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RESEARCH PAPER

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Diversity, spatial and seasonal distribution of gastropod molluscs in Taï national park (Côte d'Ivoire): Influence of environmental factors

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ABSTRACT

Terrestrial gastropod molluscs play a fundamental ecological role in tropical forest ecosystems, notably through litter decomposition, improvement of soil structure, and serve as bioindicators of environmental disturbances. Despite this importance, Taï National Park, a biodiversity hotspot in West Africa, hosts an under-documented invertebrate fauna. In this context, the present study analyzes the diversity as well as the spatial and seasonal distribution of terrestrial gastropod molluscs in Taï National Park (TNP). Through a systematic inventory combining standardized sampling areas of 20,000 m² (200 m long by 100 m wide) and litter sieving, covering different types of forest habitats, carried out from March 2021 to March 2023. A total of 13 species belonging to 7 families were recorded, dominated by Achatinidae (41.18%), Subulinidae (14.86%), Ariophantidae (11.27%), and Uniomidae (10.05%). Species richness is higher in the open understory mixed forest habitat (9 species) and lower in the closed understory mixed forest habitat (5 species). In the FMSO habitat, the Achatinidae family dominates with a relative abundance of 50.47%, with the species *Achatina achatina* being preponderant (25.07%). In the FSHD environment, Achatinidae remains the majority family (42.9%), with a notable abundance of *Euconulidae* sp. Conversely, in the FMSF habitat, the Subulinidae family strongly predominates (63.77%), with *Striosubulina striatella* as the most represented species (41.23%). Temporal abundance shows an abundance of gastropod molluscs in the rainy season with a reduction in the dry season. Overall, these results highlight the crucial importance of humid micro-habitats for the preservation of terrestrial mollusc communities and emphasize their sensitivity to climatic fluctuations. We recommend integrating terrestrial molluscs into ecological monitoring programs and management strategies for Taï National Park.

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INTRODUCTION

Taï National Park (TNP), located in southwestern Côte d'Ivoire, constitutes one of the last large humid tropical forest massifs in West Africa and a major refuge for forest fauna (Hamilton, 1976). Its exceptional biodiversity earned it an inscription on the world network of biosphere reserves (UNESCO-MAB) in 1978 and as a world heritage site in 1982 (Koné, 2014). However, TNP is under increasing anthropogenic pressure linked to the strong regional demographic growth of 10.9%, agricultural expansion, poaching, charcoal production, illegal logging, and illegal gold mining (Brou, 2010). These threats seriously compromise biodiversity, making it essential to identify conservation hotspots and monitor faunal populations (Doumengue *et al.*, 2001). Invertebrates represent about 70% of known species but suffer from a major deficit of knowledge and conservation strategies (Wilson, 1988). Among them, terrestrial gastropod molluscs remain particularly understudied, despite their key ecological role: litter decomposition, humus formation, soil fertility maintenance (Fitter *et al.*, 2005; Hylander, 2011), bio-indication of disturbances and contaminants (Schelfer *et al.*, 2006), and intermediate position in trophic networks as prey for numerous invertebrates and vertebrates (Amani, 2013). Socio-economically, edible giant snails (*Achatina achatina*, *Archachatina ventricosa*, *Limicolaria flammea*) constitute a major source of animal protein and income for riparian communities (Otchoumou *et al.*, 2005).

Their overexploitation, combined with deforestation and the use of pesticides, however, accelerates the decline of natural stocks (N'Da *et al.*, 2004). The average monthly gross profit from the sale of snails in Abidjan is estimated at 147,250 F CFA (Kouassi *et al.*, 2008). Despite their ecological and economic importance, the terrestrial malacofauna of TNP remains very poorly documented. Rare mentions only report *Achatina achatina* and *Archachatina ventricosa* (PNT, 2001), while regional studies focus on other forests (Memel, 2009; Amani, 2016) or on the biology of a few edible species in breeding (Otchoumou, 1997; Karamoko, 2011). This gap hinders the implementation of adapted conservation measures. This study aims to globally characterize the structure and dynamics of gastropod mollusc populations in Taï National Park. To this end, it seeks, on the one hand, to evaluate their specific diversity, and on the other hand, to analyze their spatial distribution in relation to environmental gradients, and finally to examine temporal variations associated with seasonal cycles.

