984) scale table

## 2.5. Reclassification and crossing of the various maps

The identification of the most suitable areas for the conservation of the plant biodiversity was done by successively crossing the synthesis maps. Cross-referencing the maps also means cross-referencing the scores previously defined in Table 1 in order to give the appropriate characteristics to each area.

## 3. Results

### 3.1. Map of plant communities

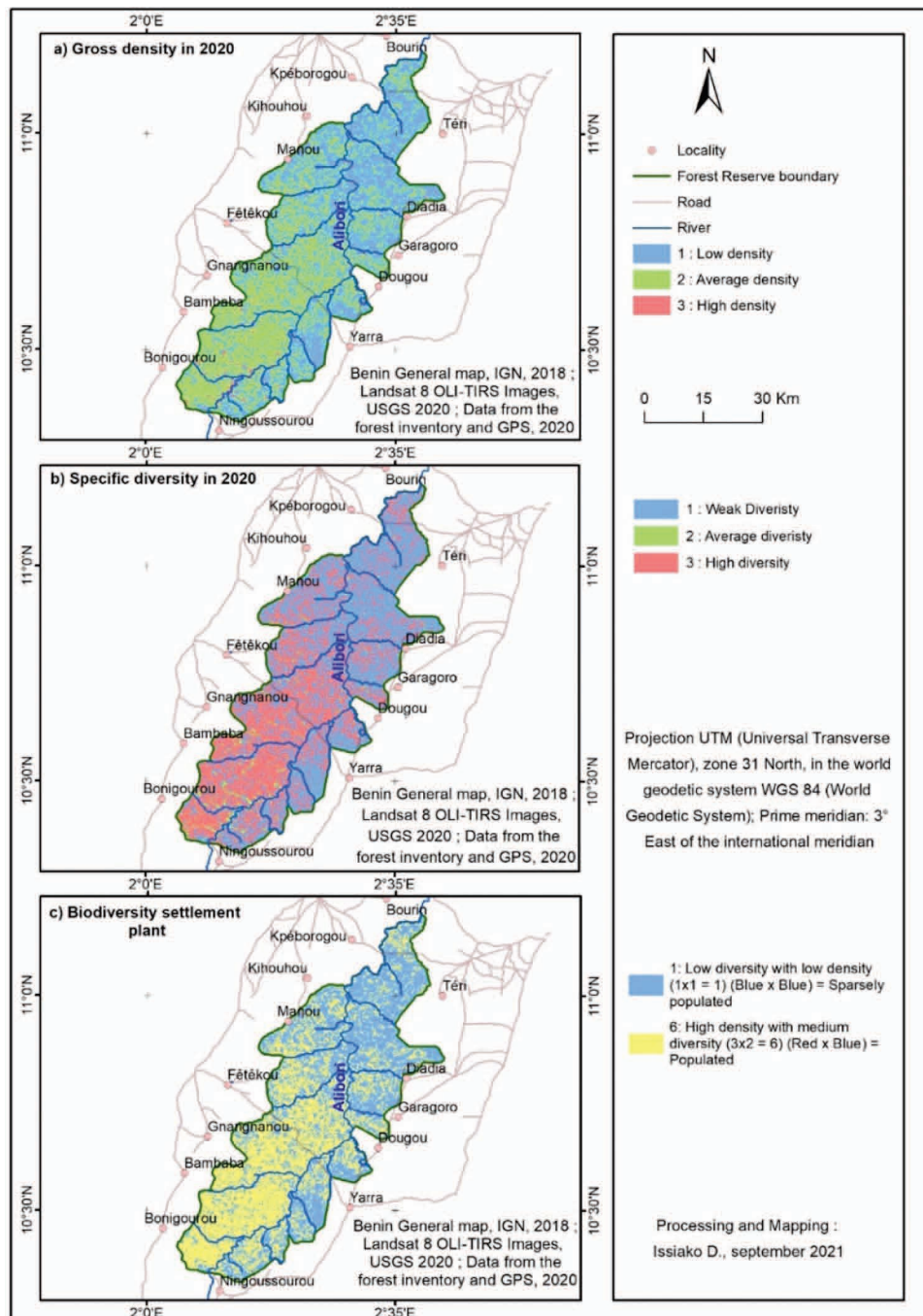
After the reclassification, the map crossings were performed. The crossing of the specific diversity map and the gross density map resulted in the stand map (Fig. 5).

This map shows the state of plant biodiversity, one of the important criteria for multi-criteria zoning.

### 3.2. Delineation of management zones based on the criteria

Figure 6 shows the minute zoning map obtained from the intersection the plant communities map and the management zone delineation map.

The observation of Figure 6 shows that the delimitation of the management series is based on the summary map. The management series delineated are the central core (32%), the production series (16%), the pastoral series (12%), the protection series (10%), the reforestation series (3%), the scientific research series (2%), and the service series (2%).

