Acadlore Transactions on Geosciences
https://www.acadlore.com/journals/ATG

Spatio-Temporal Dynamics and Degradation Factors of the Association for Forestry and Environmental Education Forest Massif in Cameroon

Kitio Zangue Ariane Sorelle[1,2*], Laëtitia Faivre[2], Pierre Valade[2], Yves Faivre[2], Adamou Souleymanou[1], Chimi Djomo Cédric[3]

[1] Regional Center for Specialized Training in Agricultural, CRESA Forestry-Wood, 8114 Yaoundé, Cameroon
[2] Association for Forestry and Environmental Education (AFEE), 17 Rue Jean Mermoz 39100 Dole, France
[3] Institute of Agricultural Research for the Development (IRAD), 136 Yokadouma, Cameroon

[*] Correspondence: Kitio Zangue Ariane Sorelle (zanguearianne83@gmail.com)

Received: 07-28-2024 **Revised:** 08-30-2024 **Accepted:** 09-10-2024

Citation: K. Z. A. Sorelle, L. Faivre, P. Valade, Y. Faivre, A. Souleymanou, C. D. Cédric, "Spatio-temporal dynamics and degradation factors of the association for forestry and environmental education forest massif in Cameroon," *Acadlore Trans. Geosci.*, vol. 3, no. 3, pp. 135–144, 2024. https://doi.org/10.56578/atg030303.

Abstract: This study investigates the landscape dynamics and management practices affecting the Association for Forestry and Environmental Education (AFEE) forest massif, located in the monomodal agroecological zone of Cameroon. Using remote sensing data, including Landsat 8 imagery from 2014, 2019, and 2024, in conjunction with field observations, the spatio-temporal changes in land use over the past decade were mapped. Additionally, interviews were conducted with 30 local residents selected through snowball sampling to assess their perceptions of the forest's degradation and the impact of their livelihood activities on the surrounding environment. The results reveal a significant decline in the forest's ecological integrity, with the AFEE massif, originally covered entirely by mature secondary forest in 2014 (200 ha), experiencing a 77.7% reduction in forest cover by 2024. This loss has been primarily replaced by anthropogenic land uses, including young secondary forests (22.9%, 45.95 ha), swamps (17.6%, 35.35 ha), fallow lands (16.8%, 33.7 ha), rubber and oil palm plantations (1.46%, 2.91 ha), and agricultural plots (18.7%, 37.48 ha). Activities such as agriculture, hunting, artisanal sawmilling, and fishing, although central to the livelihoods of local people, have contributed significantly to the degradation of the natural landscape. These practices, while essential for local economic well-being, have negatively impacted the forest ecosystem. Given the critical role of the AFEE massif in environmental education, these findings are essential for the development of strategies that can balance the conservation of natural ecosystems with the socio-economic needs of local populations. The results underscore the need for integrated management approaches that promote both environmental preservation and sustainable livelihoods to ensure the continued provision of ecosystem services for future generations.

Keywords: Landscape dynamics; Human activities; AFEE; Cameroon; Land use change; Forest degradation

1 Introduction

Forests are an important source of ecosystem goods and services, particularly in terms of agricultural services, timber forest products and non-timber forest products (NTFPs) that are useful for the well-being of people living near these forests [1]. Economically, they contribute to increasing the income and cash money of local populations nearby [2]. Ecologically, these forests play an important role in soil, air and water regulation. In short, they are important in maintaining the balance of biogeochemical cycles [3, 4]. These forests also help to preserve exceptional biodiversity among many of them which are under threat [5]. They also contribute to mitigating the effects of climate change through their potential to store large quantities of atmospheric carbon (CO_2) [6]. From a socio-cultural point of view, these forests represent for many people the sacred places; they are also the places of recreation and tourism [7]. Despite the many services provided by forests to humanity, they are currently suffering from an alarming anthropogenic threat that is compromising their multiple functions. According to the Food and Agriculture Organization (FAO) [2], Africa recorded the highest annual rate of forest loss over the period from 2010 to 2020, with a loss of 3.9 million hectares of forest. This loss would be caused by the allocation of forest land to other uses, including agriculture.

In Cameroon, agricultural development is one of the human activities that have a real negative impact on forest ecosystems [8], despite the fact that it contributes to local, national and international economic development while reducing poverty in rural and urban areas of developing countries [9]. In rainforest zones with monomodal rainfall or agro-ecological zone 4 (AEZ4), forests have largely disappeared in favor of rubber, oil palm and banana-plantain agro-industries [10]. This is the result of favorable agro-ecological conditions, cheap land and the Cameroonian government's desire to develop the agro-industrial sector [11]. Cameroon's economy has therefore been based on agro-sylvo-pastoral activities for many years [12]. At a socio-cultural level in this AEZ4, the expansion of oil palm and the economic stakes involved now have an impact on the perception of local populations. Indeed, owning a palm grove seems to be a social necessity and is often part of a rationale for affirming success within the village of origin in the Douala-Edea zone located in AEZ4, for example [13].

Faced with this situation, both the government and civil society are committed to strategies to preserve forest ecosystems in this area. Several initiatives have been taken to remedy the situation. Thus, in the district of Dizangué, which is a highly threatened area where a large part of the natural ecosystems has practically been destroyed for the benefit of various agricultural activities, a 200-hectare forest massif was erected in 2016, dedicated to environmental education with the help of the chiefs of cantons and villages in order to develop a pilot project for forest protection and management. This site is under the management of the AFEE of Cameroon, an association created in 2016 on the initiative of a group of women and men of French, German and Cameroonian origin, whose main aim is to preserve the exceptional ecosystems of southern Cameroon, while proposing sustainable management models for local populations. This AFEE site is particularly interesting because it appears to be the one of the sites in this zone that have preserved its natural landscape and resources. Rich in biodiversity and ecosystem services, the site serves as a key location for environmental education initiatives aimed at fostering local engagement in forest conservation. These efforts are designed to ensure that local populations actively contribute to the sustainable management and preservation of the forest for future generations.

