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Full Length Research Paper

Can conservation incentives promote willingness to coexist with large carnivores in the eastern Serengeti ecosystem?

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Communities living adjacent to protected areas tend to express more willingness to coexist with large carnivores in their areas when they receive tangible benefits. The aim of this study was to explore people's willingness to coexist with large carnivores, including lions *(Panthera leo),* leopards *(Panthera pardus)*, cheetahs *(Acinonyx jubatus)*, spotted hyenas *(Crocuta crocuta)*, African wild dogs *(Lycaon pictus)* and black-backed jackals *(Canis mesomelas schmidti)*. The authors used a pre-test and post-test approach by implementing a chemoprophylactic program as a conservation incentive among the Maasai and Sonjo tribes living in the eastern Serengeti, Tanzania. Chemoprophylaxis is the prevention of infectious disease by using chemical agents. The pre-test results showed that both tribes had low willingness to coexist with these large carnivores. Of the two tribes, the Sonjo tribe was less willing than the Maasai tribe. Our post-test results indicated an increase in willingness to coexist with large carnivores in their area because the livestock loss due to large carnivore depredation was significantly lower than that caused by diseases in both tribes. Therefore, this study calls for more conservation incentives to local people to promote their willingness to coexist with large carnivores in their areas.

Key words: Coexistence, depredation, diseases, large carnivores, livestock, Maasai and Sonjo tribes.

INTRODUCTION

Coexistence between humans and carnivores is only possible (Carter and Linnell, 2016) if both biological and social strategies are used wisely to curb conflict (Redpath et al., 2013; Treves and Karanth, 2003) and thereby reduce carnivore mortality (Treves and Karanth, 2003). According to Carter and Linnell (2016), coexistence is the "dynamic but sustainable state in which humans and large carnivores co-adapt to living in shared landscapes where human interactions with carnivores are governed by effective institutions that ensure long-term carnivore population persistence, social legitimacy, and tolerable levels of risk". Aiming for coexistence is the way forward to reduce human-carnivore conflict, which in turn will save carnivores in the future (Dickman, 2010; Woodroffe et al., 2005).

Many protected areas in Africa are facing great

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challenges, and the areas adjacent to their borders pose a serious threat to large carnivores and other species (Caro et al., 2013). The main target for conservation stakeholders in Tanzania is reduction of the decrease in the carnivore population adjacent to many networks of protected areas. The edges of protected areas are gradually shrinking due to human population increase, resulting in increased demand for land for settlement and farming. Such demands tend to encroach on arable and fertile lands adjacent to protected areas, which negatively impacts the conservation of carnivores and other wildlife species (Shivik 2006; Nyhus and Ronald, 2010). In rural areas, especially those close to protected areas, land for livestock husbandry is open access, which attracts pastoralists to such places. Most people in Africa live in rural areas and there are many trade-offs encountered by people living adjacent to protected areas. The livelihoods of such societies have been compromised due to the costs associated with wildlife interactions (Adams and Hutton, 2007; Nana and Tchamadeu, 2014; Vedeld et al., 2012). Thus, people living adjacent to protected areas tend to have negative attitudes towards wildlife as they impact their livelihoods negatively (Dickman et al., 2014; Romanach et al., 2007; Røskaft et al., 2007).

Previous studies have revealed that once these conservation conflicts are managed, negative impacts on biodiversity are reduced as well (Lagendijk and Gusset, 2008; Redpath et al., 2013; Vedeld et al., 2012; Woodroffe et al., 2005). The management of conflicts between people and carnivores will cultivate positive attitudes, which in turn will enhance conservation initiatives (Conover, 2002). This observation also supports findings that people affected by large carnivores through human attacks and livestock depredation normally express negative attitudes and revenge by killing the carnivores using either poison and/or snares (Abade et al., 2014; Dar et al., 2009; Hazzah, 2006; Linnell et al., 2001; Romañach et al., 2007).

Despite human population growth causing carnivore habitats to shrink, measures should be taken to merge both human activities and carnivore conservation (Treves and Karanth, 2003). If efficient management practices are implemented, coexistence between people and predators can be enhanced (Linnell et al., 2001). Livestock depredation in rural areas is the main cause of human-carnivore conflict. Consolation programs should be implemented to help the victims realize tangible benefits from to the presence of carnivores (Breitenmoser, 1998; Skonhoft, 1998). It has been found that implementing conservation incentives such as a chemoprophylactic program improves coexistence between humans and large carnivores (CDPNews, 2003). Chemoprophylaxis is the prevention of infectious disease by using chemical agents to boost livestock immunity (Jibbo et al., 2010). If local people are satisfied with conservation incentives, their conflicts with carnivores may be reduced.

Therefore, understanding local communities' attitudes towards carnivores is necessary in conservation planning. When attitudes are positive towards large carnivores, people are more willing to coexist with these animals, which contributes to their conservation (Hazzah, 2006). For instance, African lion populations are declining due to the negative attitudes of local communities living in proximity to these species and the resulting actions (Dickman, 2017). Thus, promoting and motivating local communities to increase their willingness to coexist with large carnivores will enhance their conservation initiative (Dickman et al., 2014).

The overall aim of this study was to test whether people's willingness to coexist with large carnivores would change after the implementation of a chemoprophylactic program. In testing, we had two hypotheses: (1) Livestock diseases are the main contributing factor to livestock loss and cause more deaths than carnivore depredation among the livestock of the Maasai and Sonjo tribes, and (2) therefore, the implementation of a chemoprophylactic program would be of paramount importance to these communities because it would reduce livestock losses, which would be expected to improve tolerance towards large carnivores.

MATERIAL AND METHODS

Study area

The study was conducted in the Eastern Serengeti ecosystem, Tanzania, and all surveyed villages were located in the Loliondo Game Controlled Area (LGCA) (Mbise et al., 2018, 2020). The Maasai tribe lives inside the LGCA, and the Sonjo tribe lives on the eastern border of this area. Administratively, the LGCA is under the Ngorongoro District Council (MNRT, 2013) and covers approximately 4500 km^2 (Lyamuya et al., 2016).

The LGCA is bordered by Serengeti National Park to the west, Ngorongoro Conservation Area to the south, Kenya to the north, and Lake Natron to the east (Lyamuya et al., 2016; Masenga and Mentzel, 2005). The LGCA has a rich diversity of ungulate species, including wildebeest (*Connochaetes taurinus),* zebra (*Equus burchelli)*, impala (*Aepyceros melampus*), Grant's gazelle (*Nanger granti)*, and Thomson's gazelle *(Eudorcas thomsonii*), which occur sympatrically with humans. The famous Serengeti-Mara wildebeest migration passes through parts of the LGCA. The area has all five large carnivore species: lions *(Panthera leo),* leopards *(Panthera pardus)*, cheetahs *(Acinonyx jubatus)*, spotted hyenas *(Crocuta crocuta)*, and African wild dogs *(Lycaon pictus)* (Holdo et al., 2010; Maddox, 2003). The Maasai and the Sonjo tribes experience significant livestock losses to large carnivores and diseases (Lyamuya et al., 2016). The authors collected data from six villages: three Maasai tribes (Ololosokwan, Soitsambu and Oloipiri) and three Sonjo tribes (Yasimdito, Samunge and Sale) (Figure 1). The Maasai tribe are pastoralists, while the Sonjo tribe are agro-pastoralists (Masenga and Mentzel, 2005).

Data collection

Data were collected in September 2016 and again in February 2017 using a pre-test and post-test questionnaire survey. The study villages were randomly selected; three from each tribe (the Maasai and Sonjo). In September 2016, the survey of people's willingness

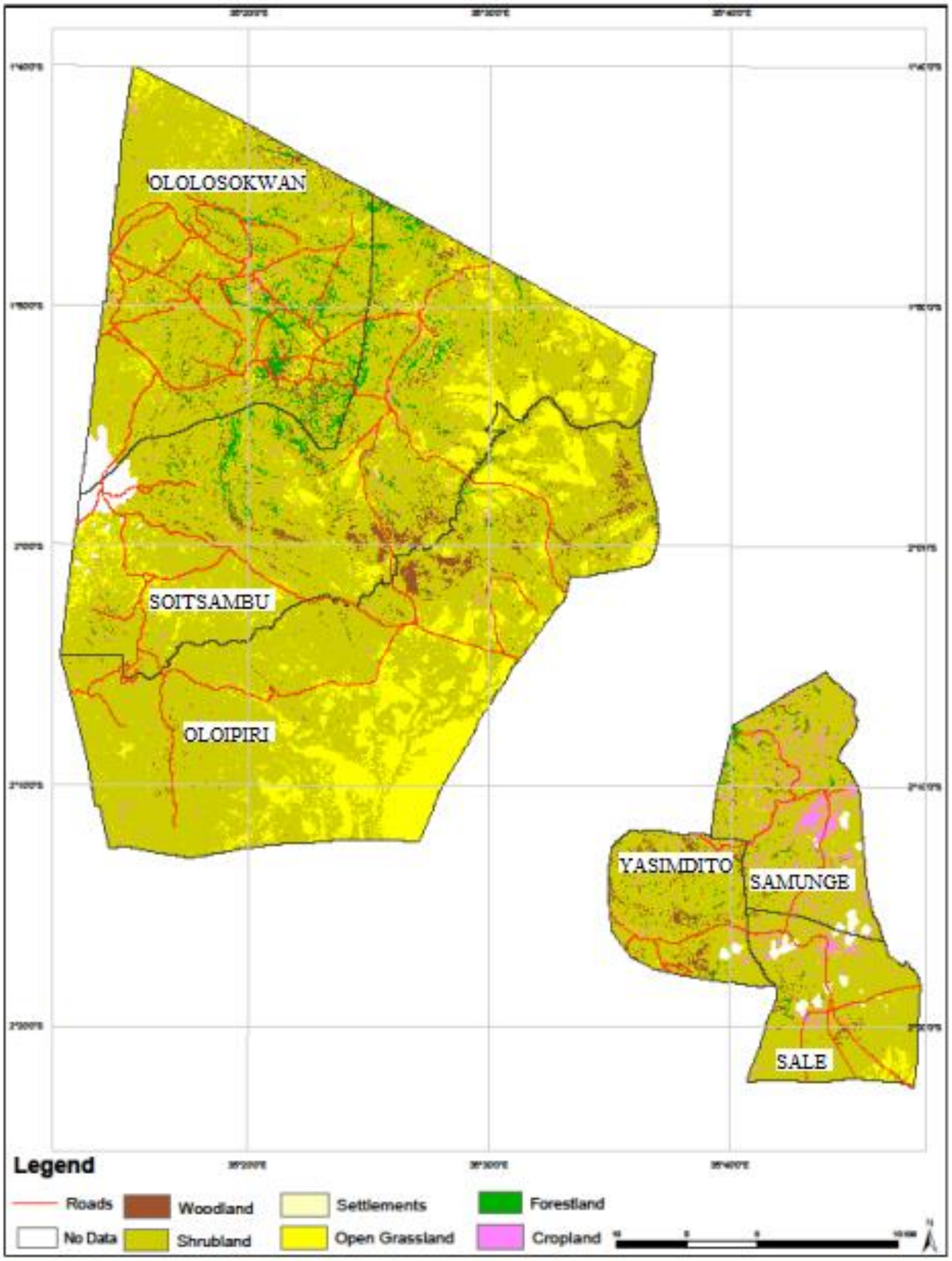

Figure 1. Map showing the study villages of Ololosokwan, Soitsambu, Oloipiri, Samunge, Sale, and Yasimdito in the Eastern Serengeti ecosystem.

to coexist with large carnivores was carried out as the pre-test with the aim of gathering responses from the Maasai and Sonjo tribes before the conservation incentive (chemoprophylactic program) was introduced. The people's willingness to coexist with large carnivores was assessed in an open way to determine whether the responses were positive, neutral, or negative. The question asked, "Will conservation incentives be helpful to motivate your willingness to coexist with large carnivores?". The question assessed the respondents' willingness to coexist with large carnivores in their area based on whether they agreed that conservation incentives promote willingness to overlook livestock loss due to depredation by large carnivores (positive), whether the respondents disagreed

Table 1. Dependent and independent variables used before and after implementing conservation incentive.

Variable			N	%
Dependent variable	Before incentive	Negative	89	74.2
		Neutral	23	19.2
		Positive	8	6.7
	After incentive	Negative	23	19.2
		Neutral	9	7.5
		Positive	88	73.3
Independent variables	Tribe	Maasai	60	50
		Sonjo	60	50
	Age	18-35	41	34.2
		36-49	47	39.2
		>50	32	26.7
	Education	No	35	29.2
		Primary	71	59.2
		Secondary	14	11.7

on the issue (negative) and whether the respondents had no opinion regarding the two ideas (neutral). To avoid influencing the respondents' answers, we did not mention what incentive would come next. In conjunction with this question, we also recorded the reported number of livestock losses for the last two years (2015 and 2016) caused by large carnivores and diseases.

Common diseases in the area were coenurosis, East Coast fever (ECF), Contagious Bovine Pleuropneumonia (CBPP), and anthrax. However, in the chemoprophylactic program we targeted helminths infestation and tick-borne haemoparasites especially ECF. ECF is caused by *Theileria parva* from infected ticks (*Rhipicephalus appendiculatus*). ECF affects lymph nodes first and then spreads to the red blood cells, resulting in severe lung edema and finally death (Gilioli et al., 2009; Kivaria, 2007). Coenurosis is a common neurological disease for both goats and sheep caused by tapeworms of the genus *Taenia multiceps*. The cyst is transmitted when infected domestic animals and large carnivores contaminate pastures with their feces. The infective *Coenurus cerebralis* cysts are then swallowed by sheep and goats (Scala and Varcasia, 2006; Sharma and Chauhan, 2006). CBPP is transmitted by infective aerosol inhalation of *Mycoplasma mycoides mycoides* (Almaw et al., 2016; Scott, 2014). Anthrax is a zoonotic disease caused by the *Bacillus anthracis* bacterium, which can be transmitted to humans through the consumption of infected carcasses or by handling infected animal products. The bacterium has no animal reservoir but is an environmental bacterium that exists in spore form in the environment and in vegetative form in infected animals, and the disease affects all warm-blooded animals, both wild and domestic (Hugh-Jones, 2014; Smith et al., 1999).

After four months (February 2017), a post-test survey was carried out at the same time that chemoprophylaxis was given to the livestock of our previous respondents. The chemoprophylactic program exercise was administered by a Tanzania Wildlife Research Institute (TAWIRI) veterinary officer. We administered two sets of drugs: (1) oxytetracycline hydrochloride 20%, a long acting antibiotic against a wide range of gram-positive and gram-negative bacteria and other microorganisms, such as *Mycoplasma pneumoniae*, *Coxiella burnetti* and *Plasmodium spp.*; and (2) albendazole 10%, a broad spectrum anthelminthic for the prophylaxis and treatment of immature and mature infectious gastrointestinal nematodes, lung worms, tape worms and trematodes.

During February, due to drought, some respondents moved their livestock to other villages, so our sample size dropped from 180 to 120 respondents. We asked the same question about their willingness to coexist with large carnivores if they received conservation incentives that was asked previously. In the Maasai and Sonjo tribes, only men have a right of say, so we had more male participants than female (Table 1) (Mbise et al., 2018). Therefore, it is a challenge to acquire an equal number of males and females, and doing so requires additional time in the field (Mbise et al., 2018). Age categories were split into three groups (youth = 18 – 35 years, adult = 36 – 49 years, and elderly = above 50 years). Most of the respondents belonged to the adult group (Table 1). Most of the respondents had a primary education (Table 1), and all the respondents were either from the Maasai or Sonjo tribes (Table 1).

Data analyses

They used SPSS version 24 for data analyses (IBM, 2016), which included Kruskal-Wallis tests, paired samples t-tests (Table 6), one-way ANOVA tests (Table 7) and chi-square tests. Kruskal-Wallis test was used to determine the predictor variable that explained most of the variation in people's willingness to coexist with large carnivores (Table 1). Paired t-tests were used to assess potential changes in people's willingness to coexist with large carnivores in both tribes. A one-way ANOVA test was used to explain the differences in livestock losses due to diseases and depredation. The chi-square test was used to explain disease frequency differences between the two tribes. The data were tested for normality, and the p-value was set to below 0.05.

RESULTS

People's willingness to coexist with large carnivores before implementing the conservation incentive

The authors used a Kruskal-Wallis test to assess the variation in the people's willingness to coexist with large

Table 2. A Kruskal-Wallis test to assess the variation in the people's willingness to coexist with large carnivores before implementing the chemoprophylactic program.

Variable	Chi-square	df	P-value
Tribe	12.900	2	0.002
Age	1.053	2	0.591
Education	1.172	2	0.557

Table 3. People's willingness to coexist with large carnivores before the chemoprophylactic program.

Tribe	Positive		Neutral		Negative	
	N	%	N	%	N	%
Maasai tribe	7	10	17	30	36	60
Sonjo tribe	1	1.7	6	10	53	88.3

Table 4. A Kruskal-Wallis test analysis to assess the variation in the people's willingness to coexist with large carnivores after implementing the chemoprophylactic program.

Variable	Chi-square	df	P-value
Tribe	28.373	2	0.000
Age	1.971	2	0.373
Education	0.777	2	0.678

carnivores before implementing the chemoprophylactic program (positive, neutral, and negative) as a dependent variable towards three independent variables (tribe, age and education) (Table 2).

Tribe was the only predictor variable explaining this variation in the people's willingness to coexist with large carnivores. Both tribes had lower willingness to coexist with large carnivores, although the Sonjo tribe was less willing than the Maasai tribe (Pearson $\chi^2 = 14.338$, df = 2, $p < 0.0001$; Table 3).

People's willingness to coexist with large carnivores after implementation of the conservation incentive

To explain the variation in the people's willingness to coexist with large carnivores after implementation of the chemoprophylactic program (positive, neutral, and negative), we tested three independent variables (tribe, age and education) using Kruskal-Wallis test (Table 4).

Tribe was the most explanatory variable to explain this variation in the people's willingness to coexist with large carnivores, with the Maasai tribe's willingness being higher than that of the Sonjo tribe (Pearson $\chi^2 = 37.833$, df = 2, $p < 0.0001$; Table 5). The willingness to coexist with large carnivores increased in both tribes after the conservation incentive was implemented (Maasai: Paired samples t-test, t = 7.812, df = 59, $p < 0.0001$; Sonjo: Paired samples t-test, t = 15.108, df = 59, $p < 0.0001$) (Table 5).

Major factors contributing to livestock losses

The results revealed that the number of livestock losses due to large carnivore depredation was significantly lower than the number caused by diseases in both tribes (Maasai: t = -5.373, df = 3 and 59, $p < 0.0001$; Sonjo: t = -7.820, df = 3 and 59, $p < 0.0001$) (Table 6). Goats and sheep were significantly more prone to diseases than cattle in both tribes (F = 34.89, df = 1 and 118, $p < 0.0001$) and (F = 25.79, df = 1 and 118, $p < 0.0001$), respectively. Additionally, predators killed significantly more goats and sheep than cattle (F = 9.47, df = 1 and 118, p = 0.003), (F = 9.16, df = 1 and 118, p = 0.009), and (F = 20.59, df = 1 and 118, $p < 0.0001$), respectively (Table 6).

East Coast Fever and Contagious Bovine Pleuropneumonia were the most common diseases causing cattle loss in the Maasai and the Sonjo tribes, respectively; however, the difference between the two tribes was not statistically significant (Pearson $\chi^2 = 1.427$, df = 2, p = 0.49; Table 7). Goats and sheep were more affected by coenurosis than by anthrax, and East Coast Fever, with no differences between the two tribes (Pearson $\chi^2 = 0.962$, df = 2, p = 0.81; Table 7).

Table 5. People's willingness to coexist with large carnivores after the chemoprophylactic program.

Tribe	Positive		Neutral		Negative	
	N	%	N	%	N	%
Maasai tribe	55	91.7	5	8.3	0	0
Sonjo tribe	33	55	4	6.7	23	38.3

Table 6. Comparison of livestock losses related to diseases and carnivore depredation in the Maasai and Sonjo tribes.

Tribe	Variable	Livestock loss - diseases			Depredation		
		Cattle	Goats	Sheep	Cattle	Goats	Sheep
Maasai tribe	Mean	12.7	25.8	20.7	2.5	3.2	14.7
	Std.	15.4	21.1	16.5	1.9	2.5	13
Sonjo tribe	Mean	5.9	10.4	6.7	1.6	1.5	1.6
	Std.	5.7	8.8	6.6	1	0.8	2.7

DISCUSSION

This study's findings give insight into what can be done for communities living in the same landscape as large carnivores, as is the case in the eastern Serengeti ecosystem, by providing cost-effective and tangible benefits to the local people who bear most of the conservation costs. This applies strongly in developing countries, especially in Africa, where many governments do not have the full potential to compensate people for the loss of their livestock to predators. In the Maasai and Sonjo tribes in the eastern Serengeti ecosystem, disease was more likely to cause livestock loss than depredation by carnivores. Exploring alternatives for promoting willingness to tolerate depredation, treating livestock against disease presents one of the option for producing harmonic coexistence between people and predators, especially in these two tribes. However, this alternative option must be implemented with caution as in a long-term will increase the livestock number which ultimately decreases wild prey, increases the rate of depredation, conflict, and retaliation.

People's willingness to coexist with large carnivores before and after the implementation of a conservation incentive

This study revealed that the Maasai tribe was more willing to coexist with large carnivores than the Sonjo tribe if their livestock were treated against diseases, which represent a much greater cause of livestock loss than large carnivore depredation. The Sonjo tribe members were more rigid in their attitude toward coexist with large carnivores in their area, even after receiving a conservation incentive. According to previous studies by Bencin et al. (2016) and Hazzah et al. (2017), for the better conservation of carnivore species, efforts should be dedicated to influencing human behavior to realize and appreciate the benefits (ecologically and economically) of large carnivores. Currently, financial compensation after livestock depredation loss is not necessarily an effective and sustainable tool for carnivore conservation (CDPNews, 2003; Naughton-Treves et al., 2003).

To explore alternatives, this study tested people's willingness to coexist with large carnivores before and after the implementation of a chemoprophylactic program, which serves as an alternative conservation incentive. The program was positively received because the Maasai and Sonjo communities lose more livestock to diseases than depredation. Many respondents indicated that they were willing to lose livestock to depredation because the rates of depredation are low. Disease-related livestock loss was three times higher for the Maasai tribe and five times for the Sonjo tribe than depredation; therefore, getting a sustainable program to treat livestock against diseases will promote willingness for coexisting with large carnivores.

Most communities living adjacent to or inside-protected areas are less willing to coexist with large carnivores (Spira, 2014). Policy makers and researchers have a challenge of addressing a long history of conflict (Kideghesho et al., 2007). If communities realize a tangible benefit, direct or indirect, due to the presence of carnivores, the probability of sustainable coexistence will be improved (Bencin et al., 2016; Newmark et al., 1993). When conservation incentives are provided to such communities, they enhance positive behavior and perceptions towards carnivores in the vicinity (Lagendijk and Gusset, 2008; Smith, 2005).

These communities bear the costs of carnivore conservation, and thus, in the long term, a sense of ownership is cultivated when tangible benefits are

Table 7. Cattle, goat, and sheep losses due to different diseases.

Tribe	Diseases-cattle			Diseases-goats		Diseases-sheep		
	Anthrax	CBPP	ECF	Coenurosis	Anthrax	Coenurosis	Anthrax	ECF
Maasai	5	18	25	46	13	29	13	15
%	10.4	37.5	52.1	78	22	50.9	22.8	26.3
Sonjo	4	8	8	37	14	20	13	10
%	20	40	40	72.5	27.5	46.5	30.2	23.3

realized, which ultimately tends to reduce the existing human-carnivore conflict (Kidegesho, 2008; Newmark et al., 1993). Tangible benefits tend to improve the tolerance level of the costs of large carnivores (Lagendijk and Gusset, 2008). For the coexistence of people and carnivores, it is imperative to minimize existing human-carnivore conflicts, such as livestock depredation (Lyamuya et al., 2014; Mbise et al., 2018; Newmark et al., 1993; Nyahongo and Røskaft, 2012).

Major factors contributing to livestock losses

In many savannah ecosystems, pastoralists live together with large carnivores, and the main threat of livestock loss is diseases, followed by depredation (Nyahongo and Røskaft, 2012). When large carnivores co-occur with livestock in the same landscape the likelihood of livestock depredation is higher (Mbise et al., 2018; Spira, 2014). Loss from diseases and depredation negatively impacts the livelihoods of the communities experiencing such problems (Gifford-Gonzalez, 2000; Nyahongo and Røskaft, 2012). The effective control of diseases with multi-host pathogens is complex (Lembo et al., 2008); however, if communities with livestock are given proper awareness of disease control and prevention, they can minimize the disease severity in their areas.

In the tropics, the prevalence of diseases that affect livestock is the major cause of income loss. Most of the pastoral communities depend on livestock for their survival (Gifford-Gonzalez, 2000). Different measures are available to treat livestock, such as chemoprophylaxis, which boosts immunity against diseases (Jibbo et al., 2010). However, in developing countries, due to a lack of disease awareness, livestock are untreated with disease prevention measures (Nyahongo and Røskaft, 2012). Most communities have a large number of livestock with suboptimal health. Large livestock herds are a sign of wealth and prestige in both the Maasai and the Sonjo communities (Hodgson, 2011). Thus, there is a need for increased awareness of the benefits of selling a few animals to buy drugs to treat the rest, as many pastoralists have no formal education to inform important life decisions.

Additionally, awareness of diseases is very important for these communities because some diseases that affect livestock are relatively simple to prevent and control if the community is well educated. For instance, during the authors chemoprophylactic program, they found that many sheep and goats were dying because of coenurosis disease. If these communities implement veterinary guidelines such as deworming domestic dogs and providing chemoprophylaxis for livestock, the long-existing problem of livestock loss due to diseases will decline. Furthermore, a compliment was given to the chemoprophylactic program for the healthy progress of all the livestock that received chemoprophylaxis. Most of the livestock were in poor condition due to drought and thus were susceptible to diseases.

This study is among few studies that have tested how conservation incentives can change people's willingness to coexist with large carnivores before and after implementing the chemoprophylactic program. Both hypotheses were supported by our findings. First, disease is responsible for more livestock losses than carnivore depredation; therefore, treating livestock against diseases will improve tolerance of depredation loss. Second, people's willingness to coexist with large carnivores increased after the implementation of the chemoprophylactic program.

Conclusion

The harmonic coexistence between humans and large carnivores goes hand in hand with providing tangible benefits to the communities living with these species. Treating the livestock of these two tribes against diseases will provide tangible benefits that will justify the costs incurred from living with large carnivores in their areas. Additionally, the Tanzanian wildlife policy can integrate this element by providing tangible benefits to communities living side by side with large carnivores in order to change people's negative attitudes to more positive attitudes towards carnivores. Although livestock losses caused by disease in the Maasai and Sonjo tribes are higher than the losses caused by depredation, there is a need to improve livestock safeguarding measures coupled with tangible benefits to the local people such as treating their livestock against diseases. If both types of measures are applied wisely, there is a promising goal of improving people's willingness to coexist with wild carnivores in the area.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Full Length Research Paper

Spatial distribution, ecological niche model of pignut and control eradication strategies in the context of climate and global change for Benin, West Africa

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Benin's native biodiversity, like other countries in the world, is facing biological invasions through the proliferation of invasive alien species. One of them, the pignut (*Mesosphaerum suaveolens* (L.) Kuntze, Lamiaceae), represents a serious threat to the biodiversity. The control of its spatial distribution and ecological niche are essential to understand its favorable spatial area and predict its dynamics. The objective of this study was to contribute to the biodiversity conservation. A total of 193 farmers and breeders, were subjected to a questionnaire in order to determine their knowledge with respect to *M. suaveolens*. The cumulative collection of occurrence data across the literature, the Global Biodiversity Information Facility (GBIF), and field data generated a total of 2900 occurrence points. Modeling across Africa using Maxent (version3.4.1) helped establish the potential and future distribution of this species. The Africlim climatic ensemble model was used with two climatic scenarios of the Intergovernmental Platform on Climate Change (IPCC): rcp4.5 and rcp8.5 horizon 2055. On 24 bioclimatic and environmental parameters tested, four bioclimatic variables who most contributed to the model were selected. Four risk level zones of invasion were identified: limited risk zone, risk zone, high risk zone, and very high risk zone.

Key words: Maxent, biodiversity, modeling, biological invasions, Benin, Africa.

INTRODUCTION

Biodiversity is the amount of variety of life on Earth (Millennium Ecosystem Assessment, 2005). It is very important to the well-being of the planet, as it provides a diverse range of goods and services to humanity (Sachs et al., 2009).

Today, biodiversity is facing many threats worldwide (Vitousek, 1988; Wilcove et al., 1998). Among these threats, invasive alien plant species represent one of the most harmful to the long-term maintenance of ecosystem integrity and native biological diversity (Vitousek, 1988; Wilcove et al., 1998; D'Antonio and Meyerson, 2002; IUCN, 2004). An invasive alien species is defined as an alien species that becomes established in natural or semi-natural ecosystems or habitats, an agent of change that threatens native biological diversity (D'Antonio and Meyerson, 2002). Invasive alien species affect food webs and can pose a threat to the extinction of native plants (Vitousek, 1988).

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The global impact of invasive alien species has been recognized by the Convention on Biological Diversity, which therefore encourages monitoring and containment of the proliferation of these species, which can modify ecosystems and reduce the number of native species (IUCN, 2000). Indeed, invasive alien species are highly disruptive to ecosystems and their impacts are generally irreversible (Dharam and Uma, 2012). Climate change, natural and anthropogenic disturbances are the main factors facilitating the spread of invasive alien species (Hobbs and Hueneke, 1992; Lozon and Maclsaac, 1997; D'Antonio et al., 1999).

Research on the impacts of biological invasions and their mechanisms has made significant progress in recent years. It has highlighted many of the consequences associated with the establishment of alien species, and demonstrated the existence of impacts that need to be identified, assessed and categorized (Simberloff et al., 2019). Invasive alien species unbalance ecosystems in the natural environment. Some invasive species are known to pose a serious threat to human health, either as direct pathogens, as vectors, or habitats for pathogens, or by producing toxins (Mazza, 2014). Biological invasions are, after habitat destruction, the second largest cause of biodiversity loss in the world and their presence has become a major concern (Pôle-Relais Lagunes Méditerranéennes, 2017). The negative ecological impacts of invasive plants include loss of biodiversity, disruption of normal functioning of ecosystems (Mack et al., 2000; Pimentel et al., 2005). Also, invasive plants can have negative economic impacts when disturbances of native species affect the normal provision of economic services (Pimentel et al., 2005). In Benin, studies by Fandohan (2015), among others, highlighted the threats posed by invasive plants and climate change to the environment and the integrity of many ecosystems, including those of protected areas. Aboh (2008) demonstrated that biological invasions change the composition and structure of plant communities and also ecosystems. Similarly, the findings of Aboh (2008) showed that, at the invasion stage, an invasive alien species such as *Mesosphaerum suaveolens,* formerly called *Hyptis suaveolens,* by itself defines the physiognomy of the herbaceous stratum. This species is particularly aggressive in areas where it is present and develops to the detriment of species in the environment. This species highly reduces the specific diversity of the ecosystems it invades. Further efforts are still needed to better understand the mechanisms of invasion, provide results to decision makers and propose control and eradication strategies.

Benin, like other countries in South of the Sahara, Asia and other countries in the world, is facing serious biological invasions, which justifies the interest on biological invasion in this work. The present work aims to improve knowledge on the danger of invasive alien species and to contribute to the conservation of Benin's biodiversity through the management of *M. suaveolens*. The research questions that guided our investigations are:

1) what is the impact of *M. suaveolens* on the biodiversity of Benin's ecosystems? 2) What is the damage caused by this species to human populations? 3) Which areas are at high risk of this invasive species in the present and in the future? Answers to those questions will surely help manage the species and its actual and potential impacts on the biodiversity of the country.

Study area

The Republic of Benin, our study area, is located entirely in the inter tropical zone, between 6°30' and 12°30' of North latitude and 1° and 3°40' of East longitude (Figure 1). It is bounded to the north by the Republics of Niger and Burkina Faso, to the south by the Atlantic Ocean, to the west by the Republic of Togo and to the east by the Republic of Nigeria. Apart from the north-western area in the Atacora mountain ranges, the center in the hill department, Benin has a relatively flat relief. Due to its extension between the coast of the Gulf of Benin and the Niger Valley, Benin presents a varied range of climates characterized by relatively low annual rainfall ranging from 900 to 1300 mm per year. The study area is characterized by the proliferation of *M. suaveolens* in natural pastures. The human influence has strongly marked the physiognomy of ecosystems.

MATERIALS AND METHODS

Plant material

This description relates to the work of Akoègninou et al. (2006) and Raizada (2006). *M. suaveolens* belongs to the Lamiaceae family and the Lamiales order. It is an erect and very aromatic annual species, reaching 1.5 m in height and propagating by seed (Figure 2). The stem is woody, polygonal, much branched, leafy, greyish, pubescent and marked with glandular spots. This species is native to tropical America, but is now widespread in tropical Africa and Asia (Hutchinson and Daziel, 1963). The species prefers fallows, coastal sand and wooded savannah, open areas and well-drained soils.

State of the occurrence data of *M. suaveolens*

In order to achieve the state of occurrence data of *M. suaveolens* we took into account three main points:

1) Downloading data from the Global Biodiversity Information Facility database (GBIF);
2) Occurrence data from literature and
3) Field data collection.

The data obtained were analyzed and subjected to a whole cleaning process using Excel and OpenRefine software (version 2.6, Chan Zuckerberg Initiative, 2010). With the help of these softwares, the check of scientific names was carried out and duplicated data were discarded. Successive filters made it possible to retain the data corresponding to the current climate (occurrences collected in the time range from 1960 to the present day).

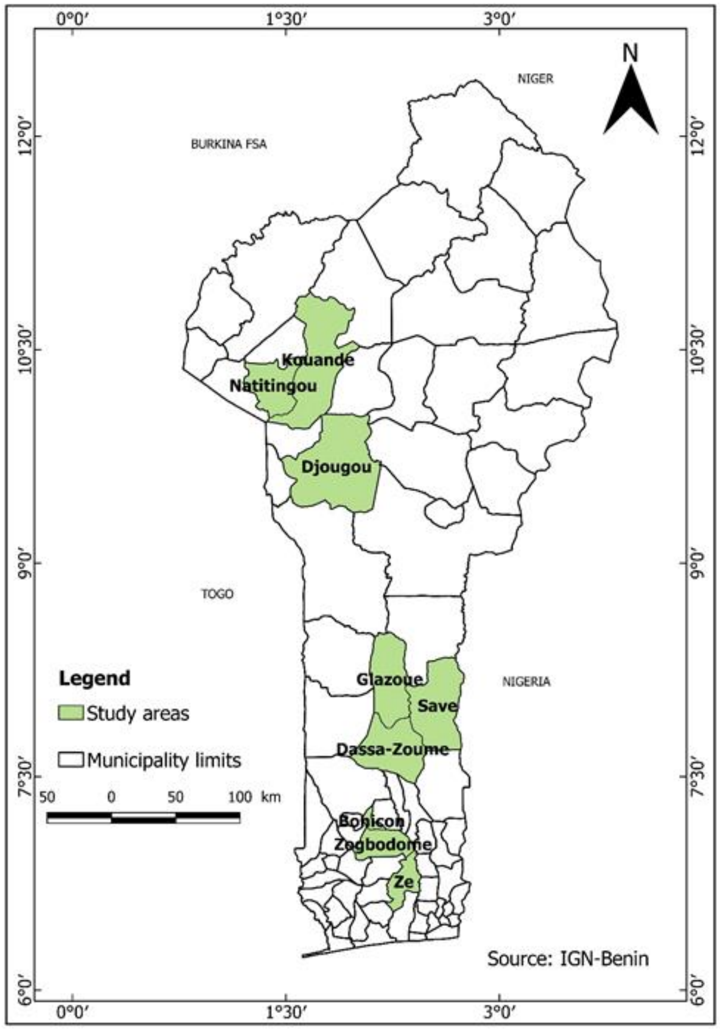

Figure 1. Study area.