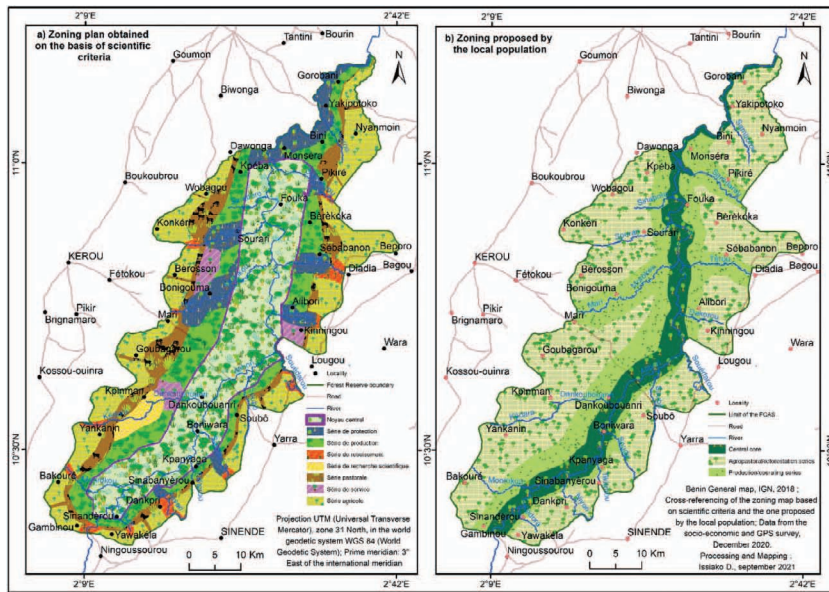


Source: Authors' own study

Fig. 5. Cross-referencing of species diversity and gross density maps: stand map

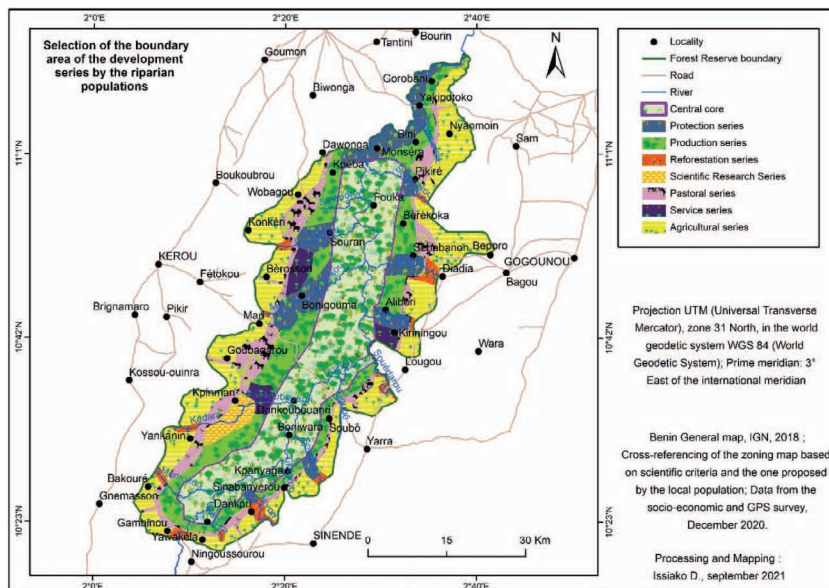






Source: Authors' own study

Fig. 7. Zoning based on scientific criteria and zoning proposed by the local population of the Upper Alibori Forest Reserve



Source: Authors' own study

Fig. 8. Integrated zoning of the Upper Alibori forest reserve

#### 4. Discussion

The spatial analysis of the Upper Alibori Forest Reserve has highlighted potential areas for biodiversity conservation. The analysis of the Shannon diversity index shows that woodlands and tree and shrub savannahs are the most diverse [1.73 – 2 bits] with a score equal to 3. Gallery forests are moderately diverse with a Shannon index that varies between [1.66 – 1.73 bits] and the score is equal to 2. Finally, field, and fallow mosaics, plantations are weakly diverse ( $\leq 1.60$  bit) with a score equal to 1. These values of Shannon index observed in forests and savannahs testify to the degree of specific diversity of the occupied areas. This high diversity index also confirms the importance of the ecological potentialities of the study area [Gning 2008].

The plant community map resulting from the cross-referencing of the density map with the diversity map reveals that the southwest and central areas are populated and diverse. This observation is also made by Ngom et al. [2012], the less anthropized the area the more populated it is. The peripheries of the forest are the low diversity areas. These low values in the peripheries confirm that plant species are highly threatened by the anarchic installation of fields. In other words, there is a huge conflict between the objective of conservation and local economic development, especially agriculture and extensive livestock. This conflict of objectives is materialized by the zoning maps resulting from the crossing of the thematic maps and the zoning map proposed by the riparian populations. The differences can be seen especially in the central core intended for biodiversity conservation and the agricultural and pastoral zones. This difference in terms of area is 46%. The research hypothesis that there is a difference between zoning based on scientific criteria and that emanating from the aspirations of local populations is thus verified.

A new alliance between the flora, vegetation, waterways, soil, and landforms that make up the natural environment allowed the delineation of potential conservation zones in the Upper Alibori forest reserve. This seems to be one of the preferred ways to manage biodiversity for sustainable development and to prevent the explosion of multiple conflicts [Ngom et al. 2012].

#### 5. Conclusion

The combination of spatial information analysis and hierarchical multi-criteria analysis (HMA) has allowed us to evaluate potential areas for forest resource conservation for decision support. This is a more thorough and objective scientific approach. It is based on raw data on flora, vegetation, soil, waterways, and terrain. This raw data was spatialized, reclassified and cross-referenced in an objective manner. Six development series were delineated and validated.

The zoning proposed by the riparian populations includes three series. There is an opposition between the zoning based on scientific criteria and that of the local populations, attesting the tension between the objectives of conservation and those of local economic development.

The emergence of rational management of forest resources, in order to respond to environmental challenges and socio-economic issues, must reconcile scientific zoning with the zoning desired by local populations. This consideration is the main contribution of this article.

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