With a view to defining management and environmental education strategies for this site, it is crucial to assess its ecological dynamism. If a sustainable management mechanism for this massif is to be put in place, it is vital to have data on the processes of land use change, using remote sensing, direct observation and surveys of local populations, aiming to identify the causes of these changes. A number of studies have shown that the use of the Geographic Information System (GIS) as a methodological tool is one of the vital tools for defining sustainable land management strategies, especially when it is complemented by the identification of the causes of these changes, which are easily perceptible to the people who live there [14, 15]. Within this context, the aim of this current study is to assess the changes in land use over the last ten years and people's perceptions of land use and management systems in the AFEE forest massif in Cameroon, using data from satellite images and field surveys.

2 Methodology

2.1 Study Site

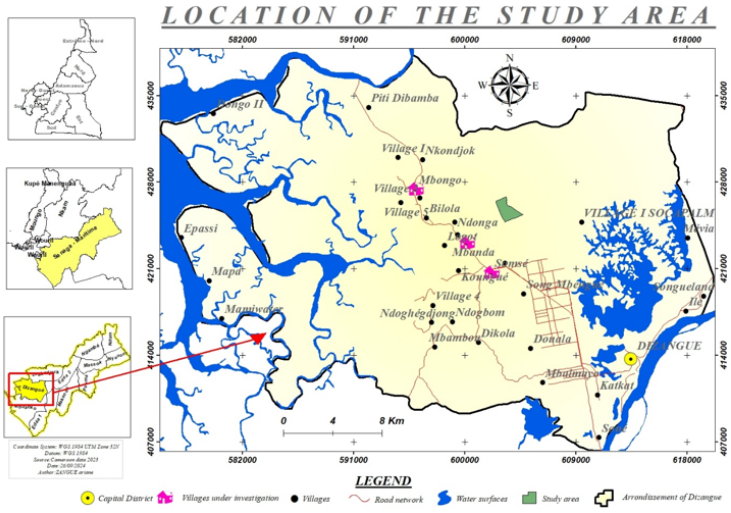

Figure 1. Location of the study area

This study was carried out in the AFEE forest massif, located at approximately 45 km from Cameroon's economic capital (Douala), more precisely in the Dizangue Sub-district of the Sanaga Maritime District of the Littoral Region of Cameroon (Figure 1). The site is geographically located at 3.75° and 3.89° north latitude and 9.15° and 9.4° east

longitude and covers a total area of 200 ha. This site has a relatively flat topography [16]. As it belongs to the monomodal rainfall agro-ecological zone, the climate is humid equatorial with two seasons: a rainy season from April to October and a dry season from November to March. The soils are essentially ferralitic and hydromorphic. From a phytogeographical point of view, Letouzey [17] classified this area as a low- and medium-altitude coastal and Biafran forest, with $Lophiraalata$ as the characteristic and dominant species. Socio-economically, activities such as shifting cultivation, hunting and the collection of NTFPs are the main occupations and sources of income for the people living around in the Dizangue Sub-district [13].

2.2 Methods

2.2.1 Data collection of spatio-temporal dynamics of the massif forest

In order to analyze the spatio-temporal dynamics of the AFEE massif forest, LandSat 8 images with Operational Land Imager (OLI) and Thermal Infrared Sensor (TIRS) sensors from 6 November 2014, 6 November 2019 and 7 February 2024 were downloaded from the United States Geological Survey (USGS) Earth Explorer website. These images were chosen due to their availability and the better spatial coverage (absence of clouds) they offer. From these downloaded images, an unsupervised classification was carried out using a 4-3-2 (red-green-blue) false color composition. The average spatial resolution of 30 m was used for the diachronic analysis of land-use dynamics in the forest massif. On the basis of the unsupervised stratification map obtained, a field trip was carried out to collect the field data points using a smart phone equipped with a GIS application (SWMAPS) needed to finalize the supervised mapping. The reference data for the year 2024 collected for each type of land use identified were used for the supervised classification in order to produce a valid land use map of the study area. In addition to these approaches, direct observations, which are a data collection technique that makes it possible, in a spatio-temporal framework, to collect information relating to the state of the site, also helped to validate the mapping of this massif.

2.2.2 Data collection of the impact of local activities on the forest massif

In order to assess the impact of local populations and the services they derive from the AFEE forest massif, interviews were conducted with 30 local residents from the villages of Mbongo, Mbanda and Koungué on the outskirts of the forest massif using the snowball principle [18]. The inquired people were especially those who have spent more time (at least ten years) in this area and are at least 30 years old and also those involving in agricultural, NTFPs, hunting, and illegal logging activities in the zone. There are resources personnel who can provide accuracy information about the perception of management of the site. The information sought related mainly to their subsistence activities and their perception about the impact of their activities on the AFEE forest. The information gathered made it possible to understand the level of exploitation of natural/forest resources and its various consequences on the site's forest cover.

2.3 Data Analysis

The images were processed using ERDAS and QGis 3.6 software. The maximum likelihood algorithm based on the Bayes rule was chosen for image classification. This method calculates the probability of a pixel belonging to a given class. Pixels were assigned to the class with the highest probability. Changes were determined by extracting the surface areas of the different strata identified in the study area for each target period. These changes were determined over three periods: 2014-2019, 2019-2024 and 2014-2024.