MATERIALS AND METHODS

Material

Biological material

The biological material used consists of terrestrial gastropod molluscs collected in the different study areas of Taï National Park.

Material for delimiting sampling sites, collecting and identifying species

A measuring tape was used to dimension the inventory areas. A GPS (Global Positioning System), Garmin MAP 64 st, was used to geo-reference the sampling areas as well as the species observation sites. A compass was used to determine azimuths. Photographs of observed specimens were taken with a Samsung digital camera to highlight certain morphological details for species identification. An inventory sheet with a pencil was used to record data on the malacofauna in TNP. Plastic bags were used to collect litter and soil. A headlamp was used for nocturnal observation of the malacofauna. Nicklès' key (1950) and photographs of different species of terrestrial molluscs allowed the identification of gastropods encountered in TNP.

Material for measuring abiotic parameters

A digital thermo-hygrometer, HTC 1 brand, was used to record temperature and humidity in the different collection areas. This device can record temperatures between 0 and 60 °C with a precision of 0.1 °C and humidities ranging from 0 to 100%.

Study of terrestrial gastropod mollusc biodiversity

Sampling site and strategy

Twenty sampling areas of 20,000 m² each (200 m × 100 m) were established in the Taï and Djouroutou sectors within Taï National Park (Fig. 1). This dimension follows that used by Memel (2009) for the study of terrestrial malacofauna in Banco National Park. Sites were selected after preliminary prospecting, taking into account the diversity of vegetation composition and structure, as well as accessibility. The surfaces were divided according to three main habitat types:

Fig. 1. Location of Taï National Park and arrangement of malacofauna sampling areas

Primary forest or mixed forest with open understory (sites S1, S3, S8, S13, S16, S18, S19); Mixed forest with closed understory (sites S2, S4, S7, S10, S11, S20); Mixed forest with open understory and mixed forest on hydromorphic soils (sites S5, S6, S9, S12, S14, S15, S17). Fig. 2 illustrates the main vegetation formations prospected. Stratified sampling was applied due to the heterogeneity of plant habitats (Memel, 2009). Collections were carried out monthly for 10 days per sector, from March 2022 to March 2023, covering the four climatic seasons. The effort was standardized: inventories ceased in each area when no new species was observed after several successive passes. Two complementary methods were used: Active visual search: intensive manual collection of individuals visible on the ground, under/on shrub leaves, on living or dead branches and trunks of trees, as well as in humid microhabitats (Memel, 2009). Sieving of litter and soil: five samples per site (25 cm × 25 cm, 5 cm depth), bagged, dried, sieved (10 mm and 0.5 mm meshes), then sorted visually and under a binocular loupe ×10-×20 (Karas, 2009; Memel, 2009). Living specimens were photographed in situ (Samsung Galaxy 7 Pixels). Only empty shells were preserved in plastic bags. Abiotic readings (temperature, relative humidity, litter thickness) were recorded on a standardized pedestrian inventory sheet.

a. Open understory mixed forest

b. Closed understory mixed forest

c. Mixed forest on hydromorphic soils

Fig. 2. View of the different vegetation formations sampled in TNP

Identification criteria

Identification was based on direct observation (naked eye or binocular loupe), photographs, and morphological criteria (shape, sculpture, aperture, umbilicus, whorls). Determinations were made down to the genus and, for most families, down to the species. The contribution of Professor

Otchoumou Atcho Malacologist, affiliated with the Animal Production Research Center of Nangui-Abrogoua University, was also crucial for the identification of these species.

