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SPECIES COMPOSITION AND RICHNESS OF TERRESTRIAL MOLLUSKS INHABITING LIMESTONE HILL AND LOWLAND FOREST DECLINE MACRO ZONE IN SUB-SAHARAN AFRICA

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Abstract

Ecosystem characteristics affect the composition, richness, diversity of species, and their ability to recolonize disturbed habitats. Here in Nigeria, two localities Mfamosing limestone hills and Odukpani lowland forest with different exposures to human activities were sampled in 2017. The study was aimed at creating inventories, comparing and evaluating the diversity of mollusk species in leaf litters and topsoil sourced from eleven 20x20m plots per locality. Results revealed a total of 593 individuals belonging to 26 species in 18 genera and ten families, and 282 individuals belonging to 18 species from 10 genera in 5 families at Mfamosing and Odukpani respectively. The mollusk composition at Mfamosing was significantly different from those at Odukpani, although they had eleven common species. In further assessing these findings against similar assessments conducted no less than a decade ago in the neighboring Oban hill and Odukpani, previously abundant species were now numerically depauperate species, while some were completely absent. While the key drivers responsible for their population decline remain unknown, how changes in habitats – due to human use over time- impinge on the mollusk species is worthy of further investigation.

***Keywords**: Biodiversity; Conservation; Endemic species; West Africa; Microhabitats*

Introduction

Natural resources are utilized by man in a population-dependent manner and with the increasing rates of human activities (for example, in urbanization, deforestation, hunting, and bush burning), knowing how species respond to habitat changes is of conservation value. Unfortunately, in Africa, little is known about the invertebrate's fauna [1], albeit the most abundant animals.

Meanwhile, incursions and fragmentation of the Afrotropical rainforests into discontinuous vegetation, may drive several species down an extinction vortex, both locally and globally especially for endemic species [2-4]. Globally, the tropical rainforests are famous for their species richness, and in Nigeria, some aspects of the forests are under threat for example, from road construction [4] and limestone exploitation [5]. The impacts thereof on topsoil, vegetation cover, and vertebrate fauna are known [5], but the leaf-litter and soil-dwelling invertebrates, like snails, are largely unaccounted for.

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Nigeria's rainforests are parts of a designated biodiversity hotspot – the Guinean Forests of West Africa - aimed at protecting the region's biodiversity and knowing the species' distributions and their preferred habitats will be vital for their sustainable conservation. Meanwhile, areas renowned for species endemism are bedeviled with a quest to construct a road that bisects the protected areas, which include but are not limited to Odukpani in Cross River state [4]. Odukpani and Mfamosing, inter alia, are notable for their rich biodiversity [6], but how much these areas have changed due to anthropogenic factors (e.g., urbanization, agriculture) is unknown.

Land mollusks are sensitive to moisture differences, and their low dispersing abilities and shell's persistence after death make them useful tools in assessing environmental health within the terrestrial ecosystem. That several mollusks are under the threats of extinction with many unaccounted for [1, 7] and the pressure to use hitherto unused habitats [4], informed the need to investigate the mollusk species in Cross River.

Several studies on terrestrial mollusks in parts of Nigeria by Oke and coworkers have led to the discoveries of novel species, e.g., *Ptychotrema shagamuense* [8], and in Oke and Alohan's assessments of Gelegele Forest Reserve additional novel species, viz.: *Ptychotrema gelegelei* (Gastropoda: Streptaxidae), *P. okei* [9] and *Ennea serrate* [10], were discovered. With these discoveries, being pointers to how poorly studied our forests are, despite being hotspots for wildlife, we herein assess the species compositions and diversities of terrestrial mollusks at Mfamosing hill and Odukpani lowland forest in the country.

Experimental part

Study Area

Two localities within the same rainforest region were selected, but both areas differed in their proximity to human settlements (Fig. 1).

