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Full Length Research Paper

Habitat preference and distribution of pangolin in Ala Forest Reserve and Onipanu Community Forest of Southwestern Nigeria

ONI Foluke[1], EJIDIKE Bernadette Nwandu[1], OLADEJI Sunday Oladipo[1]* and IJOSE Opemipo Alaba[2]

[1]Department of Ecotourism and Wildlife Management, Federal University of Technology, Akure, Ondo State, Nigeria.
[2]Department of Hospitality and Tourism Management, University of North, Texas, Denton, USA.

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Despite the ecological significance, social and economic values and the roles being played by pangolin, their ecological roles remain under-studied in context to Nigeria. There is dearth of information on the current status, distribution, habitat preferred by pangolin especially in the tropical rainforest ecoregion of Nigeria. Information on the overall habitat ecology, preference and the current distribution pattern of pangolin in the study areas were generated. Species name, height and diameter at breast height (DBH) of woody trees were recorded and Shannon-Wiener index of species diversity were used to evaluate diversity. Knowledgeable source, field guide books and indirect indices such as signs, footprints and decayed dead parts were employed. Hunters living in villages around the study sites were interviewed to facilitate opportunity to examine hunting practices, feeding and habits in areas where each species lived independently. Findings from this study reveal information on the presence of *Phataginus tetradactyla,* in the study ecosystem, habitat preference and the distribution pattern. The information provided will go a long way towards developing conservation strategies for pangolin in the study areas based on the available information on the ecological significance, social and economic values and the roles being played by this species of animal in context to Nigeria.

Key words: Conservation, ecological significance, feeding habitat, hunters, pangolin, tropical forest.

INTRODUCTION

Pangolins are the category of scaly anteaters mammals belonging to the order Pholidota, and eight pangolin species of which four are from Asia (*Manis javanica, Manis pentadactyla, Manis crassicaudata,* and *Manis culionensis*) and four from Africa (*Manis tricuspis, Manis tetradactyla, Manis gigantea,* and *Manis temminckii*) are recognised (Siew et al., 2016). Challender et al. (2014) earlier observed that historically, in Africa and Asia, pangolins have been exploited for food and medicinal purposes locally and this has resulted in an increasing threat to the animal. While Dipaola et al. (2020) stressed the use of sensory by the animal to detect and track prey with a conservation mindset.

Suwal (2011) reported on the wide distribution of

*Corresponding author. E-mail: sooladeji@futa.edu.ng. Tel: +2348030698896.

pangolins in primary and secondary tropical forests, limestone forests, bamboo forests, grasslands and agricultural fields. Similarly, Maurice et al. (2019) observed that pangolins have a wide distribution, covering an array of natural and man-made habitats including tropical rain forests, subtropical thorn forests, deciduous forests, open scrublands, grasslands, cultivated lands and human settlements in Africa, unlike what was observed in India where the presence of pangolin in the pine-dominated forest was reported (Pabasara et al., 2015; Perera et al., 2017) in a comparative.

Intensive hunting to supply the illegal wildlife trade (Fa et al., 2002; Roberton et al., 2004), low reproductive output that has adversely affected the abundance of pangolin in the wild (Sterling et al., 2006), unregulated exploitation of pangolin due to the perceived preference for this animal (Soewu and Adekanola, 2011), and shifts in market trade from Southeast Asia to Africa (CIFOR, 2017) have been identified as some of the factors responsible for decreasing conservation status of pangolin. CIFOR (2017) stressed that the four species of pangolin that are of African origin are being traditionally hunted for food in the forests of the Congo Basin, where they are still found to be relatively abundant. The CIFOR, therefore, recommended that there is a need to curtail Chinese demands for pangolin in some notable African countries like Nigeria, Sierra Leone, Uganda, Zimbabwe and Zambia in the quest to achieve sustainable conservation of pangolin. International Union for Conservation of Nature (IUCN) through the Species Survival Commission (SSC) Pangolin Specialist Group (2016) and other notable authors (Waterman et al., 2014a; Challender et al., 2015) have raised concern on the increasing illegal international trade in pangolin based on seizure data and comparatively conservative extrapolation parameter since the year 2000.

In addition to the aforementioned factors that are responsible for the decline in pangolin, high demand as a result of medicinal values of some organs of pangolin in Africa to include the skin, heart, intestines and head used for treating asthma and cardiovascular and dermatological (Soewu and Sodeinde 2015), oil extracted from pangolin scales for treating bone and muscle disorders in some parts of India (Mohapatra et al., 2015) and Nepal, pangolin scales are also used by tribal ethnomedical practitioners in treating infertility in women (Katuwal et al., 2013; Mentor-Pop Report, 2017).

The unsustainable use is also rooted in the Africa belief ideology. For instance, a typical African especially in most rural, suburban and even urban areas considered all renewable natural resources, including terrestrial and aquatic as the gifts of nature whose utilization should not be regulated or should be under the most minimal control (Soewu, 2013a; Soewu and Sodeinde, 2015). A high level of unemployment and the attendant widespread of poverty in most African countries have been documented (Soewu, 2013b). Pangolin also played a significant ecological role which is of advantage to other animals in the same ecosystem. Pangolins excavate deep burrows for sleeping and nesting and the presence of remains of prey items and fecal matter are considered as important signs in distinguishing the species of pangolin (Irshad et al., 2015).

All these aforementioned factors have resulted to the present rating of the conservation status of pangolin on IUCN Red Data Book despite the efforts IUCN has taken to address these ugly trends. This has led to the complete ban in the trade of pangolin as part of the efforts to revive the species that is at the brick of extinction (Soewu and Adekanola, 2011). Through the resolution reached at the meeting of members of IUCN in 1963, a treaty known as Convention on International Trade in Endangered Species of Wild Fauna and Flora was drafted and opened for signature in 1973 (Hutton and Dickinson, 2000). It is on this premise that IUCN developed a comprehensive inventory of the global conservation status of plant and animal species referred to as the Red List of Threatened Species using a set of quantitative criteria to evaluate the extinction risks of this biodiversity (Duarte et al., 2015). All African pangolins were previously regarded as near threatened on IUCN Red Data Book except *P. tetradactyla* and *S. temminckii* which were categorized as least concern (IUCN, 2010). All four African species are listed in Class B of the 1968 African Convention on Nature and Natural Resources (Soewu and Ayodele, 2009). African species Black-bellied Pangolin (*P. tetradactyla*), White-bellied Pangolin (*Phataginus tricuspis*), Gant Pangolin (*Smutsia gigantean*) and Temminck's Ground Pangolin (*S. temminckii*) are currently classified as vulnerable on the IUCN Red List of Threatened Species and in Class B of the 1986 African Convention on Nature and Natural Resources (Pietersen et al., 2014; Waterman et al., 2014a, b; IUCN, 2014). Due to rampant population decline, pangolin was listed as critically endangered as per International Union for Conservation of Nature (IUCN, 2014). Simultaneously, it was categorized in Appendix I (CITES) and IUCN (2016). Nigeria as one of the signatory parties to CITES has taken various initiatives at saving her biodiversity including pangolin through the promulgation of a decree and enacted of laws. For instance, three Western African species of pangolins are protected in Nigeria under Schedule 1 of Decree No. 11 (1985) of CITES.

The areas of study in this research fall within the rainforest fringe of South Western Nigeria and they are purposively selected as a result of increasing pressures on wildlife species from anthropogenic activities as reported in recent time in this particular ecological zone.

Emma-Okafor et al. (2010) reported that the destruction of natural habitats continues apace in Nigeria resulting in the depletion of the country's biodiversity. The authors noted that about 48 species of animals and 431 species

of plants are endangered, of which 16 species of mammals and 45 species of plant are categorized as rare, 30 species of animals and 20 species of plants are endemic.

The disappearance of species of animals like the forest elephant, chimpanzee, leopard, African Wild Dog, Nigeria-Cameroon Chimpanzee, and Nile Crocodile in the forest areas in South-Western Nigeria has led IUCN for placing these animals on the endangered list (IUCN Red List, 2019). Africa, a continent exceptionally rich in biodiversity, is rapidly urbanizing. Africa's urbanization is manifest in the growth of its megacities as well as that of its smaller towns and cities. The conservation planning and practice will increasingly need to account for direct and indirect impacts of the continent's urbanization. The South Western ecoregion is also one of the most densely populated areas in Africa, and already showed high levels of human activity before colonial times. There are indications that pangolins especially those that inhabit primary tropical forests are not being spared by these increasing human-induced pressures (Gomez et al., 2016). The authors reported that the recent spate of inter-continental pangolin trade originating from Nigeria has been a serious concern that requires close attention based on the possibility of the country having potential for trafficking. The author went further to affirm the record of seizures data of pangolin shipments originating in Nigeria between the years 2011 and 2015 and came out with the findings that nine seizures of pangolin were recorded with the majority of seizures occurring in 2015, with six incidents totalling no less than 5185 kg of scales. Soewu et al. (2012) affirmed that local trade in mammalian species including pangolin is a lucrative business in Southwest Nigeria. Unfortunately, there is a paucity of research carried out on international trade in pangolins especially in the tropical rainforest region of sub-Sahara Africa which has led to lack of published information in this regard.

Despite the ecological significance, social and economic values, increasing threats as a result of derivable benefits from pangolin there is a dearth of information on the current status, distribution, habitat preferred by pangolin especially in the tropical rainforest ecoregion of Nigeria. This has hampered conservation efforts towards the protection and monitoring of this species. Needless to say that, pangolins being the most traded species of the world in today's time, has attracted very little concern from the scientific community. There have been few scientific papers published on the habit and habitat of the pangolin and still, none have scientific evidence about the total number of the pangolin found in the world. International trade in pangolins is likely to be having a detrimental effect on population levels, although such pressure remains unquantified due to the paucity of research carried out on pangolins, and the lack of published information. Further investigation into the source, scale and extent of trade flows of African pangolins to Asia is desperately needed if we are to clamp down on this illicit trade, inform future policy decisions, and identify priority actions to aid in their conservation.

There is therefore a need to research the overall habitat ecology, preference and determine the current distribution pattern of pangolin in the study areas to generate updated and adequate information. Furthermore, given the threat to pangolin undermining its significance to the ecosystem and human wellbeing, there is a need to substantiate the claim with pragmatic data.

METHODOLOGY

Ondo state lies in latitude 7°15' North of the Equator and on longitude 5°15' East of the Greenwich meridian, which is within the rainforest and forest-mosaic zones of southwestern Nigeria and is bordered by Edo and Delta states to the east, Ogun and the Osun states to the west, and the Atlantic Ocean to the south (Figure 1). The state is made up of 18 Local Government Areas and had a population of 3,441,024 at the last (2006) census National Population Commission (NPC, 2006). The two selected areas of study are Ala Forest Reserve and Onipanu Community Forest, Odigbo Local Government Area, Ondo State.

Ala Forest Reserve

Ala Forest Reserve is located between longitude 5 East and latitude 70 north and falls within the high forest zone of Nigeria (Figure 2). It is located along Akure-Ondo and about 1 km away from the Cocoa Research Institute of Nigeria (CRIN) Owena substation. The reserve was gazetted as forest reserves by order number 2 of 9th January 1936 of the Western region of Nigeria. The Forest Reserve covers an area of 65.93 km^2 and is located within the old Akure Local Government bounded in the west and east by the Owena and Apomu rivers, respectively. Both the northern and southern boundaries are free areas as shown in Figure 2. The reserve lies within the Southwestern part of Nigeria populated by the Yoruba race most of whom are farmers (Pelemo et al., 2011).

Onipanu Community Forest, Odigbo Local Government Area, Ondo State

Ore with an area of 1,818 km^2 and a population of 230,351 (NPC, 2006) is the headquarters of Odigbo L.G.A. It lies between latitudes 06017'57′N and 06043'21′N and longitudes 04049'47"E and 05010'26"E of the equator. Although this area has a mixed population of diverse occupations, the people are largely farmers and hunters.

Reconnaissance survey

The reconnaissance survey was carried out before the commencement of the study at Ala Forest Reserve and Onipanu Community Forest, to get acquainted with the terrain of the Reserve and to seek the consent of the local community before the commencement of the study. Also, information on the various species of pangolin found at the Forest Reserve and Onipaanu Community Forest was gotten during the survey. This is considered an upward review of an earlier study undertaken Phenotypic

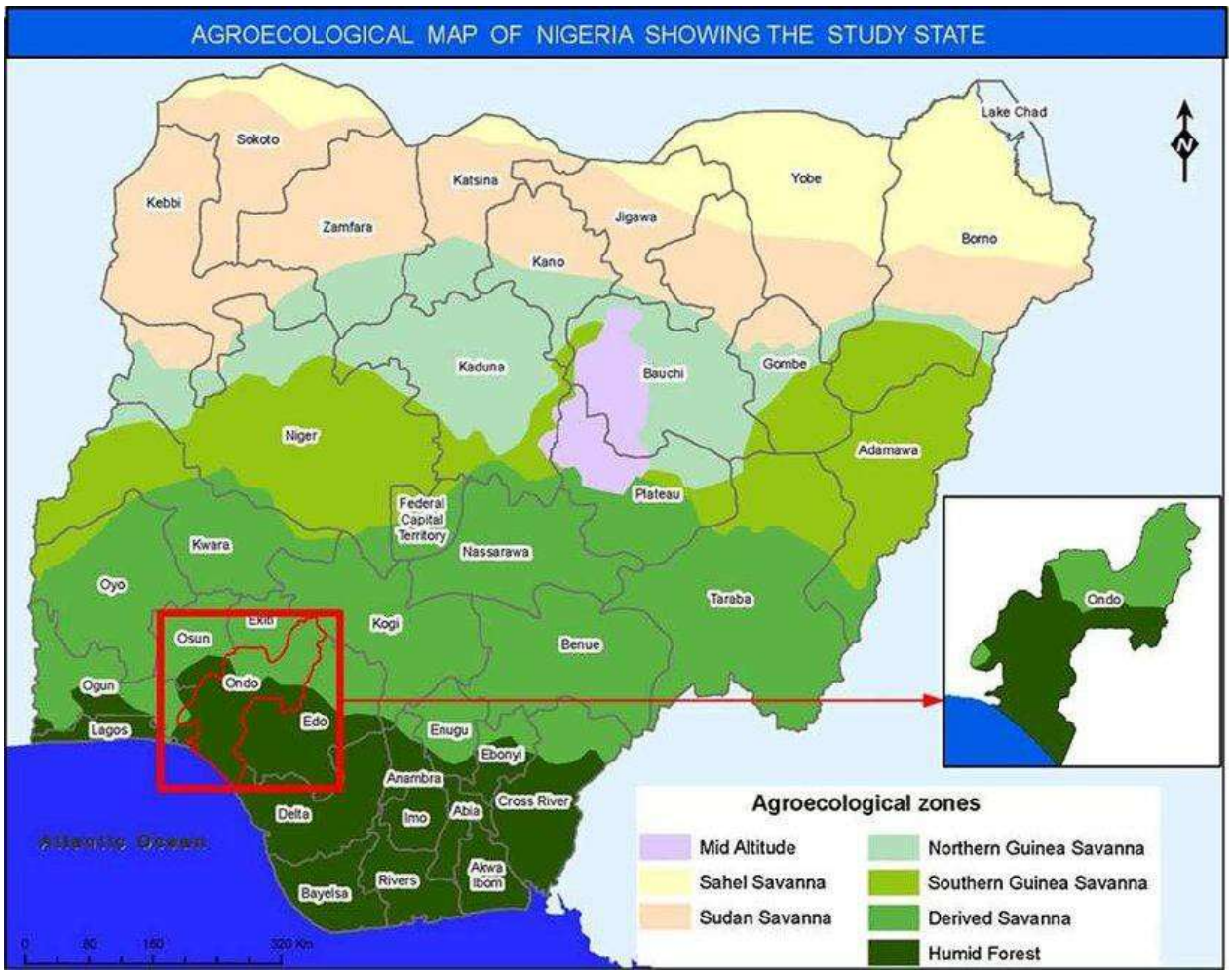

Figure 1. Map of Nigeria showing Ondo State.
Source: Authors

characterization and occurrence of pangolin species in the bushmeat market at Emure-Ile, Ondo State, Nigeria (Oguntuase and Oni, 2018). These authors established the presence of two distinct species of pangolins (*P. tricuspis* and *P. tetradactyla*) in Emure-Ile, Ondo State, Nigeria which is a few kilometers away from Ala-Forest Reserve, Ondo State. Collected information during the reconnaissance survey served as bedrock towards the success of the project. The questionnaires used for the study were also pretested to determine their validity before the commencement of the administration.

Assessment of vegetation structure and other characteristic features of pangolin habitat

The assessment of vegetation structure and other characteristic features of pangolin habitat were carried out where pangolins or other activities were sighted and indices of pangolins were established using plot sampling technique (Ogunjemite et al., 2005; Newton et al., 2007). A line transect was constructed at each study area and the characteristic features such as termite hill, hollow tree, deadwood and distance to water source were recorded. Within each of the transects, a total enumeration of the woody trees found around the pangolin activity areas was carried out. The species name, height and diameter at breast height (DBH) of woody trees were recorded. Shannon-Wiener (Magurran, 1988) index of species diversity was used to evaluate diversity. Shannon's Evenness (E) was calculated from the ratio of observed diversity to maximum Shannon-Wiener diversity. Mathematically, Shannon-Wiener Index is represented as:

$$\text{(i) } H = \sum \frac{ni}{n} \ln \frac{ni}{no}$$

where H= value of SW Diversity index and n = total number ith species.

Assessment of habitat use of pangolin

A modified method of the survey by Mahmood et al. (2013) was employed to survey the potential habitats of pangolins through field observation and traversing the line transect for their indices and signs. The researchers were accompanied by experienced local hunters that possessed in-depth indigenous knowledge on hunting,

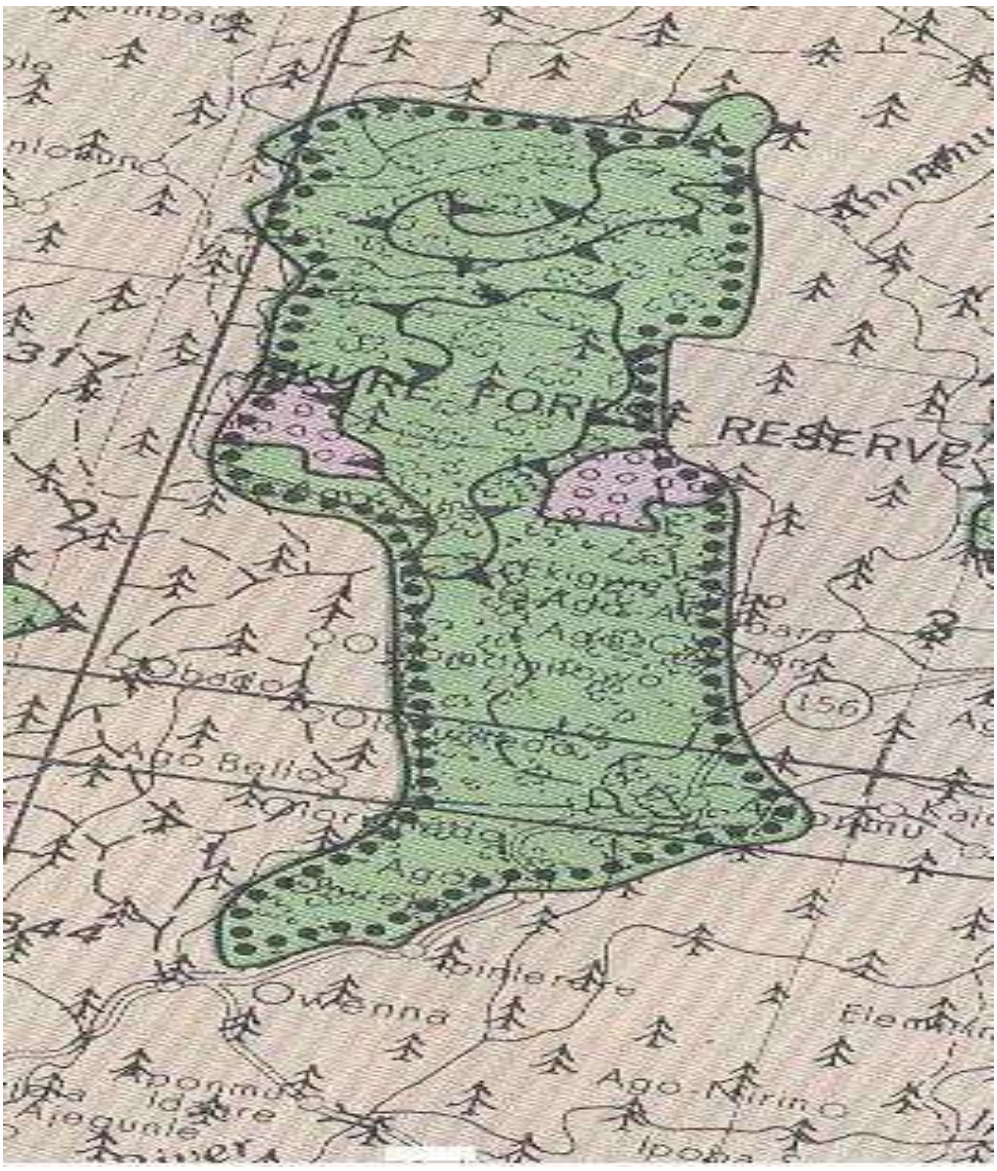

Figure 2. Map of Akure Forest Reserve, Ondo State.
Source**:** Authors

habitat structure and distribution pattern of pangolin in the study areas. The knowledgeable source coupled with the experience of the researchers acquired from a past similar study (Oguntuase and Oni, 2018) was complemented with the consultation of relevant literature and field guide book on African mammals (Kingdon, 2004). The tracks and signs observed indicated the presence of both species of pangolin is more prevalent in the rainy season, the period when pangolins are more active. The field signs most commonly reported (Allen, 1938) as being used to indicate pangolin activity including diggings made by both species when searching for food were employed in this study. Pangolin burrows were distinct from those of other species, as having a uniquely round entrance. Rodents' holes are significantly smaller, and although porcupines also live in burrows, they use natural holes and rock crevices rather than excavate their own.

The random search was also carried out for the field observation in a bid to collect necessary information on the burrows (old, new); scats, footprints and traces of tail of pangolins in the study areas. All these were noted and recorded in the field notebook. The GPS reading was taken in the place where burrows and other related matters of pangolins were found. The burrows were selected by the judgmental method and then the physical properties of the burrow such as colour, length, breadth, location, aspect, inclination, soil type were studied. Burrows were taken as the most prominent indirect signs and were searched on the other side of the transect. Burrows were classified as Fresh burrows (recently very active), new (no active this year) and old burrows (more than one-year-old). Only fresh burrows were used for the density calculation. The dominance of vegetation in each transect was calculated using a modified method of vegetation analysis (Zobel et al., 1987) while frequency, relative frequency, density, relative density, dominance and relative dominance were calculated to get important value

Table 1. Woody Plants Diversity in Pangolin Habitat of Ala Forest Reserve and Onipaanu community forest.

Species	Common name	Families	Ala forest reserve	Onipaanu Forest
Eleais guineensis	Oil palm tree	Arecaceae		+
Tectona grandis	Teak tree	Lamiaceae	+	
Cola nitida	Kola nut tree	Sterculiaceae		+
Cordia alliodora	Laurel (Omo tree)	Boraginaceae		+

Source: Author

index (IVI), that is: IVI= relative frequency+ relative density+ relative dominance.

