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Full Length Research Paper

Combining local ecological knowledge and field investigations to assess diet composition and feeding habit of forest elephants in Campo-Ma'an National Park, Southern Cameroon

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Forest elephants are nocturnal and elusive animals, making it difficult to perform direct observations on them. Data on elephants' diet and feeding habit are lacking despite most forest elephants' habitats being lost to anthropogenic activities; yet such knowledge may be important for their conservation, particularly in a human dominated landscape. Local ecological knowledge and field investigations were combined to assess diet composition and feeding habit of forest elephants in Campo-Ma'an landscape. The study also aimed to evaluate the level of concordance between the two approaches. The study reports that forest elephants in Campo-Ma'an feed on 87 plants species, including crops. Twenty-two of these plant species were reported by both methods, most of them being potential drivers of human-elephant conflict as they are simultaneously used by humans and elephants. Also, field investigations revealed that, to satisfy their energy requirements, forest elephants relied mostly on leaves and fruits during the wet seasons and mostly on barks from trees during the dry seasons. Overall, the two methods appeared to be complementary, despite field investigations yielding fewer species, as we only covered the park partially. We suggest that combining both methods could be a cost-efficient way to address forest elephants ecological and management questions.

Key words: Indigenous knowledge, *Loxodonta cyclotis*, plants species consumed, traditional knowledge

INTRODUCTION

Forest elephants (*Loxodonta cyclotis*) are now classified as critically endangered (IUCN, 2021) and up to 57.4% of their potential range is found outside protected areas (Wall et al., 2021). Indeed, landscape modification can be critical for wide-ranging elephants whose existence depends on habitat conditions (Doumenge et al., 2021;

Koirala et al., 2016; Mmbaga et al., 2017). Elephants are generalist feeders (Choudhury et al., 2008) with large body mass, and therefore need large range to collect their food (Biru and Bekele, 2012) and can spend up to 18h per day searching for food (Campos-Arceiz and Blake, 2011; Jin et al., 2006; Leggett, 2009; Sach et al., 2019). It

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may be a challenge to satisfy their needs in an environment where habitat is increasingly being lost, resulting in reduced food availability for elephants (Koirala et al., 2016). Accordingly, they feed on different biological types of plants ranging from roots/tubers and grasses to trees of different species, depending on the seasons and the ecosystems (Biru and Bekele, 2012; De Boer et al., 2000; Koirala et al., 2016; Kouamé et al., 2011). The bulk of elephant's diet comes from leaves (Kabigumila, 1993; Short, 1981) and fruits (Blake and Inkamba-Nkulu, 2004; Campos-Arceiz and Blake, 2011; White, 1994). However, various proportions of roots, barks, stems, branches, twigs, and flowers are also consumed by elephants (Biru and Bekele, 2012; Kabigumila, 1993; Koirala et al., 2016; Short, 1981; White et al., 1993). Forest elephants have been reported feeding on more than 500 plant items in Ndoki National Park, Congo (Blake, 2002), 307 food items in the Lopé Reserve, Gabon (White et al., 1993), and on at least 33 fruiting tree species in Odzala National Park, Republic of Congo (Maurois et al., 1997). Moreover, preferences for some key tree species such as *Sacoglottis gabonensis* (Ngama et al., 2019; White, 1994), *Iringia gabonensis*, *Pseudospondias macrocarpa*, *Ballonella toxisperma*, *Dusboscia macrocarpa*, *Parinari excelsa* (Blake, 2002; Campos-Arceiz and Blake, 2011; Maurois et al., 1997; Ngama et al., 2019) have been reported. In Cameroon, studies on diet and feeding habit of elephant are very limited and mostly described for savanna elephants with Tchamba (1996) and Foguekem et al. (2011) reporting respectively 45 and 20 plant species consumed by savanna elephants in the Waza Logone area. As for forest elephants, Tchamba and Seme (1993) reported 22 fruiting tree species as part of their diet in the Santchou Reserve. Primary data on diet and feeding habit of forest elephants from direct observations can be challenging to obtain due to their low population density, nocturnal lifestyle, and their elusive nature (Kambissi, 2010; Service et al., 2014). However, local people might have knowledge from their long-time interactions with nature (Service et al., 2014). This has prompted the use of alternative and less invasive methods, such as Local Ecological Knowledge (LEK) in elephant ecology (Biru and Bekele, 2012; Buchholtz et al., 2020). LEK provide reliable, timely and cost-effective data from communities living nearby and interacting with nature (Albuquerque et al., 2021; Allendorf et al., 2020; Brittain et al., 2020; Buchholtz et al., 2020; Pan et al., 2016; Service et al., 2014). LEK surveys can reduce the risk of research equipment such as camera traps being stolen (such as, Caravaggi et al., 2017).

LEK surveys can facilitate the rapid understanding of threats to wildlife, resulting in faster decision-making (Albuquerque et al., 2021; Buchholtz et al., 2020; Haenn et al., 2014). For example, LEK has been used for rapid assessment of the status and threats to pangolin (*Manis pentadactyla*) (Nash et al., 2016) and to study range shift of grizzly bear (*Ursus arctos horribilis*) (Service et al.,

2014), wildlife presence and abundance, and identification of areas where conservation actions are needed (Allendorf et al., 2020), occupancy and distribution of wildlife (Haenn et al., 2014; Service et al., 2014), and even to study elephant diet in Ethiopia (Biru and Bekele, 2012) and to predict landscape use by elephants in Botswana (Buchholtz et al., 2020). Nevertheless, LEK remains an undervalued source of information for diet and feeding habit of forest elephants. While it has been used in Botswana to model the land use pattern by savanna elephants (Buchholtz et al., 2020), in the entire Congo Basin, study on elephant diet and feeding habit using LEK is limited. In Cameroon, interviews and field investigations were recently used in Nki National Park to study forest elephants feeding pattern (Ndi et al., 2022). LEK has been combined with occupancy analyses to study the reliability and suitability of LEK in rapid assessments of forest elephants' occupancy in timber logging concessions (Brittain et al., 2020) and LEK studies focused mainly on pangolins. Indeed, Fopa et al. (2020) assessed local ecological and traditional medicine knowledge of pangolins, (*Smutsia gigantea*, *Phataginus tricuspis*, *Phataginus tetradactyla*) as well as the level of conservation awareness amongst local people around Deng-Deng and Mpem et Djim National Parks, whereas Simo et al. (2020) used LEK to tailor camera traps surveys to improve the detectability of pangolin. Similarly, Mouafo et al. (2021) investigated local peoples' knowledge of pangolin presence, perceptions of population trends, cultural importance, consumptive, and non-consumptive uses, as well as hunting of pangolins. In the CMTOU, studies referring to food for elephants focused on food crop damaged by wildlife including forest elephants using indirect observation methods such as interviews and field visits (Eyebe et al., 2012; Ole, 2011). Much is known about savanna elephant diet, particularly with respect to plant species consumed, their diversity and distribution, their feeding habit, and more importantly the impacts of seasons on their ranging behavior (Blake, 2002). Indeed, forest ecosystem is more diverse, and therefore offers more fruits and other plant items that make up the diet of forest elephants. Moreover, forest habitats are generally not subject to water and mineral shortage as it is the case in savanna (Blake, 2002). To know the elephants' diet and feeding habit in the perspective of sustainable food supply is an important conservation goal especially in areas where land-use change can cause loss of key resources (Puyravaud et al., 2019). Campo-Ma'an conservation area is plagued by increasing degradation of wildlife habitat, which would be better known to communities living nearby but less understood by scientists and decision makers. To fill this gap, this study combines LEK and field surveys to assess elephant's diet composition and feeding habit in Campo-Ma'an conservation area. Specifically, we will (1) assess which plant species and parts are reported by local population as being consumed by elephants, (2) determine through

field investigations which plant species and plant parts have signs of browsing by elephants, (3) assess the level of co-occurrence in terms of plant species between the two methods as well as their relevance and, (4) identify the influence of the seasons on field surveys of feeding habit. LEK is powerful at the local scale in understanding the resources used by elephants as people interact or share resources with them (Puyravaud et al., 2019). Therefore, the most reported plant species by LEK method are expected to be confirmed or validated by field surveys, or vice versa.

METHOD

Study area

The Campo-Ma'an National Park (CMNP), 264,064 ha, and its peripheral zone covers about 770,000 ha. There are about "111,000" inhabitants from six main native ethnic groups and 17 other ethnic groups. This area is located between 2°10'N, 9°50'E and 2°25'N, 10°48'E, in the Southern Region of Cameroon (Figure 1). The climate is coastal equatorial characterized by two dry seasons and two rainy seasons. The mean annual precipitation is about 2500 mm and the mean temperature is 25°C. Many streams, river branches and swampy areas make the study area water rich (MINFOF, 2014; Tchouto, 2004). The vegetation consists mainly of old secondary forest, but patches of primary forest of the dense humid evergreen type still occur and the area has a high level of endemism and plant species diversity. There are about "2,297" vascular plant species and ferns of which 29 species are endemic to the conservation area (MINFOF, 2014; Tchouto, 2004). About 249 plant species are Non-Timber Forest Products and 112 trees species are commercially logged (such as, *Lophira alata*, *Erythrophleum ivorense*, *Guibourtia ehie*, *Pterocarpus soyauxii*, *Piptadeniastrum africanum*, *Dalium bipindensis*, *Lovoa trichilioides*). Logging opens the forest, giving way to the growth of pioneer tree species such as *Alchornea cordifolia*, *Anthocleista shweinfurthii*, *Bridelia micrantha*, *Harungana madagascariensis*, *Musanga cecropioides*, *Trema occidentalis* and *Macaranga* spp., species on which herbivores rely for food (Bekhuis et al., 2008; Tchouto et al., 2009). In degraded areas, herbaceous species such as *Chromolaena odorata*, *Lycopodiella cernua*, *Nephrolepis bisserata*, *Selaginella myosurus* are generally found surrounding woody trees left standing in secondary vegetation. Maranthaceae, Costaceae, and Zingiberaceae families are mostly found along the abandoned logging paths and swamps (Tchouto, 2004). The area harbors threatened wildlife species, among which the forest elephant population, estimated at 544 [425-695] individuals (Nzoo-Dongmo et al., 2015).

Data collection

Open field with high visibility favors direct observation in diet studies (Biru and Bekele, 2012; Sach et al., 2019; Tchamba et al., 2014; Weladji and Tchamba, 2003). In forest area, visibility is limited by the dense vegetation and thick foliage, making it difficult to spot elusive and low-density species such as forest elephant (Blake, 2002; White et al., 1993). Here we use (1) semi structured interviews for LEK and (2) field investigations to assess diet composition and feeding habit.

Local ecological knowledge surveys

LEK data were collected from June through August 2018 using key

informant interviews (village chiefs) and questionnaires to villagers. From the 162 villages surrounding the park, 54 village chiefs authorized us to carry out the research in their hamlet. When we later came back to administer the questionnaires, we only found people in 23 villages, from which 98 households were interviewed based on their willingness to take part to the research, which they confirmed by reading and signing the consent form (Supplementary material 1). Efforts were made to interview heads of households, their wives or any adult male and female (>18 years old, the adulthood age in Cameroon (Patrice, 2019)) due to their high likelihood of encountering elephants during wood logging, farming, hunting, and gathering activities (Buchholtz et al., 2020; Tiani et al., 2005) or their ability to learn from their seniors or parents (Gilchrist et al., 2005). Also, women (27%) were interviewed because of their participation in game hunting and gathering activities (Martin et al., 2020; Tiani et al., 2005). Interviews were conducted in French wherever possible, as most people were fluent in French. In one instance, the respondent, a Bagyeli household, did not speak French, and we used a local interpreter. The interview consisted of semi-structured questionnaire similar to Granados and Weladji (2012) during which the respondent answered questions about elephant food habit, local or commercial names of plant species and/or parts consumed (foliage, root/tubers, stems, barks, and fruits), and the corresponding season (wet or dry) (Biru and Bekele, 2012; Koirala et al., 2016). Because the scope of the study was broader, involving human-elephant interactions, each interview lasted about 45 min.

Field surveys

Twenty transects of 2.5 ha each (500 x 50 m) were surveyed for a total coverage of 50 ha/month during 12 consecutive months from June 2019 to May 2020. Transects were delimited with discrete markers and all woody plant species examined for bark-stripping. Following Koirala et al. (2016), opportunistic surveys on food plants were also carried out each month along the tracks leading to the transect locations. Elephant feeding sites can be identified by tracks or food scraps. Conspicuous feeding such as uprooting or breaking plants stems and branches, pulling down climbing plants or stripping leaves are some characteristics of elephants feeding sites (Biru and Bekele, 2012; Campos-Arceiz and Blake, 2011; Koirala et al., 2016; Short, 1981; White et al., 1993). However, it was not always easy to disentangle elephant browsing signs from those of other herbivores. Therefore, additional steps were taken, such as assessing the presence of elephants' footprints, identifying fresh elephants' dung piles near leaves, stems, and fruits with signs of consumption, or by visually assessing and characterizing the impact on the damaged plant (Koirala et al., 2016). Visual and physical investigations of dung piles using a stick were also performed whenever possible to identify undigested seeds (Biru and Bekele, 2012). Caution was taken to avoid reconsideration of debarking signs during consecutive monitoring of transects whereas all other observations were considered independent from the previous visits. Plant parts were identified with local, commercial and/or scientific names to at least the genus level with the help of field assistants when necessary and recorded along with parts eaten, the day and month of the observation. Where specimens could not be identified in the field, they were collected and later identified at the Cameroon National Herbarium.

Validation of some consumed plants

In addition to transects, 9 camera traps were placed under identified fruiting trees (such as, 5 *Saccoglottis gabonensis*, 2 *Tieghemella africana* and 2 *D. macrocarpa*) reported as preferred fruit trees during LEK surveys and were active from May 2019 to

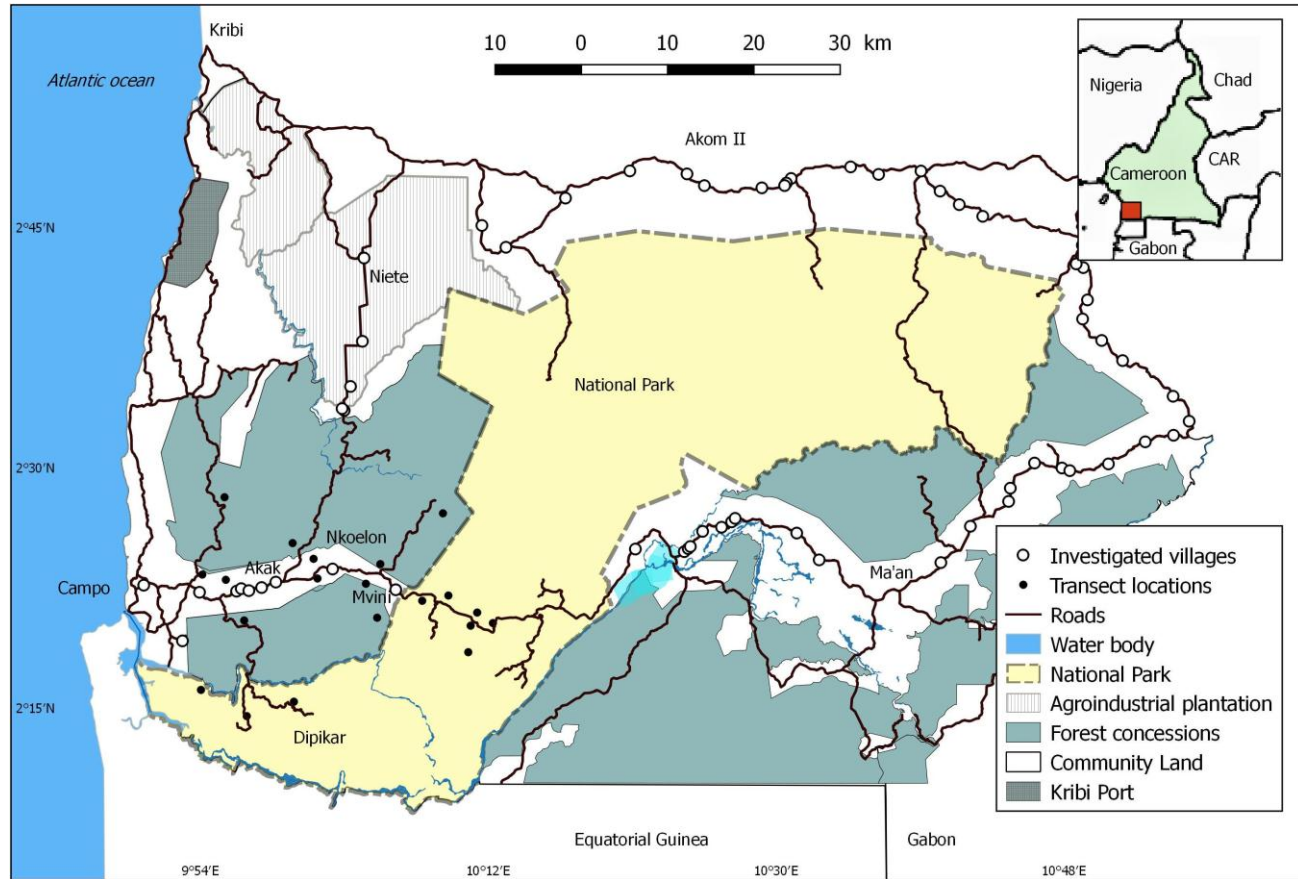


Figure 1. Location of study site and different human land use types in Campo-Ma'an Technical Operational Unit that encompasses the National Park and its multipurpose use peripheral area. Investigated villages and location of the transects (also serving as camera trap positions) are displayed.

Source: Authors

July 2020, 24 hours/day. Stations were chosen based on prior knowledge of the area by a team of four field assistants (3 local trackers/hunters, and 1 forest warden) able to identify trees and areas potentially or known to be used by elephants. Herbivores in forest are likely to use road verges to browse (Bekhuis et al., 2008), or fruiting trees as feeding sites (Blake and Inkamba-Nkulu, 2004). Accordingly, camera traps were set 80 to 150 cm in height, angled horizontal and approximately 5 to 15 m away from target features (such as, roads, fruiting trees). The quiet period was set to three seconds for photos (that is the trigger delay between consecutive photos) and a maximum of 60 seconds for videos. Camera trap photos and videos were date and time stamped.

Data analysis

Data from LEK surveys and field investigations were verified for spelling of local names and cross tabulated with one plant part per row. Botanists were consulted to identify unknown species. The local or commercial names of the plants reported eaten by elephants were searched for scientific names using Vivien and Faure (2011) or the Plant Resources of Tropical Africa database (<https://www.prota4u.org/database/>) mostly for non-commercial species. Scientific names were reported following Angiosperm Phylogeny Group classification system (The Angiosperm Phylogeny Group, 2009). For species that were still unidentified, we consulted

the National Herbarium using dried plant samples or images. After this stage, any remaining unidentified species was removed from the list. Data were grouped into taxonomic family, scientific names, local name, and parts consumed (Biru and Bekele, 2012), and biological types. For field investigations, plant parts with signs of elephant browsing during each monthly field visit were considered independent observations. In this study, while elephants' diet refers to the plant species known as consumed by elephants, feeding habit refers to the variety of plant parts and proportions, on which elephants rely for food on a seasonal basis. Diet composition, which refers to different plant species providing food for elephants were identified and grouped by taxa, biological types and feeding habit, which is the distribution of different plant parts eaten over time (stems, leaves, barks, fruits, tubers). Data were grouped into a contingency table and relative frequency of feeding signs was calculated for each plant part, and subject to chi-square analysis. When a cell in the contingency table had only a small number of counts, Fisher exact tests were used instead. We also assessed co-occurrence between the LEK and the field survey approaches by comparing the diet and the pattern of feeding habit obtained from each method. Images or videos of elephants feeding on plant species were examined for identification and validation of plant species and parts eaten (such as, barks or fruits), or sampled during the next field trip for further identification or validation. All statistical analysis were performed using R v. 3.6.3 (R Core Team, 2020), with a 95% level of significance.

RESULTS

Plant species and plant parts consumed reported by local ecological knowledge

LEK data revealed that 62 plant species from 36 taxonomic families were part of the Campo-Ma'an elephants' diet, of which 10 were cultivated food crops (Table 1). The plants parts most reported included fruits, leaves, stems, roots, and barks, with a significant difference in frequencies of the parts reported (Chi square test, $\chi^2 = 104.200$, $df = 4$, $p < 0.001$; Figure 2A). According to local knowledge, elephants consumed significantly more fruits as compared to leaves ($\chi^2 = 10.714$, $df = 1$, $p = 0.001$), stems ($\chi^2 = 34.909$, $df = 1$, $p < 0.001$), roots ($\chi^2 = 46.049$, $df = 1$, $p < 0.001$), and tree barks ($\chi^2 = 48.600$, $df = 1$, $p < 0.001$). Also, leaves were significantly more reported being consumed than stems ($\chi^2 = 9$, $df = 1$, $p = 0.003$), roots ($\chi^2 = 17.065$, $df = 1$, $p < 0.001$), and tree barks ($\chi^2 = 19.200$, $df = 1$, $p < 0.001$). No significant difference in reported consumption was observed between barks, stems and roots ($\chi^2 = 3.875$, $df = 2$, $p = 0.144$).

Plant species and plant parts consumed reported by field surveys

Field investigations showed that 47 plant species from 29 taxonomic families, of which 4 are food crops, were consumed by elephants (Table 1). Elephants' diet included 8 herbs, 6 shrubs and 33 trees. Plant parts eaten included fruits, leaves, barks, stems, and roots with a significant difference in their distribution (Chi square test, $\chi^2 = 35.500$, $df = 4$, $p < 0.001$; Figure 2B). Fruits were more consumed than stems ($\chi^2 = 7.043$, $df = 1$, $p = 0.008$) and roots ($\chi^2 = 29.121$, $df = 1$, $p < 0.001$). Similarly, more leaves were consumed than roots ($\chi^2 = 30.118$, $df = 1$, $p < 0.001$) and stems ($\chi^2 = 7.680$, $df = 1$, $p < 0.001$). Signs of consumption from stems and barks were comparable ($\chi^2 = 1.060$, $df = 1$, $p = 0.303$). No significant difference was observed between barks, leaves, and fruit consumption signs ($\chi^2 = 3.694$, $df = 2$, $p = 0.157$). As compared to signs of roots consumption, there were significantly more stems ($\chi^2 = 11.267$, $df = 1$, $p < 0.001$) and barks ($\chi^2 = 17.190$, $df = 1$, $p < 0.001$) consumption signs.

Degree of co-occurrence in plant species between the LEK and field surveys

Overall, 47% ($n = 47$) species seen with signs of feeding in the field were reported during LEK surveys. There were significant differences between the feeding habit patterns reported from LEK and field surveys (Fisher exact test, two-sided, $p < 0.001$). The proportion of barks

consumed were significantly greater than reported by local communities ($\chi^2 = 12.565$, $df = 1$, $p < 0.001$). More fruits were reported than observed in the field ($\chi^2 = 12.565$, $df = 1$, $p < 0.001$), whereas the contribution of leaves ($\chi^2 = 0.600$, $df = 1$, $p = 0.439$) and stems ($\chi^2 = 1.087$, $df = 1$, $p = 0.297$) in feeding habit were comparable for both methods. The pattern of root consumption also appeared to be similar for LEK and field surveys ($\chi^2 = 1.800$, $df = 1$, $p = 0.180$). Of the nine targeted trees (from three different species), camera trap confirmed that forest elephants fed on their fruits, barks, and leaves. In addition, 5 other plant species were seen being consumed through videos and photos (Table 1).

Influence of seasons on field surveys feeding habit

Field surveys' feeding habit patterns differed between dry and wet seasons (Fisher exact test, two-sided, $p < 0.001$, Figure 3A and B). More barks were seen stripped by elephant during dry as compared to wet seasons (Chi square test, $\chi^2 = 15.680$, $df = 1$, $p < 0.001$) whereas more leaves ($\chi^2 = 9.931$, $df = 1$, $p < 0.001$) and more stems ($\chi^2 = 4.840$, $df = 1$, $p < 0.001$) were browsed during wet as compared to dry seasons. Fruit and root consumption was comparable between wet and dry seasons (all $p > 0.05$) and no sign of root consumption by elephant was observed during the dry season.

DISCUSSION

Knowledge of diet and feeding habit of elephant is important for developing human elephant conflict mitigation strategies (Koirala et al., 2016). A total of 87 plant species which forest elephants relied on for food were found. The LEK surveys reported 62 plant species, while the field surveys found 47 plant species as part of the forest elephant diet, with 22 co-occurring plant species and eight plant species (fruit trees, herbs, and shrubs trees) validated for a total of 44 families (Table 1). Their food items came from trees, shrubs, herbs, and climbers. Elephants relied on a variety of plant parts such as roots, stems, barks, leaves, and fruits, consumed at varying proportions and seasons (Figures 2 and 3). These results are higher than the 43 species of plants from 24 families reported by Ndi et al., (2022) in Nki National Park but close to the 95 plant species found by De Boer et al. (2000) in a mosaic of forest and savanna in Mozambique, and 106 plant species consumed by Asian elephants in Shangyong National Natural Reserve in China (Jin et al., 2006). The total number of plants potentially consumed by elephants appeared to be lower than the 351 plant species found in Congo within the Ndoki National Park (Blake, 2002) and 230 species reported in Gabon within the Lopé Reserve (White et al., 1993). However, these researchers obtained those

Table 1. Distribution of plant species reported by local people as being consumed by elephants per family, scientific names, local names, biological types, and parts eaten and the source of information.