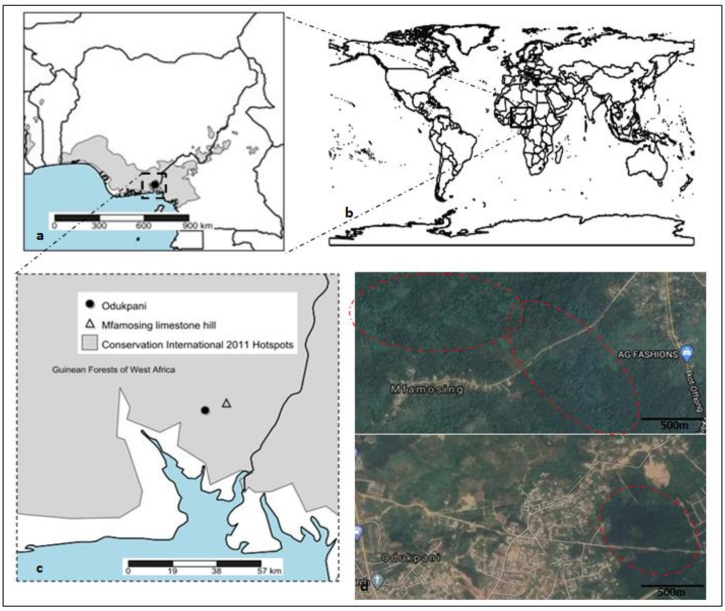

Fig. 1. The locations of the study sites, Mfamosing and Odukpani, where the terrestrial mollusks were sampled in Cross River State, Nigeria as depicted in (a) the gray area indicating the biodiversity hotspot (Guinea Forests of West Africa) in Nigeria is situated in (b) Africa; (c) an enlarged view of the sites, and (d) the vegetation cover showing the extent of urbanization at Mfamosing (at the top) and Odukpani (at the bottom)

The study localities were Mfamosing and Odukpani. While the selected sites at the former were mainly around a limestone hill that is remotely distant from human settlement, the sites selected at the latter were within a lowland rainforest with heightened human access alongside a discontinuous vegetation cover. Mfamosing (limestone) hill lies within latitudes 5° 4' 37.6" N and 5° 4' 58.0" N and longitude 8° 30' 9" E and 8° 31' 05.7" E, average 36m and its hill is dominated by sedimentary rocks covered with layers of shale units of the Ekenkpon formation characterized by minor intercalation of marks and calcareous mudstone. Odukpani is a heterogeneous primary forest situated at latitude 5˚ 07′ 0″ N and longitude 8˚ 24′ 0″ E. Both localities are situated within humid tropical areas with well-marked rainy and dry seasons. While the rainy season starts in March and ends in October, the dry season starts in November and ends in February.

Sampling Method

Samples were collected from forests at Mfamosing and Odukpani during the rainy season (between May and September 2017) by a combination of direct search for 2 hrs and leaf-litter sieving techniques as described by Tattersfield [11]. Eleven plots of 20x20m were selected in each locality, albeit bias towards microhabitats where mollusks are more likely to be found like deep litter beds, rocks, bark, and spaces between buttress roots of large trees and dead-decayed logs. Each main plot was further divided into subplots from which ten randomly selected 1.0x1.0m were marked using pegs and ropes. Each plot was sampled by two searchers for an hour (i.e., two scientific man-hours). The sampling involved the collection of leaf litters and topsoil within the plot. Both leaf litter samples and topsoil were sieved *in situ* with a 0.75mm mesh width and the content was transferred into polythene bags for transportation and onward assessments in the laboratory. The sieved samples were dried before searching for mollusks in them. All snails, slugs, and shell fragments encountered in the collections were preserved in 70% ethanol. The specimens obtained were subjected to further anatomical studies. To avoid overestimation of species richness, juvenile and or broken shells were excluded from the analysis, thus the only underestimation was likely.

Identification of specimens

Most of the observed mollusks were identified by the co-author: an expert malacologist in the department of Animal and Environmental Biology, Professor C.O. Oke (of blessed memories) at the University of Benin; alongside using reference materials (i.e., voucher specimens of mollusks) properly curated and deposited at the Egborge Museum of Natural History as situated within the same department.

Statistical analysis

Data obtained were analyzed using PAST™ [12] to compute the diversity indices such as alpha diversity, species richness (S), and Whittaker's index (I), which represents the total number of species recorded (S) divide by the mean number of species per site (α), as a measure of diversity difference between sites [13]. True diversity was computed using the Chao 2 and second-order Jackknife estimators [14, 15]. Sample-based rarefaction curves were used to produce a smooth curve that estimates the number of species that would be observed for any smaller number of samples. Hierarchical Clustering based on the Bray-Curtis similarity index was used to construct a dendrogram that grouped the species compositions according to their similarity among plots. Such cluster analysis arranged samples into groups (clusters), such that samples within the same cluster are more similar to each other than to those from different clusters [16]. A one-way analysis of similarity, ANOSIM [17], was used to test for statistical differences in species composition between locality, and Similarity Percentage (SIMPER: [17]) based on the Bray-Curtis similarity index was used to assess the taxa responsible for the most observed difference between the two groups.

