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Research Article

Diversity and Distribution of Anomalures and Squirrels in Oban Hills of Nigeria

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Abstract

The Congolian tropical forest represents the epicentre of biodiversity conservation and squirrel diversity in the Western and Central African region of sub-Saharan Africa. The scientific knowledge gap of squirrel species diversity, distribution and ecology of the region is limited. We investigated anomalure and squirrel richness and diversity in different land-use types in the Oban region, Nigeria between January 2010 and April 2013 to update species baseline information on squirrels. In total, we recorded 495 individuals of seven species and six genera representing, Anomaluridae and Sciuridae families, were detected in the Oban Hills Region. The Anomaluridae family accounted for one genus and one species (*Anomalurus beecrofti*), while the Sciuridae family is represented by the Xerini and Protoxerini tribes in five genera (*Funisciurus*, *Heliosciurus*, *Xerus*, *Paraxerus*, and *Protexerus*). Encounter rates with five different species revealed that the Protoxerini tribe (*Funisciurus anerythrus* and *Heliosciurus rufobrachium*) were the most frequently detected across all the land-use types in the region. The high diversity of squirrels detected in the region could be a reflection of its recognition as a biodiversity hotspot. Also, closed-canopy cover had the highest diversity index and evenness recorded than farmfallow. Studies on population monitoring, ecology, and conservation help species- and site-specific conservation strategies in the region. We conclude that closed-canopy forest has high conservation value, and that management should be initiated where possible to alleviate threats to its continued functioning and effort must be directed towards ascertaining the ecology and biology of squirrel species for effective conservation strategies.

Introduction

The Oban Hills Region Forest is remarkably rich lowland rainforest ecosystem, which is diverse in flora and fauna due to it climatic and topographic variation. The dramatic difference in microclimate results in a variety of ecosystems from tropical rainforest to mangrove forest, which are home to various endemic plant and animal species. It is an internationally recognized biodiversity hotspot and a centre of species richness and endemism, particularly for amphibians, butterflies, fishes, primates, and small mammals. Indeed, previous work in the region has shown that ecological diversity promotes high species richness (BirdLife International, 2021; Kormos, 2003; Marsh, 2003; Terborgh, 2002). The Oban Hills Region provides another example, as its land area occupy just 0.3% of the Nigerian landmass (BirdLife International, 2021; Oates et al., 2004).

Amongst small mammals, rodents are the largest Order in terms of both species and populations size with high rate of fecundity, and adaptability to diverse habitats (Baelo et al., 2018, 2016; Singla et al., 2008). Rodents are important globally in their impacts on agriculture, ecology, food, health, medicine, culture, religion, and ethnomedicine. However, conservation managers and protected-area authorities need to modify current conservation strategies in order to integrate rodents into the biological and environment conservation along with rest of the fauna and flora (Koprowski, 2005a; Kingdon, 1997). Rodents are one of the key indicators of ecosystem health, and play an important role in ecosystem functioning (Posthumus et al., 2015; Koprowski et al., 2005; Steele et al., 2005; Frelich, 1995). Ecologically, the Sciuridae comprises mainly ground-dwelling species, arboreal-dwelling species and flying anomalures. The squirrels and arboreal-dwelling species are dependent mature forests that provides shelters, food, cavities, stems, and canopies for nesting, navigation, and launch sites. Squirrels are believed to be important forest pollinators and forest ecosystem health indicators, (Kingdon, 2015, 1997). 278 species in 51 genera (Wilson and Reeder, 2005) of squirrels are recorded worldwide, and Nigeria is home to 11 species from seven genera, which is about 3.96% of the global known species (Kingdon, 2015, 1997).

Studies on squirrels in sub-Saharan Africa are mostly focused on preliminary studies or rarely available (Ikyaagba et al., 2020; Omifolaji et al., 2020), whereas few ecological studies of squirrel populations are conducted in relation to the landscape in Nigeria (Adeniran, 2013; Amori and Luiselli, 2011; Angelici and Luiselli, 2005). The few studies of squirrels in Nigeria have focused mainly on helminth parasites (Omonona et al., 2020), genetic and morphological variation (Coker et al., 2021, 2020; Bamidele amd Akinpelu, 2019; Ekele et al., 2014), whereas there have been no studies on squirrel ecological diversity, taxonomy and distribution in Nigeria until now. However, extensive studies to determine the ecology and distribution of squirrel richness are

Conceived and designed the experiments: JKO, LX, AA, ETI, SOJ. Performed the experiments: JKO, ETI, AA, SOJ. Analyzed the data: JKO, LX, AA, ETI, SOJ, GD, CJAK. Contributed materials/analysis tools: JKO, LX, ETI, AA, SOJ, GD, CJAK. Wrote the paper: JKO, LX, ETI, SOJ, GD, AA CJAK.