Family	Scientific names	Local names	Biological types	Parts eaten	Source
Anacardiaceae	<i>Annickia chlorantha</i>	Mfo'o	Tree	Barks	Field
	<i>Anthrocaryon klaineanum</i>	Onzabili	Tree	Barks, fruits	LEK
	<i>Pseudopondias</i> spp.	Ofos	Tree	Fruits	LEK
	<i>Pseudospondias mombin</i>	Kassemanga	Tree	Fruits	LEK
	<i>Trichoscypha arborea</i>	Ekong	Tree	Fruits	LEK
Anisophylleaceae	<i>Poga oleosa</i>	Angale	Tree	Fruits	LEK
Annonaceae	<i>Cleistopholis patens</i>	Avom	Tree	Leaves	LEK
	<i>Greenwayodendron suaveolens</i>	Otouan	Tree	Leaves	Field
	<i>Hexalobus crispiflorus</i>	Owe	Tree	Fruits	Field, LEK
	<i>Xilopia quintasii</i>	Mvoma	Tree	Fruits	Field
Apocynaceae	<i>Alstonia boonei</i>	Ekouk/ Emien	Tree	Leaves, barks	Field, LEK
	<i>Funtumia africana</i>	Mutondo	Tree	Barks, fruits, leaves	Field, LEK
	<i>Tabernaemontana crassa</i>	Etuen	Tree	Leaves	Field
Arecaceae	<i>Cocos nucifera</i>	Coconut	Herbs	Leaves, stems	LEK
	<i>Elaeis guineensis</i>	Alen	Herbs	Leaves, stems, fruits	LEK
	<i>Eremospatha macrocarpa</i>	N'kan	Climbers	Barks, stems, leaves	LEK
Bignoniaceae	<i>Spathodea campanulata</i>	Tulipier du gabon	Tree	Barks	Field
Bombacaceae	<i>Ceiba pentandra</i>	Doum	Tree	Barks	LEK
Boraginaceae	<i>Cordia</i> spp.	Cordia	Shrubs	Leaves	Field
Bromeliaceae	<i>Ananas comosus</i>	Ananas	Herbs	Fruits	LEK
Burseraceae	<i>Dacryodes igaganga</i>	Sahgoun	Tree	Fruits	LEK
Caricaceae	<i>Carica papaya</i>	Foforo	Shrubs	Fruits	LEK
Clusiaceae	<i>Allanblackia floribunda</i>	Abanka	Tree	Leaves, fruits	LEK
	<i>Garcinia kola</i>	Bitakola/onye	Tree	Fruits	LEK
Commelinaceae	<i>Palisota</i> spp.	Palisota	Herbs	Leaves, stems	Field
Costaceae	<i>Costus</i> spp. *	Costus	Herbs	Leaves, stems	Field
Cucurbitaceae	<i>Cucumeropsis manii</i>	Squash	Herbs	Fruits	Field, LEK
	<i>Luffa</i> spp. *	Luffa	Herbs	Fruits, stems	Field
Dioscoreaceae	<i>Dioscorea elephantipes</i>	wild yam	Herbs	Tubers	LEK
Ebenaceae	<i>Dyospiros</i> spp.	Mevini	Shrubs	Leaves	Field
Euphorbiaceae	<i>Anthonotha macrophylla</i>	Enack	Tree	Barks	Field
	<i>Macaranga</i> spp. *	Assas	Shrubs	Barks, leaves	Field, LEK
	<i>Manihot esculenta</i>	Cassava	Herbs	Roots, leaves	Field, LEK
Fabaceae	<i>Albizia adianthifolia</i>	Senesack	Tree	Barks	Field
	<i>Calpocalyx cauliflorus</i>	Etuen	Tree	Leaves	Field
	<i>Calpocalyx heitzii</i>	Miama	Tree	Barks, leaves	Field
	<i>Cylicodiscus gabonensis</i>	Okan	Tree	Barks	Field
	<i>Detarium macrocarpum</i>	Aboroso	Tree	Fruits	LEK
	<i>Distemonanthus benthamianus</i>	Movingui	Tree	Leaves	LEK
	<i>Erythropleum ivorense</i>	Tali	Tree	Bark	LEK
	<i>Pentaclethra macrophylla</i>	Ebai	Tree	Fruits	LEK
	<i>Piptadeniastrum africanum</i>	Atui	Tree	Fruits	LEK
	<i>Scorodophloeus zenkeri</i>	Elelom	Tree	Leaves	LEK
	<i>Tetrapleura tetraptera</i>	Akpwah	Tree	Fruits	Field, LEK
Flacourtiaceae	<i>Oncoba glauca</i>	Miamegomo	Tree	Leaves	Field, LEK
Humiriaceae	<i>Sacoglottis gabonensis</i> *	Bidou	Tree	Fruits, leaves	Field, LEK
Hypericaceae	<i>Harungana madagascarensis</i>	Atondo	Shrubs	Leaves, stems	Field, LEK
Irvingiaceae	<i>Irvingia gabonensis</i>	Ndo'o	Tree	Bark, fruits	Field, LEK
	<i>Klainedoxa gabonensis</i>	Ntee/ngon	Tree	Leaves, fruits	LEK
Lamiaceae	<i>Vitex grandifolia</i>	Bivoua	Tree	Fruits	LEK

Table 1. Contd

Lauraceae	<i>Persea americana</i>	Avocatier	Tree	Fruits	LEK
Leeaceae	<i>Leea guineensis</i>	Otebissong	Shrubs	Leaves	Field
Malvaceae	<i>Cola griseiflora</i> *	Cola	Shrubs	Leaves	Field
	<i>Desplatsia dewevrei</i>	Mfeneg	Tree	Fruits, roots	LEK
	<i>Duboscia macrocarpa</i> *	Akak	Tree	Barks, fruits, leaves	Field, LEK
	<i>Eribroma oblongum</i>	Eyong	Tree	Barks, fruits	Field
Marantaceae	<i>Haumania denckelmanniana</i>	See	Herbs	Root	LEK
Meliaceae	<i>Entandrophragma utile</i>	Sipo	Tree	Bark	LEK
	<i>Trichilia rubescens</i>	Nkieme	Tree	Barks	Field
Moraceae	<i>Antiaris africana</i>	Ako'o	Tree	Leaves	LEK
Musaceae	<i>Musa</i> spp.	Banana	Herbs	Leaves, stems, fruits	Field, LEK
Myristicaceae	<i>Coelocaryon preussii</i>	Bidou eteng	Tree	Fruits	LEK
	<i>Pycnanthus angolensis</i>	Eteng/Ilomba	Tree	Leaves, stems, barks	Field, LEK
	<i>Staudtia kamerunensis</i>	Niové	Tree	Leaves	Field, LEK
Olacaceae	<i>Coula edulis</i>	Ewomen	Tree	Fruits	LEK
	<i>Ongokea gore</i>	Nguek	Tree	Fruits	Field, LEK
	<i>Strombosia pustulata</i>	Edip	Tree	Barks	Field
	<i>Strombosia scheffleri</i>	Mbazoa	Tree	Leaves	Field
Pandaceae	<i>Microdesmis puberula</i>	Evindi afan	Tree	Barks, leaves	Field
	<i>Panda oleosa</i>	Afan	Tree	Fruits, leaves, roots	Field, LEK
Phyllanthaceae	<i>Margaritaria discoidea</i>	Ebebang	Tree	Leaves	LEK
	<i>Uapaca guineensis</i>	Assam/Oyang	Tree	Barks, fruits, leaves	Field, LEK
Poaceae	<i>Zea mays</i>	Maize	Herbs	Stems, fruits, leaves	Field
	<i>Oxytenanthera abyssinica</i>	Bambou	Herbs	Leaves	LEK
	<i>Saccharum</i> spp.	Canne	Herbs	Leaves, stems	LEK
Rutaceae	<i>Fagara heitzii</i>	Bongo H/Olon	Tree	Barks	Field
Sapotaceae	<i>Baillonella toxisperma</i>	Moabi	Tree	Fruits	LEK
	<i>Chrysophyllum africanum</i>	Abam	Tree	Leaves	LEK
	<i>Chrysophyllum lacourtianum</i>	Berema	Tree	Fruits, leaves, barks	Field, LEK
	<i>Tieghemella africana</i> *	Adjap zock	Tree	Barks, fruits	Field, LEK
Simaroubaceae	<i>Odyendyea gabonensis</i>	Oseng	Tree	Fruits	LEK
Sterculiaceae	<i>Theobroma cacao</i>	Keuka	Shrubs	Fruits	LEK
Strychnaceae	<i>Strychnos aculeata</i>	Babe	Tree	Fruits	LEK
Tiliaceae	<i>Grewia coriacea</i>	Grewia	Tree	Fruits	Field
Urticaceae	<i>Musanga cecropioides</i>	Asseng	Tree	Stems, leaves	Field, LEK
	<i>Myrianthus arboreus</i>	Bikango	Tree	Fruits	LEK
Zingiberaceae	<i>Afromomum</i> spp. *	Adjom	Herbs	Leaves, fruits	Field, LEK

Local names are given in Bulu, Ewondo, Bagyeli or French language. "*" refers to species observed being eaten by elephants in videos and photos from camera traps. LEK stands for Local Ecological Knowledge.

Source: Authors

results using different approaches by combining direct observations, dung, and food scraps resulting from long-term studies. The forest elephants of Campo ate mostly leaves, especially during wet seasons. Although the vegetation is described as evergreen, the wet period corresponds with the emergence of buds and the production of new leaves which are less lignified and more tender. Herbaceous plants (*Costus* spp., *Palisota* spp., *Luffa* spp.) or shrubs (*Leea guineensis*, *Harungana madagascarensis*, *Macaranga* spp.) and crops were

reported by field investigations during the wet seasons. Also, signs of browsing on leaves, twigs, or young stems of *M. cecropioides*, *Macaranga* spp. and *Harungana madagascarensis* saplings were generally observed in disturbed areas such as logging trails, logging decks, edges of farms, and felling gaps. Leaves have been reported as an important part of elephant's diet in Lopé Reserve in Gabon (White et al., 1993). We found that fruits play an important role in elephant diet in both dry and wet seasons in Campo-Ma'an. This can be explained

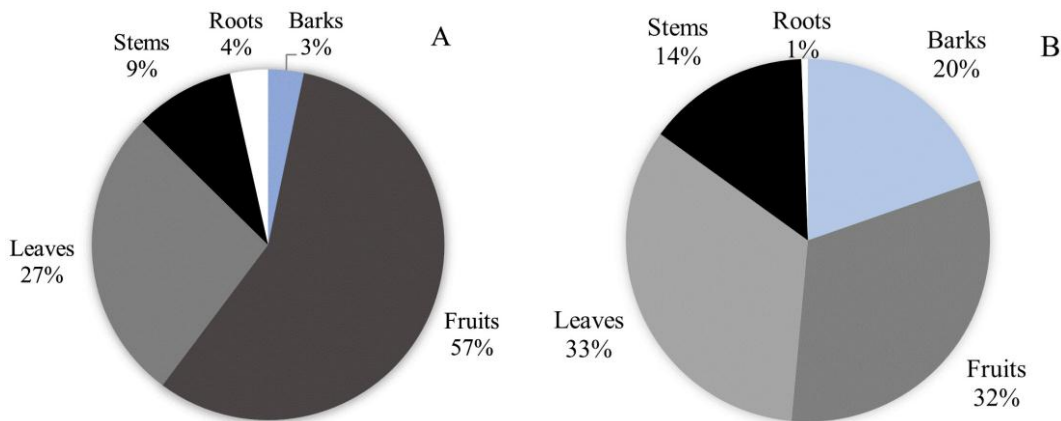


Figure 2. Percent distribution of the plants parts eaten as reported by LEK (A) and field investigations (B). Source: Authors

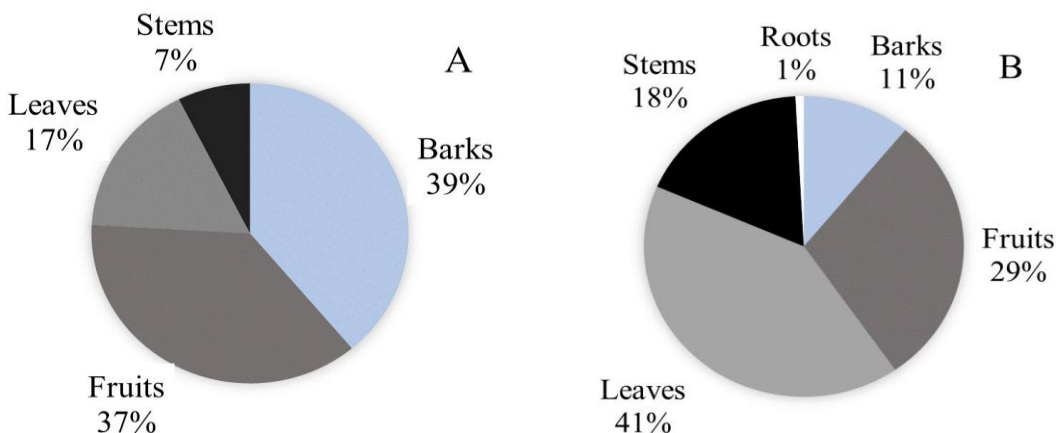


Figure 3. Distribution of plant parts eaten (%) as observed from field investigations for dry (A) and wet (B) seasons. Source: Authors

by the fact that the area is dominated by a variety of tree species with different phenology schedules, thereby securing the availability of fruits on a continuous basis, although patchily distributed. Also, fruits have high concentrations of minerals, proteins and sugars needed for metabolism. Indeed, we saw the following trees producing fruits during both dry and wet seasons *Sacoglottis gabonensis*, *Duboscia macrocarpa*, *Irvingia gabonensis*, *T. africana*, *Uapaca guineensis*, and all were reported by both the LEK and field survey methods. Seasonal movement of elephants has been related to such fruits in Ndoki National Park in Congo (Blake, 2002) and Lopé reserve in Gabon (Beirne et al., 2020; Mills et al., 2018; White, 1994). Consumption of barks by forest elephants increased during dry seasons whereas the proportion of leaves eaten decreased. This variation in proportions may suggest that key minerals needed by elephants during the dry season might be greater in

concentration in the barks of trees as compared to the leaves. Key minerals (calcium, iodine, iron, and zinc) have been documented for savanna and Asian elephants (Sach et al., 2019) but they remain unknown for forest elephants. Although debarking is not generally severe for trees, their contribution, with roots and stems in providing minerals to elephants has been reported in Tanzania (Kabigumila, 1993) and Gabon (White et al., 1993). The low concentration of food resources in minerals over seasons (Rode et al., 2006; Sach et al., 2019) is often compensated by water and soil from baobabs. In the CMNP, four potential baobabs and a lick have been monitored for ecotourism by WWF (MINFOF, 2014) but none of them was consistently used by forest elephants. Therefore, the feeding strategy of forest elephants is based on their ability to select foods that best meet their nutritional needs among the available resources (Sach et al., 2019). Root/tubers and stems appeared to be consumed at

varying proportions over seasons. Roots have been seen hollowed out during the rainy season when soil is moist in area other than swampy areas.

The results showed both similarities and dissimilarities between LEK and field surveys in reported plant species and parts eaten by forest elephants. Twenty-five species were reported exclusively by field investigations and 40 exclusively by LEK surveys. Moreover, among species reported by the two methods, differences were still observed for parts eaten. Thirty-two percent of parts reported by LEK surveys were consistent with field investigations whereas 68% were found to be partially consistent to field observations. For example, LEK reported fruits from *D. macrocarpa* were the only part eaten by elephants, whereas field investigations showed evidence of barks and leaves with forest elephant feeding signs. Also, for *S. gabonensis*, the most reported species for fruits consumption (about 13% of reports), we did not obtain evidence of leaves consumption during field investigations as reported by LEK surveys. Therefore, we argue that discordance between the two methods may be due to the influence of food selection related to seasonal availability (Jin et al., 2006). As such, the two methods might be seen as complementary, and not mutually exclusive, if we are to gather timely and inexpensive information on wildlife (Gilchrist et al., 2005; Service et al., 2014). Elephants' feeding habit may generate conflict with humans, as *I. gabonensis*, *Hexalobus crispiflorus*, *Coula edulis*, reported by both methods, are also food items used by local communities. The understories of some tree species are used as hunting sites since fruit from those trees attract several wildlife species, thereby exposing them to hunters. For example, we have noticed that *Ongokea gore* fruits are used as bait on traps for small sized mammals. Those plants have been reported by both methods as part of the forest elephant diet, suggesting that local populations have important and reliable knowledge about the diet of forest elephants in their surroundings. Field investigations were limited to the southwestern tip of the conservation area. Therefore, as compared to data from the LEK, we may have only covered a limited number of species available in the conservation area. Tchouto (2004) reported 15 different types of vegetation in Campo-Ma'an conservation area with most fruitful plant species being distributed in limited spaces. Given that direct observation of forest elephants is difficult and costly due to forest elephants being elusive and mostly nocturnal (Kambissi, 2010), relying on LEK could be beneficial for providing information on some aspects of elephant ecology, including their diet, and feeding habits. For example, LEK surveys have been recommended as a tool to be used when doing research on elusive and threaten species such as pangolins (Fopa et al., 2020; Nash et al., 2016). Local communities are likely to know a great deal about their local environment and the species with which they have interacted over time, either in competition for shared resources or when

dealing with crop damage from wildlife.

Conclusion

This study has shown considerable overlap in plant species consumed by forest elephants as reported by LEK and field surveys. LEK approach provided valuable information that was confirmed by field surveys of elephant diet composition as well as their feeding habits. Some differences were nevertheless observed between the two methods used, and we believe further investigations are needed before one can better understand what can explain the observed disparities. The findings suggest therefore that LEK can effectively give information on species that can provide important food items to forest elephants. Furthermore, this study gives an overview of the level of interactions that LEK surveys participants have with forest elephants. The combination of LEK and field surveys could be a cost-effective way to collect relevant information on species, while helping to improve the awareness of populations on the potential impacts or threats their activities could pose to forest elephants. Moreover, knowledge of elephants' diet composition can be useful for habitat restoration in a human induced habitat losses and habitat fragmentation.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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SUPPLEMENTARY MATERIAL 1

CONSENT FORM

HUMAN-WILDLIFE CONFLICT IN THE CAMPO-MA'AN TECHNICAL OPERATIONAL UNIT, SOUTHERN CAMEROON

By: _____, PhD student, _____ University. Contact: _____

Preamble:

This questionnaire is designed for research on “the human-wildlife conflicts” in your community, carried out by me, _____.

The research aims are to: (1) assess the socio-economic impact of the human-wildlife interactions around CMNP; (2) study the relationship between different stakeholders that is park staff, local people, the private organizations as well as the non governmental organizations operating in the area; (3) Assess people’s attitudes and perceptions towards wildlife, the park and the wildlife legislation; (4) Study some ecological aspects of the elephants including testing some mitigation measures; and finally (5) Propose plans to mitigate conflicts and promote ecosystem-based management for the park.

If you accept to participate, you will be asked several questions (see questionnaire), and eventually we will visit your farm to assess the level of damage caused by elephants to your crops. The answers that you will provide us on the following questionnaire, which lasts approximately 45 minutes, will remain confidential and will be used exclusively by the researchers for the study.

There is no risk in participating in this study. However, by providing your name, we may use this information in the events of a compensation program that is retroactive. There is no guaranty for this, however. You are free to decline or accept that your name be disclosed for this purpose.

It remains at your discretion to determine whether you wish to answer the questionnaire in whole or in part, or if you do not wish to participate at all. If this study is published, the anonymity and confidentiality of this questionnaire will always apply. You must also be at least 18 years old to participate.

If you have any questions, please do not hesitate to ask me during the interview or later by email at “ _____ ” or by phone at “ _____ ”.

Do you agree to participate in the study under the conditions described above?

If yes, say YES

If no, say NO

Thank you!”

Full Length Research Paper

Status of bamboo species (Poaceae) (Kunth) in Menoua, Agroecological Zone 3 of Cameroon

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Studies on bamboo resources are limited in Congo Basin. This study assessed species diversity, distribution, characterisation and socio-economic importance of bamboo to livelihood in Menoua, Cameroon. Ninety questionnaires, one focus group discussion per village, observation and interviews were administered in 9 villages. *Yushania alpina* (K. Schum.) W.C.Lin, *Phyllostachys aurea* Carrière ex Rivière & C. Rivière, *Bambusa vulgaris* Schrad. ex. J.C.Wendl., *Bambusa vulgaris* var. *vittata*, *Bambusa* species Longinternode, *Oxytenanthera abyssinica* (A. Rich.) Munro, *Dendrocalamus asper* (Schult. & Schult.f) Backer ex K.Heyne and *Dendrocalamus strictus* (Roxb.) Nees were identified. *P. aurea* dominated cultivated lands and settlement areas covered the greatest land surface of 2137 m² with an altitudinal range (1200-1400 m). Internodes vary (21.8-40 cm) per culm and length (9.8-34.5 cm). The number, length of internodes, height, diameter and number of culms varied significantly across Menoua (P<0.005). The culm (56%) was the greatest used parts. Bamboos had several uses such as aesthetics, soil erosion and landslide control, and landscape restoration. Municipalities are proper to lead bamboo resource management and conservation.

Key words: Bamboo species, biodiversity conservation, Cameroon, Menoua, Poaceae, status.

INTRODUCTION

The global management of natural resources with respect to the increasing demography relying on these resources is a call for concern (Tovissodé et al., 2015; Honfo et al., 2015; Gadinga et al., 2020), especially when millions of local population livelihoods solely depend on these resources for food, medicine, energy and other socio-economic and cultural aspects (Gadinga et al., 2019; Gadinga et al., 2020). Bamboos constitute one of the few selected categories of plants which are taxonomically related, very rich in species (1642) (Vorontsova et al., 2016) and of vital economic and ecological importance (Yigardu et al., 2016; Canavan et al., 2017; Yuen et al.,

2017; Huy and Trinh, 2019; Nfornkah et al., 2020). A total of 115 bamboo species is reported in Africa (Tinsae and Yulong, 2021). Bamboo is a non-timber forest product (NTFPs) with a rapid growing rate, and with tremendous importance to humans (Nath et al., 2015; Yuen et al., 2017; Terefe et al., 2019; Nfornkah et al., 2020). Bamboos are renewable and harvested (Wu et al., 2009), as some species grow a meter per day and attain maturity during five years (Jayaraman and Trinh, 2019).

Bamboos are cultivated in many rural areas to support subsistence agriculture through the supply of forage and manure, fencing and tools (e.g. ladders, etc.), and other

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art works like sculpting of musical instruments (Cottingham, 2011; Honfo et al., 2015; Tovissodé et al., 2015; Nath et al., 2015; Akoto et al., 2018), building fish-traps and shelter in the traditional fishing locals (Ingram et al., 2010; Tovissodé et al., 2015; Neba et al., 2020). Bamboo conserves soil moisture, as it has the ability to recharge underground water and maintain surface water, prevent soil erosion because of its well-developed rhizome or root system (Terefe et al., 2019); sequester carbon, and thus mitigate climate change (Du et al., 2010; Song et al., 2011; Nath et al., 2015; Yuen et al., 2017; Terefe et al., 2019; Nfornekah et al., 2020). Economically, bamboos generate an accrued amount of over 60 billion USD in the international market and 39.6 billion for the China Market (INBAR, 2019a; Nfornekah et al., 2020); this, however, represents just a small fraction of the overall benefits from the plant.

The circular N°059/C/MINFOF/CAB of April 21, 2016, of the Ministry of Forestry and Wildlife (MINFOF), suspended the exploitation of tree poles in the national domain of Cameroon. Since then, the exploitation of bamboo as an alternative for poles has intensified. This triggered a growing concern about the guarantee of bamboo species and ecosystem's sustainability, as very insufficient knowledge is available on bamboo distribution, diversity and resource availability, especially in natural forests (Tchamba et al., 2020; Neba et al., 2020; Zhao et al., 2018). Sustainable management can only be achieved with real statistics on the population structure and dynamics (Canavan et al., 2017; Zhao et al., 2018; INBAR 2018; Tchamba et al., 2020). Several studies have been done especially in Asia-Pacific (Nath et al., 2015; Yuen et al., 2017; Terefe et al., 2019) but little has been done elsewhere, particularly in Africa (Tovissodé et al., 2015; Honfo et al., 2015; Gurmessa et al., 2016; Nfornekah et al., 2020). In Cameroon, despite its importance, limited studies have been reported on the occurrence, distribution, availability, and utilisation of bamboo in Cameroon (Ingram et al., 2010; Ingram and Tieguhong, 2013; Nfornekah et al., 2020; Neba et al., 2020; Tchamba et al., 2020) making it difficult to put in place a management strategy.

In the Menoua Division, West Region of Cameroon, which is the focus of this study, the report of Chimi et al. (2021) identifies various bamboo uses and products in the Western Highlands of Cameroon including Menoua. Ananfack et al. (2022) report the propagation of *Bambusa vulgaris* in order to ensure the sustainability of the bamboo resource base and contribute towards improving the livelihoods of rural bamboo-dependent communities. Furthermore, Meyabeme et al. (2022) examine the different actors involved in the bamboo value chain as well as assess the different strategies to adequately develop bamboo in the Menoua Division. These recent

publications have not provided information on the diversity, distribution, and dominating bamboo species characteristics that will buffer its utilisation in diverse domains in the Menoua Division.

This study was initiated to evaluate the current bamboo status for proper conservation and management strategies for the resource. This study had the following objectives: (1) identify bamboo species and their distribution, (2) characterize the bamboo structure and (3) evaluate the socio-economic importance of bamboo to the livelihood of the local people.

MATERIALS AND METHODS

Study area

The study was carried out in Menoua Division, West Region of Cameroon, situated between longitude 9°50' and 10°20' East (E) and latitude 5°12' and 5°38' North (N). The climate is remarkable with two main seasons, including a short dry season that lasts from November to March, and a long rainy season that lasts from April to October. The annual precipitation rate rises between 1500 and 2000 mm/year. The temperature fluctuates between 18 and 30°C with a strong daily variation and an average temperature of 25°C. The relief is mountainous. In the high altitude, the soils are ferrallitic; and in the valleys, they are hydromorphic and fertile. The land is undulating and accidental (risk zones), with marshy areas and slopes at lower altitudes. The soils are generally black coloured and rich in humus, thus favourable for agriculture. Human activities have transformed the vegetation and forest cover gradually into agricultural land use systems (Letouzey, 1985). Some forest galleries are present in areas usually called "holy places" or "sacred forests" as well as in swampy areas, and around waterfalls.

Sites selection

The study site was selected purposefully based on: (1) bamboo distribution in Cameroon guided by Ingram et al. (2010), who reported bamboo availability in Menuao and (2) convenience, that is having the resource availability (fund and time), for data collection. In Menoua, 3 subdivisions out of 6 were selected based on bamboo availability and easy access to bamboo stands (forests) or collection zones during data collection. Sampled villages were selected based on their activities vis-à-vis bamboo in the subdivisions. A reconnaissance visit was carried out prior to the primary data collection in order to identify the different data collection zones within the Menoua Division. These zones were categorized after the visit according to two criteria: bamboo production and accessibility. Based on these criteria, three subdivisions and nine villages were chosen. In Dschang Foreke, Toutsang and Foto were selected. In Nkong-Ni, Baleveng, Bafou, and Sa-ah were selected and in Fokoue Fonakeukeu, Fotomena and Fomopea were chosen (Figure 1).