Hunter interviews

Hunters living in villages around the study sites were interviewed orally. This interview facilitated the opportunity to examine hunting practices in areas where each species lived independently, the feeding habits in the area where they were believed to co-exist. Hunters living in the proximity of the two sites were interviewed and data were collected based on their knowledge of pangolin ecology, historic or traditional and contemporary pangolin hunting practices, and the dynamics of the trade-in pangolins. Potential interviewees were identified based on their reputation as hunters knowledgeable about pangolins and their years of experience in hunting. The Snowball sampling method was used in identifying the hunters. Adopted respondent-driven sampling method Salganik and Heckathorn (2004), a snowball sampling method was used in identifying the hunters, since the researchers were inferred by previous interviewees or named experienced pangolin hunters in neighbouring villages or communities. Interviewees were selected according to their availability and willingness to participate in an informal interview.

Data analysis

Data collected were pooled together and analysed using SPSS package 25 and descriptive statistics, percentages and were presented in chart and tables. The physiological composition of woody species was analysed using the Shanon Wiener Index (SWI) and represented in table showing the species name, local name, and number of species found at the study areas.

Mathematically, Shannon-Wiener Index is represented as:

$$H = \sum \frac{ni}{n} \ln \frac{ni}{no}$$

where H= value of Shannon Wiener Diversity index and n = total number ith species.

The Importance Value Index (IVI), for tree species in potential sites of Conservation Priority (CP) was calculated by using formulae (Cottom and Cartis, 1956):

Relative density = number of quarter with species (k) / 4 times number of sample points × 100

Relative dominance = Total basal area of species (*k*) along the transect / Total basal area of all the species along transect × 100

Relative frequency = number of samples point along transect with species (k) / Total numbers of sample points on transect × 100

Important value index (IVI) = Relative density + Relative dominance + Relative frequency

The burrow density of the CP was calculated for each zone:

Burrow Density (D) = Number of active burrows / Area sampled 100 × 100

RESULTS

Habitat preference of pangolin

Woody trees species richness and family diversity

A total of twenty-five (25) individual tree species belonging to four (4) families (Arecaceae, Lamiaceae, Lamiaceae and Boraginaceae) were recorded in the two (2) study areas. This is made up of twenty (20) individual tree species belonging to one (1) family (Lamiaceae) recorded at Ala Forest Reserve, Akure and three (3) individual tree species belonging to three (3) families (Arecaceae, Lamiaceae and Boraginaceae) were recorded at Onipanu community forest, Ore (Table 1). The teak tree (*Tectona grandis*) was the most prevalent tree species in the Ala Forest Reserve. The Onipaanu community forest had undergone major land-use changes over the years as most of its natural forest had been converted for agricultural use (oil palm plantain and kola nut plantation).

Diameter at breast height (DBH) classes distribution of woody trees in pangolin habitat in the study areas

The total frequency distribution of woody trees in the two study areas (Table 2) revealed that DBH class 41 to 60 cm had the highest frequency of 7 (35%). In Ala Forest Reserve DBH class 4160 cm had the highest frequency of 7 (35%) while the lowest frequency of 1 (5%) was recorded in the DBH classes 1-20 cm. The DBH classes 60-80 cm had the highest frequency of 2 (40%) while DBH classes 21-40, 41-60 and 81-100 cm recorded the lowest number of occurrences 1 (20%) in the Onipaanu

Table 2. Percentage Distribution of the DBH of Woody Tree species in Pangolin Habitat in the Study Areas.

DBH classes (cm)	Ala forest reserve		Onipaanu community forest	
	No of trees	Mean ± SD	No of trees	Mean ± SD
1-20	1	15.45±0.5	0	-
21-40	2	20.50±0.02	1	23.40±1.54
41-60	7	45.62±2.10	1	41.45±0.03
60-80	3	53.80±1.03	2	60.84±0.12
81-100	3	74.50±1.50	1	70.11±3.12
101-120	2	110.21±0.5	0	-
>120	2	135.82±1.25	0	-
Total	20	65.13±2.50	5	48.95±1.50

Source: Authors.

Table 3. Percentage distribution of the height of woody tree species in pangolin habitat in study areas.

Height (m)	Ala forest reserve		Onipaanu community forest	
	No. of trees	Mean ± SD	No. of trees	Mean ± SD
≤5	1	3.68±0.11	0	-
6-10	3	7.45±0.04	1	6.65±0.28
11-15	5	13.56±0.43	2	10.34±1.29
16-20	7	18.60±1.16	1	16.53±1.12
>20	4	23.50±0.17	1	20.47±0.59
Total	20	13.36±1.52	5	13.50±1.03

Source: Authors.

community forest (Table 2).

Height distribution of woody trees in pangolin habitat in the study areas

Table 3 shows the height distribution of woody tree species in the study areas. Height class 1115 m had the highest frequency of 7 (35%). In Ala Forest Reserve, height class 11-15 m had the highest frequency 7 (35%), while height class ≤5 m had the least frequency of 1 (5%). In Onipaanu community forest, height class 11-15 m had the highest frequency 2 (40%), while height classes 6-10, 16-20 and >20 m had the least frequency 1 (20%).

Characteristic features and frequency of occurrence in pangolin habitats in the study areas

The result of other features found in the habitat of pangolin revealed that Ala Forest Reserve had a higher number of deadwood (n=9) compared to the eight (8) dead woods found in the Onipaanu community forest. Ala Forest Reserve had a higher number of termite hill occurrences in the sample area (n=5) compared to that of Onipaanu Forest Reserve (n=4). The majority of the locations are closer to the water source (10 m) except for location 1 and location 3 in Ala Forest Reserve that was farther with distances of 20 and 15 m, respectively to the water source. Also, location 3 and location 2 in Onipaanu Forest Reserve were farther with distances 30 and 15 m, respectively (Table 4).

Distribution of pangolin in the study areas (Burrow Count)

The vegetation cover of the pangolin habitat varied between the study areas. The long-tailed pangolin was more common in the study areas. The indirect indices used in determining the presence of pangolin in the study areas included the burrow count and the presence of scales. As presented in Table 4, Onipaanu Community Forest recorded a higher number of burrows found in trees (n=8), compared to (n=3) burrows found in Ala Forest Reserve. Also, near most of these burrows were the scales of these pangolin species found. These scales belonged to the long-tailed pangolin; this suggests they may be relatively abundant in the area.

Table 4. Frequency of occurrence of indices of pangolin sighted in plot sampled in pangolin habitats in the study areas.

Ala forest reserve	Location 1	Location 2	Location 3	Location 4	Total
No of Dead wood around	3	0	1	3	7
No of Termite hill found	3	1	1	0	5
Distance to water source	20m	10m	15m	10m	55m
No of burrows found in trees	1	1	0	0	2
Onipaanu community forest	**Location 1**	**Location 2**	**Location 3**	**Location 4**	**Total**
No of Dead wood around	2	2	4	0	8
No of Termite hill found	0	1	1	2	4
Distance to water source	10m	15m	30m	10m	65m
No of burrows found in trees	2	0	1	1	4

Source: Authors.

T**able 5.** Food the animals feeds on-feeding preference.

No	Food
1	Termites from the Termite Hill
2	Ant and other insects

Source: Authors.

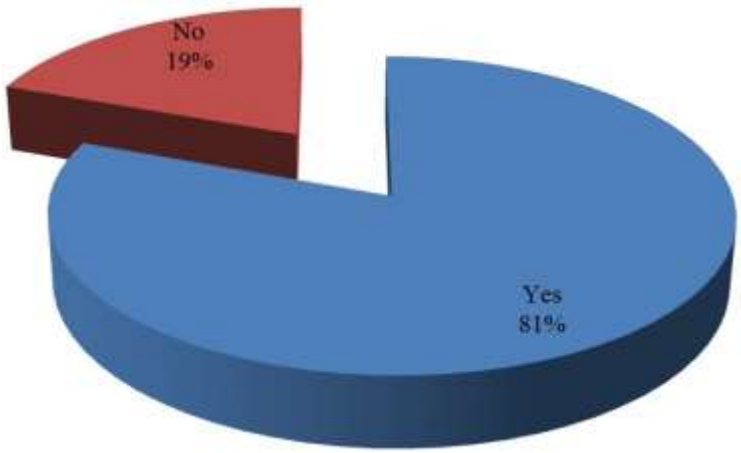

Figure 3. If ever killed Pangolin.
Source: Authors.

Mode of feeding of pangolin in the study areas

Some of the animals feed on termites and ants since termite hills were found in different locations across the study areas. All the hunters that were interacted with explained that the animal feed on insects on palm trees and other woody tree species. The animals are often said to be abundant mostly during the rainy season, maybe due to sufficient food and proximity to the water source. The presence of termite mounds and anthills within the preferred habitat of pangolins in the Ala Forest Reserve and Onipaanu Community Forest is due to their feeding preferences (Table 5).

Hunting practise and traditional significance of pangolin

The study shows that 81% of the respondents have killed pangolin before (Figure 3), while 82% of the respondents

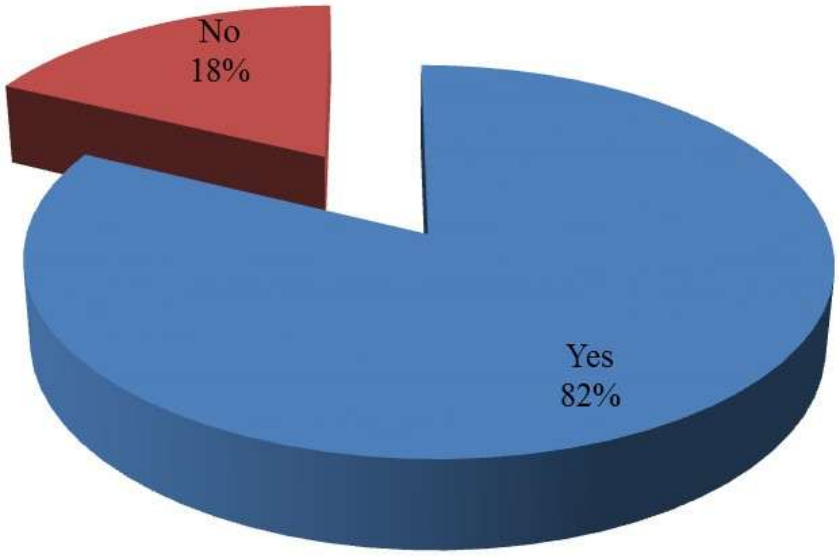

Figure 4. If ever eaten pangolin meat.
Source: Authors.

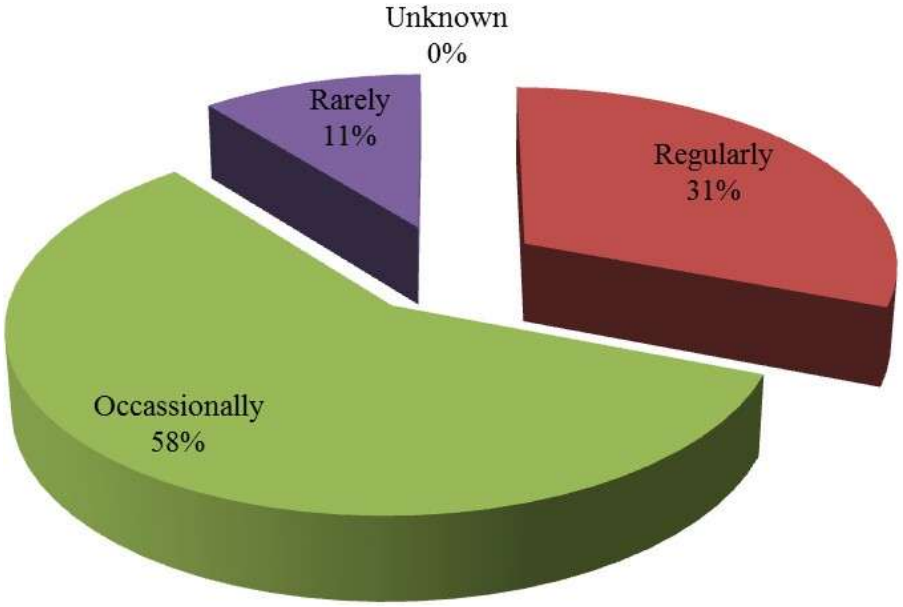

Figure 5. Frequency of hunting pangolin.
Source: Authors.

have eaten pangolin meat before (Figure 4). Furthermore, 58% of the respondents occasionally hunt for pangolin in the study areas, while 31 and 11% of the respondents regularly and rarely hunt for pangolin, respectively (Figure 5). The main reason for hunting for pangolin is for meat (74%), while 22% hunt for pangolin for trade purposes (Figure 6). The study shows that 60.5% of the respondents set traps to catch the animal, while 18.5% hunt for pangolin by finding their burrows, 11.3% make use of hunting dogs to hunt for pangolin (Figure 7).

DISCUSSION

Findings from this study reveal that *P. tetradactyla* also

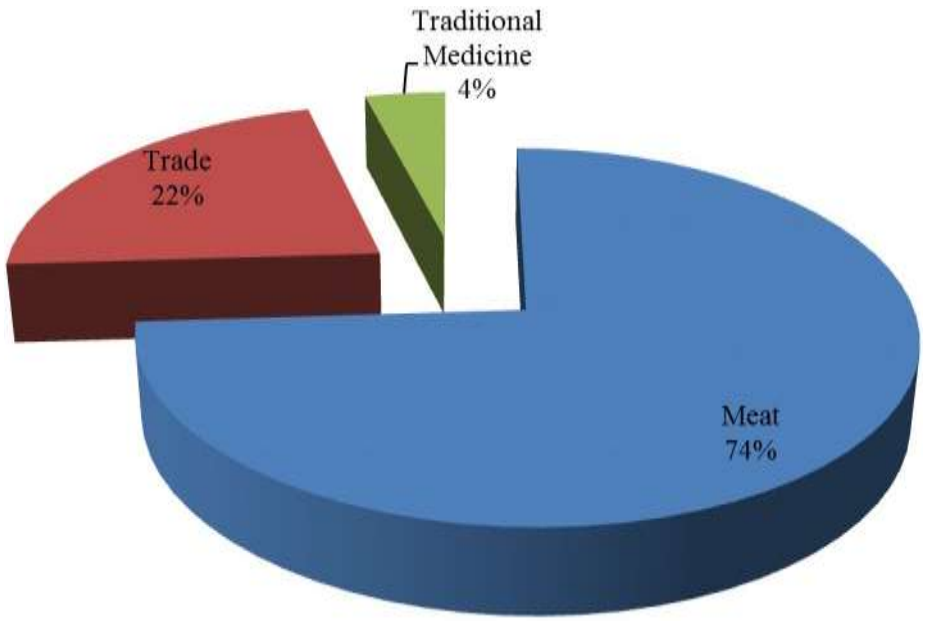

Figure 6. Reasons for hunting pangolin.
Source: Authors.

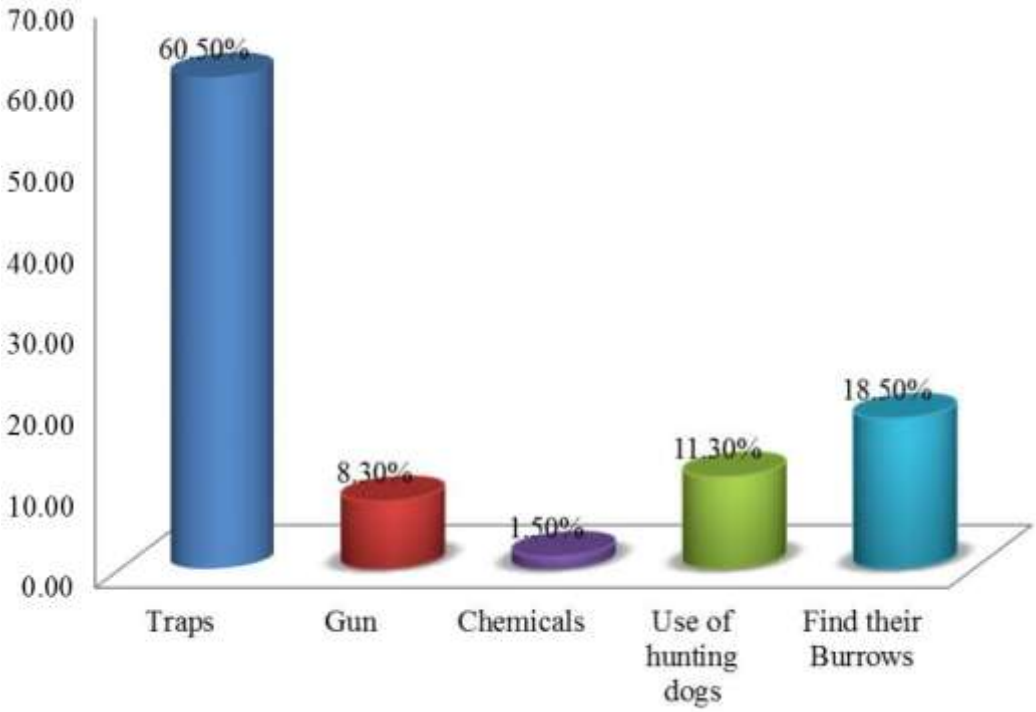

Figure 7. Techniques for hunting pangolin.
Source: Authors.

known as long-tailed was the most common pangolin species in the study areas. This supports the findings of Oguntuase and Oni (2018) who reported that *P. tetradactyla* is one of the two (2) pangolin species found

in Ondo State. This further supports the previous distribution of pangolin species in Africa with the total exclusion of giant pangolin and Temminck's pangolin from Nigeria, and the forest habitat preference of the *Phataginus* species. Findings from this study show that there were various woody tree species found in the study areas. The arrangement of vegetation influences the distribution of fauna species. The woody plants recorded in the pangolin habitat were supported by the findings of Odewumi and Ogunsina (2018) and were also among the important woody species recorded by Ogunjemite et al. (2012) in Old Oyo National Park. The habitat characteristics of the study areas are in tandem with the description of Maurice et al. (2019) that pangolin was present in various woodland and forest habitat types. Palm trees and some woody species were important to the distribution and presence of pangolin in the study areas because ants and termites are always found on the tree which provides food for the pangolin. The results of the study, therefore, supported the view of Odewumi and Ogunsina (2018) and Peteirson et al. (2014) that vegetation structure and plant diversity strongly influenced the distribution of pangolins in their habitats.

Deadwood was more common than termite hills in areas where pangolin activities (feeding) were sighted. This is because ants and insect larvae are more commonly found in dead woods. This is in accordance with the statement by Mahmood et al. (2013) and Peiterson et al. (2014) that pangolins are terrestrial animals that lived inside woody plant holes, piles of plant debris, earthen burrows, and caves so their distributions are bound to be influenced by plant species that formed their primary habitat. Also, it was observed that a higher percentage of pangolins signs were sighted not far from the water source (River). This agrees with Odewumi and Ogunsina (2018) and Challender et al. (2015) that *M. tetradactyla* were never far from permanent water and water courses as they were also known to inhabit older or abandoned tree plantations. Species richness of termites was significantly higher in a natural forest than in the oil palm plantations (Attingnon et al., 2005).

The use of trap as a traditional method of hunting by a majority of the hunters is a serious concern since it makes it very difficult to control the rate of harvesting or killing this animal in the wild. The uncontrolled use of traditional means of hunting in Africa makes the rate of harvest of wildlife resources surpass production (Fa et al., 2006). This is similar to the observation reported by Mohapatra et al. (2015) on the reasons for the use of pangolin body parts in India. The period and time of hunting this animal also vary depending on the occasion demand for instance during a festive period or regularly. The main reason for hunting the animal is for meat to meet the protein intake of the people. Lee et al. (2020) reported that rural people rely heavily on wild meat as a source of income and food and these had led to widespread unsustainable exploitation, harvesting and consumption of wildlife-based resources. In Nigeria, it is an important source of protein, widely consumed in both rural and urban areas (Soewu and Ayodele, 2009). Other reasons include hunting for subsistence (Soewu et al., 2012) and medicinal purposes (Soewu and Adekanola, 2011). In addition to all these, Oni et al. (2020) opined that conservation of pangolin could enhance ecosystem balance, promote tourism and sustainability. There are indications that the presence of *P. tetradactyla* also known as long-tailed has been established as the most common pangolin species in the study areas. This species of pangolin preferred forest habitat with characteristic features as observed in this study collaborated with findings from the literature. The diversity of woody tree species, vegetation structure and arrangement largely influence the distribution pattern of pangolin. The feeding pattern of pangolin also influences their distribution this explains the reason why this species of animal is commonly found on dead woods where ants and insect larvae are in abundance. Availability of water is also a very important factor to be considered in habitat type. The traditional method of hunting, hunting for bushmeat, source of income, medicinal purposes and other forms of traditional use are serious threats to the conservation of pangolin in the study area.

Conclusion

The presence of *P. tetradactyla* also known as long-tailed in the study area has been established as the most common pangolin species. This is largely due to the availability of diverse species of woody plants that provided suitable habitat for this species of animal and survival of ants and termites that serve as food for the pangolin. Deadwood plant holes, earthen burrow and caves as observed during the study equally formed primary habitat for the pangolin. Availability of water body is a very important features that influence the distribution of pangolin across the study area since the animal was sighted not far from the water source. Although the Percentage presence of the animal was established in abandoned oil plantation; however, species richness of termites was significantly higher in a natural forest. The uncontrolled method of hunting through the use of trap as observed in the study area is considered to be unsustainable and a serious threat to the population of the pangolin in the area of study. Various reasons were adjudged for the increasing hunting for the animal including source of food, meat or protein substitute, source of income, medicine while conservation for posterity, ecotourism is preferable. In-depth understanding based on the information provided on the ecology, traditional uses, subsistence and market values of pangolin as presented in this study is considered very important towards achieving sustainable conservation of this species of animal in the

sub-tropical rain forest belt of Africa.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Rural women vulnerability to human-wildlife conflicts: Lessons from villages near Mikumi National Park, Southeast Tanzania

Evodius Waziri Rutta

School of Environmental Studies, Queen's University, Kingston, Ontario, Canada.

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Human-wildlife conflicts (HWC) remain a serious conservation problem in Tanzania, particularly for rural communities near national parks. Despite this prevalence, research on rural women's experiences with human-wildlife conflicts is limited. To address this research gap, this study examined the impacts of HWC on rural women from two villages neighboring Mikumi National Park (MNP) in Southeast Tanzania. A total of 20 adult female victims of human-wildlife conflicts (HWC) were purposely selected and interviewed to understand the impacts of human-wildlife conflicts in their lives. Findings indicate that loss of grassland and water within MNP borders exacerbated by climate change are pushing wild animals from MNP to seek food in nearby villages, causing frequent human-wildlife tensions. Crop damages, livestock killings, household food insecurity, and fears for physical safety were found to be significant impacts of HWC increasing rural women's vulnerability to poverty. Despite these conservation threats, most interviewed HWC victims receive very little support from conservation authorities threatening the survival of wild animals from MNP. For peaceful co-existence, the study recommends empowering rural women with conservation training on HWC prevention and investment in the large-scale restoration of degraded lands and water sources to reduce competition over natural resources between humans and wildlife.

Key words: Human-wildlife conflict, rural women, Mikumi National Park, Tanzania.