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crucial to species conservation and to update baseline information for population monitoring.

Deforestation and habitats loss from human-induced activities play a critical role in global biodiversity declines (Omifolaji et al., 2020; Estrada et al., 2017; Estrada and Fleming, 2012). Understanding interspecific and intraspecific variation in species' responses to anthropogenic activities are important for developing effective conservation decision-making, such as by informing ecosystem protection and conservation targets to maintain critical ecological changes such as species-area thresholds (Fryxell et al., 2020; Husseini et al., 2019). Mammals have their own unique habitat requirement which provides an insight into the ecosystem health and integrity. Despite the important of knowledge their behaviour and ecology, documentation of squirrel species richness in the Oban region is unavailable and is mostly based on isolated collections and observations by local hunters, naturalists and researchers working on biodiversity surveys. To date, no checklist has been made or published for the region and any attempt to understand squirrel distribution and composition in this area can only be done through inference of studies done elsewhere on the continents.

Given the lack of sufficient knowledge about squirrel richness and diversity in the Oban Hills Region of Cross River National Park (CRNP), this research aimed to fulfill this gap by addressing two main objectives. The first objective was to examine squirrel species abundance and diversity throughout the Oban Hills Region. This area is known to support high vertebrate species diversity (Ikyaagba et al., 2020; Omifolaji et al., 2020), but still lacks long-term studies to quantify the abundance of different species. The objectives are to update scientific knowledge of squirrel populations and assess influence of habitats on their distribution in the landscape. The information gained from the objectives is important for the conservation and population monitoring of squirrels in the region. While the present study is only a preliminary study, it provides a solid foundation for future studies, which are essential to understand in greater details the distribution and relationship of squirrels to the rapidly vanishing forested ecosystem and updates on species population monitoring in Nigeria.

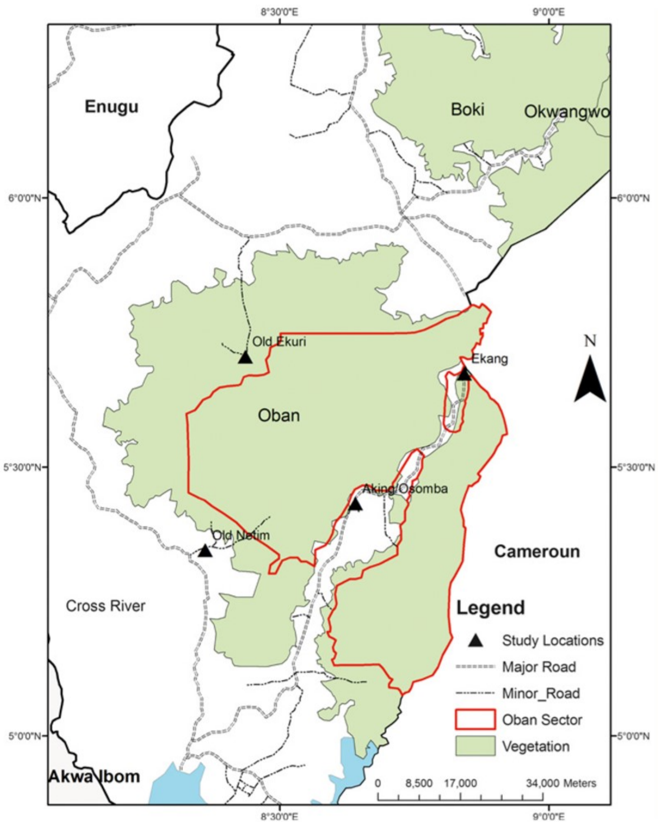

Figure 1 – Map of Cross River National Park showing Oban Hills Region.