The average rate of spatial expansion (Tc), which expresses the proportion of each land cover category that changes based on the area of these categories [19], was calculated using the Bernier [20] formula.

$$Tc = \frac{(\ln S2 - \ln S1)}{t \times \ln e} \times 100$$

where, $S1$ is the surface area of a unit area class at date $t1$; $S2$ is the surface area of the same unit class at date $t2$; t is the number of years between the two observations (date $t1$ and date $t2$); ln is the neperian logarithm; and e is the base of the neperian logarithm, with $e = 2.71828$.

The overall rate of change (Tg) was used to assess changes at the level of a land-use unit between $t1$ and $t2$ [21]. Positive values indicate progression; negative values indicate regression; and values close to zero indicate that the class is weak when analyzing the rate of change. It is expressed according to the following formula:

$$Tg = \frac{S2 - S1}{S1} \times 100$$

where, Tg is the total rate of change; $S1$ is the surface area of a surface unit class at date $t1$; and $S2$ is the surface area of the same surface unit class at date $t2$.

3 Results

3.1 Different Strata Identified in the Forest Massif

During 2024, a total of six strata were observed within the AFEE massif. These landscapes were old secondary forest, young secondary forest, swamp, fallow, perennial plantation and crops. Table 1 provides information on the characteristics of each of these strata identified in the forest massif after the validation of the site's strata mapping.

Table 1. Different strata making up the AFEE forest massif

Types of Strata	Description/Characteristics
Old secondary forest	These forests are characterized by a high density of large-diameter trees and a fairly clear undergrowth. There is a large number of trees that have reached their minimum exploitable diameter. Trees can reach heights of 3540 m . The most abundant species identified are Lophrira alata, Paraberlinia bifoliolata, Musanga cecropioides, Ceiba pentandra, Terminalia catappa, and Amophimas sp.
Young secondary forest	This is a forest layer that develops after disturbance of a mature forest. In the vertical plane, it presents an irregularly dense tree layer with a very dense undergrowth. The large trees scattered throughout this type of stand rarely exceed 25 m in height and have a diameter of between 20 and 50 cm . The species in this stratum are essentially fast-growing, sun-loving colonizing species. They represent forest stands in which the majority of trees are not old enough to be harvested. Species such as Albizia ferruginea, Mussanga cecropiodes, Distemonanthus benthamianus and Pycnanthus angolensis have been identified.
Swamp	It is located in the middle valleys on spongy, waterlogged soils. These swamps have been created downstream over time as a result of farming activities upstream, with water draining into the Mamiwater River. The height of the trees does not exceed 15 m. The characteristic species here are Uapaca heudolotii, Xvlopia staudtii and Altonia congensis.
Perennial plantation	Agro-industrial oil palm plantations less than 10 years old are the main feature of the study site and rubber plantation. The average height of the palm trees is 6 to 8 m .
Fallow	These are areas of land left to rest after a period of cultivation. They are less than 10 years old and are characterized by herbaceous vegetation and smalldiameter woody species. The main species found here is Mussanga cecropiodes, a pioneer species.
Crops	This is a mosaic of small areas of either newly burnt, fallow or cultivated land. The crops identified are mainly manioc (Mannihot esculenta), Macabo (Xanthosoma sagittifolium), plantain banana (Musa spp.), yams (Discorea alata) and maize (Zea mays), in association or not. These areas also contain a few woody plants left over from felling.

3.2 Spatio-Temporal Dynamics of AFEE Forest Cover

Satellite image analysis and field data were used to produce land use maps for the study area for the periods 2014, 2019 and 2024 (Figure 2). It can be seen that in 2014, this site consisted of only one stratum, namely the old secondary forest (100%, 200 ha). In fact, this site was in the middle of the forest and, given the remoteness of the villages from this site during this period, it had not undergone any remarkable human activities [13]. However, in 2019, old secondary forest represented only 77.1%, or 154.32 ha. Strata expressing anthropogenic activities of this site were observed, in particular fallow land and young secondary forest, i.e., 16.5% (33.18 ha) and 6.2% (12.5 ha), respectively. By 2024, old secondary forest had declined significantly, representing just 22.2% (44.6 ha). Young secondary forest and fallow have increased by 22.9% (45.95 ha) and 16.8% (33.7 ha), respectively, over the last five years. In addition, this year saw the presence of perennial plantation, crop areas and swamp of 1.46% (2.91 ha), 18.7% (37.48 ha) and 17.68% (35.35 ha), respectively. These new strata observed in 2024, i.e., ten years later, testify to the state of human activity's impact on the site, as shown by several studies [21–23].

With regard to the rates of change between 2014 and 2019, the negative values of the rates show a decline in the areas of the natural land cover. This is the case for old secondary forest, which fell by 22.85%. Between 2019 and

2024, an annual decrease of 24.82% for old secondary forest was identified. On the other hand, annual increases of 26.03% and 0.31% were identified for young secondary forest and fallow, respectively. At the same time, young secondary forest and fallow areas increased from 12.5% to 45.95% and from 33.18% to 33.7%, respectively. In general, at the end of the ten-year assessment of spatio-temporal dynamics (2014-2024), old secondary forest, which occupied 100% of the study area in 2014, had fallen to 44.6% by 2024, i.e., a reduction of 77.7%. The decline in old secondary forest at an annual rate of 15% has been offset by the appearance of strata resulting from human activity on the site (Table 2).