Data collection

Two types of data were collected; namely, social and ecological data. The social data were collected according to Angelesen et al. (2011). Semi-structured questionnaire designed for household (HH)

STUDY ZONE LOCALISATION

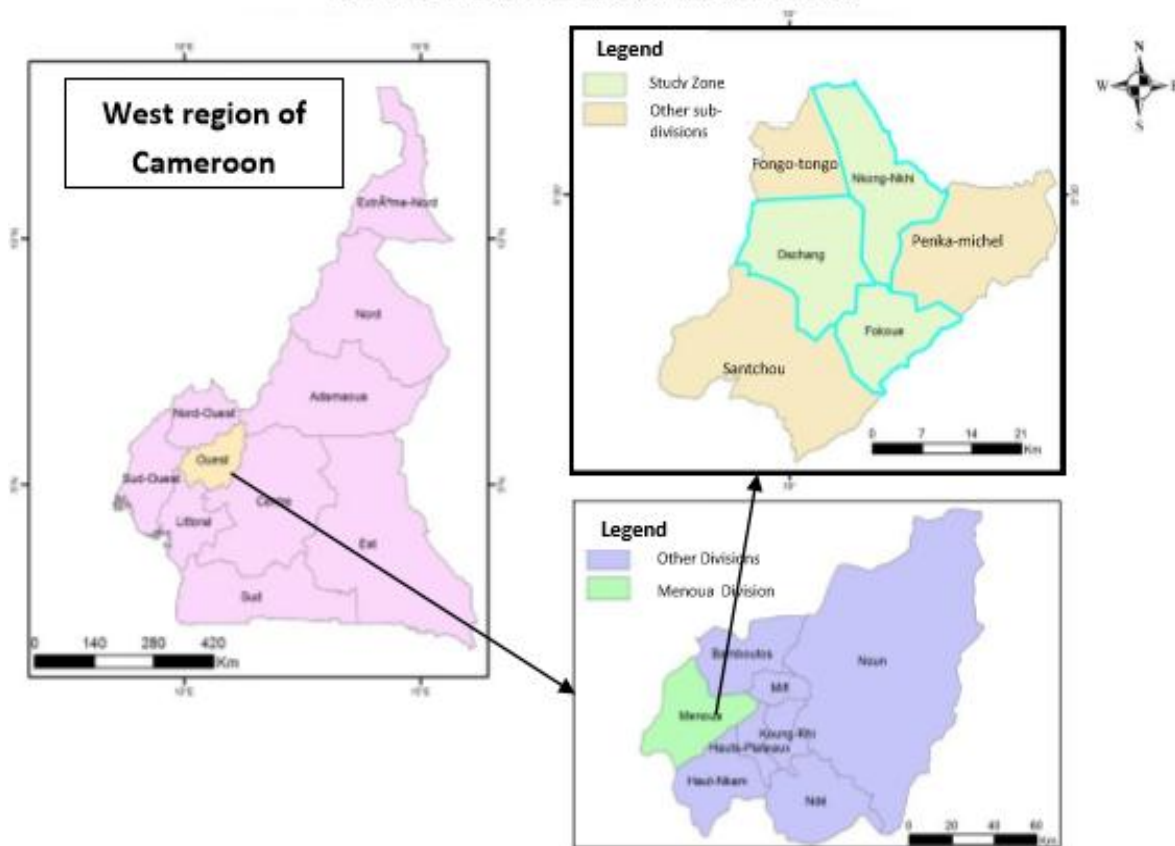


Figure 1. Study area.
Source. Authors

information, interview guide for focus group discussion (FGD), informants interview, and observations characterised the socioeconomic data collection tools and methods. A simple random selection was used to choose 10 respondents for the HH survey in each target village. Each HH must have an activity in the bamboo sector. This study was designed to pursue relatively few HHs per village but increased the number of villages in the study area (Angelsen et al., 2011). This permits us to understand variation within the study population. HH was defined, thus a home husband, wife, and children; in a polygamous family, the house of each wife was a HH, and in a compound where the children have grown, married and live within the same family concession, a couple's hut is a HH. Respondents to the questionnaires were household leaders (male or female). In nine villages in the study area, 90 questionnaires were administered to bamboo user HHs. This questionnaire was designed to capture information on collection zones, bamboo diversity, the social and economic importance of bamboo. Focus group discussions (FGD) were organised per village selected for the study. FGD was organised in a way that involves key bamboo stakeholders of the village including: traditional administration (chief) and notable in some cases, primary stakeholders (producers, harvesters, craftsmen/artisans, traders, consumers, etc.), and tertiary stakeholders (civil society

organisations). The number of participants in the group was maintained to 7-10 maximum members, to ensure easy coordination. A key informant was used to assist the numerator during discussions. This key informant acted as a translator when the need arises and assist the numerator in the entire exercise coordinating the group. The numerator animates the group in asking questions, follow-up, and taking down salient responses. The FGD captured information on, the origin of bamboo in the village, species exploited, uses, distributions, marketing, methods of conservations, etc. Nine FGD were administered in this study.

The key informant was preferably, a native of the village, who was knowledgeable in such activity. He could speak and translate difficult phrases to dialect and French. He was interviewed on missing data, and also used to triangulate the information from the group discussion.

To assess the distribution, status and cultivation needs of bamboo species, field inventory was carried out in three different plot shapes: circular plot of 200 m², rectangular plot of 200 m² and square plot of 1 m² (Huy and Trinh, 2019). Circular plot was used in bamboo stands in accidental topography having slope above 10°. The rectangular and square plots were in gentle topography. Circular and rectangular plots were used to survey both monopodial and sympodial bamboos, while the square plot of 1 m² was used to

survey only monopodial of small diameter bamboo species. Within a plot, the total number of bamboo culms was estimated by counting. To minimize the impact of destructive harvesting on bamboo stands, 3 bamboo culms representing minimum, medium, and maximum sizes and heights of bamboos per plot were harvested and information on structural characterisation was recorded. Parameters such as, mean length of internodes, mean height, and mean diameter at breast height (D) of culms of the individual species were documented using measuring and diameter tapes. The number of plots per village grows with respect to the increasing bamboo stand population. A hand pocket GPS was used to estimate bamboo surface area (coverage). During coverage estimation, the GPS was used to track the bamboo stands and obtain the area covered automatically at the end. The limitation of this method was that only accessible bamboo stands were tracked. GPS was also used to collect coordinates of different bamboo species stands and this was used to produce a map of species distribution in the study area. Herbarium vouchers were deposited at the National Herbarium in Yaounde Cameroon for identity confirmation.

Data analysis

Data from questionnaires and bamboo parameters for characterisation were entered in separate Excel spreadsheets. SPSS version 20.1 software was the main software used for data analysis. Both descriptive and inferential statistical analyses were performed. Shapiro-Wilk test showed that the data were normally distributed and the parametric test of ANOVA was performed to test for significant levels with respect to variations in the number of internodes on culms, length of internodes, the height of culms, and diameter at breast height (D) of culms in the nine selected villages. Significant levels were also tested amongst the different species of bamboo. Descriptive representations (tables, percentages, etc.) were used in the social characterisation of the study population. Focus group data were analysed by content analysis. Interpretation and triangulation were made with reference to the literature review. The QGIS version 2.18 was used to produce bamboo distribution in the Menoua Division.

RESULTS

Bamboo species and distribution in Menoua Division

Socio-demographic characteristics of respondents

The age class 20-29 years were highly represented in 30% and 30 - 39 (27%) and age class 60+ years was the least (10%). Males (75.5%) were more represented in bamboo activities than females (24.5%). Most respondents were married (58%) and had attended secondary education (44%), and 44.4% of the native villagers had large family sizes (Table 1).

Identification and distribution of bamboo species

The bamboo species identified were at least 6 species

including *Phyllostachys aurea* Carrière ex Rivière & C. Rivière, *B. vulgaris* Schrad. ex J.C.Wendl. *Bambusa* species Longinternode, *Oxytenanthera abyssinica* (A. Rich.) Munro, *B. vulgaris* var. *vittata* (painted bamboo), *Yushania alpina* (K. Schum.) W.C.Lin, *Dendrocalamus asper* (Schult. & Schult.f.) Backer ex K.Heyne and *Dendrocalamus strictus* (Roxb.) Nees. *P. aurea* dominated cultivated or agricultural lands and settlement areas, *B. vulgaris* were mostly found along streams and on the Foreke escarpment, and *Y. alpina* was restricted on hills.

Informants affirmed that the *B. vulgaris* had been planted during the colonial period by the Germans to stake crops, and those on the Foreke escarpment were planted to control soil erosion and landslides. These bamboos were identified on their natural stands and on cultivated sites, with *B. vulgaris* (44%) and *P. aurea* abundance in Fokoue (15%) with medium and small culm sizes, whereas, *Y. alpina* was restricted in some areas of Dshang and Fokue. *P. aurea* (41%) was dominant in the Menoua Division because of its availability in natural stands especially in the sacred forests, as well as cultivated lands. Also *P. aurea* was widely distributed as live fences or on cultivated plots; hence, they were the most harvested for domestic uses. The population did not know about *B. vulgaris* var. *vittata*, *Bambusa* spp. Longinternode, and *O. abyssinica* because they were newly introduced into the Botanical Garden of the University of Dshang, Cameroon.

Two growth forms of bamboo were recognised. All the *Y. alpina* grew and spread in all directions and individually (monopodial) while the *Bambusa* spp. and *O. abyssinica* grew in groups or clusters with the youngest always on the outer surface of the cluster (sympodial).

Bamboo planting and frequency of harvesting in the Menoua Division

Planting bamboo was not a common phenomenon. Only 32% of the respondents have planted bamboo on their lands. Bamboo planters were motivated by greening in live fences (75%), erosion and landslide control (14%). About 10% of respondents used planted bamboo for construction materials, 6% for live fences/hedges and land boundary demarcations and finally 03% from the local community. Dshang recorded the highest percentage of bamboo planted on plots (46%) followed by Fokoue and Nkong-Ni with 39 and 15%, respectively.

Bamboo regeneration was natural in all areas surveyed; and the resource was largely unmanaged. No regular harvesting techniques were used by harvesters to harvest culms. The local harvesters had and currently used the notion of colour to differentiate matured culms

Table 1. Demographic characteristics of respondents.

Variable	Frequency	Percentage
Age (years)		
20 - 29	27	30
30 - 39	25	27.7
40 - 49	12	13.3
50 - 59	17	18.8
60+	9	10.2
Gender		
Male	68	75.5
Female	22	24.5
Marital status		
Married	52	57.7
Single	23	25.5
Divorced	1	1.1
Widowed	5	5.5
No answer	9	10
Education level		
Primary	14	15.5
Secondary	40	44.4
High education	25	27.7
Never schooled	1	1.1
No answer	10	11.1
Family size		
2 - 4	14	15.5
5 - 8	21	23.3
9+	40	44.4
No answer	15	16.6
Origin		
Native	87	96.6
Non-native	3	3.4

Source. Authors

from young ones. Desirable matured culms were identified by the yellowish-brown colour and were harvested usually with a cutlass or manual saw. Bamboo harvesters did not have modern tools such as chain saws. The quantity harvested was difficult to estimate by the bamboo users, but it was possible to count the number of bamboo culms exploited, amounting to about 5642 bamboo in 3 years. Harvesting was more at certain periods, especially in the dry season when traditional ceremonies like funerals are many. Respondents (40%) harvested bamboos according to demand and not seasonal. Some respondents (29%) could not estimate

their harvest, while 20% harvested bamboo for fuelwood.

The growth duration of bamboo to maturity depended upon the species. Respondents said *B. vulgaris* takes between 5 and 8 years, *Y. alpina* takes 3 to 5 years to mature. *B. vulgaris* was collected for construction because of the larger diameter and height.

Constraints on bamboo planting and management strategies in Menoua Division

A number of respondents (29) had planted bamboo in

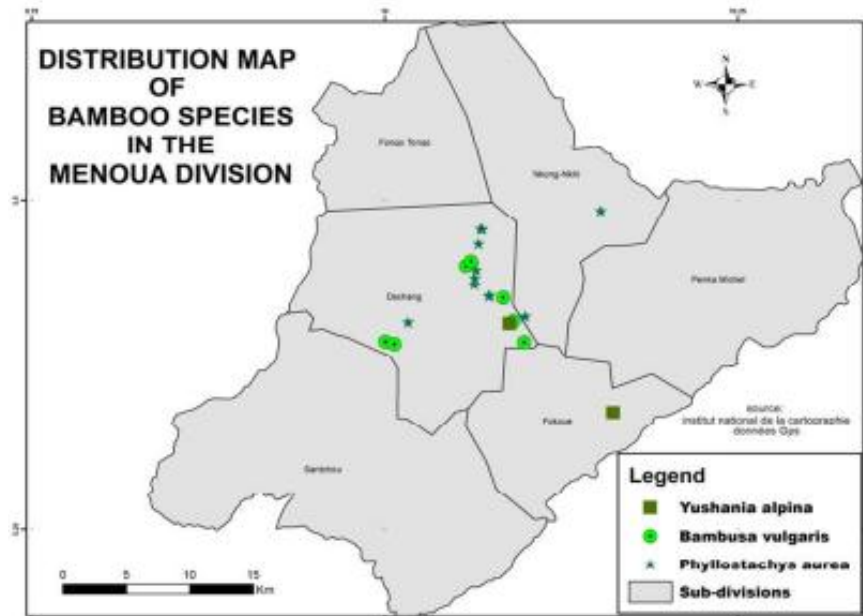


Figure 2. Bamboo distribution/location in the Menoua Division.
Source. Authors

their lands. Nine of them faced no management problems with bamboo presence on their land, while 20 encountered problems with bamboo on their land. Two main problems were reported including rapid growth and invasiveness in nature. 66% of the planters dug off bamboo to free their lands for other use; meanwhile 34% cut or pruned to reduce bamboo invasion. 93% of the bamboo sites visited were natural bamboo stands, and only 2 were planted by the National Forest Development Agency (ANAFOR) and the University Botanical Garden in Dschang. The University of Dschang has planted bamboos in its garden; amongst which were new species (*B. vulgaris* var. *vittata*, *Bambusa* spp. Longinternode, *D. asper*, *D. strictus* and *O. abyssinica*). Few farmers were interested in knowing how to cultivate bamboos by vegetative propagation. Most (59%) of the planters had no interest in cultivating bamboos.

Bamboo production zones distributed and growth morphology in Menoua Division

The surface area covered by bamboo varied across sub-divisions, villages as well as bamboo species. Generally, *P. aurea* had the highest mean surface area coverage (2137 m²) in the Menoua Division, followed by *Y. alpina* (1225 m²) and *B. vulgaris* (893.8 m²). *B. vulgaris* var. *vittata*, *Bambusa* spp. Longinternode and *O. abyssinica*

occupied an area of 960 m² each in the Botanical Garden of the University of Dschang. The altitudinal range for bamboo production was between 1200 and 1400 m. For *B. vulgaris*, it grew in a wide altitude in the tropics, this may be why it is referred to as a pantropical bamboo species. *Y. alpina* and *P. aurea* were largely seen on altitudinal range of 1300 to 1400 m. Figure 2 shows the distribution or location of different bamboo species in Menoua. For distribution pattern, all *Bambusa* spp., *Dendrocalamus* spp., and *O. abyssinica* found in the study area grow in clusters (sympodial), while all *Phyllostachys* spp. grows by spreading out its rhizomes horizontal in all directions in so far as their rhizomes are not perturbed. This growth form is called monopodial growth. *Yushania*'s growth pattern is trickish as it assumed both growth forms. It could be seen with monopodial or sympodial or mixed form.

Structural characteristics of bamboo stand in the Menoua Division

It was observed that the mean number of internodes on bamboo in the Menoua Division varied from ca. 22 to 40 internodes on a culm and its length also varied from 9.8 to 34.4 cm (Table 2).

The bamboo with the largest size was found in Dschang, precisely in the village of Foreke with an

Table 2. Characteristics of bamboo stands in the selected villages.

Village	Number of internodes on a Culm	Length of internodes (cm)	Height of Culm (m)	Diameter of Culm (cm)
Foreke	40.0±1.8	34.4±1.3	16.3±0.7	21.6±1.1
Sa-ah	40.1±3.1	34.2±2.2	16.0±1.3	20.2±2.0
Fonakeukeu	37.3±2.0	27.0±1.4	10.3±1.0	14.4±1.2
Fotomena	30.6±3.1	34.4±2.2	12.9±1.4	20.2±2.0
Fomopea	37.2±4.2	20.3±3.0	9.0±2.0	9.0±2.6
Foto	35.8±1.3	18.3±1.0	6.5±0.6	8.6±1.0
Baleveng	35.8±4.2	17.2±3.00	4.7±2.0	6.3±2.6
Toutsang	31.9±1.8	13.9±1.3	4.3±0.8	6.4±1.2
Bafou	21.8±4.2	9.8±3.0	1.5±1.8	2.1±2.6
Pr > F	0.0018	0.0002	0.0013	0.0003
LSD	6.29	4.52	2.77	3.86

Source. Authors

Table 3. Dendrometric characteristics of bamboo species in the Menoua Division.

Bamboo species	Number of internodes on a culm	The length of internodes (cm)	Height of culms (m)	Diameter	Number of bamboo/m ²
<i>B. vulgaris</i>	37.8±1.2	34.2±0.6	15.0±0.4	6.5±0.5	1.8±0.7
<i>Y. alpina</i>	41.7±2.4	18.9±1.2	8.4±0.9	2.8±1.1	56.0±16.9
<i>P. aurea</i>	32.6±1.1	14.4±0.5	4.2±0.4	1.80±0.5	130.94±12.6
Pr> F	0.0002	0.0012	0.0035	0.00024	0.0001
LSD	3.65	1.73	1.29	1.68	37.84

Source. Authors

average height (H) and diameter (D) of 16.3 ± 0.7 m and 21.6 ± 1.1 cm, respectively. The village of Foto had the most abundant distribution of bamboos. The bamboo with the smallest size was found in Nkong-Ni precisely at Bafou with an average H and D of 1.5 ± 1.8 m and 2.1 ± 2.6 cm, respectively. ANOVA test indicated that the number of internodes on a culm, the length of internodes, H of culms as well as D of culms varied significantly across the nine selected villages ($p < 0.05$).

Y. alpina had the highest number of internodes (42) with a moderate length of internodes (19 cm), with average H of 8.4 m, and average D of 2.8 cm. Meanwhile, *B. vulgaris* had a moderate number of internodes (38), with average length of internodes (34.2), average H of 15 m and average D of 6.5 cm. *P. aurea* on its part was the least, although with the largest number of shoots/m² (Table 3).

The number of internodes on a culm, the length of internodes, H of culms as well as D of culms and number of bamboos in 1 m² varied significantly across the three main species of bamboo found in the Menoua Division ($p < 0.05$).

Socio-economic importance of bamboo species in the Menoua Division

Local knowledge of bamboo

The local population (93%) identified the different bamboo species using the following: (1) H of culms, D and leaves, (2) size and (3) on very rare occasions their flowers. In Dschang, respondents (45%) identified *P. aurea*, 42% respondents identified *B. vulgaris* and 41% identified *Y. alpina*. In Fokoue, 48% respondents identified *Y. alpina* and followed by 35% with *B. vulgaris*. The local population of Nkong-Ni knew two main bamboo species: *P. aurea* (45%) and *B. vulgaris* (23%).

Uses of bamboo in the Menoua Division

All the parts of the bamboo from the roots, culms, branches and leaves were utilised differently. The culm (56%), branches (25%), roots (16%) and leaves (2.2%) in order of importance were used. Bamboos had numerous

uses (Figure 3). In Dschang, *B. vulgaris* and *P. aurea* were highly used to stake crops like bananas, plantains, tomatoes, beans, yams, protection of young plants or trees, construction of pig and rabbit houses, feeders for broilers and fishing tools. Most of the respondents said staking farm crops with bamboo increased yields.

Dschang recorded the highest uses of bamboo for live fences and hedges, as well as aesthetics or ornaments, including use for soil erosion control and landslide; followed by Fokoue community who used *P. aurea* leaves as forage for goat. Meanwhile in Nkong-Ni, bamboo was highly used as construction material (Dschang > Fokoue > Nkong-Ni). *B. vulgaris*, *Y. alpina* and *P. aurea* were used as poles in building of houses, house supports, electricity poles, antenna masts, as well as construction of traditional bridges, garner, and local football goal posts. Other uses of bamboo in the Menoua Division were domestic utensils. *Y. alpina*, *B. vulgaris* and *P. aurea* were used to manufacture domestic utensils like cups, flower plots/jars, walking sticks (13%) and water pipes to collect water from running river or streams (2%). Bamboos were also used in traditional ceremonies (10%) in funerals (e.g., *B. vulgaris*) and the birth of twins (*P. aurea*).

Bamboo trade in the Menoua Division

Trade in bamboo was not lucrative, as 93% of bamboo planters never sold bamboo. The remaining 7% sold with very low prices ranging from 200 (\$ 0.4) to 1000 F CFA (\$ 2) for each bamboo culm, depending on the size and height with respect to its maturity (Table 4). Two bamboo species were mostly sold: *B. vulgaris* during funeral ceremonies and *P. aurea* distributed to farmers cultivating crops for support (stake tomatoes, beans, yams etc). Only 7% traded bamboo directly to earn income (Figure 4).

DISCUSSION

Bamboo species and distribution in Menoua

The results revealed that males of youthful ages were largely implicated in the bamboo sector, most of which were natives and literate. This suggests that the bamboo arts are laborious, and warrant hard manual work. The literacy level suggests that respondents know more of the cultural uses of bamboo. Their marital status implies that the families were more stable in the villages.

This study results on bamboo species diversity corroborates with those of Ingram et al. (2010) who identifies similar bamboo species (*B. vulgaris* and *Y.*

alpina) in the Western Highlands of Cameroon, otherwise called Agroecological zone 3 (AEZ) and *B. vulgaris* and *O. abyssinica* in the dense forest of Centre and East Cameroon or AEZ 5, respectively.

The distribution of bamboo is determined by its growth form and origin. The results agree with the observations of different authors. The Germans were particularly influential in introducing bamboo in Cameroon to be used in the Agro plantation in the Coast of Cameroon to support bananas, rubber, palm nut harvesting and road side hedges to act as breaks to landslides and erosion (Ingram et al., 2010; Nfornkah et al., 2020). These bamboo species became naturalised in Cameroon. The *B. vulgaris* var. *green* and the *P. aurea* are introduced species in Menoua and Cameroon that have been naturalised. They are also used for roadside and water banks stabilisation to prevent landslides, beehive construction, etc. (Nfornkah et al., 2020).

The *B. vulgaris* var. *vittata*; *Bambusa* spp. Longinternode, *D. asper*, *D. strictus* and *O. abyssinica* are newly introduced in Dschang with the help of the University of Dschang in collaboration with INBAR. Note should be taken that *O. abyssinica* is an African endemic bamboo with origin in Ethiopia (Kwame et al., 2020).

Bamboo distribution was highly influenced by their growth morphology. This study identified two spatial patterns in growth forms, which were running (monopodial) and clusters (sympodial). This distribution has got particular importance in the theme of tropical ecology and theories which explain the coexistence of bamboo species (Wiegand et al., 2007; Yigardu et al., 2016). The results showed high clusters of bamboo species on small scales with a progressive reduction in density as they spread outwardly with respect to distance. The bamboos are said to be growing in clumps or sympodial form where very old bamboos are found in the centre of the clumps with young shoots on the periphery. This particular type of spatial distribution is reported by many authors (Nath et al., 2015; Tovissodé et al., 2015; Yigardu et al., 2016; Yuen et al., 2017; Terefe et al., 2019; Nfornkah et al., 2020).

Truly, aggregation is a usual phenomenon in species distribution in nature (Wiegand et al., 2007). The spatial patterns observed in bamboo individuals are reproductive characteristics which favour the regeneration species mode of life. A single rhizome develops many buds which grow up to new shoots emerging from the ground surface and differentiating into stems or culms (Jayaraman and Trinh, 2019; Huy and Trinh, 2019; Kaushal et al., 2018). The clusters whose culms grow tightly together have short necked rhizomes and those with loose culms have long necked rhizomes (Jayaraman and Trinh, 2019; Kaushal et al., 2018). The other growth form observed with *Phyllostachys* was running otherwise called

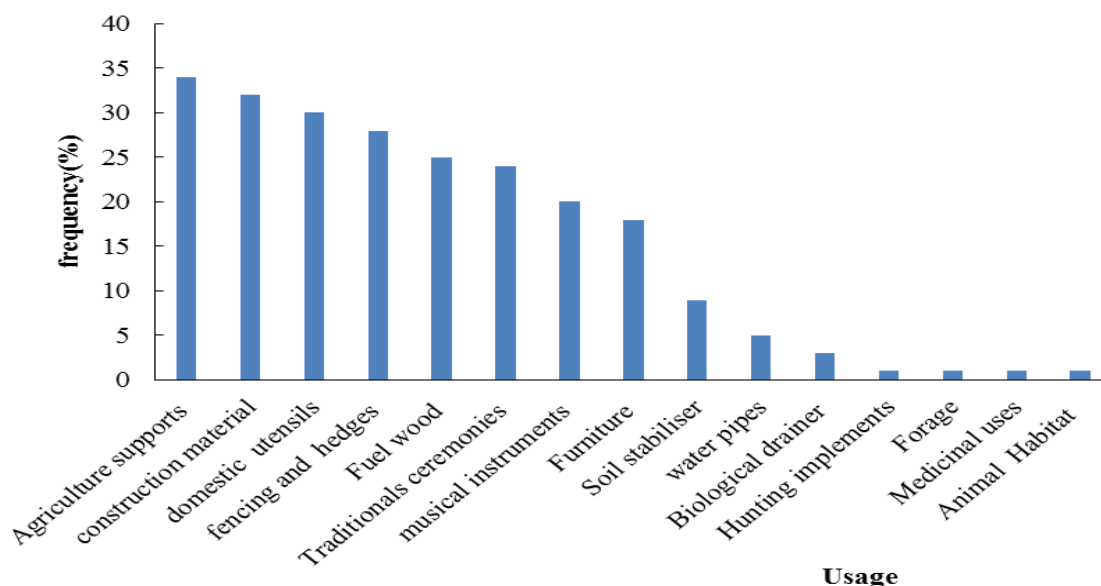


Figure 3. Uses of bamboo in Menoua Division.
Source. Authors

Table 4. Bamboo trade in Menoua.

No.	Bamboo sold	species	Prizes (CFA Frs)	
			Village	Town
1	Bamboo culms	<i>B. vulgaris</i>	200/culm	400-500/culm
2	Bamboo culms in bundles	<i>P. aurea</i>	400/bundle	700-1000/bundle

Source. Authors

monopodial. This growth form is due to the rhizomes of the plant that grow horizontally in the subsoil, with the node buds producing shoots as they spread out (Jayaraman and Trinh, 2019; Kaushal et al., 2018). The results showed that more people are getting involved in the bamboo sector. This might be as a result of the increasing scarcity and growing demand for wood. Bamboo plays a substitute role for wood for craft, infrastructural and other needs.