Material and Methods

Study Area

The Oban Hills Sector of Cross River National Park (CRNP) (5°15′25″ N, 8°30′45″ E) (Fig. 1), a UNESCO World heritage site, Important Bird Area (BirdLife International, 2010), and Biodiversity hotspot, is the most important tropical rainforest ecosystem in Nigeria as a carbon sink at an elevation ranging from 100m in the river valley to 1000m above sea level in the mountainous area (Omifolaji et al., 2020; Myers et al., 2000; Ite, 1997; Ojo and Ola-Adams, 1996). The division is contiguous with Korup National Park, Cameroon, forming a single protected ecological zone in the Central and West Africa region (Lameed et al., 2015; Jimoh et al., 2013). It is the single largest tropical forest protected area 3000 km^2 of lowland tropical rainforest ecosystem. The Park provides a suitable habitat for a diverse fauna including species like endangered African forest elephant (*Loxodonta cyclotis*), chimpanzee (*Pan troglodytes*), Mandrill (*Mandrillus leucophaeus*), pangolins (Ikyaagba et al., 2020; Kormos, 2003; Marsh, 2003), over 900 butterflies (Terborgh, 2002, 1992), an Important Bird Area (IBA) with 350 species (BirdLife International, 2010). It is home to 1568 plant species, including 1303 flowering plants, 141 lichens and 56 moss species of which 77 plants are endemic to Nigeria (Ite, 1997). The typical tree species include *Berlinia confuse*, *Coula edulis*, *Hannoa klaineana*, *Klainedoxa gaboniensis*, African Mahogany (*Khaya grandifolia*) and Red ironwood (*Lohira alata*). The study was conducted in the Oban division, which is divided into two ranges: Oban East, and Oban West. The annual rainfall is 3000 mm in the southern parts and 2500 mm in hilly and mountainous areas, and the climate is tropical humid (Bisong and Mfon, 2006). The temperature is 25 °C to 27 °C in January, but in July, it usually moves up slightly above 30 °C. Relative humidity is about 75 to 95% in January, but towards the end of the year, it reduces gradually during harmattan (Jimoh et al., 2013; Bisong and Mfon, 2006; Fa et al., 2006). It is regarded as the last stronghold of tropical rain forest in Nigeria (Eniang et al., 2008).

Data Collection

The study area in the Oban Hills Region landscape of the CRNP was fully explored from January 2010 to April 2013. For the purpose of this study, the vegetation of the area was categorised into four land-use types based on human disturbance activity around the park. The four broad categories of land use type were: Close-canopy forest (>75% canopy cover), which comprises matured, closed-canopy forest with numerous arboreal pathways and scarce forests undergrowth; Secondary Forest (>45% canopy cover) comprises a mixture of regenerating forest, and dense shrub vegetation; 3) Farm fallow (25% canopy cover), these sites had few mature trees, dense vines entangling regenerating trees; and plantation (oil palm, cocoa) farm which comprises mono-cropping and mixed farming of cocoa trees, oil palm and a few scattered mature native plants and trees species remaining as described (Ite, 1997; Schmit, 1996).The forest category types were designed to avoid bias associated with data collection on squirrels since the park is made up of different vegetation types impacted by anthropogenic activities. Line-transect survey, as described by Buckland et al. (2001) was employed for this study. This method has been employed for determination of animal species and abundance by several researchers, especially in tropical rainforest ecosystems due to the nature of mammalian species and topography of the area. In each land-use type, a 2 km transect was established across the land-use types with the aid of Global positioning system (GPS), taking into consideration the landscape topography. A total 40 2 km transects was established in the area based on a stratified sampling technique in a randomly selected and sufficiently placed at an interval of 600 m apart from two neighbouring transects (Thomas et al., 2010; Fewster et al., 2009). Line-transects were the main method employed for mammal surveys in the tropical rainforest, due to different canopy-cover and anthropogenic activities, we ensure that the starting points of all transects begins from each land-use types of the forests. The survey was conducted by walking along each transect, from 06:30 – 10:30 hours GMT and 15:30 – 18:30 hours GMT while looking ahead and literally to the direction of travel to detect and identify squirrel spe-

Table 1 – Anomalures and Squirrels sighted and their relative percentage abundance (in parenthesis) at the four habitats in Oban Hills Region of Cross River National Park.

	No. sighted per land-use type					
Species	Close canopy forest	Secondary Forest	Abandoned Farmland	Plantation	Total	% Occurrence
Funisciurus pyrropus	14(19.20)	20(27.40)	11(15.10)	28(38.40)	73	14.75
Protoxerus stangeri	40(42.60)	30(31.90)	20(21.20)	4(4.30)	94	19.00
Xerus erythropus	7(22.60)	1(3.20)	16(51.60)	7(22.60)	31	6.26
Anomalurus beecrofti	15(29.40)	20(39.20)	12(23.50)	4(7.80)	51	10.30
Paraxerus poensis	0(0.00)	11(57.90)	8(42.10)	0(0.0)0	19	3.83
Heliosciurus rufobrachium	31(27.90)	32(28.80)	29(26.10)	19(17.10)	111	22.42
Funisciurus anerythrus	40(34.50)	30(25.90)	21(18.10)	25(21.60)	116	23.43
Total	147(29.69)	144(29.09)	117(23.63)	87(17.57)	495	100.00