INTRODUCTION

Over the years, the government of Tanzania has implemented several conservation programs to mitigate potential conflicts resulting from increasing human-wildlife interactions. Despite the efforts, the government interventions have not yielded any significant results. It is estimated that annually about 100 rural residents in Tanzania lose their lives due to wildlife-related killings, with large animals, such as lions (*Panthera leo*), hippos (*Hippopotamus amphibius*), and elephants (*Loxodonta africana*), among the primary cause of these fatalities (Eustace et al., 2018; Kushnir and Packer, 2019; Linuma et al., 2022). With a large chunk of its land reserved as national parks, human-wildlife conflict (HWC) in Tanzania tends to be more intense when communities close to

E-mail: erutta83@gmail.com. Tel: +1-343-580-2444.

protected areas do not see the real benefits of safeguarding wildlife (Andrade and Rhodes, 2012; URT, 2020). Often HWC also results in crop losses, livestock depredation, and property damages, increasing poverty levels for residents living near national parks (Kideghesho and Mtoni, 2008; Linuma et al., 2022). Consequently, victims of HWC develop hate and a negative attitude towards wildlife, which, if unresolved, lead to retaliation killings of wild animals threatening the survival and sustainability of wildlife resources (Frank, 2016; Mariki et al., 2015; Mayengo et al., 2017). To resolve this complex conservation problem, other than enforcing wildlife protection laws, governments in Africa have been urged to engage locals in their conservation efforts, especially in communities that share and compete for natural resources with wild animals (Benjaminsen et al., 2013; Treves et al., 2006). Community-led conservation approaches such as Community-Based Conservation of Natural Resources (CBNRM) have therefore been widely promoted in Tanzania, and several parts of Africa to ensure economic benefits accrued through wildlife tourism trickle down to locals, especially those that reside close to protected areas (Kegamba et al., 2022).

In Tanzania, wildlife management agencies such as Tanzania National Parks Authority (TANAPA) and Tanzania Wildlife Management Authority (TAWA) have been at the forefront in establishing Village Game Scouts (VGS) that, among other things, receive conservation training and work alongside TANAPA and TAWA to prevent potential HWC and ensure sustainable management of wildlife resources in communities they come from (Bluwstein et al., 2018). While some progress has been achieved, rural women's involvement in resolving HWC has been very little and, in most cases, overlooked (Brooks et al., 2012). Rural women's experiences with HWC and the risks posed to them are under-researched and not sufficiently reflected in ongoing conservation strategies in the country (Homewood et al., 2022; Mariki, 2016). This lack of gender integration is very concerning because, as dominant food producers, rural women from communities neighboring national parks are at a greater risk of human-wildlife killings or physical injury when farming or when collecting firewood (Anderson and Mehta, 2013; Matseketsa et al., 2019). As such, ensuring harmony between humans and wildlife demands an understanding of the needs and experiences of everyone that is or may be affected by human-wildlife interactions (Andrade and Rhodes, 2012; Nyhus, 2016). Furthermore, studies have also shown that as primary caregivers in their households, women's inclusion in natural resource management efforts plays a critical role in influencing positive attitudes and conservation knowledge, particularly to children and other family members (Agarwal, 2009; Mwangi et al., 2011). In this regard, interventions to achieve sustainable wildlife management and peaceful co-existence between wild animals and rural communities may have a limited impact if women's voices are excluded or neglected (Homewood et al., 2022; Khumalo and Yung, 2015; Ogra, 2008).

Though conservation challenges emanating from HWC have been extensively researched (Dickman, 2010; Kaswamila, 2009; Kushnir and Packer, 2019; Mayengo et al., 2017) in Tanzania, very little has been explored to understand the experiences of women residing close to less popular national parks. One such community is Kiduhi and Mbamba villages, found less than 20 kilometers from Mikumi National Park (MNP) in Eastern Tanzania. Compared to other high-profile wildlife tourist destinations such as Serengeti and Ngorongoro in Tanzania, MNP has received limited attention from conservation experts within and outside Tanzania partly because of its low tourism potential. For example, between 2012 to 2020, the vast majority of wildlife conservation studies carried out by the Tanzania Wildlife Research Institute (TAWIRI)[1] and its partners were those from Serengeti, Ngorongoro, and Tarangire national parks, and none of these featured or included rural women's experiences with HWC (TAWIRI, 2022). This lack of research has affected the government response, particularly in MNP, where the impact of HWC, threats, and risks posed to rural women remain unnoticed. Focusing on communities residing close to MNP, the objectives of this research were the following: (1) Understand rural women's experiences with human-wildlife conflicts; (2) Examine and document risks and women's livelihoods challenges resulting from HWC incidences, and (3) Highlight gender-inclusive conservation strategies to mitigate HWC in MNP.

MATERIALS AND METHODS

Study area

This study was conducted in Kiduhi and Mbamba villages that neighbor Mikumi National Park (MNP). Located between 7°00' and 7°50'S, and 37°00' and 37°30'E in Morogoro region, Eastern Tanzania, MNP was first gazetted as a national park in 1964 with a land area of 1,070 km^2 and later expanded to 3,230 km2 (TANAPA, 2007). MNP shares one ecosystem with Selous Game Reserve enabling animals to migrate to and from the two protected areas. With a land area of 3,230 km2 (1250 square miles), MNP is also one of the largest national parks in Tanzania, hosting large numbers of wild animals, including Elephants (*Loxodonta africana*), Lions (*Panthera leo*), Buffalos (*Syncerus caffer*), Giraffes *(Giraffa camelopardalis*), more than 300 bird species and over 1200 plant species (TANAPA, 2007). It borders three administrative districts of the Morogoro region: Kilosa, Morogoro, and Mvomero. Its proximity to these districts and the growing human settlements in villages near MNP has become a major source of tensions between wild animals and humans (Mayengo et al., 2017).

In this study, participants were recruited from Kiduhi and Mbamba villages (Figure 1). Kiduhi, a predominantly Maasai village, is found east of MNP and has a population of 893 and 270 households, the vast majority of the Maasai tribe (URT, 2020). Livestock keeping is the primary livelihood activity for Kiduhi residents. Unlike Kiduhi, where livestock keeping is the primary

[1] https://tawiri.or.tz/publication/journal-publication/

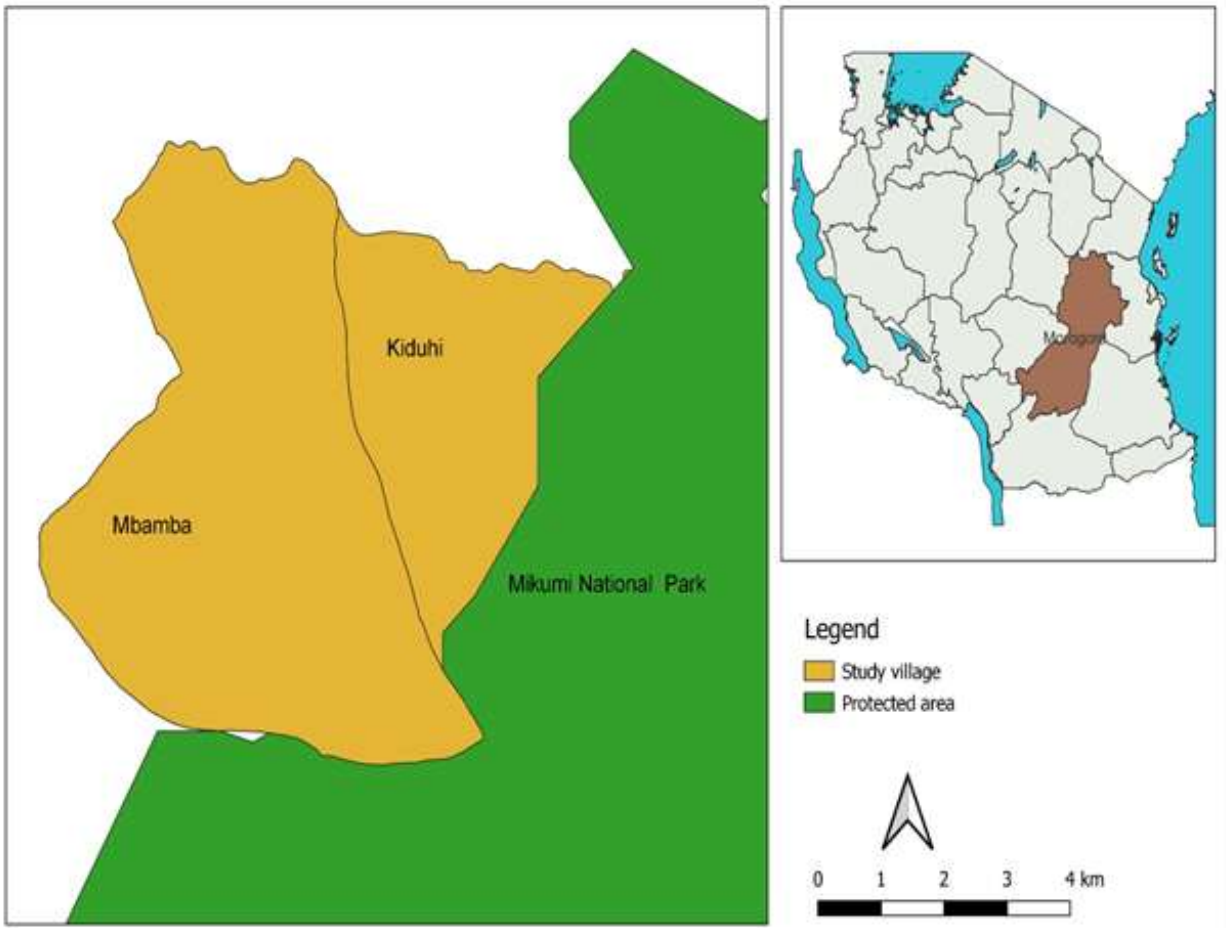

Figure 1. Lower left is the map of the study areas showing sampled villages and the location of Mikumi National Park, which shares a border with the two study sites. Top right is the map of Tanzania; the brown shaded area shows the location of the Morogoro region, which host Mikumi National park southeast Tanzania.
Source: Author

livelihood, in Mbamba, crop farming is the major source of income, with rice, maize, beans, sorghum, cassava, sesame, and sunflower as major food crops (URT, 2020). Located in the south of MNP, Mbamba village has a population of 2485 and 519 households (URT, 2020).

The rationale for selecting Kiduhi and Mbamba was based on the fact that over the last few years, clashes between wild animals from MNP and residents from these villages have been frequently reported hence a suitable site to examine HWC issues. The two villages also share a border and are close to MNP, which exposes and increases their residents' vulnerability to HWC. Additionally, the lack of research regarding women's experiences with HWC made the two villages ideal study sites to document and understand rural women's experiences with HWC. This research gap also aligned well with the researcher's overall intention and the objectives of this study.

Sampling and study population

The target population for this study was victims or survivors of HWC events that occurred between 2016-2022 in Kiduhi and Mbamba villages. Some participants were also involved in the "Larger than Lions: A Community-to-Community Photovoice Project to Protect People and Predators near Mikumi National Park" project implemented from February 2021 to November 2022 in Kilosa district and funded by the National Geographic Society (NGS). In this paper, HWC victims or survivors refer to female individuals that were directly or indirectly affected by HWC incidents such as livestock kills, physical injury, loss of a husband or a loved one, and property damage or crop losses that happened as a result of attacks or raids by a wild animal (s) from Mikumi National Park (MNP).

Due to the nature of this study, participants were purposely recruited through consultations with village government officials, Village Game Scouts (VGS), and influential leaders who had knowledge of female victims and survivors of human-wildlife conflict incidences that occurred in their villages. The researcher did these consultations to inform the community about the study's objective and ensure that only suitable candidates participated and were willing to share their experiences (stories). In general, the main criteria used to recruit participants for this study included being a victim or survivor of the HWC incidence (s) that occurred between 2016-2021, having a close relationship with the victim of HWC (if the prospective interviewee is not the primary victim), and age of the victim (must be older than 21 years old). Using these criteria, 20

Table 1. Socio-economic Information of Respondents.

Variable	Data category	Frequency (%)
Age	20-39	8 (40%)
	40-59	11 (55%)
	60+	1 (1%)
Marital status	Single	2 (10%)
	Married	13 (65%)
	Divorced	5 (25%)
Education level	No formal education	8 (40%)
	Primary school education	12 (60%)
Primary livelihood activity	Farming	7 (35%)
	Farming and livestock keeping	13 (65%)
Location of HWC incident	At residence	7 (35%)
	At the farm	13 (65%)
Received compensation after HWC Incident	YES	3 (15%)
	NO	17 (85%)
Received training on HWC mitigation	YES	3 (15%)
	NO	17 (85%)

Source: Author

victims (*n=20*) of HWC participated in face-to-face interviews, with 10 (*n=10*) respondents from each village. In addition to face-to-face interviews with HWC victims, the researcher held consultative meetings with 5 (*n=5*) key informants to gather more information on the state of HWC in Mikumi, present concerns raised by interviewed victims, and establish institutional plans to address the HWC situation. Key informants interviewed included MNP Staff, representatives from Kilosa District Government, and Non-Governmental Organizations (NGOs) engaged in wildlife conservation programs in the Kilosa district and beyond. The selection of these key informants was purposive and considered individuals' knowledge and experience on the matter being investigated and their availability to speak with the researcher.

Data collection and analysis

Face-to-face interviews were conducted with 20 female participants (*n=20*) who consented to participate in the study. Interviews were held in the participants' chosen location, some were held outside participants' residences, and others were held in a place agreed upon by both the researcher and the respondent. Before the interviews, a written consent form (Appendix 1: Respondent Consent Form) that explained the study's objective, interview questions, and respondents' right to withdraw from the interview when they felt to do so; were given to each participant for them to sign. The interview was guided by an interview guide divided into two sections (Appendix 2: Interview Guide Mbamba and Kiduhi Study). Each section had open and closed-ended questions, which included respondent demographic information, their occupation, their perspectives on what drives HWC, when and how they experienced HWC, how HWC affect their livelihood or well-being, and what can be done to prevent HWC in the future.

The interview responses were recorded in a notebook and audio recorded to ensure the researcher captured all responses, avoid data loss, and can retrieve participants' responses during data analysis. In accordance with Tanzania Wildlife Research Institute (TAWIRI) and Tanzania's Commission for Science and Technology (COSTECH) research, ethics permit number 2021-222-NA-2021-078 was obtained before the study began. Participants were also informed that their identity would be anonymous and that their personal information would not be revealed. Most interviews lasted about 90 minutes, with only two respondents going beyond that. Data were collected from June to August 2021.

Data extracted from interviews were analyzed using the thematic analysis approach. In thematic analysis, information gathered from interviews is classified and analyzed based on their reporting patterns (Braun and Clarke, 2006:79). Since the sample for this study was small, the analysis of information gathered from the interviews began by reading and listening to all interview transcripts several times to understand respondents' opinions and experiences with HWC. After listening to the interview responses multiple times, specific codes representing the original meaning of participants' responses were developed in line with the study objectives and research questions. Major themes that emerged from the analysis include *Climate Change as a driver of human-wildlife tensions*, *Risks and Vulnerabilities facing HWC victims*, and *Challenges facing HWC victims in Kiduhi and Mbamba villages*. These themes were further classified and categorized into specific sub-themes that are presented as findings in the Results section (3.2-3.4) responding to primary research questions for this study. To increase the validity of study findings, individual quotes and statements said by respondents are also used to echo participants' voices.

RESULTS

Socio-economic profile of the respondents

Table 1 summarizes the socioeconomic characteristics (age, education, place of residence, source of livelihood,

etc.) of respondents involved in the study. More than half (55%) of HWC victims interviewed were mature adult females aged 40 to 59, with the majority (65%) still married and only a few reported being single or divorced. While villages share, primary and secondary schools established almost three decades ago, more than a third of the participants (40%) had no formal education, and the remaining (60%) had primary school education. Low levels of education among the study participants were found to be significant in Kiduhi compared to their counterparts in Mbamba. In Kiduhi village, a predominant Maasai community, of the 10 participants interviewed, only 2 reported having attended primary school education, while the rest never attended formal schooling. This difference in educational levels for participants in Kiduhi could be attributed to socio-cultural barriers that still exist in most pastoral communities in Tanzania, where girl child tends to be neglected or denied their rights to attend school by their parents. This finding is consistent with previous studies that have indicated that despite the increase in primary and secondary school enrollments in Tanzania, over-engagement of school-age children in taking care of cattle and other household responsibilities has left many youths from pastoral communities with low levels of education when compared to other communities (Ndibalema, 2022; Rweyemamu, 2019; Saruni et al., 2018).

Other studies report that early child marriages and socio-cultural barriers have prevented most girls from the Maasai and other pastoral communities from attending and receiving a formal education (Pesambili and Novelli, 2021; Raymond, 2015; Temba et al., 2013). Parents' lack of knowledge on the significance of formal education in their children's lives and poor educational services has also contributed to educational inequalities and school dropouts among children from pastoral communities (Komba, 2012; United Republic of Tanzania, 2019d; UNICEF, 2018).

Concerning conservation education, the study found that only a few (15%) of the participants received conservation education or attended training on how to mitigate HWC. Respondent's lack of awareness on how to respond when wild animals from MNP attack their cattle or raid their farms is alarming and needs to be urgently addressed before it escalates the HWC problem. In several parts of Africa, conservation education for women has proved to have several long-term benefits, with studies showing that educated women are more likely to be active in the management of natural resources and can play a critical role in issues affecting their livelihoods (Costa et al., 2017; Krietzman, 2019).

Crop farming and livestock rearing are the primary economic activities for all participants. While in Mbamba, almost all respondents were crop farmers, in Kiduhi, some participants reported doing livestock rearing and crop farming. In both villages, maize, rice, and sesame are the major food crops produced for household consumption and commercial sale. Participants were also asked to share how, when, and where the HWC incident occurred. More than half (65%) of the respondents mentioned that the HWC incident happened on their farms, while the remaining (35%) reported that the incident occurred at their residence. Those who experienced the HWC incident at their residence were mostly victims of HWC from Kiduhi village. According to these participants, most predator attacks, especially from Lions and Hyenas, happen at midnight or during dark hours inside cattle enclosures traditionally known as ‘bomas’ located within their residences. Though Tanzania’s 2011 Wildlife Conservation Act demands victims of HWC be compensated for any losses, only a few 3 (15%) of the victims of HWC interviewed reported receiving compensation after the attacks. The vast majority, 17 (85%) of the participants, mentioned that they had not been compensated anything despite filing official claims to the responsible government authorities.

Drivers of HWC in villages near Mikumi National Park (MNP)

Climate-change induced drivers

Interviewed participants identified a number of factors that fuel conflicts between residents of the two villages and wild animals from MNP. In both villages, respondents believed HWC is driven by environmental factors, especially a significant decrease in rainfall and habitat loss, forcing large animals such as Elephants to look for food and water outside MNP. According to victims from Mbamba village, recently, it has become so common to see a group of Elephants roaming in their village with the problem worsening during peak harvest seasons. This concern raised by respondents from Mbamba was also echoed by one of the officials from MNP who was interviewed during data collection.

“As rainfall dries, nutritious grasses and other natural vegetation that antelope, deers, and other herbivores could feed on have also dried up, forcing large herbivores like Elephants to raid farms and water sources outside MNP,” said one MNP park official.

The lack of rainfall has also disrupted the local food chain within the MNP ecosystem. Wildlife authorities from MNP interviewed in this research pointed out that due to prolonged drought conditions, potential prey for lions such as deer, wildebeest, and others migrate and move to far distances in search of areas with enough grassland and water. To survive, lions and other carnivores resort to goats and cows; they can easily prey in villages that neighbor MNP. In Kiduhi, a predominantly Maasai community where livestock keeping is a primary source

of livelihood, hyena attacks and killings of goats were reported by HWC victims to be so frequent, endangering the lives of Maasai men and women.

"In February 2021, a lion attacked my boma and killed eleven goats but ended up eating just one goat. Though the attack happened at midnight, after the killings, the lion didn't leave immediately; it stayed until early morning. I reported the incident to wildlife authorities, who came and freed the lion." - a Maasai victim of HWC in Kiduhi village.

Another victim from Mbamba believed that the rise of the elephant population in MNP is a problem that causes tensions. According to her, in the past, Elephants could still be seen roaming in their village; however, what has changed is a large number of Elephants that flock and raid their farms, frequently damaging and causing substantial crop losses. In Kiduhi, some HWC victims believe the village's proximity to MNP is a major contributing factor to the frequent attacks they experience from wild animals from MNP. Unlike Mbamba, Kiduhi village shares a border with MNP, and due to the nomadic lifestyle of Maasai pastoralists, in some cases, the Maasai negligently allows their cattle to roam inside MNP. The encroachment of cows, goats, and sheep inside MNP reserve areas has been reported by wildlife authorities to attract most predators, including lions and hyenas, who find it easy to prey on cattle in Masai residences. Overall, respondents' experiences with HWC suggest that climate change and variability in weather conditions could be one of the driving forces for human-wildlife tensions in Kiduhi and Mbamba villages. When asked, most victims claimed that frequent wild animal attacks are fueled by shortages of food and water that have become scarce within the MNP, forcing elephants and other wild animals to seek these resources outside the MNP.

HWC risks and vulnerability- A woman's perspective

Food insecurity

In both villages, participants reported that due to HWC, their lives and livelihoods are vulnerable and exposed to several risks. In Mbamba, almost all respondents mentioned experiencing significant losses of their maize, cassava, and other crops because of Elephants. Crop losses due to human-elephant conflicts have a devastating impact on the Mbamba community because the vast majority of Mbamba residents are small-scale farmers, with rice, maize, cassava, sesame, and sunflower as major food crops they produce. Unfortunately, most of these food crops are Elephants' favorite meals (said one victim I interviewed), which also fuels the conflict between local farmers and Elephants from MNP.

"*For me, it happens almost every year; they raid and eat all the crops, especially maize and cassava. I have now accepted that when I grow maize, I also grow for Elephants because they come every season"- A female farmer, a victim of human-wildlife conflict in Mbamba village.*

Interviewed participants also mentioned that HWC tends to be intense between May and August because it is a peak harvest season for most village community members. According to HWC victims in Mbamba, during this period, Elephants raids tend to happen almost every day, and because Elephants roam in groups, the damage they cause is substantial; they can wipe out a few acres in a matter of hours, says another victim of human-elephant conflict in Mbamba village. As a result of crop losses, some households have become food insecure, needing more maize and other food crops for consumption before the next farming season. Consistent crop losses due to human-wildlife conflicts also affect their income. The little they produce is damaged by Elephants and other wild animals, including wild pigs, leaving them with no surplus to sell.

Fear of life and death

In Kiduhi, it is not just that the livelihoods are at risk; HWC is also putting the life of Maasai women in danger. As most attacks happen in dark times and, in most cases, at midnight, Maasai men and women in Kiduhi risk their lives by embarking on regular night patrols to chase away hyenas and lions to protect their cattle. Those married and with husbands present at home are at lower risk. The husband takes on the responsibility of protecting cows and goats at night. However, singles, divorced, or widowers sometimes have to risk their lives and protect their cattle from potential attacks.

"Hyenas come here every day. You cannot sleep; the moment it gets dark, you hear them. Sometimes you wake-up and just put on the torch (flashlight), it scares them away, they are so scared of light, so they run away"- HWC victim in Kiduhi village.

Many of the victims in Kiduhi recounted a number of occasions where they felt their life was in danger due to the number of times hyenas were present and the frequency of hyena attacks in their village. One victim mentioned that, though she heard hyenas screaming outside, she could not go out because her Boma was far from her residence. It was also unsafe for her to go out. And when she woke up that morning, she found that her sheep and goats had been killed by hyenas that night.