The ministry in charge of forestry in Cameroon has regulated Non-Timber Forest Products (NTFPs) with Decision No. 0209/D/MINFOF/CAB of 26 April 2019, that classifies special forest products and NTFPs. On the list of NTFPs, bamboo is one and indicated that its conservation status is not threatened. Decision N° 0034/D/MINFOF/CAB of 05 February 2020, lay down conditions for transportation of NTFPs from plantations. Ingram et al. (2010) in their study point out that even in the absence of statutory laws, continued customary regulation is important in ensuring sustainable harvesting

of these species. The people believe that bamboo invades lands and excludes existing biodiversity. This problem is most critical in the case of monoculture bamboo stands where bamboos aggressively invade, replacing local species, and reducing existing biodiversity (Kleinn et al., 2006), although introducing a new form of ecological system.

The results on altitudinal distribution showed bamboo within a range of altitudes. Thus, it is clearly noticed that bamboo species distribution varies according to the altitude. This corroborates with the results of Deo Kumar et al. (2013) who report the altitudinal range of *Bambusa* spp. as 300 to 1500 m.a.s.l., and *P. aurea* as 600 to 1400 m.a.s.l. It was also reported that bamboo can develop well at altitudes of about 1400 m and above (Tran, 2010; Ram et al., 2010; Song et al., 2011). Grimshaw (1999) in a review reports that *Y. alpina* characteristically occurs between 2,400 and 3,000 m, with isolated occurrences in altitudes as low as 1,630 m. This study shows the very rear occurrence of *Y. alpina* at altitudes < 1,630 m in

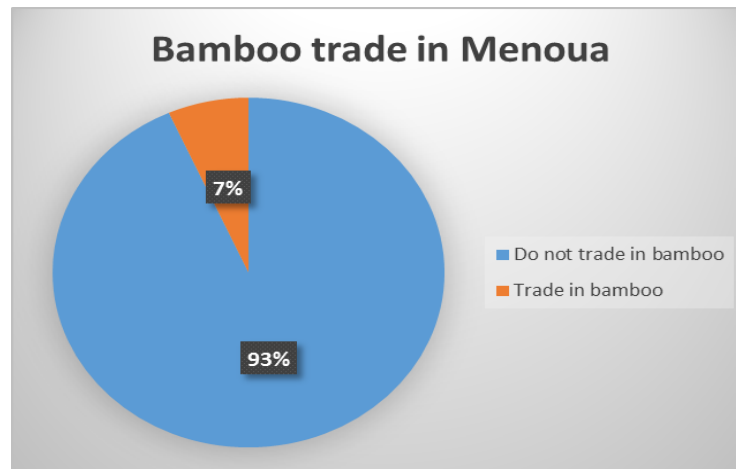


Figure 4. Participation in bamboo trade in Menuoa.
Source. Authors

Menuoa. Tovissodé et al. (2015) however, find a significant difference between wetlands and plateaus ($p < 0.001$) on bamboo species development indicating a strong influence of the topographical units on the relative neighbourhood density. Most bamboo species were found distributed around valleys with high humidity. Bamboo is very important in water recharging and pulling the water table towards the earth surface (Terefe et al., 2019; Kaushal et al., 2018).

Structural characteristics of bamboo stands

These structural characteristics of bamboo is of importance here as it permits to make choices of which bamboo species is good for use depending on the type of project e.g. construction, transformation or wood processing. These study results are in accordance with the findings of Nforokah et al. (2020) with respect to *O. abyssinica* recording the range of 2.01 to 6.61 cm and with the mean value of 3.93 ± 0.66 cm, with the diameter and height of range of 2.00 to 11.02 m with the mean value of 8.40 ± 0.36 m.

Tovissodé et al. (2015) found that culms with a diameter ≥ 50 mm were more frequent for *B. vulgaris* than for *O. abyssinica* and when only *B. vulgaris* was considered, culms with $D \geq 50$ mm were mostly encountered in the Ouémé-valley phytodistrict.

Socio-economic importance of bamboos

The results showed that local people differentiate three bamboo species found in the study area using

morphological differences. This was in agreement with the results of Honfo et al. (2015) which support that different local grouping of bamboo species based on morphological variations of the culms (colour: green, yellow, brown; internode, height, internal, and external diameters) and leaves (colour and texture) to identify different bamboo species. With respect to age morphological differentiation using phenology, many authors have described the different observations found on different species of bamboo during their growth cycle (Li et al., 2016; Kaushal et al., 2018; Jayaraman and Trinh, 2019).

Bamboo occupies a very important place in the socio-cultural and economic aspects of the population. Its uses were numerous. These results corroborate with those of Ingram et al. (2010) and Ingram and Tieguhong (2013). The different parts of bamboo have been used for different purposes. Although all parts of the bamboo plants were used, the most used bamboo part was the culms (73%) and leaves (23%) (Honfo et al., 2015). Honfo et al. (2015) in Benin found a total of nine categories of uses recorded including material, implement, agriculture, medicine, firewood, commercial, worship, environment, and social purposes. In the three sub-divisions of this study, Dschang registered the highest uses of bamboo for live fences and hedges as well as aesthetics or ornaments.

This shows that *P. aurea* is very good for live fences, which is in accordance with the research work of Ogunjinmi and Ijeomah (2009). Ingram and Tieguhong (2013) report that bamboo is used as yam props and supports for plantain and bananas. Bamboo is also used as fishing stick (Ogunjinmi and Ijeomah, 2009; Honfo et al., 2015), to build fish-traps and shelter in the traditional

fishing systems (Tovissodé et al., 2015). Again, bamboo is greatly used as soil stabilizers in this area. The bamboo species found in Menoua Division were also used to control soil erosion and landslide. The main reason *B. vulgaris* was planted in the Foreke escarpment of Dschang was to protect the asphalted road linking the West region to the Littoral region of Cameroon. According to Ingram and Tieguhong (2013), bamboo leaves serve as fodder or forage for elephants in the Lobeke National Park of Cameroon. This result showed bamboo leaves used as medicine. This is supported by other results of Anonymous (2013), Honfo et al. (2015) and Yigardu et al. (2016). However, East Africans mostly use bamboo for furniture and specially to make ladders, market tables, rack to dry maize, hanging screens, and dress traps. Bamboo is mostly used in India for furniture (Prasad, 2009), bamboo pulp and paper; textile, composites, panels, boards, chemicals, energy (bio-ethanols) (Anonymous, 2013).

The short supply of timber and other conventional construction materials accompanied by rising costs makes it imperative to increasingly use bamboo as a building material (Nath et al., 2015; Yuen et al., 2017; Terefe et al., 2019; INBAR, 2019b). Bamboo is also used in this community as fuel wood, because of its availability, workability and low cost (INBAR, 2019b). According to the study of Prasad (2009), bamboo is used to manufacture household items and bamboo pipes used for rain water collection from roof tops. Ingram and Tieguhong (2013) also report that musical instruments are made from bamboo.

Trade in bamboo in Menoua was not lucrative. The local people have other activities that are more lucrative such as market gardening and other forms of farming, livestock (poultry and piggery) and petit trading. This agrees with the findings of Bystriakova and Kapos (2006) that international trade in bamboo products across Africa is not well-developed owing to little cultivation of bamboo species, but there are promising experiments being carried out in many African countries (Kokutse et al., 2014). Honfo et al. (2015) find that Bamboo culms have gained marketable value only in the last decade; that was not the case some fifteen years ago and that about 26% of informants were bamboo traders of which 16% were sellers and 10% buyers. The price of bamboo culms was determined by the area (village and town) and on the species (Ingram et al., 2010; Neba et al., 2020). Analogously, the price is higher for species with large and tall culms (Neba et al., 2020). Two bamboo species highly sold were: *B. vulgaris* during funerals ceremonies for the construction of make shift tents; which are cost effective when compare with hiring a readymade canopy and *P. aurea* to farmers cultivating crops to stake tomatoes, beans and yams. This corroborates with

previous economic studies on bamboo that led to the conclusion that characteristics such as diameter, height, and hardness determine bamboo price (Wong, 2004).

Honfo et al. (2015) observe that housing materials demand for *D. asper* and *B. vulgaris* was increasing with that of *O. abyssinica* for both housing and fishing materials in Benin. This is especially true since: (1) bamboo harvesting is becoming an important economic activity that could contribute to the overall income of local people (Mukul and Rana, 2013), (2) the insufficient management strategies that may in some decades, lead to the rarity of the bamboo species because of unsustainable exploitation (Bystriakova and Kapos, 2006) and (3) the increasing demand for wood and biofuels.

Conclusion

This study identified 9 bamboo species in Menoua Division: *P. aurea*, *Phyllostachys* spp., *B. vulgaris* var. *green*, *Bambusa* spp. Longinternode, *O. abyssinica*, *B. vulgaris* var. *vittata*, *Y. alpina*, *D. asper*, and *D. strictus* with five recently introduced (*Bambusa* spp. Longinternode, *O. abyssinica*, *D. asper*, *D. strictus* and *B. vulgaris* var. *vittata*) in Dschang Cameroon. Two bamboo growth morphologies were observed: sympodial for *Bambusa* spp. Longinternode, *O. abyssinica*, *B. vulgaris* var. *vittata*, *B. vulgaris* var. *green* and the monopodial for all *Y. alpina*. *P. aurea* occupied the greatest surface area coverage (2137 m²) in the Menoua Division, followed by *Y. alpina* (1225 m²) and *B. vulgaris* (893.8 m²). The mean number of internode ranges from 21.8 to 40.1 on culms and its length also varied from 9.8 to 34.5 cm. This showed a significant ANOVA result with (P<0.05). Out of the three bamboo species in the communities, two (*P. aurea* and *B. vulgaris*) were of great importance to the population as they were used for funeral ceremony, crop support and soil stabilization, thus improving on their livelihood. A majority of the population could identify the three different bamboo species using morphological differences. The bamboo marketing was still not lucrative in Menoua but has a promising future when valorised. There has been no management and conservation strategy put in place for Bamboo in Menoua. The Council Support Fund for Mutual Assistance (FEICOM) is a veritable income source to the local councils in Menoua, with INBAR as technical partner could invest in the bamboo sector development. Local Council could integrate this in the Council Development Plans, source funds from FEICOM and other development partners to develop this sector to respond to the sustainable development goals 1: no poverty; 7: sustainable energy; 11 sustainable consumptions; 13: combat climate, and 15: life on terrestrial land.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Full Length Research Paper

Sampling techniques for the optimal measure of macromycetes diversity in the Soudano-Guinean ecozone (West Africa)

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Fungi range among the most important organisms in the world thanks to their ecological roles in the ecosystems and their socio-economic importance for human beings. Still, the global fungal species richness is full of uncertainties as evidenced by various estimates. Estimating fungal species richness and diversity is raising many questions related to the sampling effort (in space and time). This study aims to determine the effect of the sampling technique on the diversity measure and natural productions of wild macromycetes in the soudano-guinean forests. Six concentric plots different in the sizes and in the shape were installed in the Isoberlinia doka dominated woodlands. We recorded the number of fruit bodies and the fresh biomass of the species for each plot from June to October 2017. Dendrometric parameters were assessed by counting individual trees with dbh ≥ 10 within plots. A mixed linear model was applied through lme4 package to assess the influence of the size and shape of the plots on the abundance and species richness of macromycetes. An analysis of variances was used to assess the influence of the size and shape of the plots on the fresh biomass. Results showed that the abundance is higher in square plots at sizes 400 and 625m² but the biomass does not differ significantly from one shape of plot to another ($P = 0.228$). Fresh biomass is higher in rectangular plots compared to the square and circular ones. Highest values of specie richness are obtained in the 25 m² for circular plots.

Key words: Diversity indices, sampling technique, macromycetes, natural production, Soudano-Guinean zone, Benin.

INTRODUCTION

Forest ecosystems of the world contain an extraordinary biological diversity. This biodiversity includes all the

processes and functions that contribute to the maintenance of life and offering essential services to

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human beings (Tiecoura et al., 2015). Biodiversity measurement utilizes some techniques and methods that are specific to each taxonomic group of organisms, but the overall output depends upon the sampling effort invested. For each taxonomic group, sampling techniques (Picard, 2007) are defined by considering the specific objective of the study, the geographical and temporal heterogeneity and the human resources required to perform the sampling (Rondeux and Lecomte, 2002). Many others parameters related to the characteristics of the sampling units also should be considered. These include the nature, size, form and sometimes the orientation of the plots. Indeed, the minimal area approach is often used to identify the size of the sampling units in order to characterize plant communities (He and Legendre, 2002). The success of these techniques in the study of plant communities for example depends upon very precise choices of the shape, sizes and nature of the sampling units; whereas, the sampling frequency can vary from one observation per year (Straatsma et al., 2001, Straatsma and Krisai-Greilhuber, 2003) to a weekly interval (Al-thani, 2010). In addition, it is shown that the size of the plots is inversely proportional to the precision of the estimation (Shearer et al., 2007; Salako et al., 2013; Houéto et al., 2013).

Yet, there is no precise standardized technique for optimal measure of mycodiversity in the tropics (Vanié-Léabo et al., 2017; Milenge et al., 2018). Different sampling techniques are used to make an inventory of the fungal communities in an ecosystem (Martínez-Peña, 2008), ranging from opportunistic sampling for inventory purposes to a plots-based survey when it comes to monitoring. Sampling techniques for mycodiversity measures are either executed within permanent plots of square, circular or rectangular shapes, or based on transects of variable sizes (Yorou et al., 2001; Mueller et al., 2004; Hawksworth, 1991, 2003; Vanié-Léabo et al., 2017; Hayward et al., 2015).

Permanent plots of 900 to 2500 m² have been used in some mycodiversity studies in tropical Africa (Vanié-Léabo et al., 2017; Milenge et al., 2018; Yorou et al., 2001; Kangas and Maltamo, 2006). Still, because the size of permanent plots differs and that the frequency of plots visited has changed from one investigation to another, it becomes difficult to make reliable comparisons even for similar ecosystems. Here we test the influence of plot size and shape on the species richness and fresh biomass of macromycetes in a tropical ecosystem.

MATERIALS AND METHODS

Study area

The Okpara woodland forest is located in the Northern zone of Benin, 15 km from Parakou City between 9° 18' and 9° 22' North latitude, 2° 33' and 2° 37' East longitude (Figure 1). It covers an area of 33,000 ha and peaks at an altitude of 295 m. It is a typically tropical climate with one rainy season (from May to October) that

strongly contrasts with one dry season. The soil texture in this area is sandy, sandy-clay or loamy in places (Youssao et al., 2000). The vegetation is dominated by *Isoberlinia doka* and *Uapaca togoensis*, two forest trees typical for the soudano-guinean zone (White, 1983).

Collection, identification and preservation of specimens

Permanent plots of different shape and sizes were installed in one single vegetation type dominated by *I. doka*. Three shapes were used: Square (K), Circular (C) and Rectangular (R). For each shape, 6 concentric plots (25, 100, 225, 400, 625 and 900 m²) were installed. Plots are labeled according to their shape, notably; K1 to K6 for square, C1 to C6 for circular and R1 to R6 for rectangular plots. The Geographic Positioning System Garmin Etrex 20™ was used for georeferencing each plot. The surveys were performed at a fixed frequency of 48 h between two surveys during the mycological season from June to October 2017. Thus, 45 visits were carried out per plot, which corresponds to a total of 810 surveys for all 18 plots. During surveys, all fruit bodies of any Ectomycorrhizal (EcM) fungi were harvested and arranged according to the sampling date, plots shape and size. The samples were then transported to the laboratory. The specimens were identified by means of a compound microscope type Leica LMD6 Microdissection Systems available at the Laboratory of Ecology of Botany and Plant Biology (LEB) of the University of Parakou, using some field guide manuals (De Kesel et al., 2002, 2017, Eyi-Ndong et al., 2011) and a catalogue with more than 1000 color pictures. After counting the number of carpophores and measuring the fresh weight with a Sunto™ electronic balance (0.01g precision), the specimens were assigned a unique voucher number. The best specimens of each species were sorted and placed in sieves before final preparation for drying using the Stockli Dorrex™ brand electric dryer. Drying was done at a temperature between 40 and 45°C for 24 h. Dried specimens were preserved in plastic bags type minigrip and deposited at the Mycological herbarium of the University of Parakou and the dried specimens were kept desiccated in the laboratory.

Data processing and analysis

Dendrometric parameters

The floristic homogeneity of the site was tested by measuring the dendrometric parameters of the trees in each shape of the plots.

Tree density: This is the average number of trees per plot. It is expressed in stems / hectare and mainly concerns trees with a dbh ≥ 10 : $N_i = n / s$, where n: the total number of trees with dbh ≥ 10 cm in the plots and s: the area of the plots (block 6 plots) (ha).

The basal area: It expresses the sum of the basal sections of all trees of dbh ≥ 10 cm found in each block of plots. It is expressed in m² / ha and is represented by the formula below:

$$G = \frac{\pi}{4s} \sum_{i=1}^n di^2$$

n: the total number of dbh trees ≥ 10 cm in the plots; di: diameter of the tree i (m) and s: area of the plot (s = 0.01 ha).

Mycological data

The species richness, the number of fruit bodies, as well as

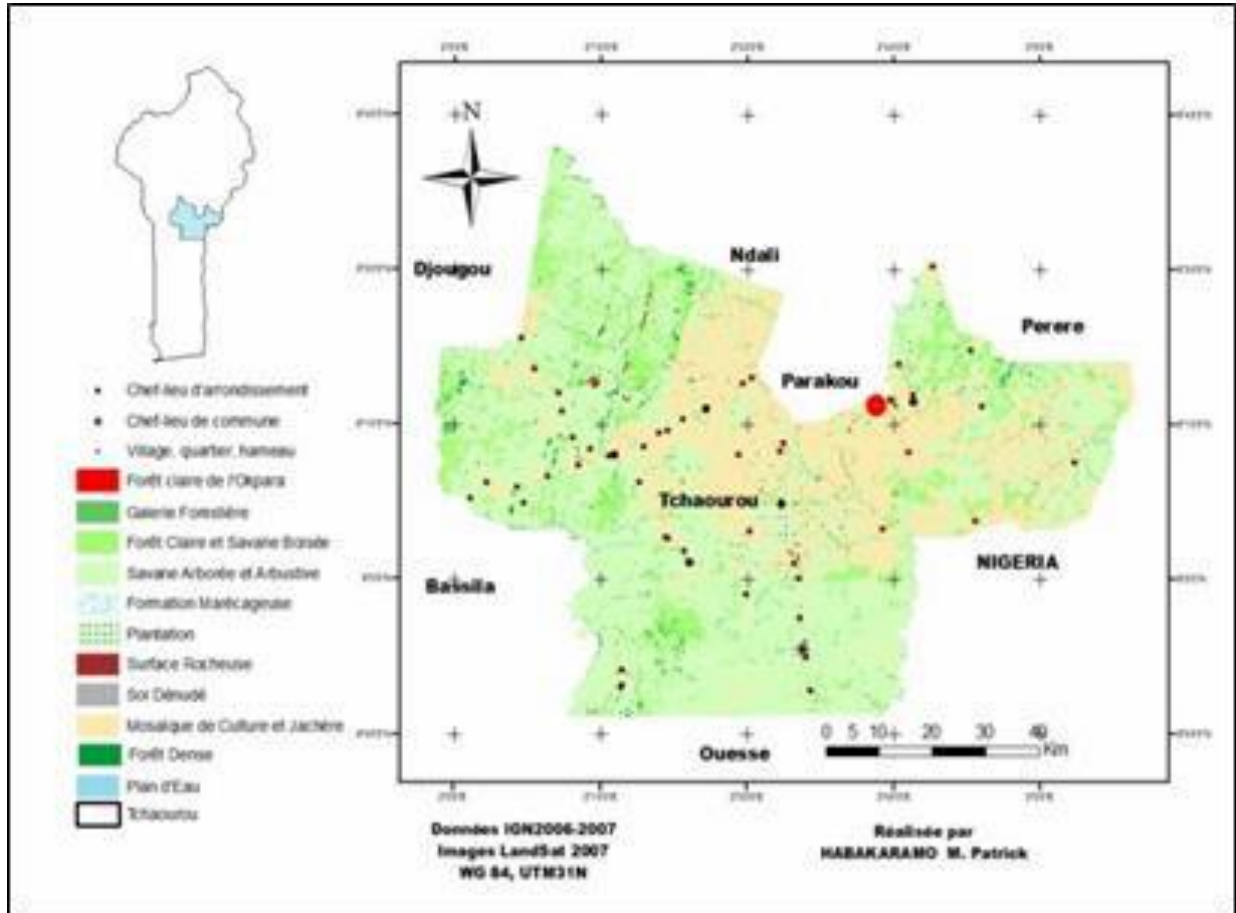


Figure 1. Okpara woodland forest (red point) in Tchouarou municipality.
Source: Authors.

the fresh biomass of each species is computed per sampling date, shape and size of the plot. Time series analysis was applied to assess the evolution of abundance, fresh biomass and species richness by shape of plots as a function of time during the whole fruiting season. The statistical software R version 3.4.2 R was used (Oksanen et al., 2017; R Core Team, 2017). The rank-frequency curves of the sampled species were constructed for each shape of the plots in order to choose the appropriate diversity index to assess the diversity of macromycetes in the ecosystem. The Shannon diversity index (H) and Pielou equitability index (P) were calculated using the vegan package (Oksanen et al., 2017). Subsequently, the specific estimator (Chao1) was calculated under the Biodiversity R package (Kind and Coe, 2005). To assess the influence of the size and the shape of the plots on the number of fruit bodies and species richness of macromycetes, a Generalized Linear Mixed Effect Model (GLMM) was applied through the lme4 package™. To choose the appropriate minimum model, five models were compared on the basis of the Akaike Information Criterion (AIC). The chosen model was one with the lowest AIC. Analysis of variance (ANOVA) was used to assess the influence of the size and the shape on the fresh biomass of macromycetes by applying the statistical software R version 3.4.2 (R Core Team, 2017; Bates et al., 2015). The temporal sampling effort was assessed by constructing the species accumulation curves as a function of the number of surveys according to the rarefaction method for each shape by using the vegan package (Walker et al., 2008). The

certification of floristic homogeneity of the site and the relationship between the dendrometric parameters and the fungal variables (number of fruit bodies, fresh biomass and species richness) was made by the Spearman's correlation test in statistical software R version 3.4.2 (R Core Team, 2017).

RESULTS AND DISCUSSION

Species richness of macromycetes by shape and size of the plots

During 19 weeks of investigations, 90 species of macromycetes sorted into 41 genera were harvested. The most represented genera in the ecosystem are essentially *Amanita* (11 species), *Russula* (9 species), *Termitomyces* (7 species) and *Lactifluus* (6 species). In particular, 63 species accommodated into 26 genera were listed in the square plots against 62 species accommodated into 32 genera within the circular and 60 species sorted into 25 genera in the rectangular plots. A large temporal variation of the species richness of macromycetes among the plots was observed throughout

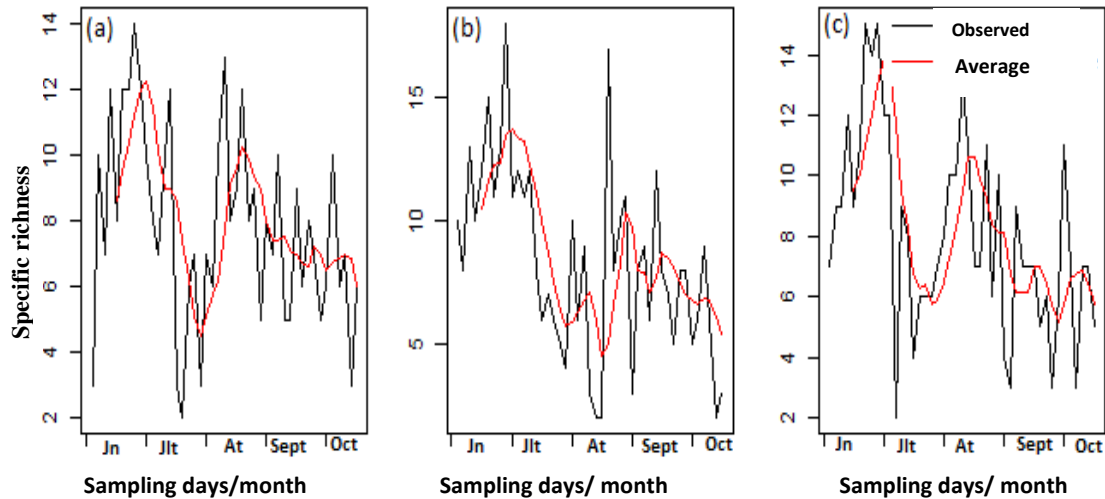


Figure 2. Temporal variation of the specie richness of macromycetes by the shape of plots: (a) circular, (b) square, (c) rectangular.
Source: Authors.

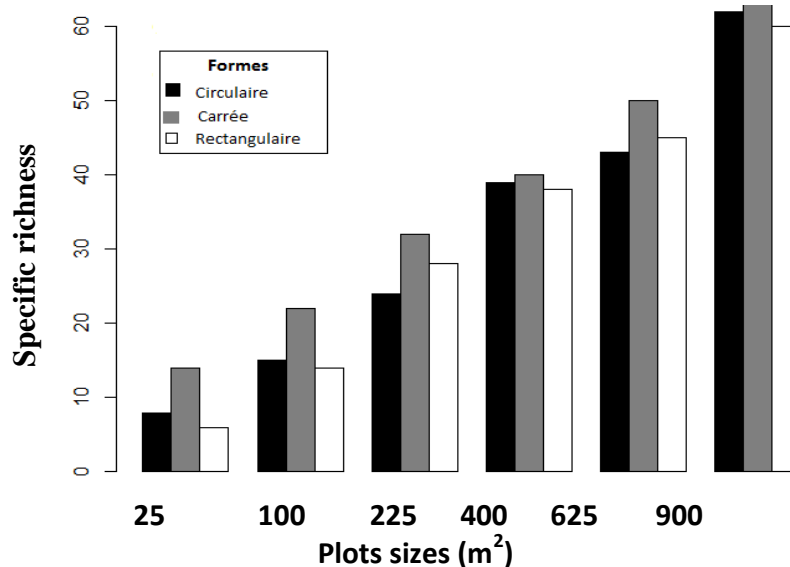


Figure 3. Spatial variation in the species richness of macromycetes by size and shape of plots.
Source: Authors.

the mycological season. This taxonomic richness recorded is smaller than those reported from similar but close to other forest ecosystems. Yorou et al. (2001), identified 126 EcM species after various surveys in different regions of Benin. Furthermore, in the Comoé National Park in the Ivory Coast, Vanié-Léabo et al. (2017) mentioned 123 species distributed in 23 genera; while Kamou et al. (2017) identified 179 species and 52 genera in the Fazao - Malfakassa National Park in Togo. Although these variations in species richness among

studies can be due to the years covered by each of those surveys, it can obviously be explained by climatic variability, soil composition and also differences in host tree composition.