Results and discussion

Sampling the limestone hill at Mfamosing yielded 593 individuals representing 26 species, 18 genera, and 10 families of terrestrial mollusks. The individuals of a species recovered per plot varied from 34 to 112 (mean: 53.91±21.49 sd), while species per plot varied from 11 to 22 species (mean: 16.36±3.12). The limestone hill (at Mfamosing) was dominated by 7 species of Streptaxidae which constituted 27% of all species encountered at Mfamosing, followed by Urocyclidae with 5 species (i.e., 19%) but the latter had a higher abundance than the former (Table 1). Of the ten families encountered at the limestone hill, six (namely Ailliyidae, Ampilaridae, Cyclophoridae, Euconulidae, Succineidae, and Thiaridae) only had a single species; with all, but *Quickia* species, being seemingly localized to the limestone hills (Table 1: the shaded areas).

Table 1. Species composition of terrestrial mollusks surveyed from eleven plots situated within the limestone hills of Mfamsoing, Cross River State, Nigeria

	Plots											
Taxon	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**Total**
Archatinidae (129)												
Archachatina marginata	10	7	3	9	3	8	2	1	5	3	1	**52**
Lignus auaripigmentum	3	2	1	4	2	1	-	1	4	7	3	**28**
Limicolaria sp.	12	10	1	1	5	2	1	-	1	1	5	**39**
Pseudachatina sp.	-	-	1	1	2	-	-	-	3	3	-	**10**
Ailliyidae (6)												
Aillya camerunensis	1	-	3	1	-	-	-	-	-	-	1	**6**
Ampularidae (108)												
Lamistes sp.	8	16	16	10	7	5	5	10	3	20	8	**108**
Cyclophoridae (16)												
Cyclophorus sp.	4	1	5	-	1	-	-	3	-	2	-	**16**
Euconulidae (17)												
Afropunctium seminium	4	3	-	1	2	-	-	-	-	6	1	**17**
Streptaxidae (113)												
Gulella gemma	2	-	-	-	-	-	1	-	1	2	1	**7**
G. poenses	1	2	4	5	6	1	8	3	2	17	3	**52**
G. germaini	4	-	-	-	-	-	2	2	3	1	-	**12**
Ptychotrema collumenlaris	-	-	2	3	-	1	3	1	2	3	-	**15**
P. anceyi	2	3	1	1	-	-	2	1	-	1	1	**12**
P. martensi	2	-	-	1	2	-	1	-	-	2	2	**10**
Streptostile sp.	1	1	-	-	-	-	-	2	1	-	-	**5**
Subulinidae (46)												
Curvella feai	1	4	1	-	-	-	3	-	-	4	-	**13**
Pseudoglessula sjostedi	2	2	1	-	-	-	-	1	-	1	1	**8**
Pseudopeas sp.	2	-	1	-	-	-	-	-	-	1	-	**4**
Subulina sp.	2	2	1	1	2	2	1	1	1	7	1	**21**
Urocyclidae (153)												
Trochozonites calabaricus	4	1	2	5	7	6	5	10	3	7	9	**59**
T. suturalis	-	1	2	2	6	3	1	6	5	4	3	**33**
T. bifilaris	-	1	3	2	3	1	-	-	5	10	5	**30**
T. lystrix	-	2	-	3	4	4	2	-	-	9	1	**25**
T. theeli	2	-	1	-	-	-	1	1	-	-	1	**6**
Succineidae (2)												
Quickia sp.	-	1	1	-	-	-	-	-	-	-	-	**2**
Thiaridae (3)												
Potadoma sp.	-	-	1	-	-	-	-	1	-	1	-	**3**
Total no. of individuals	67	59	51	50	52	34	38	44	39	112	47	**593**
Total no. of species	19	17	20	16	14	11	15	15	14	22	17	

N.B: Rows that were highlighted with gray symbolize mollusk species that with only present at the site compared to those at Odukpani

In contrast, the Odukpani lowland forest had a much lower individual count of 282 representing 18 species from 10 genera in 5 families (Table 2). The individuals encountered per plot ranged from 12 to 37 (25.64±6.77), and the species per plot ranged from five to 16 (10.36±3.44). The dominant family of mollusk at Odukpanu was also Streptaxidae with 8 species (i.e., 44% of all species) as contributed by 61 individuals. Of the five families observed at Odukpani, some members of the Streptaxidae and Subulinidae were localized (Table 2; the shaded areas).