cies. Each transect was walked by three trained observers, within a radius of 50m on both sides of the transect at a distance of $0.5\,\mathrm{km\,h^{-1}}$. Within all the land-use types, we focused on concentrated searches in the tree branches, forest canopy covers and forest floor, once we observed the presence of squirrels. We followed pre-existing human trails and maintained a straight line to have a little or no influence on perpendicular estimation with the aid of Nikon rangefinder. Intensive search were conducted in all the land-use types for squirrels and the following data were recorded: species, number of individuals, location, time, vocalization, signs, anthropogenic activities, for each sighting, perpendicular distance from the transect was measured and recorded to the nearest metre with the aid of a Nikon® rangefinder. Also, we categorised perpendicular distance data into five groups: 0–10 m; 11–20 m; 21–30 m; 31–40 m; and 41–50 m across all land-use types. All surveys were conducted by trained observers, who were familiar with distance estimation using rangefinders. Any squirrels or other animal species and anthropogenic activities were photographed with a digital camera. No surveys were conducted on rainy days since that could introduce bias.

Data analysis

We calculated the species diversity index (Shannon and Weaver, 1949), species richness (Pielou, 1996; Margalef, 1958; Simpson, 1949), and relative abundance of each species to quantify squirrel diversity and distribution in Oban Region. The Shannon-Weiner diversity index provides information about community composition of species. Simpson index is a weighed arithmetic mean of proportional abundance and measures the probability that two individuals randomly selected from a sample belong to the same sample. Species abundance denotes the total number of individuals observed during the study period. Additionally, Pearson correlation Analysis of Variance was used to test and compare the significance of the relationship between species land-use types and species abundance. Significance levels were considered at $p<0.05$ and $p<0.001$ with confidence intervals set at 95%. Data analysis of species diversity was conducted in PAST 3.21 (Hammer et al., 2001). Land-use type was used as a covariate in modelling detection probability for the squirrel species sighted during the survey, and population densities were calculated using DISTANCE 6.0. (Stenkewitz et al., 2010; Galela and Roscom, 2004). To estimate detection probability, half-normal and hazard-rate keys were fitted to pooled data from each habitat and for all study sites combined for data, and to pooled data from all habitats (and all sites) data. The half-normal key with cosine adjustments was selected for the survey, whereas hazard-rate keys with cosine adjustments were selected for all remaining analyses. Model selection was based on the Akaike information criterion (AIC); the model with minimum AIC value were considered suitable for the data collected from field observations.

Results

Species diversity and relative abundance

Altogether, 495 individuals of seven species representing two families of anomalure and squirrels were encountered and recorded in the study area. Among them, Thomas's rope squirrel (*Funisciurus anerythrus*, 116 individuals), and red-legged sun squirrel (*Heliosciurus rufobrachium*, 111 individuals) were the most abundant, followed by forest giant squirrel (*Protoxerus stangeri*, 94 individuals), fire-footed rope squirrel (*Funisciurus pyrropus*, 73 individuals), Beecroft's flying anomalure (*Anomalurus beecrofti*, 51 individuals), striped ground squirrel (*Xerus erythropus*, 31 individuals), and the green bush squirrel (*Paraxerus poensis*, 19 individuals) respectively (Tab. 1). Both the families Anomaluridae and Sciuridae families were recorded. The Sciuridae family is represented by two tribes: the Xerini was represented by *Xerus erythropus*; and the Protoxerini tribe by 4 genus (*Funisciurus*, *Heliosciurus*; *Paraxerus*; *Protoxerus*) and five species: *F. pyrropus*; *P. stangeri*; *P. poensis*; *H. rufobrachium*; and *F. anerythrus*) respectively. Beecroft's flying anomalure (*A. beecrofti*) is the only species from the Anomluridae. In all, a total of five genera were observed and recorded in the Sciuridae.

The land-use types with the most observed number of individual squirrels were the closed-canopy forest (147 individuals, 6 species) and Secondary Forest (144 individuals, 7 species), followed by Abandoned Farmland (117 individuals, 7 species) and Plantation (87 individuals, 6 species). *Funisciurus* spp. (38.18%) were recorded most frequently across all land-use types, followed by *H. rufobrachium* (22.42%) and *P. stangeri* (19%), *A. beecrofti* (10.30%), *X. erythropus* (6.26%) and *P. poensis* (3.83%) (Tab. 1). In the study area, we detected six squir-

Table 2 – Encounter rate and Density of anomalure and squirrel species in Oban Hills Region. L = survey effort; n = number of sightings; N = Abundance; ER = Encounter rate; D (km^{-2}) = Density per km^2; 95% CI = Confidence Interval; AIC = Akaike Information Criteria.