Verification of geographic coordinates was then carried out. Indeed, the coordinates were displayed in the cartographic software QGIS (version 2.18.4; Tim Sutton, 2016) and superimposed on the vector data of the boundaries of Africa in order to verify their ranges.

Description of the impacts of *M. suaveolens* on biodiversity in Benin

Data concerning the impact of *M. suaveolens* were collected from populations facing problems caused by the species; we therefore envisioned to understand and appreciate their knowledge. To this end, a questionnaire was sent to the respondents. The description of the different impacts of *M. suaveolens* cited by the populations was collected. The target groups surveyed were mainly livestock breeders and farmers, who are confronted to the damages of this species. The sampling of the people to be surveyed was based on the reported presence of the species through the geographical coordinates downloaded from the GBIF website (www.gbif.org) and on the localities where the species has been reported in the flora of Benin (De Souza, 2009). The juxtaposition of these data made it possible to target three communes per climatic zone in Benin in order to cover different areas of the territory while taking into account the species presence criterion. The selected localities were the following municipalities: Djougou, Natitingou and Kouandé in the Sudanian zone (Zone I); Dassa-Zoumè, Savè and Glazoué in the Sudano-Guinean zone (Zone II); Zogbodomè, Bohicon and Zè in the Guinean zone (Zone III). The sample size was determined using Dagnelie's formula (Dagnelie, 1998) and using statistics from the national census (RGPH4).

$$n = \frac{U^2 \times p(1-p)}{d^2} \quad (1)$$

With n: the number of respondents; U: Value of the confidence level of a normal distribution; p: the proportion of the agricultural population in relation to the total population; d: the margin of error set at 7% for this study.

Ecological niche modelling of *M. suaveolens*

The modelling was done in the Maxent software (Phillips, 2006), one of the best frequently cited in the literature (Phillips, 2006)

Figure 2. Picture of *M. suaveolens*.

using present and future climate variables downloaded from the Africlim website at a resolution of 2.5 min under the rcp4.5 and rcp8.5 scenarios at horizon 2055 (Platts, 2015). A mask has been created to cover the points of occurrence. This is the area of accessibility or presence (P) of the species in the sense of Soberón and Peterson (2005). The environmental variables of the present and future downloaded were carefully cut out according to the mask and then converted into ASCII format using the mapping software QGIS (version 2.18.4; Tim Sutton, 2016). Part of the occurrence data (75%) was used to calibrate the model, the second part to test it. A selection of appropriate environmental variables was then made to determine the environmental variables that most govern the distribution of the species.

Strategies for the control and eradication of *M. suaveolens* in the context of climate and global changes

The fight against invasive species requires the elaboration of laws and regulations to limit their introduction and expansion, but also and above all the establishment of a strategy and management tools to control and even eradicate them. Based on the results of modelling, surveys carried out and previous work on the species, effective control and eradication strategies in the context of climate and global changes were deduced and proposed.

RESULTS

State of the occurrence data of *M. suaveolens*

M. suaveolens is a species widely distributed in the world, found in Africa south of the Sahara. It is present in Benin and has a wide distribution. The collection of occurrence data through the Global Biodiversity Information Facility (GBIF); the data collected in the field and data obtained through literature has enabled us to have a total of 2900 occurrences of which, 2065 from GBIF, 22 from literature and 813 from field collection (Figure 3). The points of occurrence of this species are distributed over Africa south of the Sahara, mainly West and East Africa. In Benin, this species is geographically distributed along the territory and affects all the departments.

Description of the socio-economic and environmental impacts of *M. suaveolens* in Benin

M. suaveolens commonly known as "Zansoukpè man" in “Fongbé’’, a local language of Benin, is recognized by respondents as an invasive alien species causing enormous damage. Respondents unanimously agreed that *M. suaveolens* is not eaten by ruminants and its heavy presence and expansion considerably reduces forage resources. The species is reported to be the cause of several weeding in fields and fallows, increasing the cost of production. The spread of the species has been attributed to various factors. Wind, runoff and accidental transport were the most frequently cited factors. In fact, 30.29% of the respondents considered wind to be the most important factor in the spread of the species.

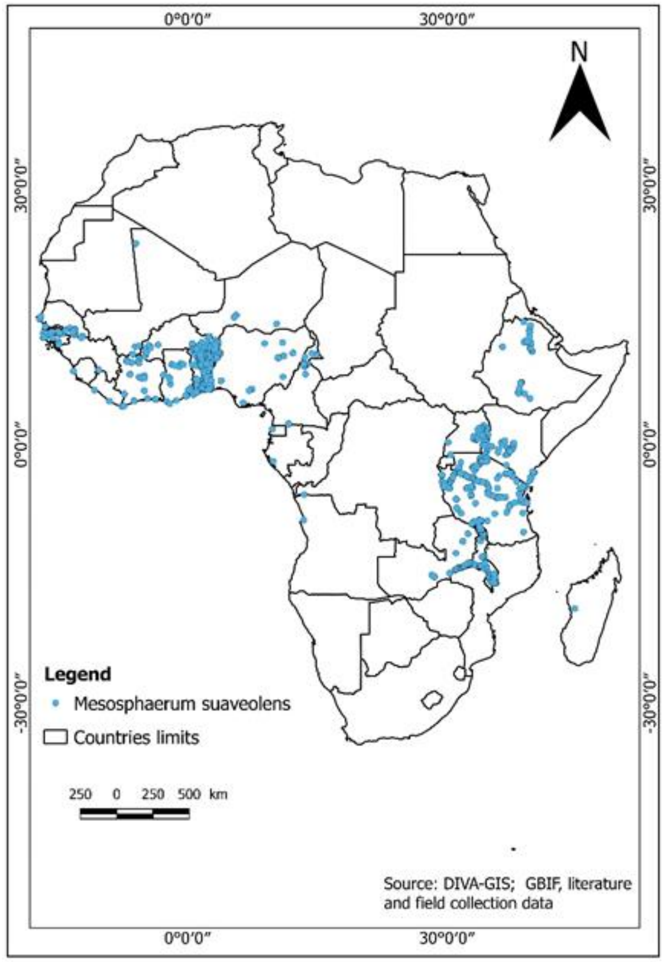

Figure 3. Spatial distribution of *M. suaveolens* across Africa.

However, 20.44% believe that the spread of the species is induced by runoff water. On the other hand, 18.22% of the respondents believe that the spread is by accidental transport. However, concerning a possible use of the plant, a proportion of 24.87% of the participants cited medicinal virtues notably against wounds, fever and as a repellent to fight against mosquitoes.

Ecological niche model of *M. suaveolens*

Selection of environmental variables

A total of 4 bioclimatic variables were selected. These are: bio4 (Temperature Seasonality), bio6 (Minimum Temperature of Coldest Month), bio12 (Annual Precipitation) and bio 17 (Precipitation of Driest Quarter). The importance of these variables was also assessed using the jackknife test, whose analysis showed that the variables that contributed most to the development of the model when used in isolation were, in order of importance: bio12, bio17, bio4 and bio6 (Figure 4). For each environmental variable, the green bar shows how much the total gain is reduced if that specific variable is excluded from the analysis, while the blue bar shows the gain if a variable if used solely in the analysis. The value of the Area Under Curve (AUC) from the implementation of the Maxent model (0.790) (Figure 5) confirmed the good performance of the Maxent algorithm in capturing variations in the environmental data. The TSS value was 0.47 and the Partial ROC test indicated that the model performed better than random.

Current and future distribution of M. suaveolens habitats

The modelling results showed that Africa south of Sahara is globally threatened by the species with the exception of part of southern Africa (Figure 6). For the future projections to 2055, the model predicted a considerable increase in the current ranges of the species. It appeared

Figure 4. Importance of variables (Jackknife test) on model calibration data.

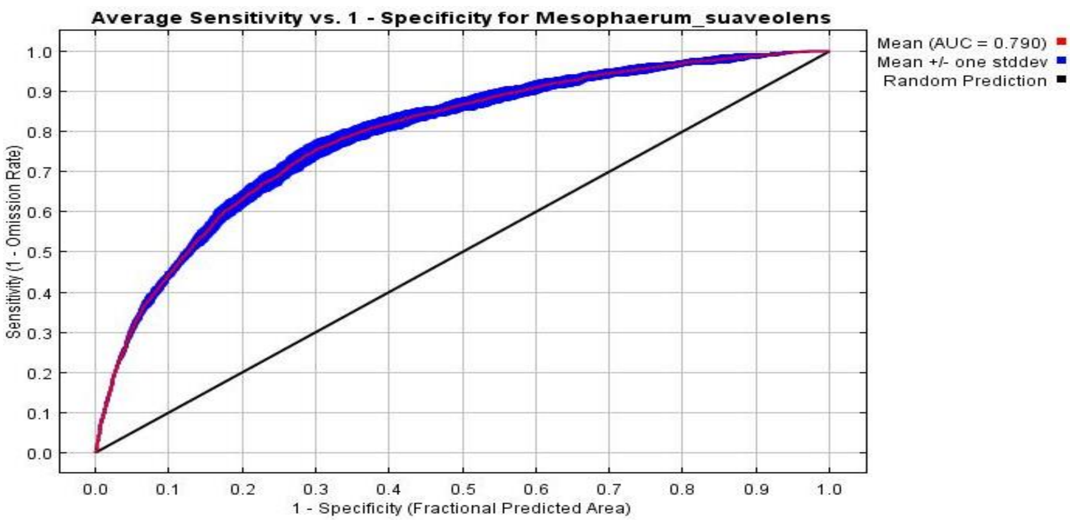

Figure 5. Curve of the mean CUA value of the *M. suaveolens* distribution model.

that climate change will lead to an increase in the current ranges of M. suaveolens. The standard deviation map help to understand uncertainties related to the projections. Indeed, we globally have zero as the value of uncertainties except in Central Africa, East Madagascar and South of South Africa where the value of uncertainty is about 0.25 (Figures 7 and 8). With the standard deviation map (Figure 9), we observed limited uncertainties, which indicated a reliable model prediction. However we notice 0.25 as uncertainties value in south of West Africa (Figure 10). For the scenario RCP 4.5, the standard deviation map also indicate generally limited uncertainties except at the north of the East Africa (Figure 11).

DISCUSSION

Socio-economic and environmental risks of the invasion of alien species in general and of *M. suaveolens* in particular in Benin and Africa

The present study highlights the problem of invasive alien plants in general and that of *M. suaveolens* in particular. Spreading of alien species cause biodiversity degradation and have important socioeconomic and ecological impacts (Duguma et al., 2019).The results of the surveys confirmed that the invasion of *M. suaveolens* represents a serious threat to agricultural and pastoral activities as well as to native biodiversity. Indeed, this plant has an adverse impact on the vegetation of invaded areas in terms of reduction of number of species and diversity (Oumorou et al., 2010). It establishes and develops to the detriment of native species, whose germination is considerably hindered, thus leading to the scarcity of native species. In fields and fallows, it causes a series of repetitive maintenance operations, thus increasing production costs. Furthermore, it considerably reduces the plant biomass available for consumption in pastures. Since the invasive plant is not palatable, cattle, through selective grazing, exert a strong pressure on grasses and other palatable resources.

The economic and social impacts of invasive species in general and of *M.suaveolens* in particular include both directed effects on agricultural productivity, public utility operations, tourism and outdoor recreation, as well as

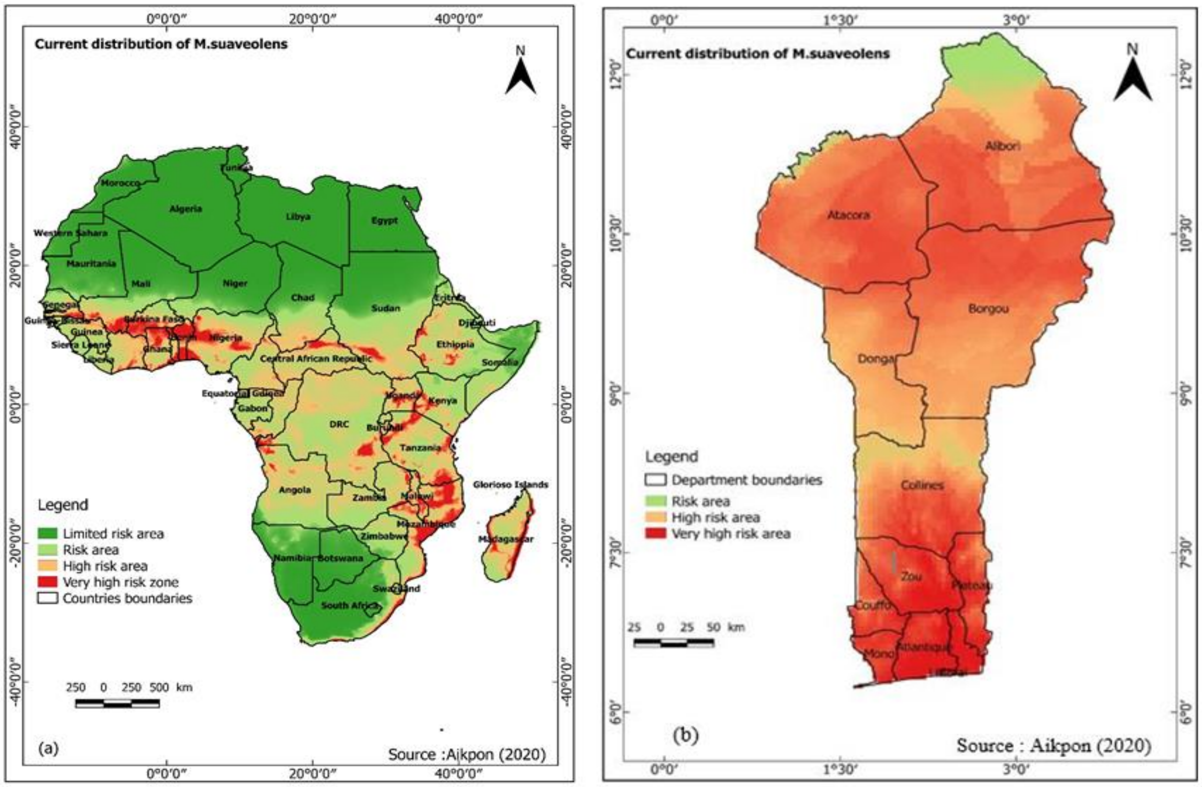

Figure 6. Spatial distribution of *M.suaveolens* at present: a) in Africa; b) in Benin.

costs associated with control efforts that this species generates (Leistritz et al., 2004). Indeed, *M. suaveolens* is responsible for significant maintenance costs for crop fields, which contributes to the increase in food costs for certain producers.

Also, the presence of this species in cities and agglomerations makes maintenance costs while having a negative effect on tourism activities (U.S. Fish and Wildlife Service, 2012).For example, "a study has estimated that the economic damage associated with invasive species in the United States is approximately $ 120 billion per year" (U.S. Fish and Wildlife Service, 2012).

Ecology of *M. suaveolens* and environmental factors governing its distribution

The results of the field work revealed that *M. suaveolens* grows in fallows, pastures, unmanaged plots, and alongside roads. It also infests ploughed land and grows less under woody areas. It adapts to several types of soil, prefers open, well-drained environments and shows a great ecological amplitude. The results of our model are consistent with the ecology of the species. In fact, annual precipitation (bio12), temperature and its seasonality (bio4) are among the variables that contributed most to the species distribution prediction models. The distribution of this species is also influenced by several environmental factors (Sharma et al., 2017). Indeed, the destruction of natural ecosystems and poor land use leave a free field for the establishment of this species and contribute greatly to its expansion. Strong air currents, run-off water and various human activities (transport, etc.) all contribute to the species dispersal.

Impact of climate and global change on the distribution of *M. suaveolens*

Since climate is one of the main determinants of plant distribution, climate change influences plant expansion (McNeely et al., 2001). The coming decades will be more marked by global changes, which will have major impacts on ecosystems and biological invasions (National Research Council, 1989). Indeed climate change and proliferation of invasive species are now considered as two very important factors acting on global biodiversity change (Taylor et al., 2014). Ecological niche modeling to understand and predict the impact of climate change on species depends a lot on environmental factors (Ganglo et al., 2017). Climate change modifies two of the main factors that control the distribution of biomes: temperature and precipitation. This means that the ecosystems found

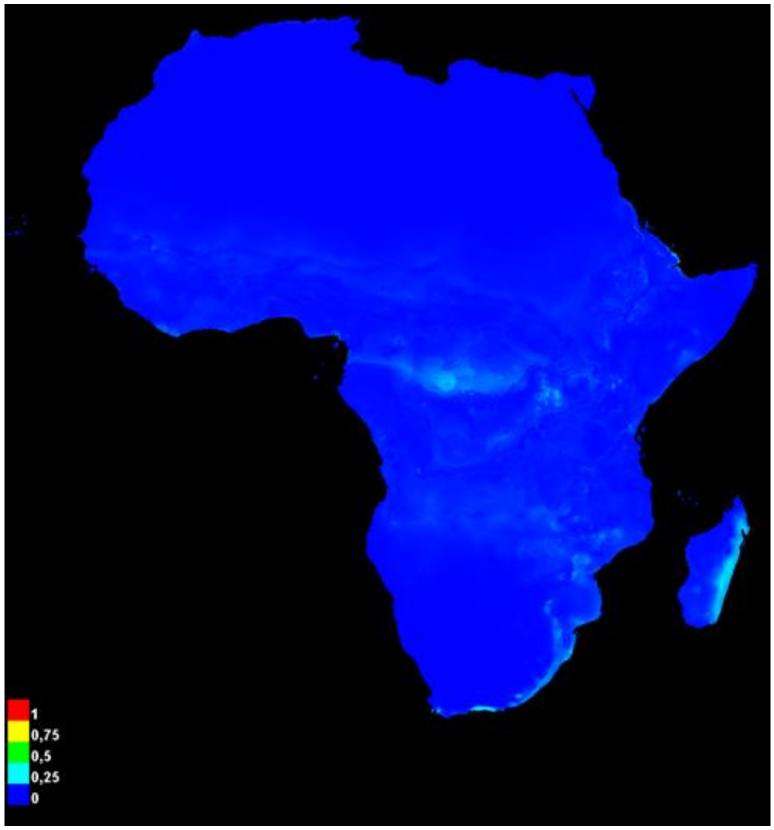

Figure 7. Standard deviation map of the current distribution model of the species.

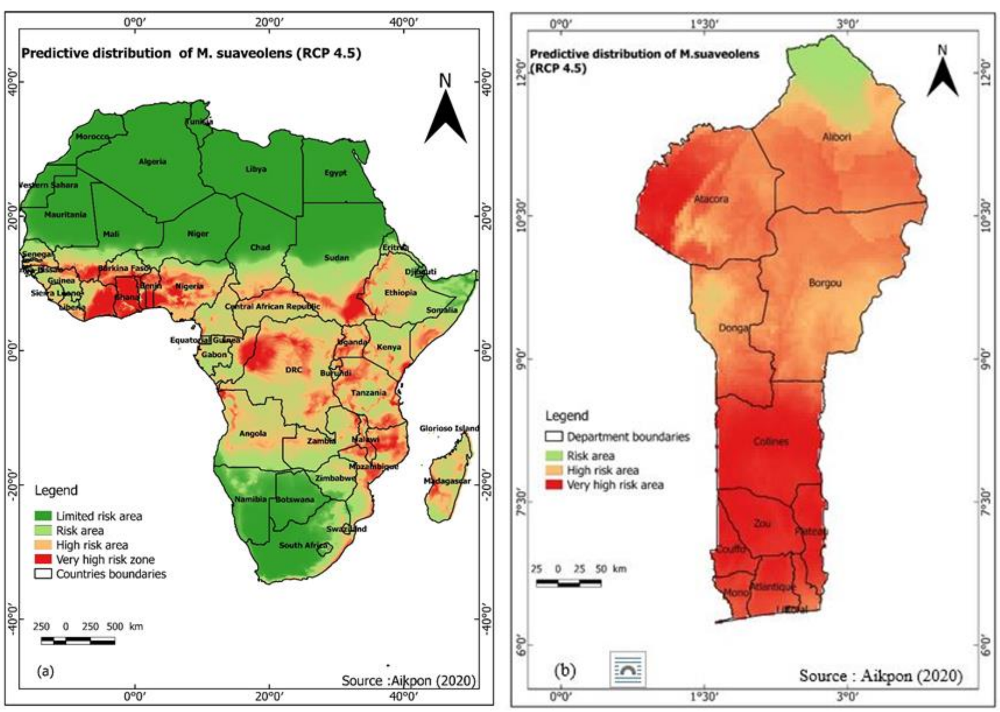

Figure 8. Projected spatial distribution of *M. suaveolens* under RCP4.5 horizon 2055: a) in Africa; b) in Benin.

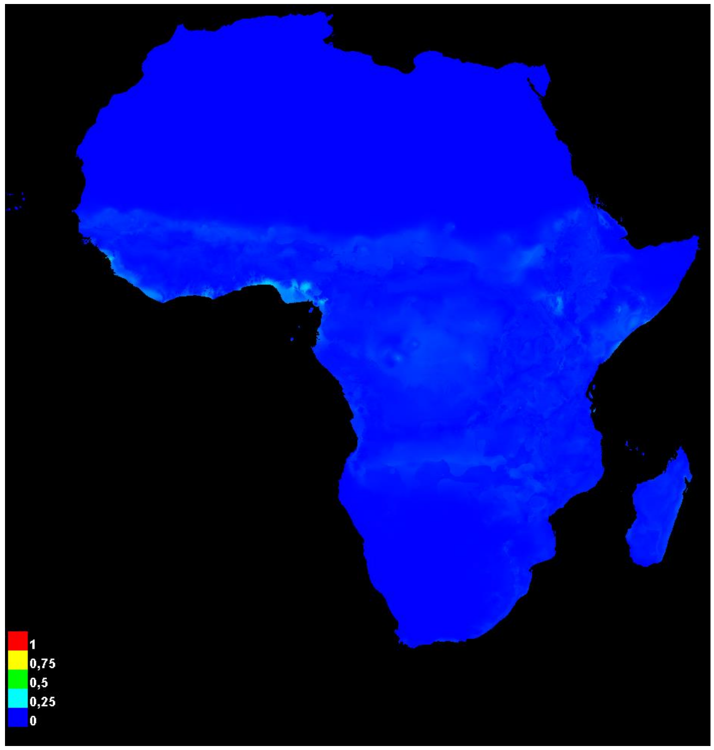

Figure 9. Standard deviation of the projected distribution under scenario RCP 4.5 horizon 2055.

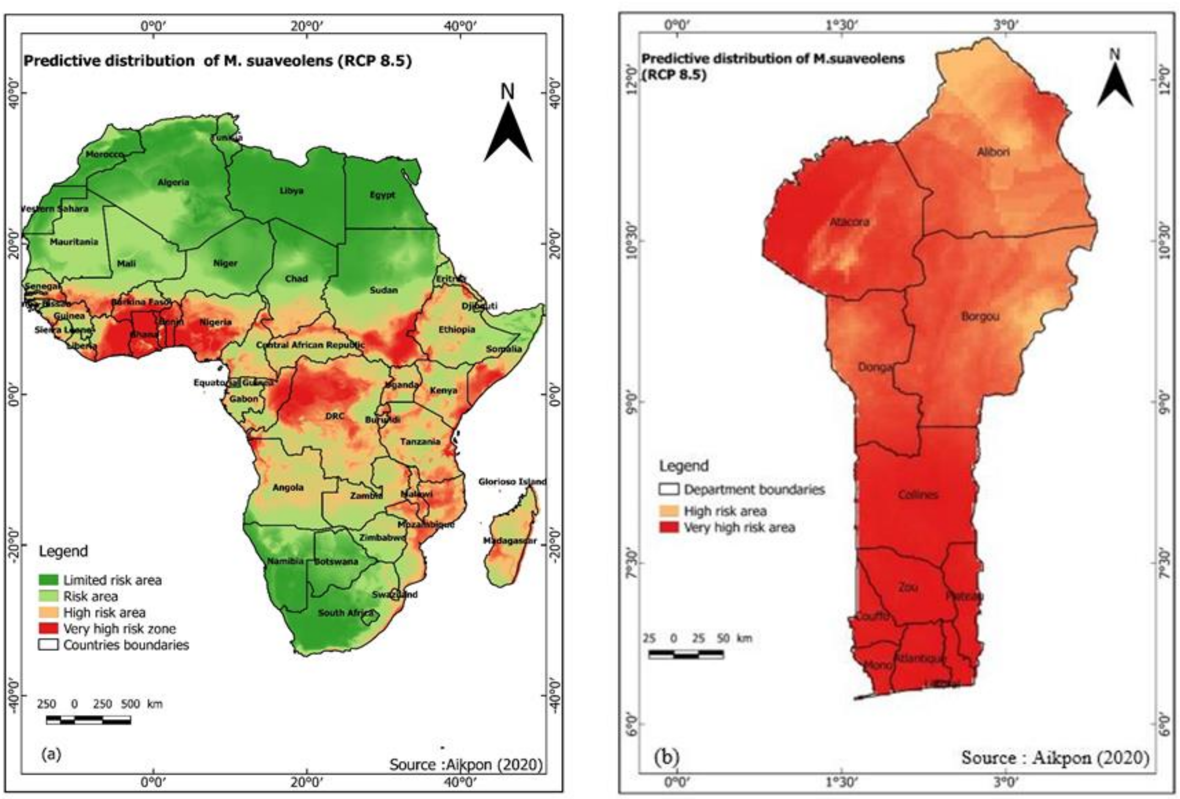

Figure 10. Projected spatial distribution of *M. suaveolens* under RCP8.5 horizon 2055: a) in Africa; b) in Benin.

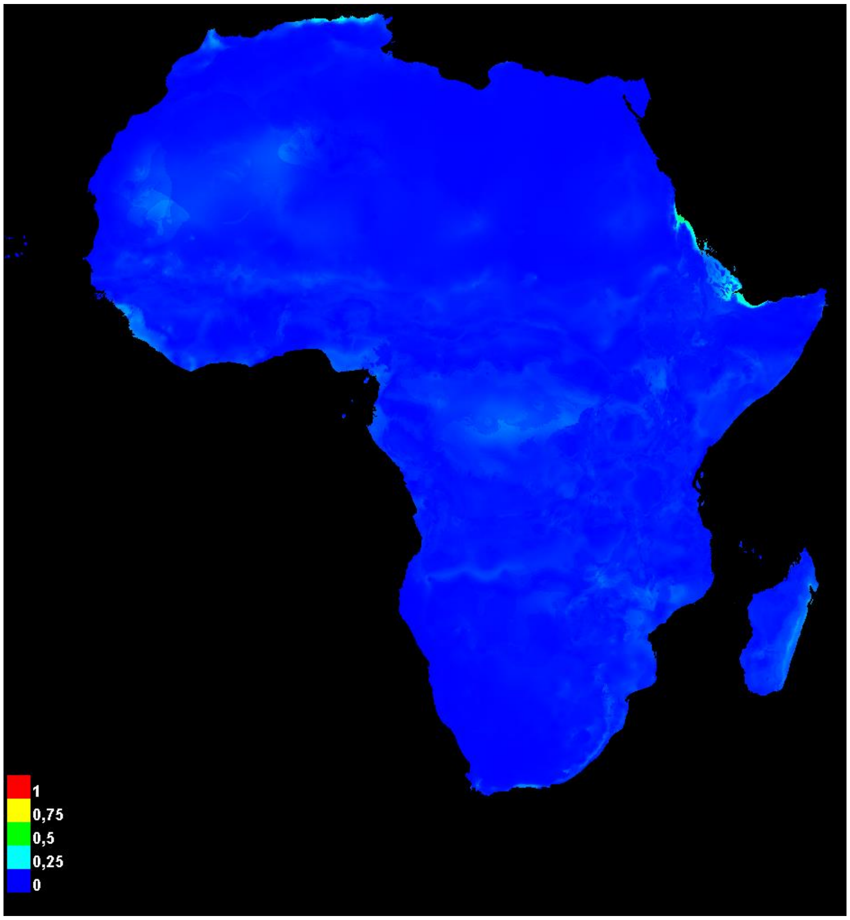

Figure 11. Standard deviation of the scenario RCP 4.

within the biomes are directly affected by climate change. The results of our work clearly showed an expansion of areas at risk for *M. suaveolens* under any scenario considered. This species, already widely distributed in Benin and sub-Saharan Africa with the exception of part of southern Africa, will expand under the influence of climate change. These results obtained corroborate those of other research work carried out in the field. Indeed, invasive species are benefiting from climate change (IUCN, 2000). When the climate varies rapidly, invasive plant species, which are more adaptable, far better than other species, increase their pressure on ecosystems (Peterson et al., 2003). Their threat is therefore bound to increase, both for biodiversity and for human activities.

Species control and eradication strategies

The proliferation of *M. suaveolens* is a major problem today. In particular, its proliferation is a major pastoral problem for pastoralists, disrupting farmers and having a negative impact on ecosystems and native biodiversity. It is important and capital that management actions are and undertaken to save rangelands, biodiversity in general to relieve farmers. It is therefore imperative to regularly raise public awareness on the danger that this species presents to biodiversity and its long-term impact. Raising awareness and regularly sensitizing populations is very important in invasive species control (Natukunda et al., 2019). It is also imperative to develop programs and activities to combat this species; to involve the population in decision-making and in the development of programs of activities to combat this species; and to intensify awareness-raising sessions on good land-use practices for the population; to train the populations in techniques for monitoring, cutting, bark removing and eradication of this species from their fields and surrounding environments; to introduce monitoring and targeted actions; to implement biological control measures aimed at protecting natural ecosystems, a refuge of great diversity, as a matter of priority. Biological control is the long-term, less costly and environmentally friendly solution. Several authors have suggested the use of competitive species such as perennial grasses to control invasive herbaceous species (D'Antonio and Meyerson, 2002).

In addition to the statements made by some respondents about the mosquito control properties of this species, studies have shown its insecticidal effect. We also suggest working towards the implementation of well-developed plans to induce large-scale use of this species. This will not only reduce the density of this species but will also be profitable. The implementation and evaluation of different methods are essential on invasive species control (da Silveira et al., 2018).

Conclusion

This study found that, consistent with its ecology, the spatial distribution of *M. suaveolens* is primarily controlled by precipitation and temperature variables (seasonality of temperature, minimum temperature of the coldest month, annual precipitation, and precipitation of the driest quarter). Our study also demonstrated that the invasion of *M. suaveolens* has a significant adverse impact on biodiversity, which in turn affects the local populations that depend on this biodiversity. The species induces a negative impact in terms of reduction in species numbers, diversity, richness and uniformity. As a result, the species has socio-economic implications for local populations such as depleted grazing for livestock and the loss of major plant species used by local people. It is therefore urgent that more efforts be made to manage this species. For future investigations, it will be useful to focus on the propagation mechanism, the quantification of socio-economic implications and the best possible values of this species in order to control it effectively.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Impact of protected areas on the livelihood of locals: A case study in Saadani National Park, Tanzania

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We randomly selected 200 households from the four villages (50 per village) based on the household distance from the park: villages settled close to the park and villages settled further away from the park. Besides, qualitative methods including focus group discussions and direct observations, were used. Community activities differed between the two groups of villages (close and far from the park). Furthermore, local communities benefited directly and indirectly from employment, ecotourism, and support through social services. Education level was a significant factor influencing the perception of the benefits gained from the park. Crop raiding was the biggest problem reported by most people in the study area (31.5%, n = 200), followed by livestock losses. This study revealed that the establishment and expansion of a protected area can have positive and negative socio-economic, cultural, and political impacts on the livelihoods of local people. Households close to the park had little access to land; thus, few of them practiced agricultural activities and had crop production incomes. The needs of local people and poverty alleviation should be considered as important factors during the planning and designation of protected areas (PAs) in order to meet conservation and livelihood goals. The objective of the present study was to assess the perceptions of impact of PAs on the livelihoods of local people in terms of costs and benefits in the area adjacent to Saadani National Park in Tanzania with those not adjacent to Saadani NP.

Key words: Attitudes benefit sharing, livelihood, local communities, protected areas.

INTRODUCTION

Protected areas (PAs) are considered to play important roles in the conservation of habitats of different plant and animal species throughout the world (Allendorf, 2020; Maxted et al., 2013). For the surrounding local communities, protected areas can restrict access to livelihood resources, force relocations, and provide opportunities for income generation through tourism revenues (Nepal and Weber, 1995). PAs are believed to play an important role in poverty alleviation by supplying ecosystem services, developing ecotourism, and providing conservation benefits for social and economic development (Barrow et al., 2005).

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PAs cover approximately 17% of the terrestrial Earth surface (IPBES, 2019). Protected areas are managed for different reasons, such as the protection of species and ecosystems, safeguarding of landscapes, scenic, and historic features, tourism and recreation, education, science or research, protection of watersheds, and protection of important reserves of timber, fisheries, and other biological resources (Pearson, 2016). They are also increasingly being managed for the sustainable use of natural resources by local people (Kattumuri, 2018). In Tanzania, 43.7% of the total land is protected, whereby forest reserves cover 15.7% and wildlife protected areas cover approximately 28% (UNEP-WCMC and IUCN, 2021). PAs include National Parks, Game Reserves, Ngorongoro Conservation Area Authority (NCAA), Game Controlled Areas, and Wildlife Management Areas. Conservation and management of these areas are facing different challenges, but the most important one is the current human population growth, which leads to over-exploitation, resource degradation, habitat loss and squeezing of animal species (Toonen et al., 2013; Veldhuis et al., 2019).

The livelihoods of poor rural people are particularly vulnerable to the establishment of PAs, particularly in developing countries, because their livelihoods are mainly dependent on agriculture and on the available natural resources (Young and Goldman, 2015). The impact of PAs on local livelihood has been widely studied (Roe, 2008; West et al., 2006). Benefits gained and costs paid by local people as a result of the presence of PAs in their vicinities can encourage positive or negative attitudes toward conservation activities (Clements et al., 2014; Kideghesho et al., 2007; Røskaft et al., 2007). Currently, balancing the conservation goals and needs of local people is particularly challenging (Bennett and Dearden, 2014; Clements et al., 2014). Understanding the factors that influence the relationship between local people and PAs is important for achieving conservation and livelihood goals (Kideghesho et al., 2007). During recent years, people living adjacent to PAs have been competing with wild animals, such as African elephants (*Loxodonta africana*), over resources, as well as conflicting with them because of the crop loss due to crop raiding (Hariohay et al., 2018; Hariohay and Røskaft, 2015; Redpath et al., 2013).