Table 2. Species composition of terrestrial mollusks surveyed from eleven plots at Odukpani lowland forest, Nigeria

	Plots survey at Odukpani											
Taxa	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**Total**
Archatinidae (87)												
Archachatina marginata	7	8	4	3	4	3	3	-	-	5	7	**44**
Ligus auaripigmentum	5	3	1	7	3	2	2	1	4	1	2	**31**
Pseudachatina sp.	1	1	3	2	-	-	-	1	2	1	1	**12**
Streptaxidae (61)												
Gulella gemma	-	1	1	1	-	-	2	-	-	1	3	**9**
G. obani	-	1	1	1	1	1	-	-	-	-	1	**6**
G. opoboensis	-	1	2	-	1	1	-	-	-	2	2	**9**
G. jonkindi	-	1	-	-	1	-	2	-	-	-	2	**6**
G. germaini	-	1	1	-	1	1	2	-	-	-	3	**9**
Ptychotrema sp.	-	2	-	-	-	1	-	-	-	2	1	**6**
P. anceyi	-	1	2	1	1	1	1	1	-	-	2	**10**
P. martensi	-	1	1	2	-	-	-	1	-	-	1	**6**
Subulinidae (11)												
Curvella feai	-	2	-	-	-	-	-	-	-	-	-	**2**
Subulina striatella	1	-	-	2	1	-	1	1	-	-	1	**7**
Pseudopeas sp.	-	-	-	-	-	-	1	-	-	-	1	**2**
Urocyclidae (119)												
Trochozonites calabaricus	4	6	8	5	9	5	2	3	6	9	7	**64**
T. suturalis	1	1	4	2	4	8	-	4	2	2	-	**28**
T. lystrix	3	3	1		-	4	2	-	10	2	2	**27**
Succineidae (4)												
Quickia sp.	-	1	-	-	-	-	1	-	-	1	1	**4**
Total number of individuals	22	34	29	26	26	27	19	12	24	26	37	**282**
Total number of species	7	16	12	10	10	10	11	7	5	10	16	

NB: Rows that were highlighted with gray symbolize mollusk species that with only present at the site compared to those at Mfamosing

Our results showed that the terrestrial mollusks within the same ecoregion in Nigeria are sensitive to habitat differences between limestone hills and forested lowlands. Herein reported are the first inventories of terrestrial mollusks at Mfamosing limestone hill, and the first monitoring of previously reported mollusk fauna at Odukpani lowland forest. The community of terrestrial snails inhabiting the limestone hills at Mfamosing is more diverse and numerically abundant than those at the Odukpani lowland forest. The low species diversity at Odukpani may be due to habitat fragmentation, reduce forest cover, and increased perturbation arising from anthropogenic activities in neighboring settlements. Also, calcium availability at Mfamosing and low anthropogenic pressure on account of its hilly terrain may explain the higher species diversity albeit with low heterogeneity as the Whittaker index was less than one. The snail community at Mfamosing was dominated by Archatinidae (total individuals) and by Streptaxidae (total species), while Odukpani was dominated by Urocyclidae (total individuals) and Streptaxidae (total species).

The relative abundances of the terrestrial mollusks from both localities (Fig. 2) showed that few species were relatively abundant and rare while most of the mollusks were moderately abundant. Four species had at least 50 individuals at Mfamosing representing 46% of the total number of individuals (593), and in their order of dominance, these were *Lamistes* species (18%), *Trochozonites calabaricus* (10%), *Gullela poenses* (9%), and *Archachatina marginata* (9%). At Odukpani, only a single species, *T. calabaricus* had 50 individuals (i.e., 23% of 282 individuals). The images of the species' shells encountered at both Mfamosing limestone hill and Odukpani lowland forest were displayed in figures 2A-2R, 2S-2Z, and 2A1-R1 with relevant captions.

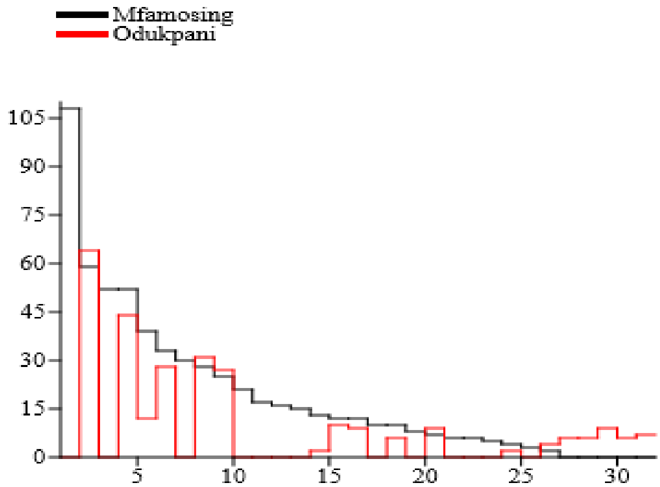

Fig. 2. Relative abundance of mollusks at both the limestone hill at Mfamosing and the lowland forests at Odukpani, Cross Rivers, Nigeria