The standardized average curve in red (Figures 2 and 3) shows that maximal species richness is recorded in June with a peak observed towards the end of June (25 to 30); whilst lowest richness is recorded in July (15 to 25). We found out that the species richness increases with the size of the plots regardless of the shape (Figures

Table 1. Variation in the specie richness of macromycetes depending on the shape and the size of the plots.

	Coefficient (β)	Error	Statistics (z)	Probability
Constance		0.1587	-0.4940	0.6213
FC	2.0822	0.1595	13.0540	<0.0001
FR	0.2587	0.2002	1.2920	0.1962
225m ²	0.8979	0.1784	5.0320	<0.0001
25m ²	-1.0761	0.2983	-3.6080	0.0003
400m ²	1.4785	0.1667	8.8710	<0.0001
625m ²	1.8215	0.1621	11.2360	<0.0001
900m ²	2.1101	0.1593	13.2500	<0.0001
FC:225m ²	-0.8979	0.1936	-4.6380	<0.0001
FR:225m ²	-0.2048	0.2409	-0.8500	0.3953
FC:25m ²	1.0761	0.3076	3.4990	0.0004
FR:25m ²	-0.0225	0.3985	-0.0560	0.9550
FC:400m ²	-1.4785	0.1828	-8.0870	<0.0001
FR:400m ²	-0.1839	0.2237	-0.8220	0.4108
FC:625m ²	-1.8215	0.1787	-10.1950	<0.0001
FR:625m ²	-0.2735	0.2179	-1.2560	0.2092
FC:900m ²	-2.1101	0.1761	-11.9840	<0.0001
FR:900m ²	-0.2235	0.2133	-1.0480	0.2945

Source: Authors.

2 and 3). Whatever the size of a square plot is, higher specie richness was recorded in square-shaped plots, while the low scores are observed on the rectangular plots.

Effect of the shape and size of the plots on the species richness of macromycetes

The GLMM results (Table 1) show that the species richness of macromycetes is significantly higher in circular plots ($\beta = 2.0822$, $p < 0.0001$) compared to square plots, but there is no difference between the rectangular ($\beta = 0.2587$, $p = 0.1962$) and square plots. Considering the sizes, the richness is significantly lower ($\beta = -1.0761$, $p = 0.0003$) at 25m² for all three shapes of plots. The interdependent effect between the size and the shape of the plots indicate that the greatest richness was noticed for the circular shape compared to the square one ($\beta = 1.0761$, $p = 0.0004$). Above this size, the richness becomes significantly low for circular plots. Guinberteau and Courtecuisse (1997) indicated that the number of fungal taxa collected depends on the sampling period and the size of the area (plot) as well as the survey frequency during the sampling campaign.

Diversity of macromycetes by shape and size of plots

Our results indicate the predominance of rare species

than abundant in all blocks of plots (Figure 4). The Shannon diversity index was used for the specific diversity and Pielou's equitability index for the distribution of fruit bodies within the species (Table 2). The Shannon index shows that as the size of the plots increases, the diversity of species becomes more important regardless of the shape of the plots with a high diversity recorded at 900 m². Thus, circular plots harbor the highest diversity index (3.05) for 900 m² followed respectively by the rectangular (2.95) and the square plots (2.85).

Species diversity estimated in the different plots is calculated with Chao 1 index from the effective specie richness observed in the field (Table 3). The specie richness and the estimated diversity are higher in square-shape plots. Species recovery from our sampling effort is higher in circular (84.64%) compared to rectangular (83.20%) and square (64.81%) plots. This attests that the fruit bodies are less distributed in the circular plots compared to the other two forms.

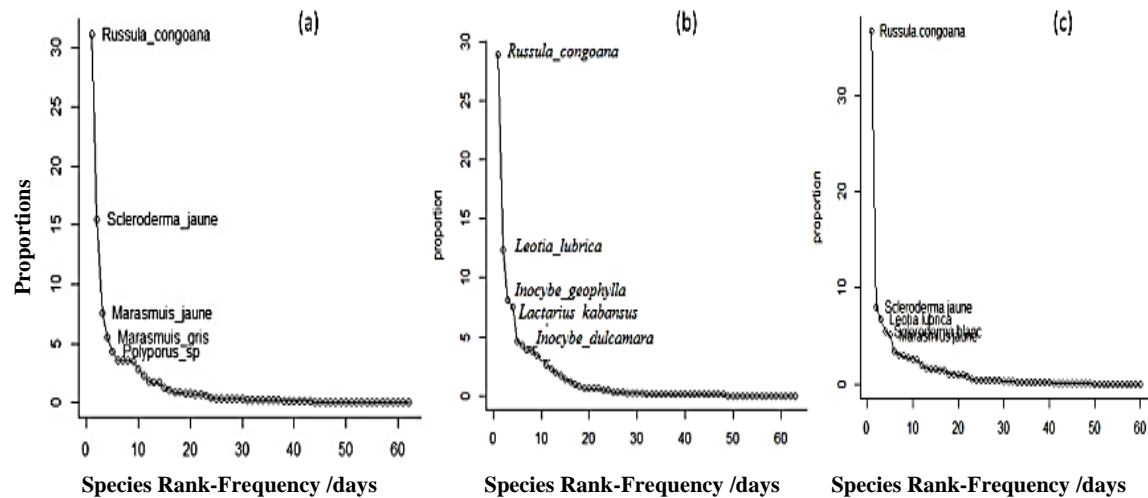
Abundance of macromycetes by shape and size of plots

We collected 7499 fruit bodies from all plots during the whole mycological season. Among these, 2782 were recorded in square plots, 2584 in rectangular and 2133 in circular plots. The standardized average curve of the abundance of fruit bodies shows almost the same dynamic regardless the shape and size of the plot (Figure

Table 2. Shannon (H) and Pielou equitability (P) index of the different forms and sizes of the plots.

Sizes (M ²)	Circular plots		Square plots		Rectangular plots	
	H	P	H	P	H	P
25	1.29	0.62	1.39	0.63	1.29	0.57
100	2.02	0.75	2.11	0.68	2.36	0.6
225	2.17	0.68	2.26	0.65	2.5	0.6
400	2.51	0.69	2.44	0.66	2.68	0.63
625	2.61	0.69	2.57	0.66	2.92	0.68
900	3.05	0.74	2.85	0.69	2.95	0.75

Source: Authors.

**Figure 4.** Frequency rank of species by form of plots: (a) Circular, (b) Square, (c) Rectangular.

Source: Authors.

Table 3. Specie richness observed, estimated diversity and recovery within various forms of plots.

Forms of plots	Observed Specie richness	Estimated specific Diversity, Chao1	Recovery of samples (%)
Squares	63	97.20	64.81
Circulars	62	73.25	84.64
Rectangulars	60	72.11	83.20

Source: Authors.

5). June constitutes the period of highest abundance with a peak observed on mid-June (10 to 15) for all plots. The other months (July to October) recorded lower abundance.

Effect of the shape and size of the plots on the species abundance

According to the GLMM, the results show that the date of

the survey impacted on the abundance at 50% and accounts for the random effect. The fruit bodies abundance is significantly higher in square plots ($\beta = 0.1939$, $p = 0.0297$) compared to circular plots, but this difference was not significant between rectangular and square plots (Table 4). However, our results also indicate an interdependent effect between the size and the shape of the plots. The higher abundance observed in square plots compared to circular plots is observed especially for 400 m² ($\beta = 0.2769$, $p = 0.0052$), and 625 m² ($\beta = 0.2705$,

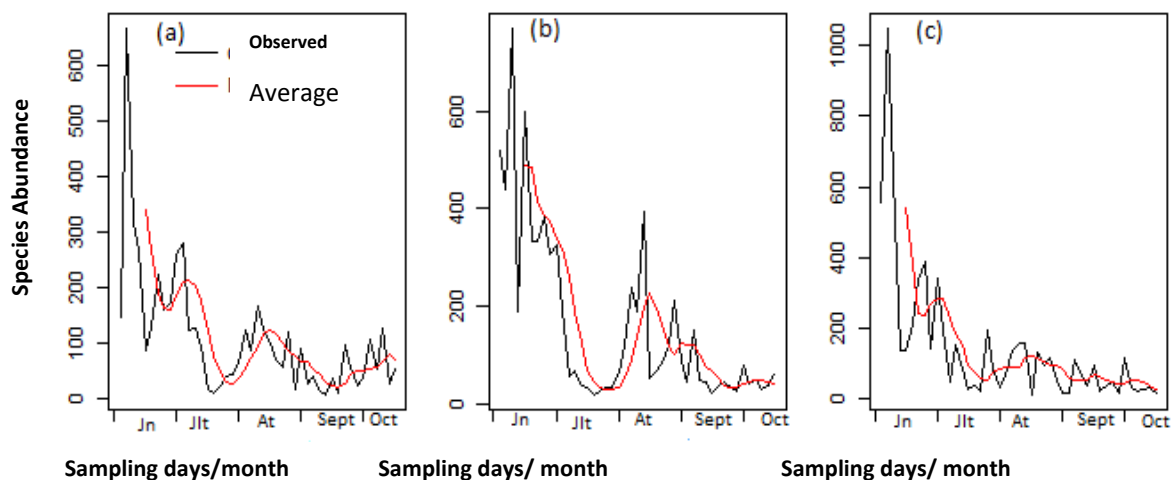


Figure 5. Temporal variation of fruit bodies abundance in the plots: (a) Circular, (b) Square, (c) Rectangular. Source: Authors.

Table 4. Variation of macromycetes abundance by shape and size of the plots.

	Coefficient (β)	Error	Statistics (z)	Probability	Average
Constance	1.1968	0.1503	7.9600	<0.0001	18.22222
FK	0.1939	0.0892	2.1700	0.0297	26.09259
FR	0.1037	0.0911	1.1400	0.2550	23.90000
225 m ²	0.7546	0.0801	9.4200	<0.0001	13.4666667
25 m ²	-1.3228	0.1440	-9.1900	<0.0001	1.39259267
400 m ²	1.3267	0.0743	17.8600	< 0.0001	25.474074
625 m ²	1.6112	0.0723	22.2700	< 0.0001	34.9111113
900 m ²	2.2316	0.0695	32.1100	< 0.0001	55.548148
FK:225 m ²	0.2026	0.1067	1.9000	0.0576	16.088889
FR:225 m ²	0.1166	0.1095	1.0600	0.2870	13.488889
FK:25 m ²	-0.3158	0.2069	-1.5300	0.1270	1.200000
FR:25 m ²	0.0760	0.1958	0.3900	0.6982	1.622222
FK:400 m ²	0.2769	0.0992	2.7900	0.0052	30.711111
FR:400 m ²	0.2210	0.1014	2.1800	0.0294	26.533333
FK:625 m ²	0.2705	0.0968	2.7900	0.0052	40.555556
FR:625 m ²	0.3136	0.0987	3.1800	0.0015	38.688889
FK:900 m ²	0.0717	0.0937	0.7700	0.4441	61.822222
FR:900 m ²	0.0881	0.0957	0.9200	0.3568	57.422222

Source: Authors.

$p = 0.0015$) sizes. The same results are noted by Engeman et al. (1994), Kangas and Maltamo (2006), mycological studies, and in several floristic studies reported by Houéto et al. (2013) and Salako et al. (2013) which recommend square plots.

Natural production of macromycetes

The natural production of all species harvested amounts

to 92.95 kg/ha per year during the mycological season. The rectangular plots with the highest fresh biomass represent 95.53 kg/ha per year, 94.30 kg/ha and 89.04 kg/ha per year, respectively, for the square and circular plots (Figure 6). Highest fresh biomass was recorded in June (10 to 15) with a highest peak in the circular and rectangular plots and at the end of June (25 to 30) for the square plots. Our results are similar to those mentioned by Yorou et al. (2001) in Wari-Maró forest, but different than those noted by Vanié-Leabo et al. (2017). The

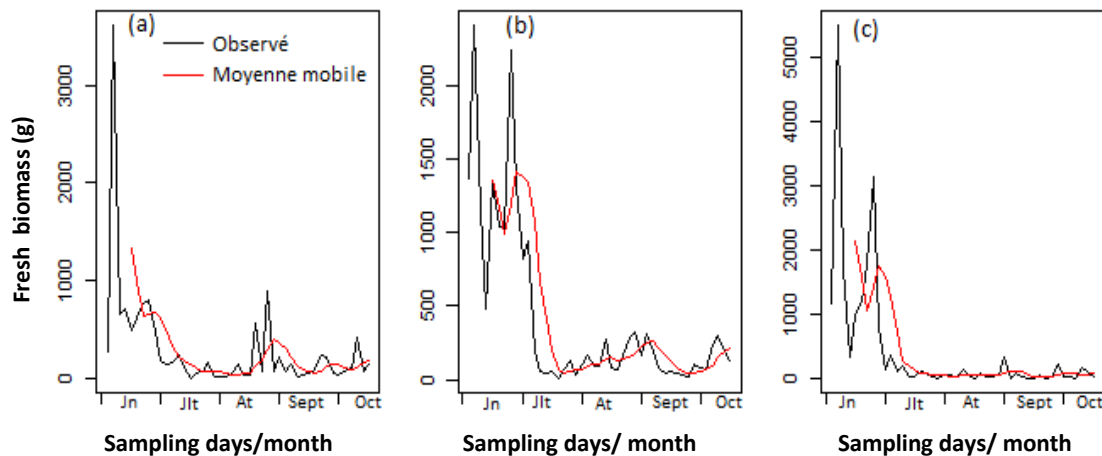


Figure 6. Temporal variation of the fresh biomass of macromycetes by form of the plots: (a) circular, (b) square, (c) rectangular.
Source: Authors.

Table 5. Variance test of the fresh biomass of macromycetes within the different shapes and sizes of plots.

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Shapes	2	73802	36901	1.482	0.228
Sizes	5	3128783	625757	25.140	<2e-16
Shapes: Sizes	10	24522	2452	0.099	1.000
Residuals	792	19713743	24891		

Source: Authors.

difference observed in natural production of macromycetes in this study can be explained by the biotic and abiotic characteristics of the habitats as also noted by Ducouso et al. (2002) and Bonet et al. (2004). In accordance with Straatsma et al. (2001), the fresh biomass and specie richness of macromycetes show several fluctuations from one year to another and it is subjected to habitat fragmentation and climatic fluctuations. In addition, natural production as well as number of fruit bodies shows strong intra-annual fluctuation as already reported in similar ecosystems (Yorou et al., 2001, 2017). In the Soudano-guinean zone, on one hand, macromycetes are very abundant from mid-June to the end of the same month. On another hand, macromycetes are very few (abundance, specie richness and fresh biomass) between the end of July and the end of September during the mycological season.

Effect of the shape and size of the plot on the fresh biomass of macromycetes

According to the ANOVA test, only the size of the plot has a significant effect on the fresh biomass of macromycetes (Table 5). At identical size, the fresh

biomass does not differ significantly from one shape of plot to another ($p = 0.228$); whereas, it does vary significantly according to the size of the plots regardless of the shape ($p = <2e-16$).

Optimal mycodiversity measure: Temporal sampling effort

Figure 7 illustrates the species accumulation curves as a function of the number of surveys (frequency of visits) within the plots. These curves have almost the same temporal sequential trends. The accumulation curves are all ascending and have not reached an asymptote; the temporal sampling effort was not satisfactory because the specie richness increases during the new visit. As noticed by Vanié-Léabo et al. (2017) and Tedersoo et al. (2007), the species accumulation curves, performed as a function of frequency of visits, did not reach a horizontal asymptote. This would indicate the highest species richness of the study area. It means that the visit frequency is an important factor for estimating the species richness of fungal communities in order to have a standardized temporal sampling effort. Many other studies demonstrated that the mycodiversity studies

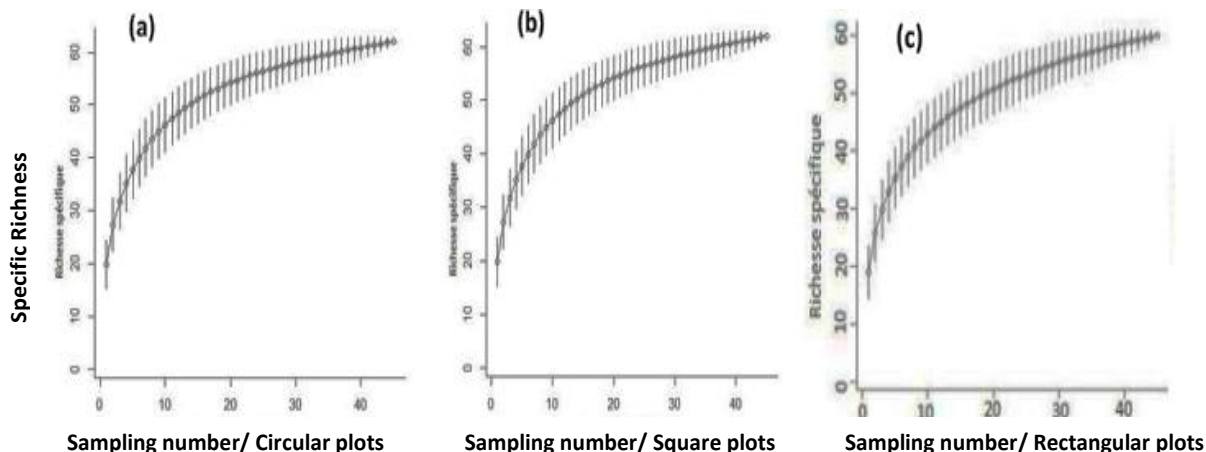


Figure 7. Accumulation and rarefaction curve of macromycetes per sampling number for each form of plots.
Source: Authors.

Table 6. Correlation matrix between floristic and fungal parameters.

Floristic parameter ^a	Macromycetes parameter		
	Species richness	Abundance	Fresh biomass
Trees density	$p = 0.01344$	$p = 0.0609$	$p = 0.1434$
Basal area of trees	$p = 0.02434$	$p = 0.09756$	$p = 0.2626$

Source: Authors.

require several years (3, 8-12, 10 and 21 years, etc.) of sampling to reach the asymptotic curve and that this should be conditioned by standardization of sampling techniques (Guinberteau and Courtecuisse, 1997; Lodge et al., 2004; Mueller et al., 2004; Smith et al., 2011; Straatsma et al., 2001, Straatsma and Krisai-Greilhuber, 2003).

Effect of dendrometric parameters on fungal communities

We recorded 18 tree species ≥ 130 cm in height in the rectangular plots against 17 and 13 species within respectively the square and circular plots. The total density of trees in our inventory plots was 4,811 stems/ha, of which 488 stems/ha were in rectangular plots, 478 stems/ha in square and 333 stems/ha in circular plots. As for the total basal area, it was 943.36 m^2/ha ; or 977.45 m^2/ha for rectangular plots, 923 m^2/ha and 647.21 m^2/ha , respectively, for square and circular plots. It therefore appears that the density and the basal area differ from one form of plot to another. The results of Spearman's test shows that there is no correlation between the dendrometric parameters (density and basal area of trees) and those of fungi (abundance and fresh

biomass of macromycetes) with the exception of species richness (Table 6). Indeed, the species richness is correlated with the density ($p = 0.01$) and the basal area ($p = 0.02$) of trees (Spearman test).

Conclusion

The main results of this research showed that the abundance is higher in square plots at sizes 400 and 625 m^2 , but the biomass does not differ significantly from one form of plot to another ($p = 0.228$). Fresh biomass is higher in rectangular plots compared to the square and circular ones. The highest values of species richness were obtained in the 25 m^2 for circular plots. The information and data collected within this research will allow, in addition to extend the scientific knowledge on fungi (macromycetes) biodiversity, to provide a good methodology and appropriate sampling unity and frequency as well as planning and management of the soudano-guinean tropical forest heritage. We would like to investigate and monitor the aboveground mycodiversity of the Okpara woodland forest for several years using constant sampling units and increasing the number of surveys. It is also desirable to further integrate the floristic, soil and microclimatic parameters to identify all

the factors that govern the fruiting of macromycetes in the soudano-guinean zone.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Full Length Research Paper

Distribution, diversity and abundance of small mammals in different habitat types in the Usangu area, Southern Tanzania

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Habitat type and their vegetation composition play important role in determining the abundance and diversity of animals including small mammals, hence any change in habitat type will influence their abundance and spatial distribution. This study aimed at investigating the influence of habitat types (that is, Wetland grassland, Miombo and *Vachellia* woodlands) on small mammal abundance, diversity, and richness in the Usangu area, in southern part of Ruaha National Park, in Tanzania. Sherman and pitfall plastic bucket traps were employed both for trapping small mammals. A total of 92 small mammals were captured in 2124 trap nights giving 13% trap success representing two families, namely, Muridae (6 species) and Soricidae (1 species). Furthermore, trap success differed among habitat types with the highest being in wetland grassland. Species diversity was higher in *Vachellia* woodlands compared to other habitat types. It would therefore seem that wetland grassland and *Vachellia* woodland habitats are very crucial in maintaining small mammal abundance and diversity in Usangu Area. Therefore, future management plan should incorporate these refuge habitats for continued existence of small mammals in Usangu. Further study is warranted in wet season in order to have comparison information that will assist in management of small mammal in Usangu.

Key words: Conservation, habitat preferences, habitat restoration, Miombo woodlands, rodents, Ruaha National Park, Tanzania, *Vachellia* woodlands, wetland grassland.

INTRODUCTION

Small mammals form an important component in all most every terrestrial ecosystems despite their low status among wildlife enthusiast, especially when compared with charismatic mega-fauna and the abundant avifauna

found in the tropical regions (Gbogbo et al., 2017). It is well documented that they are fundamental component of the food chain in almost every ecosystem as they feed on various foodstuff including plants, lichens, fungi,

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invertebrates and in turn they are also preyed by large array of mammals, avian predators and snakes (Byrom et al., 2014; Ecke et al., 2002; Kiwia, 2009). Based on this important facts, small mammals presence as well as changes in their diversity and abundance is used to influence to a great extent the dynamics of these organisms as well as their future existence (Angerbjörn et al., 1999; Ecke et al., 2001). Previous studies have shown that small mammals can also act as keystone species (Delibes-Mateos et al., 2011; Kelt, 2011) as they facilitate carbon cycle and energy flow and influence soil fertility (Mbugua, 2004; Michael et al., 2016) as well as affect the structure and composition of habitats through the consumption and dissemination of plants (including seeds and fruits), lichen, and fungal spores (Carey and Johnson, 1995; Angelici and Luiselli, 2005).

The abundance and population dynamics of small mammals in heterogeneous landscape are most likely influenced by various factors (Batzli, 1992; Stenseth et al., 2002). Such factors are the distribution and abundance of habitat resources which may influence their distribution pattern (Hieronimo et al., 2014). In addition, the most critical factors such as food availability and shelter have been found to influence small mammals population dynamics and abundance (Hansson, 1997), and they are of great importance for their reproduction and survival (Batzli, 1983). On the other hand, land use/land cover types (Fraschina et al., 2014) and inter-specific competition for crucial resources have also been shown to be of great importance in explaining the distribution of small mammals species in different habitats (Morris, 1995; Johannesen and Mauritzen, 1999).

The principal factor for small mammals composition and abundance within their geographic range is habitat conditions (Geier and Best, 1980). The connection of these species to a particular habitat is very steady and their conservatism in the selection of habitats is believed to be amongst their ecological adaptations (Peterson et al., 1999; Yakimova and Gaidysh, 2021). Small mammals are good indicator of habitat condition and environmental health and they are among the first to respond to any habitat alterations (Bock et al., 1984; Magige, 2013). Despite the nature and extent of disturbance, if vegetation is changed and habitat is altered the composition and abundance of some species may benefit while others may be affected negatively.

Little is known about the small mammal's community composition, abundance and diversity of Usangu area in Ruaha National Park. The Usangu area was previously a game reserve that was fragmented and degraded by uncontrolled human activities (WWF and WCS, 2003). In 2008, the area was gazetted to be part of Ruaha National Park resulting into prohibited anthropogenic activities. Following the exclusion of human activities in the Usangu area, natural vegetation has been recovered since then and wetlands grassland has also been re-established (Kihwele et al., 2012). However, the information on the

distribution and abundance of small mammals of this area with contrasts in landforms and habitats types is not well understood. The most recent publicity available of the area was conducted over seven years ago documenting their presence and absence in four study sites, however the results of the study so far do not allow the derivation of small mammals-habitat type relationship (Stanley et al., 2015). This study therefore attempts to investigate the spatial variation of small mammal abundance, composition, diversity and species richness in the three main habitat types (wetland grassland, Miombo and *Vachellia* woodlands), that are found within the Usangu area in Ruaha National park and providing a baseline for future work. The hypothesis to be tested is that the small mammals are randomly distributed in Usangu area, irrespective of type of the habitat.