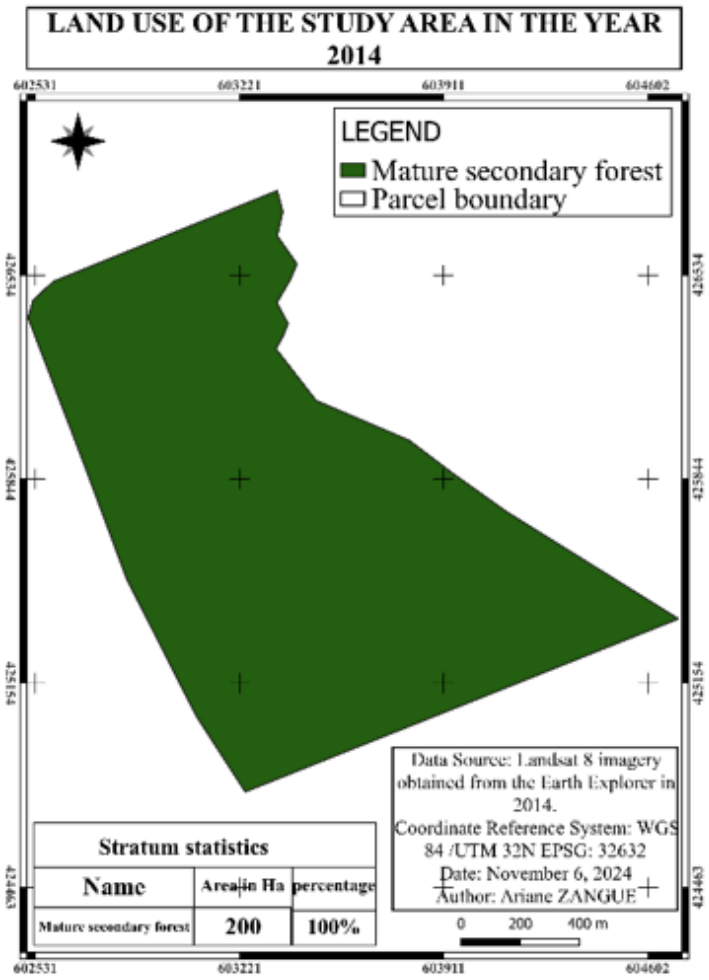

Figure 2. Map of land use over time in the study area

After assessing the spatio-temporal dynamics and the rates of change observed in the site, it can be concluded that the 77% decline in old secondary forest observed over the last ten years in favor of other types of land use, in particular young secondary forest, fallow, perennial plantation and crops in the area, is attributable to high human pressure on the site in exploration of means of subsistence. Indeed, given the forested nature of the site, with the population explosion, people have ended up moving closer to the site in search of agricultural land, timber and animal protein food sources [1, 24], which has a negative impact on the vegetation cover [15]. This information is similar to that observed by Mbente et al. [22] and Nguekam et al. [23], where it is clear that human activities carried out on a site that are supposed to be natural are counted as the cause of its regression.

The high densities of fallow (17% in 2024) and crops (19%) observed are justified by the cultivation techniques used. In fact, these local residents are much more involved in shifting cultivation. Once the agricultural areas become less productive, they move to another area for the same process, leaving the previous areas in fallow [21, 25, 26]. It is these observations that justify the high proportions of farm areas and fallows in this study area. It has also been observed that one of the agricultural practices of the local women is to drain their fields on the AFEE site using water collected from the Mamiwater River, which is on the southwestern edge of the site. This drainage has created water stagnation downstream, resulting over time in a landscape characteristic of swamp formations [27, 28]. Therefore, the latter can be observed on the stratification map for the year 2024. While these agricultural activities undeniably exert

pressure on the natural environment, they remain crucial for the subsistence and economic well-being of the local population. In fact, agricultural products are intended for self-consumption and only the surplus is sold. Ebouele et al. [10] obtained similar results in the Moungo District of the Littoral Region of Cameroon.

Table 2. Areas of the different strata and rates of change in occupancy classes based on Landsat images

Strata	Areas						Rate of Change					
	2014		2019		2024		2014-2019		2019-2024		2014-2024	
	Ha	%	Ha	%	Ha	%	*Tg*	*Tc*	*Tg*	*Tc*	*Tg*	*Tc*
OSE	200	100	154.32	77.1	44.6	22.2	-22.84	-5.18	-71.09	-24.82	-77.7	-15
YSE	0	0	12.5	6.2	45.95	22.9	/	/	267.6	26.03	/	/
FA	0	0	33.18	16.5	33.7	16.8	/	/	1.56	/	/	/
PP	0	0	0	0	2.91	1.46	/	/	/	/	/	/
CR	0	0	0	0	37.48	18.7	/	/	/	/	/	/
SW	0	0	0	0	35.35	17.6				/		/
Total	200	100	200	100	200	100						

Note: OSF indicates the old secondary forest; YSF indicates the young secondary forest; FA indicates the fallow; PP indicates the perennial plantation; CR indicates the crops/farms area; SW indicates the swamp; Tc indicates the average annual rate of spatial expansion; and Tg indicates the rate of change.

3.3 Impact of Local Riparians' Activities on the AFEE Forests

Surveys carried out among households living near the AFEE site have enabled us to identify the activities carried out by these households and which have an impact on the forest. These activities include agriculture, illegal logging, fishing, hunting and NTFP collection. These activities represent an important source of income for them, as they provide not only the supply and support services but also the economic spin-offs they need on a daily basis for their well-being [1, 7, 29].