Species encountered at the former were sorted in descending order, while those encountered in the latter were plotted following the already established order (Fig. 3). The first bar then represents the most abundant species at Mfamosing and in that order, the species are (1) *Lamistes sp*., (2) *Trochozonites calabaricus* (3) *Gulella poenses*, (4) *Archachatina marginata*, (5) *Pseudachatina sp*., (6) *Trochozonites suturalis* (7) *Trochozonites bifilaris* (8) *Lignus auaripigmentum*, (9) *Trochozonites lystrix*, (10) *Subulina sp*., (11) *Afropunctium seminium* (12) *Cyclophorus sp*., (13) *Ptychotrema collumenlaris* (14) *Curvella feai* (15) *Ptychotrema anceyi* (16) *Gulella germaini* (17) *Limicolaria sp*., (18) *Ptychotrema martensi* (19) *Pseudoglessula sjostedi* (20) *Gulella gemma* (21) *Trochozonites theeli*, (22) *Aillya camerunensis* (23), *Streptostile sp*., (24) *Pseudopeas sp*., (25) *Potadoma* sp., (26) *Quickia sp*., (27) *Gulella jonkindi* (28) *Gulella obani*, (29) *Gulella opoboensis*, (30) *Ptychotrema sp*., and (31) *Subulina striatella*.

Certain species viz.: *C. feai*, *Pseudopeas spp*. and *Quickia spp*. occurred as doubletons and as such could be considered rare species. While *C. feai* and *Pseudopeas spp*. were rare at Odukpani, *C. feai* was missing and the latter was twice as abundant at Mfamosing. On the other hand, *Quickia sp*. was the only doubleton at Mfamosing. Both localities had no singletons. The presence of singletons may have been interpreted by some as being indicative of the possibility of encountering more species if samplings were increased *Oke et al.* [6], but this may not always be true. Reasons being that the presence of rare species may well be pointers that validate concerns that some species are gradually being lost to several anthropogenic pressures. Suggesting that not having rare species meant that all resident mollusk species had been surveyed is simplistic as fewer species were recorded at Odukpani now than they were a decade ago [6].

Fig. 3. The main molluscs at both the limestone hill at Mfamosing and the lowland forests at Odukpani, Cross Rivers, Nigeria: (A) *Aillya camerunensis*; height, h = 4.5mm; (B) *Lignus* sp. h = 46mm; (C) *Ptychotrema collumenlaris* h = 9.8mm; (D) *Cyclophorus* sp. h = 5.5mm; (E-G) *Subulina* sp. h = 23mm; (H-N) *Ptychotrema collumenlaris* h = 15.8mm; (O-R) *Curvella* sp. h = 5.6mm. **A1-R1.** *Streptostele* sp1 h = 21.5mm; (V-Y) *Limicolaria* sp. h = 51mm; (Z) *Gulella* sp. h = 15.4mm; (A_1) *Gulella jonkindi* h = 4.08mm; (B_1-C_1) *Gulella gemma* h = 4mm; (D_1-E_1) *Gulella opoboensis*, h = 4.7mm; (F_1-G_1) *Gulella obani* h = 3.5mm; (H_1-I_1) *Quickia* sp. H = 4mm; (J_1) *Trochozonites lystrix*, h = 6.1mm; (K_1-M_1) *Archachatina marginata* h = 155mm; (N_1) *Pseudopeas* sp. h = 11.3mm; (O_1-P_1) *Thapsia* sp., h = 8.5mm; (Q_1-R_1) *Trochozonites* sp. h = 6.1mm.

Thus, the species missing herein may have been negatively affected by changes in microclimatic differences in habitats and could have been driven into local extinction. While the non-parametric estimator Chao2 is notably suitable in predicting species richness for small samples [6], and it yielded 26 species (at Mfamosing) and 18 species (at Odukpani), which coincided with the actual number of species encountered; nonetheless, it cannot tell which species were lost or added over time. That a past assessment of Odukpani, albeit in a cave, yielded 52 mollusk species [6] and Oban hills yielded 53 species [9], suggest that the Odukpani lowland forest could have been fantastically depauperated given its low species richness here. The same comparison is tenable when the species richness at Mfamosing is related to Odukpani.

Given the less impact of anthropogenic pressures around Mfamosing relative to Odukpani as seen in the vegetation cover depicted in the map, chances are that more terrestrial snails will be present there as seen here. However, the absence of certain species at both Mfamosing and Odukpani, as opposed to the species composition at Oban hill [9] situated within the same ecoregion, suggests that the abundances of the terrestrial mollusks are on a decline and that some mollusk species are more resilient to habitat changes than others.