Conservation activities have been aiming at the establishment of PAs with the exclusion of local people on land and resource use as well as displacement of people from their lands (Lele et al., 2010). Different studies have suggested that the successful sustainable management of PAs and the acceptance of PA establishment and expansion are dependent on the participation of local communities (Bennett and Dearden, 2014; Bode et al., 2015; Campbell and Vainio-Mattila, 2003; Kideghesho, 2008).

The recognition of local support in management and conservation has increased because of ensuring that PAs play a central role in sustaining local livelihoods. Locals' livelihoods can be sustained by providing them incentive benefits to offset the costs of conservation (Kideghesho et al., 2007; Sekhar, 2003). Participatory approaches such as the Integrated Conservation and Development Project (ICDP) and community-based conservation approaches (CBCs) are new strategies that aim to include local communities in conservation. Such strategies have been developed worldwide, including in Tanzania (Kideghesho, 2010; Lele et al., 2010).

However, there is not much information and there is still an ongoing debate as to when and how to include local communities in conservation, in order to achieve sustainable conservation (Wang et al., 2012). Benefits include social support-related projects, ecotourism benefits, employment, and cultural and environmental benefits (Bennett and Dearden, 2014). On the other hand, local people living adjacent to PAs experience certain costs and losses, such as crop damage, livestock depredation, human injuries, and restrictions on access to resources from the park (Khumalo and Yung, 2015). Thus, surveys on the perceptions on impact of PAs (including benefits and costs) on local people living in and around such areas are fundamental to balance the conservation goals and needs of these people (Sekhar, 2003).

The gained benefits and experienced costs associated with living adjacent to PAs can influence local people's attitudes towards conservation activities both positively and negatively (Røskaft et al., 2007). Therefore, an understanding of the factors that influence the relationship between local people and PAs is important for achieving PA conservation and secure the locals a sustainable livelihood. The objective of the present study was to assess the perceptions of impact of PAs on the livelihoods of local people in terms of costs and benefits in the area adjacent to Saadani National Park in Tanzania with those not adjacent to Saadani NP.

METHODS

Study area

Saadani National Park (SANAPA) is a coastal protected area in Tanzania covering an area of 1100 km^2. It is the only national park that includes both terrestrial and marine habitats, and it is the only national park bordering the sea. The park is located in south-eastern Tanzania (5º21' 22–6º21' 53 S, 38º34'13–38º51'2 E), and it spreads across three districts (Bagamoyo, Handeni, and Pangani). It was officially gazetted as a national park in 2005 from the former Saadani Game Reserve established in 1969, as well as the former Mkwaja Ranch Area, the Wami River, and the Zaraninge Forest. The area experiences a bimodal rainfall with short rains from October to November, annually averaging 100–250 mm, followed by a mild dry season from January to February, and a long rainy season from March to June with temperatures ranging between 20-30ºC (Sitters et al., 2013).

The park supports a wide range and unique combination of both marine and terrestrial flora and fauna. Approximately 30 species of large mammals are present in the park, as well as a variety of reptiles and birds. In addition, over 40 species of fish, alongside turtles, whales, and dolphins, occur in the ocean. The park is dominated by *Acacia zanzibarica* and a variety of other vegetation types, including forestry-savanna-grassland mosaics, coastal forests on the Zaraninge Plateau, a shoreline with salt flats, coastal fringe forests, herbaceous vegetation, mangrove forests, and maritime ecosystems (Bloesch and Klötzli, 2004). SANAPA shares the ecosystem with Wami-Mbiki Wildlife Management Area, which is inhabited by animals such as elephants and buffalos (*Syncerus caffer*) (Bloesch and Klötzli, 2004).

The park is surrounded by 17 villages (Figure 1) engaged in different activities with negative impacts on the PA. The study was conducted to assess the impacts of SANAPA on local communities living in four villages (Saadani, Matipwili, Mkwaja, and Gongo): three villages (Saadani, Matipwili, and Gongo) are found in Mkange Ward, Bagamoyo District, and one (Mkwaja) is found in Mkwaja Ward, Pangani District. The selection of these villages was based on their different activities and impacts on the National Park. The locals in the two villages closer to park (Saadani and Mkwaja) depend on fishing for their livelihoods, whereas the locals in the two villages further away from the park (Gongo and Matipwili) depend on agriculture as the main income-generating activity. Crops such as maize, cassava, rice/paddy, pineapples, and coconuts are cultivated in the study area. Among them, maize, cassava, and rice/paddy are mostly for household use, whereas pineapples and coconuts are mostly cultivated as cash crops. In addition, native people in the study area have small businesses such as restaurants and shops for selling food and other basic needs.

Data collection

The study assessed through questionnaires (Appendix 1) the impacts of the SANAPA protected area on local people's livelihoods in terms of community cost and benefit. Survey data were collected, and questionnaire surveys were carried out from June to August 2015. Both closed-and open-ended questions were included, and a total of 200 randomly selected respondents from the four villages (50 per village) were interviewed (Figure 1). The villages were in two wards, Mkange and Mkwaja, and in two districts, Bagamoyo and Pangani. In each village, 50 households were randomly selected, and surveys were carried out with the head of the household, his wife, or another adult person who represented the household. The study villages were grouped into two groups based on the household distance from the park: villages settled close to the park (0.5–2 km, Saadani and Mkwaja) and villages settled further away from the park (4–10 km, Gongo and Matipwili). Before data collection, information was provided to the regional and district offices to obtain the introduction letter when visiting the villages. A survey of the study area was conducted for the purpose of familiarising with the area. Relevant information about the number of people in each village was provided by the village leaders. In addition, information was sent out in advance to the households to check their availability for the interview.

Information about household characteristics (age, gender, level of education, and number of household members), different economic activities (e.g., crop production, fishing, and business), costs and benefits, and types of assets owned (e.g., land size, livestock, and other physical assets) were gathered.

Qualitative methods, including focus group discussions and direct observations, were used as described by Hancock et al. (2016). Focus group discussions were conducted with the key informants such as the village leaders, experienced people, elders, and teachers + (5–8 people in each village). Focus group discussions were useful for collecting information such as the benefits gained from SANAPA. Collecting such information at the individual level was difficult because the benefits provided by SANAPA were at the community level. Based on perception measurements, this study sought to find out about how people perceived the presence of a park adjacent to their villages and to what extent they were willing to support park management (behavioural component). Different methods used during data collection enhanced its reliability.

Data analysis

The data collected from the field were entered into a computer, coded, and statistically analysed using SPSS version 21 (IBM, 2016). Descriptive statistics were run before starting the analyses to clean the collected data and to acquire knowledge of the nature of the data. Categorical responses were analysed using Pearson's Chi-square tests to determine whether the two variables were independent of each other. T-tests were used to test for differences between the number of local people in favour or against the creation of this national park as well as for the average age-sex distribution of people living across all study villages. The association among the variables was regarded as significant when $P < 0.05$.

RESULTS

Socio-demographic variables

In the total sample, 109 of people were men (54%) and 91 were women (46%). The minimum age was 24 years, maximum age was 67 years, and the average age was 43.7 years (SD = 13.12). The average number of household members was 4.9. (SD = 1.3), the minimum being 2 and the maximum 7. Most respondents (66%) had only the primary education level, 19% have never attended school, and only 15% had the secondary education level or above. The population's occupational structure showed two dominant occupations, with 46% (n = 200) crop farmers and 26% fishermen, whereas 28% of the respondents had other occupations. The frequency of different occupations differed between the two genders ($\chi2 = 56.1$, df = 32, $P = 0.005$).

Perceptions of positive impacts of SANAPA on the livelihoods of local people

Households recognized the different direct and indirect benefits from living adjacent to SANAPA. The perceived direct positive impacts were grouped as employment, benefits from ecotourism, and support in social services such as dispensaries, classrooms, firewood collection, water services, and emergency transport. Other perceived benefits included community participation in sustainable resource management and development schemes (or Integrated Conservation and Development Projects, ICDPs), which strengthened land tenure. Among the

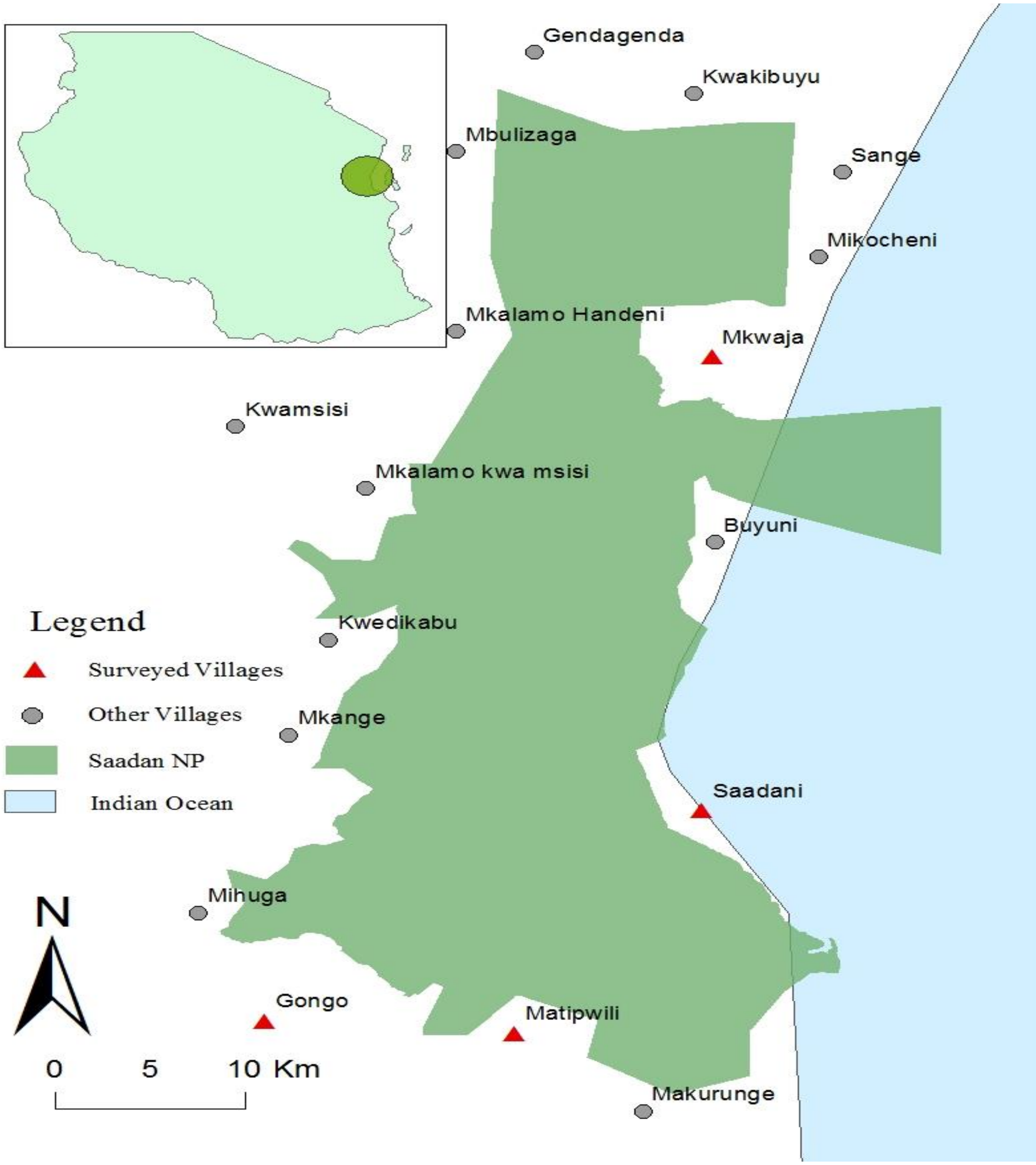

Figure 1. Map showing villages adjacent to Saadani National Park. The smaller map in the upper left part indicates the location of Saadani National Park in Tanzania.

respondents, 53.2% claimed that they benefited from SENAPA. Benefit types did not differ significantly between the two types of villages ($\chi 2 = 1.60$, df = 3, P = 0.66; Table 1).

Half of the total respondents (50%, n = 200) did not perceive any benefit or support from the conservation activities. Education level was a significant factor influencing the perception of the benefits gained from the park ($\chi 2 = 8.95$, df = 2, P = 0.01), as the majority of people with formal education (75%) appreciated the benefits gained, whereas this percentage was significantly lower (25%) in people with no formal education (Table 2).

Table 1. Types of perceived benefits from SANAPA for the local communities in relation to village distance from the park.

Village type	Types of perceived benefits			
	Employment	Help in social services	Ecotourism benefits	No benefits
Close to the park	8 (8%)	35 (35%)	8 (8%)	49 (49%)
Far from the park	4 (4%)	35 (35%)	10 (10%)	51 (51%)
Total	12 (6%)	70 (35%)	18 (9%)	100 (50%)

Table 2. Influence of education level on perceived benefits.

Perceived benefit	Education	
	None	Formal education
Yes	25 (25%)	75 (75%)
No	13 (13%)	87 (87%)
Total	38 (19%)	162 (81%)

According to the interview with the Chief Park Warden and Community Outreach officers, 7.5% of annual revenue accrued from conservation activities was used to support different development projects in adjacent communities. The provision of support is based on request from the village, i.e., the village is supposed to initiate a project and request funds from SANAPA. In 2005/2006, SANAPA constructed two classrooms and toilets in Matipwili village. In 2006/2007 and 2014/2015, SANAPA rehabilitated the Doctor and Teachers houses, respectively, in Saadani village. In addition, in 2012/2013, SANAPA constructed a water dam in Gongo, and in 2010/2011 SANAPA provided laboratory equipment to the Mkwaja village hospital.

The findings from the focus group discussions showed that the villages received indirect benefits by hosting different guests, visitors, and researchers visiting the park. When researchers or tourists visited the park, they contributed to the local economies through purchasing basic necessities such as food and paying for accommodation services to the local guesthouses and lodges. Information from focus group discussions revealed that more than 50% of the villages close to the park benefited more from indirect benefits compared to the villages farther away from the park. SANAPA also reported providing opportunities for school children to visit the national park in order for them to be able to discover and enjoy the beauty of natural amenities and learn about conservation issues and ecosystem processes.

Perceived negative impacts of SANAPA on the livelihoods of local people

Perceived problems and costs reported by the respondents included crop raiding, livestock losses, restriction in accessing certain resources, boundary conflicts, and human injuries (Figure 2). Crop raiding was the biggest problem reported by most people in the study area (31.5%, n = 200), followed by livestock losses. The differences in perceived problems reported by the two village groups were statistically significant ($\chi 2 = 41.69$, df = 4, $P \leq 0.001$), with the highest incidence of crop raiding (52%, n = 200) and the lowest incidence of human injuries in the villages further away from the park. All interviewed households, 24.5% reported a problem in accessing resources, including forest, land, firewood, and water resources. In addition, people reported a lack of area for collecting firewood as well as a lack of free movement, and some were not allowed to conduct certain activities such as agriculture, especially in the villages closer to the park. During the study, it was reported that one person from Matipwili village had been killed by lions in 2014 in Saadani village. Furthermore, there was no physical boundary to separate the park area and village land; thus, people reported boundary conflicts.

DISCUSSION

The results showed that even though the local communities were engaged in different activities, agriculture and fishing were the main sources of income in all investigated communities. The locals used agriculture as an alternative source of income but seemed to be facing a growing problem of crop damage by wild animals such as elephants and monkeys, which is the same problem as reported in the western part of the Serengeti National Park (Nyahongo et al., 2005). Community activities differed between the two groups of villages (close and far from the park). Most local

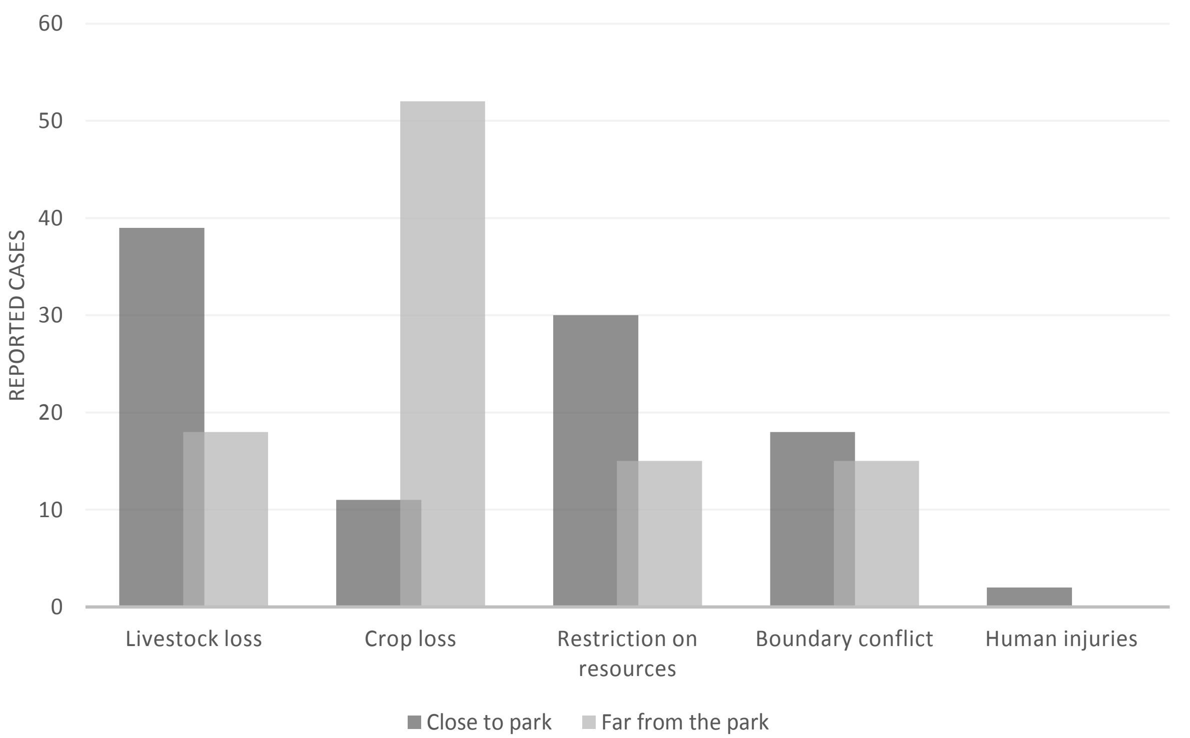

Figure 2. Different types of perceived costs in the two village types of different distance from the park.

communities close to the park depended on fishing, whereas villages far from the park depended on agriculture. Moreover, villages close to the park had the highest number of people with no income-generating activities, which affected their livelihoods. The reason for this might be that compared to the villages closer to the park, the villages far from the park had larger landholdings. During the establishment of SANAPA, the villages close to the park had to sacrifice more of their land than the villages far from the park, resulting in small land areas, which is why they were not able to diversify their economic activities as much as the villages far from the park.

Access to different resources, especially land, was considered to be an important factor in the diversification of different activities, as most people did not have other strategies and they mostly depended on agriculture and fishing. This finding corroborates the findings of Ellis and Allison (2004) on rural livelihood and diversity, which revealed the importance of accessing different assets for the diversification of livelihood strategies, which in turn reduced the dependence on natural resources. It is important for institutions such as SANAPA and other stakeholders to target the immediate livelihood needs and help create opportunities for the local communities to diversify their livelihood. The needs of local people and poverty alleviation should be considered as important factors during the planning and designation of PAs in order to meet conservation and livelihood goals and objectives (Pfaff et al., 2014).

Furthermore, local communities benefited directly and indirectly from employment, ecotourism, and help and support through social services related to the project because they are adjacent to SANAPA. The participation, involvement, support from local people, and equal provision of the benefits obtained from conservation activities are important in achieving conservation goals (Nyaupane and Poudel, 2011). Effective and sustainable conservation of wildlife can be achieved through strengthening the capabilities and knowledge of local people and different stakeholders (Langton et al., 2014). The costs experienced by local communities were associated with living adjacent to PAs, which in turn affected people’s livelihoods. The respondents acknowledged they did not have enough food throughout the year, and most of them did not know how to mitigate these problems. Problems were common in villages located close to the park boundary because there were no physical boundaries to separate the park and village lands.

Laws and regulations on the establishment of PAs are founded on the grounds that resource access is restricted to the local people (Vedeld et al., 2012). The establishment and expansion of PAs was found to have impacted and undermined the livelihood of locals, as most of them depended on agriculture and available resources. The restrictions of resource access, costs associated with living closer to the park boundaries, and poor involvement of locals in conservation activities contributed to more negative attitudes toward conservation activities**.** Several researchers have pointed out that the exclusion of local communities in conservation has led to difficulties in achieving conservation goals (Ban et al., 2013; Pullin et al., 2013). The needs and interests of local people should be given priority during the establishment and expansion of PAs, and they should be provided with alternative sources of livelihood. According to Røskaft et al. (2007), the support of local people to conservation will be compromised if their needs and interests are threatened.

Conclusion

The authors found that benefits were most provided in the form of social-related projects, and most local communities were not aware of the benefits due to poor involvement and participation in conservation activities. To achieve a good and sustainable relationship between the park and local communities, it is important for the park management to provide to the locals with different alternatives for income-generating activities in order to improve their livelihoods. Furthermore, due to costs associated by living closer to the PAs, conservation managers and policy makers should provide reliable solutions to the local communities who bear most of the conservation costs such as crop raiding and livestock depredation.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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APPENDIX

Household Questionnaire
Questionnaire number___________________________ District________________________ Ward_________________________
Village__
Date___
Household GPS: Lat_____Long___

Personal information

1. Respondent age
i) ≤ 37 Years ( ) ii) 38-48 Middle aged ( ) iii) 49+ Older ( )
2. Sex: Male ( ) Female ( )
3. Occupation
Farmer ( ) Fisher ( ) Teacher ( ) Businessman ( ) others (specify)__________2_____________
4. Level of Education
None ( ) Primary level ( ) Secondary level ( ) others (specify) __
5. Do you have child/children in school? i) Yes ( ) ii) No ( )

Age (years)	Sex	Education level

If no what is (are) the reason(s)_

Assets and Wealth

6. What is the area of land owned by household? ____
7. Do you own a House? i) Yes ( ) ii) No ( ) iii) How many houses do you own?
____

No. of Room	Wall material	Roof material	Floor material
	i)Cement ( )	Grass ( )	Cement ( )
	ii)Burnt Bricks ( )	Iron/steel ( )	Soil ( )
	iii)Unburnt Bricks ( )	Mud/Cow dung ( )	Tiles ( )
	iv)Mud ( )		

8. Do you own Livestock? Yes ( ) No ( )

Livestock owned	Number
Cow	
Goat	
Sheep	
Chicken	
Ducks	
Turkeys	
Pigs	
Others Specify	

9. Do you owned any of this equipment?

Name of Equipment	No. owned	Name of Equipment	No. owned
i)Ox-plough		viii)Wheelbarrow	
ii)Bicycle		ix) Tractor	
iii)Motorcycle		x)Refrigerator	
iv)Sewing machine		xi) Cell phone	
v)TV		xii)Other(specify)	
vi)Cannoe/fishingnet			
vii)Radio			

10. What are the main sources of income?
Agriculture ( ) Fishing ( ) Business ( ) hunting ( ) others (Specify) 1.______2.______3.______
11. What other activities do you do as alternative source of income? ___
12. Do you think your activities have any impacts on wildlife population?
Yes ( ) No ( )
13. If yes what impacts1.__2.______3.______
14. Do you have any of these?
Farm ( ) Backyard garden ( )
15. If yes how far from the park?
1-3 km 4-6 km 7-9 km Others (specify)

16. What are the major three crops you cultivate in your farm/garden?
1.______2______3.______
17. What best describes the food situation in your household for the past 12 months?
a. In most cases, we do not have enough food
b. We have food but with some months of food scarcity
c. We always have enough throughout the year
18. What are the copying strategies used in the period of food shortage?
i) Sell livestock
ii) Borrow money
iii) Sell household assets
19. What are the sources of energy used for cooking in your household?
i) Firewood
ii) Charcoal
iii) Kerosene
iv) Gas
iv) Electricity
v) Others Specify ……………….
20. Where does your household obtain the energy used for cooking?
Village forest General land within the national park
Own farm land others specify 1.____2.______3.______
21. Do you receive any benefits from SANAPA? i) Yes ii) No

	Types of benefit	Yes	No
1	Are you employed or have you been employed by SANAPA?		
2	Do you have children at school constructed by SANAPA?		
3	Do you access to medicinal plants and ritual sites?		
4	Do you participate in eco-tourism activities?		
5	Do you have access to water for domestic use/livestock?		
6	Do you have access to firewood and building materials?		
7	Others (specify)		

22. Do you think there is fair distribution of benefits obtained from the Park i)Yes ( ) No ( )
23. Who do you think benefit more from the NP?
i) Government leader (Village council leader) ii) Rich people
iii) Poor people iv) Females v) Males
vi) Young people vii) Old people

Expenses of living adjacent to PA

24a. Do you experience any problem by living adjacent to NP? i) Yes ( ) ii) No 24b. If yes, which of the following is a problem?
i) Crops loss ( )
ii) Livestock loss ( )
iii) Human injuries ( )
v) Others specify_
25. Which crops were destroyed and how much was your loss?

Crops destroyed by Wildlife	Loss/year

26. Which domestic animals were killed, injured, killed or affected by wildlife?

Domestic animals	Problem types	Number of animal killed

27. Which animals are the main causes the problem?
a. baboon ( )
b. warthog ( )
c. elephant ( )
d. lion ( )
e. Others (specify) 1._______2.______3______

28. What do you think should be done to control these problems?
i) Remove animals ( )
ii) Compensation ( )
iii) Others (specify) ( )

Perception and attitudes

29. How do you rate your relation with the park? i) Bad ( ) ii) Good ( )

Indicators of relations	Yes	No
Do you report any illegal activities which conducted inside the Park?		
Are you or any member of your family employed by the park?		
Do children attend a school constructed by SANAPA?		
What are the household benefits from the income generated from the activities conducted by SANAPA?		
Are you allowed to access medicinal plant or ritual sites?		
Are you allowed access to water for domestic use/for livestock inside the park?		
Do you have access to firewood or building materials inside the park?		
Do you enjoy the services provided by SANAPA?		

30. How does your household obtain information about conservation issues?
a. By participating in the meeting ( )
b. By being a member of the village government ( )
c. By being a member of committee in the village ( )
d. By being an employer in the village ( )
e. From friends ( )

31. Do you know how decisions are made? i) Yes ( ) ii) No ( )
32. Is your household involved in the decision making process? i) Yes ( ) ii) No ( )
33. How are decisions communicated at the village level?
i) Through the village meeting ( )
ii) On the village notice board ( )
iii) Through talking with a friend ( )
iv) Others (specify) _

34. How would you like to be involved in the management of natural resources?
1.______2.______3______

35. What is your opinion about the presence of the Park in this area?
a. It should be removed
b. It should exist, but the animals should be controlled
c. It should exist with villagers being involved in its management

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Forest cover change due to large scale plantation agriculture and community perception of its impact on climate variability in Nguti sub-division, South West Cameroon Region

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This study was carried out to evaluate the effects of plantation agriculture on land use, land cover change in the Nguti sub division and to investigate resident's perception about the effects of land use, land cover change on local climatic variability. Satellite maps from Landsat multispectral images were processed using Arc GIS 8 to assess land cover change overtime. Structured questionnaires, focused group discussions and interviews were used to gather relevant data on resident's perception on the impacts of land use, land cover changes on climate variability. The statistical package for social science (SPSS) version 19 was used to analyze respondent's perception on the impacts of land use land cover change on local climatic variability. Results indicate a slow change in dense forest of -2% between 2006 and 2012 when no large scale agricultural practice existed, as opposed to a rapid change of -14% between 2012 and 2015 when such practice existed, indicating a massive loss of forest cover. Plantations increase slightly between 2006 and 2012 (51 ha) but witnessed a massive increase (210ha) between 2012 and 2015. Residents of Nguti sub division attest that there has been variability in the climatic condition in the area experience in the form of increase temperature, reduction in rainfall and changes in seasonality. Authors recommended a need for a participatory land use planning to delimit and allocate land into various land uses and to avoid future land use conflicts.

Key words: Dense forest, palm plantation, settlements, respondents, variability, livelihood change.

INTRODUCTION

Plantations are essential for human survival and economic wellbeing as well as for the ecosystem structure, functioning and stability (Bargali et al., 1993).

However, environmental groups, ecologists, economists, and others have expressed concern that agricultural programs that stimulate production can have unintended

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and undesired environmental consequences. This view is based on two ideas: first, that as more land is used in agricultural production, less land remains for wildlife or other environmental purpose which can cause climate variability and change both locally and globally. In addition, the less productive agricultural lands are particularly susceptible to environmental damages (Johansson, 2008). Human modification of the land surface through the conversion of natural land into other land uses like agriculture has affected regional and global climate processes by changing the fluxes of mass and energy between an ecosystem and the atmosphere (Dai, 2014). This is because Land use/cover forms the lower boundary of the atmosphere and is thus a major component of climate variability.

Over the past decades, land use and land cover change especially in the form conversion of forest to other land uses has been widely recognized as a critical factor mediating global climate change (IPCC, 2001). According to the Intergovernmental Panel on Climate Change (IPCC), agriculture is responsible for 10-12% of global anthropogenic greenhouse gas (GHG) emissions. Not all types of agriculture, however, have equivalent impacts on global warming. Industrial or conventional agricultural practices make use of high-yielding plant and animal varieties, large-scale monocrops, high stocking densities, decreased or absent fallow periods, high levels of agrochemicals and high degrees of mechanization. In addition, Industrial agriculture use large areas of natural land disturbing natural processes which often lead to climate variability and change (Hulme et al., 2010).

On 17th September 2009, SG Sustainable Oils Cameroon PLC (SGSOC), an agro-industrial company signed a contract with the Cameroonian government to develop a large industrial oil palm plantation and refinery. SGSOC obtained rights to73,086 ha of land in the Ndian and Kupe-Manenguba Divisions of South West region of Cameroon through a 99-year land *lease (*Cameroon Tribune, 2012*).* By December 2012, SGSOC had planted four palm nurseries and cleared over 60 ha of forest to this end. The company has reportedly applied for a land lease covering the 73,000 ha it hopes to exploit (Carrere, 2010). Local communities, conservation groups, and NGOs expressed opposition to the project due to its numerous negative socialand environmental impacts. Some of its anticipated impacts were; deforestation, land use change, effects on local climate and regional climate. After few years of operation, there has been limited research to investigate the impacts of the company's activities on land use and cover change (De Schutter, 2012). There has been limited research on the impacts of land use, land cover change on climate variability. It is because of this knowledge gap that this research was carried. The research was out to determine land use/land cover changes between 2006 and 20015 and to evaluate community's perception of the effects of land use/land cover changes on local climatic variability in the area.

Study area

The study was carried out in Nguti subdivision of the KupeMwanenguba Division of the South West Region of Cameroon. It lies between latitude 005.10862 and 005.19782 North and longitude 009.40075 and 009.31609 East (UCCC, 2014). It is surrounded by Mamfe and Upper Bayang in the North, Konye, Tombel in the South, Mundemba in the West and Littoral Region in the East. The area has 56 villages and eight main clans. It has a surface area of 1444 km^2 and a population of 67,218 people. The project zone outlined for plantation agriculture is bounded by four protected areas: the Korup National Park, the Banyang-Mbo Wildlife Sanctuary, the Bakossi Forest Reserve and the Nguti Council forest (Figure 1).

MATERIALS AND METHODS

Desk study

Extensive review of secondary data was carried out. This was done on published reference books, journals, scholarly articles, internet, in order to have a broader knowledge on the study and inform the theoretical and empirical literature on large-scale plantation agriculture and its impacts on forest cover change and climate variability.

Field surveys

A reconnaissance survey was carried out in the study area in order to get familiarized with the area under study and to choose sampling sites. A trip was made to the concession area and villages were selected based on their closeness to the concession area. Meetings were held with resource persons in villages and other institutions who were directly or indirectly involved in SGSOC.

Data collection and analysis

Land use land cover change, the use of GIS and remote sensing

Landsat multispectral images were used to assess land cover change overtime and the effects of such changes on the environment. Satellite images for three different periods; 2006, 2012 and 2015 were used. The 2006 image was used as baseline map before the coming of SGSOC, 2012 to indicate normal variation without the pressure of SGSOC, while the 2015 image was used to show the current land cover change under the influence of SGSOC activities and operation. Satellite images included Landsat 8 OLI + scenes path 187, row 57 for 10th January 2015 and two Landsat 7 ETM + scenes path 187, row 56 for the 10th January 2012and 10th January 2006.

Procedure for data analysis

Land use/land cover

Data was analyzed based firstly on semi-automatic, object-based

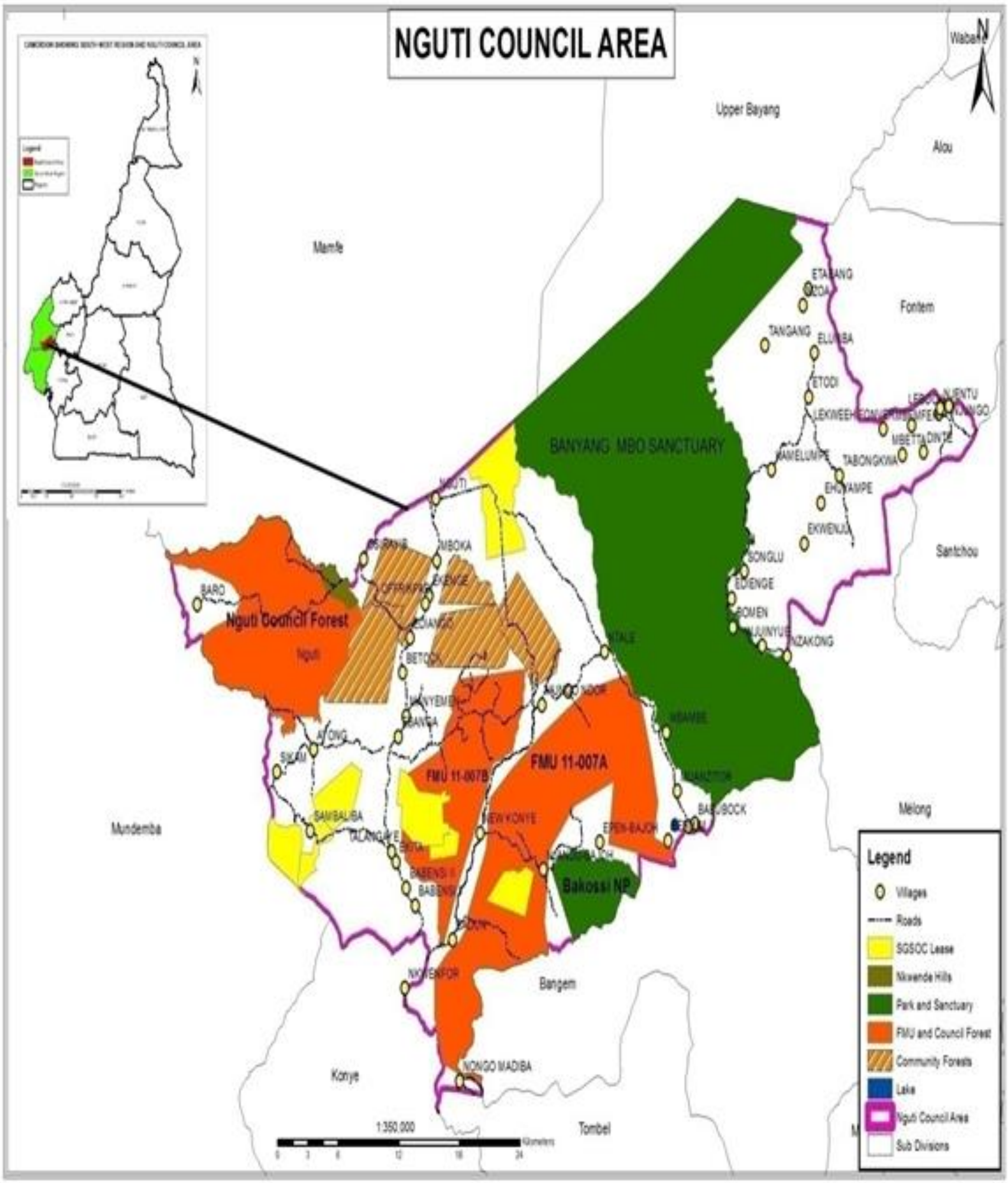

Figure 1. Map of South West Region of Cameroon showing location of Nguti and SGSOC plantation area.
Source: Mor Achankap (2013).

approach, using segmentations to automatically create polygons and assigning class attributes manually based on a visual interpretation as explained by Tamungang and Bakia (2016). Areas of doubt were marked and later checked in the field through ground-thru thing. Data from previous land cover analysis for South West Regional Delegation of Forestry and Wildlife were obtained from different land cover classes based on expert field knowledge. Classes were obtained from areas that could be identified as dense forest, open forest, plantations, farmlands, settlements. Several plots were constituted where scatter plots, histograms and statistics could be viewed. These plots were then combined to form a single class (dense forest).The following classification procedure was performed:

(i) Initially, an unsupervised classification was performed to get a general over view of the major land cover types in the area,

(ii) Then followed a supervised classification by creating plots using major cover types based on some field data and knowledge from the previous classification,
(iii) The final raster cover map obtained passed through some steps aimed at rendering the pixels more informative and giving a seamless presentation. This includes boundary cleaning and regional grouping.