In the past, several studies have shown that in forested rural areas, agriculture is recognized as the main activity that keeps people busy and is therefore a source of forest degradation [25, 26, 30]. On the outskirts of the AFEE site, agriculture is the main socio-economic activity practiced by the local population. The establishment of their agricultural plots precedes the demarcation of their site, the felling and cutting down of the trees on it and then slash-and-burn (over-slash shifting cultivation) (Figure 3). This process was common to all the households surveyed that practiced agriculture (100%), and was confirmed by Abassombe et al. [13] in the Dizangue Sub-district. Once productivity decreases, these areas are left fallow for a period of between one and ten years and new fields and farms are created. This justifies the increase in agricultural plots, fallow land and perennial plantations observed over the last years, mainly for the period from 2019 to 2024. The main crops grown by these local residents are, in order of importance, cassava (*Mannihot esculenta*, 60%), macabo (*Xanthosoma sagittifolium*, 6.67%), plantain banana (*Musa spp.*, 3.33%), yams (*Discorea alata*, 3.33%) and maize (*Zea mays*, 3.33%); these are grown in association or not. In addition to these crops, there are also cash crops (perennial plantations) such as oil palm (*Elaeis guineensis*) grown in agro-industrial systems, which account for 1.46% of crops grown in the AFEE forest. However, according to local perceptions, most of these crops require almost complete felling of the trees before they can be planted. This farming is essentially family-based (90%) and intended for self-consumption by the household; according to local people, only surplus harvests are marketed.

Given that the resources generated by agriculture are temporary and insufficient, bushmeat represents the food supplement and also the main source of protein for these forest-dwelling populations [1, 31]. Analyses have shown that in the study area, hunting is also a popular activity for local people. Hunting products are mainly used for self-consumption, with any surplus sold and the money used to buy basic household necessities (cooking oil and salt, soap, etc.). The main hunting techniques are gun trapping and steel cable trapping. During the surveys, a total of 11 animal species were identified as being hunted in the study area, namely the giant pangolin (*Manis gigantea*) and chimpanzee (*Pan troglodytes*) for class A; the boa (*Boa constrictor*) and tortoise (*Cheloniamydas*) for class B; the rat (*Cricetomys spp.*), monkey (*Cercopithecus spp.*), hedgehog (*Erinaceus europaeus*), wild boar (*Sus scrofa*), hares (*Cephalophus spp.*), porcupine (*Atherurus africanus*) and antelope (*Antilope cervicapre*) for class C. It should be noted that the chimpanzee and the pangolin are highly protected species both nationally and internationally, as they belong to class A. Article 2 of Order No. 0648/MINFOF of 18 December 2006 stipulates that class A wildlife are those that are fully protected and whose capture is prohibited unless special authorization is granted by the administration in charge of wildlife for scientific research or the protection of people or their property [32]. However, the illegal hunting of these species in the AFEE forest is a threat to these species, whose role in forest dynamics and regeneration is no longer proven.

Figure 3. Felling and burning of trees by a local resident of the AFEE forest for agricultural use

Wild sawmilling, or illegal logging, is also one of the activities that not only helps to improve people's living conditions (cash money and support services) but also has a negative impact on the forest cover of the AFEE forest massif. The surveys made it possible to identify the eight timber species most exploited (wild sawing) by local people, 63% of which have a vulnerable status according to the International Union for Conservation of Nature (IUCN) red list. The species exploited are azoe (*Lophira alata*, vulnerable), ayous (*Triplochiton scleroxylon*, vulnerable), sapelli (*Entandrophragma cylindricum*, vulnerable), moabi (*Baillonella toxisperma*, vulnerable), movingui (*Distemonanthus benthamianus*, insufficient data), fraké (*Terminalia superba*, threatened in the near future), ceiba (*Ceiba pentandra*, minor concern), red eyoum (*Dialium bipendensis*, vulnerable), and ilomba (*Pycnanthus angolensis*, not assessed). Overexploitation of these timber species can constitute a menace for their local survival, with some of them being threatened, and then has a negative impact on the biogeochemical function (air, soil, and water regulation) of the natural landscape. It appears important to apply sustainable exploitation of these species and also think about reforestation with endangered timber species to ensure they can provide the same services to future generations.

According to the people interviewed, all the people living near the site have unrestricted access to the river for fishing. The species most commonly caught is the viper fish (*Chauliodussloani*). However, given the absence of a watercourse running through the site, this activity has no direct impact on the vegetation cover of the AFEE site. Nevertheless, the practice of smoking caught fish used by local fishermen does have an impact on the site's wood resources insofar as they cut down the trees, leave them to dry and use them as firewood to smoke the fish [33].

As is the case in forest areas, the collection of NTFPs is part of the subsistence activities of the surrounding populations. Despite the fact that the study site has lost a large part of its natural ecosystem, NTFP harvesting is another key activity carried out by local residents, and its socio-economic and ecological impact is no longer in doubt. Ecologically, despite the lack of awareness of the abusive impact of NTFPs, this has a negative impact on both natural regeneration and sustainable management. Indeed, based on surveys conducted and observations made in the field, it has been realized that the collection of bark by some local residents is not environmentally friendly, instead contributing to the death of the tree [34]. However, this activity is seasonal and only takes place during periods of availability, notably *Cocos nucifera*, *Irvingia gabonenesis*, *Baillonnella toxiperma* and *caterpillars on Entandrophragma cylindricum* [35].