Differences in habitats (e.g., leaf-litter density, tree cover, moisture content, etc.) and anthropogenic factors (e.g., mining, and deforestation) are notable drivers of snail distribution, abundance, and recolonization potentials. While identifying the actual drivers responsible for a decline in resident mollusks is unknown, juxtaposing our findings with [6] survey, one could hypothesize that terrestrial mollusks are not equally resilient to anthropogenic pressures, as the rare species (singletons and doubletons) are more likely to rescind numerically than the abundant species. For example, *Limicolaria flammea* (Achatinidae) occurred as a doubleton at Odukpani [6] and *L. aurora* (only occurred in one plot) but were missed in this current study.

In another instance in the same study, Streptaxid singletons (e.g., *Gonaxis camerunensis*, *Gulella buccholtzi*, and *G. conospira*) and doubletons (*Edentulina liberiana*) that were previously encountered [6] remained unseen ten years later (current study). Meanwhile, a streptaxid species like *Gulella gemma* that was abundantly present then, had become numerically depauperated here. The absence of certain snail species at Odukpani is not likely unconnected to human interferences arising from its proximity to settlers who may exploit the forest of its resources.

Nonetheless, the presence of certain species, e.g., *Quickia* species here as opposed to the previous study, adds credence to [6] predictions of encountering additional species in subsequent samplings; alas, even previously abundant species have also declined here and in some cases are now absent.

Generally, the areas that are underlain with limestone harbor a diverse community of snails [6, 19]. Albeit largely driven by available calcium –the predominant mineral in limestone- other abiotic (microclimatic variability) and biotic factors do influence species richness [20]. While limestone outcrops may continually release calcium to resident organisms through weathering, native flora can remobilize subterranean calcium through their roots to plant organs, and from their leaves through abscission to the forest floor, where the resident snails utilize the dead leaves and their inherent calcium for dietary purposes [21]. Such processes sustain nutrient recyclability, and the advantage of such plexus of interactions involving terrestrial mollusks is sufficient a reason for conservation to be prioritized anywhere in the world.

A decline in flora composition (e.g., through deforestation) can reduce the density of leaf litters and increase the desiccation rate in the forest floor. While a reduction of leaf litter may alter calcium dynamics and its availability to micro snails, an increase in desiccation will further limit snail recolonization potentials after disturbance; thus, cascading into a multiplicity of negative effects on the terrestrial snails especially the fewer ones [3, 20].

The rarefaction curves of mollusk species encountered at both localities have closely reached their asymptotes at the end of sampling yielding 26 and 18 species with low probabilities of yielding additional species (Fig. 4). Non-parametric species estimates, Chao2, and second-order Jackknife gave the values of 26 each at Mfamosing, and values of 18 and 18.48 at Odukpani respectively, showing a high level of inventory completeness at both localities. While Mfamosing had relatively low species dominance (0.08), Odukpani had (0.12). Shannon_H showed a higher species diversity index at Mfamosing (2.85) than at Odukpani (2.46).

The sample rarefaction curves (Fig. 4), suggest that the outcome of the survey sufficiently represented the resident terrestrial mollusks at both sites as the curves approached their respective asymptotes before sampling ended. Thus, they demonstrate the adequacy of the sampling regime as the chances of getting a new species in subsequent samples are low. In furtherance of this, the values for inventory completeness obtained from the non-parametric richness estimators Chao 2 and Jackknife 2 alluded to the observed trends [18].

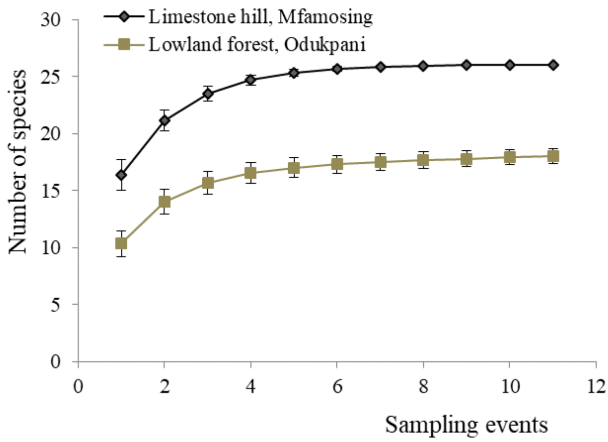

Fig. 4. Rarefaction curves of land mollusks recovered from the limestone hills at Mfamosing and the lowland forest at Odukpani

Hierarchical clustering (dendrogram) presented figures 5 and 6, based on the Bray-Curtis index showed that the mollusk compositions among the eleven plots ranged from 45-75% at Mfamosing and 40-75% at Odukpani.