(a) **Land cover class:** Pixels generated were vectorized and symbolized to obtain the land cover class for 2006, 2012 and 2015 images.
(b) **Land cover change:** Attributes of the pixel generated were extracted to generate alphanumeric data to obtain cover class quantification and hectares.
(c) **Trend in degradation:** The changes in the land use pattern were then compared using Bar charts and percentages to obtain the trend in degradation over nine year's interval.

Resident's perception on the impacts of land covers change on climate variability

Two techniques were used to achieve this objective; questionnaires, interviews, and focus group discussions.

Sampling location and respondents

Nine villages fall under the SGSOC concession area but the magnitude to which they are affected by the concession were different. Among the nine villages five (Manyemen, Ebanga, Talangaye, Ekita and Babensi 2) were purposely selected for this study based on the impacts of the concession area on them as read from literature. Respondents were residents aged 25 years who have lived in villages or settlements adjacent to the SGSOC oil palm plantation area for at least eight years. Respondents were randomly selected from four main classes;

(i) Local communities; farmers, forest users (hunters, fishermen, NTFP collectors, traditional doctors), community authorities (Chiefs and traditional councils), women and Youths.
(ii) Government Institutions; Agriculture and Rural Development, Environment and Nature Protection Authorities, Forestry and Wildlife Officers.
(iii) Environmental defenders; Worldwide Fund for Nature (WWF), Wildlife Conservation Society (WCS), Nature Cameroon NGO.
(iv) SGSOC Company; Top Management staff (Authorities) and general labourers (Field supervisors and hourly paid staff).

Questionnaires administration

Questionnaires were administered to the five primary impact villages whose population stands at 7755.388 respondents (5% of the population) from the primary impact villages were randomly selected for questionnaires distribution.

Interviews

Semi-structured interviews were conducted with SGSOC Staff (6 out of 12 Top Management Staff, 6 out of 13 field supervisors, 22 out of 149 hourly paid staff). These interviews were to assess the amount of land already covered by the plantation, further expansion plans and their perceived impacts on the environment. In addition, three interview sessions were carried out with the Chief of Post and staff (2) of the Delegation of Agriculture and Rural Development (MINADER), 2 Staff of Forestry and Wildlife (MINFOF). 28 key informants were interviewed (15 from primary impact villages, 5 from secondary impact villages, 8 from SGSOC cutting across from top management to field staff). Participants for this exercise comprised village heads/Kingmakers, forest management committee members, farmer's committee members, government representatives including some former workers of SGSOC. The interviews were out to gather information on the perceived impacts of the plantation on local climates.

Focused group discussion

Six focused group discussions were held to get an overview of perceptions on the impacts of the plantation forest cover change and climatic variation around neighboring community's communities. Participants for these discussions came from different villages with diverse ideas, consisting of village authorities, farmers, hunters, fishermen, non-timber forest products (NTFP) gatherers, traditional doctors and other community members. With the help of village leaders (Chiefs or representatives and traditional council secretaries), the researcher invited participants including men, women and youths alike. Participants for these discussions ranged from 8 to 12 depending on the size of the population. For this exercise, women were separated from men, just like youths were separated from their parents or elderly. The reason for this separation was basically because women in this area are not allowed to speak in the presence of men due to the cultural barrier.

Data analysis

Completed questionnaires and interview guides were cross-checked for data integrity and data cleaning. Data was then coded for analysis along key themes, emerging patterns and consistency. Coding and interpretation was done along key themes to determine its relevance in answering the research questions. The results of the study were presented in the form of tables, pie charts explanatory texts, and summary statistics to show relationships between key variables. Qualitative data analysis was done using Statistical Package for Social Sciences (SPSS) version 21 and Ms Excel version 2013.

RESULTS

Vegetation cover and land use, land cover analysis

Results from satellite images revealed five land use classes; dense forest, open forest, plantation settlement and farmlands. These land use classes have been change overtime (Figures 2 to 4). Dense forest recorded a decrease of -2.43% (1077 ha) within six years between 2006 and 2012 prior to the intensification of SGSOC's activities on the ground. Open forest equally recorded a decrease of-3.4% (322 ha) from 2006 to 2012. Plantation surface increased to 76.5 ha in 2012 as opposed to 25 ha in 2006, recording an increase of 67%. The settlement area increased by 33% (295), while farmland witnessed a slight increase by 12% (407 ha) (Table 1).

Dense forest reduced by -14% (5,225) between 2012 and 2015. This was the period when SGSOC's activities were intense leading to a reduction in open forest. Open forest recorded a percentage change of -16% (1,819 ha)

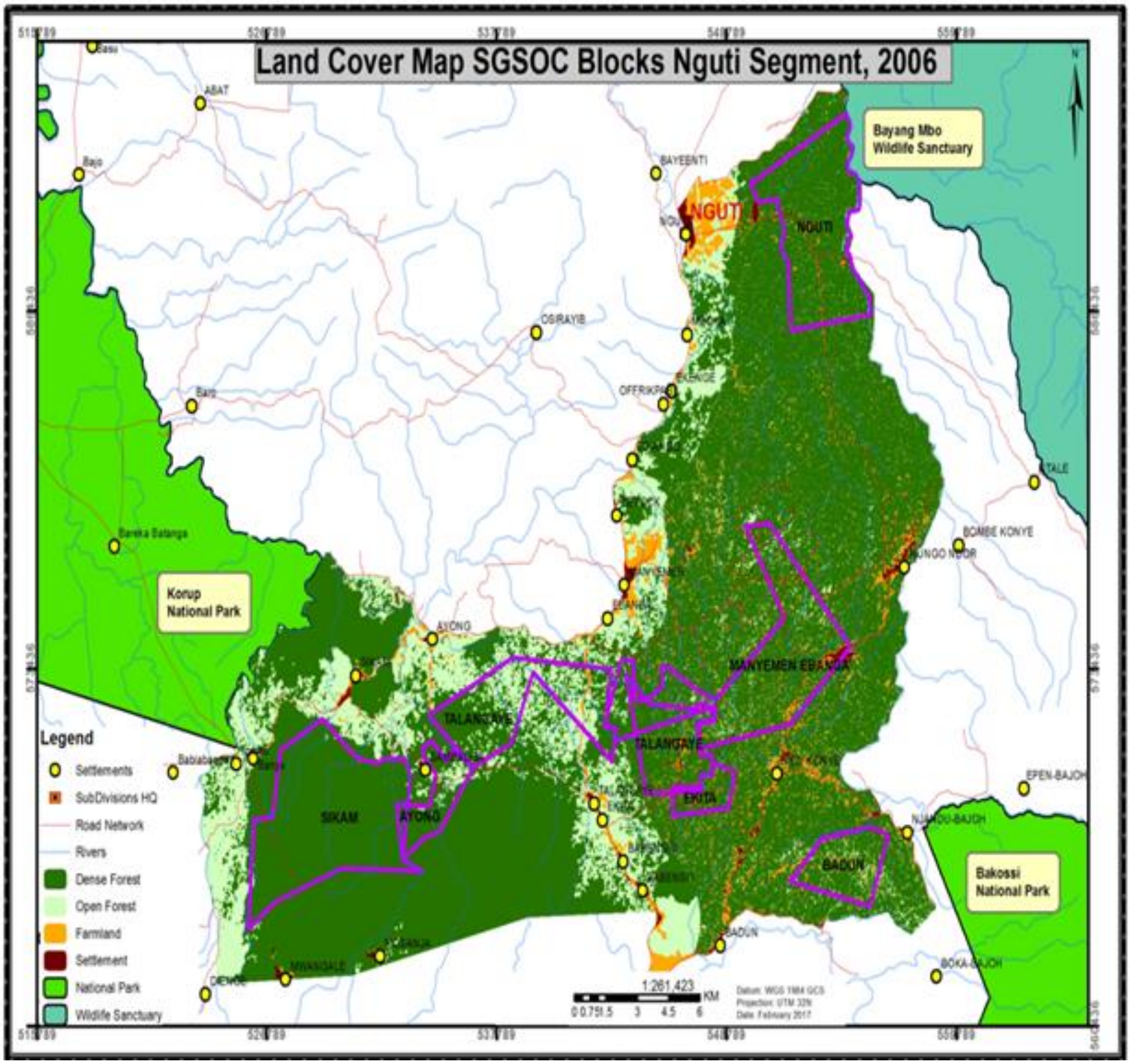

Figure 2. SGSOC land Cover blocks of 2006.

from 2012 to 2015. Plantation surface area was at 286.9 ha in 2015 as opposed to 76.5 ha in 2012, recording an increase of 73% (210). The settlement area increased by 44% (718), while farmland witnessed an increase of 42% (2,477) (Figure 5).

Perception on the impact of land use, land cover change on local climate variability

82% of respondents confirmed that there has been an increase in surface temperatures within the past five years while 17% of respondents believed that there has been no change in surface temperatures in the study areas within the same period (Figure 6).

According to respondents, land use land cover change has affected the precipitation pattern in the area through main ways; through decrease rainfall amounts and through extreme rainfall events. 58% of respondents believed that there has been a decrease in rainfall in past few years, 19% believed climate variability is evident in the area through extreme rainfall events while 19% think that the area has experience both decrease rainfall and extreme rainfall events (Figure 7). The effects of seasonality have also been felt in the area. 40% of respondents confirmed that there has been a prolonged dry season within the past few years, 19.1% think there been an increase in dry season temperature while 59% think there been a decrease in rainfall amount with the rainy season (Figure 8).

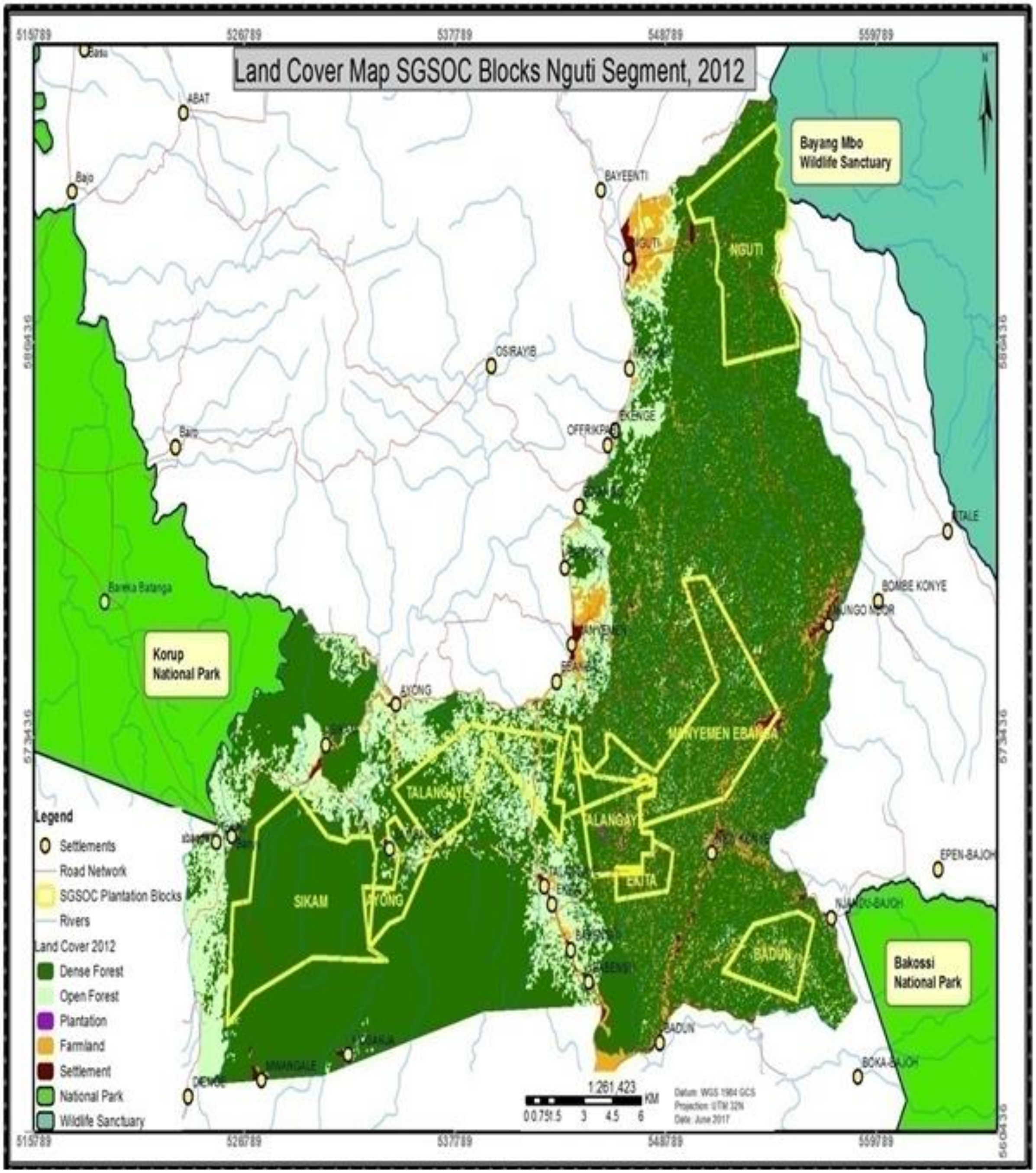

Figure 3. SGSOC land cover blocks of 2012.

DISCUSSION

Dense forest decreased slightly between 2006 and 2012 and further witness a significant decrease (5,225 ha) between 2012 and 2015. This change may be due to a change in land use from forest to large-scale plantation between 2012 and 2015. This is almost similar to the findings of Henson (2013) who pointed out that agriculture and grazing are the major causes of land use, land cover change. In like manner, Abbas and Iguisi (2007) confirmed that agricultural expansion and urbanization have also been identified as the major and proximate causes of land use, land cover change. A reduction in dense forest may have adverse impact on climate and other ecosystem services, since forest provide a diversity of ecosystem services including converting carbon dioxide into oxygen and biomass, acting as a carbon sink, aiding in regulating climate,

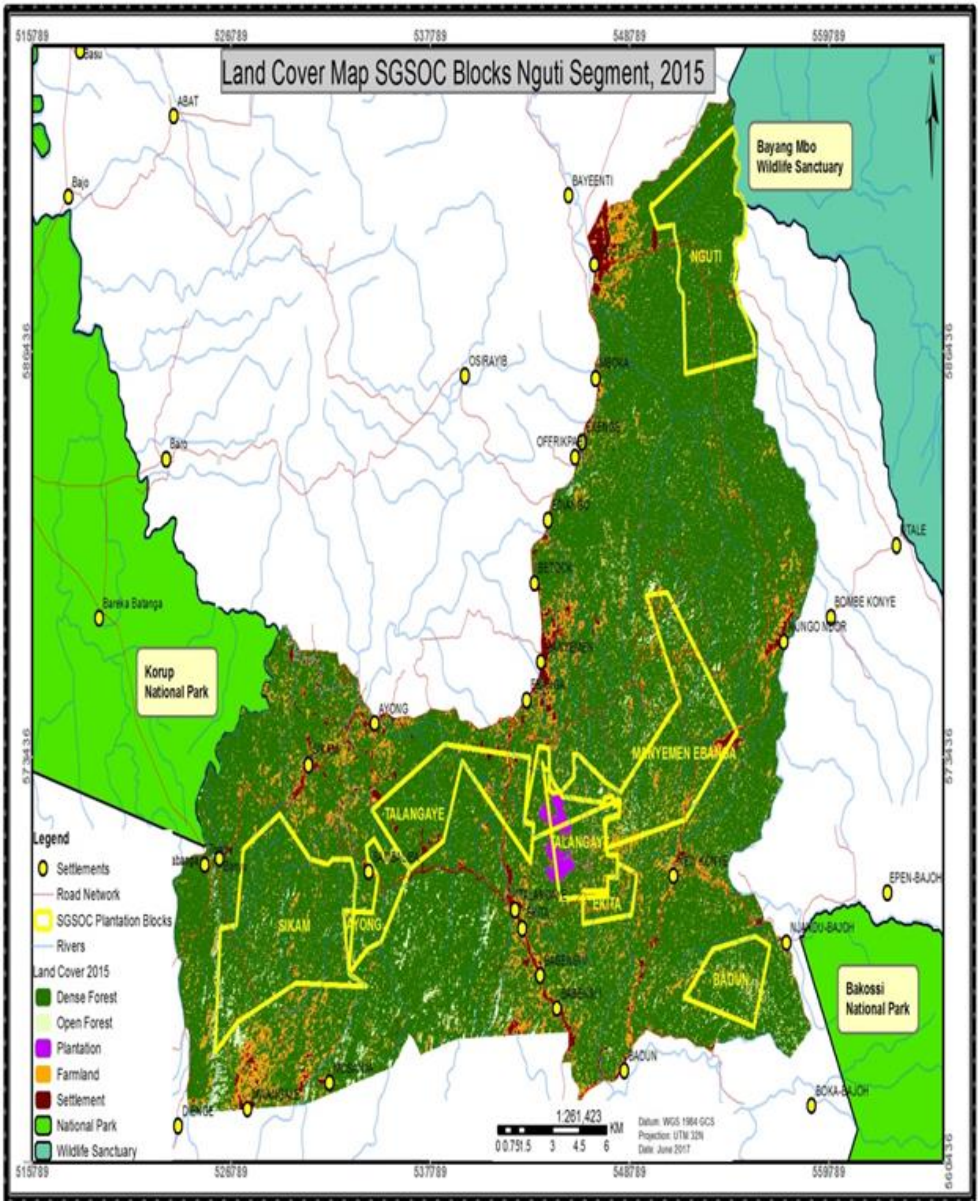

Figure 4. SGSOC land cover blocks of 2015.

purifying water, mitigating natural hazards such as floods, and serving as a genetic reserve (Hartemink, 2005).

Open forest witnessed a slight decrease (322 ha) between 2006 and 2012 and tremendous decrease (1,819 ha) between 2012 and 2015. Though other activities have been taking place in this area between 2012 and 2015,

Table 1. Presentation of change detection in SGSOC concession area between 2006, 2012 and 2015.

Land use Type	Land use change between 2006 and 2012				Land use change between 2012 and 2015			
	2006 (ha)	2012 (ha)	Land use change (ha)	% Change	2012 (ha)	2015 (ha)	Land use change (ha)	% change
Dense forest	44,295	43,218	1,077	-2	43,218	37,993	5,225	-14
Open forest	9,465	9,787	322	3.4	9,787	11,606	1,819	16
Palm plantation	25	76.5	51	67	76.5	286.9	210	73
Settlement	606.4	902	295	33	902	1,620	718	44
Farmland	2,993	3,401	407	12	3,401	5,878	2,477	42
Total	**57,385**	**57,384**	**322**	**113**	**57,384**	**57,384**	**10,450**	**161.**

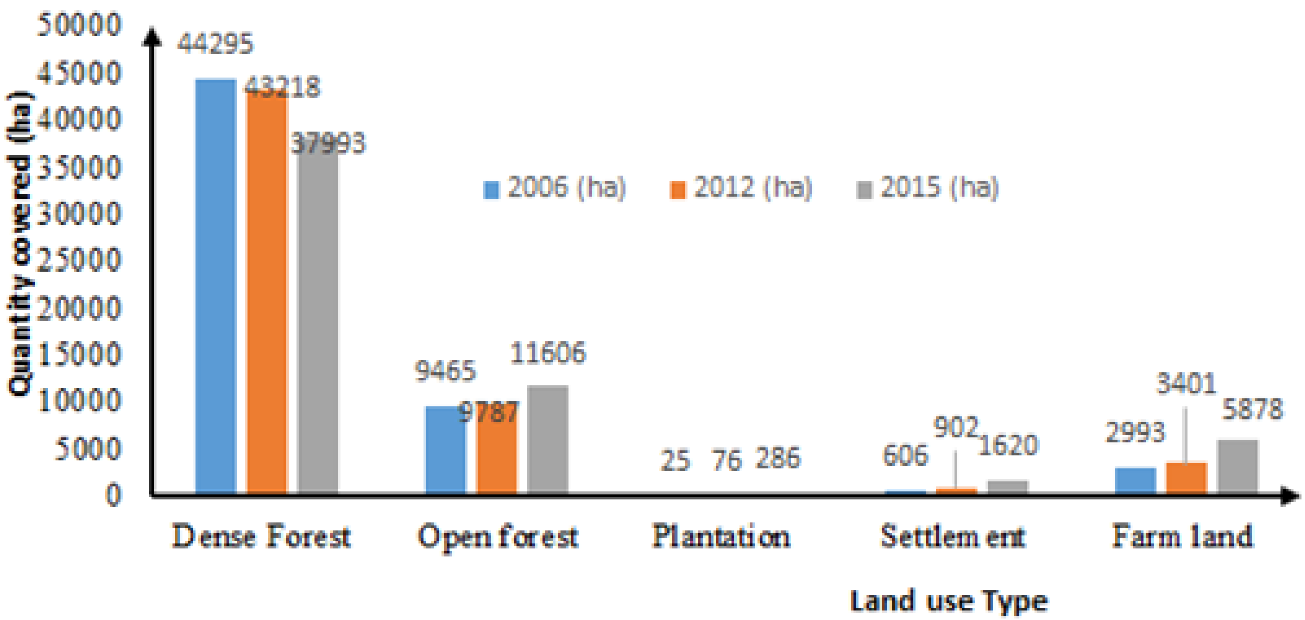

Figure 5. Changes in land cover in SGSOC concession area between 2006 and 2015.

the presence of oil palm plantation may have a major influence to the rapid increase in open forest recently. As plantation expands coupled with other factors like population increases, more pressure is exerted on the land for farming to meet up with food demand, construction of new houses and other anthropogenic activities. When this happens, more and more forest is opened leading to fragmentation.

Plantation agriculture takes a different change pattern from dense and open forest but with more pronounced figures. Within the periods of 2006 and 2012, dense forest decreased slightly (51 ha) but between the periods of 2012 and 2015, plantation agriculture increase significantly (210 ha). The reason for this change is that SGSOC intensified their expansion activities between 2012 and 2015. Between 2006 -2012, the surface area of land occupied by plantation was low because they were owned by community members in low scale (0.5 -1 ha), while 2012-2015 witnessed a comparatively rapid expansion because it was large scale due to the presence of SGSOC. As oil palm plantation expands, more land is fragmented due to deforestation and hence, degradation.

In the same pattern as plantation agriculture, farmlands registered a slight increase (12%) between 2006 and 2012 and significant increase by 42% between 2012 and 2015. These changes occurred for two reasons; population increase within these years aggravated the demand for food and consequently opening of more farms. Secondly the creation or expansion of access roads to plantation from foot path to about 10meters opening farm to market roads which encourages more farmers to take up marginal lands for cultivation. Arhem (2011) also highlighted that the creation of farm to market roads can increase agricultural productivity in rural Africa.

Most of the respondents in this study attested that they

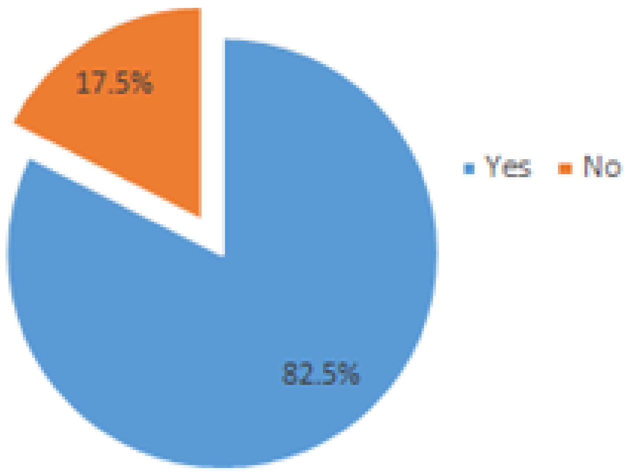

Figure 6. Respondents perception on the effects of land use land cover change on surface temperature.

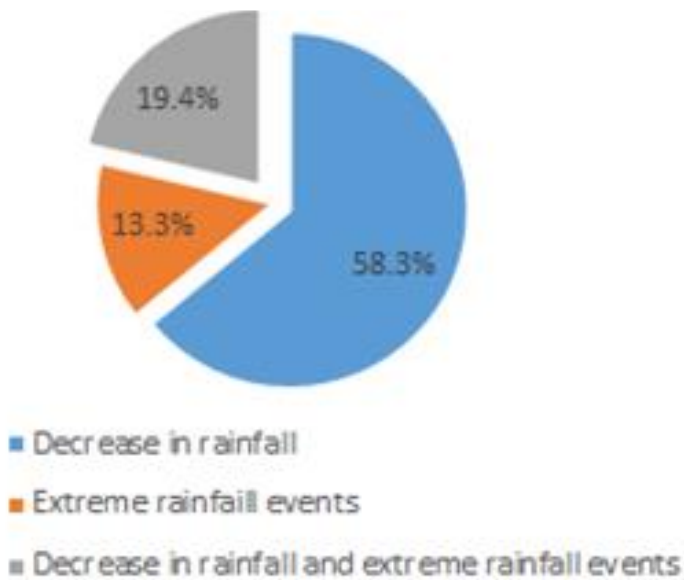

Figure 7. Effects of land use, land cover on rainfall patterns.

have experiences climatic variability in many forms such as increase in surface temperatures, a reduction in rainfall and changes in seasonality patterns of the area. Climate variability experienced in the study area is a result of a reduction in forest cover. The loss of canopy exposes the earth to direct heat, which results in an increase in surface temperature. In the open canopy the sun as well as rains directly hit the earth surface which adversely affect the biodiversity and enhance the surface run off and consequently decrease the soil nutrients and biomass (Bargali et al., 1993). The livelihood of indigenous people may in this process be compromised, as they depend on the forest and its resources for their survival directly as a source of food, medicine, and income (Sheil et al., 2009). Evans (1987) also pointed out that the expansion of plantation activities leads to increase in surface temperatures in the neighboring areas since the surface is allowed bare and there are no trees to ameliorate the climatic situation of the area. Changes in seasonal pattern may also lead to significant reduction in farmers output especially peasant farmers. In forest cover in the Nguti division in the South West region of Cameroon. Forest cover witnessed a 1,819 ha reduction between 2012 and 2015, which correlated the period of tremendous increase in plantation agriculture (plantations agriculture increased by 210 ha between

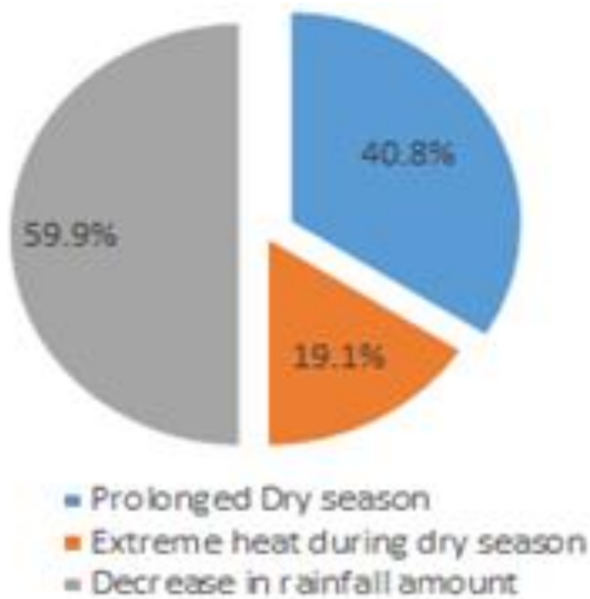

Figure 8. Perceived effects of land use, land cover on seasonality.

2012 and 2015). This has led to a significant decrease in dense and opened forest. However, the effects of plantation agriculture on changes in land use cannot be over emphasized, as there are also other causes of forest cover change such as increase in buildup areas. Eighty-two of respondents have also attested that there has been variation in the local climatic pattern in the form increase daytime temperature, decrease in rainfall and delay in the coming of rains during the rainy season. Climate variability may have serious impacts on the lives and livelihoods of people in the community especially as communities depend on rain fed agriculture.

There is need for the government to develop a participatory land use scheme in the study area to allocate areas of different land use in other to ensure sustainability and avoid conflict between the population and plantation companies. There is also need for the government to follow up and make sure large-scale plantations implement their environmental management plan. Since communities depend on rain fed agriculture, which is affected by climate variability, there is need for communities to have adapted seeds to cope with the impacts of climatic variability in the area. NGOs working on agriculture, environmental protection agencies and the Cameroon agricultural research institute (IRAD) can provide communities with seeds that can resist climatic variability in the area.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Assessment the conservation status and vulnerability of the ichthyological population of the Bandama River in the Marahoué Region (Central West of Côte d'Ivoire)

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The conservation status and the vulnerability to fishing pressure of the ichthyological population of the Bandama River located in the Marahoué Region (Côte d'Ivoire) were assessed. Sampling of fish fauna was conducted from September 2019 to November 2020 using experimental and artisanal fisheries. The results of International Union for Conservation of Nature show that, the majority of the fish species (88.7%) inventoried were classified as "least concern". The "high to very high" and "very high" categories are represented respectively by two species and one species. These include *Heterobranchus longifilis* and *Malapterurus electricus*, which belong to the "high to very high" vulnerability category, and *Clarias gariepinus*, which belongs to the "very high" category. In addition, 79.87% of the species in this stand have vulnerability between "low" and "moderate".

Key words: Vulnerability to fishing pressure, Ichthyofauna, *Heterobranchus longifilis, Malapterurus electricus*, *Clarias gariepinus.*

INTRODUCTION

Aquatic environments are a reservoir of great biodiversity and also play a very important bio-ecological role (Ndour et al., 2011). Unfortunately, these aquatic ecosystems are under increasing pressure from human activities (construction of dams, pollution from various sources, etc.) (Paul, 2017). Thus, man, through his activities, considerably threatens the survival of aquatic species and biological diversity. In Côte d'Ivoire, threats to aquatic biodiversity from anthropogenic activities are increasing (Kouamélan, 1999; Ouattara et al., 2007; Simmou et al., 2015; Monney et al., 2016). The portion of the Bandama River located in the Marahoué region in Central West of

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Côte d'Ivoire does not escape these anthropogenic pressures. Indeed, this watercourse is subject to numerous disturbances, among others, fishing, the discharge of industrial effluents from the company of lemonade and breweries of Africa (SOLIBRA) in Bouaflé, the use of fertilizers and of pesticides in the large sugar cane plantations of the integrated agricultural production unit of SUCRIVOIRE in Zuénoula. In addition, the politico-military crisis in Côte d'Ivoire has had a severe impact on the agricultural sector, the main source of income for farmers. In order to diversify sources of income, gold mining appeared as an alternative (Kouadio, 2008). Thus, in recent years the Bandama River watershed in the Marahoué region has been subject to heavy illegal mining operations and in violation of environmental protection regulations.

Faced with such a threat, the implementation of a system of management measures is necessary for the preservation of these fishery resources. These measures are based mainly on the knowledge of the state of the fishery resources. Indeed, knowledge of the conservation status and vulnerability to pressure are necessary in decision-making for the conservation of aquatic biodiversity (IUCN, 2020; Froese and Pauly, 2019). The present study aims to analyze and make available to the country's decision makers, information relating to the conservation status and vulnerability to fishing pressure of the ichthyofauna of the Bandama River in the Marahoué region (Central West of Côte d'Ivoire) for a better conservation.

MATERIALS AND METHODS

Study area

The Bandama watershed is located between longitudes 3°50' and 7°W, and between latitudes 5°10' and 10°20' N (Figure 1). This basin covers an area of 97500 km^2 and extends from the north to the south of the country (Ire et al., 2015). It is made up of two sub-watersheds:

(i) The sub-watershed of the Bandama rouge or Marahoué located between longitude 5°5' and 7°1' W and latitude 6°7' and 9°5' N. It has an area of 24300 km^2. The Marahoué River, with a length of 550 km, is the most important tributary of the right bank of the Bandama River. It is fed by two tributaries: the Béré in the East and the Yani or Bahoroni in the West (Irié et al., 2015).
(ii) The sub-watershed of the White Bandama is located between latitudes 5°14' and 10°21'North and longitudes 4° and 7° West. It is on the branch of White Bandama Blanc that the Kossou hydroelectric dam is built.

According to Diarra (2020), this immense expanse of water has favored numerous anthropic activities, including agriculture with the irrigation of nearly 50,000 ha of arable land and fishing with an average of around 100 tons of fish landed per year. In addition, the Bandama River watershed in the Marahoué region is subject to heavy formal and informal mining.

Sampling and identification of ichthyofauna

Sampling of fish fauna was conducted from September 2019 to November 2020 using experimental and artisanal fisheries. For experimental fisheries, nets were set in the evening between 17 and 18 h and retrieved the next day between 6 and 7 h for night fishing and rested between 7 and 8 h and then retrieved between 15 and 16 h for day fishing. The experimental fishing was carried out with 30 mesh nets of between 10 and 40 mm side length. Each of these gillnets was 50 m long and 2.5 to 3.5 m high. Concerning artisanal fisheries, the data collection team analyzed the catches of artisanal fishermen in order to complete the list of species actually present. The artisanal fishing was carried out using: seines (with mesh sizes varying from 12 to 17 mm), gillnets (with mesh sizes varying from 20 to 40 mm)

Sampling of fish fauna was conducted and caught species was identified and released. Identification of fish specimens encountered was performed down to the specific level using keys proposed by Paugy et al. (2003a, b); Sonnenberg and Busch (2009), Fricke et al. (2021); Froese and Pauly (2019).