Species	L	n	Sightings (%)	N	ER	D (km^{-2})	95% CI	AIC
Funisciurus pyrropus	243	73	14.75	3524	2.05	6.47	7.940–22.916	344.58
Protoxerus stangeri	243	94	18.99	4928	2.71	8.20	8.284–25.647	500.45
Xerus erythropus	239	31	6.26	1920	1.12	3.70	3.127–16.756	144.33
Anomalurus beecrofti	239	51	10.30	3372	1.95	6.27	9.033–57.543	175.17
Paraxerus poensis	243	19	3.83	1648	0.93	2.91	2.814–27.081	252.11
Heliosciurus rufobrachium	258	111	22.42	5448	1.52	11.13	7.175–17.430	557.00
Funisciurus anerythrus	258	116	23.43	6568	3.12	14.59	9.496–34.207	628.34

Table 3 – Comparison of anomalure and squirrel abundance between habitats under four different land-use types in Oban Hills Region. Significance Level: * = $p<0.05$; ** = $p<0.001$.

Land-use type	*Funisciurus pyrropus*	*Protoxerus stangeri*	*Xerus erythropus*	*Anomalurus beecrofti*	*Paraxerus poensis*	*Heliosciurus rufobrachium*	*Funisciurus anerythrus*
Closed-canopy Forest vs.							
Secondary Forest	2.00	5.77**	18.00*	2.94	0.00	1.18	4.32
Abandoned farmland	0.52	17.51*	0.93	0	0.22	0.24	7.56*
Plantation	8.25*	54.15*	0.00	20.43*	0.00	0.61	0.01
Secondary Forest vs.							
Abandoned farmland	9.13*	8.32**	32.00*	0.00	1.84	0.24	8.31*
Plantation	4.20	45.15*	0.00	17.38*	0.00	1.53	0.04
Abandoned farmland vs.							
Plantation	19.76*	5.96	2.00	9.80*	0.00	0.46	1.75

rel species common to all the land-use types with the exception of *P. poensis*. Our findings reveal that *H. rufobrachium* and *F. anerythrus* were the most frequently recorded with 116 individuals and 111 individuals respectively followed by 94 giant forest squirrel, and 73 fire-footed squirrels. Among the seven species, the green bush squirrel was the least recorded with 19 individuals in only two of the four land-use types. The encounter rates (ER) for the squirrel species ranges from 2.05 km^{-2}, 2.71 km^{-2}, 1.12 km^{-2}, 1.95 km^{-2}, 0.93 km^{-2}, 1.52 km^{-2} and 3.12 km^{-2} respectively. Squirrel population density in the Oban region varies among species with *F. anerythrus* had the highest estimated density of 14.59 km^{-2} followed by red-legged sun squirrel with an estimated population density of 11.13 km^{-2}. In contrast, green bush squirrel and the ground squirrels had the lowest estimated population densities of 2.91 km^{-2} – 3.70 km^{-2} respectively (Tab. 2). The diversity of squirrel species varied between land-use type in the region, abandoned farmland had the highest Shannon-Weiner diversity index of 1.84 while plantation had lowest diversity index with a value of 1.54. *P. stangeri* was significantly abundant across all the land use types, followed by *F. pyrropus* and *A. beechrofti* respectively. *X. erythropus* preferred the Closed-canopy Forest over Secondary Forest ($p<0.001$, r=5.77; $p<0.05$, r=18.00) compared with the rest of the species in the region. To compare and ascertain each squirrel species abundance association with land-use type revealed different significance level ($p<0.05$; $p<0.001$; Tab. 3). Population diversity of squirrels were summarized, the highest diversity index and evenness were recorded in the abandoned farmland and secondary forest while lowest diversity indices were recorded in plantations (Tab. 4).

Effects of land-use on anomalure and squirrel species distribution

Our findings reveal that individual species composition and distribution varies across different land uses with both forest giant and redless rope squirrels were more widely distributed in the closed-canopy forest than the rest of the species whereas *F. anerythrus* was commoner in the secondary forest than all other species (Fig. 2). Our results indicate that detection rate of squirrel species population in the Oban decreases from 1.0–0.2 with increasing perpendicular distance from the transect line. Squirrel species population density differs across the land-use types; the detection function was plotted and superimposed on the histogram showing the detection probability as decreasing further from the transect line to the squirrel detected (Fig. 3). Population density across the four land-use types varies among and within species with red-legged sun squirrels having the highest recorded density of 3.49 km-2 in Abandoned farmland and striped ground squirrel the lowest population density of 0.25 km^{-2} in secondary forest and giant forest squirrels of 0.18 km^{-2} in plantation respectively. Mean Encounter Rate (MER) in Close-canopy Forest is 1.06 km^{-2} and 1.03 km^{-2} for forest giant and redless tree squirrels with 0.12 km^{-2} for flying anomalure in plantation and 0.31 km^{-2} for ground striped squirrel in secondary forest (Tab. 5).