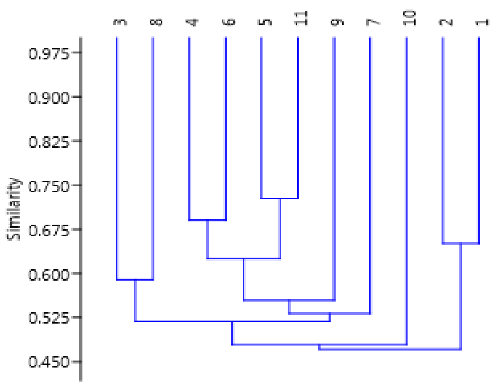

Fig. 5. Dendrogram of similarity based on Bray-Curtis among plots in the limestone hill at Mfamosing

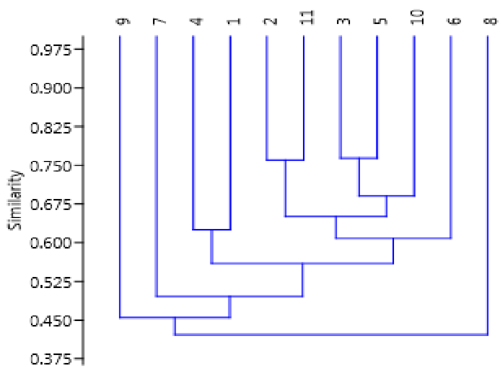

Fig. 6. Dendrogram of similarity based on Bray-Curtis among plots in the lowland forests of Odukpani

The compositions of mollusks between Mfamosing and Odukpani were significantly different (ANOSIM: $R = 0.93$, $p < 0.001$). The top three species with the highest contribution to the dissimilarities between both localities were *Lamistes* species (18%), *G. poenses* (8%), and *A. marginata* (7%). Student T-test showed that the Shannon_H index of both the limestone hill (2.85±0.00) and lowland forest (2.46±0.00) were significantly different ($t = 6.17$, $p < 0.001$) likewise Simpson Index D for the limestone hill (0.08±0.00) and the lowland forest (0.12±0.00) ($t = - 3.7$, $p < 0.001$). Beta diversity (Whittaker index) showed a low level of differentiation among plots with Mfamosing being 0.63 and Odukpani being 0.74.

In comparison to the previous account at Odukpani [6], all but *Gulellla opoboensis*, *G. jonkindi*, *G. germaini*, *Ptychotrema* sp. and *Quickia sp*. were new additions in this current study. Meanwhile, some previously abundant mollusk species, e.g., *G. reesi* and *G. fernandensis* [6], were missing here and a similar pattern can be seen relative to Mfamosing and Odukpani in this current study. These findings here add credence to Oke's concerns in the literature that some species may be lost even before they are known.

Conclusions

Given that the faunal integrity of the terrestrial snails at Mfamosing and Odukpani have been compromised as evident in the numerically depauperate species, to halt this trend, the findings here demand urgent attention to conserve what is left of the two sites and other such forested areas within the Guinea forests of West Africa as failure to act will culminate in the local extinction of several micro snail's resident in our forests. To do so, it would be apt to identify the key drivers responsible for their decline and disappearance to ensure the preservation of endemic species and other indigenous species that rely on forest resources for survival.

It is recommended here that there is the need of stakeholders (i.e., the relevant government agencies, researchers, indigenous people, and non-governmental agencies) redress this trend and should be prioritized. Conclusively, if the habitats are protected to conserve the terrestrial mollusks, other life forms would equally be conserved.

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References

[1] C. Lydeard, R.H. Cowie, W.F. Ponder, *The global decline of nonmarine mollusks*, **Bioscience**, **54**, 2004, pp. 321–330.

[2] L. Unah, *In Nigeria, a highway threatens community and conservation interests*. Available at https://news.mongabay.com/2019/07/in-nigeria-a-highway-threatens-community-and-conservation-interests/. [Accessed on 17 March 2021].