Conservation status

The assessment of the conservation status of the fish fauna was done using the IUCN Red List (IUCN, 2020; Froese and Pauly, 2019). The IUCN Red List Categories and Criteria are intended to be an easily and widely understood system for classifying species at high risk of global extinction. It divides species into nine categories: Not Evaluated, Data Deficient, Least Concern, Near Threatened, Vulnerable, Endangered, Critically Endangered, Extinct in the Wild and Extinct.

Vulnerability to fishing pressure

The assessment of the degree of vulnerability of fish species was done according to Cheung et al. (2005) and Brodie (2010) from the Fishbase site (Froese and Pauly, 2019). Brodie (2010) defines vulnerability as the sensitivity displayed by organisms to impacts caused by fishing activities or other factors threatening their existence such as habitat loss. Thus, the probability of an impact occurring and the responsiveness of the target community should be considered when determining its vulnerability to fishing activities. According to Cheung et al. (2005), the vulnerability of a species refers to the exposure of fish to fishing pressure. For these authors, the model developed to estimate the risk of depletion of fish populations by fishing relies on historical and ecological parameters to predict the intrinsic vulnerability of fish populations. Overall, Cheung et al. (2005) established different levels of graded vulnerability (1-100): ″low″ (≤ 25), ″low to moderate″ (] 25; 35]), ″moderate″ (] 35; 45], ″moderate to high″ (] 45; 55]), ″high″ (] 55; 65]), ″high to very high″ (] 65; 75]), and ″very high″ (75 ≤).

RESULTS AND DISCUSSION

Conservation status

Using the IUCN Red List system, the 71 fish species collected in the Bandama River located in the Marahoué region and identified to the specific level were divided into 5 categories (Table 1 and Figure 2). The categories

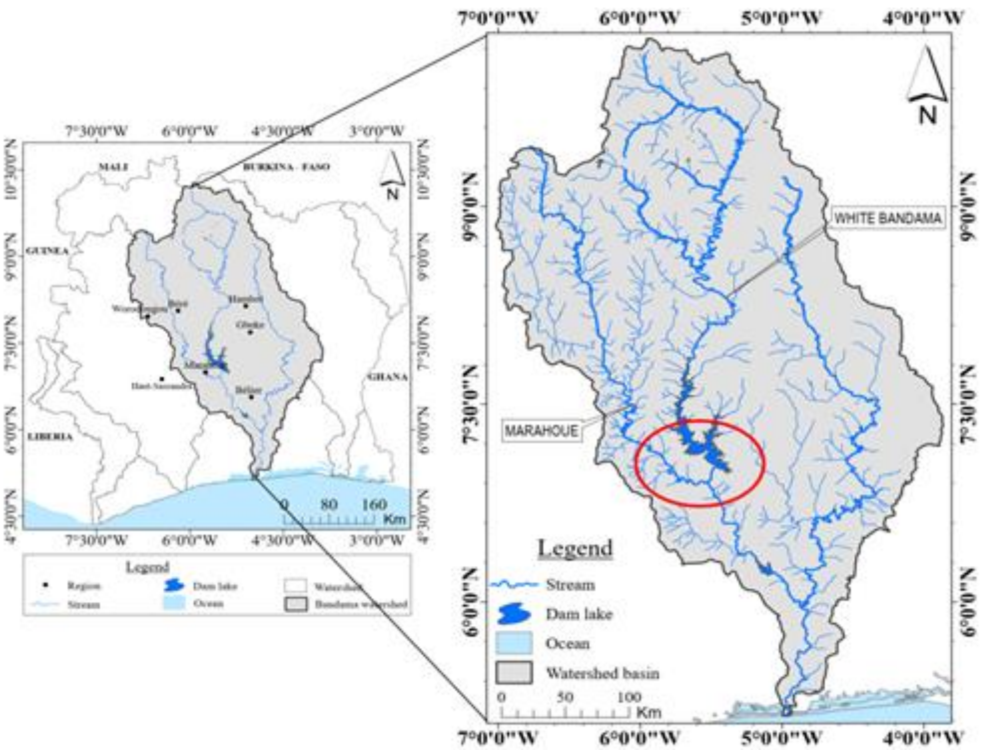

Figure 1. Location of the study area.

selected are as follows: Least Concern (LC); Not Evaluated (NE); Near Threatened (NT); Data Deficient (DD) and Vulnerable (VU). Among the fish species, the conservation status of 3 species (4.2%) observed has not yet been assessed. They are therefore classified as Not Evaluated (NE). 1 species (or 1.4%) is described as Data Deficient (DD). The majority of species (63 species, or 88.7%) were described as Least Concern (LC). 4 species or 5.63% of the total species have a Special Conservation Interest. Among these species, 1 species (1.4%) (*Tilapia busumana*) is described as Vulnerable (VU) and 3 species (4.2%) are described as Near Threatened (NT). These are: *Marcusenius furcidens*, *Sarotherodon galilaeus*, *Sarotherodon occidentalis*.

Vulnerability

Regarding vulnerability to stress due to fishing pressure, the species are divided into seven classes ranging from "low" to "very high" (Table 1 and Figure 3). The "low" vulnerability is the most widespread with 28 species, or 39.4% of all species. Eighteen species (25.4%) belong to the "low to moderate" vulnerability range and ten species (14.1%) are in the "moderate" vulnerability category. The "moderate to high" and "high" vulnerability categories are represented by eleven species or 15.5% and one species or 1.4% respectively. The "high to very high" and "very high" categories are represented respectively by two species, or. 2.8% and one species, or. 1.4% of the entire stand. These include *Heterobranchus longifilis* and *Malapterurus electricus*, which belong to the "high to very high" vulnerability category, and *Clarias gariepinus*, which belongs to the "very high" category.

DISCUSSION

Investigations on the ichthyofauna of the Bandama River located in the Marahoué region showed that based on the classification of the International Union for Conservation of Nature (IUCN), the majority of the fish species (88.7%) inventoried were classified as "Least Concern". In addition, 79.87% of the species in this stand have vulnerability between "Low" and "Moderate". This result shows that the majority of the fish species in this environment do not face significant threats. The conservation status is an indicator to evaluate the magnitude of the risk of a species. However, this indicator is not fixed, as it may change over time as threats to the species increase or decrease. Its reassessment is therefore regularly necessary (IUCN,

Table 1. Conservation status and vulnerability of the fish species encountered from Bandama River in the Region of Marahoué.

Species	Conservation status	Vulnerability
Alestes baremoze	Least concern (LC)	Low vulnerability (22 of 100)
Amphilius atesuensis	Least concern (LC)	Low to moderate vulnerability (35 of 100)
Auchenoglanis occidentalis	Least concern (LC)	Moderate vulnerability (38 of 100)
Auchenoglanis biscutatus	Least concern (LC)	Moderate to high vulnerability (48 of 100)
Enteromius macrops	Least concern (LC)	Low to moderate vulnerability (33 of 100)
Brienomyrus brachyistius	Least concern (LC)	Low vulnerability (19 of 100)
Brycinus imberi	Least concern (LC)	Low vulnerability (10 of 100)
Brycinus macrolepidotus	Least concern (LC)	Low to moderate vulnerability (31 of 100)
Chiloglanis occidentalis	Least concern (LC)	Low vulnerability (10 of 100)
Chrysichthys maurus	Least concern (LC)	Moderate to high vulnerability (46 of 100)
Chrysichthys auratus	Least concern (LC)	Low to moderate vulnerability (27 of 100)
Chromidotilapia guntheri	Least concern (LC)	Low vulnerability (25 of 100)
Chrysichthys johnelsi	Least concern (LC)	Low to moderate vulnerability (35 of 100)
Clarias anguillaris	Least concern (LC)	Moderate to high vulnerability (54 of 100)
Clarias buettikoferi	Least concern (LC)	Low vulnerability (16 of 100)
Clarias gariepinus	Least concern (LC)	Very high vulnerability (79 of 100)
Clarias laeviceps	Not Evaluated (NE)	Low to moderate vulnerability (26 of 100)
Coptodon guineensis	Least concern (LC)	Low vulnerability (19 of 100)
Coptodon zillii	Not Evaluated (NE)	Low to moderate vulnerability (27 of 100)
Ctenopoma kingsleyae	Least concern (LC)	Moderate vulnerability (38 of 100)
Ctenopoma petherici	Least concern (LC)	Low to moderate vulnerability (31 of 100)
Distichodus rostratus	Least concern (LC)	Moderate to high vulnerability (52 of 100)
Enteromius leonensis	Least concern (LC)	Low vulnerability (10 of 100)
Enteromius macrops	Least concern (LC)	Low to moderate vulnerability (33 of 100)
Enteromius pobeguini	Least concern (LC)	Low vulnerability (13 of 100)
Enteromius sublineatus	Least concern (LC)	Low vulnerability (16 of 100)
Enteromius trispilos	Least concern (LC)	Low vulnerability (20 of 100)
Hemichromis fasciatus	Least concern (LC)	Low vulnerability (14 of 100)
Hemichromis bimaculatus	Least concern (LC)	Low vulnerability (19 of 100)
Hepsetus odoe	Least concern (LC)	Low vulnerability (21 of 100)
Heterobranchus isopterus	Least concern (LC)	Moderate to high vulnerability (50 of 100)
Heterobranchus longifilis	Least concern (LC)	High to very high vulnerability (69 of 100)
Heterotis niloticus	Least concern (LC)	Moderate to high vulnerability (55 of 100)
Hydrocynus forskahlii	Least concern (LC)	Moderate vulnerability (39 of 100)
Labeo coubie	Data deficient (DD)	Moderate vulnerability (39 of 100)
Labeo parvus	Least concern (LC)	Moderate to high vulnerability (51 of 100)
Labeo senegalensis	Least concern (LC)	Moderate vulnerability (40 of 100)
Labeobarbus bynni	Least concern (LC)	Moderate vulnerability (39 of 100)
Lates niloticus	Least concern (LC)	Moderate to high vulnerability (47 of 100)
Malapterurus electricus	Least concern (LC)	High to very high vulnerability (74 of 100)
Marcusenius furcidens	Near threatened (NT)	Moderate vulnerability (35 of 100)
Marcusenius senegalensis	Least concern (LC)	Moderate vulnerability (35 of 100)
Marcusenius ussheri	Least concern (LC)	Low to moderate vulnerability (34 of 100)
Mastacembelus nigromarginatus	Least concern (LC)	Moderate vulnerability (43 of 100)
Micralestes occidentalis	Least concern (LC)	Low vulnerability (10 of 100)
Mormyrops anguilloides	Least concern (LC)	Moderate to high vulnerability (47 of 100)
Mormyrus hasselquistii	Least concern (LC)	Moderate to high vulnerability (47 of 100)

Table 1. Contd.

Mormyrus rume	Not evaluated (NE)	High vulnerability (63 of 100)
Oreochromis niloticus	Least concern (LC)	Low to moderate vulnerability (30 of 100)
Papyrocranus afer	Least concern (LC)	Moderate vulnerability (38 of 100)
Parailia pellucida	Least concern (LC)	Low vulnerability (22 of 100)
Pellonula leonensis	Least concern (LC)	Low vulnerability (12 of 100)
Pellonula vorax	Least concern (LC)	Low vulnerability (13 of 100)
Pelmatochromis nigrofasciatus	Least concern (LC)	Low vulnerability (15 of 100)
Petrocephalus bovei	Least concern (LC)	Low vulnerability (13 of 100)
Pollimyrus isidori	Least concern (LC)	Low vulnerability (11 of 100)
Polypterus endlicherii	Least concern (LC)	Moderate to high vulnerability (48 of 100)
Raiamas nigeriensis	Least concern (LC)	Low to moderate vulnerability (25 of 100)
Raiamas senegalensis	Least concern (LC)	Low to moderate vulnerability (32 of 100)
Sarotherodon galilaeus	Near threatened (NT)	Low to moderate vulnerability (35 of 100)
Sarotherodon melanotheron	Least concern (LC)	Low vulnerability (16 of 100)
Sarotherodon occidentalis	Near threatened (NT)	Low to moderate vulnerability (35 of 100)
Schilbe mandibularis	Least concern (LC)	Low to moderate vulnerability (29 of 100)
Synodontis bastiani	Least concern (LC)	Low to moderate vulnerability (25 of 100)
Synodontis koensis	Least concern (LC)	Low vulnerability (14 of 100)
Synodontis punctifer	Least concern (LC)	Low vulnerability (24 of 100)
Synodontis schall	Least concern (LC)	Low vulnerability (21 of 100)
Thysochromis ansorgii	Least concern (LC)	Low vulnerability (12 of 100)
Tilapia busumana	Vulnerable (VU)	Low vulnerability (15 of 100)
Pelmatolapia mariae	Least concern (LC)	Low to moderate vulnerability (28 of 100)
Tylochromis jentinki	Least Concern (LC)	Low vulnerability (22 of 100)

Source: Central West of Côte d'Ivoire, UICN (2020) and Froese and Pauly (2019).

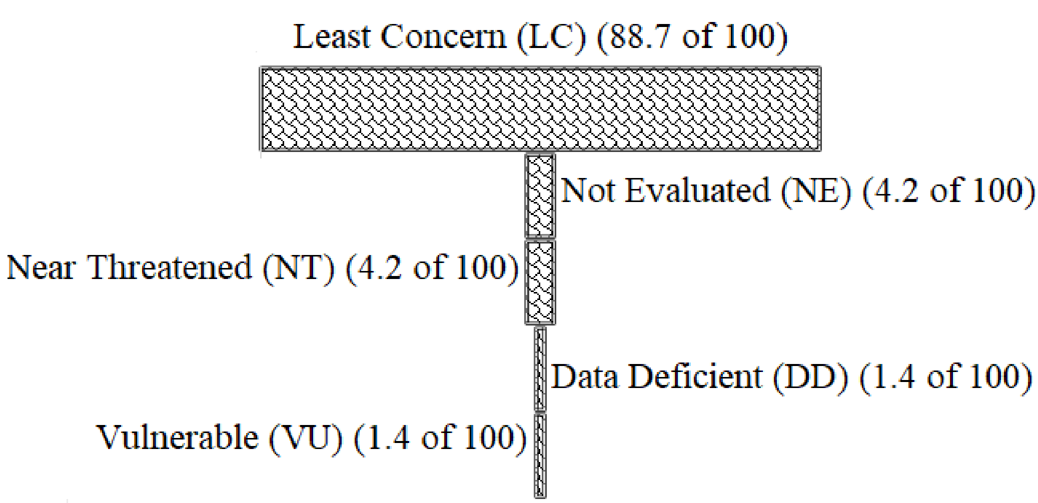

Figure 2. Proportion of the different categories of conservation status of the ichthyofauna of the Bandama River in the Region of Marahoué (Central West of Côte d'Ivoire).

2020). Founded on a solid scientific basis, the IUCN Red List is recognized as the most reliable reference tool for knowing the level of threats to specific biological diversity. On the basis of precise information on endangered

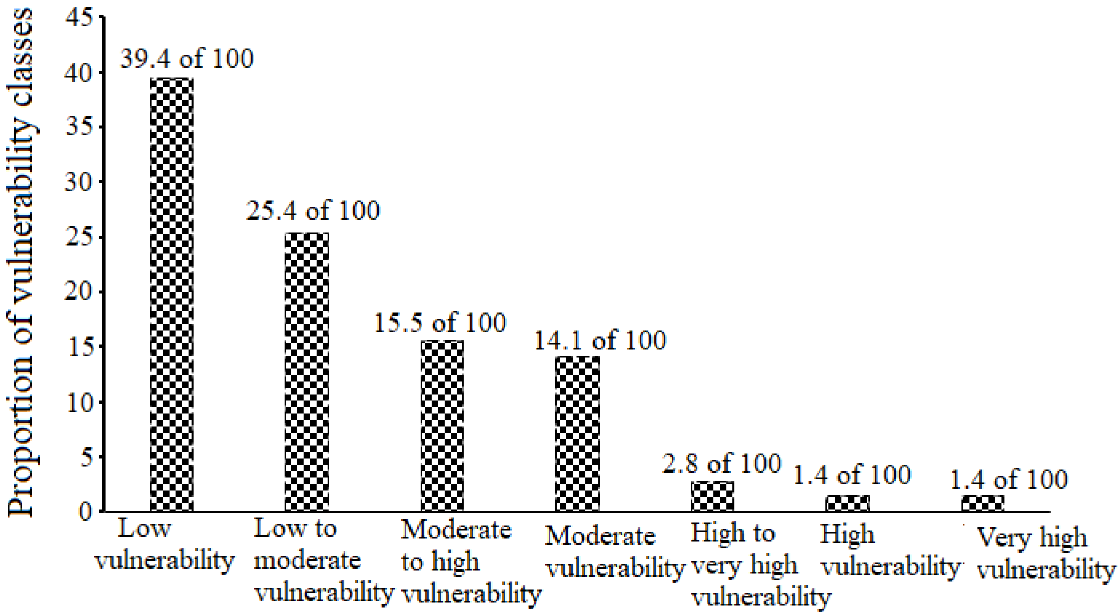

Figure 3. Proportion of the different vulnerability classes of the ichthyofauna of the Bandama River in the Region of Marahoué (Central West of Côte d'Ivoire).

species, its essential aim is to identify priorities for action, to mobilize the attention of the public and political leaders on the urgency and extent of conservation problems, and encourage all stakeholders to act to limit the rate of species extinction (IUCN, 2020; Froese and Pauly, 2019).

Moreover, among this population there is a significant percentage (5.63%) of species with a special status. Among these species, 1 species (*Tilapia busumana*) this species was listed by IUCN in 2020 as Vulnerable (VU) and 3 species (*Marcusenius furcidens*, *Sarotherodon galilaeus* and *Sarotherodon occidentalis*) these species were listed by IUCN in 2020 as Near Threatened (NT). According to Cheung et al. (2005), 21.13% of species have a vulnerability greater than the “Moderate” category. Consequently, these species with a restricted geographical distribution and the population size is due to deterioration of the ecological quality of their environment (IUCN, 2020; Froese and Pauly, 2019).

Conclusion

The present work revealed that the majority of fish species inventoried in the Bandama River in the Marahoué Region were classified as "Least Concern". However, three species have a special conservation status. These include *H. longifilis* and *M. electricus*, which belong to the "high to very high" vulnerability category, and *C. gariepinus*, which belongs to the "very high" category. In addition, 79.87% of the species in this stand have a vulnerability between "Low" and "Moderate".

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Full Length Research Paper

Tree species composition and diversity in Agoro-Agu Central Forest Reserve, Lamwo District, Northern Uganda

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Tree species composition and diversity were assessed in Agoro-Agu Central Forest Reserve located in Lamwo district-Northern Uganda. Fifteen transects, each 2 km long, were established in the reserve. A procedure of nested quadrats was employed for a systematic sampling of mature trees, saplings and seedlings at 100 m interval(s). Vegetation analysis was conducted in Species Diversity and Richness (SDRiv) software. A total of 100 species of trees belonging to 36 families were recorded. The dominant tree species, also with high Importance Value Indices were *Combretum molle* G. Don, *Albizia grandibracteata* Taub. and *Vachellia hockii* De Wild. Tree species diversity was higher in the intact part (H'=3.46) than in the degraded part (H'=2.86). Lower diversity in the degraded part of the reserve could be due to human disturbance and resulting conducive condition for the early establishment of pioneer species during succession. The occurrence of mixed species with indicator species for both savannah woodlands and Afromontane tree species indicates that Agoro-Agu is an enriched forest for enhanced conservation. Management options that limit continuous degradations such as the enforcement of environmental laws, tree enrichment planting, and *ex-situ* conservation should be undertaken to restore the status of trees in the degraded part of the reserve.

Key words: Afromontane, biodiversity, East Africa, forest conservation, national forestry authority and species richness.

INTRODUCTION

Afromontane forests are forests that occupy the mountainous landscapes of East and West Africa (Mairal et al., 2017). In East Africa, Afromontane forests are widely scattered but geographically similar. Such forests often share similar features of mixed trees and plant species which are distinct from the surrounding lowlands

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(Gadow et al., 2016). The Afromontane altitudinal geographical limit falls within the range of 1000 to 2700 m above sea level (UNEP-WCMC, IUCN, 2020). Typically occurring above 1500 m in elevation, Afromontane forests extend from the Arabian Peninsula south along the rift to the Drakensberg Mountains in the east. The mountains are rich in biodiversity and are centers of endemism with many range-restricted species (Abiem et al., 2020).

Agoro-Agu Central Forest Reserve is located at the border between Uganda and South Sudan. It is the extension of Imatong Mountains into the Northern Region of Uganda, and basically lower than the southern part in South Sudan (Zhao et al., 2018). In Uganda, Afromontane forests include among others Bwindi forests and mid elevation forests at the border of Republic of South Sudan. The forest reserves of Imatong hills in South Sudan and Agoro-Agu in Northern Uganda are some of the outlying patches of the Eastern Arc Afromontane vegetation (Newmark and McNeally, 2018). Studies conducted in other Afromontane regions showed that such Afromontane outliers are hot spot areas with high diversity of flora and fauna but are often neglected (Kidane et al., 2019).

The high elevations in South Sudan that adjoins Agoro-Agu Central Forest Reserve in Northern-Uganda border are equally known to harbour a mixture of various kinds of forests including Afromontane forests, shrub lands, woody grasslands and bamboo - *Sinarundinaria alpina* (Zhao et al., 2018; Omoding et al., 2020). The distribution of East African Montane, its extension and elevations in South Sudan and Uganda border form part of the medium-altitude archipelago landscapes of the East African Afromontane for which Agoro and Agu hills are part of the landscape covered by Agoro-Agu Central Forest Reserve. It should be noted, however, that montane forests such as the hills of Agoro-Agu currently covered by the Agoro-Agu Central Forest reserve, have had very little attention in the past; yet they are becoming increasingly important for the conservation of fauna and flora (Omoding et al., 2020).

Agoro-Agu Central Forest Reserve has been reported to be extensively encroached with both temporary and semi-permanent housing, gardens, sambas and schools throughout the lower and medium altitude areas, particularly in the southern and eastern areas. Most of the disturbance and settlements were concentrated in the mid slope area where the landscape remains relatively flat. The human activities included settlements, cultivation, cutting of trees for fuel wood/building poles, timber, and rearing of domestic livestock including dogs, chicken, goats and cattle (NFA, 2018).

The situation was exacerbated by the presence of both the Lord's Resistance Army (LRA) and the Sudanese People's Liberation Army (SPLA) who operated within the reserve for many years. Despite the aforementioned, this forest reserve remains a source of building poles (especially bamboo), honey, bush meat, medicinal plants and firewood to the adjacent communities. The status quo to date indicates high level of encroachment from the resettling population as people return from captivity (Environmental Alert, 2017).

In the last 20 years or so, civil wars have negatively affected highlands and mid-altitudes forests in Northern Uganda including Agoro-Agu. The Agoro-Agu Forest Reserve suffered from persistent conflict in the mid-1980s, including the Lord's Resistance Army civil war against Uganda's Government and conflicts in neighbouring South Sudan. The Agoro-Agu Forest Reserve (264 km^2) established in 1937, and gazetted as a Central Forest Reserve (CFR) in 1948 is part of a trans boundary protected area complex with South Sudan's Imatong Forest Reserve. Apart from massive areas being converted to farmland, trees also got continuously cut for firewood and building poles by the resettling population (NFA, 2018).

To understand the rate of forest cover loss, a precise, fine scale demographic data would be needed to fully understand where returnees settled and how their land use practices have affected forest cover in Agoro-Agu Central Forest Reserve. Assembling information on tree species diversity and composition is not only key in understanding important aspects of tropical forest ecosystem, but can also help in determining the diversity and structure of the tropical forests ecosystems than any other living component of the system (Mori et al., 2017).

Furthermore, having a proper data on patterns of tree species diversity and composition is a prerequisite if any meaningful management interventions related to conservation of tropical forests are to be carried out (Gebeyehu et al., 2019). Apart from providing the necessary context for planning and interpreting long-term ecological research (Haruna et al., 2018), data from such a study would be equally relevant to Agoro-Agu Central Forest Reserve given the current pressure from resettling war returnees and the need to making choices and decisions for biodiversity conservation in this forest landscape.

Much as the tropical flora remains chronically understudied, thousands of plant and animal species in tropical regions provide a variety of non-timber products that are used by billions of people all over the world. Indeed conservation and long term utilization of these species require that they be harvested on a sustainable basis (Young et al., 2017). This implies that understanding tree species diversity and composition patterns in such a reserve would be of utmost interest to conservationists when interpreting long-term ecological data (Gonçalves et al., 2017) and monitoring changes in ecosystem health, as well as the composition of flora and fauna (Strassburg et al., 2019).

Policy makers, conservationists, the public and other professional (Planners, foresters, health workers, help researchers, etc.) would also need such information to them understand the implication of environmental and population trends including designation of appropriate conservation actions to be taken (Gavin et al., 2018).

Even if Uganda Forest Department surveyed and recorded 254 useful trees and shrubs in Agoro-Agu with moderate to high levels of biodiversity, the study was limited in scope due to the insecurity situation within the reserve (NFA, 2018). Difficulty of access to an area during war combined with no clear spatial or temporal definition for the extent of conflict also made it extremely challenging to conduct accurate and timely assessment of the impacts of wars on tree species composition. Satellite image analysis on the same forest reserve by Gorsevski et al. (2012) was also reported only on slight decreasing forest and increasing tree cover of the reserve with no details on tree diversity and composition.

These scenarios, thus, necessitated an assessment of tree species diversity and composition in the reserve. Such knowledge of floristic composition and diversity is useful for conservation by identifying ecologically and economically important plants and their diversities. The information on plant diversity is also required for facilitating proper planning and management of biodiversity, and ecosystem services provided in such a reserve. Indeed long-term biodiversity conservation also depends basically on the knowledge of the structure, species richness, and the ecological characteristics of vegetation (Ifo et al., 2016).

MATERIALS AND METHODS

Location and size of the study area

Agoro-Agu forest landscape falls within the Agoro-Agu Sector that covers 17 central forest reserves in Aswa river range. The Agoro-Agu Central Forest Reserve is a savanna woodland reserve considered among patches of diverse Eastern Afromontane landscape in the region; at the border between Uganda and South Sudan. It is the extension of Imatong Mountains into the Northern Region of Uganda, and basically lower than the southern part in South Sudan (Zhao et al., 2018). Agoro-Agu is located in Lamwo District, Northern Uganda between 3°40-3°53′ N and 32°42′-33°04 E (Figure 1). It has at altitudinal range of 1100 to 2700 masl, and at a distance of 463 km from Kampala city and covers a total of 26,508 ha (IUCN, 2015).

According to National Forestry Authority, the reserve covers a total area of 236 km^2/26,508 ha (NFA, 2018). This constitutes 2.9% of the total tropical forest area coverage in Uganda. The forest reserve lies along the border between Uganda and Republic of South Sudan.

Description of the study site

Physiographically, Agoro-Agu Central Forest Reserve is characterized by hills, escarpments, valleys, relatively flat mid slopes and isolated ridges. The forest reserve is constituted by a series of small hills whose peaks are marked by Lumwaka hills (3100 m) in the North and Agu hills (1810 m) in the North-West and Agoro hills (2850 m) in the eastern part of the forest reserve (Olanya, 2020b). These three hills stretch across the international border of Uganda and the Republic of South Sudan (Environmental Alert, 2017). Apart from being connected to the Imatong hills, other small hills in the reserve include: Talamudu, Lowa matidi, Lowa madit, Podolo, Loturtur, Lacer, Lamwo, Alila and Katomo hills (Zhao et al., 2018). Agoro-Agu Central Forest Reserve had for the last two decades served as a rebel hideout which rendered it inaccessible to the conservation authority (Omoding et al., 2020).

Vegetation characteristics

The vegetation of Agoro-Agu Central Forest Reserve has been broadly classified as dry *Combretum* savanna, forest-savanna mosaic and dry montane forest. Accordingly, land cover map for Agoro-Agu indicates that the vegetation of this area includes Afromontane forests, shrub lands, woody grasslands and bamboos (Zhao et al., 2018).

According to NFA Master Plan, about 100 km^2 (38%) of the reserve is occupied by forest/savanna mosaic at high altitudes. About 71 km^2 (29%) is occupied by *Combretum-Acacia-Themeda* savanna. *Juniperus-Podocarpus* trees typical of dry montane forest occupies 48 km^2 (20%), of the reserve landscape while *Cyperus papyrus* Swamp; *Acacia-Cymbopogon-Themeda* grassland and *Butyrospermum-Hyparrhenia* savanna occupies 4, 2 and 2% of Agoro-Agu forest landscape, respectively. The 16 CFRs within the Agoro-Agu Landscape cover 65,548 ha under one Forest Management Planning Area (the Agoro-Agu Sector) which are managed with a common Forest Management Plan (NFA, 2018).

Climate and topography

The climate of Agoro-Agu Central Forest Reserve is tropical Afromontane and rainfall is fairly constant throughout the season with warm day time temperatures up to 35°C that cools to 15°C at night (at Katire, 800 masl). Precipitation increases with altitude, resulting in a transition of the montane forest zone to the alpine zone. Rainfall across the study region is seasonal with the rainy season beginning in late March and lasting until the end of October (Gorsevski et al., 2013). The mountains in Agoro-Agu Central Forest Reserve consist of granitic crystalline rocks, most of which are folded and foliated with soils largely falling within the following four categories: (i) dark cracking clays, (ii) non-cracking clays, (iii) red loam and ironstone soils, and (iv) hill or mountains soils (Uganda Land Use Dialogue, 2020).

Conservation issues

Agoro-Agu Central Forest Reserve is of relatively high conservation value for all taxa compared to other forest reserves in Northern Uganda. The forest is contiguous with the Imatong Mountains of south Sudan and known for their high rates of endemism and unique species composition. In northern Uganda, it is among the 15 forest reserves that were surveyed and reported to have had at least one species found in no other protected area in Uganda. Although a study commissioned by the Ugandan Forest Department recorded moderate to high levels of biodiversity; extensive encroachment evidenced in the lower and medium altitude areas raises conservation concern (NFA, 2018).

Data collection

Research design

The study followed a design by Delgado-Aguilar et al. (2017) in

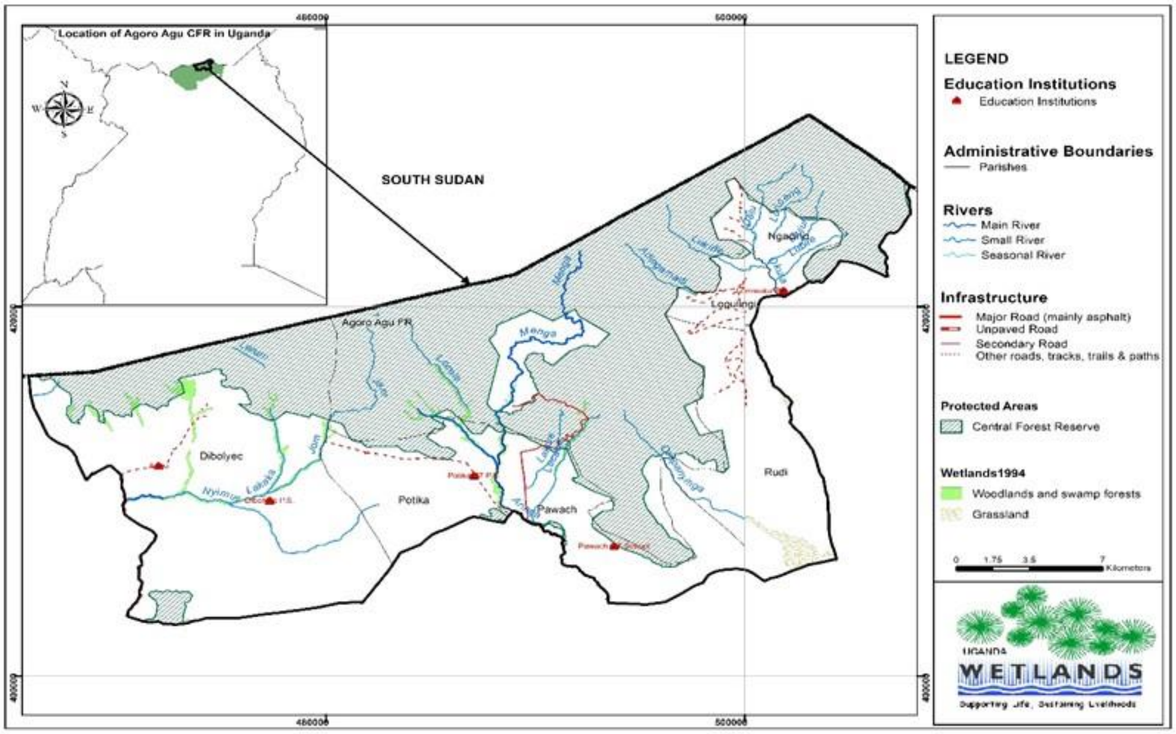

Figure 1. Map of agoro-agu central forest reserve.

which the naturalness or the integrity of the ecosystem and human disturbance features were used as a basis for landscape description of intact (non-degraded) and disturbed (degraded) landscapes. The criterion therefore described intact area as an unbroken expanse of natural ecosystems within the reserve with no signs of significant human activity. According to Haurez et al. (2017), intact site usually consists of forested, treeless, grassland or non-forest ecosystems minimally influenced by human economic activity. Based on the two descriptions, two study sites were identified in the study area.

While the disturbed/degraded areas consisted of relatively flat mid slope areas with settlements, cultivation zones had significant human activities (e.g. fallow lands or previously cultivated lands and anthropogenic evidences like remnants of tree cuttings and stumps); the intact part had features similar to those described by Haurez et al. (2017), compared to the intact part of the forest reserve. This was based on the idea that the degraded section of the forest reserve constituted less than 5% of the total reserve area. The vegetation community landscape was furthered categorized and subdivided into three topographic positions that were defined as Ridge top, Mid slope and Valley bottom topographic positions following Mligo (2018).

Using the two categories of forest parts and three topographic positions of the landscape in the assessment of tree species diversity, structure and composition, a total of 12.7 ha of the forest reserve was surveyed consisting of 9.5 ha of the intact part and 3.2 ha of degraded part of the forest reserve. Efforts were made to select plot locations based on representation of possible aspect and slope topographic position combinations.

Reconnaissance study

Fieldwork started with a preliminary visit (reconnaissance) to the forest reserve. This was intended to plan the stratification of sample sites based on naturalness and intactness or extent of human disturbance on the forest reserve. The disturbance evidence considered included human activities like crop cultivation, tree stumps and settled areas. The non-degraded areas were considered to be at least 1 km away from the motorable paths and half a kilometer from the foot paths. This guided the laying of transects and establishment of plots during data collection (Solomon et al., 2018).

Transect establishment and plot lay out

A total of 15 transects were laid throughout the study area; nine in the intact part and six in the degraded part of the forest reserve. Transects (2 km long) were laid and on each; nested quadrants (alternating on either side of each transect) were laid out systematically at 100 m intervals. The inter-transect distance was 600 m and the inter-plot distance was 100 m (Figure 2).

Global Positioning System (GPS), compasses and 50 m ribbon tape measure were used to mark the plots along transects. A compass bearing was used to indicate direction during plot setting. Within the 25 m × 25 m plot, smaller plots of 10 m × 10 m and 5 m × 5 m were nested for sampling mature trees, saplings and seedlings, respectively (Dibaba et al., 2020).