MATERIALS AND METHODS

Study area

The study was conducted in Usangu area located on 08° 30' South and 34° 15' East in southern part of Ruaha National Park (Figure 1). It orientates slightly SW to NE from 33° 05' East to 34° 50' East. In west, the park is bordered with volcanic hills of Mbeya, to the SW the volcanic heights of the Poroto Mountains and to the south the ancient crystalline mountains of the Kipengere and Poroto ranges. Formerly Usangu area was a game reserve; in 2008, the Usangu Game Reserve and other adjacent important and remarkable wetlands were annexed into Ruaha National Park, making it the largest National Park in Tanzania and East Africa with an area of about 20,226 km² (7,809 m²) (Sirima, 2010; Tanzaniatourism, 2021). All sampling sites were selected in the Usangu area within Ruaha National Park. The climate of the park is characterized by tropical semi-arid with a pronounced dry season from May to November every year. The average annual rainfall is about 650 mm increasing towards the West with increasing altitude. Mean annual temperature is 24°C with three hottest months from October to December (39-40°C), while June through August is the three coolest months (21.7°C)

Habitat type selection

The study consisted of three main habitat types in Usangu area: Miombo woodland, *Vachellia* woodland and wetland grassland. Each habitat type was selected based on their percentage coverage, whereby each habitat selected consisted of more than 80% cover of one of the selected species in each habitat (Figure 1). The Miombo woodland harbored a variety of trees species including *Brachystegia spiciformis*, *Julbernardia globiflora*, *Pterocarpus angolensis*, *Combretum psidioides*, *Cassipourea mollis*, *Gardenia ternifolia*, *Catunaregam taylorii* and *Phyllanthus inflata*. Also, the ground floor was devoid of grass cover including *Themeda triandra*, *Hyparrhenia* species and *Andropogon* species. *Vachellia* woodland was dominated by trees such as the *Vachellia tortilis*, but other selected areas were mixed with *Vachellia drepanolobium*, *Senegalia mellifera*, *Vachellia kirkii* and *Vachellia nigrescens* and with *Commiphora* species. Common forbs include *Solanum*, *Leonotis*, *Vernonia*, *Hygrophyla*, and *Sesamum*. The grass layer was dominated by annuals including *Aristida*, *Dactyloctenium*, *Urochloa* and *Dichanthium* species. Finally, the wetland grassland habitat was dominated mostly by *Vachellia seyal* and *Vachellia*

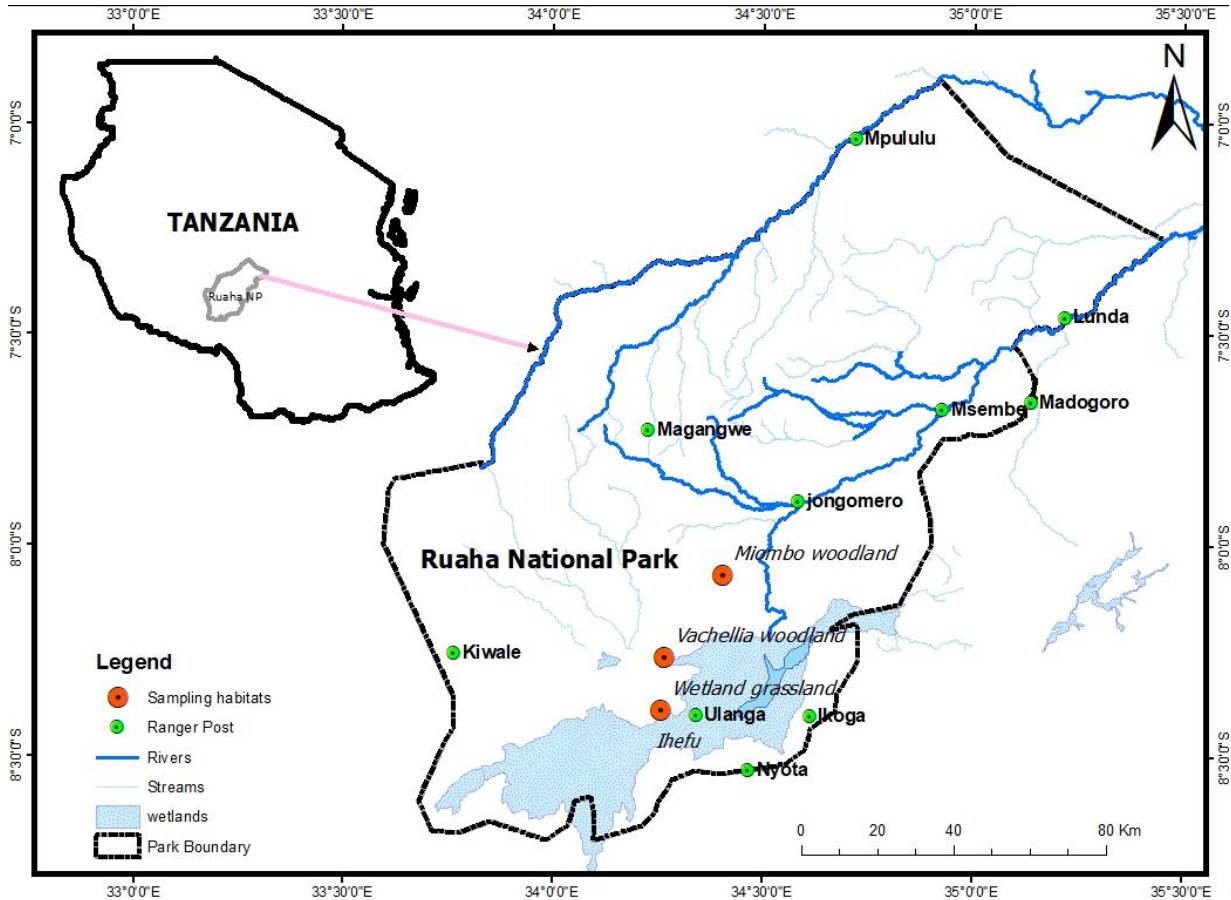


Figure 1. Map showing the location of three sampled habitats in Ruaha National Park.
Source: Authors

dreponolobium. Herbs include *Ormocarpum trichocarpum*, *ygrophilla auriculata* and *Blepharis affinis*. Dominant grasses were *Andropogon mannii*, *Andropogon gayanus*, and *Exothea abyssinica*, *Setaria incrassata* and *Themeda triandra*. *Hygrophilla auriculata* was also present and was an indicator of constant wetness.

Small mammals trapping

Small mammals were trapped in the three habitats from 15 to 20th October 2018, during the dry season. A total of nine separate trapping points each covering a total area of approximately 4900 m² were established in the Usangu area in the three habitats. In each selected habitat, a total of three trapping points were established and spaced at a distance of 500 to 600 m from each point. 49 commercially available Sherman's live traps made of Aluminium, (230 mm × 95 mm × 80 mm, H. B. Sherman Traps, Inc., Tallahassee, Florida, USA) were placed per trapping point in 7 lines, each with 7 traps spaced at 10 m apart. The Sherman's traps were baited following every check with a mixture of lightly fried fresh coconut, peanut butter and mixed with sardines and millet. Pitfall plastic buckets with a volume of 10 L in lines were buried in the soil such that the rim was at the level with the ground (Timbuka and Kabigumila, 2009). Each pitfall line contained ten buckets spaced at intervals of 10 m apart. All buckets had tiny drainage holes at the bottom to allow rain water to drain away (Sangiwa and Magige,

2019). A polythene drift fence was placed to intercept and redirect animals moving on the ground into pitfall traps in each trapping points (Bury and Corn, 1987). Global Positioning System (GPS) was used to record the location and altitudes of all sampling sites. Traps and pitfall lines were checked twice daily for four consecutive days, immediately after sunrise and in the evening. The live captured animals were identified, weighed and marked using permanent marker pen on their first capture before being released into the field.

Data analysis

Small mammal abundance

Small mammals in this study refer to rodents and shrew. The percent occurrence (R) of small mammals was calculated using Equation 1:

$$R = \left(\frac{\text{Total number of a particular species}}{\text{Total number of small mammals caught in the area}} \right) \times 100 \quad (1)$$

Small mammal relative abundance (R.A) was expressed as percentage trapping success which is the proportion of captures relative to the number of traps set over a given period (Odhiambo et al., 2005). Trap success usually expressed as the number of individual of particular species per 100 trap-nights or bucket nights

(that is, the proportion of catches relative to the number of traps set over a given period), was used to determine the relative abundance of the caught species (Stanley et al., 1996). Trap success (TS) was calculated using the Equation 2:

$$TS (\%) = (N_i / T_n) \times 100 \quad (2)$$

where N_i = the total number of animals of species i trapped. T_n = trap-nights (a product of the number of traps used and trapping effort, where trapping effort = number of days of trapping). A trap night was defined as a single trap set for one night, T_n = total number of trap-nights (traps set for one night), N_i = the total number of animals of species i trapped.

Community similarities

Similarities in pairs of small mammals' communities were determined with Jaccard Index given in Equation 3:

$$SJ = c / (a + b + c) \quad (3)$$

where SJ is the similarity index, c is the number of shared species between the two sites and a and b are the number of species unique to each site.

Small mammals' diversity

Diversity indices for the rodents were calculated using Shannon-Weiner diversity indices (Shannon, 1948) by using Equation 4:

$$H' = - \sum (pi)(\ln pi) \quad (4)$$

where H' is the diversity index and pi represent the proportion of species i in the total number of animals captured.

All data were tested for normality using tests for kurtosis and skewness. Because all datasets were not normally distributed, the relative abundance and diversity index values of the small mammal species across the three different habitats were compared using Kruskal-Wallis a non-parametric test. All statistical analyses were carried out using R software version 3.6.3.

RESULTS

Small mammal's species composition

Ninety-two (92) individuals of small mammals belonging to 7 species, 2 families and two orders (Rodentia and Eulipotyphla) were captured from 2,124 sample-nights (1,764 Sherman trap-nights and 360 bucket-nights). The Rodentia which constituted 92.39% of the total number of captures, included *Arvicanthis neumanni* (Neumann's grass rat) (8.70%), *Mastomys natalensis* (multimammate rats) (53.26%), *Mus minutoides* (The African pygmy mouse) (5.43%), *Myomys fumatus* (14.13%), *Praomys* species (1.09%) and *Taterillus harringtoni* (Harrington's tateril) (9.79%). The Eulipotyphla consisted of 7.61% of the total number of captures with all individuals being *Crociodura hirta* (Lesser red musk shrew) shown in Table 1 and

Figure 2. The wetland grassland habitat accommodated a total number of 5 species, whereby four species (that is, *Taterillus harringtoni*, *Mus minutoides*, *Mastomys natalensis* and *Myomys fumatus*) belonged to Muridae family while only one species, that is, *C. hirta* belonged to Soricidae family. On the other hand, *Vachellia* woodland habitat comprised of 4 species all from Muridae family while Miombo woodland habitat contained only 3 species all belonging to Muridae family (Figure 1 and Table 1). The number of species did not differ significantly between the three habitats ($H(2) = 2.4363$, $P=0.2958$).

Abundance and distribution of species of small mammals in the three habitats of Usangu

The present study found that, wetland grassland habitat had the highest trap success (10.169%) followed by *Vachellia* woodland habitat (1.836%), while Miombo woodland habitat had the lowest trap success rate (0.989%) (Table 2). *M. natalensis* was the most abundant species accounting about 6.921% of the total captures. Other abundant species was *M. fumatus* whereas *Praomys* species was the least common species, accounting for only 0.141% of the total captures (Table 2). *A. neumanni* had the highest trap success in *Vachellia* woodland (1.130%) while in Miombo woodland habitat *T. harringtoni* was the most abundant species (0.706%) and in Wetland habitat *M. natalensis* was the most dominant species (6.780%) (Table 2). Two species *M. fumatus* (1.836%) and *C. hirta* (0.989%) were trapped only in wetland grassland habitat while *A. neumanni* (1.130%) and *Praomys* spp. (0.141%) were trapped only in *Vachellia* and Miombo woodlands habitats, respectively. *M. natalensis* was trapped in two habitats, that is, *Vachellia* woodland (0.141%) and wetland (6.780%) while *M. minutoides* and *T. harringtoni* were the most widely dispersed species, trapped in all three habitats (Table 2).

Species diversity

The highest Shannon-Weaver Index (H') of 1.03 was recorded in *Vachellia* woodland habitat while Miombo woodland had the lowest H' (0.796) (Table 3 and Figure 3). The three diversities were not significant different from each other ($H(2) = 2$, $P = 0.3679$).

Coefficient of community similarities

The 4 species encountered in the *Vachellia* woodland against 3 species in the Miombo woodland and 5 species in Wetland resulted into highest Jaccard coefficient index value between Wetland and Miombo woodland habitats (0.97) and lowest similarity index between Miombo and *Vachellia* woodlands (0.76) (Table 3).

Table 1. Capture data of small mammals trapped in Usangu area.

Order	Family	Species	Number of individuals capture (% Occurrence in parenthesis, - absence)			
			Vachellia woodland	Miombo woodland	Wetland grassland	Total
Rodentia	Muridae	<i>Taterillus harringtoni</i>	3 (3.26)	5 (5.43)	1 (1.09)	9 (9.79)
		<i>Praomys</i> spp.	-	1 (1.09)	-	1 (1.09)
		<i>Mus minutooides</i>	1 (1.09)	1 (1.09)	3 (3.26)	5 (5.43)
		<i>Arvicanthis neumanni</i>	8 (8.70)	-	-	8 (8.70)
		<i>Mastomys natalensis</i>	1 (1.09)	-	48 (52.17)	49 (53.26)
		<i>Myomys fumatus</i>	-	-	13 (14.13)	13 (14.13)
Eulipotyphla	Soricidae	<i>Crocidura hirta</i>	-	-	7 (7.61)	7 (7.61)
Total number of individuals			13 (14.13)	7 (7.61)	72 (78.26)	92 (100)

Source: Authors

DISCUSSION

Small mammal's species composition, trap success and richness

This study reveals spatial patterns of small mammal assemblages across the three main habitats in the Usangu Area, in Ruaha National Park (Figure 1). This study was considered to contribute to a database for small mammal communities in wetlands grassland and woodlands habitats of southern Tanzania. Although our research results reveal the common species of the small mammals across the three main habitat types in the Usangu area, in Ruaha National Park, the comparative studies that can be used to determine whether our findings typify these habitats are still lacking. The only comparable study is the one carried out by Stanley et al. (2015), who recorded a total of 20 small mammals (three species of shrew and 17 species of Rodentia) in Isunkaviola Plateau and Makindi Springs of the Ruaha National Park. In the study, fewer species were found at the Usangu area compared to what was found across the Ruaha National Park in Stanley et al. (2015). Interestingly, different small mammals' community composition was not found compared to Stanley et al. (2015) findings at Ruaha National Park study sites. In addition, these disparities in species richness between the two studies might be related to sample design, survey length, timing, or study coverage

The type of traps used in this study might have also influenced the lower abundance and richness of small mammals captured. Numerous studies have shown that, the use of combination of variety of trap types is the best means for examining general composition and structure of small mammal community (Voss and Emmons, 1996; Woodman et al., 1996; Astúa et al., 2006; Santos-Filho et al., 2006). Stanley et al. (2015) employed three types of traps (Museum Specials, Victor Rat Traps and Sherman

Traps), and sampled a large number of small mammal species than the present study which used only two types of traps (Sherman Traps and Pitfall Plastic buckets). Similarly, Stanley et al. (1998) in Eastern Arc Mountains, Tanzania documented the small mammal individuals using Museum Specials, Victor Rat Traps and Sherman Traps and obtained a higher number of 28 species than that of present study. In addition, Magige (2016) in Serengeti ecosystem, Tanzania employed four types of traps (employed Sherman's live traps, tomahawks, wire mesh trap and pitfall traps) to assess small mammal population across different habitat types and captured ten small mammal individual species which is higher than the present study. However, a number of studies have shown that a complimentary use of both live traps and pitfall is effective at documenting wide range of taxa of the small mammal species in many sites or habitats (Stanley et al., 1998; Lyra-Jorge and Pivello, 2001; Dizney et al., 2008; Caceres et al., 2011). Therefore, Sherman Traps and Pitfall Plastic buckets were used in this study in order to maximize the capture, as none of the two methods is enough to be used alone, and thus, both methods positively complemented each other as it has been indicated in other small mammal studies (Stanley et al., 1998; Nicolas and Colyn, 2006; Shilereyo et al., 2021). In addition, the effectiveness of Sherman Traps and Pitfall traps have also been widely tested, and the use of these methods in capturing a wide variety of small mammal with different taxa, sizes and weight has become somewhat acceptable (Pizzimenti, 1979; Dickman, 1995; Voss and Emmons, 1996; Goodman et al., 2001; Astúa et al., 2006; Santos-Filho et al., 2006; Umetsu et al., 2006). Furthermore, the complimentary use of Sherman Traps and Pitfall Plastic buckets together with different types of baits in this study is thought to be efficient in evaluating the small-mammal community in Usangu area. Numerous studies have emphasized the use of different types of baits as they increases the number of species

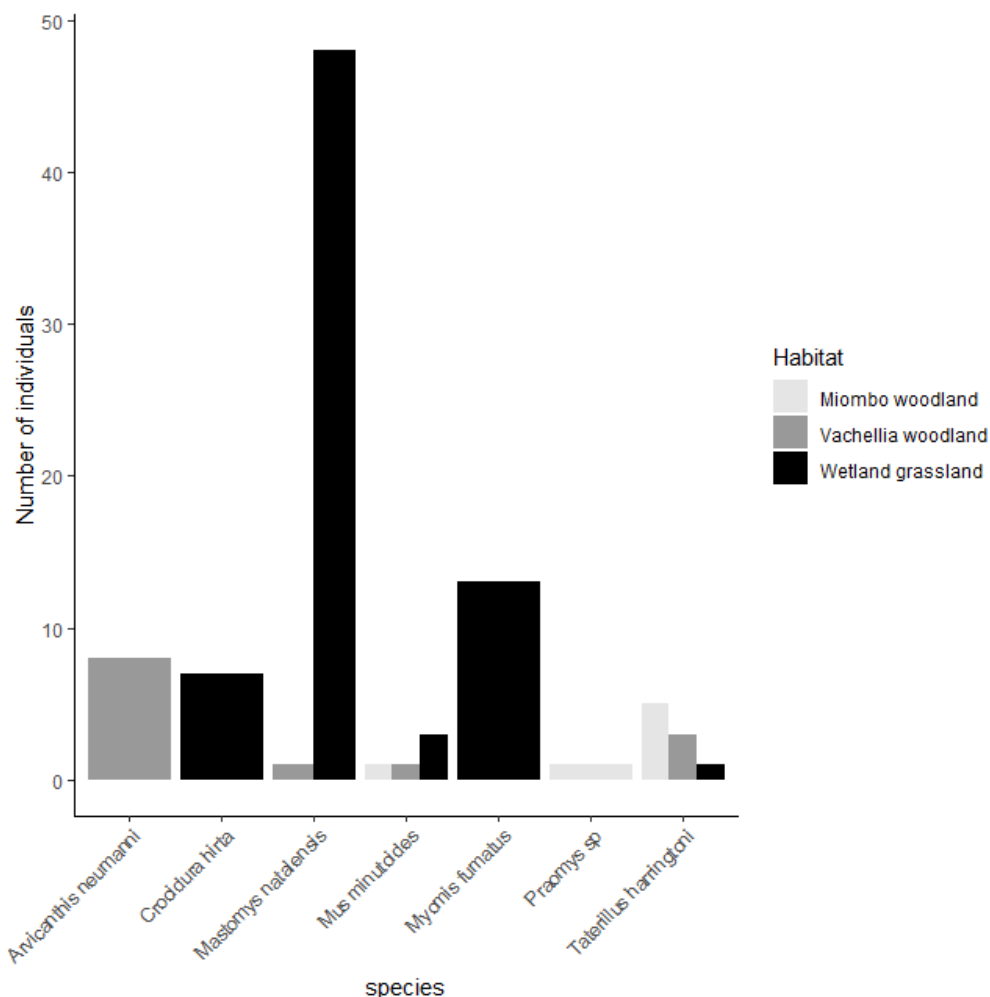


Figure 2. Percentage of occurrence of small mammals trapped in different habitats.
Source: Authors

Table 2. Relative abundance in % of overall capture and distribution of species of small mammals in three habitats of Usangu area in Ruaha National Park.

Species	Vachellia woodland	Miombo woodland	Wetland grassland	Total trap success rate
<i>Taterillus gerbil</i>	0.4237288	0.7062147	0.1412429	1.271186
<i>Praomys spp.</i>	0.000000	0.1412429	0.000000	0.141243
<i>Mus minutoides</i>	0.1412429	0.1412429	0.4237288	0.706215
<i>Arvicanthis neumanni</i>	1.1299435	0.000000	0.000000	1.129944
<i>Mastomys natalensis</i>	0.1412429	0.000000	6.7796610	6.920904
<i>Myomys fumatus</i>	0.000000	0.000000	1.8361582	1.836158
<i>Crocidura hirta</i>	0.000000	0.000000	0.9887006	0.988701
Total trap success rate	1.836158	0.9887005	10.1694915	12.99435

Source: Authors

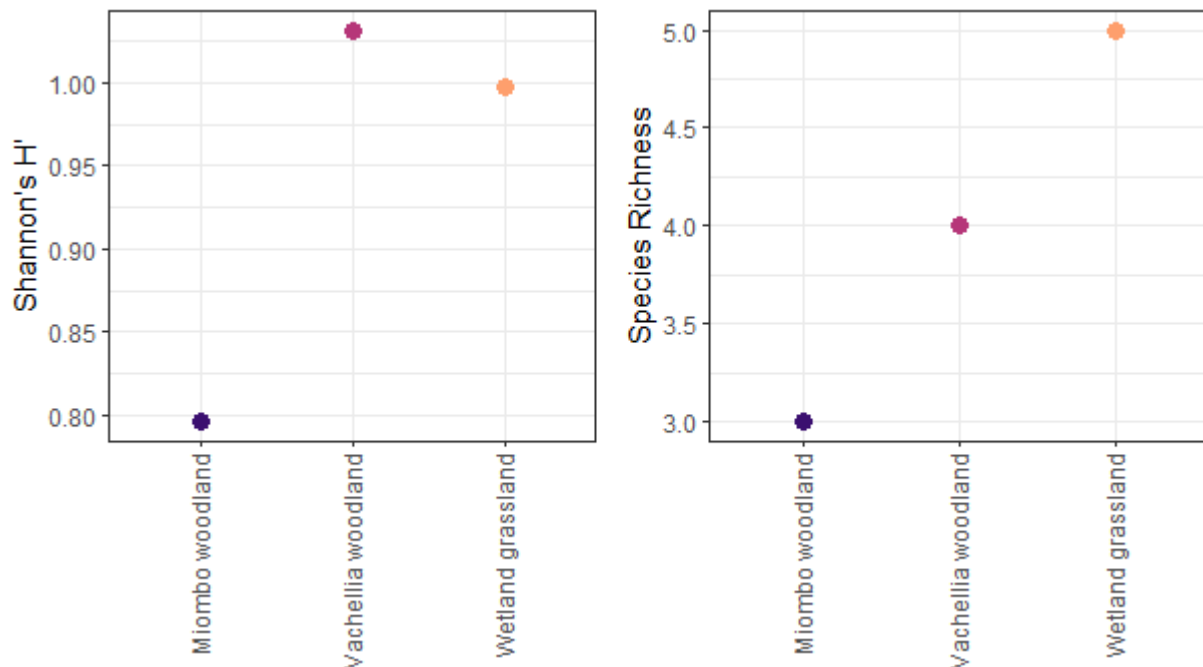
and individuals that are captured (HiCe and VeLazCo, 1961; Woodman et al., 1996). In this study, a mixture of four different types of baits was placed in the Sherman's

traps. The use of combination of baits in this study was particularly important and is highly encouraged for small mammals study because different species get attracted

Table 3. Indices of species diversity and Jaccard coefficient of community similarity in and between the three habitat types.

Habitat type	Shannon-wiener Diversity Index (H')	Jaccard coefficient of community similarity	
<i>Vachellia</i> woodland	1.031	Miombo woodland vs. <i>Vachellia</i> woodland	0.75
<i>Miombo</i> woodland	0.796	Wetland grassland vs. <i>Vachellia</i> woodland	0.96
<i>Wetland</i> grassland	0.998	Wetland grassland vs. <i>Miombo</i> woodland	0.97

Source: Authors

**Figure 3.** Graphs illustrating the species richness and Shannon's H' within the three habitat types, in Usangu Area.
Source: Authors

to different types of baits (Timbuka and Kabigumila, 2009).

Generally, the present study findings found higher species richness in the wetland grassland habitat than in the *Vachellia* and *Miombo* woodlands habitats. Higher number of species might be due to dense vegetation ground cover which was available in wetland grassland habitat compared to other habitats, that could be responsible for providing good shelter for small mammals and accounts more species richness. Results from the present study were consistent with the multiple studies that have found higher species richness in wetland and grassland areas compared to other habitats. Bowland and Perrin (1993) found higher species richness and abundance in wetland habitats in Kamberg Nature Reserve, South Africa. In addition, Scott et al. (2008) recorded higher species richness in habitat with tall grasses compared to developing woodland habitats. Furthermore, Aubry et al. (1991) found both wetland and

grassland habitats contained higher species richness in KwaZulu-Natal, South Africa. Small mammals prefer habitats with tall grasses because they provide them with enough food, vegetation cover and protection from predators and most of them tend to avoid open patches such as those found within woodland habitats as they provide less food and protection (Eccard et al., 2000; Tattersall et al., 2001; Scott et al., 2008). Conversely, the results did not agree with those of Magige (2013) and Mulungu et al. (2008) who found that woodlands habitat contained more species of rodents and shrew than grassland habitats.

The study findings indicated that the abundance of small mammals varied among the habitat type, with wetland grassland habitat was found to contain a great number of individuals compared to other habitats. According to Bowland and Perrin (1993), the higher abundance of small mammals in wetland grassland habitat might be due to the fact that wetland usually act

as their reservoir during drought. Furthermore, wetland grassland habitat was clearly identifiable by higher plant cover than woodland habitats. Manson et al. (1999) and Hamilton et al. (2015) have noted that habitats with high plant cover are often selected by small mammals as a mechanism to reduce predation. Additionally, the *Vachellia* woodland contained higher diversity of small mammals compared to other habitats which is similar to previous findings (Magige, 2013; Byrom et al., 2014). The higher species diversity in *Vachellia* woodland habitat might be due to the availability of vegetation cover from predation and nesting sites (Nyirenda et al., 2020). From this study variation of species diversity was contributed to variations in vegetation physiognomy. Slightly diversity differences were found possibly due to differences of habitats in term of supporting ability for the survival of small mammal's species. Despite of the normal situation that past anthropogenic disturbances lessen the diversity and abundance in the ecosystems; this study findings show that diversity was higher in the former disturbed areas as a result of cultivation and livestock keeping in *Vachellia* woodland than in Miombo woodland which was not used for agricultural activities and settlement. On the other hand, the Miombo woodland harbored the least number of small mammal diversity and abundance in the study area due to poor suitable habitats for small mammals (Caro, 2001, 2002; Nkwabi et al., 2018). This is also reflected by other investigators. For instance, Bayo (2019) reported lowest diversity and abundance of small mammals in the miombo woodland compared to other habitats in Handeni Hill Forest Reserve in Tanzania. The lower abundance and diversity in Miombo woodlands could possibly be due to frequent disturbances from fires (Bayo, 2019) as well as grazing from large herbivores as Miombo woodlands are known to provide the suitable habitat for large wild herbivores but in turn these species can cause significant impacts on vegetation which can indirectly affect small-mammal populations (Deweese et al., 2010; Ellis and Cushman, 2018). Furthermore, Miombo habitats are considered as a vegetation formation growing on soils that have low nutrient content, hence not productive and are mostly marked with low faunal biodiversity (Deweese et al., 2010). Various studies (Ecke et al., 2001; Lambert et al., 2006; Mengistu et al., 2015; Magige, 2016; Shilereyo et al., 2019) have also reported variation in small mammals abundance in response to variation in habitat types and composition since vegetation diversity and composition can influence the availability of food and shelter which remain key factors for small mammals' survival and reproduction.