Others mentioned it is hard to stay out at night because it is very dangerous as the village is close to the MNP; not just hyenas can attack them, but sometimes lions and other dangerous animals tend to show up in their village.

Figure 2. Small Solar Light installed outside Maasai Boma to scare away potential predators.
Source: Author

Since going out at night is unsafe and the entire village is off-grid and lacks electricity, it was interesting to note that some victims' have become creative by installing solar lights outside near the bomas and in front of their residences. When asked, respondents mentioned that when it gets dark, the solar lantern is left ON the whole night to scare aware hyenas and other potential predators that regularly roam the village. Due to the cost of solar lighting devices, only a few victims were noted to have access to or have installed solar lighting outside their residences. Figure 2 shows the small solar light installed outside Maasai Boma to scare away potential predators.

Challenges facing victims of HWC

Lack of financial compensation

Interviewed victims of HWC in both villages reported facing several challenges when seeking support from responsible wildlife and government authorities. A major challenge that was consistently mentioned by respondents is the long delays or the lack of financial compensation to them even when they report the HWC incidents with evidence to the local government office. For many victims, poor government response and unnecessary compensation delays indicate that the government does not care about their lives and livelihoods. In Kiduhi, HWC victims interviewed felt that the local government in the Kilosa district and MNP officials had failed them and were not concerned about the livestock losses they experienced from hyena and lion attacks.

"In 2020, I collected all the evidence, including pictures of goats and sheep killed by hyenas, and delivered them to the local government office; nothing has been compensated to me" – HWC victim in Kiduhi village.

Many victims were also noted to feel that the MNP management and officials from the local government in Kilosa district were more concerned with the safety of animals regardless of the damage they cause to humans (them).

Referencing one incident, one victim mentioned that even though MNP officials were present when the lion attack happened in Kiduhi and were the ones that freed the lion. Her family has never heard from an MNP official, and none of the MNP officials visited them after the incident.

Although HWC incidences were noted to be frequent in both villages, it was surprising to note that no revenge killings were mentioned by interviewed victims. For example, even during interviews, no victim from Kiduhi mentioned having thoughts of harming lions or hyenas that consistently attack their livestock. It was later found out that for many victims, the decision not to revenge by attacking or killing the wild animal after the incident is tied to recognizing the economic and social-cultural value of wildlife in Tanzania. While this is encouraging, with limited government support, this level of patience and understanding could quickly fade away, creating a hostile relationship between HWC victims and wildlife authorities and fueling human-wildlife tensions.

No Institutional Support

Long institutional delays for victims' compensation and government prioritizing wild animals over victims' welfare were consistently mentioned to be a significant challenge to HWC victims. In Mbamba, some HWC victims mentioned that they accepted the problem of elephants' raids on their farms and did not feel the need to report to wildlife authorities as no action would be taken despite their efforts. This lack of government support for HWC victims is echoed by these victims' statements.

"When Elephants raid your farm, they destroy the farms and eat everything in the farm, including rice and maize. I usually report to Game Officers; sometimes they come, but most of the time they do not come". – HWC Victim, Mbamba Village.

"I lost 11 goats that a lion killed in February 2021; I have videos and pictures of the whole incident. The wildlife authorities from MNP and Kilosa were here after it happened and saw the damage that was caused, but until today, no shilling has been given to me" – another victim of HWC in Kiduhi village.

Tanzania's 2011 Wildlife Conservation Act demands that any person who has experienced damage, injury, or loss of life due to attack or raid by a dangerous wild animal (s) receive financial payment upon assessment by the wildlife authorities. While such policies exist, only a few of HWC's victims have benefited due to institutional bureaucracies, lengthy and unnecessary payment delays, and budget constraints. Most victims of HWCs in Kiduhi were noted to have lost hope in government support. Despite their quest for compensation, no financial payment has been made. Most respondents mentioned only being given promises that their cases would be resolved soon.

DISCUSSION

The study examined rural women's experiences with HWC and how risks associated with HWC affect their livelihoods. Results indicate that increased HWC incidences are a serious threat to rural women's livelihoods. HWC-related risks revealed by participants included fear of animal attacks, crop losses, and inability to protect their assets (farms and livestock) when encountering wild animals from MNP. While no human death or injury was reported, the frequency of animal attacks has pushed most rural women to risk their lives by doing night patrols to chase away predators and safeguard their livelihoods. These findings demonstrate that unresolved HWCs have much more impact on rural women and their livelihood opportunities, increasing their vulnerability to poverty.

HWC impacts on rural women

As noted in Table 1, reported HWC incidences occurred at victims' farms and in their residences. In Mbamba, some interviewed HWC victims revealed that they had to skip farming for days as they waited for elephants' raids on their farms to slow down. When asked about the impact of crop raids, most Mbamba victims mentioned that almost every season, their maize farms are damaged by elephants from MNP. These frequent crop raids lower their maize yields leading to household food shortages. Due to the subsistence nature of farming for most Mbamba victims, unprevented human-elephant conflicts could increase food insecurity challenges for these women and other community members in Mbamba and other villages neighboring MNP. In Tanzania, crop raids resulting from human-elephant conflicts remain a serious conservation problem threatening the livelihoods of many rural folks, especially those adjacent to national parks (Kaswamila et al., 2007; Malley and Gorenflo, 2023; Mariki et al., 2015).

Over the last few years, due to enhanced wildlife protection, particularly for Elephants who were in great danger due to rampant poaching, Tanzania has witnessed a drastic increase in the elephant population in its several national parks. Several media reports and conservation experts in Tanzania have reported that the increase in the elephant population and other wildlife species could be linked to the improved protection of wildlife enforced by authorities in the country (Al Jazeera, 2019; Independent, 2019; VOA, 2022). While this positive trend is commendable, it presents new conservation challenges that may have been overlooked. As noted by Malley and Gorenflo (2023), due to habitat loss, climate variability, and growing human population near protected areas, tensions between large wild animals such as elephants will likely increase and could be unmanageable hence equipping villagers with friendly and effective conservation practices that limit HWC impacts is necessary.

Furthermore, though under-researched, rural women's vulnerability to HWC has been reported by previous studies (Linuma et al., 2022; Mukeka et al., 2019). For instance, a study by Linuma et al. (2022) in Ngorongoro Conservation Area (NCA) indicated that women in villages neighboring NCA were more likely to interact with wild animals from NCA because of their active engagement in farming and firewood collection. Similar observations have been noted by other studies in Botswana (Mayberry et al., 2017), Kenya (Mukeka et al., 2019), and Namibia (Khumalo and Yung, 2015). Therefore, training rural women and other vulnerable and promoting conservation strategies that enhance peaceful human-wildlife coexistence could be instrumental in reducing the potential impacts of human-wildlife conflicts.

Lack of training increases women vulnerability to HWC

The lack of formal training on preventing conflicts also exposed study participants to potential harm, injury, and even death linked to human-wildlife conflicts. During interviews, it was evident that women in both villages had limited knowledge of mitigating dangerous interactions with wild animals from MNP. Nearly all participants reported having never attended or received training on HWC prevention. Given their proximity to MNP and the frequency of animal attacks, unresolved HWC and endless threats from elephants, hyenas, and lions from MNP may perpetuate negative attitudes and hate towards wildlife. Limited training for rural women on effective countermeasures to avoid HWC could also instigate negative attitudes towards wild animals from MNP resulting in retaliation killings and worsening human-wildlife tensions in MNP.

As noted by studies by Kohi and Lobora (2018) and Mayengo et al. (2017), addressing these tensions is critically important because as the rural population keeps growing paired with increased wildlife incursions to

human settlements, HWC would likely escalate in several parts of Tanzania, with women paying a heavy a price. As such, empowering women with appropriate conservation training to mitigate HWC and promoting alternative livelihoods that minimize their dependence on nature-based incomes will be instrumental in reducing HWC. Rural women's active and meaningful engagement in wildlife conservation programs can also yield significant conservation benefits over the long term (Costa et al., 2017; Krietzman, 2019).

Climate variability fuels HWC

The results of this study also indicate that climate change could be a significant driver of conflicts between wildlife from MNP and humans residing close to MNP. As narrated by the study participants and MNP officials, the lack of rainfall coupled with the shortage of grassland (food) within MNP borders forces large herbivores like Elephants and carnivores (hyenas and lions) to move outside the park in search of food and water. This climate-driven animal migration has serious consequences for residents of nearby villages, especially women whose livelihoods are severely impacted due to crop raids, food loss, and livestock depredation caused by wild animals that invade their farms and residences. The findings also reveal that elephant raids on village farms were more prevalent in Mbamba village, while predation and attacks of goats, sheep, and cows by hyenas and lions were frequent in Kiduhi village, which is home to the Maasai community.

Participants' response on what drives HWC also reveals the devastating impact of climate change on wildlife resources demonstrating how this ongoing environmental crisis could lead to several other complex community problems in Tanzania. In Tanzania, though the effects of climate change on wildlife have been recognized in Tanzania, however, for many years, government efforts to minimize climate risks and its impact on rural communities have concentrated on the agriculture sector, with sectors such as wildlife tourism getting less attention from the policymakers. Consistent with several other studies (Abrahms et al., 2023; Mariki et al., 2015; Mukeka et al., 2019), findings in this study suggest that the ongoing climate crisis could aggravate human-wildlife conflicts in most parts of Tanzania and hence derail conservation progress achieved in the region. With both humans and wildlife species highly threatened by climate variability, understanding, and promoting climate-change adaptation measures that minimize competition over natural resources will be very critical for Tanzania's efforts to conserve its rich wildlife resources and ensure peaceful coexistence between rural communities and wildlife (Kilungu et al., 2017; Mkiramweni et al., 2016). Inadequate policy attention on the increasing threats of climate change to wildlife and biodiversity in Tanzania places rural communities, especially women close to national parks, at more risk and vulnerable to human-wildlife conflicts.

Limited financial and institutional support for HWC victims

Even though the 2011 Wildlife Conservation Act demands that victims of HWC be compensated immediately after filing their claims to wildlife authorities, the study reveals that none of the majority of HWC victims received financial compensation for their losses. As food producers and their significant dependence on natural resources for living, lack of compensation has more devastating consequences for rural women residing close to national parks whose livelihoods are threatened by the presence of wild animals. When asked, many of the victims believed the government is more concerned with the welfare of wild animals because of their economic contribution to the tourism industry and careless of the damage they cause to humans. Like in many other national parks, concerns over lack of financial compensation and poor institutional response to victims of HWC have been widely reported in Tanzania. In Northern Tanzania, studies by Kaswamila (2009) and Mbise (2021) have found that institutional negligence and unnecessary delays to refund victims of HWC have resulted in retaliatory killings of wild animals with several victims not reporting the HWC incidents but revenge for their losses.

Respondents' concerns with poor government support to HWC victims in Tanzania are also consistent with findings from most recent studies by Felix et al. (2022) in Tarangire National Park and Mbise (2021) in Serengeti National Park that also found a similar pattern. According to these two studies, limited support from wildlife authorities to victims of HWC and poor engagement of local communities residing near national parks in government conservation efforts were the primary causes for retaliation killings of several wild animals in Serengeti and Tarangire national parks. These concerns raised by interviewed victims in Mbamba and Kiduhi underscore the need for a more immediate institutional response to financial compensation claims from HWC victims whose livelihoods rely on livestock and farming. Given the critical role of wildlife tourism in Tanzania's economy, more investment and innovative HWC victims support schemes are needed to reduce tensions and enhance peaceful coexistence between humans and wild animals from several national parks in Tanzania.

CONCLUSION AND RECOMMENDATIONS

It is clear that both humans and wild animals from MNP are threatened by changes in weather patterns that are propelled by the climate crisis. As the impacts of climate change in terms of significant loss of rain and habitat loss

for wild animals become intense, tensions between rural communities near MNP and wild animals from the MNP could become unmanageable, making their co-existence more challenging. Countering these climate-induced conservation challenges requires allocating more financial resources to climate-responsive and adaptation strategies that focus on restoring degraded land and water sources to benefit wild animals and humans over the long term while minimizing their competition over natural resources (Kupika and Nhamo, 2016).

Furthermore, since HWC victims in both villages were noted to rely on farming and livestock keeping as their primary sources of income, training and promoting alternative livelihoods for these women could be the most effective way to reduce their vulnerability to poverty when impacted by human-wildlife conflicts. Kiduhi village being a Maasai community and close to Mikumi National Park has a huge potential for cultural tourism activities that will attract local and foreign tourists. Given this potential, TANAPA, MNP management, and other responsible wildlife authorities should provide business-development training to rural women from both villages on establishing a cultural tourism center in Kiduhi. Similarly, to address existing gender-based constraints, innovative and rapid financial compensation schemes should be developed and implemented by TANAPA to ensure that female HWC victims are equally benefiting from such compensation. Finally, while the sample of this study was small, the study offers important highlights on rural women's experiences with human-wildlife conflicts and provides valuable insights into the need for more research to understand the risks and hidden costs of HWC to rural women in Tanzania and beyond.

CONFLICT OF INTERESTS

The author has not declared any conflict of interests.

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Appendix 1. Respondent consent form

Consent to participate in research

Study title: Understanding Rural Women's Experiences and Vulnerability to Human-Wildlife Conflict (HWC): A case of villages near Mikumi National Park, Morogoro, Tanzania.

Hello,

We would like to request your participation in this research. The goal of the study is to examine rural women's vulnerability and responsive mechanism to Human-Wildlife Conflicts in Tanzania. Your participation in this study will help the government of Tanzania develop effective ways to address human-wildlife tension between rural communities living near national parks.

Things to consider

- You are being invited to participate in this research to understand your experiences, regarding your day-to-day interactions with wild animals from Mikumi National Park (MNP). As a resident near MNP your experiences and interactions with wildlife from Mikumi will enrich our research findings.
- A researcher will ask you a few questions regarding your previous and current experiences and interactions with wildlife from MNP.
- The interviewing questioning may last for about 45 minutes. You have a right to withdraw from the interviews if you feel so. The interview will be audio recorded to ensure the researcher is able to capture all the interview conversation. If you wish not to be recorded, you can say so before the interview begins.
- Your participation in this research will help the government, Mikumi National Park Staff and Management, NGOs and other conservation experts working in Tanzania towards establishing sustainable conservation programs to mitigate and end Human-Wildlife conflicts in Tanzania.
- The researcher may ask for photos or videos on when and where the events happen.
- The recorded interview and all the information you provide will be kept in safe place and in computer protected with password only accessible by the researcher. Your name will not be disclosed during data analysis or presentation of research findings.
- The study questions and ethical procedures have been reviewed and approved by Tanzania Wildlife Research Institute (TAWIRI) and the Commission for Science and Technology (COSTECH) with research permit approval number 2021-222-NA-2021-078.

☐ By checking this box, I agree to participate.

…….. …….

Name & Signature of Research Participant **Name & Signature of the Researcher**

Appendix 2: Interview Guide Mbamba and Kiduhi Study

INTERVIEW GUIDE FOR WOMEN PARTICIPANTS ABOUT HWC EXPERIENCES

Mbamba and Kiduhi Villages, Mikumi National Park, Kilosa District, Morogoro Eastern Tanzania

Name of the Respondent: **Village:**

SECTION A: PARTICIPANT INFORMATION

A1. Age of Respondent. **1**. 20-39 years [ ] **2**. 40-59 years [ ] **3**. 60+ years [ ]

A2. Respondent's Marital Status 1. Married [ ] 2. Single [ ] 3. Divorced [ ]
4. Separated [ ]

A3. Respondent's Level of Education. **1.** No Formal Education [ ] **2.** Primary Education [ ]
3. Secondary Education [ ] Other [ ] (Specify)……

A4. Respondent's occupation:

A5. How long have you lived in this village? **1**. 1-3 years [ ] **2**. 3-7 years [ ] **3.** More than 7 years [ ]

A6. Were you born in this Village 1. Yes [ ] 2. No [ ], if NO, when and where did you immigrate from?

A7. Do you own livestock? 1. Yes [ ] 2. No [ ]

A8. If YES, how many Livestock do you own
1. Cattle ……
2. Goats ……
3. Sheep ……..
4. Donkey…….
5. Other ……

A9. Do you own Land 1. Yes [ ] 2. No [ ]

A10. If YES, how many ha of Land do you own **1**. Less than 1ha [ ] **2**. 1-3ha [ ] **3.** More than 5ha [ ]

A11. If NO, how do you get food for consumption?.....

A12. Are you involved in any income generating activity besides farming or livestock keeping?
1. Yes [ ] 2. No [ ]

A13. If YES, which income generating activity are engaged in?.....

SECTION B: HWC Drivers, Experiences, and Perceptions

B5. Since you live near Mikumi National Park, do you think wild animals such as Lions, Elephants, Buffalo are beneficial to you and your community**?** 1. Yes [ ] 2. No [ ] 3. Don't know [ ]

B6. If YES, how are wild animals from Mikumi beneficial to you?.....

B7. If NO, why do you think they are not beneficial?.....

B8. Do wild animals from Mikumi NP raid your residence or farms? 1. Yes [ ] 2. No [ ], if YES, how often and at what time……

B9. Where do you often encounter wild animals? 1. At my residence [ ] 2. At my farm [ ] 3. In the bush when collecting wood [ ] 3. Other (specify)…….....

B10. Which wild animal (s) do you encounter more often 1.Elephants [ ] 2. Lions [ ] 3. Hyenas [ ] 4. Buffalo [ ] 5. Other (specify)……..

B11. What do you think drives or pushes wild animals to raid village residence or farms?
1. Search for food and water [ ]
2. Loss of trees, bushes, and habitat [ ]
3. Overpopulation of wild animals [ ]
4. Natural factors such as drought [ ]
5. Poaching [ ]
6. Other (specify) [ ]

B12. Tell me about your personal experience with Human-Wildlife Encounter…….

B13. When did this happen and what do you think caused the incidence/attack?.....

B14. How were you affected by the incidence/attack?
1. My farms and crops were destroyed [ ]
2. My property (house) was damaged [ ] ***ask for photo on the incidence, gender/age of***
3. I was seriously injured [ ] ***of the victim, # of property damaged or lost***
4. I lost a family member (s) [ ]
5. My livestock were killed [ ]
6. Other (specify) [ ]

B15. Which wild animal was involved in the incidence? 1. Lion [ ] 2. Buffalo [ ] 3. Elephant [ ] 4. Hyena [ ] 5. Other

B16. What did you do after that experience?

1. Reported to Village Government [ ] 2. Report to Park Authorities in Mikumi [ ] 3. Retaliated and attacked the animal [ ] 4. Other (specify)……...

B17. After the incidence did your relationship with wild animals from Mikumi changed?.....

B18. Were you compensated for any loss, damages, or injury you experienced from HWC?

1. Yes [ ] 2. No [ ]

B19. In your opinion, do you think HWC encounters have increased than in the past?

1. Yes [ ] 2. No. [ ], if YES, Why?.....

B20. How has HWC affected your livelihood?.....

B21. What measures do you take to protect yourself and your properties from wild animals' attack or damage

1. Regular patrols with my partner and village members [ ]
2. Use lethal weapons to limit wild animal attacks or damage [ ]
3. Kill dangerous wild animals whenever we encounter them [ ]
4. Report to Mikumi Park Authority/Rangers [ ]
5. Other (specify)…….

B22. In your opinion, do you think women are more vulnerable to HWC than men, and why?.....

B23. What do you think needs to be done to reduce rural women's vulnerability to HWCs?.....

B24. Have you received any conservation education/training to mitigate HWCs? 1. Yes [ ] 2. No [ ]

B25. If YES, who provided the training

1. Part rangers from Mikumi NP [ ]
2. NGOs (names…..) [ ]
3. Village Environmental Committee [ ]
4. Other [ ]

B26. In your opinion, what are the socio-economic benefits of wild animals from Mikumi NP?

B27. Do you think wild animals should be protected against Human attacks or killings, and Why?

B28. What do you think should be done to improve the women-wildlife/villagers' relationship with wild animals from Mikumi National Park?

B29. Can you describe this village community relationship with Mikumi National Park management?.....

B30. What needs to be improved between the village community near Mikumi and Mikumi National Park management?.....

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Socioeconomic determinants of Cameroon's Mefou Wildlife Sanctuary visitors' willingness to pay for seeing animals in the wild

ACHEY Baudelair NKENFACK DJIKE[1,2]*, Serge SILATSA NANDA[2,5], Marcien KUETE FOGANG[1,2], Mohamed Mounir MFONDEN POUMIE[2], Abdoulaye NCHANKOU NJOYA[3], Marceline EKOM ANGO[4] and Lucie Félicité TEMGOUA[2]

[1]Institute of Agricultural Research for Development (IRAD), P. O. Box 44 Dschang, Cameroon.
[2]Department of Forestry, Faculty of Agronomy and Agricultural Sciences, University of Dschang, P. O. Box. 222, Dschang, Cameroon.
[3]Faculty of Science, Department of Biology and Plant Organisms, University of Douala, P. O. Box. 24157, Douala, Cameroon.
[4]Ministry of Forestry and Wildlife, P. O. Box 34430, Yaoundé, Cameroon.
[5]Sustainable Tropical Actions (STA), Yaoundé - Cameroon

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Protected areas (PAs) in Cameroon witness chronic underfunding, with most operating with only around 10% of the necessary funds. This study aimed to explore socioeconomic factors affecting Mefou Wildlife Sanctuary (MWS) visitors' willingness to pay (WTP) for wildlife species observation in their natural habitat. The study was based on semi-structured questionnaires conducted with 637 respondents and the contingent valuation method was used to estimate visitors' WTP. The findings reveal an average WTP of $US 170 for foreign visitors and $US 81 for national visitors to see animals in the wild. Income level and education significantly influenced WTP, with higher-income individuals and those with higher education demonstrating a greater willingness to pay. By recognizing the factors that drive visitor spending behavior, policymakers and park managers can implement targeted marketing campaigns and allocate resources effectively. This study emphasizes the importance of providing diverse and high-quality wildlife experiences to enhance visitor satisfaction and encourage repeat visitation and make the country an attractive world destination for eco-tourists. The country can, therefore, contribute to sustainably fund conservation while supporting local development and boosting its tourism industry.

Key words: Eco-tourism, iconic wildlife species, Mefou Wildlife Sanctuary (MWS), natural habitat, protected areas, visitors, socioeconomic determinants, willingness to pay.

INTRODUCTION

Wildlife conservation and the sustainable management of protected areas (PAs) have gained significant attention globally due to the increasing threats posed by habitat loss, climate change, and poaching (Wilcox et al., 2019). PAs cover 15.3% of the world's terrestrial surface (Spenceley et al., 2017) and are recognized as one of the most effective ways to conserve natural ecosystems and related services (Molina et al., 2019). They also hold the

potential for revenue generation through proper investments (Ralph, 2021). Consequently, understanding the socioeconomic factors that influence visitors' willingness to financially contribute to conservation has become crucial for effective conservation strategies (Huang et al., 2021).

Mefou Wildlife Sanctuary (MWS) is an *ex-situ* conservation site, located in the vicinity of the capital city Yaoundé. According to Doumenge et al. (2021), it is among the most visited eco-touristic site in Cameroon far ahead of national parks where emblematic species are present in their natural habitat. The MWS thus serves as an outstanding case study for investigating the complex relationship between socioeconomic determinants of visitors and their willingness to pay (WTP) for observing animals in their natural environment in Cameroonian National parks. Those PAs not only harbours more diverse wildlife species but also provide numerous ecosystem services and has the potential to contribute to local economies through nature-based tourism (Ivanic et al., 2020; Scholte, 2022).