In this study, seedlings were considered as young trees with root collar diameter (rcd) between 1 and 2.9 cm and the data were obtained from the 5 m × 5 m plots; saplings were considered to be of diameter at breast height (Dbh) range from 3 to 9.9 cm and the data were collected from 10 m × 10 m plots. Mature trees were considered as trees with Dbh ≥10 cm and the data were recorded from 25 m × 25 m plots throughout the inventory (Dibaba et al., 2020). The total number of plots for the entire sampled area for both intact and degraded parts of the reserve was 203 of which 152 were in the intact and 51 were in the degraded part of the forest reserve.

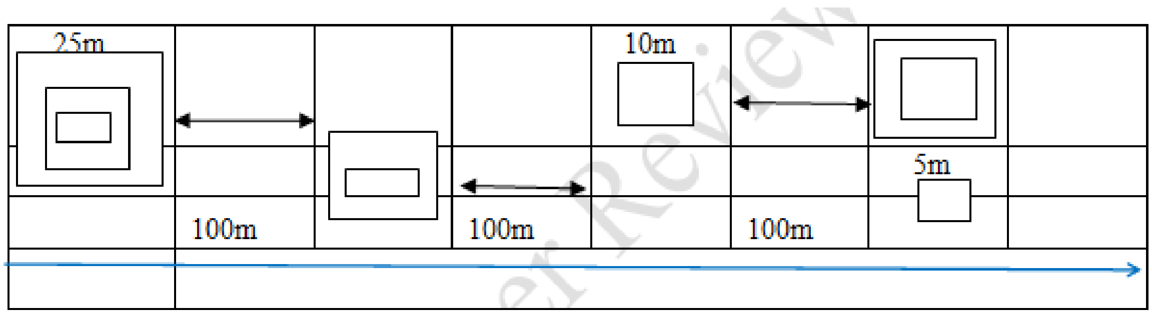

Figure 2. Diagrammatic presentation of Plot Layout along Transects.

Table 1. Plot size, diameter class size and tree category.

Plot size (cm)	Diameter size class in dbh/rcd (cm)	Tree category assessed
25 × 25	>10 cm	Adult/mature trees
10 × 10	3-9.99 cm	Saplings
5 × 5	1-2.99 cm	Seedlings

Source: Dibaba et al. (2020).

Assessment of tree species composition and diversity

At each plot center, GPS coordinate readings were recorded. Following Dibaba et al. (2020), measurements of Dbh of mature trees and saplings were carried out at 1.3 m from ground surface and root collar diameters (rcd) for seedlings (Table 1).

For the tree trunk with buttresses near breast height, the Dbh were measured just above the buttress. Tree species were assessed in the 25 m × 25 m plots where the diameter at breast height (Dbh) of the trees were measured using either Vernier caliper (for smaller trees), tape measure (for very big trees) and recorded under different diameter class sizes (Table 1). Specimens of unfamiliar trees were collected and taken to Makerere University Herbarium for proper identification.

Data analysis

Vegetation data were entered and analysis conducted in Species Diversity and Richness (SDRiv) software (Kacholi, 2019; Birhanu et al., 2021).

Analysis of tree species composition

Tree species composition was considered to be an assemblage of tree species that characterized the forest vegetation (Ifo et al., 2016). Tree species encountered in each plot were counted, and the composition measures in Equations 1 to 5 were considered in the calculation of Important Value Species Indices (IVI): Density (D), Frequency (F), Relative Density (RD), Relative Frequency (RF) and Relative Dominance (RDn) following methods by Tolangara et al. (2019) and Reshad et al. 2020).

$$\text{Frequency (F)} = \frac{\text{Number of sample plots at which particular species occures}}{\text{Total number of sampled plots}} \times 100 \quad (1)$$

The degree of dispersion of individual species in an area in relation to the number of all the species that have occurred called Relative Frequency (RF):

$$\text{Relative Frequency (RF)} = \left(\frac{\text{Frequency value for a particular species}}{\text{Toal frequency value for all species}}\right) x100 \quad (2)$$

Relative density is the study of the numerical strength of a species in relation to the total number of individuals of all the species and can be calculated as:

$$\text{Relative Density (RD)} = \left(\frac{\text{Number of indvidulas of tree species}}{\text{Total number of individual}}\right) x100 \quad (3)$$

$$\text{Basal area (BA)} = \{¼\ (3.14 \times dbh^2)/1000\}\ m^2 \quad (4)$$

$$\text{Relative Dominance (RDn)} = \left(\frac{\text{Tota basal area of a particular species}}{\text{Total basal area of all specis}}\right) \times 100 \quad (5)$$

The Importance Value Index (IVI) was calculated by summing up the Relative Density (RD) % + Relative Frequency (RF) % + Relative Dominance (RDn) % of each species (Reshad et al., 2020). Thus,

IVI= Relative frequency + Relative density + Relative dominance (6)

Every species was ranked according to their importance values and the species with the highest importance value in the stand was considered as trees with the highest value that existed in the greatest number or are of the greatest size, dominant species and may have the greatest effect on the community (Asigbaase et al., 2019). Thus, the index reflected the overall importance of each species within the community. This provided a basis for highlighting species of conservation significance (Gebrewahid and Abrehe, 2019).

Analysis of tree species diversity

Species diversity has two components: richness and evenness. Species richness is the number of species in a sample while evenness refers to their relative abundance. Species Diversity and Richness (SDRiv) software (Tecimen et al., 2017) was used to carry out the analyses of tree species diversity and richness indices for Degraded and Intact Forest Reserve. The same analysis was done for tree species diversity indices and richness along topographic positions (ridge top, mid-slope and slope bottom).

To assess the woody species diversity in the forest reserve, the Shannon-Wiener diversity index (an information statistic index, which assumes that all species are represented in a sample and that they are randomly sampled) was used (Joshi and Dhyani, 2019).

Its equation is:

$$H' = -\Sigma Pi \times (\ln Pi) \quad (7)$$

where H′ = is the Shannon Diversity index, Pi = is the importance value of a species as a proportion of all species (that is, the proportion (n/N) of individuals of one particular species found (n) divided by the total number of individuals found (N), ln = is the natural log, Σ = is the sum of the calculations, and s is the number of species.

Shannon Tree Species Diversity and Richness (SDR) were calculated as follows (Equation 8):

$$SD = -\sum_{i=1}^{S} Pi \ln Pi \quad (8)$$

where SD=Shannon Diversity (H'), S = the number of species at that site, Pi = ni/N, that is, proportion of the individual trees of the i^{th} species to the total, ni = total number of individuals in the i^{th} species, N = total number of individual of all species, and ln= Natural logarithm to base *e*.

Simpson's index of diversity

Concentration of dominance was measured by Simpson's index (Simpson 1949) and was calculated as follows (Equation 9):

$$D = \frac{\sum_{i=1}^{S} n_i(n_i - 1)}{N(N-1)}, \quad (9)$$

where D= Simpson Diversity Index, n*i* is the number of individuals of *i*th species and N is the total number of individuals.

The Simpson index is a dominance index because it gives more weight to common or dominant species. In this case, a few rare species with only a few representatives will not affect the diversity.

Pooled analysis using rarefaction method

Rarefaction technique was also used to standardize samples from intact and degraded parts of the forest reserve; and also sample sizes along topographic locations (ridge top, mid-slope and slope bottom) that differed in terms of sizes. The standardization was derived from hyper geometric distribution whose outputs were hyperbolic curves depicting Species Accumulation Curves for the various sample plots (Jenerette et al., 2016).

Pairwise analysis using Sørensen and Jaccards Similarity Index (JSI)

Jaccard's Similarity Index was used based on the presence/absence of species that were shared and uniqueness between samples of tree species (Rahman et al., 2019). For this study, analysis of similarity was carried out between intact verses degraded parts of the reserve; and between topographic positions.

Thus, in measuring the similarity indexes, Sørensen Similarity Index was calculated from (Equation 10):

Cs = 2a / (2a + b + c); and Jaccards Similarity Index was calculated from:

$$Cj = a / (a + b + c) \quad (10)$$

where c = represented the number of species found in site A (that is, Intact part of the reserve); b = represented the number of species in site B (that is, degraded part of the reserve) and a = represented the number of species shared by the two sites, that is, intact and degraded parts of the reserve (Santini et al., 2017).

RESULTS

Tree species composition

The inventoried trees of Agoro-Agu Central Forest Reserve were composed of 100 species belonging to 36 families. The most abundant families in the intact part of the reserve were Fabaceae with 20 species, Moraceae and Euphorbiaceae with eight species each, and Anacardiaceae and Rubiaceae with five species each. These were followed by Combretaceae and Meliaceae each with four species, Canellaceae, Celastraceae and Sterculiaceae with three species each and the rest of the families had either two or one species each (Table 2).

While Fabaceae was the most diverse; followed by Moraceae, Euphorbiaceae, Anarcaidaiceae, Rubiaceae and Combretaceae with a minimum of 4 species each (in intact part), Fabaceae was the most diverse; followed by Combretaceae, Moraceae, Euphorbiaceae, and Anarcaidaiceae, with 3 species each in degraded parts of the reserve. The rest of the families had either one or two species only (Table 2).

Of the encountered 36 families, the first ten families (Table 2) contributed 74 and 64.2% of the total species in the intact and degraded parts of the reserve, respectively. The remaining 26 families accounted for only 26 and 35.8% of the total tree species in the intact and degraded parts of the reserve, respectively.

Eleven families that were exclusively observed in the intact part of the reserve included Ulmaceae, Podocarpaceae, Sterculiaceae, Sapindaceae, Polygalaceae, Phillanthoceae, Ochnaceae, Meliaceae, Apiaceae, Bignoniaceae, Celastraceae and Ebenaceae (Table 2).

Table 2. Top 10 families of tree species inventoried in the Intact and Degraded parts of Agoro-Agu Central Forest Reserve.

Tree family	Number of species in the intact part	Number of species in the degraded part
Fabaceae	20	11
Moraceae	08	03
Euphorbiaceae	08	03
Anacardiaceae	05	03
Rubiaceae	05	01
Combretaceae	04	04
Meliaceae	04	01
Canellaceae	03	02
Celastraceae	03	00
Sterculiaceae	03	01
Annonaceae	02	02
Total species contribution	74%	64.2%

Table 3. Ten most important species in the Intact part of the reserve.

Tree species	Relative density	Relative dominance	Relative Frequency	Importance Value Index
Combretum molle R.Br ex G. Don	18.56	7.19	8.42	34.16
Vachellia hockii De Willd.	16.15	7.14	10.15	33.44
Albizia grandibracteata Taub	8.11	7.46	4.13	19.70
Hagenia abyssinica Steud.ex. A. Rich	4.17	13.69	1.24	19.10
Grewia mollis Juss	6.57	2.13	4.95	13.65
Vachellia amythethophylla (Steud. ex A.Rich.) Kyal. & Boatwr.	3.60	3.88	1.57	9.05
Pleurostylia africana Loes.	3.11	4.68	0.74	8.53
Lannea schimperi	1.55	1.86	4.04	7.46
Terminalia glaucescens Benth	1.94	2.60	2.56	7.09
Combretum collinum Fressen.	3.14	0.16	3.05	6.35
Sub-total	66.90	50.79	40.84	158.53

Importance value indices of tree species

Important value indices (IVIs) provide knowledge on important species of the tree community in the reserve. The list of species and their IVIs for first 10 most important species are shown in Tables 3 and 4.

Based on IVI, the most important species in the intact part of the reserve were *Combretum molle, Acacia hockii*, *Albizia grantibracteata* and *Entada abyssinica*; while *Combretum collenum* and *Terminalia glaucescens* were the least ranked species among the first 10 species in the intact part of the reserve (Table 3).

On the other hand, *C. molle, A. hockii, T. glaucescens, A. grandibracteata, Grewia mollis* and *Ficus sycamore* were some of the most important species in the degraded part of the reserve (Table 4).

C. molle and *A. hockii* had the highest IVIs, while *Vitex doniana* and *Stereospermum kunthianum* had the least IVIs (Table 4).

In general, the IVIs for the 10 species represented 52.8 and 70.7% of the total Importance Value Indices for the intact and degraded parts of the reserve, respectively. Along topographic gradient, *A. hockii*, *Pleurostylia africana* and *C. molle* had the highest Importance Value Indices (IVIs) for Mid slope, Valley bottom and Ridge top topographic positions, respectively.

The summary for the species in order of their decreasing IVI is provided in Table 5a to c. While *A. hockii* had the highest IVI (82.98) followed by *C. molle* (64.05) in the bottom Ridge top topographic positions, *P. africana* (52.25) followed by *A. grandibracteata* (25.64) and *C. molle* (41.00) followed by *A. hockii* (30.19) had the highest IVIs in the Valley bottom and Mid slope topographic positions, respectively (Table 5a to c).

Table 4. Ten most important species in the Degraded part of the reserve.

Tree species	Relative density	Relative frequency	Relative dominance	Important value index
Combretum molle R.Br ex G. Don	24.49	9.49	21.75	55.73
Vachellia hockii De Willd.	17.55	10.13	9.64	37.32
Terminalia glaucescens Benth	5.85	07.17	16.33	29.35
Albizia grandibracteata Taub.	07.99	4.85	03.61	16.45
Grewia mollis Juss	05.60	06.75	02.83	15.19
Ficus sycomorus Linn	01.68	02.11	10.54	14.33
Annona senegalensis	04.85	06.54	02.41	13.80
Bridelia micrantha (Hochst.) Baill	04.66	06.33	02.23	13.21
Vitex doniana Sweet	01.46	03.59	03.71	08.75
Stereospermum kunthianum Cham	03.78	03.38	00.84	07.99
Sub-total	77.89	60.34	73.89	212.12

Tree species diversity

Tree species richness

One hundred tree species were encountered throughout the study area. The intact part of the reserve had 95 tree species and was richer than the degraded part with only 51 tree species. Along topographic positions (valley bottom, mid slope and ridge top), mid slope was the richest, followed by valley bottom and ridge top with 87,69 and 22 tree species, respectively (Table 6).

The species diversity given by Shannon-Diversity and Richness index was higher in the intact part of the reserve (H'=3.46) than in the degraded part (H'=2.86). The tree species diversity declined from valley bottom with (H'=3.48) to ridge top with (H'=1.83).

Tree species evenness

Pielou evenness index was highest for the intact part of the reserve (E=0.80) and lowest for degraded part (E=0.50). Similarly, mid slope had the highest evenness (E=0.70) and ridge top had the least evenness (E=0.46) among topopositions. The value for concentration of dominance was lowest for intact portion (0.06) and highest for the degraded (0.10) part of the reserve.

Along the topographic gradient, evenness value increased from valley bottom (0.04) to ridge top (0.27). While all values for concentration of dominance (cd) showed reverse trend as compared to Shannon diversity indices, species diversity and concentration of dominance appeared inversely related (Table 6).

Tree species similarity

The Jaccards Similarity Index showed an average of 50% similarity in species composition between the intact and degraded parts of the reserve. Along topographic positions, high similarity values were observed between mid- slope and valley-bottom; the least comparison was observed between ridge-top and other topographic positions (Table 7).

The rare faction and assemblages of the intact and degraded parts of the reserve including topopositions showed similar hyperbolic curves (asymptote) with maximum plateau shapes for all samples for both degraded and intact parts of the reserve (Figure 3).

Similarly, along topographic position, the generated curves had hyperbolic shape which flattens out and eventually begins to level off. This is an indicator that the sampling captured maximum proportion of the species richness (Figure 4).

DISCUSSION

Tree species composition

The most common tree families recorded in the study included Euphorbiaceae, Moraceae, Combretaceae and Fabaceae which were well represented in both intact and degraded parts of the reserve. According to Ifo et al. (2016), such families are common in most savannah woodland mosaics in Africa and are typical of the Sudano-Sahelian zone. The dominance by Combretaceae, Euphorbiacea and Fabaceae are therefore good indicators for Sudano-sahelian vegetation composition (Dangulla et al., 2020).

On the contrary, families that included Ulmaceae, Podocarpaceae, Sterculiaceae, Sapindaceae, Polygalaceae, Phillanthoceae, Ochnaceae, Meliaceae, Apiaceae, Bignoniaceae, Celastraceae and Ebenaceae were not encountered in the degraded part of the reserve. It is possible that such families contributed most of the bigger trees that had been harvested for fuelwood, building poles and expansion of cultivation lands leading to compositional differences (Tenzin and Hasenauer, 2016). The most probable reasons for the harvest of such tree species could include among others factors like

Table 5. Ten most important species along valley bottom, mid slope, and ridge top topographic positions.

Tree species	Relative density	Relative frequency	Relative dominance	Important value index
Valley bottom topographic position				
Pleurostylia africana Loes	6.41	37.26	8.58	52.25
Albizia grandibracteata Taub.Taub.	11.20	5.47	8.97	25.64
Vachellia hockii De Wild.	8.73	8.68	3.81	21.21
Entada abyssinica Steud.ex A.Rich	7.54	3.22	10.24	21.00
Ficus barteri Sprague	3.67	3.54	12.85	20.06
Combretum molle R.Br ex G. Don	9.00	6.43	4.40	19.83
Balanites aegyptiaca	0.12	13.55	0.30	13.97
Vachellia amythethophylla (Steud. ex A.Rich.) Kyal. & Boatwr	6.03	2.57	4.20	12.80
Terminaliabrownii Fressen.	3.54	3.22	5.02	11.77
Grewia mollis Juss	6.66	3.86	1.16	11.68
Sub-total	62.89	87.79	59.53	210.21
Mid slope topographic position				
Combretum molle R.Br ex G. Don	24.35	9.12	7.53	41.00
Vachellia hockii De Willd.	18.46	11.26	0.47	30.19
Entada abyssinica Steud.ex A.Rich	3.35	0.67	13.63	17.65
Grewia mollis Juss	7.84	1.61	2.23	11.68
Albizia grandibracteata Taub	2.07	4.56	3.96	10.59
Stereospermum kunthianum Cham	5.61	4.02	0.94	10.57
Terminalia glaucescens Benth	2.38	3.35	4.15	9.88
Terminalia brownii Fressen.	0.88	2.82	5.84	9.54
Senegalia brevispica (Harms)	0.41	0.80	7.76	8.97
Combretum collinum Fressen.	2.40	3.22	2.08	7.69
Sub-total	67.75	41.42	48.59	157.76
Ridge top topographic positions				
Vachellia hockii *De Willd.*	41.07	12.00	29.90	82.98
Combretum molle R.Br ex G. Don	24.04	13.60	26.40	64.05
Myrianthus holstii Engl.	04.23	09.60	10.90	24.73
Maystenus senegalensis (Lam.) Excell	06.81	04.00	07.29	18.10
Stereospermum kunthianum Cham	07.77	04.80	03.04	15.60
Lannea schimperi (A.Rich.) Engl.	01.30	05.60	05.14	12.04
Grewia mollis Juss	00.70	05.60	01.03	07.33
Hagenia abyssinica (Bruce) J.F. Gmel.	00.88	04.00	02.18	07.06
Prosopis madiensis	01.91	01.60	01.24	04.76
*Bridelia micrantha*Steud.ex A.Rich	01.03	01.60	01.92	04.56
Sub-total	89.74	62.40	89.06	241.20

agricultural encroachment and increased demand for fuelwood (Ministry of Water and Environment, 2017; Kalema and Hamilton, 2020). Indeed Agoro-Agu Central Forest Reserve had been inhabited by the displaced people who exploited it for building poles, firewood, medicine, and bush meat (Omoding et al., 2020).

Extraction of these resources could have caused habitat fragmentation and loss in this protected area, altering its structure and functioning (Olanya, 2020a).

The encountered tree families that consisted of species such as *Podocarpus latifolia, Lovoa trichilioides* (African Walnut), *Lovoa swynnertonii, Mimusops bagshawei*, *Pterygota mildbraedii,* and *Hagenia abyssinica* are typical forest species. This could be attributed to (among other factors), the absence of single mature tree remnants to serve as a seed bank (Martínez-Ramos et al., 2016). Although, other scholars have maintained that the absence of such species may be due to micro-site factors like moisture, soil characteristic and landscape position (Fazlollahi et al., 2017), it is also possible that clearance

Table 6. Tree species diversity and richness indices for the forest and topositions.

Parameter	Forest		Topopositions in the Forest		
	Degraded part	Intact part	Valley Bottom	Mid Slope	Ridge top
Number of families	25.00	33.00	33.00	33.00	34.00
Number of species (N)	51.00	95.00	69.00	87.00	22.00
Shannon-Diversity index (H')	02.86	03.46	03.48	03.32	01.83
Concentration of Dominance(CD)	00.10	00.06	00.04	00.08	00.27
Evenness index (E)	00.50	00.80	00.61	00.70	00.46
Jaccards index of similarity (J)	00.54	00.54	-	-	-

Table 7. Pair wise comparison of species in the different topopositions.

Site	Ridge top	Mid slope	Valley bottom
Ridge top	-	0.606	0.466
Mid slope	0.555	-	0.792
Valley bottom	0.466	0.792	-

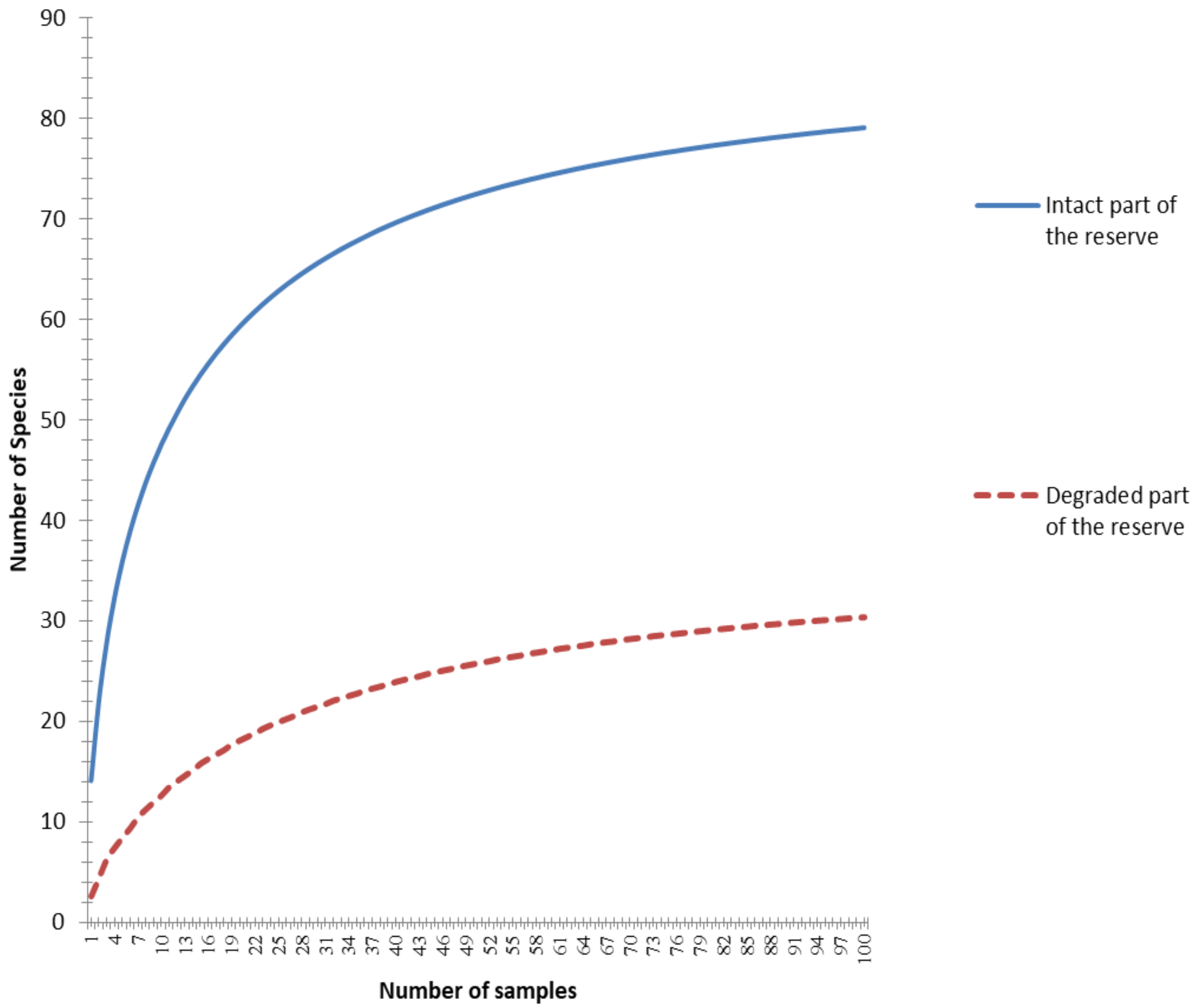

Figure 3. Rarefaction curves for both the Intact & Degraded parts of the reserve.

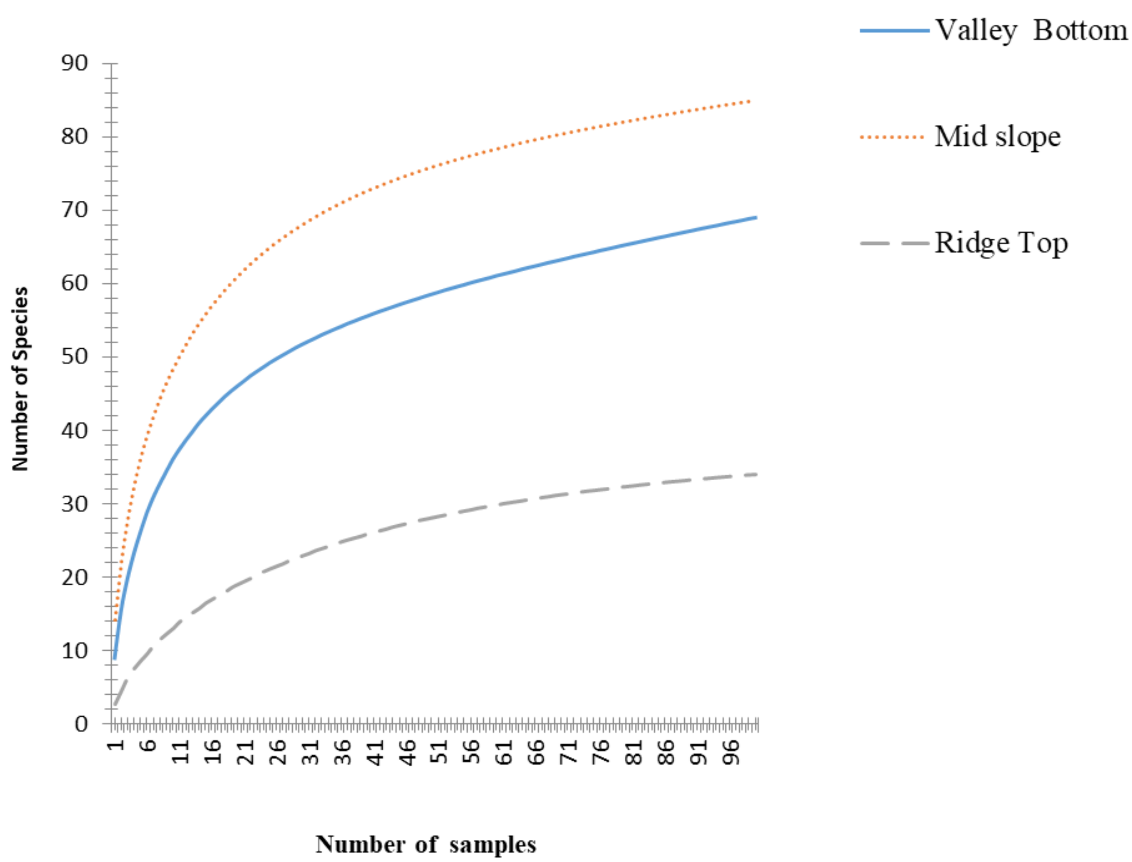

Figure 4. Rarefaction curves for Valley bottom, Mid slope and Ridge top (Topopositions).

of mature trees that serve as seed bank can affect recruitment from seeds (Chen et al., 2017). The removal of such seed sources could have certainly led to local extinction of certain tree species and subsequently altered tree species composition (Aynekulu et al., 2016; Ranjan, 2018).

Tree Importance Value Indices

In forest ecological studies, IVI indicates the ecological importance of a species in a community and provides an overview of the social structure of a species. IVIs also indicate dominance of species in mixed population and give a total picture and knowledge about important species and their composition in such a forest reserve (Siraj and Zhang, 2018). Since IVI is an important parameter that reveals the ecological significance of species in a given ecosystem, it reflects the combined effect of species density, frequency and dominance (Demies, 2019). Moreover, it enables prioritizing species for conservation interventions such that species with lowest IVIs might benefit from conservation and management interventions. Tree species such as *C. molle*, *A. grandibracteata* and *A. hockii* are species with high IVIs and constitute the dominant species in both portions of the reserve. Some of these species recorded with high IVIs are multipurpose in nature and are valued by many communities in Africa for fuel and medicines.

For example, *C. molle* and *Terminalia* species are documented as important medicinal species not only by communities in Uganda but also other parts in Africa (Hegazy et al., 2020). *A. hockii* is valued for construction purposes and medicine in treating tuberculosis and allied diseases (Nabasumba et al., 2016) in south Western Uganda. According to Asigbaase et al. (2019), such trees with high IVIs have more ecological advantage and require less conservation management efforts. This implies that conservation measure on the contrary should now be shifted to trees with low IVIs.

In this study, *L. trichilioides* and *L. swynnertonii*, which recorded low IVIs are listed as vulnerable and endangered. While species like *P. latifolia* and *Strombosia scheffleri* are considered nationally threatened species (MTWA, 2018); and *L. swynnertonii* is considered internationally threatened species (Migliore et al., 2020). Indeed some of these species with low IVI values in this reserve are included in the 2017 IUCN Plant Red list either as vulnerable or endangered; mainly due to high exploitation rates (IUCN, 2020) and being subjected to heavy felling (Mengich et al., 2020). Such important trees with low IVIs, would thus, require more attention and prioritization because they are probably less adaptive with least ecological advantage (Asigbaase et al., 2019).

Other species with low IVIs that are also enlisted under IUCN Red list as threatened or endangered species and that need to be considered for conservation are *M. bagshawei*, *Polyscias fulva, P. mildbraedii* and a synonym of *H. abyssinica*. *Afzelia africana*, *L. trichiloides* and *Securidaca longipedunculata* are also among the species of special conservation interest. This observation defines the ecological significance and the urgency needed in developing mechanisms for the restoration and conservation of Agoro-Agu Central Forest Reserve.

In order to understand where returnees are resettling and how their land use practices are affecting forest cover, a fine scale demographic data combined with a well-executed socio-economic surveys also would be necessary (Salazar et al., 2018). This is quite important given that these forests may not only provide timber and firewood, but is part of a larger water catchment system. The results suggest that the species having low IVI value should be prioritized for conservation. Accordingly, these lower IVIs indicate that these woody species are threatened and need immediate conservation measure (Demie, 2019). Since IVI is used for prioritizing conservation of species, species with low IVI index values should be given higher priority in conservation than those with high IVIs.

Tree species diversity

In a survey covering 12.7 ha, 5,936 stems of trees belonging to 100 tree species and 36 families have been encountered. The value for richness(R) and species diversity (H') varied among sites (intact and degraded parts of the reserve) and along the topographic gradient as provided in Table 6. The variation in species richness and diversity in such sites could be attributed to physical heterogeneity (Shirima et al., 2016) and anthropogenic perturbation (Yuan et al., 2016). The intact part registers higher species richness and diversity (Table 6). This could be probably correlated with greater diversity and community stability in such a reserve.

According to Ifo et al. (2016) high species diversity indicates a highly complex community, for a greater variety of species that allows for a larger array of species interactions. The diversity index in intact part was significantly higher than degraded part perhaps due to the high number of families, number of genera, and number of species that were recorded in the intact compared to the degraded part of the reserve. As has also been reported by Arroyo-Rodríguez et al. (2017), the development and changes of floristic composition and diversity of plants during early stages of succession could have been mostly influenced by secondary succession processes and fallow periods in the intact and degraded parts of the reserve, respectively.

On the contrary, the degraded part of the reserve has lower species richness and diversity. This could probably be attributed to the impact of anthropogenic perturbations such as firewood harvesting, felling, lopping and clearing of land for cultivation and settlement (Ifo et al., 2016). Such disturbances are likely to impact on tree species richness and diversity of the reserve. In some cases, such disturbances could reduce not only the number of species in the ecosystem but also the number and extent of places where species coexist. According to Wegasie et al. (2018), the effects of such disturbance may even be more on certain tree species depending on the purpose for which the trees are needed.

In addition to anthropogenic disturbance, suppression by the pioneer species such as *C. molle, A. hockii* and *A. grandibracteata* may also not be ignored (Swinfield et al., 2016). According to Muluneh et al. (2021), pioneer species usually establish very early in succession and are able to suppress other species very rapidly. The recruitment of such species may probably account for the observed variation in species richness and diversity in both intact and degraded part of the reserve. As has also been reported by Yahya et al. (2019), the absence of certain species like *P. latifolia*, *M. bagshawei*, *P. fulva, Pterygota mildbraedii*, *H. abyssinica*, *A. africana*, and *L. trichiloides* from the degraded part of the reserve could be attributed to dominance by the pioneer species such as the genus *Combretum*.

Indeed, the genera *Combretum* and *Acacia* are recorded as light tolerant and have characteristics of dominating the previously disturbed savannah woodlands while also suppressing the regeneration of other tree species (Sangeda and Maleko, 2018). Apart from these, other pioneers species that are capable of growing to forest canopy within a decade to become important timber species have to be assessed and protected.

Although Shannon-Wiener's diversity index is the most preferred index among the other diversity indices and values are between 0.0 and 5.0 with results generally in the range 1.5 to 3.5 and very rarely exceeding 4.5 (Deo et al., 2016), the overall diversity index value of 3.40 for Agoro-Agu Central Forest Reserve is equally considered high. This is so because the value is higher than the diversity values for other woodland reserves in East Africa such as the ones for Maruzi Hill (Kiyingi et al., 2010), Miombo Forest Reserves (Gonçalves et al., 2017; Jew et al., 2016), Ruvu South Forest Reserve (Mligo, 2018), Nongeni Forest Reserve (Kacholi, 2019), Taita Hills (Wekesa et al., 2019) and Kitui woodlands (Kiruki et al., 2017). It is also still higher and compares well above with the diversity results from studies in other East African Reserve such as Mabira (Weldemariam et al. 2017) and Southern Rangelands Forests of Kenya (Jawuoro et al., 2017).

Since a reserve with a diversity value (H') greater than two (H’ ≥ 2) can be regarded as highly diverse in terms of species (Demies et al., 2019; Ifo et al., 2016), it implies that Agoro-Agu Central Forest Reserve with a diversity of 3.40 harbours rich tree diversity and high species richness. The reason for higher diversity values in the present study may be due to the protected status and a wider range of geographic factors like altitude, aspect, and productive soil (Bhat et al., 2020). Subsequently, more conservation efforts are urgently needed to buffer such a reserve from further degradation and habitat loss.

According to Heywood (2019), conservation and protection efforts should be prioritised in areas experiencing a high rate of habitat loss such as Agoro-Agu Central Forest Reserve. This is expected to enhance the natural ecological restoration and regeneration of species at risks of local extinction in the degraded part of the reserve. One such effort may involve establishment of buffer zones in order to help conserve species richness and diversity; and also to regulate the utilization of tree resources by local dwellers (Siraj et al., 2018). There is also a need to enforce the provision of environmental awareness in the local communities on the importance of forests and build-up a “we feel” for the communities, which will actually promote responsible management, protection, utilization and conservation of such species (Kacholi, 2019).