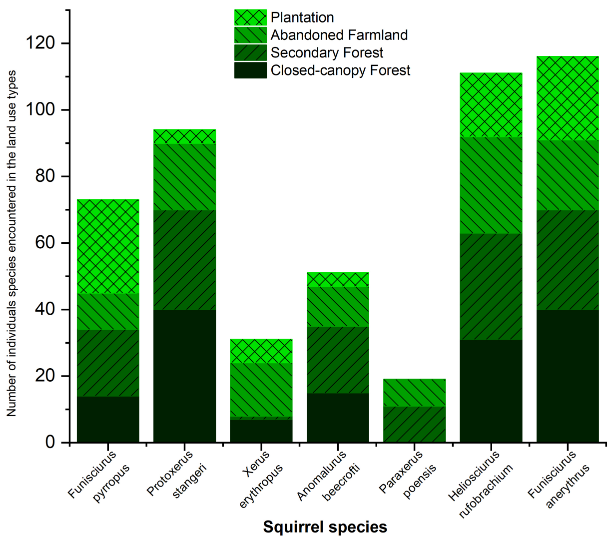

Figure 2 – The number of individuals and species of each anomalure and squirrel sighted across land-use types in Oban Hills Region.

Table 4 – Descriptive measures of diversity indices (Shannon-Weiner diversity index, Simpson diversity index, Fisher-Alpha diversity, species richness, Peilou's evenness) calculated for anomalure and squirrel species in different land-use types in Oban Hills Region.

Land-use type	Shannon index	Simpson index	Fisher Alpha	Species richness	Species Evenness	Margalef Richness index
Closed-canopy Forest	1.64	0.79	1.26	6.00	0.86	1.00
Secondary forest	1.77	0.82	1.54	7.00	0.84	1.20
Abandoned Farmland	1.87	0.83	1.63	7.00	0.92	1.26
Plantation	1.54	0.76	1.46	6.00	0.78	1.12

Table 5 – Distribution, Mean Encounter rate of the anomalure and squirrel species across different land-use types in Oban Hills Region. L = survey effort, n = number of sightings, N = Abundance, ER = Encounter rate, MER = Mean Encounter rate, D (km^{-2}) = Density per km^2, CI = Confidence Interval, AIC = Akaike Information Criteria .

Species	Closed-canopy Forest			Secondary Forest			Abandoned Farmland			Plantation		
	n	MER	D (km^{-2})	n	MER	D (km^{-2})	n	MER	D (km^{-2})	n	MER	D (km^{-2})
Funisciurus pyrropus	14	0.31	0.90	12	0.66	2.26	11	0.54	1.66	28	0.53	1.65
Protoxerus stangeri	40	1.06	3.57	30	0.84	2.39	20	0.75	2.06	2	0.06	0.19
Xerus erythropus	7	0.25	0.65	1	0.03	0.25	16	0.62	2.23	7	0.21	0.80
Anomalurus beecrofti	15	0.50	1.63	20	0.83	2.79	12	0.50	1.38	4	0.12	0.47
Paraxerus poensis	0	-	-	11	0.21	0.78	8	0.20	0.62	0	-	-
Heliosciurus rufobrachium	31	0.34	3.16	32	0.53	3.03	29	0.45	3.49	19	0.18	1.45
Funisciurus anerythrus	40	1.03	1.01	30	0.78	1.70	21	0.87	1.35	25	0.43	0.53

Discussion

A total of 495 individuals from seven species representing two family families, and six genera of squirrels were encountered and recorded in the region. *H. rufobrachium* and *F. anerythrus* have the highest individual species abundance across the landscape whereas *P. poensis* has a relative low species abundance and encounter rate in the land-use types. Similarly, Baelo et al. (2018) recorded a total of seven squirrel species in Kisangani Region in the Democratic Republic of Congo (DRC), and four of the squirrels detected in DRC were also encountered in the current study and all belong to same Protoxerini tribe. The findings supported previous studies conducted in the Southern Nigeria (Adeniran, 2013; Amori and Luiselli, 2011; Angelici and Luiselli, 2005). The rainforest of West and Central Africa, especially the Oban Hills Region in Nigeria, habours the highest squirrel species diversity that includes flying anomalure, ground-dwelling squirrel and arboreal squirrel species, but these species distribution are missing in the literature. The Oban Hills Region, a division of the Cross River National Park, is the largest remaining continuous area of closed-canopy rainforest in Nigeria (Omifolaji et al., 2020; Caldecott et al., 1990, 1999) and represents a protected area in the tropics with high species endemism in the region and a global biodiversity hotspot, which is inhabited by many mammal species including squirrels. However, data on diversity, distribution and richness are scarce and only available in a few studies focused on genetics and morphology of squirrels with on studies related to diversity based on the checklist of inference from hunter observations, historical account, literature, biological diversity assessment report and management plan reports of mammals.