However, like many PAs in the Congo Basin, they face the challenge of inadequate funding for conservation (CBD, 2019). The current funding available for PAs in Cameroon, which predominantly relies on external sources (Pyhälä et al, 2016; Doumenge et al., 2015), falls significantly short of the required amount, rendering the current conservation model unsustainable with continuous decline of biodiversity (Brugière et al., 2016; Scholte et al., 2018). Hence, exploring sustainable funding options, such as visitor contributions, becomes paramount.

Tourism has been identified as a sector that can significantly contribute to the funding of PA networks globally (CBD, 2019; Leung et al., 2018). When managed sustainably, tourism can play a pivotal role in effective PA management, as demonstrated by successful cases in various African parks. For instance, profitable tourism activities have covered a significant portion of the operational costs in Zakouma National Park, Chad (APN, 2018), while revenue generated from gorilla visits in Volcanoes National Park, Rwanda, has supported up to 90% of park activities (APN, 2021). Furthermore, such tourism activities create employment opportunities for surrounding communities, highlighting the potential socio-economic benefits (Visit Rwanda, 2021).

Despite Cameroon's immense touristic potential, it remains largely underdeveloped and undervalued (Frida-Tolonen, 2014). Several factors, including unprofessional guide staff, inadequate infrastructure, poor marketing, and security concerns, contribute to the underutilization of tourism opportunities (Kimbu, 2011). Notably, visitors have shown a greater interest in *ex-situ* conservation sites like MWS, the Mvog-beti zoo in Yaoundé, and the Limbe botanic garden (Nlom et al., 2013). However, it is crucial to assess their willingness to visit and experience natural ecosystems within Cameroon's national parks, along with the necessary conditions and the amount they are willing to spend for such visits. This data can inform conservation stakeholders in creating suitable conditions to attract more tourists and generate funds for the sustainable management of PAs.

Previous studies have emphasized the significance of socioeconomic factors in shaping visitors' attitudes, preferences, and behaviors towards wildlife conservation and ecotourism (Hvenegaard, 2017; Nyaupane et al., 2018). WTP approach has been widely employed to evaluate visitors' monetary valuation of wildlife experiences and assess the potential for generating financial resources to support protected area management (Ginsburgh, 2017).

This study aims to contribute to the existing body of knowledge by specifically investigating the socioeconomic determinants that influence Mefou Wildlife Sanctuary visitors' WTP for observing animals in Cameroon national parks. By exploring the key factors that shape visitors' preferences and behaviours, the findings of this research can inform the development of targeted strategies for sustainable funding, effective conservation management, and enhanced visitor experiences within protected areas (Reimer et al., 2020; Biggs et al., 2020). Specifically, this study is focusing on (i) identifying tourists visiting the MWS, (ii) evaluating their willingness to see wildlife species in their natural national park system and (iii) determining the amount of money they would be willing to spend for such experience.

MATERIALS AND METHODS

Study area

MWS was specifically chosen as the study area for this research due to its significance and characteristics. It serves as an *ex-situ* conservation site and has garnered substantial attention, with over 6,800 visitors in 2013, making it the third most frequented eco-touristic destination in Cameroon, particularly popular among foreign visitors (Doumenge et al., 2021). The sanctuary spans a total area of approximately 800 ha, yet only around 60 ha have been effectively utilized and developed including the administrative block, a souvenir shop, the education and visitors' office, a restaurant, a kitchen, dormitories, and animal enclosures. Geographically, it is situated in the Centre region of Cameroon, within the Mefou-and-Afamba Division, Mfou Subdivision, encompassing the villages of Ekali I, Ekali II, and Metet (Figure 1) at coordinates 3°57'09"N and 11°55'20"E.

*Corresponding author. E-mail: nkenfack.achey@yahoo.com. Tel: +237676283701.

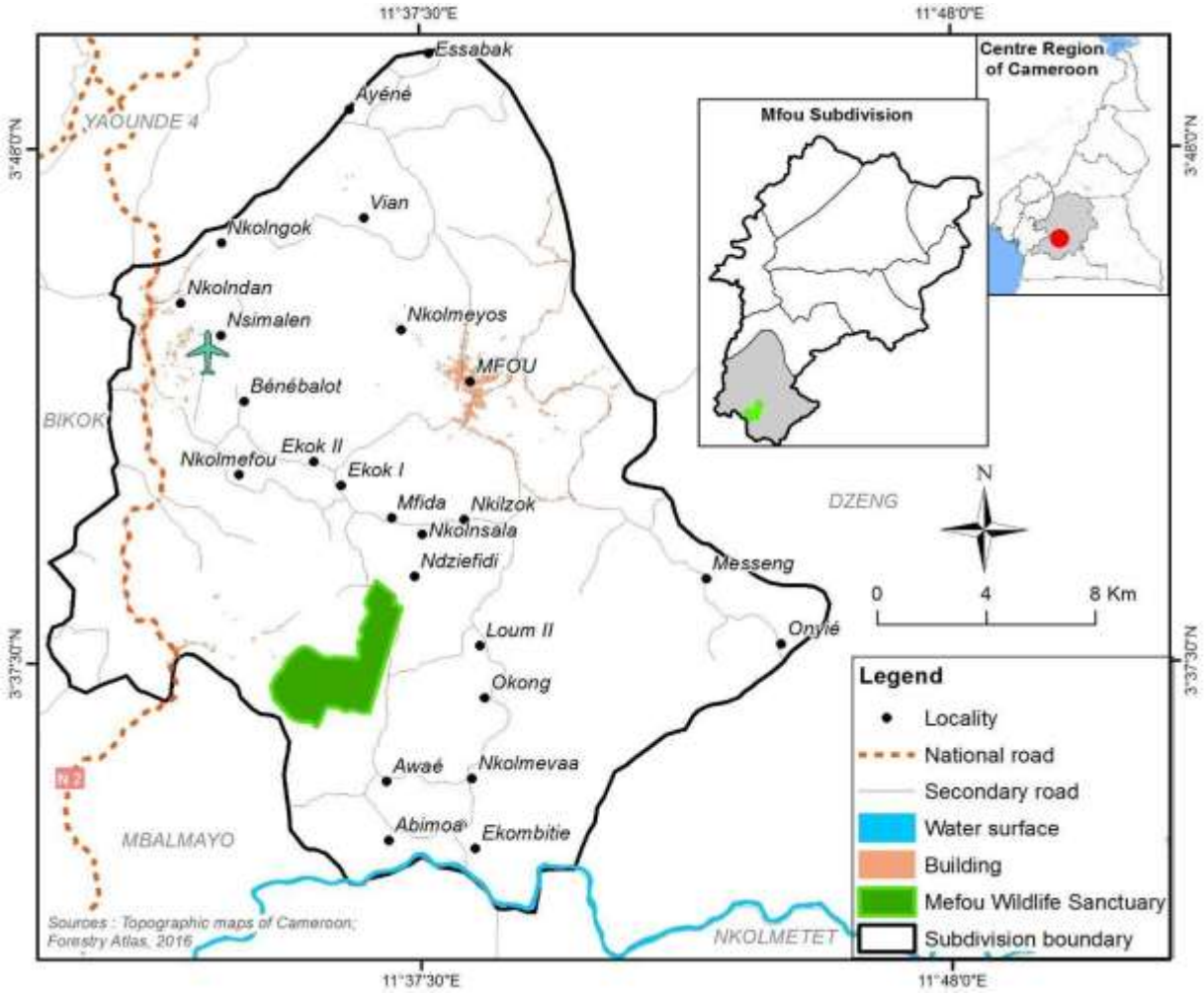

Figure 1. Location of the Mefou Wildlife Sanctuary (MWS).
Source: Authors

The management of MWS is entrusted to the Non-Government Organisation (NGO) Ape Action Africa, which primarily focuses on primate conservation within the sanctuary, an aspect that captivates a significant number of visitors, along with the diverse flora species found in the forest.

In the wild, poachers kill adult apes for meat and the young ones are sold as pets or abandoned when government officials arrest these criminals, these orphans are sent to the MWS for proper treatment before being released in natural ecosystems when they can survive on their own. The sanctuary is home to a remarkable primate population, comprising 287 apes, all of which are orphans, including 125 chimpanzees, 24 gorillas, and 138 monkeys representing 10 different species.

The animals are housed in enclosures where the surface area is relatively flat, each covering an area of approximately 2 ha, featuring natural vegetation such as large trees and various flora species that closely resemble the natural habitat of apes (Maurice et al., 2020). To ensure the well-being of the animals, each enclosure is overseen by a team of at least three animal caregivers who diligently attend to their feeding, hydration, and overall health, while also monitoring their behavior for any signs of illness or negative changes. The valuable insights and observations provided by these caregivers contribute to the feedback and reporting process to the Ministry of Forestry and Wildlife, facilitating effective management practices within the sanctuary.

The MWS is conveniently situated at a mere 45 km from Yaoundé, the capital city of Cameroon. To enter the sanctuary, visitors are required to pay an entrance fee. For adult foreigners, the fee is set at FCFA 10,000 (US$ 16), while resident foreigners are charged FCFA 7,500 (US$ 12). Foreign children are admitted at FCFA 4,000 (US$ 7), whereas adult Cameroonians pay FCFA 2,000 (US$ 6), and national children are granted entry for FCFA 500 (US$ 0.8). These fee structures serve as an indication that visitors possess a genuine interest and passion for wildlife conservation prior to their arrival at the sanctuary.

Within the MWS, the apes are housed in enclosures that span up to two hectares, featuring the presence of natural, towering trees. This arrangement provides visitors with a vivid glimpse into the habitat and lifestyle of these apes in their natural surroundings (Wamba et al., 2022). The sanctuary offers two visitation sessions per day, the morning session taking place from 9 to 11 am, and the afternoon session occurring between 2 and 4 pm.

Upon entering the sanctuary, visitors are welcomed by the tour operators and visitation rules are given to them (no feeding, all cameras without flash light, no form of communication with the

Table 1. Sociological characteristics of the respondents.

Sociological feature	Category	Number of respondents	Percentage
Gender	Male	392	61.6
	Female	245	38.4
Origin	National	189	29.6
	Foreigner	448	70.4
Age	10-20	25	4.4
	20-30	112	17.6
	30-40	331	52
	40-50	102	16
	50-60	67	10.4
Education	Primary	15	2.3
	Secondary	203	31.9
	University	419	65.8

Source: Authors

animals). Visitors are advised to ease themselves in the comfortable toilet since the tour is more than an hour to avoid interruptions. To ensure an optimal experience, each session is limited to a maximum of 20 individuals. After the tour, visitors are presented the shop where souvenirs (pictures, post cards, t-shirts, pens and pencils) and local handcrafts could be bought to support the NGO and the local community. Visitors also support by buying food and drinks from the restaurant.

Data collection

In order to assess the willingness of visitors to pay visits to protected areas (PAs), a socio- economic survey was conducted among individuals visiting the MWS. The survey took place from March to April 2022 and involved a representative sample of 637 respondents from the 257 visitor groups that toured the MWS during that period. Following their visit, the respondents undertook a semi-structured questionnaire to gather information following the contingent valuation approach (Ginsburgh, 2017).

The questionnaire encompassed various aspects, including the visitors' satisfaction with the visit, their awareness of where they could observe the animals in their natural habitat, the expenses incurred during their trip, their willingness to witness the animals in the wild, the amount they were willing to spend for such an excursion, and whether they would be willing to pay additional fees to observe iconic species such as elephants, leopards, and crocodiles. Furthermore, general inquiries were made concerning the respondents' demographic characteristics, such as their gender, age, monthly income, place of origin, how they learned about the MWS, the frequency of their visits to PAs, and their level of education. Table 1 provides an overview of the respondents' sociological characteristics, encompassing their gender, age, nationality, and education level.

Data analysis

The data collected during the survey were entered into Microsoft Excel for encoding and subsequently analyzed using the commercially available software, R (version 4.1.1, R Core Team 2022). To assess the respondents' willingness to observe wildlife in its natural habitat, the Chi-Square test of independence in conjunction with the Fisher test was employed as suggested by McHugh (2013). This statistical analysis aimed to determine whether any associations existed between the respondents' willingness (yes or no) and their sociological characteristics, including origin, gender, education level, age, and monthly income.

The contingent valuation method was used to estimate visitors' willingness to pay for observing wildlife in its natural habitat (Ginsburgh, 2017). Then, the analysis of variance (ANOVA) and mean separation through Tukey's HSD (Honestly Significant Difference) were utilized. These statistical techniques facilitated the comparison of results across each of the sociological features mentioned earlier, namely origin, gender, education level, age, and monthly income.

RESULTS AND DISCUSSION

Identification of eco-tourist at the MWS

Number of visitors of the MWS

Among the 637 respondents who visited the MWS throughout the study period, 331 were Cameroonian, accounting for 52% of the total visitors, while 306 were foreign visitors from various countries, representing 48% of the total visitors (Table 2). Notably, the category with the highest number of visitors was foreign men, whereas the category with the lowest number was foreign children. This disparity in visitor demographics can be attributed to the fact that many foreign visitors were accompanied by male drivers or guides who were nationals. Additionally, the relatively high number of national children visiting the sanctuary was influenced by the participation of four schools, which brought a total of

Table 2. Origin of visitors at the Mefou Wildlife Sanctuary.

Gender	National visitors		Foreign visitors	
Male	130	20.4	145	22.7
Female	66	10.4	122	19.2
Children	135	21.2	39	6.1
Total	331	52	306	48

Source: Authors.

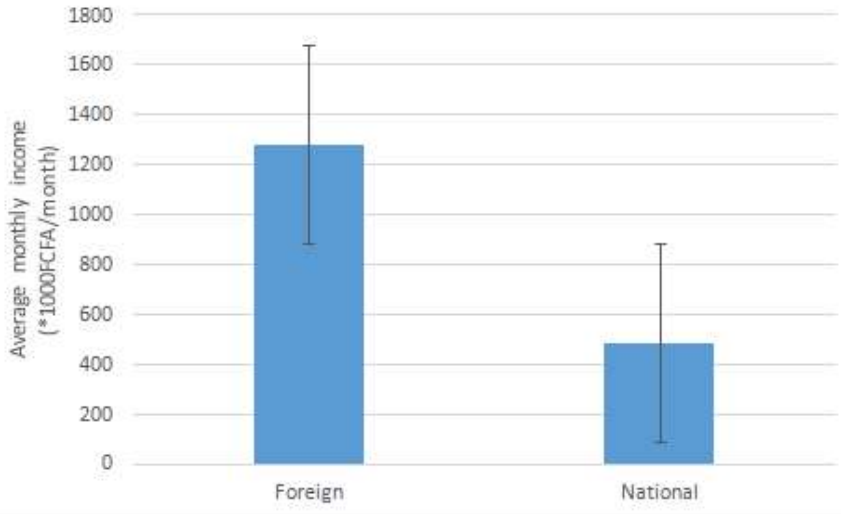

Figure 2. Average monthly income of visitors.
Source: Authors.

104 students for an educational excursion.

The total amount collected in entrance fees during the two-month period amounted to FCFA 3.2 million (US$ 5,195), with foreign visitors contributing FCFA 2.7 million (US$ 4,383) and national visitors contributing FCFA 0.5 million (US$ 812). Additionally, the Mefou Wildlife Sanctuary's eco shop generated sales of approximately FCFA 1,800,000 (US$ 2,922) within the same timeframe.

Nationality and monthly income of the visitors

Out of the 637 interviewed visitors, there was a diverse range of nationalities represented. Most visitors at the MWS were Cameroonian, with 188 individuals accounting for 29.6% of the total number of visitors. Foreign visitors came from various regions including Europe, America, Asia, and other African countries. Among the foreign visitors, France had the highest number with 127 visitors (20%), followed by England with 56 visitors (8.8%). Germany and the USA each had 40 visitors (6.4%), while Belgium and Spain had 30 visitors each (4.8%). Israel and Italy had 20 visitors each (3.2%), and several countries including Algeria, Senegal, India, Poland, and Switzerland had 10 visitors each (1.6%). Additionally, Canada, Rwanda, Mexico, Portugal, Sweden, and Slovenia each had five visitors (0.8%). Figure 2 showcases the average monthly income of visitors based on their origin (national or foreigner).

The average monthly income of national visitors was approximately FCFA 500,000 (US$ 812), ranging from a minimum of FCFA 100,000 to a maximum of FCFA 900,000. For foreign visitors, the average monthly income was about FCFA 1.3 million (US$ 2,110), with a minimum of approximately FCFA 900,000 (US$ 1,475) and a maximum of FCFA 1.7 million (US$ 2,786).

Proportion of resident and the city of visitors

The findings indicate that the vast majority (90%) of the visitors to the MWS were residents of Cameroon, visiting the sanctuary primarily for leisure purposes. Only 10% (63 individuals) of the visitors were classified as tourists who have traveled from other countries specifically to explore Cameroon. In this context, "resident" refers to

Table 3. Provenance city of visitors.

City	Number of visitors	Percentage
Yaoundé	576	90.4
Douala	21	3.3
Mbalmayo	20	3.1
Metet	10	1.6
Kribi	5	0.8
Lobeke	5	0.8
Total	**637**	**100**

Source: Authors.

individuals who were in Cameroon for reasons other than tourism, such as work, assignments, or health-related matters.

As seen in Table 3, the survey also revealed that approximately 90.4% (576 individuals) of the visitors originated from a single city, namely Yaoundé, the capital city. This city is located just 45 km away from the MWS, making it easily accessible. This high proportion can be attributed to the presence of various embassies and the headquarters of international NGOs in Yaoundé. Moreover, since much of the information about the MWS spreads through word of mouth, it is understandable that most of visitors come from the same city.

Among the other cities surveyed, Douala, the second-largest city with nearly 4 million inhabitants, accounted for only 21 visitors, despite being located 337 km away from the MWS. Similarly, only 20 visitors came from Mbalmayo, a significant city with over 120,000 residents situated just 25 km from the sanctuary. Additionally, only 10 visitors originated from Metet, a village within the MWS. Interestingly, no visitors were recorded from Ebolowa, the capital city of the South region, which has a population of over 250,000 and is located just 135 km from the MWS.

Source of information about the sanctuary

According to the survey results, a significant proportion of visitors (86%) obtained information about the MWS through personal connections, primarily from relatives. This "word-of-mouth" method involved friends, family members, neighbors, or colleagues who had previously visited the MWS. On the other hand, only a minority (14%) relied on online advertisements, including various platforms such as websites and social media channels like Facebook, Instagram, or TikTok.

Furthermore, the survey revealed that a majority of visitors (91% or 579 individuals) expressed satisfaction with their experience at the MWS. Many visitors were particularly impressed by the presence of great apes and monkeys, while others expressed delight in witnessing a tropical forest with its majestic large trees and hanging lianas. However, a small proportion of visitors (9%) reported some level of dissatisfaction. Although they enjoyed observing the apes, they had expected to encounter a wider variety of wildlife species during their visit.

The willing to see wildlife species in their natural habitat

The level of visitor interest in wildlife was initially assessed by analyzing their frequency of visits to the MWS. Figure 3 presents the distribution of the number of times visitors have come to the sanctuary. It is evident that the majority of visitors, accounting for 81.6% (520 individuals), have visited the MWS only once. This could be attributed to the perception that there are limited species to observe during a single visit, leading to the belief that subsequent visits may not offer anything significantly new or different. However, a small percentage of visitors, 9.6%, have visited twice, 7.2% have visited thrice, while 0.8% have visited for the fifth time and another 0.8% have visited for the tenth time.

The visitors' inclination to observe wildlife in their natural habitat is presented in Table 4, categorized by their sociological characteristics. Table 4 reveals that an overwhelming majority of visitors, 98%, express a willingness to see animals in the wild based on their sociological features. In terms of gender, all female visitors express this desire, while only 15 males were not interested. Regarding their origin, almost all foreign visitors were willing, with the exception of five who remains skeptical, along with ten national visitors. Considering the age groups, ten visitors from the 20-30 age group and five visitors from the 40-50 age group did not wish to witness wildlife species in the wild. Conversely, all visitors from the 10-20, 30-40, and 50-60 age groups expressed a desire to observe these wildlife species in their natural habitat.

Furthermore, all visitors with low monthly incomes (less than FCFA 0.5 million) and high incomes (above FCFA 1.5 million) were willing to see wildlife in their natural habitat. However, 15 visitors with monthly incomes ranging from FCFA 0.5-1 million did not share

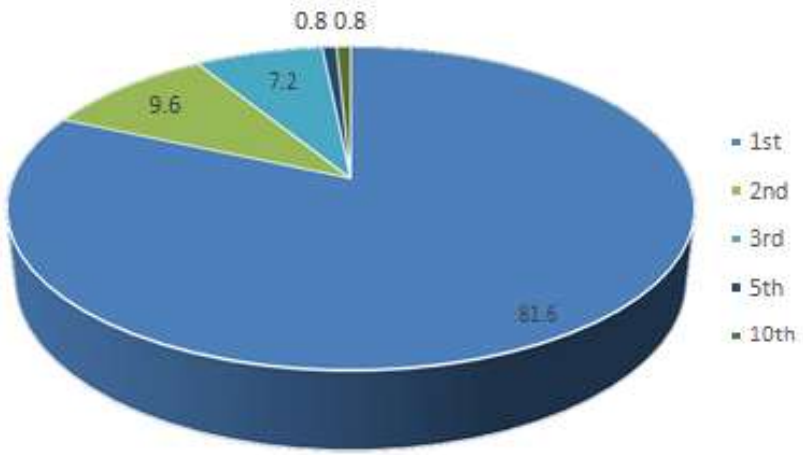

Figure 3. Frequency of visitors.
Source: Authors.

Table 4. Comparing willingness to see with sociological characteristics of visitors.

Sociological feature	Category	No	Yes	Chi-square (X^2 value)	test (X^2) P-value	Fisher test (p-value)	Conclusion
Gender	Female	0	245	1.85	0.17	0.29	Independent variables
	Male	15	377				
Origin	Foreigner	5	443	2.02	0.15	0.21	Independent variables
	National	10	179				
Age	10-20	0	25	6.82	0.14	0.10	Independent variables
	20-30	10	102				
	30-40	0	331				
	40-50	5	97				
	50-60	0	67				
Education	Primary	0	15	1.82	0.40	0.29	Independent variables
	Secondary	14	189				
	Tertiary	6	418				
Average monthly Income (*FCFA1000)	40-500	0	133	3.48	0.32	0.44	Independent variables
	500-1000	7	153				
	1000-1500	8	158				
	1500+	0	178				

No= Number of No (unwilling to see); Yes=Number of Yes (willing to see).
Source: Authors.

the same willingness.

Foreign visitors primarily originated from France (20% of visitors), followed by England (8.8%) and Germany (6.4%). This can be attributed to historical colonial ties and the existing cooperation between Cameroon and these countries, which encourage citizens to visit Cameroon (Mabeu and Pongou, 2023). This result differs from the tourist profile in Uganda, where about three-quarters of tourists come from other African countries, with Kenya accounting for more than 50%, followed by Tanzania and Rwanda (MTWA, 2014). This can be attributed to the strong wildlife tourism culture in East

African countries and the ease and affordability of travel between these nations (Nibigira, 2019). Therefore, the Cameroonian government and private sector should invest in tourist infrastructure such as roads, hotels, and restaurants in and around protected areas, making them more appealing destinations for international tourists. Additionally, increased advertising of Cameroon's significant tourist potential is crucial.