[3] N. M. Haddad, L. A. Brudvig, J. Clobert, K.F. Davies, A. Gonzalez, R.D. Holt, T.E. Lovejoy, J.O. Sexton, M.P. Austin, C.D. Collins, W.M. Cook, E.I. Damschen, R.M. Ewers, B.L. Foster, C.N. Jenkins, A.J. King, W.F. Laurance, D.J. Levey, C.R. Margules,

B.A. Melbourne, A.O. Nicholls, J.L. Orrock, D.X. Song, J.R. Townshend, *Habitat fragmentation and its lasting impact on Earth's ecosystems*, **Science Advances**, **1**(2), 2015, Article Number: e1500052, DOI: 10.1126/sciadv.1500052.

[4] M.L. Mahmoud, S. Sloan, M.J. Campbell, M. Alamgir, I. Imong, O. Odigha, H.M. Chapman, A. Dunn, W.F. Laurance, *Alternative routes for a proposed Nigerian superhighway to limit damage to rare ecosystems and wildlife*, **Tropical Conservation Science, 10**, 2017, DOI: 10.1177/1940082917709274.

[5] P.O. Ilalokhoin, A.J. Otaru, J.O. Odigure, A.S. Abdulkareem, J.O. Okafor, *Environmental impact assessment of a proposed cement plant in southwestern Nigeria*, **Journal of Environmental Science, Toxicology and Food Technology**, **3**, 2003, pp. 83-99.

[6] O.C. Oke, F.I. Alohan, W. Ahulimen, *Land snail diversity in a threatened limestone formation in Odukpani, Cross River State, Nigeria,* **Global Journal of Applied and Science, 13**, 2007, pp. 487-492.

[7] C. Régnier B. Fontaine, P. Bouchet, *Not knowing, not recording, not listing: numerous unnoticed mollusk extinctions,* **Conservation Biology, 23**, 2009, pp. 1214-1221.

[8] O.C. Oke, W.O. Odiete, *New species of land molluscs from south western Nigeria*. I. A new species attributed to *Ptychotrema* (Mollusca, Gastropoda), **Journal of African Zoology**, **110,** 1996, pp. 61–64.

[9] O.C. Oke, F.I. Alohan, *Land snail diversity in a patch of rainforest in Cross River National Park: high species richness, abundance and heterogeneity*, **Nigerian Journal of Applied Science, 22**, 2004, pp. 166-173.

[10] A.J. de Winter, W. de Gier, *A new Nigerian hunter snail species related to Ennea serrata d'Ailly, 1896 (Gastropoda, Pulmonata, Streptaxidae) with notes on the West African species attributed to Parennea Pilsbry,* **ZooKeys, 840**, 2019, pp. 21–34.

[11] P. Tattersfield, *Local patterns of land snail diversity in a Kenyan rain forest*, **Malacologia, 38**, 1996, pp. 161–180.

[12] O. Hammer, D.A.T. Harper, P.D. Ryan, *PAST: Paleontological Statistics Software package for education and data analysi,* **Palaeontologia Electronica, 4**, 2001, pp. 1–9.

[13] M. Schilthuizen, H.A. Rutjes, *Land snail diversity in a square kilometre of tropical rainforest in Sabah, Malaysian Borneo,* **Journal of Molluscan Studies, 67**, 2001, pp. 417–423.

[14] J.A. Coddington, L.H. Young, F.A. Coyle, *Estimating spider species richness in a southern Appalachian cove hardwood forest,* **Journal of Arachnology, 24**, 1996, pp. 111–128.

[15] J. Soberon, R. Jimenez, J. Golubev, G. Koleff, *Assessing completeness of biodiversity databases at different spatial scales*, **Ecography**, **30**, 2007, pp. 152-160.

[16] H.G. Gauch, R.H. Whittaker, *Hierarchical classification of community data,* **Journal of Ecology, 69**, 1981, pp. 537–557.

[17] K.R. Clarke, *Non-parametric multivariate analyses of change in community structure*, **Australian Journal of Ecology, 18**, 1993, pp. 117–143.

[18] R.K. Colwell, J.A. Coddington, *Estimating terrestrial biodiversity through extrapolation*, **Philosophical Transactions of the Royal Society (Series B), 345**, 1994, pp. 101-118.

[19] M. Schiltuizen, H. Chai, T.E. Kimsin, J.J. Vermuelen, *Abundance and diversity of land snails (Mollusca: Gastropoda) on limestone hills in Borneo,* **The Raffles Bulletin of Zoology, 51**, 2003, pp. 35-42.

[20] D.D. Douglas, D.R. Brown, N. Pederson, *Land snail diversity can reflect degrees of anthropogenic disturbance*, **Ecosphere, 4**, 2013, p. 28.

[21] T.H. Nation, *The influence of flowering dogwood (Cornus florida) on land snail diversity in a southern mixed hardwood forest,* **American Midland Naturalist, 157**, 2007, pp. 137–148.

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