The results of this study showed that, according to local perception, there are no appropriate strategies implemented by local populations for the sustainable management of the AFEE massif forest. This is why AFEE wishes, through environmental education, to improve the capacity building of these local residents in terms of sustainable management and preservation of the natural resources of the AFEE forest massif. As shown by Ngoukwa et al. [36] in the East Cameroon region, strategies that can greatly contribute to the preservation of forest resources in the rural sector and that AFEE should take into consideration in their environmental education should include avoiding slash-and-burn cultivation in the agricultural sector, promoting eco-agriculture and sedentarization, and using improved seeds and agroforestry systems. With regard to hunting, environmental education could focus mainly on avoiding the hunting of wild animals, especially those of classes A and B (bearing in mind that those of class C do not have a special menace status), and promoting animal husbandry so that the products derived from them serve as alternative sources of animal protein for their diet. With regard to NTFPs, gatherers could be educated about ecologically sustainable harvesting and value-adding activities. With regard to illegal logging, given that many of the species exploited are threatened locally and even internationally, and that the population needs timber for construction and

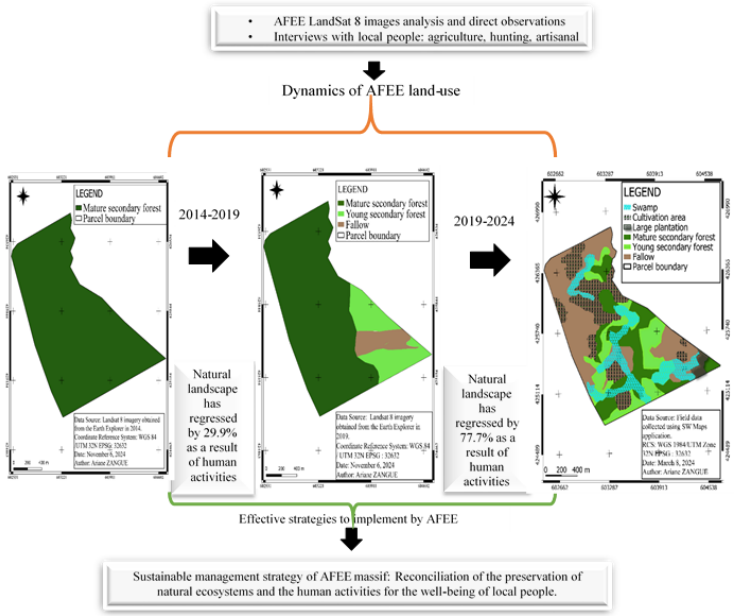

Figure 4. Methodology and result of this study

handicrafts, sustainable management of the latter is necessary, as is tree planting (reforestation). All these strategies will help to demonstrate the role that local communities should play in the conservation of the AFEE forest and their involvement in sustainable management practices, thereby benefiting future generations. In addition, indigenous knowledge, as highlighted by Teteli et al. [37], is a critical factor that should be integrated into the conservation efforts of the AFEE massif forest. By leveraging this traditional knowledge, AFEE can better orient its participatory conservation initiatives, ensuring that local communities are actively involved in the sustainable management of the forest. Figure 4 shows the methodology and result of this study.

4 Conclusions

The aim of this study, carried out in the Sanaga Maritime District, Dizangué Sub-district, was to assess the changes in land use between 2014 and 2024 and the impact of human populations on natural resources in the AFEE forest massif in Cameroon. It appeared that in recent years, the site, which at one time consisted solely of mature secondary forest, has experienced strong human pressure, leading to the regression of old secondary forest by around 77% over ten years to the benefit of man-made strata (young secondary forests, fallows, plantations and fields). This was confirmed by interviews with local people, who identified slash-and-burn agriculture, hunting, wild sawing and the collection of NTFPs as the main activities of the local people, which not only constituted their daily sources of subsistence but also were seen as local factors contributing to the degradation of the natural ecosystems in favor of man-made land-use types. In view of the fact that it is a forest massif dedicated to environmental education, the information obtained in the course of this study is vital and could help AFEE to define effective management strategies for this massif so that it can take account of its sustainable management character, which would encompass preservation of the forest cover and the well-being of the local populations.

Author Contributions

Conceptualization, K.Z.A.S., L.F. and P.V.; methodology, K.Z.A.S. and C.D.C.; software, K.Z.A.S. and C.D.C.; validation, K.Z.A.S., Y.Y. and Z.Z.; formal analysis, X.X.; investigation, X.X.; resources, X.X.; data curation, X.X.; writing—original draft preparation, K.Z.A.S. and C.D.C.; writing—review and editing, K.Z.A.S., L.F., P.V., YF., A.S., C.D.C.; supervision, L.F.; project administration, L.F.; funding acquisition, L.F. All authors have read and agreed to the published version of the manuscript." The relevant terms are explained at the CRediT taxonomy.

Funding

This study was funded by the Association for Forestry and Environmental Education (AFEE) in Cameroon.

Data Availability

The data used to support the research findings are available from the corresponding author upon request.

Acknowledgements

We thank the Association for Forestry and Environmental Education (AFEE) in Cameroon for the logistical and financial support and the local populations of the site for their hospitality during the study.

Conflicts of Interest

The authors declare no conflict of interest.