Effective advertising campaigns should target European, American, Asian, and African nationals, utilizing both conventional (in embassies, for example) and social media platforms.

The willingness to see wildlife species in their natural habitat

The majority of visitors (91%) reported being satisfied with their tour, although 81.6% were visiting for the first time. Visitors were satisfied because they had the opportunity to see various groups of animals. However, the overall touristic potential is not sufficient to encourage many visitors to repeat the trip. According to Doumenge et al. (2021), having a single "flagship" touristic product is not enough. Tourism thrives on the diversity of offerings at each site, within each country, and across sub-regions. Therefore, to attract tourists on a long-term basis, multiple touristic products or destinations should be associated. A touristic circuit could be created, linking several protected areas so that tourists can have multiple experiences during their visit.

The results indicate that 78% of visitors were unaware of any protected areas where they could observe wildlife species in Cameroon. This lack of knowledge is due to the poor advertisement of eco-touristic sites, with limited efforts made by protected area managers in Cameroon. For example, very few protected areas have active social media pages on platforms such as YouTube, Facebook, Instagram, and TikTok. This limited promotion contributes to the low number of tourists; these areas receive annually, often less than 100. This finding contrasts with the work of Peet and Saayman (2016) conducted at Kruger National Park in South Africa. SAN parks, responsible for the advertisement of all national parks in South Africa, actively promoted Kruger National Park on various online platforms such as Facebook and Instagram, regularly showcasing its touristic potential. This contributed to attracting over one million tourists in 2016. Therefore, each protected area in Cameroon should establish an active online presence to showcase the species that can be observed by tourists if they visit.

The analysis of visitor willingness to observe wildlife species reveals that 98% of visitors expressed a desire to observe these species in their natural habitat. This finding aligns with the research by Hvenegaard (2017), which found that the vast majority of society expressed their willingness to visit and support the Miquelon Lake provincial park in Canada. This passion for wildlife species among eco-tourists drives their desire to witness firsthand how these species interact with each other, other species, and their environment, despite the wild nature and associated risks. Additionally, many visitors understand the importance of their contribution to the protected area's income and its impact on the conservation of wildlife species. However, despite their willingness, only a few have had the opportunity to visit protected areas in Cameroon due to limited access and a lack of information about where to observe these species. Moreover, there are few success stories from those who have visited protected areas in Cameroon. For instance, Germain, a French visitor to the MWS, mentioned that he visited Campo-Ma'an National Park but did not have the opportunity to see any animals.

The amount visitors are willing to pay to see wildlife species in their natural habitat

The findings as presented in Table 5 reveal that foreign visitors are willing to pay an average of FCFA 105,000, while nationals are willing to pay only FCFA 50,000 to see apes in their natural habitat. Rachelle, an American visitor to the MWS, stated, "I am ready to pay US$1,500 if I am sure to see these great apes because that's what people pay in Rwanda." Similarly, Brighton, a British visitor, expressed, "Money is not a problem; I am willing to pay any amount if the park can assure comfort in terms of lodging, logistics, and the opportunity to see iconic species in the wild." This aligns with the economic model of entrance fees in Volcano National Park in Rwanda, where foreign tourists pay higher fees compared to regional and national tourists. In response to the international tourism crisis caused by the Covid-19 pandemic, temporary entrance fees for foreign international tourists were set at $US 1,500 (FCFA 750,000), $US 500 (FCFA 250,000) for residents and tourists from the African Union, and $US 200 (FCFA 100,000) for national tourists and the East African community (Visit Rwanda, 2021). This is due to the higher financial capacity of foreigners in many African countries (IMF 2022), and their passion and eagerness to see these wildlife species in their natural habitat, as they are not commonly found in their home countries (Karam, 2020). Therefore, if they are guaranteed the opportunity to see these species, they are willing to pay.

The results also indicate that older visitors (50-60 years) are willing to spend more than younger visitors (Table 5). This can be attributed to older visitors having more leisure time and a greater understanding of the importance of these wildlife species. This finding aligns with Zyndron et al. (2021) research, which found that older individuals, particularly those over 60, expressed the highest willingness to bear financial costs for the

Table 5. The amount visitors are willing to pay to see apes in the wild.

Sociological feature	Category	N	Mean ± sd (*FCFA 1000)	ANOVA		Sig.	Conclusion
				F	Pr(>F) Value		
Gender	Female	245	72.2±51.5	4.45	0.04	0.05	Significantly different
	Male	392	99.1±77.5				
Origin	Foreigner	448	105.7±67.4	19.49	0.2×10^{-4}	0.001	Significantly different
	National	189	49.3±49.4				
Age	10-20	25	19.0±8.9[a]	2.16	0.07	0.01	Significantly different
	20-30	112	73.9±53.8[b]				
	30-40	331	93.1±66.0[b]				
	40-50	102	91.9±84.1[b]				
	50-60	67	116.53±86[b]				
Education	Primary	15	30.0±17.3[a]	1.09	0.33	0.01	Significantly different
	Secondary	203	90.7±81.8[b]				
	Tertiary	419	90.3±64.3[b]				
AMI (*FCFA 1000)	40-500	133	42.9±41.4[a]	9.30	0.1×10^{-4}	0.001	Significantly different
	500-1000	160	70.3±58.2[a b]				
	1000-1500	166	111.5±77.1[b c]				
	1500+	178	118.6±67.9[c]				

n=Number of respondents; sd=standard deviation; ANOVA=analysis of variance; sig.= level of significance; AMI=average monthly income; Values followed by different letters (a, b, and c) in the same column and line block are significantly different at p≤0.05.
Source: Authors.

benefit of Wielkopolski National Park in Poland. Respondents in the 41-60 age group also declared large amounts. Conversely, the age group least likely to incur expenses for the park comprised individuals aged 26-40. Therefore, when developing touristic infrastructure in and around protected areas, logistics, transportation, and catering should consider the needs of older people, as they are more likely to visit if the conditions are suitable for them. Additionally, men are willing to pay significantly more than women, as men tend to spend more time and money on leisure activities (Bruce, 2013). Hence, advertisement efforts can focus on men to encourage them to bring their families.

Furthermore, visitors with a primary level of education are willing to pay significantly less than those with secondary and tertiary levels. This finding aligns with Sintayehu and Raminder (2020) study, which indicated that WTP was positively influenced by education, suggesting that advanced education would enhance visitors' WTP. Witt (2019) also emphasized that education and awareness have a positive impact on personal growth and can increase knowledge, ultimately leading to more positive environmental attitudes.

The results also reveal that wealthier visitors are willing to pay more than those with lower incomes. This can be explained by the fact that wealthier individuals have greater financial means to support their touristic activities. This finding aligns with that of Zyndron et al. (2021) research, which showed a clear correlation between wealth and the willingness to financially support Wielkopolski National Park in Poland. The group with the lowest monthly income per family member was less likely to incur financial costs compared to those with higher incomes. The findings of Ghazanfar et al. (2021) also support the notion that visitation is income dependent, and the demand for ecotourism is highly influenced by household income.

This study underscores the untapped potential of eco-tourism in Cameroon by capitalizing on the diverse wildlife, creating appealing touristic circuits, improving advertising efforts, and addressing visitor preferences, Cameroon and other Congo basin countries can position themself as attractive destinations for eco-tourists from around the world. Through responsible and sustainable tourism practices to value protected areas, the countries can simultaneously contribute to funding biodiversity conservation, support local communities, and enhance its tourism industry for the long term.

Conclusion

This study sheds light on various socioeconomic factors

affecting Mefou Wildlife Sanctuary (MWS) visitors' willingness to pay (WTP) for wildlife species observation in national parks. It reveals the current state of visitor demographics, satisfaction levels, willingness to see wildlife species in their natural habitat, and the amount of money visitors are willing to pay for this unique experience. The findings emphasize the need for strategic planning and promotion of eco-touristic sites in Cameroon. While visitor satisfaction levels are high, the study highlights the importance of diversifying the touristic offerings and creating touristic circuits that connect multiple protected areas. This approach would allow visitors to have a range of experiences and encourage repeat visits, ultimately boosting tourism revenue and conservation efforts. One crucial aspect that requires attention is the limited awareness among visitors regarding the existence of other protected areas where wildlife species can be observed in the wild. It is essential for park managers to enhance their advertising efforts, particularly through active engagement on various social media platforms, as demonstrated by successful examples from other countries. The study also highlights the significant role of visitor WTP, particularly among foreign visitors. The findings suggest that foreign tourists are willing to pay higher fees, reflecting their enthusiasm to witness iconic wildlife species in their natural habitats. This can generate increased revenue that can be reinvested in conservation efforts and improving the overall tourist experience. Furthermore, the study reveals that age, gender, education level, and income play a role in visitor preferences and WTP. Understanding these factors can guide the development of tailored marketing strategies and touristic infrastructure to cater to different visitor segments, such as targeting older individuals, emphasizing educational outreach, and considering the needs and preferences of wealthier tourists to become attractive destination for eco-tourists from around the world. By effectively showcasing the rich biodiversity and unique wildlife experiences, Cameroon can attract both international and domestic tourists, contributing to the country's tourism industry and conservation goals while supporting local development.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Full Length Research Paper

Phenology and early growth performance assessment of the endangered Afromosia (*Pericopsis elata)* of the high forest zones in Ghana

Amponsah J. O.[1]*, Kwarteng A. D.[2], Eshun B.[2] and Arhin A. A.[3]

[1]CSIR-Forestry Research Institute of Ghana, P. O. Box UP 63, Kumasi Ghana.
[2]Institute of Nature and Environmental Conservation Ghana, P. O. Box 799 KNUST, Kumasi, Ghana.
[3]Beareau of Integrated Rural Development, Kwame Nkrumah University of Science and Technology, Kumasi, Ghana.

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Pericopsis elata **is a tall tree of high commercial value within moist and dry semi-deciduous West African forests. It is threatened with extinction, mainly due to overexploitation. Information on the reproductive phenology of such threatened but highly demanded trees remains crucial for taking conservation measures. This study examined the reproductive phenology of 50 individual trees relative to climatic variables, within three selected forests in Ghana. Period and intensity of the various phenophases of trees under study were monitored and scored. The effects of planting distance on early growth performance in plantation were also evaluated. Leaf flushing in the species across all sites occurred at the onset of the wet season (April-July). This was closely followed by flowering between August - September. Fruiting and seed dispersal occurred between October - February. Seed dispersion across all sites was observed for approximately 3 months (November-January), when mean monthly maximum temperatures exceeded 30^{o}C. It was concluded that it is the ideal season for seed collection. The findings further suggest that although increasing in the species reduced survival in the first two years, planting distance of 4mx4m will result in a higher periodic annual height increment, indicating faster primary growth of seedlings.**

Key words: *Pericopsis elata,* reproductive phenology, leaf flushing, flowering, fruiting and planting distance.

INTRODUCTION

Phenological monitoring involves the careful observation and documentation of the timing of recurring biological events in plant and animals, the causes of their timing, regarding biotic and abiotic forces, and the interrelation among phases of the same or different species (Leith, 1974; Badeck et al., 2004; Zhang et al., 2006). Plant phenology, the seasonal growth cycle of plant developmental stages, is sensitive to climatic changes (IPCC, 2007), and strongly influenced by the terrestrial carbon and water balance (Richardson et al., 2013; Piao et al., 2019a). Phenological information has been a reliable data in predicting how species respond to

*Corresponding author. E-mail: jamesamponsah15@gmail.com.

Table 1. Study sites location and vegetation types.

Study site	Latitude	Longitude	Forest type
Amantia	06°15'6.14"N	01° 7'48.79"W	Moist semi- deciduous
Bobiri	6°41'45.78"N	01°21'41.18"W	Moist semi-deciduous
Abofour	07°10'46.10"N	01°43'26.76"W	Dry semi-deciduous

weather variations or climatic changes (Archeti et al., 2013; Fitchett et al., 2015). Small variations in climate could have significant influence over vegetation. Pattern of phonological events is variously used for characterization of vegetation type (Jadeja, 2010). Phenological patterns in plants may have direct implication for their survival, reproduction and subsequent fitness of a population (Gezon et al., 2016). Some studies have correlated phenological events such as flowering, leaf flushing and seed dispersal to subsequent survival of seedlings, and predation rate in plant communities (Borchert et al., 2005). Phenological studies can inform us about the timing and duration of resource availability in ecological communities. For instance, through phenology observation, we can predict when pollen and nectar are available to pollinators, when fruits are available to fruit eating animals, when leaves are available for herbivory and whether plants must compete for the services of pollinators and seed dispersers (Lechowicz, 2001).

Pericopsis elata (Harms) Meeuwen is tall tree timber tree species of high commercial value belonging to family Fabaceae. It occurs mostly in moist and dry semi-deciduous tropical west-African forests (Hawthorne and Gyakari, 2006). The tree has a cylindrical bole often identified with large reddish patches on the bark. *P. elata* is currently classified as “endangered with declining population” by the International Union for the conservation of Nature (IUCN). This is due to decades of unsustainable exploitation for its precious wood (Dickson et al., 2005; Hills, 2020). Wood from this species is highly valued on the international market, not only for furniture and as decorative veneer, but also for interior and exterior joinery, stairs, flooring and boat building. It is considered a substitute for teak and suitable for heavy and light construction (NDF, 2017). *P. elata* is also listed on CITES Appendix I, and therefore subject to stricter controls in harvesting and international trade to prevent possible future extinction (Betti, 2008; CITES, 2016).

Clearly, understanding the phenology and early growth performance of endangered tree species such as *Pericopsis elata,* is a key requirement for their conservation and use in reforestation activities. At the moment, there is scanty information on improving propagation success, ex-*situ* conservation techniques and protocols for plantation establishment for this important but threatened tree. To ensure sustainability, there is the need to generate reliable data on phenology and early growth performance within range countries. Such information will guide the timely collection of high-quality germplasm from the field for raising seedlings or foe seed banking purposes (Amponsah et al., 2018).

While a host of literature exists on international trade and industrial uses of the wood of *P. elata,* there seems to be little known about the essential biological parameters controlling population dynamics, reproduction, and its phenological patterns (Doucet, 2003; Bourland et al., 2012). This study aimed to contribute to existing useful scientific information required for *P. elata* conservation. The specific objectives were to: (1) Observe and document the timing of the recurring reproductive life cycle of the species across the moist and dry semi deciduous forest ecological zones in Ghana. (2) Determine the relationship between the various phenological phases and local weather variables including temperature and rainfall. (3) Assess the early growth performance of *P. elata* in plantation establishments at varying seedling spacing or planting distances.

MATERIALS AND METHODS

Study sites

Phenological monitoring was undertaken across selected forest reserves within three ecological zones for a two year reproductive cycle. These forest reserves were located in Amantia (AM) within the moist semi deciduous Pranum forest reserve, Bobiri (BO) forest reserve in the moist semi-deciduous ecozone and Abofour (AB) located in the dry semi deciduous Afram Headwaters Forest reserve in Ghana (Table 1). These sites were selected based on the natural distribution range of the target species, and also to ensure a wider coverage of the high forests and forest-savannah transitional ecological zones of Ghana (Hawthoerne).

Phenological survey

A total of fifty matured individuals of P. *elata* were selected and tagged with laminated labels across all sites (Figure 1). Geographical position system (GPS) coordinates of sampled individuals were recorded to facilitate easy access to the trees. Individual trees were selected if they appeared to be healthy, had a crown easily observed from the route and were of reproductively matured size of at least 20 cm diameter at breast height (DBH; 1.3m above ground) following Amponsah et al. (2018).

The sampled trees were monitored fortnightly, from January 2019-December 2021. Tree crown assessment was carried out visually with the use of binoculars, digital cameras, and with the assistance of tree climbers. The various phonological phases were scored using the widely adopted Biologische Bundesanstalt, and

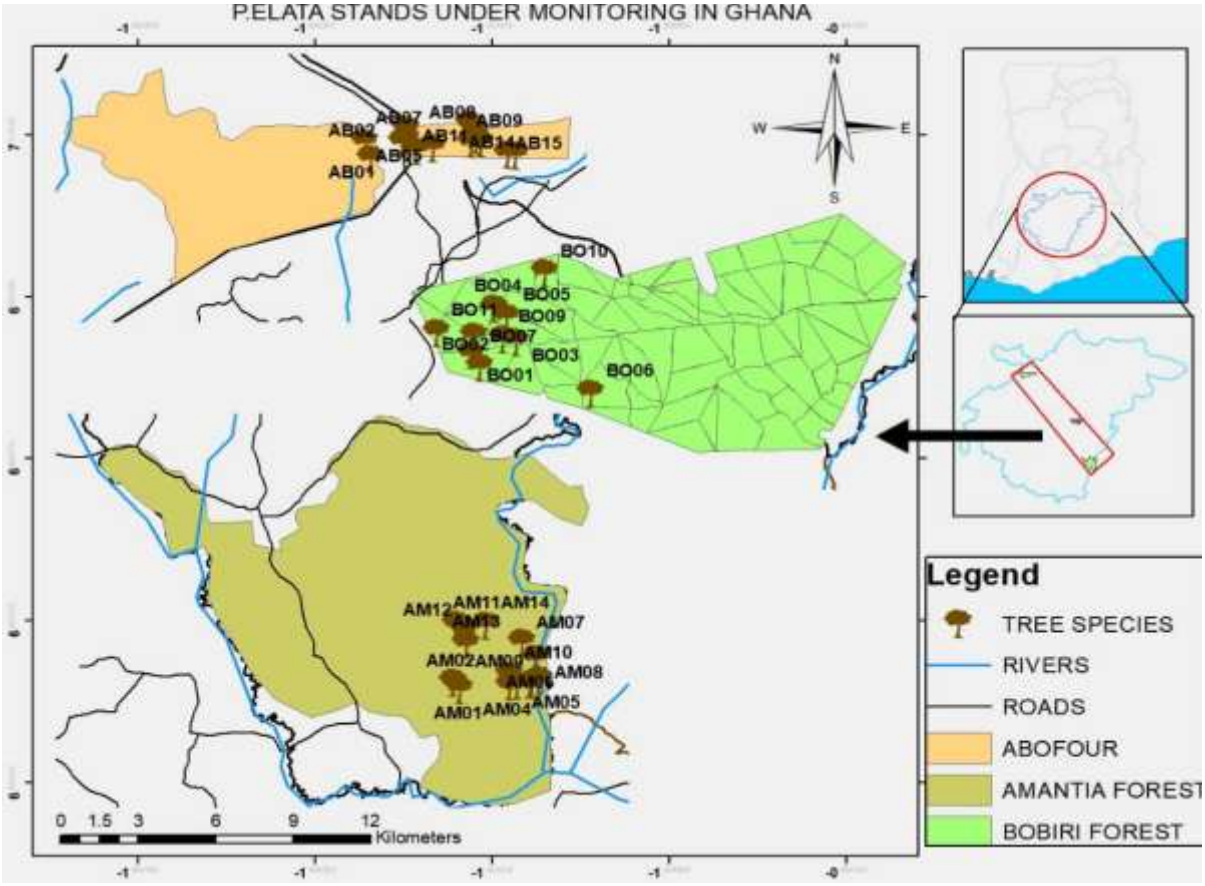

Figure 1. Map of the three study locations.

Chemical Industry (BBCH) system of coding plant phenology (Borchet et al., 2005; Schwartz, 2003). An image analysis computer software (*Image J* version 10.12) was used in transforming digital images of tree crowns phenophases into nominal percentages. A species was considered to be passing through the peak of a phenophase when more than 50% of the individuals of that species under observation were found to be in that same phase. As no observations were made during the interval between two sampling dates (approximately 15 days), a standardised protocol established by Singh and Kushwaha, (2006) was adopted. This protocol, assumes that in a tree, a particular phenophase began before, or continued beyond, the date of first/last record by one half of a sampling interval.

Weather data on rainfall as well as minimum and maximum daily temperatures of the study site were recorded, and their monthly means calculated. The weather data was further validated using the nearest computerized weather stations or data from the Ghana Meteorological Department located near the three study sites. The duration of a phenological event in the species was computed by obtaining the number of days required for the completion of an event from the first observation date of that event (Borchet, 2005; Amponsah et al., 2018). Pearson correlation analysis was carried out between the mean days of phenological events and weather data variables, mostly temperature and rainfall.

Early growth performance assessment

Early growth performance assessment was carried in the Asenanyo Forest Reserve near Akota in the Ashanti Region of Ghana (GPS). *P. elata* seedlings raised at the same time and under similar growth conditions at the Nursery, were transplanted using various planting distances (3 x 3m, 4 x 4m and 5 x 5m) as treatments. At the experimental site, three replicates of 20 m^2 P*. elata* plots were demarcated for each treatment, where data were recorded on seedling survival rate, seedling height, collar diameter, and number of leaves. These variables were defined as follows (equations 1 and 2):

$$\text{Survival rate (\%)} = \frac{\text{Number of seedlings surviving}}{\text{Number of seedlings planted}} \times 100 \quad (1)$$

$$\text{Seedling volume index } (cm^3): = Cd^2 (h) \quad (2)$$

where, Cd is the collar diameter of the seedling measured using a digital Vernier calliper placed at the base of the seedling just above the soil surface, and H is the total height (m) of the seedling measured from base to the tip of the leading stem. Also, Periodic Annual Diameter Increment (PAId) and the Periodic Annual Height Increment (PAIh) were calculated using the following equations as proposed by Yahya et al. (2020) for the first two years of seedling growth (equations 3 and 4).

$$PAId = [(dt + k - dt) / k] * t \quad (3)$$

$$PAIh = [(ht + k - ht) / k] * t \quad (4)$$

Where ht + k = total seedling height at the end of the early growth period (cm), dt = diameter at the beginning of early growth period

(cm), ht = total height at the beginning of growth period (cm), k = length of the growth period in (days) and t = 365 x 2 days.

To enable measurement on leaf area, high resolution images of sampled leaves within each plot were taken and analysed using the *Image J* computer software.

RESULTS

Results of the weather data across all three study sites are presented as Ombrothermic diagrams (Figure 2). Also, a summary of flowering/fruiting, seed maturity/ dispersal and leaf flushing phenology is presented as a colour-coded Phenological chart for the species (Figure 3).

Across all three locations, a bi-modal climatic pattern was observed. A dry period spanning mid to late November - through April with high maximum temperatures and a major wet seasons from May - June and September - October. Leaf flushing in *P. elata* generally began in early April through May and June for all three sites; although leaf flushing in Amantia seems to have been somehow delayed during the same period.

Leaf flushing

For *P. elata* populations observed in the Pranum Forest Reserve in Amantia, leaf flushing began in early May to late July with 30% of individuals under observation initiating intensive leafing for Year 1 (Y1). Similarly, 43% of sampled populations-initiated leaf flushing earlier (in mid-April) of Year 2 (Y2) at this same location. This period also coincided with end of the dry season from November- March for each year, and the onset of rains in late April for Y1 and Y2.

There were records of low mean monthly maximum temperatures with relatively increased rainfall for this period. Leaf flushing in the species at the other two locations followed a similar pattern and weather conditions with the exception of leaf flushing of *P. elata* in Abofour that lasted until September in Year 2.