We observed that sciurid (squirrels) occur throughout the landscape of the Oban Hills Region of CRNP, where species diversity was highest at seven species; 90% of these occur in two (Closed Canopy and Secondary Forests) land-use types in the Oban Hills Region. Equatorial countries with significant topographic relief and forest cover have been observed to play an important role in global hotspots of diversity and endemism of tree and flying anomalures as evidenced in Asia, Africa, Central and South America. The high diversity might be related to geographical location and habitat heterogeneity (Koprowski and Nandini, 2008; Koprowski, 2005a,b; Dutta and Devi, 2013). The green bush squirrel species is the only species detected and recorded in only two land-use types (Secondary Forest and Abandoned Farmland), whereas the remaining species were well distributed across the four land-use. *H. rufobrachium* and *F. anerythrus* had the highest number of individuals encountered and recorded respectively. Low abundance of the green squirrel could be attributed to the fact that a small population sample was obtained in only two land-use types in the study area, unlike other species which were well distributed in all the land-use types. The abundance of forest giant and redless squirrel species decreases from primary forest to plantation land-use types which indicates that less undisturbed habitats are the most suitable for these species which suffer less disturbance from anthropogenic activities. The majority of the species' populations are stable and well adapted to secondary and abandoned farmland except for fire-footed squirrels which are associated with plantations with the highest occurrence of 38.4%. Moreover, squirrels are an integral part of many habitats both terrestrial and arboreal, ranging from undisturbed to modified ecosystems and are hence indicators of ecosystem health. Our findings supported previous studies (Khalili et al., 2016; Parker et al., 2014; Jessen et al., 2013; Jimoh et al., 2013; Gwinn et al., 2012; Lurz et al., 2003) in showing that primary forest harbours higher levels of arboreal mammal diversity than neighbouring habitats with a high level of human disturbance, and that primary forest and secondary forest habitats support all the species of squirrels found in the area area (Thorington et al., 2012; Koprowski and Nandini, 2008; Koprowski, 2005a,b; Koprowski et al., 2005; Terborgh, 1992). Although we found more species and higher estimated levels of species richness and occurrence in primary forest and secondary forest than farm fallow and plantation habitats, the overall difference was modest and driven largely by the difference among the species-rich primary forest habitats and the relatively impoverished monocropping habitats (Gurnell et al., 2002; Gurnell, 1987; Viljoen, 1977). Nonetheless, the results are consistent with the general expectation that primary forest support higher vertebrate diversity than other

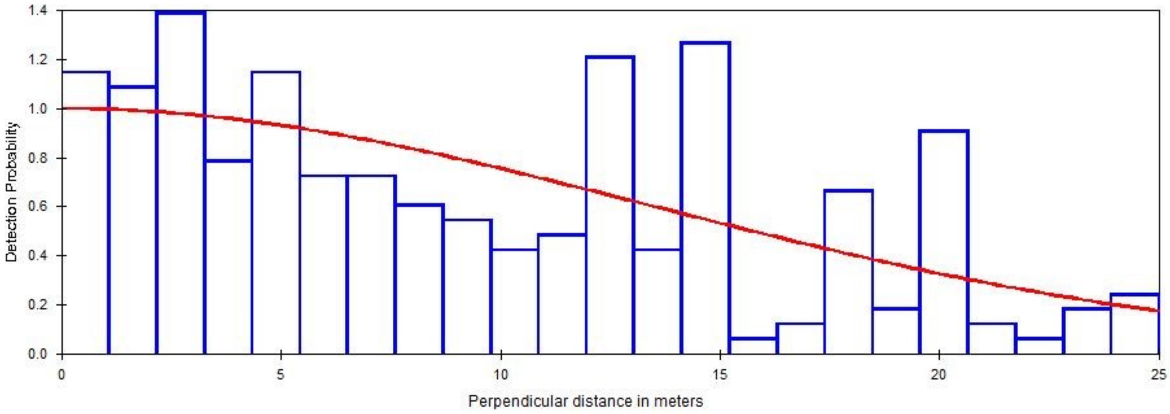

Figure 3 – Histogram showing detection probability of the anomalure and squirrel population in Oban Hills Region as a function of the perpendicular distance from the transect line (interval distance), as generated by Distance 6.0.