References

[1] S. Lhoest, C. Vermeulen, A. Fayolle, P. Jamar, S. Hette, A. Nkodo, K. Maréchal, M. Dufrêne, and P. Meyfroidt, "Quantifying the use of forest ecosystem services by local populations in Southeastern Cameroon," *Sustainability*, vol. 12, no. 6, 2020. https://doi.org/10.3390/su12062505

[2] FAO, *Global Forest Resources Assessment 2020 - Main Report*. FAO, 2020. https://doi.org/10.4060/ca9825fr

[3] C. Djomo Cédric, E. Y. Christian, N. T. Marlène *et al.*, "Local population perspectives of the ecosystem services provided by the Kebe block forest in the East Region of Cameroon," *Forestist*, vol. 73, no. 2, pp. 191–196, 2023. https://doi.org/10.5152/forestist.2022.22054

[4] R. R. B. Laekey, A. M. L. Tientcheu, N. P. Awazi, A. E. Assogbadjo, M. Tafadzwanashe, P. S. Hendre, A. Degrande, S. Hlahla, and L. Manda, "The future of food: Domestication and commercialization of indigenous food crops in Africa over the third decade (2012-2021)," *Sustainability*, vol. 14, no. 4, p. 2355, 2022. https://doi.org/10.3390/su14042355

[5] J. C. Zekeng, M. T. Van der Sande, J. L. Fobane, W. N. Mphinyane, R. Sebego, P. A. Ebanga, and M. M. A. Mbolo, "Environmental, structural, and taxonomic diversity factors drive aboveground carbon stocks in some semi-deciduous tropical rainforest strata in Cameroon," *Afr. J. Ecol.*, vol. 61, no. 1, pp. 163–175, 2023. https://doi.org/10.1101/2021.03.12.435155

[6] L. Zapfack, V. N. Noumi, K. P. J. Dziedjou, L. Zemagho, and T. F. Nembot, "Deforestation and carbon stocks in the surroundings of lobeke national park (Cameroon) in the Congo Basin," *Environ. Nat. Resour. Res.*, vol. 3, no. 2, 2013. https://doi.org/10.5539/enr.v3n2p78

[7] G. N. Gouwakinnou, S. Biaou, F. G. Vodouhe, M. S. Tovihessi, B. K. Awessou, and H. S. S. Biaou, "Local perceptions and factors determining ecosystem services identification around two forest reserves in Northern Benin," *J. Ethnobiol. Ethnomed.*, vol. 15, no. 1, 2019. https://doi.org/10.1186/s13002-019-0343-y

[8] T. Desalegn, F. Cruz, M. Kindu, M. B. Turrion, and J. Gonzalo, "Land-use/land-cover (LULC) change and socio-economic conditions of local community in the central highlands of Ethiopia," *Int. J. Sustain. Dev. World Ecol.*, vol. 21, no. 5, pp. 406–430, 2014. https://doi.org/10.1080/13504509.2014.961181

[9] D. Da Silva, A. W. Baker, J. Shepherd, S. Chakib, and S. Miranda-da Cruz, *Agroindustries for development*. The Food and Agriculture Organization of the United Nations and the United Nations Industrial Development Organization, 2009. https://www.fao.org

[10] E. Ebouele, N. Tankeu, J. Njipnang, D. Nadine, D. E. Nsako, D. Wirsiy, Yungsi, K. W. Edith, and N. E. Ghislain, "Spatial evolution and socio-economic consequences of agricultural activities on the north face of Mount Nlonako (Moungo, Cameroon)," *Int. J. Sci. Eng. Res.*, vol. 13, pp. 862–876, 2022.

[11] D. Hoyle and P. Levang, "Le développement du palmier à huile au Cameroun," 2012. https://awsassets.panda.org

[12] M. Gaétan and N. C. Karim, "Food crop production in West Cameroon and the economic vulnerability of producers: The case of the maize and bean sector in the Bamboutos production basin," *Eur. Sci. J.*, vol. 20, no. 13, p. 142, 2024.

[13] G. D. Abassombe, M. Tchindjang, and R. Voundi, "Culture du palm à huile, curée foncières et déforestation dans la commune de Ngwel (Littoral-Cameroun)," *Rev. Int. Rech. Afr.*, vol. 11, no. 2, pp. 55–68, 2022.

[14] A. Gnoumou and A. B. Adouabou, "Étude de la dynamique spatio-temporelle de la réserve de la comoé-léraba et de ses terroirs environnants (Burkina Faso, West Africa)," *J. Appl. Biosci.*, vol. 157, pp. 16 213–16 222, 2021.

[15] J. C. Zekeng, R. Sebego, W. N. Mphinyane, M. Mpalo, D. Nayak, J. L. Fobane, J. M. Onana, F. P. Funwi, and M. M. A. Mbolo, "Land use and land cover changes in Doume Communal Forest in eastern cameroon: Implications for conservation and sustainable management," *Model. Earth Syst. Environ.*, vol. 5, pp. 1801–1814, 2019.

[16] *Enquête complémentaire à la quatrième enquête Camerounaise auprès des ménages (EC-ECAM) Monographie de la région d'enquête du Littoral sans Douala*, 2020. https://ins-cameroun.cm

[17] R. Letousey, *Notice de la carte phytogéographique du Cameroun au 1:500000*. Institut de la carte Internationale de la végétation, Toulouse, 1985.

[18] P. Biernacki and D. Waldorf, "Snowball sampling-problems and techniques of chain referral sampling," *Sociol. Methods Res.*, vol. 10, no. 2, pp. 141–163, 1981.

[19] J. Oloukoi, V. Mama, and F. B. Agbo, "Modelling land use dynamics in the hills department of Benin," *Rev. Télédétection*, vol. 6, no. 4, pp. 305–323, 2006.

[20] B. Bernier, *Introduction à la macroéconomie*. Dunod, Paris, 1992. https://www.scirp.org

[21] R. N. Makak, M. Tchindjang, F. Palla, L. Zapfack, and J. S. Makak, "Dynamique paysagère du Parc national de Mpem Djim entre 1986 et 2022," *Rev. Int. Donni*, vol. 4, no. 1, pp. 237–251, 2024.