Tree species evenness

The general tree species evenness as a measure of equitability of species distribution in Agoro-Agu CFR is 0.80. This is a bit higher than that of the degraded part (0.52). This implies that up to 80% of the tree species are fairly and evenly distributed in the intact part of the reserve; an indication that every encountered species was distributed evenly within the plant community in the intact part of the forest (Mekonen et al., 2015). According to Ifo et al. (2016), such high a value of species evenness can be attributed to less competition for space among tree species in intact part of the reserve.

Along topopositions, maximum value of species evenness of 0.70 is witnessed in the mid-slope and least (0.50) in the ridge top (Table 6). This is probably caused by favourable environmental conditions in the mid slope as oppose to harsher environmental conditions (shallower soils, strong winds, low moisture) that usually characterize the ridge top. The existence of such extreme conditions is likely to affect the distribution of species in such a ridge top with limited space due to rock outcrops (Moradi et al., 2020). However, given the recent rise in population for returnees/influx of South Sudan refugees and the heavy dependence of people on the forests for food, fuel and construction materials, future planned development should consider how additional human pressure could impact long-term sustainability of the region.

On the other hand, the fact that parts of the reserve largely left intact during LRA and SPLA wars had high species diversity is encouraging. Accordingly these findings should be used to boost the creation of a National Park to protect key vegetation types and their associated biodiversity in Agoro-Agu and neighbouring forest reserves (Corrigan et al., 2018). Finally, by the refugees leaving the encroach part of the reserves and getting settled outside Agoro-Agu Central Forest Reserve, is a positive sign that a reduction in population pressure can allow for the recovery of forests in this area (Watson et al., 2018); potentially paving the way for a trans-boundary park with related conservation benefits (Trogisch and Fletcher, 2020; Pouya and Pouya, 2018) between Uganda and South Sudan.

In some cases, natural regeneration is associated with rural outmigration (returnees) or remittance economies. Since reestablishing native forest cover does not have to require mass exodus of families and decline of rural livelihoods or traditions, new ways of thinking about how natural regeneration (coupled with other solutions), may promote a rural resurgence where communities and local economies thrive along with expansion of native forests should be taken up by concerned authorities. It should, however be noted that, one challenge for policy initiatives that promote natural regeneration is to address the social costs and drivers of rural outmigration. This is so, because, enhancing natural regeneration of native forests is not a viable option for forest restoration if these changes fail to provide benefits for rural residents and forests are short-lived (Chazdon and Brancalion, 2019).

Subsequently, in the new era of restoration, rural livelihoods should be re-envisioned through new opportunities created by growing native forests and trees in agricultural landscapes. For example, community based rural development projects should be implemented with the support of rural organizations and decision makers at local and regional levels (Hissa et al., 2019). This can make rural communities become stewards of community-managed forests that provide local, regional and global benefits. When done, this can promote rural resurgence based on proactive and integrated land management and landscape-scale restoration, where forests and new generations of people have room to grow and prosper together (Chazdon et al., 2020).

The outlined research issues emphasize that understanding the relationship between armed conflicts and land-change will require interdisciplinary research efforts, bringing together specialists from forestry, agricultural, geographical and environmental sciences; in addition to political sciences, and anthropology. It is unlikely that any research discipline alone will be able to uncover and delineate the causal linkages between armed conflict and biodiversity conservation. This implies that working together should be beneficial to improving our understanding of the potential for scientific and conservation engagement to mitigate negative biodiversity impacts in war zones, and the importance of the postwar period for incorporating biodiversity priorities into reconstruction and recovery efforts (Hanson, 2018).

Conclusion

The tree composition consisting of mixed species with indicator species for both savannah woodlands (*C. molle, G. mollis*, *A. grandibracteata* and *T. glaucescens)* and Afromontane/medium altitude tree species (*Podocarpus* spp.*, L. trichilioides* (African Walnut) and *L. swynnertonii*) is an indication that Agoro-Agu Central Forest Reserve is an enriched forest reserve with a mixture of medium altitude Afromontane and savannah woodland trees.

The absence of trees species such as *Podocarpus* spp., *Strombosia scheffleri*, *L. swynnertonii, M. bagshawei*, *P. fulva, P. mildbraedii, Hagenia abyssinica*, *A. africana*, and *L. trichiloides*, *S. longipedunculata* is an sign of low regeneration potential of such species in the intact part as oppose to the degraded part of the reserve. This could probably be attributed to either an unidentified threats or loss of adult seeding trees and change in species representation which after anthropogenic disturbance is dominated by pioneer species.

The presence of locally threatened species like *Podocarpus* spp. and *S. scheffleri*; and internationally threatened species like *L. swynnertonii* and *L. trichilioides* display the uniqueness of Agoro-Agu Central Forest Reserve and its potential as biodiversity hotspot for conservation.

The development and changes of floristic composition and diversity of plant seedlings and saplings during early stages of secondary succession process could have been mostly influenced by secondary succession processes and fallow period in various ages of secondary forests in the intact and degraded parts respectively. Such information on the composition and diversity of different species are useful for predicting future trends in the vegetation succession, especially on secondary succession of degraded parts; and ought to be ascertained.

Understanding the composition and diversity of plant regeneration at early stages of secondary succession on the degraded parts also generates useful information for enhancing biodiversity conservation, and social and economic values for future forest.

Recommendations

The total absence of *P. latifolia, S. scheffleri*, *L. swynnertonii*, *M. bagshawei*, *P. fulva, P. mildbraedii* and *H. abyssinica* from the degraded part of the reserve raises issues of conservation concern and a need for long term monitoring or research on the life-cycle, propagation (both sexual and asexual) methods and regeneration potentials of these woody species in order to understand their population dynamics.

Considerable management options that limits continuous degradations such as enforcement of environmental laws, tree enrichment planting and *ex-situ* conservation should be undertaken to restore particularly the status of trees in the degraded part of the reserve.

Agoro-Agu Central Forest Reserve with a diversity of 3.40 harbours rich tree diversity and high species richness warranting more conservation efforts aimed at buffering such a reserve from further degradation and habitat loss. Ideally, conservation and protection efforts should be prioritised in areas experiencing a high rate of habitat loss in order to augment the natural ecological restoration and regeneration of species at risks of local extinction in the degraded part of the reserve. One of such efforts may involve establishment of buffer zones in order to help conserve species richness and diversity; and also to regulate the utilization of tree resources by surrounding local dwellers.

Agoro-Agu forest landscape is huge with several forest tenures including central forest reserves, community forests, local forest reserves that should be conserved and sustainably managed with an immense potential for scale up of Community Forest Management (CFM) within its landscape.

CONFLICT OF INTERESTS

The authors declare that there has been no conflicting/ competing interest, financial or personal relationships in relation to this manuscript that may have inappropriately influenced the writing and publication of this article.

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Assessment of the diversity and abundance of tree species in Afe Babalola University, Ado- Ekiti, Ekiti State, Nigeria

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In this study, an assessment of trees diversity and abundance in the Afe Babalola University Ado Ekiti, Ado Ekiti, Nigeria was carried out. Stratified sampling method was employed. The University was divided into four strata for adequate sampling (Stratum A, B, C, D). The results revealed a total of 816 individual trees of 21 tree species belonging to 16 families. The family Aracaceae has the highest number of species (3 (14%) species), The families of Caesalpiniaceae, Combretaceae, Verbenaceae had 2 species each, while other families (Anacardiaceae, Annonaceae, Apocynaceae, Araucariaceae, Caricaceae, Euphorbiaceae, Malvaceae, Meliaceae, Moraceae, Myrtaceae, Papilonaceae, Pinaceae families) had only one specie each respectively. The family Verbanaceae has the highest number of individual tree flora while Moraceae has the least with 1 tree stand in the study area. *Gmelina arborea* was the most frequently occurring tree species with a total of 472 (58%) individuals while *Ficus benjamina* was the least frequently occurring tree species with only 1 (0.12%) tree individual in the study area. This is suspected to be as a result of their poor establishment, thus special attention needs to be applied both to intensified efforts on planting as well as conserving the available species to avoid their extinction.

Key words: Abundance, tree species, diversity, frequency, planting.

INTRODUCTION

The relevance of trees cannot be overemphasized. There are several uses of trees to man. Trees are determinants of a forest ecosystem as they considerably influence forest microclimate such as (available light, wetness, temperature). In Nigeria, (Raji and Babalola, 2018; Ihenyen et al., 2009; Keay, 1989) reported there are about 560 species of trees. Trees give oxygen, store carbon dioxide hence helps slow the rate of global warming, stabilize the soil and give life to the world's wildlife (Dwyer et al., 1992; Berman et al., 2012; Bratman et al., 2015; Lohr and Pearson-Mims, 2006; Mayer et al., 2009). They also provide man with materials for tools and shelter. They reduce wind speeds and cool the air as they lose moisture and reflect heat upwards from their leaves. It is estimated that trees can reduce the temperature in a city by up to 7ºC (Omoro et al., 2010). Trees also prevent flooding and soil erosion. Trees, apart from forming the major structural and functional basis of

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tropical rainforest also serve the functions of carbon sequestration, watersheds, provide shades and homes to many life forms and above all, act as purifier to the ecosystem Fuwape and Onyekwelu (2011) and (Singh, 2002). A university campus should be promoted as a model environment for sustainable development. Trees in academic institutions located in cities are part of forests resources and the trees can be used as its defining features. The presence of trees defines the landscape by their beauty and, in particular long-lived species, which can endure periodic reproductive features without direct negative demographic consequences (Suratman, 2012; Ashman et al., 2004). A higher number of tree species increases the number of ecologically niches as well as the number of associated species (Agbelade et al., 2016a; Adekunle et al., 2013; Kanowski et al., 2003; Wunderle, 1997).

Planting of trees are deliberately carried out in academic environment for reasons which including aesthetic and other environmental services (Olajuyigbe and Akwarandu 2019; Egunjobi, 1989; Babalola 2010; Martens et al. 2011).

However, trees have undergone different levels of disturbance due to unprecedented increase in human population which have led to cutting of trees for firewood collection, charcoal production, and infrastructural developments (Omoro et al., 2010).

To protect trees from declining, it is essential to examine the current status of species diversity, composition and abundance this will provide guidance for their management and valuable reference for assessment as well as improve knowledge in the identification of ecologically useful species. Therefore, the main objective of this study is to assess tree diversity and abundance in Afe Babalola University, Ado-Ekiti campus with the view to providing baseline information useful to development and conservation of the tree species in the study area. Thus, such information will be useful for tree managers seeking to maximize species diversity and the environmental benefits provided by trees.

MATERIALS AND METHODS

The study was conducted in the campus of Afe Babalola University, Ado-Ekiti, Ekiti State, Nigeria. Afe Babalola University is geographically located in Ado-Ekiti (Latitude 7º40'N and Longitude 5º18'E). Ado-Ekiti has two climatic seasons–a rainy season and a dry season, the rainy season lasts for about eight months and the dry season for about four months. The annual rainfall is about 1150mm.

Survey of trees species on campus

A stratified sampling technique was used in this study, the entire Afe Babalola University Campus was divided into four strata and each stratum was further sub divided into sub-strata. All the trees within each of the sub-stratum were counted and identified to species level with their scientific authentication, local and family names with the assistance of the curator in the Herbarium unit of the Department of Plant Science and Biotechnology as well as with the aids of tree identification guide books, including Tropical Tree Crops (Okpeke, 1987), Trees of Nigeria (Keay, 1989), Flora of West Tropical Africa (Hutchinson and Dalziel, 1968) and Useful Plant of West Tropical Africa (Burkill, 1985, 1995, 1997, 1994, 2000). Voucher specimens of the identified trees species were equally prepared and deposited at the herbarium unit. The names of the trees were recorded for all the strata and sub-strata and its number of occurrence were determined. Frequency of occurrence, relative frequency, Shannon-Weiner index, and Simpson diversity index and species evenness was calculated for each stratum, sub-strata and for the entire sampled area.

Data analysis

The data collected during the tree survey were analyzed and calculated using different indices such as Shannon and Wiener, Simpson diversity and species evenness. Statistical analysis was carried out using Statistical Package for the Social Sciences (SPSS 20.0).

RESULTS AND DISCUSSION

This study described the taxonomy, diversity, and environmental relevance of tree flora in Afe Babalola University, Ado-Ekiti, Ekiti State. Diverse tree species were identified and collected at this higher institution of learning. Field observation revealed a total of 816 tree flora spread across 21 tree species belonging to 16 families in this study area (Table 1). The results obtained revealed that the abundance and diversity of trees in the academic area of this University were high. This may be attributed to provision of an aesthetic environment and beautification of the landscape for students, staff and other inhabitants of the University. The study revealed that the family Arecaceae has the highest number of 3 (14 %) species (Table 1). These results corroborate the assertion of Ogwu et al. (2016) on the abundance and diversity of trees in University of Benin. This family mainly occur in tropical and subtropical regions, with most genus and species found in Asia, Indonesia, and the Americas.

Also, the predominance of this family may be as a result of its great economic importance. The poor establishment of some trees under the families (Moraceae, Papilonaceae), could be attributed to anthropogenic activities that both endangered, unsettled and negatively target these families. This was supported by the reports of Wardle et al. (2004), who recorded that anthropogenic activities affected the establishment of certain families of trees and placed them at more risk of extinction if not properly and intentionally conserved. Other members of the family in the campus include *Cocos nucifera*, *Acrocomia aculeata*, *Phoenix dactylifera* and *Mauritia flexuosa.*

The Arecaceae family was closely followed by the Verbenaceae and Combretaceae families. These were well known for their economic and medicinal purposes as

Table 1. Demography of trees sampled in ABUAD **(%).**

Families	No. of tree species	Total no. of tree individuals (%)
Anacardiaceae	1	0.61
Annonaceae	1	3.58
Apocynaceae	1	1.36
Araucariaceae	1	2.34
Arecaceae	3	9.00
Caesalpiniaceae	2	1.85
Caricaceae	1	0.37
Combretaceae	2	3.08
Euphorbiaceae	1	4.56
Malvaceae	1	0.99
Meliaceae	1	2.34
Moraceae	1	0.12
Myrtaceae	1	5.30
Papilonaceae	1	0.25
Pinaceae	1	0.62
Verbenaceae	2	63.63
Total	21	100

Table 2. Occurrence of the identified tree species in the study area.

S/N	Botanica Name	Family	Common name	local name
1	*Araucaria cunninghamii (Aiton)*	Araucariaceae	Colonial pine, Queensland pine	Igi Oyinbo
2	*Azadirachta indica (A. Juss.)*	Combretaceae	neem	Dongoyaro
3	*Carica papaya (L.)*	Caricaceae	pawpaw	Ibepe
4	*Cassia fistula (L.)*	Caesalpiniaceae	Golden shower	Igi gbigbe
5	*Cocos nucifera (L.)*	Arecaceae	coconut tree	Igi Àgbọn
6	*Dalbergia latifolia (Roxb).*	Papilionaceae	Indian rose wood	Igi gbigbe
7	*Delonix regia (Hook Raf).*	Caesalpiniaceae	Flame of the forest	Eko omode
8	*Elaeis guinensis (Jacy)*	Arecaceae	african oil Palm	Igi ọ̀pẹ
9	*Eucalyptus Camaldulensis (Dehnh)*	Myrtaceae	river red gum	Igi igbo
10	*Ficus benjamina (L.)*	Moracaceae	weeping fig	Igi ọpọtọ
11	*Gmelina arborea (Roxb).*	Verbenaceace	Bleech wood,goomar teak	Gamhar
12	*Hibiscus rosa (sinensis L.)*	Malvaceae	Chinese hibiscus	Ododoabiscosi
13	*Hura crepitans (L).*	Euphrobiaceae	possum wood, jabillo	Egungun Odo
14	*Mangifera indica (L).*	Anacardiaceae	mango	Mangoro
15	*Morinda lucida (Benth).*	Pinaceae	pinus taxa	Igi pini
16	*Polyalthia longifolla (Lam.)*	Annonaceae	false ashoka/ buddha tree	Igi olopa
17	*Plumeria alba (L.)*	Apocynaceae	dok champa	Fragipani
18	*Roystonea regia (kunth 0. F. Cook)*	Arecaceae	cuban royal palm	Igi ope Oba
19	*Terminalia catappa (L).*	Combretaceae	Country almond	Furutu
20	*Terminalia ivorensis (A Chev).*	Combretaceae	black afara/ivory coast almond	Afara
21	*Tectona grandis (L.F)*	Meliaceae	Teak	Igi opo ina

earlier asserted by Kayode (2008) that *Gmelina arborea* (a member of the Verbenaceae family) was one of the plants used for the construction purposes as well used in the treatment of sexually transmitted diseases in Ekiti State Nigeria. It was equally observed that out of the 21 tree species encountered in the study area, (Table 2 and 3) some were present in all the strata of the campus. For instance, *Hura crepitans*, *Cocos nucifera*, *G. arborea*, and *Tectona grandis* were found in all the strata. The factor responsible for the abundance of these

Table 3. Occurrence of identified tree species in the study area.

S/N	Tree species	Occurrence of tree species / stratum			
		A	B	C	D
1	*Araucaria cunninghamii*	-	+	+	-
2	*Azadirachta indica*	-	+	+	+
3	*Carica papaya*	+	-	+	-
4	*Cassia fistula*	+	-	+	+
5	*Cocos nucifera*	+	+	+	+
6	*Dalbergia latifolia*	+	-	-	-
7	*Delonix regia*	-	+	-	-
8	*Elaeis guinensis*	+	+	+	-
9	*Eucalyptus camaldulensis*	+	-	+	-
10	*Ficus benjamina*	-	+	-	-
11	*Gmelina arborea*	+	+	+	+
12	*Hibiscus rosa*	-	+	+	+
13	*Hura crepitans*	+	+	+	+
14	*Mangifera indica*	+	+	-	-
15	*Morinda lucida*	-	+	-	-
16	*Polyalthia longifolia*	+	+	-	+
17	*Plumeria alba*	-	+	-	-
18	*Roystonea regia*	+	-	+	+
19	*Terminalia catappa*	-	-	+	-
20	*Terminalia ivorensis*	+	-	-	+
21	*Tectona grandis*	+	+	+	+

species might be their perceived economic importance or more probably the ease of establishment.

It was also observed that the *G. arborea* has the highest frequency of occurrence while *C. papaya*, *F. benjamina* have the least. The availability of *G. arborea* in all the divisions of the study area was found to constitute the most frequently encountered tree in the campus of ABUAD, having a total of 472 (58.20%) individual trees (Table 4). One of the suspected reasons for this predominance is the intentional cultivation of the species for its industrial uses. *G. arborea* is economically important in its use in constructions, furniture, carriages, sport, prosthetics and musical instruments.

Similarly, the results of relative frequency, relative diversity and relative abundance of the tree species surveyed in strata A, B, C and D were observed in the Tables 5 to 9 respectively. *G. arborea* has the highest relative frequency in all the four strata with 60.75 in strata A, 36.67 in strata B, 38.10 in strata C, and 60.18 in strata D. This is followed by *E. camaldulensis*, in strata A with 8.35 relative frequencies, *T. grandis* in strata B with 10.67 relative frequencies, *A. cunninghamii* in strata C with 15.24 relative frequencies, and *C. nucifera* in strata D with relative frequency of 8.85. It was also observed that *G. arborea* has the highest relative density in all the four strata, with 72.16 in strata A, 37.00 in strata B, 37.25 in strata C, and 59.41 in strata D. It was followed by *E. camaldulensis* in strata A with a relative density of 8.24, *T. grandis* in strata B with 11.00 relative density, *A. cunninghamii* in strata C with 14.71 relative density and *C. nucifera* in strata D with 9.00 relative density. Similarly, *G. arborea* has the highest relative abundance in all the four strata, with a relative abundance 0.72, 0.37, 0.37, 0.59 in strata A, B, C and D respectively, followed by *E. camaldulensis* with relative abundance of 0.08 in strata A, Tectona grandis with relative abundance of 0.11 in strata B, *A. cunninghamii* with relative abundance of 0.15 in strata C while *C. nucifera* with relative abundance of 0.09 in strata D.

Most of the trees planted in ABUAD were exotic breed, information from the respondents revealed that the residents of the campus could not ascertain the reason for this, however, the planting of exotic breeds forms a trend as reported by Alfred et al. (2014) who found that exotic species flourished and grew more rapidly from the period of emergence to the maturity of the plants. *G. arborea is* an economic plant that was used to construct various furniture works. Also, *G. arborea* tree was used to carve out a lion throne, the last surviving of the eight royal thrones of myañmar, now in the national museum of Yangon Ma (Thanegi, 2017). Amazingly, a few tree species such as *C. papaya*, *F. benjamina* and a few others however had a total count of less than five stands in the whole of the study area, the reason for this is suspected to be their poor establishment, thus special attention needs to be applied both to intensified

Table 4. Frequency of occurrence of the identified tree species in ABUAD campus.

Rank	Tree species	Number of Individual (%)
1.	*Gmelina arborea*	58.20
2.	*Tectona grandis*	5.43
3.	*Eucalyptus camadulensis*	5.30
4.	*Hura crepitans*	4.56
5.	*Polyathia Longifera*	3.08
5.	*Cocos nucifera*	3.08
5.	*Elaesis guinensis*	3.08
8.	*Roystonea regia*	2.84
9.	*Araucaria cunninghamii*	2.34
9.	*Azadirachta indica*	2.34
11.	*Terminalia ivorensis*	2.22
12.	*Flumeria alba*	1.36
13.	*Cassia fistula*	1.11
14.	*Hibiscus rosa*	0.99
15.	*Terminalia catappa*	0.86
16	*Delonix regia*	0.74
17	*Pinus amygdalus*	0.62
18	*Maggifera Indica*	0.62
19	*Carica papaya*	0.37
20	*Dalbergia latifolia*	0.25
21	*Ficus benjamina*	0.12

Table 5. Indices of abundance in strata A (roadside).

Trees	RF	RD	Pi
Gmelina arborea	69.75	72.16	0.72
Eucalyptus camaldulensis	8.35	8.24	0.08
Tectona grandis	5.42	5.15	0.05
Elaeis guinensis	3.16	3.09	0.03
Polyathia longifolia	3.38	3.09	0.03
Cassia fistula	2.03	2.06	0.02
Terminalia ivorensis	2.03	2.06	0.02
Roystonea regia	2.48	2.06	0.02
Hura crepitans	1.35	1.03	0.01
Mangifera indica	0.67	1.03	0.01
Carica papaya	0.45	0.00	0.00
Dalbergia latifolia	0.45	0.00	0.00
Cocos nucifera	0.45	0.00	0.00

Keys: Frequency (F), Relative frequency (RF), Density (D), Relative density (RD), Relative abundance (PI).

efforts on planting as well as conserving the available species to avoid extinction of the species. The study also revealed the poor establishment of some trees under the families (Moraceae, Papilonaceae), this could also be attributed to anthropogenic activities that unsettle and negatively targets these families, this school of thought agrees with Wardle et al. (2004) who also recorded that anthropogenic activities affected the establishment of certain families of trees and placed them at more risk of extinction if not properly and intentionally conserved.

Table 6. Indices of abundance in strata B (car pack).

Trees	RF	RD	Pi
Gmelina arborea	36.67	37.00	0.37
Tectona grandis	10.67	11.00	0.11
Hura crepitans	10.00	10.00	0.10
Polyalthia oliveri Engl.	8.00	8.00	0.08
Plumeria spp.	7.33	7.00	0.07
Cocos nucifera	5.30	5.00	0.05
Azadirachta indica	4.67	5.00	0.05
Elaelis guinensis	5.33	5.00	0.05
Delonix regia	4.00	4.00	0.04
pinus amygdalis	3.33	3.00	0.03
Araucaria cunninghamii	2.00	2.00	0.02
Ficus benjamina	0.67	1.00	0.01
Magnifera indica	1.33	1.00	0.01
Hibiscus rosa	0.67	1.00	0.01

Keys; Frequency (F), Relative frequency (RF), Density (D), Relative density (RD), Relative abundance (PI).

Table 7. Indices of Abundance in Strata C. (Office area).

Trees	RF	RD	Pi
Ginelina arborea	38.10	37.25	0.37
Araucaria cunninghamii	15.24	14.71	0.15
hura crepitans	8.60	8.82	0.09
Restonea regia	7.62	7.84	0.08
Terminalia catappa	6.67	6.90	0.07
Azadirachta indica	5.71	5.88	0.06
Hibiscus rosa	4.76	4.90	0.05
cocos nucifera	4.76	4.90	0.05
Tectona grandis	2.86	2.94	0.03
Elaeis guinensis	2.86	2.94	0.03
Eucalyptus Ccamaldulensis	1.90	1.96	0.02
carica papaya	0.95	0.98	0.01

Keys; Frequency (F), Relative Frequency (RF), Density (D), Relative Density (RD), Relative abundance (PI).

Conclusion

This study found out that most of the trees planted in the University campus were exotic breed. The distribution of trees in the study area could be based on specific needs of the University system as well as its relevance to the resident living on campus (such as noise attenuation, landscaping and beautification, cooling). The relevance of trees is very important as it encourages all the beneficiaries of services of the trees to become involved in preservation and conservation of trees.

However, special attention must be paid to trees that are not easily established such as *F. benjamina* and others to prevent their extinction. The study also revealed the poor establishment of some trees such as *F. benjamina,* and *D. latifolia* under the families (Moracaceae and Papilonaceae respectively) this could be attributed to anthropogenic activities that unsettle and negatively targets these families, this is in accordance with the work of Wardle et al. (2004) who reported that anthropogenic activities affected the establishment of certain families of trees and placed them at more risk of extinction if not properly and intentionally managed and conserved.

Therefore, the tree compositions on Afe Babalola University Campus could be described as relatively available and well diverse. However, there is need to

Table 8. Indices of abundance for strata D.

Trees	RF	RD	Pi
Gmelina arborea	60.18	59.41	0.59
Cocos nucifera	8.85	9.00	0.09
Terminalia ivorensis	7.06	8.00	0.08
Hura crepitans	6.19	6.00	0.06
Azadirachta indica	5.31	5.00	0.05
Roystonea regia	3.54	4.00	0.04
Eucalyptus camaldulensis	3.54	4.00	0.04
Hibiscus rosa	1.76	2.00	0.02
Polyalthia longifolia	1.76	2.00	0.02
Tectona grandis	0.88	1.00	0.01

Keys; Frequency (F),Relative Frequency (RF),Density(D),Relative Density (RD), Relative abundance (PI).

Table 9. Indices of similarities in the occurrence of trees in ABUAD campus.

Strata	Similarity indices				
	IS	Sj	So	Ss_D	Sas
strata A-B	51.85	0.21	0.77	0.41	0.50
Strata A-C	64.00	0.24	0.86	0.46	0.47
Strata A-D	69.57	0.26	0.86	0.46	0.47
Strata B-C	61.54	0.24	0.86	0.46	0.47
Strata B-D	58.33	0.23	0.78	0.41	0.50
Strata C-D	63.64	0.27	0.86	0.46	0.47

Keys: So: Ochio index, SsD: Sorensen dice index, Sas: assymetrical similarities, IS: index of similarity. SJ: jaccard index.

properly and adequately handle and conserve the trees so as to ensure its continuous availability as the need arises.

CONFLICTS OF INTERESTS

The authors have not declared any conflicts of interests.

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Ethnobotanical study of the coconut palm in the Coastal Zone of Benin

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The coconut palm (*Cocos nucifera* L.), also known as "tree of life", is widely distributed across the Coastal Zone in Benin, where its cultivation is most important. Using participatory research appraisal tools and techniques, a survey was conducted in this zone to assess the diversity of coconut ecotypes, associated endogenous knowledge and their utilization. Nineteen villages randomly selected, and comprising seven ethnic groups were surveyed. Ten different vernacular names were recorded across the study sites. The local diversity is very low. In particular, the number of ecotypes varied from 1 to 5. Moreover, recorded ecotypes were grouped in three categories including the *tall ecotype* known as endogenous ecotype, *dwarf ecotypes* known as introduced ecotypes and *medium-sized ecotypes* resulting from the crossing between the first two. The most important preference criteria used by producers were productivity (43%) followed by sweet taste (33%) and quantity of water (33%). Apart from being used for food, the species is also used for construction, traditional medicine, and traditional ceremonies. This study provides important information on the genetic resources of coconut palm while highlighting the socio-economic importance of the species in the Coastal Zone of Benin.

Key words: Endogenous knowledge, diversity, *Cocos nucifera*, palm uses, preference criteria, Benin.

INTRODUCTION

Coconut palm, *Cocos nucifera* L. (2n = 2X = 32), the sole species of the genus *Cocos*, is a diploid perennial oilseed plant, belonging to the Arecaceae family (Batugal et al. 2005). Coconut tree is the most widespread cultivated tree in the world and is found in all intertropical regions (Nayar, 2017; Sobral et al., 2018). Southeast Asia is

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reported to be its domestication center with the greatest genetic diversity (Perera et al., 2016). It was spread through human migration and travel, first in India, then in East and West Africa and then throughout the intertropical zone (Gunn et al., 2011; Ribeiro et al., 2013). The species is able to adapt to all types of soils. Coconut palm is easily grown on sandy soils in areas with low rainfall and tolerates high salinity compared to many other crops. It is a multi-purpose tree whose parts are used by humans for food, arts and crafts, housing, and traditional medicine (Ahuja et al., 2014). Although its importance in the global market is recent, the use of coconut palm by indigenous populations has a long history. Ten countries together account for 90% of global production (FAO, 2009), and the largest producing countries in Africa are Mozambique, Tanzania, Ghana and Ivory Coast. In addition to these, there are other small producer countries including Benin. Various products are obtained from the fruit. These are coconut water, coconut milk, coconut oil and fibers which are also used in the textile industry (Batugal et al., 2009). Coconut water obtained from immature nuts is a refreshing exotic drink consumed by many people. It also has dietary and medicinal properties that are undoubtedly linked to its biochemical composition making it a good rehydration drink (Prades, 2011). The main constituents are soluble sugars, proteins, minerals, salts, vitamin C and vitamins B. In Benin, coconuts are consumed fresh as coconut juice, fresh almonds, coconut milk and coconut cream. They are also exploited for the production of coconut oil. Cultivation of coconut palm provides through its sale significant income for producers and traders.

The cultivation of coconut palm in Benin dates back more than a century and has spread all over the coastal zone (Chaillard et al., 1983). However, there are concerns about the anarchic felling of coconut trees (Report of Council of Ministers (N°38/2018/PR/SGG/CM/OJ/ORD), which could reduce the species' diversity. In order to avoid disruption and loss of local diversity, Benin Government prohibited the slaughter of coconut palms without prior authorization (https://sgg.gouv.bj/cm/2018-12-12/). Till date little is known about the cultivated material and its state of local diversity remains unknown. Previous studies focused on agromorphological characterization of four ecotypes, and on the pest of coconut fruits (Negloh et al., 2011). While these studies have provided important information, they did not cover the whole Coastal Zone of Benin. In addition, we have little endogenous knowledge about the species cultivation, the production constraints, folk nomenclature, and gender role in the value chain of coconut. To fill this gap, the present study did a very large survey across areas of production of coconut. The study aims to document information related to producers, the level of diversity, the number of cultivated ecotypes, endogenous knowledge on cultivation, production constraints, folk nomenclature, traditional uses of coconut, and gender role in the value chain of coconut. Findings from this research are essential to assist the conservation strategy and promotion of coconut cultivation in Benin.

MATERIALS AND METHODS

Study area

The present study was carried out in the entire Coastal Zone of Benin (Figure 1). It is located between 1°35' and 7°30' East and between 6°20 and 7°30 North; it covers approximately 12,000 Km^2, that is, 10.5% of the total land surface of Benin (Teka et al., 2019). The Coastal Zone of Benin includes four administrative departments namely Ouémé, Littoral, Atlantique and Mono. The climate is of equatorial type with two rainy (from April to July, and from October to November) and two dry seasons (from August to September, and from December to March). The mean annual rainfall is 1200 mm (Zanvo et al., 2021). The main ethnic groups are Fon, Xwla, Pédah, Mina, Adja, Wémè, Yorouba (Teka et al. 2019).

Sampling and data collection

Prior to ethnobotanical survey, data on coconut cultivation and villages of production were gathered from the "Agence Territoriale de Développement Agricole" and through a preliminary survey of coconut sellers. A total of 19 villages where the species was cultivated were randomly selected and considered for the study in the districts of Sèmè-Podji, Ouidah, Abomey-Calavi, Cotonou, Comè, Bopa, and Grand-Popo. Figure 1 shows distribution of villages and area surveyed. The sample size of the study population was determined according to the binomial distribution formula (Dagnelie, 1998): $N= U^2_{1-\alpha/2} * p(1-p)/d^2$. In this formula, N = sample size; is the value of the random normal variable; for a probability value of $\alpha = 0.05$; $U^2= 1.96$; p is the proportion of individuals who know and use coconut palm products and taken as p = 0.5; d is the marginal error set at 7%. As a result, a total of 173 persons were surveyed. In each village, the village chief / or the head of the producers' association was involved in the identification of persons having an activity related to the coconut palm such as producers, sellers, and craftsmen.

Data were collected using participatory research appraisal tools and techniques such as group discussion, direct observation, individual interviews using a questionnaire and field visit (Adéoti et al., 2010). The questionnaire was edited using the KoBoCollect v1.30.1 collection tools. Data collected were the vernacular names of the ecotypes grown, ecotype diversity, uses (food, medicine, construction, cultural values, etc.), criteria for preference of a given ecotype, and constraints related to the species cultivation.

Statistical analysis method

All analyses and graphics were done in the R 3.5.1 software environment (R Core Team, 2018). Socio-demographic characteristics of the informants were described using descriptive statistics.

Socio-economic factors (sex, age category, instruction level, and ethnic group) determining the use of coconut were tested with a generalized linear models (GLM) of the Poisson family and extensions in the package MASS (Venables and Ripley, 2002). Barplots of means and standard errors were constructed in the package ggplot2 (Wickham, 2010). Simple correspondence analysis (CA) was used to describe the relationships between the preference criteria and ecotypes.