Small mammals chiefly Muridae were highly caught in *Vachellia* woodland and wetland than in Miombo woodland which seems not a favorable habitat type as previously reported (Magige, 2016). However, there was a higher similarity in the species between Wetland and *Vachellia* woodland, Wetland and Miombo woodland. The presence of similarities in species between these habitat

types was probably contributed by the presence of good availability feeding resources, soil types and cover. Similarly, the wetland grassland had a slight heterogamous habitat including variety of grazing vegetation, fruits, seeds, arthropods, some shrubs to escape from predators and vast open land which facilitates easy detection of crawling predators in particular. On the other side, the Miombo habitat had good cover except for category of homogenous vegetation which could provide fewer grains and grazing varieties. The habitat heterogeneity hypothesis developed initially by MacArthur and Mac-Arthur (1961), proposes that an increase in number of different habitats can lead to an increase in species diversity and abundance which corroborates to the findings of this study. Furthermore, a study done in Serengeti kopjes revealed a high diversity of small mammals associated with the availability of food and cover in different habitats (Timbuka and Kabigumila, 2009). Another possible explanation of comparatively higher small mammals' similarities in wetland and *Vachellia* woodlands could also be related to secondary succession of the former Usangu as recovery from anthropogenic disturbances. Secondary succession could have supplied a great variety of food materials which favor population growth of different species. The results on similarities of small mammals in between different habitats indicate the health and state of wetlands and *Vachellia*/Miombo woodlands had rapid turnover rate, high biotic potential, ability to invade reclaimed areas and sensitivity to environmental disturbance (Griffin et al., 2011). Therefore, the three sampled habitats support small mammal's communities and represent area of considerable conservation importance.

Out of seven species recorded during this study, the *M. natalensis* was the only species that was significantly more abundant species as indicated by the multiple captures. Multiple captures are known to be used as an index of high density (Leirs et al., 1995; Timbuka and Kabigumila, 2009). *M. natalensis* was also the most dominant species in the wetland grassland habitat. High abundance of *M. natalensis* in Usangu area, particularly in wetland grassland may be due to their being an omnivorous species and generalists and the availability of other environmental resources, such as vegetation cover for protection from predators (Mulungu et al., 2011; Mamba et al., 2019; Nyirenda et al., 2020). Furthermore, *M. natalensis* has been recorded as the most adaptable in a wide range of habitats and environmental condition and most prevalent small mammals species in East Africa (Andresen, 1972; Byrom et al., 2015; Fichet-Calvet et al., 2008; Mulungu et al., 2011; Shilereyo et al., 2019; Timbuka and Kabigumila, 2009) as well as throughout sub-Saharan Africa (Granjon et al., 1997; Leirs et al., 1995).

M. fumatus was the second most abundant species in the study area. This species was captured in wetland

grassland habitat but not in *Vachellia* and Miombo woodlands. This result agrees with the findings of Gezahegn et al. (2016) from Yetere Forest and Venance (2009) from Mikumi National Park. Several factors could be responsible for the higher abundance of *M. fumatus* in wetland grassland habitat. Food availability and cover may be higher and predator abundance might be lower in wetland grassland habitat compared to woodlands habitat (Bantihun and Bekele, 2015; Shileroyo et al., 2019; Nyirenda et al., 2020). However, this species has been recorded in different habitats, ranging from forests at 1000 m up to the Afro Alpine moorlands above 4000 masl, and is most widely distributed across African countries (Gezahegn et al., 2016).

Praomys spp. was the least abundant species of rodents recorded during the present study. This species was trapped only from the Miombo woodland habitat. This result goes in line with Bayo (2019), who found that *Praomys* spp. was confined only to the Miombo woodland habitat and avoided dense vegetation and moist areas. In addition, the presence of this species in Miombo woodland in Usangu area can be attributed to numerous factors, such as the availability of vegetation cover and array of food items across seasons (Nyirenda et al., 2020). Although Miombo woodland has been documented to contain relatively low fauna species, the presence of rodents could have contributed by the resource-rich termite mounds found in these habitats (Fleming and Loveridge, 2003). However, Meliyo et al. (2014) reported that this species was among the most abundant and dominant species of rodents in most of the study habitats, with more abundance in plateau and plain habitats. In addition, Isabirye-Basuta and Kasenene (1987) have found this species in both tropical evergreen forest and undisturbed mature forest habitats. *Praomys* spp. is also one of the most widely distributed and abundant rodents in Africa in the intertropical zone (Nicolas et al., 2005).

Conclusions

This study has demonstrated that biodiversity management should aim at incorporate refuge habitats such as wetland grassland and *Vachellia* woodlands within Ruaha National Park as they have been found to be not only of major importance for maintaining terrestrial small mammal abundance and diversity, but also very crucial for their population recovery. Miombo woodland habitat seems to be poor in small mammal diversity and abundance compared to wetland grassland and *Vachellia* woodlands habitats. Differences and similarities on small mammal species richness, diversity, and abundance in three habitats appear to be influenced by general effect on habitat conditions for the small mammals, such as the amount of vegetation cover and food as well as the recovery rate of the formerly Usangu area inhabited by

human. The presence of few species recorded justifies the reasons for repeated sampling in different habitats and seasons is of paramount importance for reliable information and better comparison of spatial and temporal species abundance, richness and diversity in Usangu area.

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CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Full Length Research Paper

The effect of human-mediated mortalities of African leopard (*Panthera pardus pardus*) in Ethiopia

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Even though the challenges to the conservation of African leopard (*Panthera pardus pardus*) in Ethiopia are wide ranging, little is known about the trend of their potential threats. Similarly, the impacts of direct human-induced mortalities of leopards are poorly understood. Available literature sources that include published and unpublished reports and manuscripts on African leopard were reviewed in order to investigate the effect of human-mediated mortality like trophy hunting, poaching and retaliatory killing of leopards in Ethiopia. From our review, we concluded that poaching is the prominent problem as compared to the other human mediated mortalities of leopards. It is therefore recommended to put in place concrete protection measures to reverse the existing crimes against leopards and undertake further field assessment on their possible habitats and threats.

Key words: Impact, threats, human-mediated mortality, trophy hunting, poaching, retaliatory killing, illegal killing.

INTRODUCTION

Like the case of other African countries, large carnivores in Ethiopia are facing a serious threat to their survival as most of the natural habitats in Ethiopia are under high human pressure. Habitat loss, fragmentation, and degradation of natural habitat, retaliatory killing, and poaching are some of the major threats to the survival of carnivores and their prey populations (Jacobson et al., 2016; Ramesh et al., 2017; Yirga et al., 2017; Kebede and Gebretensae, 2018; IUCN SSC Cat Specialist Group, 2018).

The African leopard (*Panthera pardus pardus*) is no exception to this pattern. African leopards experience across their range severe declines (40-60%) in populations and they are classified by the International Union for Conservation of Nature (IUCN) Red List

Assessment as vulnerable (IUCN SSC Cat Specialist Group, 2018; Stein et al., 2020). The primary threats to leopards are anthropogenic. Habitat fragmentation, reduced prey base and conflict with livestock and poaching have reduced leopard populations throughout most of their range (Ray et al., 2005; Yirga and Bauer, 2011; Hunter et al., 2013; Westerberg et al., 2017).

The challenges to the conservation of African leopard in Ethiopia are wide ranging and human-mediated killings are among the main anthropogenic threats to the species in question. The risk factors for vulnerability of leopards to various forms of human-caused mortality include adaptation of leopard to inhabit human-dominated landscapes, level of protection of its habitats, and incidence of human-leopard conflict versus response to

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the problem (Yirga and Bauer, 2011; Stein et al., 2016; Kebede and Gebretensae, 2018; Stein et al., 2020). Moreover, high demand for leopard products, coupled with inadequate preventative measures is believed to result in an increase of illegal killing and illicit trade in recent years (Karanja, 2012; Ramesh et al., 2017; Tessema, 2017; Tessema et al., 2021). Unlike the case of southern Africa countries, little is known about the status and trend of potential threats to leopards in Ethiopia, especially concerning direct human-induced mortalities (Kebede and Gebretensae, 2018). Therefore, this review aims to examine the trends of trophy hunting, poaching and retaliatory killing of leopards in Ethiopia based on the available data from various published and unpublished studies related to the subject matter.

Distribution of African leopard in Ethiopia

Despite the ever-increasing anthropogenic pressures, the leopard populations in Ethiopia inhabit a wide range of different ecosystems, with extreme variation in conditions and habitat types. It is found in most ecosystems of Ethiopia which range from cool afro-alpine to evergreen montane forests, to dry desert scrublands. Leopard can also occur close to major towns, including Addis Ababa, the capital city (Stein et al., 2016; Kebede and Gebretensae, 2018). It is generally true that there is lack of data on present distribution of leopards in Ethiopia since range-wide assessments have not been undertaken. However, there are considerable reports of series of recent assessments (Wendim et al., 2010, 2015; Wendim, 2018; Kebede et al., 2011; Asefa et al., 2014; Yadeta et al., 2014; Zerfu et al., 2014; Kebede et al., 2015a; Deksis et al., 2015b; Tsegaye et al., 2017; Yadeta and Getachew, 2016; Deksis et al., 2017; Pohlstrand, 2019) which indicate numerous sightings of leopards. There are also some details about depredation cases by leopards from various parts of Ethiopia (Yirga et al., 2011; Girmay and Teshome, 2015; Acha and Temesgen, 2015; Westerberg et al., 2017; Mohammed et al., 2017; Tsegaye, 2017; Biset et al., 2019; Tadesse and Zewde, 2019).

Therefore, the sightings and depredation cases indicated earlier reveal that leopards are widely distributed though their abundance varies from one habitat to another (Figure 1). Apparently, there is a need to update the possibly extant portions shown in the distribution map adopted by Kitchener et al. (2017) and IUCN SSC Cat Specialist Group (2018). Given the existence of ample prey population, combined with relative intactness of their habitats, it appears that some areas are specifically the main stronghold sites of the extant populations of leopard in Ethiopia. These areas include the south eastern Bale, Arsi and Harerge Massifs and the Omo Valley, Gambella and Mao-Komo forest areas in the south, south western and western part of Ethiopia (Wendim et al., 2015; Wendim, 2018; Kebede

and Gebretensae, 2018).

METHODOLOGY

Study area

Ethiopia is located in the Horn of Africa, bordering Eritrea in the North, Djibouti and Somalia in the East, Kenya in the South, and Sudan and South Sudan in the West. The country stretches from 3°N of the equator to 15°N latitude and from 33°E to 48°E longitude, and has an area of 1,127,127 km². Ethiopia has great geographic diversity with high and rugged mountains, flat topped plateaus, deep gorges, incised river valleys and rolling plains. The climate pattern of Ethiopia is mainly determined by the alternations of inter tropical convergence zone and the influence of the Indian Monsoon throughout the year. The differences in altitude, topography and climate have created various ecosystem types of Ethiopia, which range from cool afro-alpine to evergreen montane forests, to dry desert scrublands (Biodiversity Indicators Development National Task Force, 2010; Hussein, 2021). Ethiopia is consequently endowed with a diverse suite of biological resources and the isolation of its mountain and desert areas has given rise to numerous endemic species of flora and fauna found nowhere else on Earth (IBC, 2005; Biodiversity Indicators Development National Task Force, 2010). Various efforts have been made to conserve the rich wildlife resources of Ethiopia and the Ethiopian Wildlife Conservation Authority (EWCA) is the federal institution mandated to ensure the development, conservation, and utilization of wildlife (Federal Negarit Gazeta, 2008; EWCA, 2015).

Literature sources

Various scholarly sources, published and unpublished reports as well as strategic documents related to the target species are the main sources for the review. This review has taken into account the national report of Leopard (*Panthera pardus*) quota of Ethiopia (EWCA, 2020), EWCA's hunting database (2011-2019) and the strategic plans of wildlife sector (EWCA, 2015). Google Scholar (<http://scholar.google.com>), Science Gate (<https://www.sciencegate.app>) and Science Direct (<https://www.sciencedirect.com>) were the academic search engines used to get the review material that is not found in local libraries and archives.

Specifically, the data on human-mediated mortality of leopards is based on reports of nine years (2011-2019). However, for the entire study, a total of 33 leopard related articles and books published in the past 24 years (since 1999) have been reviewed. Moreover, 21 unpublished reports of wildlife assessments (Gebretensae et al., 2008; Ewnetu et al., 2008; Wendim et al., 2010, 2015; Kebede et al., 2011, 2015a, 2015b; Yadeta et al., 2014; Zerfu et al., 2014; Deksis et al., 2015, 2017; Tsegaye et al., 2017; Yadeta and Getachew, 2016) which were submitted since 2008 to the concerned units of EWCA and regional offices were used as key sources for the review. These materials were supplemented by 5 policy-based documents (Federal Negarit Gazeta, 2008; EWCA, 2015; IBC, 2005; IUCN SSC Cat Specialist Group, 2018; IUCN, 2019).

RESULTS AND DISCUSSION

Licensed/Trophy hunting

Like the case of majority of sub-Saharan African

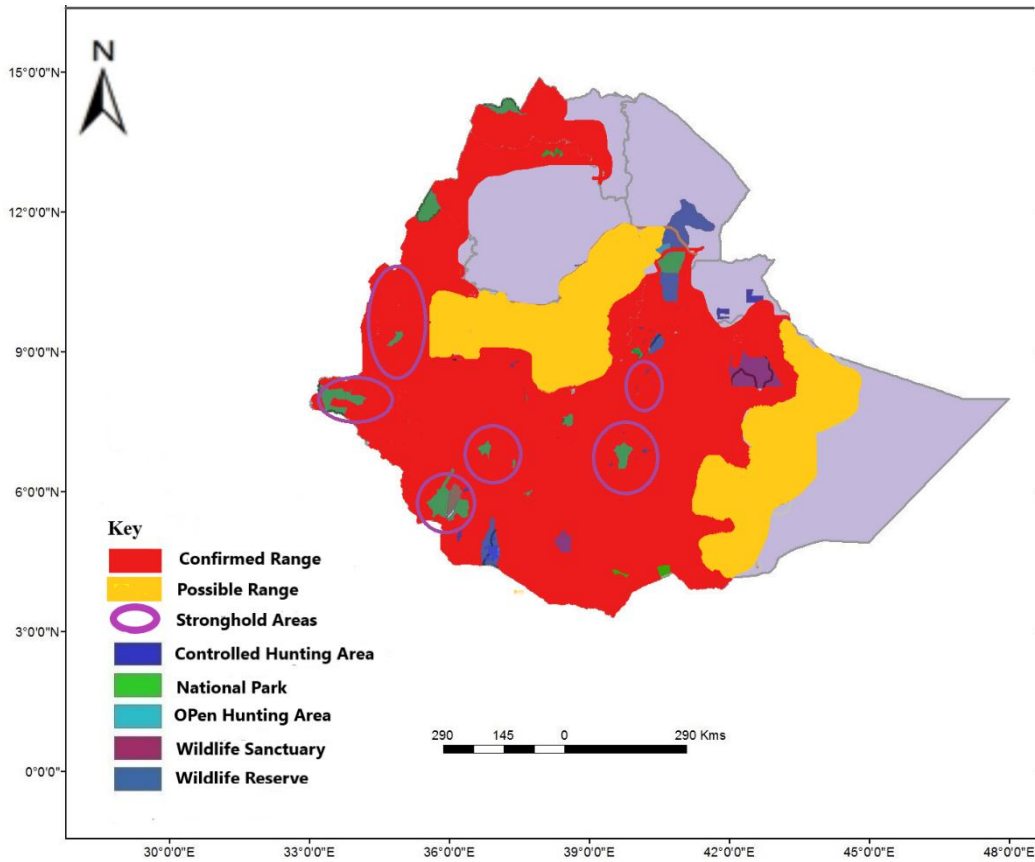


Figure 1. Distribution and stronghold sites for leopards in Ethiopia.
Source: Adopted from Kebede and Gebretensae (2018).

countries, Ethiopia officially authorizes sport hunting. In Ethiopia, sport hunting activity is carried out in Controlled Hunting Areas (CHAs) and open hunting areas. Sororo-Torgam, Besmena-Odobulu, Abasheba-Demero, Munesa-Kuke, Arbagugu, Dindin, Shedem Berbere and Welishet-Sala are the main CHAs where hunting of leopard has been practiced. It is practiced in accordance with the wildlife conservation and utilization regulation no. 163/2008, adopted based on proclamation no. 541/2007 and with the following directives: revised directive No.31/2009 (Ethiopian Calendar) for wildlife hunting utilization and directive No.26/2007 (Ethiopian Calendar), for huntable wild animal's census and quota setting. With the exception of birds, hunters with valid permit are allowed to hunt an old male animal only and trophy size is typically used to determine the age of the animal (EWCA, 2020).

Annual offtake quota is set every three years through field surveys and population estimates for all huntable species based on quota setting directive mentioned earlier and the preceding laws. Accordingly, quotas have been set for leopard, which is listed on the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) Appendix I in

which trade is restricted to skins and body parts of limited number of individuals (Stein et al., 2016, 2020). Leopard is one of the 54 huntable species, and a total of 121 leopards of quota were set (Table 1) for the past nine years (2011-2019, excluding the Covid-19 season) in six CHAs that are considered as strongholds for leopard populations in Ethiopia (Kebede and Gebretensae, 2018). Only 33 leopards were hunted (EWCA, 2019, 2020) out of the allocated quota and this shows that low proportions (27%) of the proposed huntable leopards were harvested (Table 1).

Sport hunting, also known as trophy hunting is one of the oldest wildlife-based recreational activities. Some researchers have indicated that sport hunting can benefit the development and economy of local communities, thereby promoting the protection of wildlife resources as well as both ecological and economic sustainability (Di Minin et al., 2016; Saayman, et al., 2018). However, important debates remain regarding the social impacts of sport hunting and other forms of wildlife tourism on local communities near protected areas (Yasuda, 2012; Mbaiwa, 2018). Other studies also argue and raise questions on the sustainability of trophy hunting in most sub-Saharan African countries (Lindsey et al., 2016).

Table 1. Nine years quota allocation for leopard in CHAs.

Year	Total quota set	Number of hunted leopards	% hunted leopards
2011	14	3	21
2012	14	3	21
2013	14	6	43
2014	14	4	29
2015	10	5	50
2016	10	5	50
2017	12	5	42
2018	15	2	13
2019	18	0	0
Nine years total	121	33	27

Source: EWCA Database.

Additional studies are required to understand more regarding the main reasons behind the limitations of the hunting industry in Ethiopia. The low rate of harvest can be attributed to the limited interest of the hunters to spend more time searching for large carnivores since most of tourist hunters visiting Ethiopia are attracted mostly by some of the endemic species such as the Mountain Nyala (*Tragelaphus buxtoni*) and Menelik's Bushbuck (*Tragelaphus scriptus meneliki*). For this reason, wild animals like leopard, which are also found in other African countries are not commonly harvested by tourist hunters in Ethiopia (EWCA, 2020). Furthermore, the fact the aforementioned regulation (Regulation no. 163/2008) prohibits baiting indicate that there are no ways to attract the huntable leopards and save time for hunting. This restriction differs from the cases of other African countries which have higher hunting success. For example, in the case of Tanzania, baiting of lion and leopard is allowed as long as the bait animal is on license (Majamba, 2001).

Poaching

The data collected by Tessema et al. (2021), from concerned regional and federal offices indicate that 114 products of leopards, which include claws, teeth and skins were seized in nine years (2011-2019). Data gathered for this review show that a total of 117 skins of leopards were seized in the same nine years. Seizure of a total of 107 skins of leopards (92% of the total skins seized, see Figure 2) in Metema (Ethio-Sudan border), Bahirdar (confiscated from various parts of the region), Humera (May Tselot) and Bambasi (EWCA, 2019; DW Amharic News, 2020) can reveal that the western, north western and northern parts of the country are the most poaching prone areas. Remarkably, these areas are situated far away from the south eastern stronghold sites for leopards.

Poaching remains a serious conservation issue and

has now grown into organized criminal activity having international ramifications as it is a major existential threat to numerous wild organisms worldwide and is an important contributor to biodiversity loss (Cooper et al., 2009; Karanja, 2012; Ramesh et al., 2017). Nowadays, poaching is being undertaken through highly organized, networked and technologically well-equipped systems and resulting in significant loss of wildlife resources (Lawson and Vines, 2014; Gebretensae and Gebremicael, 2018).

Since the recent past, Ethiopia appears to be facing an escalating poaching and trafficking threat tied to organized crime and cross-border trafficking networks. High demand for wildlife products, coupled with inadequate preventative measures and weak institutions has resulted in an explosion of illicit trade in wildlife in recent years (Tessema, 2017; Gebretensae and Gebremicael, 2018; Tessema et al., 2021).

In Ethiopia, leopards are intentionally poached for illegal trade of their skins. The fact that significant number of seizures were made at different checkpoints of the country indicates the extent of the problem. High demand for wildlife products, coupled with inadequate preventative measures is believed to result in an explosion of illicit trade in recent years (Kebede and Gebretensae, 2018; Tessema, 2017; EWCA, 2020; Tessema et al., 2021). In some cases, leopards are also killed to use their skins for traditional ceremonies especially in the southern part of the country. A very recent study by Torrents-Ticó et al. (2022) has come up with alarming report indicating that 204 skins of cheetah (*Acinonyx jubatus*), leopard (*Panthera pardus*), African civet (*Civettictis civetta*), common genet (*Genetta genetta*) and serval (*Leptailurus serval*) were counted across two years ceremonies of the Daasanach community that take place every year or every second year in Kenya and Ethiopia.

The result of this study shows that the rate of seizure is higher in the western, north western and northern parts of the country as compared to the south eastern

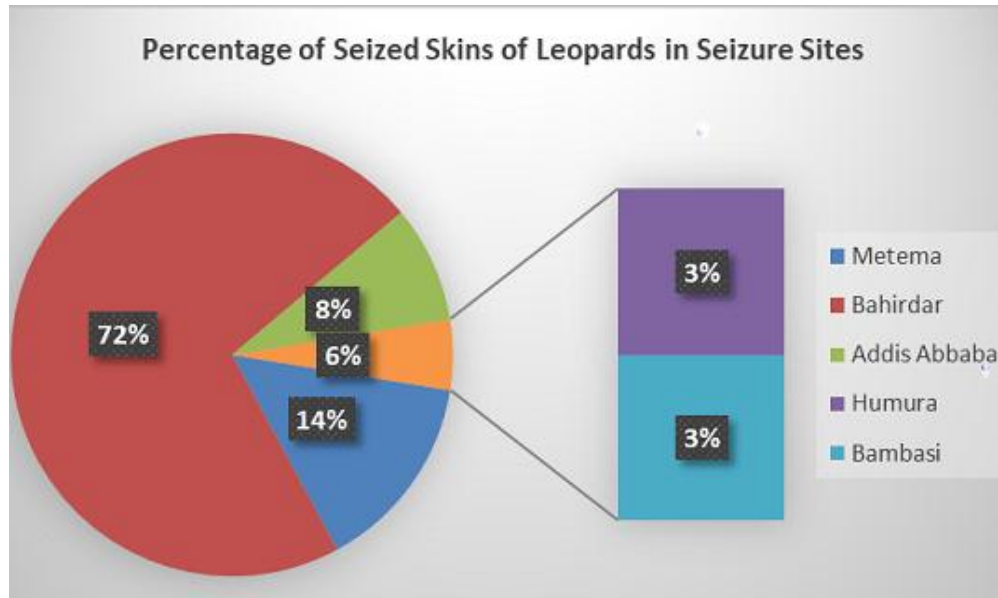


Figure 2. Proportion of seized skins of leopards in different sites for nine years (based on the data obtained from EWCA and concerned regional offices).

stronghold sites for leopards. Inclination of the rate of seizure towards these areas is one of the interesting questions to be examined further through systematic analysis.

Through theoretical analysis, different logics can be framed regarding such trends. Either way, there could be an increase in demand for the products of leopard in Sudan or/and its outlets and a favorable environment for traffickers in the regions. This has also been explored in prior reports of INTERPOL-UNEP (2016), Hailu (2019) and Tessema et al. (2021) which disclose that illegal wildlife trade and trafficking ever-increasing trend is driven by consumers' increasing demand, gaps in protection and the world's increasingly interconnected systems of finance, communication and transport. On the other hand, it may indicate that strong law enforcement has been established along the north western and northern routes since in most cases, rate of seizure is positively correlated with strength of capacity of law enforcement (Lawson and Vines, 2014; Gebretensae and Gebremicael, 2018; Tessema et al., 2021).

Retaliatory killing

Even though exceptions exist due to leopard's highly adaptable hunting and feeding behavior (Bertram, 1999; Stein et al., 2016), the conversion of natural habitats typically leads to the depletion of its natural prey base (Ray et al., 2005; Hunter et al., 2013). Depletion of wild prey population and the existing expansion of livestock where wild grazers progressively being replaced by domestic ones obviously increases the possibility of attack

of livestock by leopards (Kebede and Gebretensae, 2018). Consequently, the livestock herders may be intolerant to leopard conflict and kill the leopards for real or perceived threats to their lives and livelihoods (Gebretensae et al., 2008; Yirga and Bauer, 2011; Mohammed et al., 2017; Westerberg et al., 2017; Tadesse and Zewde, 2019; EWCA, 2019).

Reports from various parts of the country for 9 years (2011-2019) indicate that 8 leopards were lost in Borena Saint (2), Chebera Churchura (2), Aluto-Adami Tulu (2) Yechilay (1) and Huruta (1) due to retaliatory killing (Biset et al., 2019; Acha and Temesgen, 2015; Westberg et al., 2017; EWCA, 2019). It is however wise to assume that most retaliatory killings are concealed and hardly ever reported. This is also true in the case of other African countries in which many leopards killed due to livestock depredation stay unrecorded, and the extent of mortality due to conflict remains unknown (Stein et al., 2016).

In spite of this trend, considering the existing limited data, human-leopard conflict is minimal around the CHAs, which are stronghold sites for leopard populations. This can be attributed to presence of a relatively adequate prey base in the CHAs as opposed to other populations of leopards in which the larger proportion of their range extends beyond protected areas with scarcity of prey (Stein et al., 2020). It can also be as a result of tolerance of the local community which are aware of the economic benefits gained through trophy hunting of wild animals since this industry has become a main source of income for some members of local community living around CHAs (Di Minin et al., 2016; EWCA, 2020).