[22] P. Mbente, D. Chauvelin, Ayessa-Leckoundzou, D. Espoir Makita, and K. Felix, "Impact of logging on the spatial structure and residual diversity of the Jua-ikie Forest Management Unit (FMU) in northern Congo," *Rev. Ramres*, vol. 8, no. 2, 2020.

[23] T. W. Nguekam, S. C. Nguemhe, J. Etouna, and S. N. Tenku, "Analysis of deforestation in the western periphery of the Dja Biosphere Reserve in Cameroon, based on a multi-annual series of Landsat images," *Rev. Fr. Photogramm. Télédétection*, 2020.

[24] D. C. Chimi, B. N. Nfornkah, G. W. Forje *et al.*, "Indigenous knowledge of Bamboo products and uses in the Western Highlands of Cameroon," *Asian J. Res. Agric. For.*, vol. 7, no. 2, pp. 22–30, 2021. https://doi.org/10.9734/ajraf/2021/v7i230125

[25] F. C. Ahononga, G. N. Gouwakinnou, S. S. H. Biaou, and S. Biaou, "Facteurs socio-économiques expliquant la déforestation et la dégradation des écosystèmes dans les domaines soudanien et soudano-guinéen du Bénin," *Ann. Univ. Parakou-Sér. Sci. Nat. Agron.*, vol. 10, no. 2, pp. 43–60, 2020. https://doi.org/10.56109/aup-sna.v10i2.36

[26] W. Atakpama, B. Badjare, E. Y. K. Aladji, K. Batawila, and K. Akpagana, "Alarming degradation of forest resources in the classified forest of the Doungh pit in Togo," *Rev. Afr. Droit Polit. Geogr. Sci. Hum.*, 2023. https://doi.org/10.48346/IMIST.PRSM/ajlp-gs.v6i3.39046

[27] D. Wichelns, "The water energy food nexus: Is the increasing attention warranted, from either a research or policy perspective?" *Environ. Sci. Policy*, vol. 69, pp. 113–123, 2017. https://doi.org/10.1016/j.envsci.2016.12.018

[28] J. A. Foley, N. Ramankutty, K. A. Brauman *et al.*, "Solutions for a cultivated planet," *Nature*, vol. 478, no. 7369, pp. 337–342, 2011. https://doi.org/10.1038/nature10452

[29] W. F. Gadinga, M. Tchamba, B. N. Nfornkah, D. C. Chimi, and R. M. Fokeng, "Bush Mango (irvingia spp.) as an important alternative livelihood source for the indigenes of the korup national park communities, South-West, Cameroon," *Environ. Earth Sci. Res. J.*, vol. 6, no. 4, pp. 141–148, 2019. https://doi.org/10.18280/eesrj.060401

[30] D. C. Chimi, J. C. Noudem, J. C. Zekeng *et al.*, "Modelling carbon stock trends in a previously exploited forest protected area: An opportunity for the redd+ initiative?" *Environ. Earth Sci. Res. J.*, vol. 11, no. 3, pp. 43–49, 2024. https://doi.org/10.18280/eesrj.110301

[31] M. R. B. Tabue, D. C. Chimi, S. P. Djanteng *et al.*, "Indigenous knowledge as a tool for wildlife conservation in the Dja Biosphere Reserve, Cameroon," *Int. J. Soc. Sci. Humanit. Res.*, vol. 6, no. 4, pp. 148–156, 2018.

[32] R. Djeukam, "La législation faunique Camerounaise comme outil de protection des espèces animales menacées d'extinction au Cameroun," 2012. https://www.laga-enforcement.org

[33] P. U. Ajonina, G. N. Ajonina, E. Jin, F. Mekongo, I. Ayissi, and L. Usongo, "Gender roles and economics of exploitation, processing and marketing of bivalves and impacts on forest resources in the Douala-Edea," *Int. J. Sustain. Dev. World Ecol.*, vol. 12, pp. 161–172, 2005. https://doi.org/10.1080/13504500509469627

[34] N. T. Marlène, D. Sonwa, F. F. Evariste, E. H. Biyé, F. P. Funwi, T. Oishi, Takanori, and B. A. Nkogmeneck, "Identification of main non-timber forest products and related stakeholders in its value chain in the Gribe village of Southeastern Cameroon," 2019.

[35] M. Tchindjang, F. Saha, P. Levang, E. Voundi, P. C. I. Njombissie, and F. Minka, "Palmeraies élitistes et villageoises et développement socio-économique dans la Sanaga maritime: Impacts, consequences and perspectives," *Rev. Sci. Tech. Forêt Environ. Bassin Congo*, vol. 7, pp. 37–52, 2016.

[36] G. Ngoukwa, D. C. Chimi, B. L. P. R. Kabelong *et al.*, "Perception and adaptation strategies of forest dwellers to climate variability in the tropical rainforest in eastern cameroon: The case of the inhabitants of the belabo-diang communal forest," *Heliyon*, vol. 9, p. e15544, 2023. https://doi.org/10.1016/j.heliyon.2023.e15544

[37] C. S. Teteli, E. A. Padonou, A. M. Langa, G. C. Akabassi, S. M. Mukotanyi, and B. K. Kokou, "Pratiques agroforestieres prioritaires de conservation des sols dans la zone soudanienne au Benin," *Altern. Rurales*, vol. 9, 2023. https://doi.org/10.60569/9-a9