Flowering and fruiting

Flowering and fruiting in the species covered the months of June to late October across all the three study locations for the two-year period. Remarkably *P. elata* populations in both Pranum and Bobiri extended their fruiting season to November, which slightly overlapped with seed maturity and dispersal. It was also observed that flowering and fruiting phenological phases overlapped with leaf flushing for all two years, but this trend was much more pronounced in Abofour and Bobiri for Y1 and Y2 respectively. Peak flowering of the species occurred in the months of October for all sites (>83% and >85% for Y1 and Y2, respectively). No flowering activity was observed in December for both years, when rainfall was lowest (>1cm for Y1 and Y2). This occurred at the onset of the dry season with high mean monthly maximum temperatures of 31.6 °C.

Seed maturity and dispersion

Closely following flowering and fruiting for the species across all three locations were seed maturity and subsequent dispersion. The peak period of seed dispersion was recorded in mid-to-late. December, where >75 and >83% of *P. elata* individuals under observation across all sites dispersed their seeds. Seed dispersal occurred alongside leaf fall in the dry cool season when deciduous species within the various ecological zones were shedding leaves. Periods of complete leaflessness was observed in some individuals during the drier months of December-February for both years. *P. elata* individuals under observation in Pranum forest reserve (Amantia) recorded the longest seed dispersion period in Y1 from late November to early March. This was during a period of low rainfall (1.3 mm on average) and high maximum temperatures (>31^0C). Markedly, seed dispersion in the *P. elata* stands that were observed in Abofour started earlier (as early as October), but did not go beyond January for all the two years, compared to all the other sites.

Phenology weather variable correlation

The duration of a phenological event in the species was computed by obtaining the number of days required for the completion of an event from the first observation date of that event (Borchet, 2005; Amponsah et al., 2018). Pearson correlation analysis was carried out between the mean days of phenological events and weather data variables, mostly temperature and rainfall. Summary of the results of this analysis is presented in Table 2. There was a strong positive correlation (0.934) between Leaf flushing in the species across all sites and rainfall. Similarly, the data indicated a strong positive correlation between seed maturity/dispersion and temperature

Early growth performance

Mean seedling height and root collar diameter of *P. elata* seedlings did not show significant differences as a result of planting distance (F= 0.096 and 0.036, respectively). Figure 4 presents a boxplot of the mean seedling height and root collar diameter as influenced by planting distance after 2 years of seedling establishment.

Also, Figure 5 presents the summary of survival rate as calculated from 3 replicated plots under the various planting distances. It is evident that 3x3m planting distance treatment showed a slightly higher survival rate

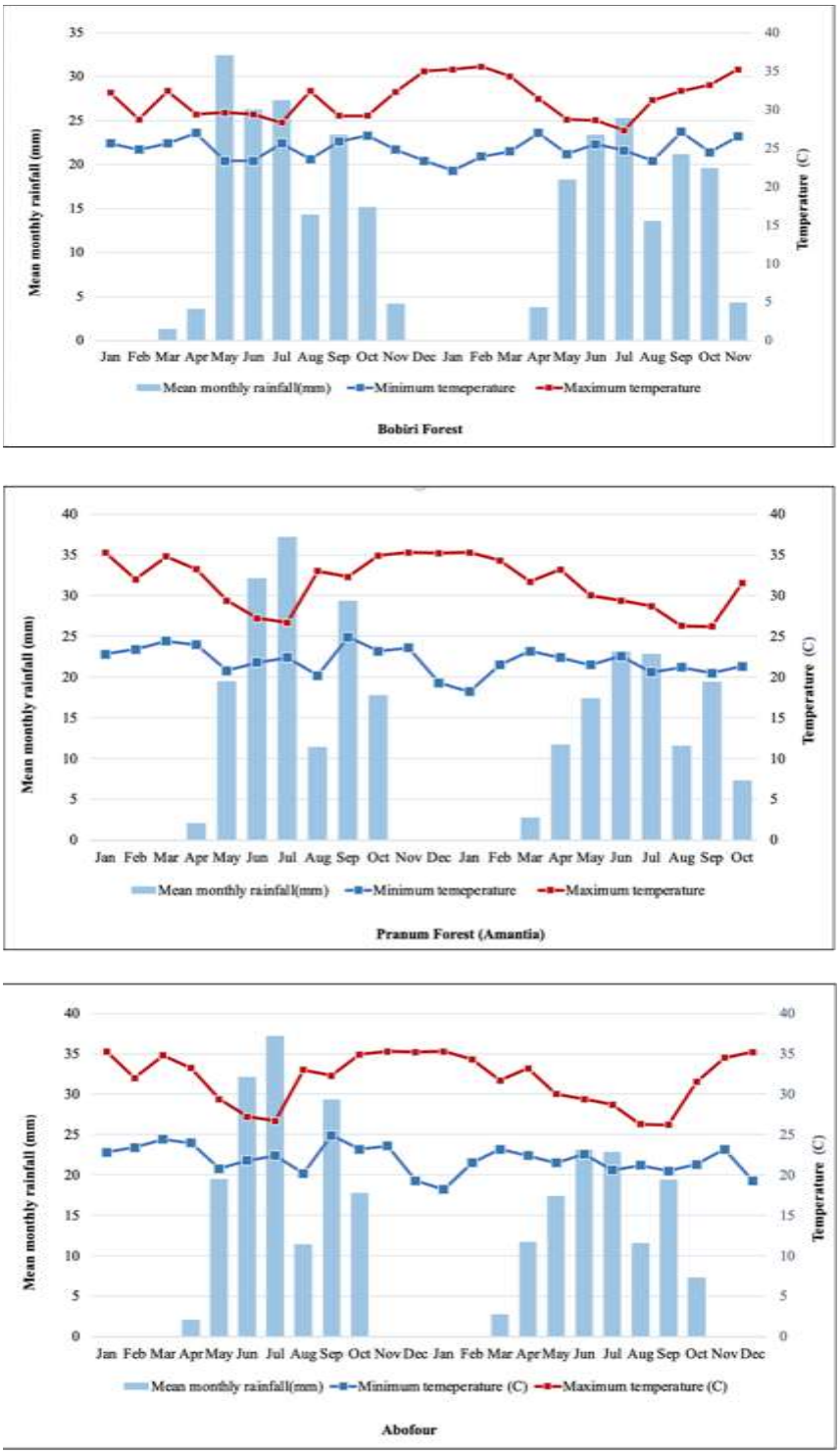

Figure 2. Ombrothermic diagrams for the three research locations during a two-year period.

compared to the rest of the treatments. Comparatively, the highest seedling survival rate (92.5%) was recorded in the first plot of the 3m planting distance treatment, whiles plot 3 of the 5 m planting distance treatment showed the lowest survival. Generally, the data seem to suggest that increasing planting distances across the treatment resulted in higher seedling mortality.

Similarly, volume index of seedlings across the various

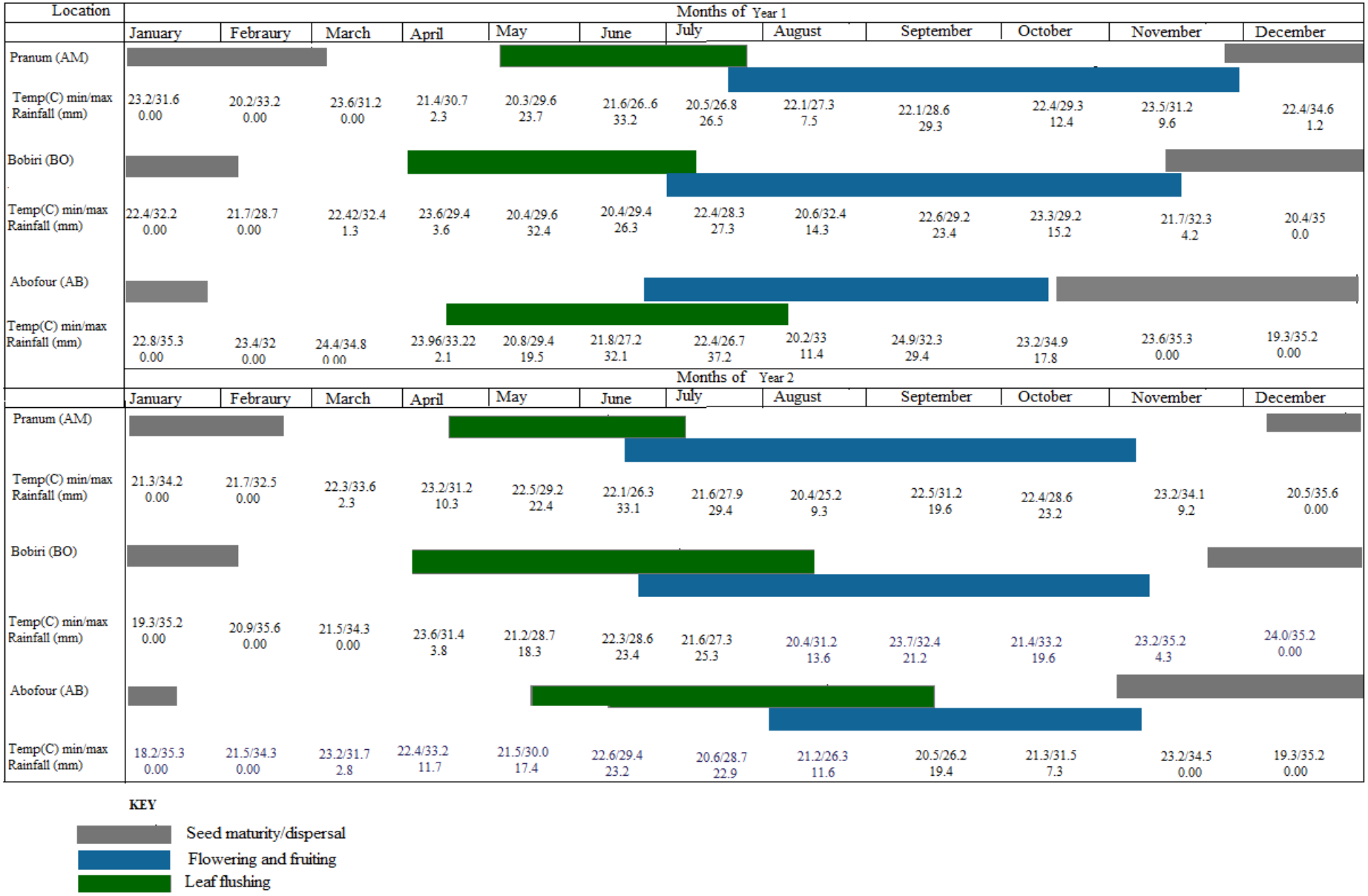

Figure 3. A Phenological Chart of *P. elata* across the 3 forest ecological zones in Ghana for a two-year reproductive cycle.

Table 2. Pearson correlation coefficients of weather variables and mean days of phenological events.

Phenophase	Temperature	Rainfall
Flowering/fruiting	-0.741	0.312
Leaf flushing	0.633	0.934
Seed maturity/dispersion	0.872	-0.314

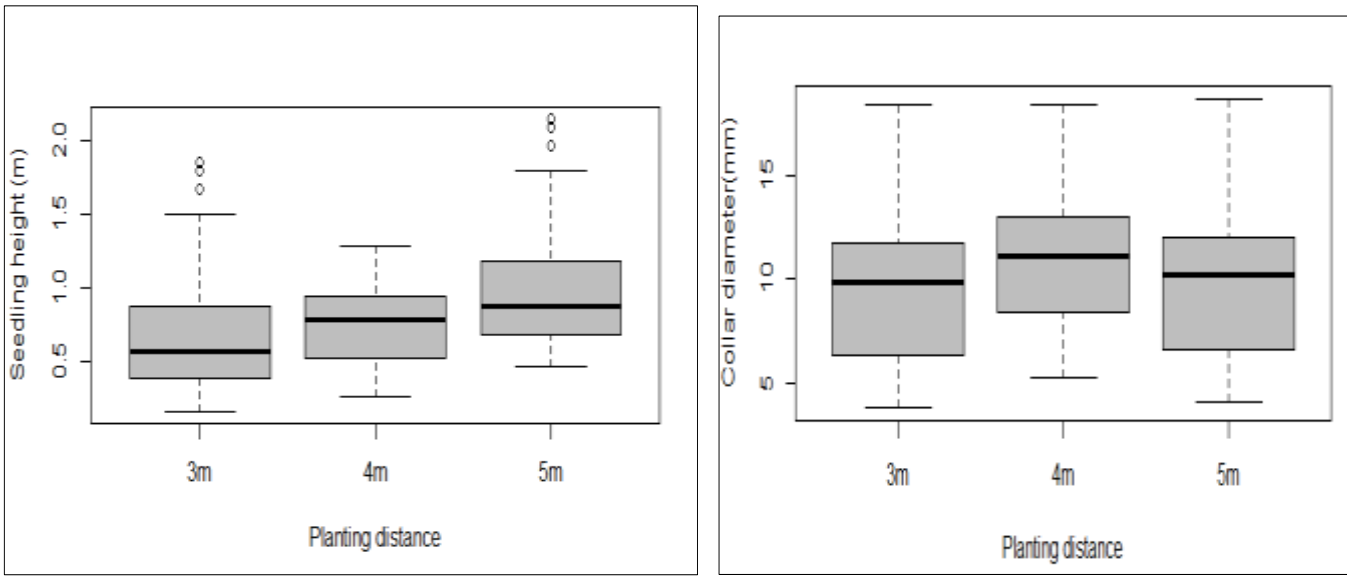

Figure 4. *P. elata* seedling height and collar diameter with planting distance after 2 years of establishment.

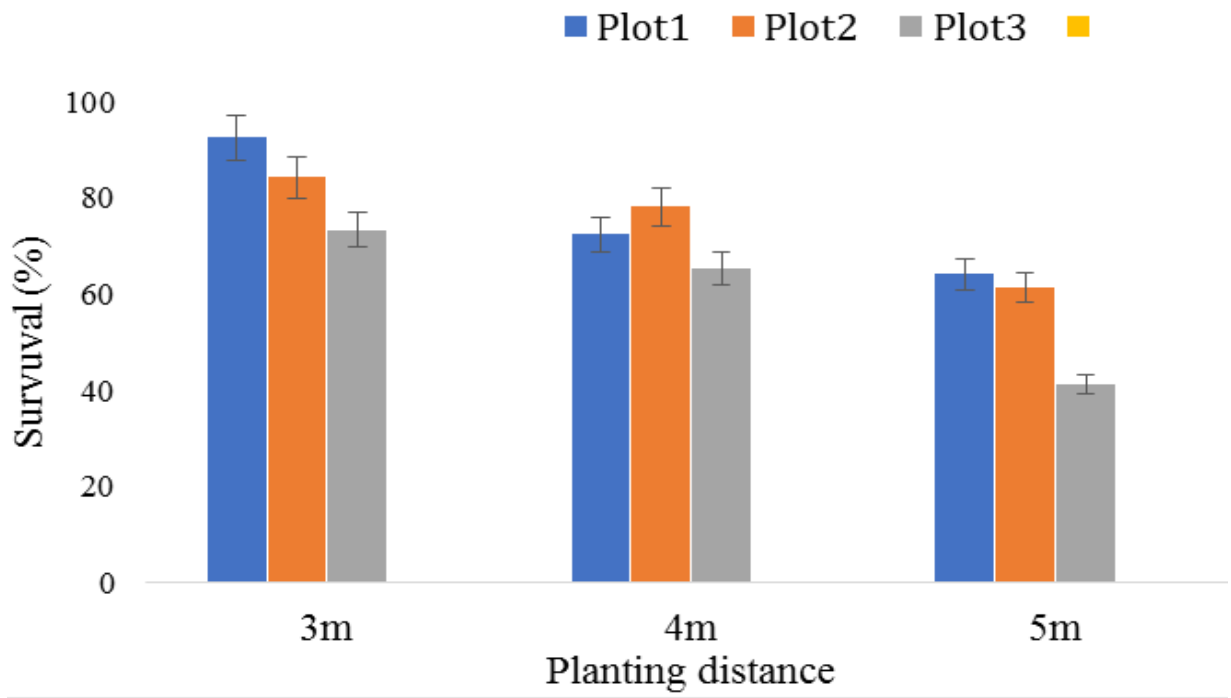

Figure 5. *P. elata* seedling survival in the 3 replicated plots at the various planting distances.

Table 3. Summary of the mean values of the various parameters for early growth performance assessment in *P. elata* seedlings.

Planting distance	Volume index (cm^3)	Leaf area (cm^3)	PAId (cm $year^{-1}$)	PAIh (m $year^{-1}$)
3 m x 3 m	96.327^a	35.22^a	0.872^a	0.124^a
4 m x 4 m	112.28^a	53.322^b	0.524^b	0.923^a
5m x 5 m	126.56^b	31.23^a	0.476^b	0.635^a
SEM (±)	9.06	12.42	0.02	0.96

PAId is the periodic annual diameter increment (cm $year^{-1}$)
PAIh is the periodic annual height increment (m $year^{-1}$)
Values with the same alphabet letters were not statistically significant at the 5% probability level.

treatments declined with seedling spacing. For instance, the 5 m x 5 m spacing recorded the highest seedling volume index of 112.28 cm^3; while the 3 m x 3 m planting space recorded the lowest volume index of 96.32 cm^3 (Table 3). Again, periodic annual increment in height as well as the periodic annual increment in diameter were identified to be highest in 3mx3m planting distance treatment closely followed the 4mx4m planting spacing (0.923).

DISCUSSION

The timing of the reproductive life cycle in *P. elata,* like other tree species, is affected by seasonal peaks and depressions common in tropical rainforests with pronounced dry periods (Borchert et al., 2005; Forrest and Miller, 2010; Sonnentag et al., 2012). Leaf flushing and flowering occurred mostly in the wet season, but were virtually absent in the dry cool months of November-March. This trend in *P. elata* was also observed by Dean et al. (2005), who worked on closely related species in the Ivory Coast. The response of the species to rains indicated that *P. elata* floral phenology was largely driven by water availability than photoperiod.

Intense flushing and flowering of *P. elata* across all study sites at the onset of the rains in May indicated intensive use of stored resources. Moreover, van Schaick et al. (1993) observed that in moist semi-deciduous tropical forests, community wide leaf flushing peaks tend to occur during the time of the year with high temperatures, rainfall and longer hours of sunshine. This is an adaptive strategy that enabled the species to use the favourable wet season for leafing and flowering. It is essential in order to accumulate sufficient photosynthate, and initiate reproduction prior to the steep fall in soil water reserve during the drier periods in the annual cycle.

A relatively extended flowering phenophase (June to mid-November) was observed in *P. elata* stands under monitoring in Pranum for both Y1 and Y2. This phenomenon observed in other tropical trees is believed to aid in the attraction of insect pollinators since their activity is greater in the months with warm and dry days (Augspurger, 1982).

Bhat (1992) argues that an advantage of dry season flowering enhanced visibility of flowers to pollinators since neighbouring trees may lack leaves and other floral parts. At all study sites, periods of complete leaflessness were observed in some individuals under observation during the drier months of December-February for both years. This leafless period is an adaptation to avoid water stress which affects flowering time of tropical forest trees (Bullock et al., 1995).

An increase in the period of leaflessness in deciduous species also causes a reduction in vegetative growth to avoid water loss through excessive evapotranspiration.

Dispersal of matured seeds across all three sites occurred in the dry-cool months of November - January with the exception of individual *P. elata* stands in Abofour, which seems to have initiated dispersal as early as October of Y1. Dispersal seems to have occurred in the dry-cool months when average monthly maximum temperatures were above 30^oC.

For seedling early growth experiment, the differences in mean seedling height was not statistically significant. This indicates that seedling planting spacing within the first two years of *P. elata* likely has no influence on height and root collar diameter. However, there were significant differences in volume index, leaf area and periodic annual height increment. This indicates that although planting *P. elata* seedlings in 5 m x 5 m spacing will increase seedling volume index during early stages of growth, a planting distance of 4 m x 4 m results in higher periodic annual height increments, indicating possible faster primary growth of the seedling.

Conclusions

Pericopsis elata stands within the selected ecological zones of Ghana tend to undergo consistent and synchronized annual reproductive cycles, influenced by temperature and rainfall. Leaf flushing in the species across is triggered by the onset of the wet season in April – July or August. Leaf flushing is closely followed by an extended flowering and fruiting phenophase from August to mid-November. Seed dispersion in *P. elata* across the various forests takes place for approximately 3 months in

the year (November-January); where average monthly maximum temperatures are high (>30^{o}C). This period, therefore, is an ideal season for seed collection towards propagation and germplasm conservation.

For early growth performance assessment, a planting distance of 4mx4m will result in a higher periodic annual height increment, indicating faster primary growth of the seedling. Thus, 4m seedling planting spacing is highly recommended to attain relatively better primary growth.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

ACKNOWLEDGEMENT

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A comparative ecophysiological study of two forest understory ferns (*Dryopteris marginalis* and *Polystichum acrostichoides*) during summer drought and excessive heat

O. Roger Anderson

Biology and Paleo Environment, Lamont-Doherty Earth Observatory of Columbia University, Palisades, 10964 New York, USA.

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This is a study of the photophysiology of two understory fern species growing on Torrey Cliff, Palisades, N.Y. during the summer of 2022 when the northeast incurred a significant period of drought and elevated temperatures. During the peak period of stress (July and August), mean photosynthesis rates of both species were lower than during more moderate weather in early summer and in autumn. Leaf fluorescence analyses indicated that the mean F_v/F_m values, combining the data for both species, were fairly similar across the 5 months suggesting that the quantum yield efficiency of photosystem II may be less susceptible to climate stress. However, there was a significant positive correlation between ET_0/RC values and net photosynthesis rate (r = 0.68, n =10, p = 0.03). This indicates that some of the variation in photosynthesis rates between species across the summer weather pattern may be accounted for by the rate of transfer of electrons from PS II through the intermediate quinone to the site of CO_2 fixation as measured by the ET_0/RC variable. Dark respiration rates were lower for both species during the most severe heat and drought in July and August.

Key words: Carbon exchange balance, climate change, dark respiration, effect of heat and drought, leaf fluorescence analysis, photosynthesis rate.

INTRODUCTION

With increasing evidence of climate change, including rising temperatures and less predictable, but sometimes heavier precipitation in temperate regions; research on the adaptability of plants including ferns has become a topic of interest, especially toward understanding their adaptability and survival in a changing climate. Understory ferns, adapted to more shaded, mesic environments, may be particularly affected by climate shifts toward elevated temperatures and less predictable precipitation.

Ferns arose historically during the middle Devonian approximately 390 million years ago (mya) becoming a dominant part of the flora in the Carboniferous. They expanded in diversity during the Cenozoic (65 mya), but lost ground when angiosperms were becoming more

E-mail: ora@ldeo.columbia.edu.

dominant (Schneider et al., 2004; Schuettpelz and Pryer, 2009). However, the understory environments of forests provided hospitable habitats where some fern species diversified and flourished on the forest floor, or through adaptive radiation they became epiphytes on the trunks and limbs of trees (Watkins and Cardelús, 2012). Other fern species have evolved to thrive in diverse environments spanning deserts to marshlands and at varying elevations in mountain ranges (Mehltretter, 1995: Bhattarai et al., 2004; Moran, 2008; Kessler, 2010; Kluge and Kessler, 2011; Anderson, 2021; De Arruda et al., 2021). However, in many temperate locations, ferns are particularly evident in forest understories or other shaded locations.