habitats. We recorded seven squirrel species which gives an updated account of the squirrel species present in the Oban Region. Only one species, the green bush squirrel, is the most restricted in habitat occurring only in secondary forest and fallow farmland. The distribution of the green bush squirrel increased from secondary forest to farm fallow which is one of the least disturbed land uses in the area. However, forest giant and Thomas rope sun squirrels were more abundant in the primary forest whereas red-legged squirrel were more distributed in plantation forest and farm fallow. It is interesting to highlight that all the species rely on mosaic habitats in the region. This indicates that the majority of the observed squirrel species show a wide range of tolerance to microhabitat variations prevailing across the area (Parker et al., 2014; Weigl, 2007; Koprowski, 2005a; Goheen et al., 2003; Goszczyński et al., 2000). The green bush squirrel has the lowest range of preference among the species encountered and recorded in all land-use types whereas the other six species have a diverse range of habitat preferences. This indicates that the green bush squirrel may well be adaptable to mosaic forests (secondary forest and farm fallow forest) due to being regarded as a pest species in cocoa farmland (Baelo et al., 2018; Kingdon, 2015). *H. rufobrachium*, *F. anerythrus*, and *P. stangeri* have the highest levels occurrence in undisturbed forest with a high tolerance of a degree of habitat modification among the species observed, and their population are widely distributed across all the land-use types. The undisturbed forest has the highest species diversity with individuals of six out of seven species recorded there. This is probably a result of little or no human influences with access to a variety of microhabitats resources which are readily available to in the area (Wells, 2006; Heckenberger et al., 2003). Undisturbed forest harbours more species diversity compared to other habitats type which are under the influence of human activities globally (Koprowski and Nandini, 2008; Koprowski, 2005a). Vertebrate species are often used as a major strategy use in biodiversity planning and conservation, even more, their diversity (Baelo et al., 2016; Oates et al., 2004). We showed that squirrel abundance is closely related to land-use type; moreover, species within the same family and genera have different levels of tolerance to changes in habitats. From the study, all species have different levels of tolerance under different land-use types. In a nutshell, closely related species can have different tolerance levels when the habitat is altered or affected. This, however, can be further studied to know the threshold level of each species within the same genus under the same environmental conditions. The abundance, diversity and population density of squirrels is closely related to the structure and other resources available in the habitat, such as food water and shelter. Alteration of any of these factors directly or indirectly affects squirrels' abundance. Some squirrel species spend time gliding or moving from tree to tree looking for young leaves. For them to be able to carry out these activities, it is presumed that the trees must be at a particular distance away from each other to allow for effective gliding. In contrast, if this habitat has been tampered with as a result of logging and clear-cut activity, it will negatively affect the species which will be forced to migrate to a more suitable area. In addition, some squirrels prefer old-growth forest where there is diverse food, trees with hollows and dead leaves which are key factors influencing populations with a number of species favouring dense vegetation (Minor and Koprowski, 2015; Parker et al., 2014; Colombaroli et al., 2013; Dodd et al., 2006,?; Koprowski, 2005b; Goheen et al., 2003; Gurnell et al., 2002; Gurnell, 1987). An alteration to such a forest will inevitably affect the distribution and population density of the species. Habitat loss is the major threat to species of squirrels (Khalili et al., 2016; Koprowski, 2005b; Koprowski et al., 2005). This study emphasizes the importance of land-use impact on species conservation. Protection and maintenance of squirrel species diversity requires not only conservation of their primary habitat, but also the adjacent landscape, which often consist of mosaic forests. Thus, protected forests and their surrounding environments are a critical for the conservation of squirrels and other vertebrates, and local stakeholders should be encouraged to protect such resources.

Conclusions

The Oban tropical forest represents a biodiversity conservation hotspot for squirrel diversity in the Western and Central African region of sub-Saharan Africa. In common with many areas, the diversity of squirrels is poorly described. Seven species of squirrels belonging to two families, Anomaluridae and Sciuridae, were recorded as well distributed across the forest landscape in the region. The present study gives an updated account of the squirrel species present in the Oban Region. The diversity of squirrel species varied from one land-use type to another in the area. The highest diversity index and evenness were recorded in the farm fallow. Only one species, the green bush squirrel, is the most restricted in habitat occurring just in secondary and farm fallow. Species composition, abundance, diversity and population density of squirrels is closely related to structure and other resources available in habitats. We recommend further studies on the conservation ecology of squirrels and population monitoring in the region especially those occurring in the Okwango, Mbe and Afi mountain forests and adjacent Korup National Park and Takamamda forest in Cameroon is strongly encouraged.

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