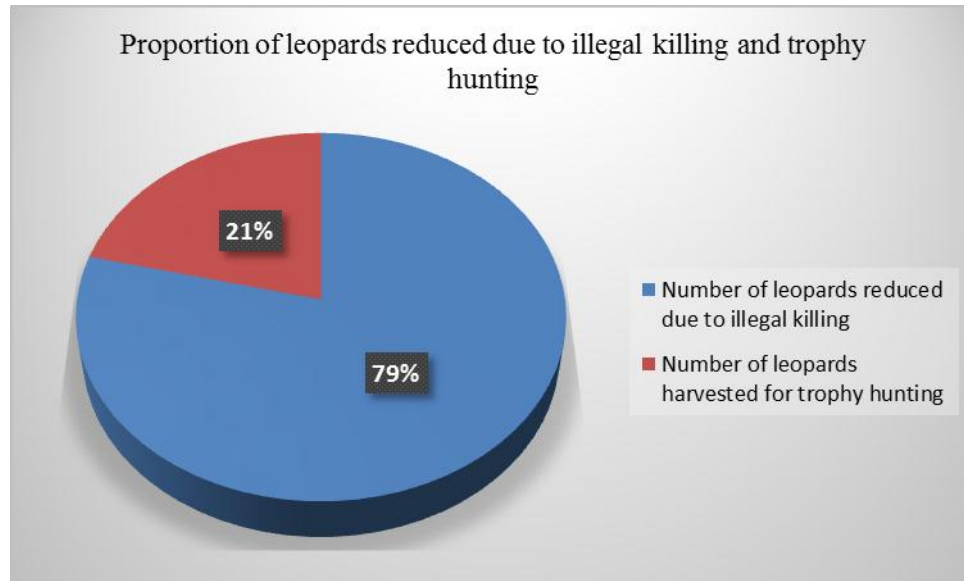


Figure 3. Proportion of leopards reduced due to illegal killings and trophy hunting for nine years (based on the result of this review).

Comparing the impact of the three human-mediated mortalities of leopards

Among the three human-mediated mortality of leopards, trophy hunting is licensed (legal) while poaching and retaliatory killing are illegal. This study that based on the reported data for nine years (2011-2019) has indicated that the threat and negative impact of the illegal killings (poaching and retaliatory killing) on the existing populations of the species in question is much larger as compared to licensed hunting. In other words, trophy hunting which is regulated and recurrently reported accounts for a smaller proportion of leopard deaths (Figure 3). The illegal killings of leopards appear to be driven mainly for the reasons discussed earlier.

The result of this review is consistent with Karanja (2012), Stein et al. (2016), Ramesh et al. (2017), Tessema (2017), Gebretensae and Gebremicael (2018) and Stein et al. (2020) which have plainly pointed out that poaching and retaliatory killing due to human wildlife conflict and illegal trade have resulted in considerable population losses of leopards. It however differs from EWCA (2020) which is not able to consider poaching as the prominent problem in this context and also argues that leopard is not threatened nor endangered in Ethiopia nor is likely to be in the future.

Conclusion

In conclusion, it is generally assumed that most illegal killings are rarely reported. However, taking into account the reported data, poaching is considered the highest

threat of the three human mediated mortalities of leopards. If the existing situation keeps on this pace, poaching along with other anthropogenic threats is expected to put the leopard populations in Ethiopia at substantially greater risk despite its wider range. Therefore, there is a need to put in place concrete protection measures to reverse the existing crimes against leopards. Moreover, it is equally important to note that there is limited information on the overall status of leopard populations and their threats across their range and thus it is imperative to undertake further assessments on the possible habitats and threats in the south western and western parts of the country and establish national Red list category for the threatened species based on the final reports of the ongoing assessments.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Full Length Research Paper

Photophysiology and respiration of the temperate fern *Onoclea sensibilis* in spring and during summer stress in a changing climate

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***Onoclea sensibilis* L. is a temperate fern species of horticultural importance, and widely distributed in the natural environment of North America, Eastern Europe, and parts of Asia. With increasing climate change, including excessive heat and unpredictable, sometimes severe precipitation events, ferns such as *O. sensibilis* may come under increasing loss of habitat and possibly survival threat. This is a study of the photophysiology and dark respiration in *O. sensibilis* growing on the cliffs overlooking the Hudson River in Palisades New York, United States of America (USA), with documentation of changes it incurred after severe heat and drought-like conditions ensued following a moderate spring season. After the extreme summer events, photosynthesis and respiration rates declined, but leaf fluorescence analyses indicated no major change in quantum yield of photosystem II or electron transport per reaction center, suggesting that *O. sensibilis* may have survival strategies to succeed if climate change is not too severe. Data are also presented on the photosynthesis rate in relation to variations in light intensity expressed as photosynthetic active radiation (PAR) from 20 to 100 $\mu\text{mol photons m}^{-2} \text{s}^{-1}$, and the results are discussed in relation to prior published findings.**

Key words: Habitat loss, leaf chlorophyll fluorescence analysis, physiological ecology, plant conservation, plant ecology.

INTRODUCTION

This is a study of the photophysiology and respiration of the temperate fern *Onoclea sensibilis* L. (Figure 1), commonly known as the 'sensitive fern' due to its intolerance of early winter frost. The geographic range of *O. sensibilis* encompasses temperate locales in the northern hemisphere, including much of mid to eastern

regions of North America, Eastern Europe including Russia, China and temperate Eastern Asia; although it also has been reported from New Zealand.

During the summer of 2022, the extreme climate in the northeastern United States of America (USA), that is, drought-like conditions and elevated peak temperatures

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exceeding 35°C (including the Hudson River palisade cliffs where this study was done) produced severe stress for many species of shade plants, including ferns and forbs dwelling in the forested areas and open locations on the cliffs. The effects were most pronounced for understory plants on higher ground where insufficient ground water and soil moisture led to wilting, decreased new growth and die back. However, other understory plants growing at the base of steep slopes, or in ravines where down-slope ground water seepage contributed to intermittent flowing springs, often were more resilient; especially in locations where gaps in the tree canopy provided sun flecks and dappled shade. Multiple factors (e.g., topography, elevation, microclimate, and quality and quantity of root substrate) contribute to variations in understory plant survival. Fern species that are particularly adapted to shaded understory environments, with typically consistent sources of moisture, are most susceptible to extreme heat and drought conditions in summer. In addition to the aesthetic qualities of ferns (Singh and Johari, 2018), they provide important ecological services (Moran, 2004; Sharpe et al., 2010); and their conservation in the face of increasing extreme climate events is a growing concern, including other environmental challenges that pose serious threats to a stable global habitat (Arcand and Ranker, 2013; Nowicki and Kowalska, 2018; Turkmen, 2022).

With increasing climate change, especially elevated summer temperatures and less predictable moderate rainfall, temperate fern species globally may be particularly susceptible to habitat stress with consequent decline in species richness and density (Sharpe, 2019; Testo and Watkins, 2013). Additional research evidence is needed to evaluate the effects of extreme climatic conditions on temperate species of ferns that are likely to incur deleterious growth effects or die back, especially if conservation efforts are to be successful in ensuring the survival of possibly sensitive species across broad geographic ranges (Amberber et al., 2014; Anderson, 2021; Ibars and Estrelles, 2012; Mehlreter, 2010; Ramírez-Barahona et al., 2011).

Although *O. sensibilis* is widely grown as an ornamental fern and is distributed broadly geographically in the natural environment; it appears there are relatively few research studies on its response to adverse environmental events. Khrapko and Tsarenko (2015) studied the adaptive strategies of *O. sensibilis* and *Matteucia struthiopteris* (both members of the Onocleaceae family) located in the south of the Russian Far East, and reported that the adaptive strategies of the two species vary depending on the ecological and coenotic conditions, but these variations were more significant in *M. struthiopteris* than in *O. sensibilis*. They also noted that under favorable conditions, *O. sensibilis* is a codominant and constitutes the herbaceous layer with other herb species. However, in locations with

unfavorable soil moisture and light conditions, the density of the fern is much lower, and the plants are largely non-fertile. The competitive capacity of *O. sensibilis* was also noted by Cousens et al. (1985) who studied ferns growing on marsh hummocks in Florida (USA) and reported that biomass of *O. sensibilis* growing alone was much greater than when it was growing competitively with a co-inhabiting fern, *Lorinseria areolata*.

A comparative study of the physiological and morphological properties of deciduous and wintergreen ferns growing in southeastern Pennsylvania (USA), including *O. sensibilis*, *Dryopteris intermedia*, *Polystichum acrostichoides* and *Polypodium virginianum*, was published by Reudnik et al. (2005). Among other relevant ecophysiological variables, they reported that *O. sensibilis* had the highest total chlorophyll (2000 $\mu\text{g ml}^{-1}$) and largest chlorophyll *a:b* ratio (ca. 3.0). They also assessed leaf chlorophyll fluorescence for the ratio of variable fluorescence to maximum fluorescence (F_v/F_m). The value for *O. sensibilis* (0.76) was intermediate to that of the other three species that varied between ca. 0.71 and 0.78. They noted that *O. sensibilis* is most typically found in the sun, but was also occasionally found under forest canopy. The capacity for *O. sensibilis* to occur in sun-laden environments as well as forest floor habitats suggests it is potentially adaptable to widely different ecological and coenotic conditions.

The sampling site for this study was a fern patch growing at the top of a north-facing moderate slope, surrounded by broad leaf trees on the east and west margins, located on Torrey Cliff, Palisades, New York (part of the Lamont-Doherty Earth Observatory campus of Columbia University). As explained more fully previously, this patch of mixed fern species included scattered individuals of *O. sensibilis* situated among other fern species at the top of this north facing slope with minimal surrounding elevated topography that could serve as a watershed source. Thus, this locale was particularly affected by the decreased precipitation that accrued during summer 2022. Consequently, it was a suitable location to study the possible effects of extreme summer heat and drought on the physiological status of *O. sensibilis*, a species that may be a good indicator species for climate change effects on survival of fern species with adaptive capacity to varied environmental locales.

The objectives of this study were as follows:

- (1) To assess the photophysiology (photosynthesis rate, chlorophyll fluorescence indicators of photosystem II effectiveness) and dark respiration of *O. sensibilis* leaves in late spring (June, 2022) as a potential baseline for comparisons to mid-summer climate effects.
- (2) To reassess these variables in mid to late July 2022 to determine what effects on *O. sensibilis* leaves, if any, could be attributed to the extreme climatic conditions.



Figure 1. *Onoclea sensibilis* growing among other ferns in the sampling site used in this study on Torrey Cliff, Palisades, New York. Scale marker = 5 cm.
Source: Author

(3) To document the rate of photosynthesis of *O. sensibilis* leaves under varying light intensities, and to determine the photosynthetic compensation point during mid to late July, as evidence of primary productive potential while under climatic stress.

MATERIALS AND METHODS

Study site

The study site was located at the northern edge of the Lamont-Doherty Earth Observatory campus on Torrey Cliff, Palisades New York (41° 00' 17.19" N, 73° 54' 24.71" W; elevation 113 m). The fern patch containing *O. sensibilis* was located at the top of a north-facing slope surrounded by broad-leaf trees on the east and west sides, and shaded by a two-story building façade on the south side. Consequently, it received largely diffuse sunlight most of the day, with occasional dappled sunlight filtering through the tree canopy to the east during early morning hours. At mid-day under cloudless, open sky, the photosynthetic active solar radiation (PAR) was ca. 100 $\mu\text{mol m}^{-2} \text{s}^{-1}$ (LiCor solar monitor Li-1776; LiCor Biosciences, Lincoln, Nebraska). In addition to scattered stands of *O. sensibilis* (Figure 1), other ferns at the site included *Athyrium* species, *Dryopteris marginalis* (wood fern), *Cystopteris fragilis* and also sparsely occurring grass.

Sample collection of *O. sensibilis* and laboratory analysis

Sample collection

Representative leaf samples of *O. sensibilis* were collected in the

morning on each sampling date, enclosed in zip-lock bags with a small quantity of deionized water, and immediately taken to the nearby laboratory for analysis. Three leaf samples were collected in late spring 2022 (June 18th) to obtain some baseline data before the onset of mid-summer. Six leaf samples were taken in mid-summer 2022 (July 24 - 28th) to obtain a more representative sample of the status of *O. sensibilis* after exposure to a week-long heat wave that enveloped much of the north eastern, U.S.A., including Rockland County, New York where the Lamont-campus is located on Torrey Cliff. Temperatures varied from 32.2 to 35.6°C during the extreme temperatures, and there was minimal precipitation in the preceding months, incurring a deficit of precipitation that was 50 to 75% of the norm.

Photosynthesis and respiration measurements

The photosynthesis rate of the *O. sensibilis* leaves was assessed using an infra-red gas analyzer (IRGA) system, with an optically clear, 163 cm^3 cuvette (Vernier, Beaverton Oregon), and illuminated with a Light Emitting Diode (LED) light source at 100 $\mu\text{mol m}^{-2} \text{s}^{-1}$ PAR (LiCor Biosciences, Lincoln, Nebraska), equivalent to the ambient PAR during mid-day at the sampling site, and at a temperature of 25°C. In addition, photosynthesis rates were determined at four light intensities (20, 40, 80 and 100 $\mu\text{mol m}^{-2} \text{s}^{-1}$ PAR) for the six samples collected in July to obtain evidence of potential photosynthesis rates under varying PAR for *O. sensibilis* plants during the summer climate stress. The data for each PAR was expressed as the mean assimilation rate \pm Standard Error of the Mean (SEM). The mean photosynthesis rate as a function of the four PAR levels is reported in the text and plotted as a graph to display the gain in photosynthesis rate with increasing PAR. Based on these data, linear regression analysis (GraphPad Software, San Diego, California) was used to derive an equation representing the

Table 1. Means \pm SEM for photosynthesis rate, respiration, F_v/F_m and ET_0/RC for *Onoclea sensibilis* leaf samples collected in June and July 2022.

Sample	Photosynthesis ^a	Respiration ^b	F_v/F_m	ET_0/RC
June ^c	1.61 \pm 0.20	0.38 \pm 0.07	0.752 \pm 0.01	1.11 \pm 0.07
July ^d	1.20 \pm 0.08	0.28 \pm 0.04	0.748 \pm 0.01	1.33 \pm 0.05

^a $\mu\text{mol CO}_2$ assimilated $\text{m}^{-2} \text{s}^{-1}$, ^b $\mu\text{mol CO}_2$ released $\text{m}^{-2} \text{s}^{-1}$, ^c $N = 3$, ^d $N = 6$.

Source: Author

predicted rate of CO_2 assimilation during net photosynthesis as a function of varying light intensity (PAR). A Kolmogorov-Smirnov test confirmed that the data were sufficiently normally distributed to apply the parametric linear regression analysis. Furthermore, the compensation point (where CO_2 gain by photosynthesis is balanced by respiratory loss) was determined by assessing the PAR intensity where the net photosynthesis rate approached zero.

Dark respiration was measured by enclosing the IRGA cuvette containing the leaf sample in an opaque enclosure to determine the rate of CO_2 production in complete darkness at 25°C. The leaf sample was maintained in the dark condition until the reaction centers of the photosystems of the leaves came to equilibrium with the darkened state, and measurements were begun when there was a steady state respiration rate.

Each leaf was imaged digitally and the total area was computed based on pixel count analysis with reference to a standard, 4 cm^2 opaque square. The mean photosynthesis and respiration rates \pm SEM were expressed per leaf area as $\mu\text{mol CO}_2 \text{ m}^{-2} \text{ s}^{-1}$ based on the digital estimated area of each leaf preparation.

Leaf stomatal density estimates

Mean stomatal density, on the abaxial surface of the *O. sensibilis* leaves sampled in July, was made by using a leaf peel method (acetate varnish was applied to the abaxial surface, and a replica of the leaf epidermis was obtained by gently peeling away the thin layer of hardened varnish). A wet mount slide preparation using deionized water was made, and the acetate peel was examined at a magnification of 400X using a Nikon phase contrast compound light microscope (Nikon Instruments, Melville, NY). Twenty optical fields were viewed, and the number of stomata per field was tabulated, then the counts were converted to equivalent number per cm^2 based on the diameter of the objective visual field. Mean number of stomata per cm^2 was determined based on the composite counts in the twenty observations.

Assessment of F_v/F_m and ET_0/RC

An OS-30p+ Chlorophyll Fluorometer (Opti-Sciences, Inc., Hudson, New Hampshire) was used to obtain the quantum yield efficiency for variable fluorescence/maximum fluorescence (F_v/F_m) and electron transport (ET_0) per reaction center (RC) (ET_0/RC) based on the JIP test application in the OS-30p+ instrument. Leaf samples were dark adapted for 20 to 30 min before the measurements were made to ensure that the reaction centers (RC) had come to equilibrium with the darkened state. Measurements were made in triplicate for each leaf sample taken in June and in July. Thus, for the nine samples of leaves (three in June and six in July), 27 leaf fluorescence measurements were made. The results were

expressed as the mean \pm SEM for the F_v/F_m and ET_0/RC measurements.

RESULTS

Results for photosynthesis rate, dark respiration, and leaf fluorescence data (F_v/F_m and ET_0/RC) are presented in Table 1.

The mean rates of photosynthesis and respiration in June were higher than for leaves collected in July after the month-long deficits in precipitation and several days of excessive heat. However, the leaf fluorescence results show that the photosystem two (PSII) quantum efficiency estimates (F_v/F_m) are nearly equivalent for the June and July samples, at ca. 0.75. This is a reasonably strong F_v/F_m value, indicating that the quantum efficiency of the leaves is not so severely affected as was the net photosynthesis rate in the leaf samples collected subsequent to the excessive heat. The electron transfer estimates from PSII to the quinone intermediate (Q_A) and beyond in the electron transfer chain (TR_0/RC), are substantial for both the June and July leaf samples. Given the appreciable values of the leaf fluorescence results, these data suggest that *O. sensibilis* is down regulating net photosynthesis through response mechanisms further along the carbon fixation pathway beyond the light photon reaction centers, perhaps morphologically through stomatal down regulation of gas and water vapor exchange with the atmosphere, as discussed more fully earlier. To further augment the leaf physiology data, the mean stomatal density for the abaxial surface of the leaves of *O. sensibilis* collected in July was determined to be 2164 stomata per cm^2 .

The results of the analysis of mean photosynthesis rate related to varying intensities of PAR (20 to 100 $\mu\text{mol m}^{-2} \text{s}^{-1}$) are as shown in Figure 2.

The mean net photosynthesis rate \pm SEM expressed as $\mu\text{mol CO}_2 \text{ m}^{-2} \text{ s}^{-1}$ per variation in light intensity (20 to 100 $\mu\text{mol photons m}^{-2} \text{ s}^{-1}$) is as follows: 20 (0.52 \pm 0.07), 40 (0.78 \pm 0.09), 80 (1.00 \pm 0.10) and 100 (1.20 \pm 0.08). A linear regression estimate ($p \ll 0.01$) of the net photosynthesis CO_2 assimilation rate (A) relative to the varying levels of PAR light intensity (I) yielded Equation 1:

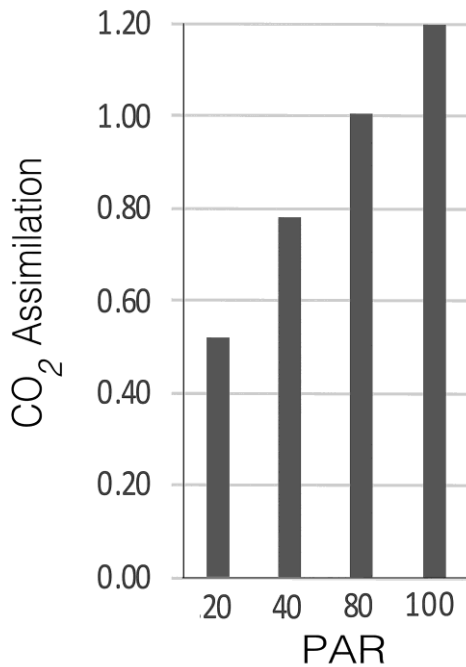


Figure 2. Photosynthesis assimilation rate ($\mu\text{mol CO}_2 \text{ m}^{-2} \text{ s}^{-1}$) plotted relative to increasing photosynthetic active radiation (PAR) of 20, 40, 80 and 100 $\mu\text{mol photons m}^{-2} \text{ s}^{-1}$.

Source: Author

$$A = 0.00788 * I + 0.4025 \quad (1)$$

where A is expressed as $\mu\text{mol CO}_2$ assimilated $\text{m}^{-2} \text{ s}^{-1}$ and I is in units of $\mu\text{mol photons m}^{-2} \text{ s}^{-1}$. This is applicable only within the limits of the variation in PAR used in this analysis (20 to 100 $\mu\text{mol m}^{-2} \text{ s}^{-1}$), which spans the range in PAR found at the sampling site as explained earlier. The photosynthetic compensation point was estimated to be at a PAR of ca. 1 to 2 $\mu\text{mol m}^{-2} \text{ s}^{-1}$.

DISCUSSION

As a largely temperate fern, widely distributed in the northern hemisphere and of considerable horticultural interest, *O. Sensibilis* is worthy of much more research attention; especially its role in the understory of forests and its growth in open locations including wetlands, marsh hummocks, and sunny margins of wooded areas (Cousins et al., 1985; Khrapko and Tsarenko, 2015; Reudnik et al., 2005). It has a rich biogeographic and geological history, with a long and abundant fossil record that includes most of the major forested regions of the northern hemisphere. This includes substantial evidence throughout the Paleocene in North America (Rothwell and Stacey, 1991). Its history spans late Cretaceous and

Tertiary in some regions of North America, and the Eocene in northwest Europe and Japan. Its modern, less widely distributed location (largely absent in western and mid European regions), is probably due to extinction of populations in these intervening geographic locales due to climate change, resulting in its present disjunctive global distribution across north America, eastern Europe and parts of Asia (Barrington, 1993).

With increasing major changes in climate in the northern hemisphere, and globally, additional research is needed to clarify how increasing annual temperatures, and less predictable (but likely more severe) precipitation events may affect plant communities, including those of ferns and other herbaceous plants that have become adapted to more amenable annual climate regimes. Although some ferns have diversified and become adapted to harsh environments including desert and drylands (e.g., cheilantheid ferns, and others), many fern species have evolutionary, long-established niches in the understory of forests or relatively moist, moderate temperate or tropical environments (Anderson, 2021; Sessa, 2018; Watkins and Cardelús, 2012).

Given evidence that *O. sensibilis* may be sufficiently adaptable to survive in varying habitat regimes (Reudnik et al., 2005), more research on its susceptibility to, or resilience against, major changing climate patterns may be worthwhile. The results of the current study spanning late spring and into mid-summer, when the northeastern USA incurred major heat waves and limited precipitation, indicate that the sample of leaves from *O. sensibilis* had a lower net photosynthetic rate following a major heat wave in mid-July than in late spring (June, 2022) of that year. The mean net photosynthesis rate in July was ca. 75% of the rate in June, and there was sufficient difference between the two means that there was no overlap of the \pm SEM values.

However, the July mean rate of 1.20 $\mu\text{mol CO}_2 \text{ m}^{-2} \text{ s}^{-1}$ at 100 $\mu\text{mol m}^{-2} \text{ s}^{-1}$ PAR is still appreciable, although the June rate (ca. 1.6 $\mu\text{mol CO}_2 \text{ m}^{-2} \text{ s}^{-1}$) is closer to the value reported for other ferns, such as the widely distributed fern *Asplenium platyneuron*. Based on graphical data of Anderson and Griffin (2021), the estimated net photosynthesis rate for *A. platyneuron* growing in a partially shaded location was ca. 1.6 $\mu\text{mol CO}_2 \text{ m}^{-2} \text{ s}^{-1}$ at PAR of 100 $\mu\text{mol m}^{-2} \text{ s}^{-1}$. It was higher for *A. platyneuron* plants exposed to brighter sunlight (2.2 $\mu\text{mol CO}_2 \text{ m}^{-2} \text{ s}^{-1}$ at PAR of 100 $\mu\text{mol m}^{-2} \text{ s}^{-1}$). In addition to the immediate or direct effects of climate stress on plant physiology, the lack of appreciable new leaf growth may have skewed the existing foliage of *O. sensibilis* toward a more mature or somewhat senescent state. This situation could also contribute to differences in the photophysiology and respiration of the samples collected in July compared to June. However, overall, the leaf samples were in good condition morphologically and rather typically chlorophyllous as shown in Figure 1.

With a compensation point for *O. sensibilis* of 1 to 2 $\mu\text{mol m}^{-2} \text{s}^{-1}$ PAR, and evidence of appreciable net photosynthesis rates with variations in PAR from 20 to 100 $\mu\text{mol m}^{-2} \text{s}^{-1}$ (Figure 2), there is further evidence that *O. sensibilis* appears to be adaptable to habitats that are widely different in light intensities. Moreover, the substantial values of PSII quantum efficiency ($F_v/F_m = 0.75$) during the late spring season, and also after the summer climate extremes, suggest that *O. sensibilis* has strong potential to rebound from some adverse climate effects. The value of $F_v/F_m = 0.75$ reported here is substantially similar to the value of 0.76 published by Reudnik et al. (2005) for *O. sensibilis* growing in Pennsylvania (USA).

It is not possible, presently, to determine the precise physiological response that accounts for the net photosynthesis decline in July. However, given the decrease in respiration as well as net photosynthesis rates during July compared to June, there may be increased stomatal closure during the climatic stressful events; thus, decreasing transpiration loss, and also lowering gas exchange with the atmosphere, thereby limiting the amount of photosynthetic CO_2 assimilation as well as decreasing CO_2 loss during respiration.

Further research on the physiological status of the leaf gas exchange and more generally on hydraulic status of water use by *O. sensibilis* during extreme climate events is warranted. It is worth noting that the stomatal densities on the abaxial leaf surface of *O. sensibilis* (ca. 2000 cm^{-2}) is somewhat less than reported for other naturally occurring ferns where values are closer to 3000 to 7000 cm^{-2} (Anderson and Griffin, 2021; Ludlow and Wolf, 1975).

Stomatal density in combination with dynamic control of stomatal gas conductance (g_s), through regulation of stomatal opening, may contribute to variations in gas exchange rates with the atmosphere; and hence, affect net photosynthesis rates. There is a strong limiting role of g_s on photosynthesis, as confirmed in numerous prior publications—a topic reviewed more generally by Xiong and Flexas (2020). Hence, stomatal density and regulation of stomatal conductance (g_s) are likely factors in the varied rates of photosynthesis in *O. sensibilis* and warrant more intensive investigation. Further research on the physiological status of the leaf gas exchange, and more generally on the hydraulic status of water use, including water use efficiency (WUE), during extreme climate events for this fern species is likely to be productive in better understanding the resilience and potential adaptive capacity of *O. sensibilis* during increasing challenges of climate change.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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