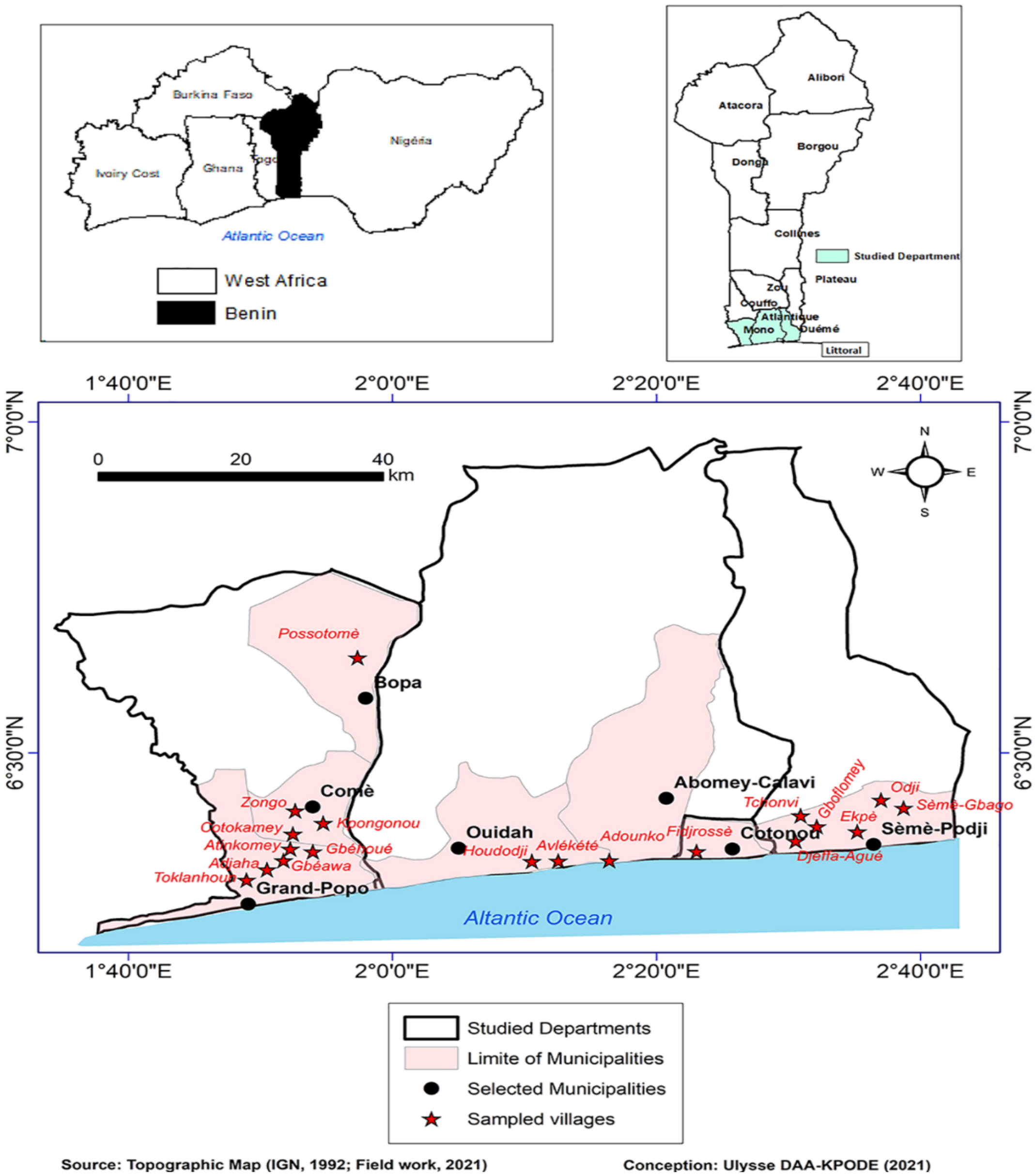

Figure 1. Graphical representation of study area.

RESULTS

Socio-demographic characteristics of informants

About one third (34.68%) of the informants were women and 65.32% were men. Among these, 69.36% were young (aged from 18 to 29 years), 27.1% were adults (aged 30 to 59 years) and 3.47% were old persons (aged above 60 years). Most of the informants had low educational level; 24,28% have reached primary school, 38,15% secondary school and 19,65 % have never been to school. Among the ethnic groups investigated, the most representative is the "goun" ethnic group (40.46%), followed by "fon"(24.86%), Xwla (16.18%), "Adja" (9.83%), "Yoruba" (4.62%) and "Peda" (4.05%). Across all surveyed villages, production of coconut is combined with other activities like fishing. Farming is the main activity. During the first 5 years, coconut palm cultivation is associated with other crops such as market gardening, namely vegetables.

Diversity and origins of cultivated ecotypes

The number of cultivated ecotypes varies among villages. Indeed, the number of ecotypes per village varied from 1

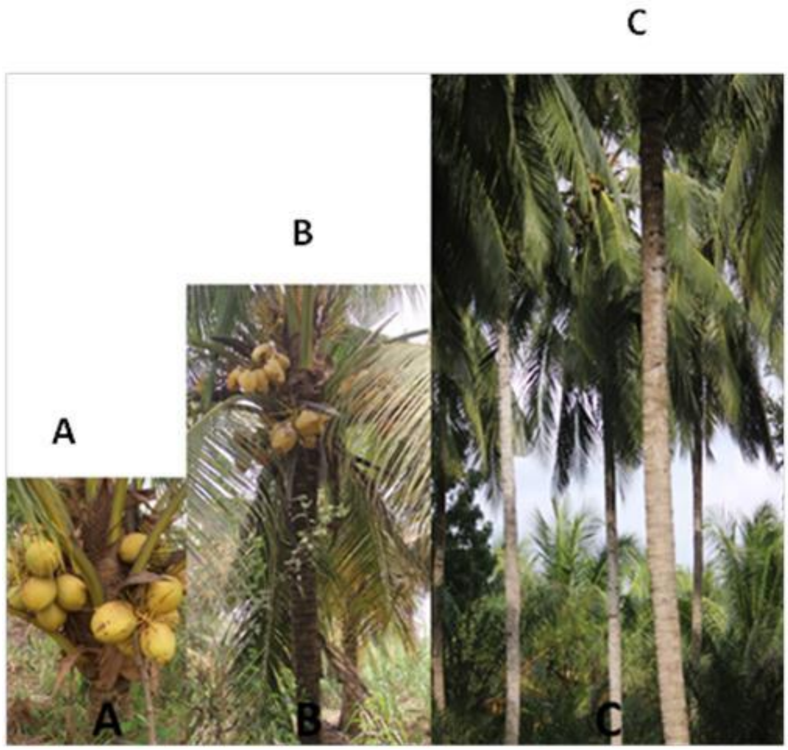

Figure 2: Ecotypes of coconut palm; (**A**) Dwarf ecotype; (**B**) Hybrid ecotype, medium size; (**C**) Tall ecotype.

to 5. The highest number of ecotypes (05) was observed at Fidjrossè in the municipality of Cotonou and the lowest number of ecotypes (01) was recorded at Kpongonou in the municipality of Comè. However, three main types of coconuts were observed and reported by producers. There are the dwarf ecotypes, the medium-sized ecotypes and the tall ecotypes (Figure 2). According to the producers, tall ecotypes are generally large and can reach 50 meters height. Tall ecotypes were considered by producers as indigenous across all villages. In addition, this coconut palm ecotype was found across all villages surveyed and was described as the first cultivated since more than a century and inherited from forefathers. The remaining ecotypes (medium-sized or dwarf ecotypes) were considered as introduced from other countries such as Ghana and Ivory Coast, or by researchers from the "Institut national de la recherche agronomique du Bénin (INRAB)" through the coconut program. These groups of coconuts were not found across all villages surveyed. There were mainly found in the district of Sèmè-Kpodji and differed from the ecotype so called endogenous by the fruit color and size, form of the fruit, shape of the trunk and the production cycle.

Folk taxonomy and vernacular names

According to the ethnic groups, there are diverse local names used to designate coconut. Producers and traders, use only one criterion for each ecotype to classify the existing diversity. Thus, generally, the selected criterion concerns the color of the fruit, the kernel, the water, the form of the fruit or the size of the fruit (large or small fruits) (Figure 3).

When no other trait could be associated with an ecotype, a generic local name was attributed to the coconut palm. Across the villages and ethnic groups surveyed, a total of ten (10) vernacular names were recorded. Coconut was designated by specific generic names which vary across ethnic groups. For example coconut palm is designated by "*Agon"* or "*Agounk*è" by Fon' ethnic group and ''*Agban''* or ''*Agbon*" by people belonging to Yoruba ethnic group. Moreover, the names ''*yovonain''*, ''*Gonnin''* are also used for coconut respectively by Adja and Xwla ethnic groups. Table 1 summarizes the local names recorded for different ecotypes and their meaning according to the ethnic group.

In general, a basic term "*Agon*" is found in most of the vernacular names recorded across ethnic groups. Very often, to name or describe such ecotype, people use different traits which refer to the origin or the main characteristics of the ecotype. Then, the generic name attributed by populations is mostly accompanied by a suffix to designate a distinctive aspect of plant or ecotype. For people belonging to Fon ethnic group, the

Figure 3. Varietal and morphological diversity of cultivated coconut.

Table 1. List of different vernacular names and their meaning.

Ecotype	Vernacular name	Ethnic group	Meaning	Main characteristics
Local (Tall coconut trees)	*Agon miton,*	Goun, Fon	Endogenous coconut	Local coconut ecotypes with large green fruit
	Agon vè,	Goun, Fon, Adja,	Red coconut	Orange-fruited local coconut ecotype before ripening
	Agon koun,	Goun, Fon, Adja,	Unknown	Local coconut ecotype with brown fruits before ripening
	Xwla gon	Xwla	Coconut palm cultivated by Xla ethnic group	Local coconut ecotypes with large green fruit
	Agban	Yorouba	Unknown	Local coconut ecotypes with large green fruit
Dwarf and Medium (Hybrids)	*Agon Hybridi,*	Goun, Fon	Hybrid coconut ecotype	Hybrid coconut tree with red fruits
	Agon Abidjanton,	Goun, Fon, Adja, Xwla	Coconut imported from Abidjan (Ivory Coast)	Hybrid coconut tree with large yellow fruits
	Sèmè gon	Goun, Fon	Coconut introduced by the INRAB under coconut program	Hybrid coconut tree with large green fruits
	Agon yovoton	Goun, Fon	White people coconut	Dwarf coconut palm
	Agon engraiton	Goun, Fon	Improved coconut	Hybrid coconut tree with large red fruits
	Coppa	Xwla, Pédah	Imported or improved coconut	Hybrid coconut tree with large green fruits and Dwarf coconut palm
	Agban ognibo	Yorouba	White people coconut	Hybrid coconut tree

Table 2. Names of the different parts of the coconut palm and derivatives according to ethnic groups.

Coconut palm and its derivatives	Goun	Fon	Yoruba	Cotafon	Adja	Pédah	Xwla
Coconut	*Agonkê, Agounkè*	*Agonkè, Agon*	*Agbon, Agban, Agboun*	*Agonkè, Agon*	*Yovonain*	*Agonkè, Agon*	*Gonnin*
Coconut palm	*Agonkêtin, Agounkètin*	*Agonketin, Agontin*	*Égui agbon, Igui Agban, Igui agboun*	*Agonketin, Agontin*	*Yovonaintchi,*	*Agonketin, Agontin*	*Gonnin Tin*
Coconut water	*Agonkêsin, Agounkèsin*	*Agonkesin, Agon sin*	*Omi agbon, Omi Agban, Omi agboun*	*Agonkesin, Agon sin*	*Yovonainchi*	*Agonkesin*	*Gonnin sin*
Coconut milk	-	*Agonkè si lè*	*Iyefou*		*Lait yovonintô*		
Coconut oil	*Agonkêmi, Agounkèmin*	*Agonkè mi, Agonmi*	*Épko agbon, Épko agboun*	*Agonkè mi, Agonmi*	*yovoninmi*	*Agonkè mi*	*Gonnin mi*

generic name "*Agon miton* "designates endogenous coconut. Similarly, "*Agon vè*" designates coconut with red or yellow fruits. Depending on the part of the plant, different vernacular names were also attributed. Sometimes, the same names "*Agontin*" or "*Agounkè tin*" designates coconut palm in Fon, Cotafon and Goun ethnic groups and illustrate the case of synonymy. In Adja and Xwla ethnic groups, coconut palm is called respectively "*Yovonaintchi*" and "*Gonnintin*". The common suffix "*tin*" and "*tchi*" used means tree. When considering coconut water, a prefix or suffix is often added to the basic term used according to the ethnic groups. For example, in Fon, Goun, Pédah and Cotafon a suffix "*sin*" is added to "Agon", and "*chi*" in Adja. A prefix "*omi*" is used in Yoruba and the coconut water is designated "*omi agbon*". Thus, to designate coconut water in Fon, Goun, Pédah and Cotafon, for example, one must add the suffix "*Sin"* which means water. Water is called "*Omi"* in Yoruba, and "*Chi"* in Adja. The different names are summarized in Table 2 according to each ethnic group. The names used to designate coconut milk in Yoruba, Fon and Adja are respectively "*Iyefou*", "*Agonkè si lè"*, and "*lè yovonintô"*.

Preference criteria

The preference criteria are essential in determining the choice and maintenance of ecotypes by producers. For coconut production and across the villages and ethnic groups surveyed, five preference criteria (productivity, that is, number of fruits per tree, quantity of water per coconut, availability, quality of the kernel, taste of the water and its aroma) were identified among which productivity ranks the first (43% of responds) followed by quantity of water (33%), taste (33%), availability of coconut (16%) and kernel (14%) (Figure 4).

A correspondence analysis (Figure 5) on the preference criteria and the ecotypes revealed three main groups. Group I is composed of Agon miton, Agon koun, Xla gon and Agban. Ecotypes of this group are mainly preferred for the quality of their kernel and the quantity of water of the coconut. Group II is composed of a single ecotype, named "Agon vè" and differed from the others and preferred for its aroma. The last group (Group III) is composed of dwarf and hybrid ecotypes which were preferred for their productivity, sweet taste and availability all the year.

Factors determining coconut uses

Table 3 summarizes the results of the GLM. Overall, coconut uses vary significantly according to ethnic group and age of people (Prob <0.05), Figure 6a and b). Indeed, the Fon ethnic group followed by Goun ethnic group had higher uses of coconut palm than Xla and Adja ethnic groups. Furthermore, elderly people have more knowledge about the uses of the coconut palm than younger people. Apart from firewood (Figure 6g) use, the other uses (construction, food, medicinal) varied significantly (Prob<0.05; Figure 6c, d, e, f and h) according to the ethnic groups. However, among the ethnic groups, Fon had higher knowledge on coconut uses than the other ethnic groups. In addition, age had significant effect (Prob < 0.05) on food and heat uses. Educational level (Figure 6i) also appears to influence medicinal and construction uses.

Diversity of uses of the coconut palm

The coconut palm is a tree whose parts can be used for various purposes, notably food, construction, traditional medicine, and during traditional ceremonies (Figure 7). Table 4 summarizes the various uses of the coconut palm. The first and most important use is the fruit consumption and its by-products obtained from its processing. The food uses of coconut are numerous and similar across ethnic groups. Coconut's consumption

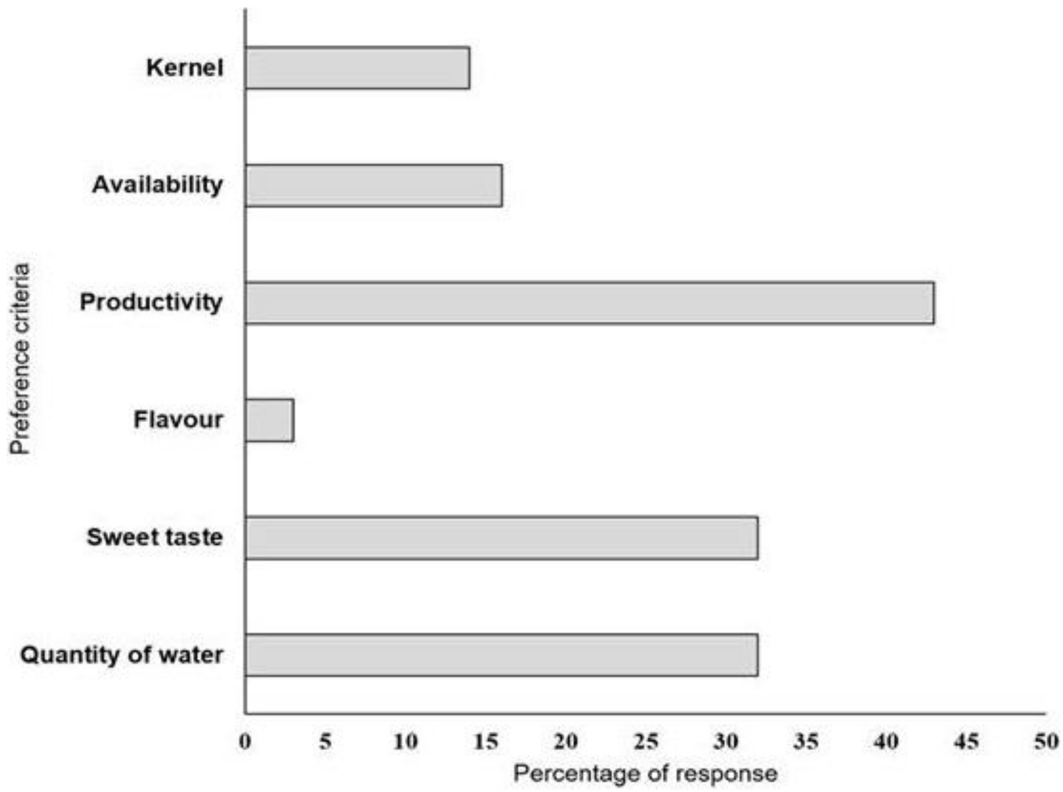

Figure 4. Relative frequency of citation of preference criteria.

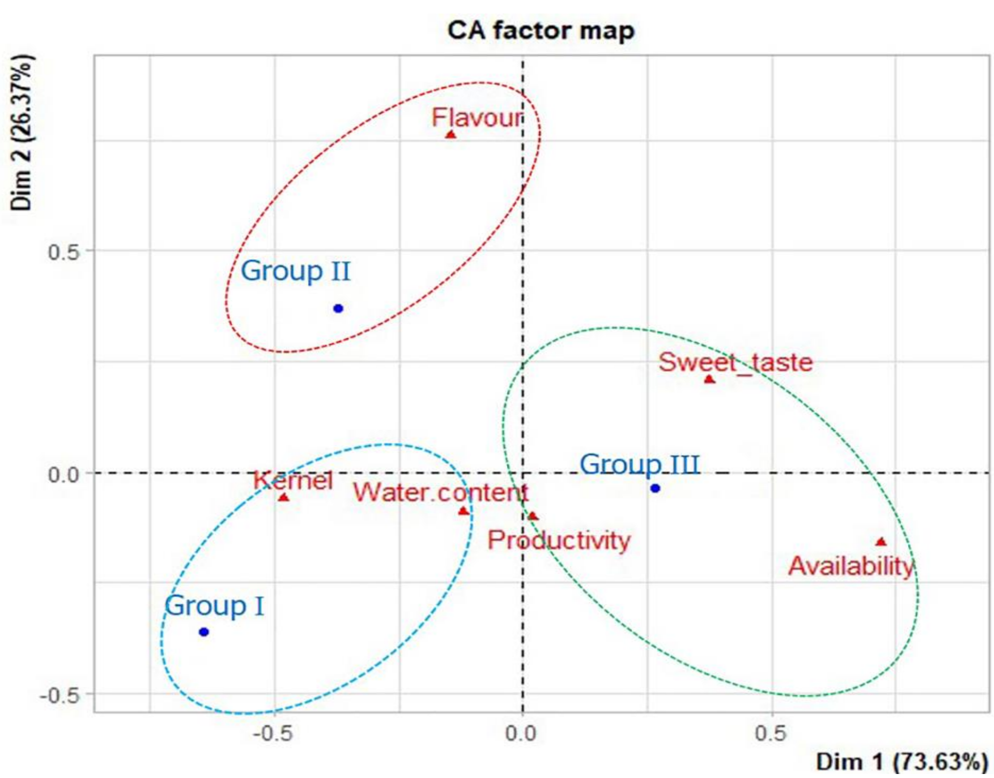

Figure 5. Correspondence factor analysis showing the relationship between coconut ecotype and preference criteria.

Table 3. Effect of socioeconomic factors on coconut use value.

Use value	Socio-demographic characteristic	Df	Deviance	Prob
Total	Sex	1	0.05	0.526
	Age category	2	1.04	0.028
	Instruction level	4	1.15	0.096
	Ethnic group	3	1.95	0.004
Construction	Sex	1	0.01	0.892
	Age category	2	0.13	0.217
	Instruction level	4	0.55	0.012
	Ethnic group	3	0.34	0.046
Food	Sex	1	0.16	0.127
	Age category	2	1.39	<0.001
	Instruction level	4	0.11	0.817
	Ethnic group	3	0.78	0.013
Heating	Sex	1	0.05	0.470
	Age category	2	1.01	0.006
	Instruction level	4	0.26	0.631
	Ethnic group	3	0.40	0.261
Medecinal	Sex	1	0.01	0.960
	Age category	2	0.13	0.797
	Instruction level	4	4.69	0.002
	Ethnic group	3	3.65	0.005

Df : degree of freedom ; Pr: Probability.

begins from the first stage of fruit development to the final stage of maturity resulting in the formation of copra. Indeed, coconut water is consumed as refreshing drink.

The terminal bud called "palm heart" is edible and consumed raw, and the extracted sap is used to make wine palm mainly by the Xla ethnic group. For the ethnic groups Fon and Goun, the extracted kernel (Figure 8) is consumed fresh, with bread, gari (cassava flakes) or with hypocotyls obtained from seed germination of African fan palm (*Borassus aethiopum* Mart). Moreover, milk is also extracted from the kernel and consumed by people. The oil extracted from copra is used to cook foods and the obtained cakes are used to produce new food products. For the medicinal uses (Figure 9), coconut water is consumed to improve sexual performance (40,46 %), and mixed with lemon to treat malaria disease (69 %). Additionally, the stipe is used for frame construction due to its resistance and the leaves for building house fence and crafts.

Coconut palm production constraints

Many constraints related to coconut palm production have been reported by informants. These constraints differ between men and women. Both men and women are involved in the nurseries and seedlings' production activities. However, the harvest is exclusively done by men who are more skilled to climb the tree. According to producers, the major constraints are productivity and plant height. Improved ecotypes are most productive than the endogenous ecotypes. Endogenous ecotypes are more appreciated due to their organoleptic characteristics. However, from a certain number of years, the tree size of endogenous ecotype becomes so high that it is difficult to climb and harvest the coconuts. So, to circumvent this difficulty, producers opt more for improved and dwarf ecotypes.

Women are mainly involved in activities related to collection and selling. They represent at least 70% of coconut water and copra traders. Another important constraint is which related to biotic stress. Three (03) main diseases were reported across area across the study villages. The first one is the dry rot of the coconut heart, which most often attacks young plants. The two others are the leaf dieback disease and yellowing leaf disease which attack adult coconut palms.

DISCUSSION

Diversity and conservation status are important aspects

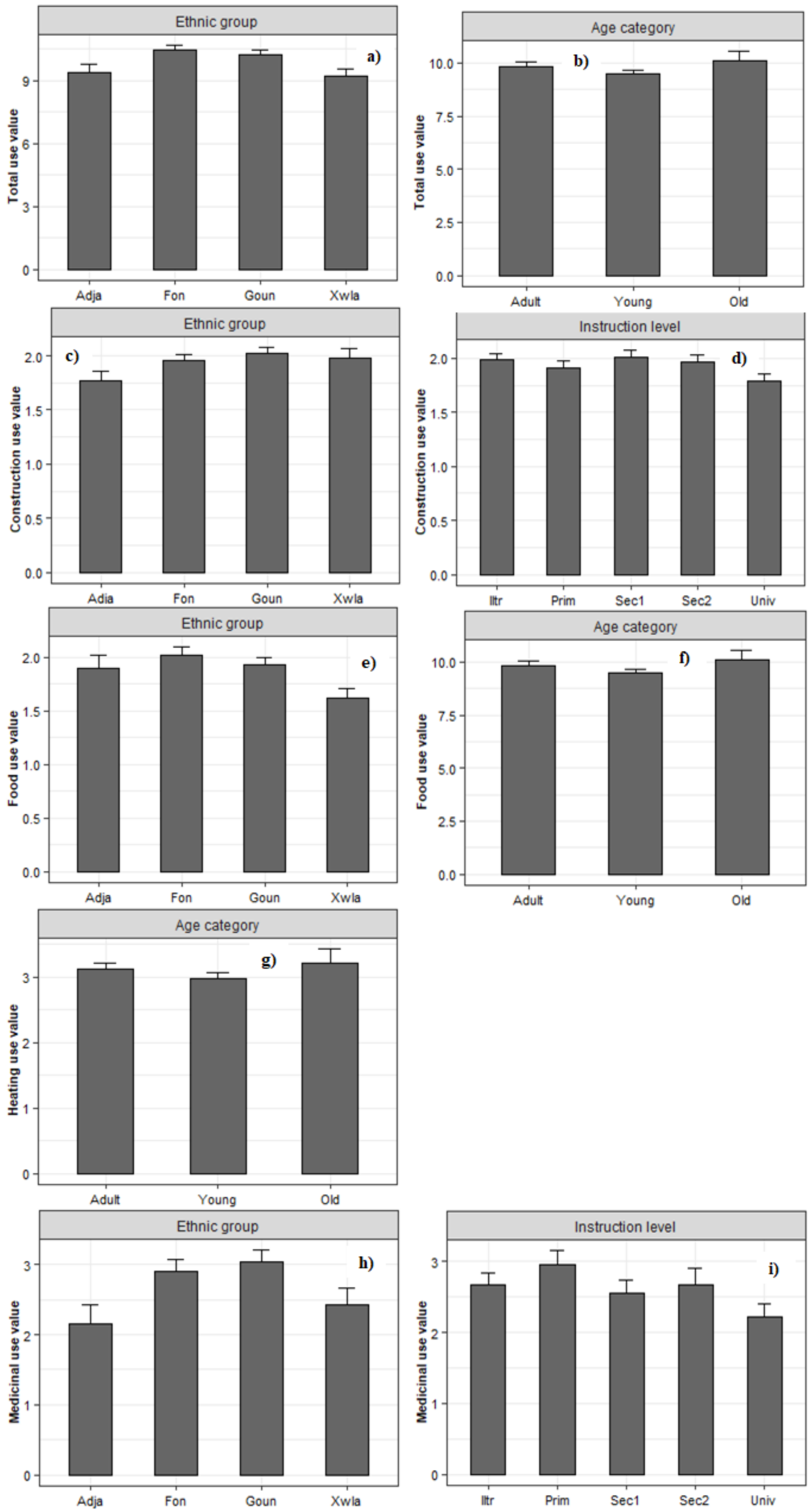

Figure 6. Variation of coconut use values in relationships to socioeconomic factors.

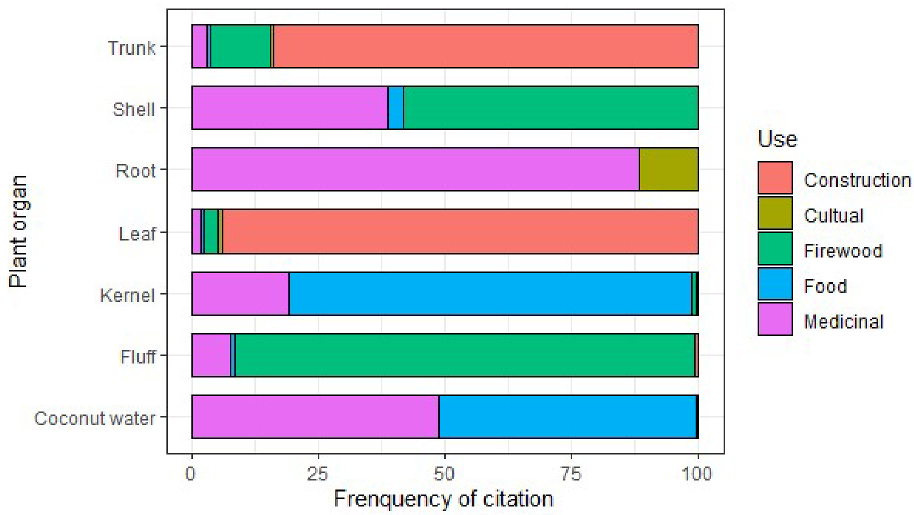

Figure 7. Uses of the coconut tree.

Table 4. Uses of the different parts of the coconut palm tree in the study area.

Parts of the plant	Medicinal recipe	Food recipe	Construction	Cultural recipes	Other uses
Leaf	Unknown	Unknown	Roof, fence	Unknown	Ropes, garden boards, broom, hat
Trunk	Anemia, painful menstruation	Unknown	Carpentry, fences	Unknown	firewood
Root	Anemia, malaria, infection, icterus, mouth sores, general fatigue, stomach ache, calcium deficiency, aphrodisiac, sexual weakness, newborn tea, sperm purification, hemorrhoids, newborn head deformity	Unknown	Unknown	power of luck	Unknown
Fibre	Anemia	Unknown	Unknown	Unknown	Cooking fire, textiles
Hull	Anemia, malaria, newborn head deformity	Unknown	Unknown	Unknown	Cooking fire
Kernel	Oligospermia, Aphrodisiac, calcium deficiency, virility, typhoid fever, malaria, general fatigue	Milk, coconut oil, snacks, dried grated coconut, copra,	Unknown	Unknown	Ebauty cream,
Water	Serum, malaria, sexual weakness, premature ejaculation, fertility, ulcers, general fatigue, infection, hypertension, cleansing of the body, white loss, fibroids, cysts, strengthening the immune system	Refreshing drink	Unknown	Power of luck	Infusion

to be elucidated to guide development of strategies for sustainable plant genetic resources conservation and management. This study focused on the case study of coconut tree in Benin. The number of local names recorded for all ecotypes, subject to synonymy, was low compared to other crops species. This low diversity could be related to the ethnic groups living in the area of study. Indeed, the ethnic groups located in the coastal area could be qualified as derived mostly from Fon ethnic group with which they share a lot of linguistic expression. Contrary to the 10 vernacular names recorded in our study, 38 local names were enumerated in the Vêtuboso' village on the island of Vanua Lava (Caillon, 2011) with an area of only 314 Km^2. In addition, the system of designation of coconut ecotypes in Benin coastal zone is very similar to the ones described by Caillon (2011) on

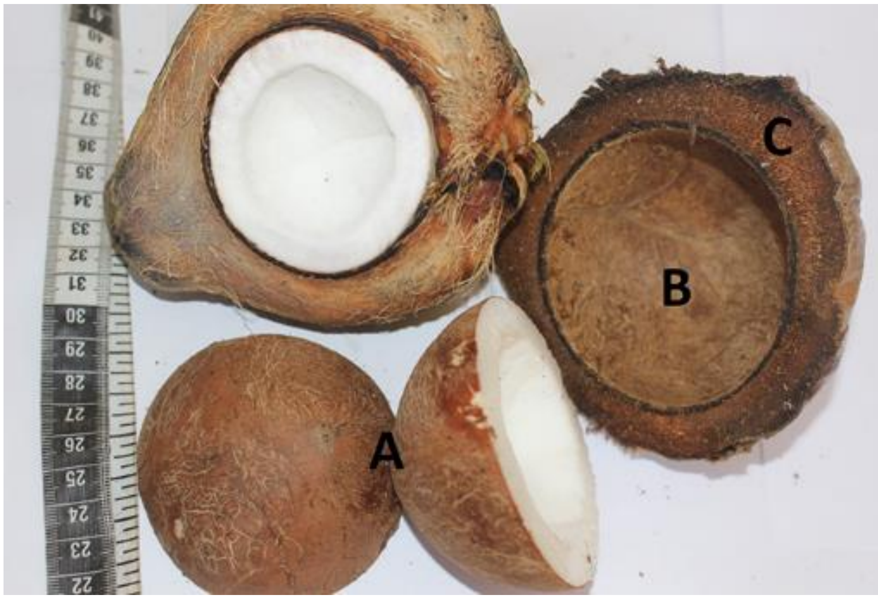

Figure 8. Cross section of a coconut; **A**) kernel; **B**) Shell; **C**) Fluff.

Figure 9. Coconut water for medical use; Lemon is added for malaria treatment, milk to improve sexual performance.

the island of Vanua Lava. Almost all of the names listed by local populations are made of two names where the first designates the "coconut" and the second often related to a morphological characteristic of the fruit or tree.

Determining preference criteria is very important for promotion and maintenance of ecotypes by producers. For coconut palm, productivity and organoleptic characteristics are the priority criteria used by producers. Indeed a good productivity means higher yield, and hence more money. Productivity had been reported as the first criterion of preference for many crops (Weltzien et al., 2020; Marimo et al., 2020). For coconut, this criterion is followed by organoleptic characteristics that meet the needs of consumers. In general, palms were reported to be a multi-purpose species whose part can be used by human for food, construction, medicine, cultural ceremonies and other uses (Araújo Neto et al., 2016; Zon et al., 2021). Different uses were recorded for coconut palm. As most of edible palm species, coconut is primarily used for food. Fruit is the main part of coconut palm consumed for human food. Coconut water is used for refreshing when immature; the kernel is consumed raw; and mature oil is extracted from kernel for cooking or for other uses. The apical meristem of coconut is also consumed like palm heart. Many authors also reported the same and various uses of coconut in human food (Ahuja et al., 2014; Lima et al., 2015; Erawan et al., 2018; Moreno et al., 2020). In Benin coastal zone, coconut uses have significant relationship with informant age category; older people use the species more than younger informants probably because older are more knowledgeable about coconut uses. In addition, knowledge on medicinal uses is mainly held by people with very low educational level.

A recent study by Gruca et al. (2015) underlined palms as prominent elements in African traditional medicines. Concerning medicinal purposes, apart from the leaves, all other parts of coconut palm are used alone or in combination with other ingredients to treat different pathologies and vary among ethnic groups. Indeed, several studies had reported various medicinal properties of coconut (Lima et al., 2015). At least ten medicinal uses such as malaria treatment, stomach pain medication, improving sexual performance and sexual pathologies treatment, menstrual cramps, anemia, calcium deficiency and others were reported by respondents. Most of the medicinal uses reported in our study had been also listed in Indonesia by Erawan et al. (2018). Several studies reported on the role and importance of palm species included coconut palm in meeting the health needs of indigenous people. Besides the different uses described and discussed above, another aspect listed by local people is the magical use of coconut palm to attract good luck. Indeed, traditional medicine is also in close association with endogenous spirituality or belief which makes difficult certain explanations. Gruca et al. (2015) reported that ritual use of palms is an inextricable part of African medicinal and spiritual systems. Coconut palm in the ritual uses has been already among certain ethnic groups in Kenya, Madagascar and Nigeria (Nagata et al., 2011). Many authors had reported the socio-economic importance of palm species especially for making handicrafts, objects for domestic uses and others (Zon et al., 2021). Here coconut palm leaves were used by local people to make hat, ropes, garden boards and sometimes to make fire for cooking. This same coconut utilization were also reported in Tanzania by Muyengi et al. (2015). Our results showed the importance of coconut palm in the lives of people across the coastal zone. In view of the diversity of products obtained from the exploitation of the coconut palm, it appears important to evaluate its contribution to the local economic chain and especially in household income.

Conclusion

This study provides useful information on genetic resources of the coconut palm cultivated in the coastal zone of Benin. Currently, there is a low diversity of coconut cultivated across the area of study. Three main types of coconut were distinguished: local and tall ecotype, improved dwarf ecotypes, and the medium size (height). These results can serve as guidelines for the implementation of conservation strategies of the species across the zone. Up to now, the management of coconut plantations remains family-owned and this production is essentially for domestic market. Increasing production requires highly productive ecotypes, and resolving constraints of coconut production such as training farmers on farm and soils management, insect and pests' management, etc. Additionally, molecular genetic diversity study will contribute to clearly identify the cultivated ecotypes. It is also important to assess physico-chemical composition of coconut products from cultivated ecotypes in order to identify the best ecotypes that can be candidates in the development and/or genetic improvement program. Assistance from the authorities to producers and development of technologies for enhancing productivity and the income of coconut farmers are important to boost the value chain of coconut palm.

CONFLICT OF INTERESTS

The authors declare that they have no conflict of interests.

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