Considerable research has focused on fern physiological ecology in temperate and montane habitats, and some of these advances have received attention in review articles (Kessler et al., 2016; Zotz, 2005). However, temperate habitats vary substantially in geographic location, elevation, and climate patterns; and as a consequence, the fern flora of a temperate region may vary substantially from one location to another. Nonetheless, ferns in rocky understory locations, and those adapted to grow on human constructed stone structures, may incur particularly challenging habitat demands, including relatively less substrate for anchorage and root development, and more variable moisture; especially at higher elevations where excessive drainage may produce less consistent availability of moisture. Under conditions of climate change and more variable patterns of precipitation, ferns in these locations are likely to incur stress due to insufficient moisture, a situation made more severe if temperatures are higher and evapotranspiration is elevated. Some of these aspects have been addressed more fully in publications that are particularly focused on changing climate and environmental stress (Proctor, 2009; Bystriakova et al., 2014; Rapp and Silman, 2014; Baer et al., 2016; Sharpe, 2019; Testo and Watkins, 2013; Alarcón and Cavieres, 2018; De Gasper et al., 2021; Anderson, 2022; Kessler and Kluge, 2022; Winkel and Wood, 2022). Pittermann et al. (2013) published a review highlighting how functional morphology of the xylem combined with physiological analysis of water relations can account for the capacity of ferns to successfully endure drought-induced stress in the sporophyte stage as well as factors favoring survival of the gametophyte stage. Information of this kind can be useful in planning and interpreting research on fern adaptations and resistance to changing detrimental climate conditions. Increasing attention has also been given to comparative analyses of the physiological mechanisms regulating stomatal conductance under varying environmental conditions, especially comparing ferns to angiosperms. McAdam and Brodribb (2015) examined the effects of transitions in vapor pressure deficit (VPD) and its relationship to foliar concentrations of the plant hormone, abscisic acid (ABA). They reported that species of conifers and ferns are unable to rapidly increase foliar ABA levels during a VPD transition, which is unlike angiosperm species, suggesting possible differences in mechanisms of stomatal regulation across evolutionary lineages.

In addition to their ecological roles, ferns may serve an important role in the biogeochemical C cycle among other plants on the forest floor. The overall objective of this research was to document the role of ferns in the biogeochemical C cycle at varying locations on Torrey Cliff with emphasis on the balance of carbon gain and loss (assimilation during photosynthesis and loss during dark respiration) in relation to desiccation stress and excessive heat occasioned by seasonal changes in climate. As a consequence, part of the intention of the research was to provide additional evidence of fern resilience during increasingly unfavorable climatic conditions. Two fern species (*Dryopteris marginalis* (L.) A. Gray and *Polystichum acrostichoides* (Michx.) Schott) studied in this research occur on rock ledges and terrestrial shallows in the understory of trees.

The following variables were investigated:

(1) Net photosynthesis rate (μmol CO_2 assimilated m^{-2} s^{-1}).
(2) Leaf chlorophyll content index (CCI), a relative index measuring chlorophyll content per unit leaf area.
(3) Leaf chlorophyll fluorescence including: (i) evidence of quantum efficiency expressed as ratio of variable fluorescence to maximum fluorescence (Fv/Fm) and (ii) electron transfer per reaction center beyond the quinone intermediate (Q_A) in the electron-transport chain (ET_0/RC).
(4) Dark respiration rate (μmol CO_2 released m^{-2} s^{-1}).

MATERIALS AND METHODS

Sample site conditions and collection methods

The study site was located at the northern edge of the Lamont-Doherty Earth Observatory campus on Torrey Cliff, Palisades New York (41° 00’ 26” N, 73° 54’ 27” W; elevation 110 m). The flora of the Hudson River Palisade Cliffs is varied and expansive, with remarkably diverse local ecosystems and biologically rich habitats, spanning ledges on the vertical walls of the cliffs to more substantial stands of trees and understory vegetation on the higher elevations of the ridge overlooking the Hudson River (Airola and Buchholz, 1984). This is a study of the photophysiology of 2 forest understory ferns: *D. marginalis* (Figure 1A) and *P. acrostichoides* (Figure 1B) during 5 months (June to October) including the period of excessive heat and limited precipitation during the summer of 2022. All sites occurred beneath the canopy of overlying deciduous trees with typical light intensities of approximately 100 μmol photons m^{-2} s^{-1} (LI-COR solar monitor, Li-1776, LiCor Biosciences, Lincoln Nebraska).

Fern leaf samples were collected from three different patches of growth for each of the 2 species (*D. marginalis* and *P. acrostichoides*) and immediately taken to the laboratory for analysis. The number of leaves collected for each species varied during the period of 5 months based on the climatic conditions. In June (2022) when the weather was fairly typical for early summer, 4

Figure 1. *Dryopteris marginalis* (A) and *Polystichum acrostichoides* (B) growing on rock ledges beneath a forest canopy on Torrey Cliffs, Palisades, New York. Scale bar = 10 cm.

leaves were collected from each species to provide baseline data. In July, 4 leaves were collected from the *P. acrostichoides,* but six were collected from the *D. marginalis* to more carefully document its response because it exhibited more severe signs of desiccation stress. In August, 5 leaf samples were collected from each species to more fully represent their physiological status in response to the continuing heat and drought. In September, when the temperature returned toward normal and precipitation increased, the 2 fern species showed evidence of recovery with less apparent desiccation stress. Three leaf samples were collected in September ad October from each fern species when the weather conditions were more amenable for growth. Each sample of fern leaves was collected in the morning, and the base of the dissected petiole was immediately inserted in 50 ml of distilled water in the bottom of a plastic zip-lock bag containing a pad of absorbent paper moistened with deionized water to provide humidity. The leaf sample was immediately taken to the laboratory located on the campus for analysis.

The sampling dates each month in 2022 as follows: June 3 and 4; July 8, 9, 13 and 16; August 8-15; September 19-22; and October 14-18. The range of dates corresponds to the days when leaves were collected from the sampling sites. It was not possible to complete all laboratory analyses during one day, given that there were 2 species of ferns to be analyzed, and there were several laboratory assessments of variables, including replications to be made for the several leaves collected from each fern. Therefore, several days of sampling were necessary. During the peak period of excessive heat in July and early August, daytime air temperatures reached maximum values approaching 35°C, with uncommonly warm nights. Table 1 contains a report of the minimum, average and maximum temperatures for each of the months from June through October.

There was minimal precipitation in the months preceding June, although temperatures were not extreme, incurring a deficit of precipitation at 50 to 75% of the norm. Therefore, the precursor of severe drought stress had already been initiated prior to the onset of the severe heat wave in July. During this study, the total precipitation (cm) for each month was as follows: June (6.7), July (0.2), August (1.6), September (2.13), and October (1.0). The precipitation for June and September constituted reasonably moderate values compared to the exceedingly low precipitation amounts during the peak of the heat and drought in July and August. Photographic images of the ferns (Figure 1) were obtained using a Canon PowerShot digital camera (Canon Inc., Ōta, Tokyo).

Physiological analyses

The net photosynthesis rate of the leaves (expressed as µmol CO_2 assimilated m^{-2} s^{-1}) was assessed using an infra-red gas analyzer (IRGA) system (model BTA, Vernier, Beaverton Oregon), with an optically clear, 163 cm^3 assay chamber and illuminated with a Light Emitting Diode (LED) source at 100 µmol m^{-2} s^{-1} PPFD (LiCor Biosciences, Lincoln, Nebraska), equivalent to the ambient PAR during mid-day at the sampling site, and at a temperature of 25°C. Each sample leaf in the zip-lock bag was removed, the end of the petiole was further cut close to the base of the leaf lamina and immediately immersed in deionized water and remained immersed in deionized water during the photosynthesis and respiration measurements. Relative humidity in the sample cuvette ranged from 85–90% to reduce excessive vapor pressure deficit. The CO_2 concentration in the assay cuvette was at ambient atmospheric concentration (417 ppm). The time for measurement of each leaf was c. 10 min. Mean respiration rate (expressed as µmol CO_2 released m^{-2} s^{-1}) was determined at 25°C using the same apparatus with a completely darkened assay chamber. 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 (c. 2 min.), and measurements were begun when there was a steady state respiration rate.

The chlorophyll concentration index (CCI) for each leaf sample was obtained using a CCM-300 chlorophyll content meter (Opti-Sciences, Inc., Hudson, New Hampshire). At least 20 measurements were made for each leaf sampled from each of the fern species

Table 1. Minimum, average and maximum temperatures (°C) for each of the 5 sampling monthly intervals June to October (2022) at Palisades N. Y.[a]

Sampling date	Minimum temperature	Average temperature	Maximum temperature
June	16.1	21.1	25.0
July	19.1	28.3	29.4
August	23.9	30.6	32.2
September	15.9	23.9	24.4
October	7.6	18.3	19.9

[a]Sparkhill Creek weather station, Palisades, New York.

collected on a specified collection date. Each of these mean values, obtained from the 20 measurements, was used to calculate the overall mean CCI value for the replicates of a given fern species on the specified date (Table 2). An OS-30p+ Chlorophyll Fluorometer (Opti-Sciences, Inc., Hudson, New Hampshire) was used to obtain the leaf fluorescence data. This included leaf quantum yield efficiency expressed as variable fluorescence/maximum fluorescence (Fv/Fm), and evidence of electron transport per reaction center (ET_0/RC) from photosystem II (PS II) to the quinone intermediate (Q_A) and beyond in the electron-transport chain as 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. All results of the assays are presented as the mean ± standard error (M ± SE) calculated using an Excel spreadsheet (Microsoft, Inc. Redmond, WA, USA). Pearson product moment correlation coefficient calculations were obtained using an Excel spreadsheet. Linear regression estimates relating photosynthesis rate (A_C) to environmental temperature in °C (T) were obtained using the Vassarstats online calculator (http://vassarstats.net/vscor.html). A Kolmogorov-Smirnov test was used to verify that the data was sufficiently normally distributed to perform the linear regression analysis.

RESULTS

The results for the leaf photophysiology and dark respiration measurements are presented in Table 2. In general, the mean rate of photosynthesis for the two species was higher during early summer (June) and early autumn (September into October) than during the peak of the summer drought and heat stress (July and August). During July and August, the overall mean respiration rates (μmol m^{-2} s^{-1}) were *D. marginalis* (0.36 ± 0.05), and *P. acrostichoides* (0.24 ± 0.04). In general, the mean photosynthesis and dark respiration rates for *D. marginalis* tended to be higher than for *P. acrostichoides*. With respect to the C balance (C lost by respiration/C gained by photosynthesis) the mean respiration rate as a % of photosynthesis ± SEM is as follows: *D. marginalis* (31% ± 3.5) and *P. acrostichoides* (23% ± 4.7). It is interesting to note that the overall mean leaf chlorophyll concentration index (CCI) was consistently higher for *P. acrostichoides* (16.6 ± 0.30) than for *D. marginalis* (5.5 ± 0.53). The leaves of *P. acrostichoides* are deep green in color and relatively thick, suggesting that they may contain more chlorophyll per unit leaf area. The overall mean F_v/F_m values ± SEM for the 2 species during the 5 months was fairly similar: *D. marginalis* (0.75 ± 0.01) and *P. acrostichoides* (0.78 ± 0.11). The mean F_v/F_m values, combining the June and autumn data for both species were fundamentally equivalent (0.76 ± 0.01). There was no significant correlation between F_v/F_m and photosynthesis rate (r = - 0.4, n = 10, p = 0.15).

The mean ET_0/RC values ± SEM for the 2 species during the 5 months were *D. marginalis* 1.14 ± 0.04 and *P. acrostichoides* 1.01 ± 0.01. The mean ET_0/RC value combining the data for the two species for the mild June and autumn time period was 1.12 ± 0.04, and for the stressful July and August data was 1.01 ± 0.02; the means are not significantly different (t = 1.91, df = 8, p = 0.09). However, there was a significant positive correlation between ET_0/RC values and net photosynthesis rate (r = 0.68, n =10, p = 0.03). This indicates that some of the variation in photosynthesis rates between species and across the summer weather pattern may be accounted for by the rate of transfer of electrons from PS II through the intermediate quinone to the site of CO_2 fixation and its reduction to produce the first carbohydrate product as measured by the ET_0/RC variable.

Overall, there is no statistically significant difference in the mean value of the photosynthesis rate for *D. marginalis* (1.75 ± 0.49) and *P. acrostichoides* (1.37 ± 0.24); although, given the limited sample size (N = 10), this may contribute to a lack of significance. The ratio of mean CO_2 fixation rate (A_c) during the most stressful months (July and August) to the mean rate in less stressful months (June, September and October) can provide evidence of resiliency. Combining data for both species, the ratio in July and August (during the greatest climate stress) compared to the 3 months with more moderate climate (June, September and October) was 0.36. That is, the CO_2 fixation rate for the stressful months was c. 40% of the fixation rate in the less stressful months. This indicates that there may be a substantial decrease in atmospheric C assimilation during

Table 2. Means and standard errors of the mean (parentheses) for chlorophyll concentration index (CCI), photosystem II quantum yield efficiency (F_v/F_m), electron transfer per reaction center (ET_0/RC), photosynthesis CO_2 assimilation rate (A_C) and dark respiration rate (R_D)[a].

Sampling date	CCI	F_v/F_m	ET_0/RC	A_C (µmol CO_2 m^{-2} s^{-1})	R_D (µmol CO_2 m^{-2} s^{-1})
June 2022					
Dryopteris marginalis	4.13 (0.60)	0.72 (0.01)	1.25 (0.03)	3.67 (0.71)	1.49 (0.35)
Polystichum acrostichoides	10.39 (1.10)	0.79 (0.01)	0.98 (0.05)	1.60 (0.12)	0.38 (0.02)
July 2022					
Dryopteris marginalis	4.69 (0.20)	0.73 (0.04)	1.03 (0.07)	1.32 (0.44)	0.44 (0.07)
Polystichum acrostichoides	19.73 (3.85)	0.78 (0.01)	0.96 (0.04)	1.24 (0.42)	0.26 (0.04)
August 2022					
Dryopteris marginalis	5.44 (0.69)	0.76 (0.005)	1.08 (0.01)	1.01 (0.19)	0.27 (0.07)
Polystichum acrostichoides	16.4 (2.85)	0.76 (0.01)	0.96 (0.03)	0.52 (0.22)	0.22 (0.06)
September 2022					
Dryopteris marginalis	6.07 (1.42)	0.78(0.001)	1.12(0.04)	1.27(0.26)	0.45(0.17)
Polystichum acrostichoides	12.98 (2.81)	0.78 (0.004)	1.03 (0.03)	1.54 (0.34)	0.23 (0.06)
October 2022					
Dryopteris marginalis	7.13 (0.54)	0.76 (0.002)	1.22 (0.04)	1.49 (0.10)	0.31 (0.04)
Polystichum acrostichoides	23.53 (3.41)	0.77 (0.004)	1.11 (0.03)	1.95 (0.29)	0.31 (0.02)

[a]Data are means and standard error of the means in parentheses.

the summer stressful period. Consequently, increasing climate stress due to global warming may result in considerable reduction in mean CO_2 fixation by ferns and other herbaceous understory plants, potentially contributing to an increased "greenhouse effect" and greater global warming.

Some of the decreased CO_2 uptake during the climate stressful months may be explained by reduced stomatal opening and less conductance of CO_2 into the leaf. This is particularly likely because the fluorescence evidence of leaf physiological functions (e.g., Fv/Fm and ET_0/RC) are not substantially different between normal and stressful months. Stomatal closure is a physiological response to conserve leaf hydrature by reducing loss of water by leaf evapotranspiration, but concurrently it also limits diffusion of CO_2 into the leaves.

As shown in Table 1, mean dark respiration (R_D) declined considerably during the five-month study from a high value in June of 1.49 for *D. marginalis* and 0.38 for *P. acrostichoides* to 0.31 for both species in October. Some of the decline in the later months may be due to increasing leaf senescence preceding desiccation in the autumn. The mean R_D for *P. acrostichoides* was consistently lower than the mean R_D for *D. marginalis*, particularly for June through September. However, with only 4 measurements, the degrees of freedom are too small to likely find a statistically significant difference.

The ratio of dark respiration to photosynthesis rate (R_D/A_C) provides an estimate of balance of C exchange by the fern with the environment (that is, CO_2 release/CO_2 assimilation). In June, the ratio was 0.41 for *D. marginalis* and 0.24 for *P. acrostichoides*. During the more stressful months, the ratios for *D. marginalis* in July and August were lower (0.33 and 0.27, respectively). Likewise, the values for *P. acrostichoides* in July and August were 0.21 and 0.42. The somewhat higher value of 0.42 in August is explained by a relatively larger decline in the photosynthesis rate during August compared to the respiration rate. The mean ratios during the subsequent milder period (September and October) were also low: 0.31 for *D. marginalis* and 0.18 for *P. acrostichoides*. At this time most of the leaves were becoming senescent and the relatively low values may be explained by decreasing physiological vigor.

Linear regression analysis

A linear regression analysis of the relationship between photosynthesis rate (A_c) and temperature (T) was made for *D. marginalis* and *P. acrostichoides*. The resulting equation for *D. marginalis* (A_c = - 0.02 T + 2.27) was not statistically significant (t = - 0.34, df = 19, p = 0.74), though the slope of the relationship was negative indicating decreasing photosynthesis rate with increasing environmental temperature. However, the equation for *P.*

acrostichoides (A_c = - 0.09 T + 3.49) was statistically significant (t = - 2.92, df = 18, p = 0.009). Differences in the physiological ecology of the 2 ferns may account partially for the differences in the regression results. As explained subsequently, *P. acrostichoides* is typically a more cool-temperature species, surviving winter as a wintergreen fern and exhibiting substantial photosynthesis activity during winter and cool weather of early spring (Noodén and Wagner, 1997). This cooler temperature niche of *P. acrostichoides* may explain the statistically significant negative effect of increasing summer temperatures on its photosynthesis rate as expressed in the linear regression equation.

DISCUSSION

The drought and heat of summer 2022 produced substantial stress for plants growing on Torrey Cliff, particularly ferns and other herbaceous plants located at more elevated portions of the terrain, leading to severe wilting and in some cases evidence of complete desiccation and death (Anderson, 2022). Evidence presented here, particularly documents the status of 2 commonly occurring temperate fern species on Torrey Cliff during the summer of 2022: (i) the milder early summer (June), (ii) the period of most heat and desiccation stress (July and August) and (iii) autumn (September and October), when more moderate temperatures and precipitation prevailed. Overall, the 2 ferns in this location survived the stressful summer; although during peak stress there was considerable evidence of wilting in some cases, and the physiological evidence indicates substantial decreases in photosynthesis. As of July (2023) when this report was being written, both of the ferns exhibited robust growth further suggesting that they were capable of surviving at least one very serious climate stress and resuming substantial growth in the succeeding year.

D. marginalis and *P. acrostichoides* are commonly observed growing as understory terrestrials in occasional patches, typically in depressions near rock outcrops, or other locations where moisture is more prevalent and persistent. One of the *D. marginalis* ferns in this study was growing from a cleft in a north-facing, large rock outcrop beneath a shrub and tree canopy, while all others were growing on rock ledges with relatively thin soil substratum and overlying shrub and tree growth (Figure 1A). *P. acrostichoides* (Figure 1B) known informally as the “Christmas fern” is decidedly wintergreen, and its thick, leathery leaves persist even beneath winter snow. The rachis of the leaf is hinged or softened near the base, thus allowing at least some of the leaves to decline and lie prostrate on the substratum throughout the winter months (Noodén and Wagner, 1997). The position of the leaves (more upright in summer and prostrate in winter) may have important positive adaptive value as shown by experimental physiological research in field settings (Forget et al., 2018). In some temperate, North American locations, *P. acrostichoides* is a dominant member of the pteridophyte community, occurring in 92% of the plots and constituting 52.4% of the relative importance (Greer et al., 1997).

To place the findings of this laboratory-based study in a broader context, the photosynthesis results reported here are compared to prior published findings for *D. marginalis* and *P. acrostichoides.* During the peak of the summer stress in July and early August, the fern leaves showed signs of wilting, and there was minimal new growth. Nonetheless, after intermittent rain events, the leaves recovered exhibiting normal turgidity. However, the *D. marginalis* mean photosynthesis rates in July through October (in a range of 1.01 to 1.49 μmol m^{-2} s^{-1}) were lower than the mean in June (3.67) during more favorable growth conditions. The latter rate of 3.67 is comparable to a rate of ca. 3.5 μmol CO_2 m^{-2} s^{-1} reported by Sessa and Givinish (2014) at a light intensity of 100 μmol m^{-2} s^{-1} as interpreted from their graphical data for *D. marginalis* growing in eastern North America.

In the current study, *P. acrostichoides*, growing in shallow soil on the rocky ledges, exhibited major declines in photosynthesis during the period of summer stress reaching a low mean value of 0.52 μmol CO_2 assimilated m^{-2} s^{-1} in August, compared to 1.60 in June. The higher June value of 1.60 is comparable to a value of 1.40 reported by Prats and Brodman (2020) for photosynthesis measurements at similar light intensities used in this laboratory research (100 μmol m^{-2} s^{-1}). In the results reported here, a peak photosynthesis rate of 1.95 was reached when temperatures were more moderate and soil moisture increased in late October. Minoletti and Boerner (1993) reported comparable mean photosynthetic values of 1.96 to 2.14 μmol CO_2 assimilated m^{-2} s^{-1} for *P. acrostichoides* growing within ambient CO_2 levels in forests of Neotoma valley, Ohio during mild winter days. Values of 1.81 to 2.24 μmol CO_2 assimilated m^{-2} s^{-1} were published by Noodén and Wagner (1997) for *P. acrostichoides* in early spring while growing in a woodlot near Ann Arbor, Michigan. A value of 1.95 reported here for *P. acrostichoides* during October is within the range reported by Noodén and Wagner. The mean F_v/F_m values found here, in the range of 0.76 to 0.79 for *P. acrostichoides*, are in agreement with values of approximately 0.79 reported by Reudink et al. (2005) for *P. acrostochoides* growing in southeastern Pennsylvania.

With respect to the biogeochemical C cycle, evidence presented in Table 2, and data from the linear regression analyses, indicate that increasing temperature tends to reduce photosynthesis fixation of CO_2, and thus may contribute to relatively higher loss of CO_2 to the atmosphere through respiration. That is, increasing temperatures tend to shift the balance of CO_2 exchange toward more CO_2 loss by the plants. Furthermore, the mean ratio of respiration to net photosynthesis (R_D/A_C) for

the 2 species was c. 30% and may account for an appreciable remobilization and release of CO_2 into the atmosphere. Additionally, the lack of new foliage production, particularly during the stressful peak growing season, further limits the potential for drawing down atmospheric CO_2 through photosynthesis fixation due to less physiological activity of senescent leaves (Thomas and Stoddart, 1980).

Overall, the results of this study suggest that these 2 fern species exhibit substantial resilience in the face of increasing evidence of climate change stress, particularly increased mean summer temperatures and reduced precipitation, at least within the weather pattern incurred in summer 2022. However, longer term effects of repeated cycles of exposure to climate change stress over several annual cycles need to be examined to determine if there are accumulated detrimental effects, or if the results reported here within a 5-months period are more indicative of stress resilience across multiple years of climate change. Further research combining laboratory studies such as reported here with field-based research is needed to more fully document the response of ferns in the natural environment to changing climate patterns. Additional research is also needed to assess changing climatic effects on a broader range of temperate fern species, including those in different geographic locales and among more diversified habitats, spanning open locations to more deeply shaded woodlots and forests.

CONFLICT OF INTERESTS

The author has not declared any conflict of interests.

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