Study of spatiotemporal distribution

Sampling strategy

Temporal and spatial segmentation allowed monitoring the seasonal evolution of populations and abiotic parameters. The 20 areas were prospected (Fig. 2). The inventory covered eight sessions during the rainy season (March-October) and four sessions during the dry season (November-February). In total, twelve 10-day missions were carried out by sector between March 2021 and March 2023.

Measurement of abiotic variables

Climatic variables: Temperature and relative humidity were measured in situ using a thermo-hygrometer hung for 3 min on a central trunk in each area. The season was recorded (N'Dri, 2021).

Type of vegetation and litter size: The vegetation habitat was classified according to the TNP ecological monitoring guide (2019). All potential microhabitats were prospected (Memel, 2009). Litter thickness was measured at three points per parcel; the average was retained (N'Dri, 2021). This combined methodology ensures comprehensive and reproducible coverage of malacological communities in a highly heterogeneous humid tropical ecosystem.

Measurement of edaphic variables: Sampling Samples were collected from a vertical pit 20 cm deep (pickaxe). At each station, five random points were chosen within the main vegetation formations of Taï National Park. At each point, 500 g of soil were collected from bottom to top, homogenized on site, conditioned in hermetic plastic bags, labeled (GPS coordinates, date, station), and transported to the Central Analysis Laboratory (LCA) of Man Polytechnic University.

Analyses carried out at LCA

pH: soil/water suspension and calibrated pH-meter.

Granulometry: sieving for fractions > 0.05 mm and sedimentation method for fractions.

Retained classes:

Fine sand: 0.05–0.2 mm

Fine silt: 0.002–0.02 mm

Clay: < 0.002 mm Percentage of each fraction = (fraction mass / total dry mass) × 100. Textural class assigned according to the USDA triangle (Soil Survey Staff, 1999). Determination of mineralogical composition: Ca^{2+}, Mg^{2+}, Fe^{2+}, K^{+}, SiO_4^{2-}, Al^{3+} of the soils.

Processing of results by ecological indices

The exploitation of the results obtained from this study was carried out using ecological indices of composition and structure.

Ecological composition indices

Total richness: The total observed richness (S) is equal to the total number of species that a given biocenosis comprises (Ramade, 1984) expressed as follows:

$$S = sp1 + sp2 + sp3 + sp4 \ldots\ldots + spn$$

S: is the total number of observed species.

Sp1 + sp2....+ spn: the species observed and collected.

The total richness (S) will be determined for the surveys carried out in each collection zone and according to the sampling periods.

Relative abundance: The relative abundance of a species corresponds to the ratio of the number of individuals of that same species to the total number of individuals of all species combined. Its expression is:

$$A\_rel = (Na / (Na + Nb + Nc + N\ldots)) \times 100$$

A_rel = relative abundance of the species under consideration

Na, Nb, Nc, N = number of individuals of species a, b, c

Relative abundance indicates the importance of each species in relation to all present species (Dajoz, 1985).

Ecological structure indices

The ecological structure indices used in this study are: Shannon Diversity Index, Pielou's Evenness Index, and Sørensen Similarity Index.

Shannon diversity index: The calculation of the Shannon-Weaver index informs about how species are distributed within a community (Daget, 1979). The Shannon index is calculated using the following formula:

$H' = - \Sigma^s (pi * \log 2\ pi)$ S= specific richness. pi = ni/N= probability of encountering a species in the environment (contact rate). Where ni= number of contacts with species i. N = total number of contacts for all species. H' = Diversity index expressed in bits (Shannon Weaver, 1963).

Evenness Pielou's: Evenness index (E) (1966) is expressed by the following formula:

E= H'/H'max= H'/log2 S E: is evenness. H': is the Shannon diversity index expressed in bits. H'max: is the maximum diversity index expressed in bits. Log 2: is the logarithm base 2. S: is the total richness.

Sorenson's similarity index: The degree of similarity in composition this index is expressed by the following formula:

Cs = [2J / (a + b)] x 100 with Cs: Sorenson's index; a: number of species present in site (A);
b: number of species present in site (B); J: number of species common to sites (A) and (B).

Statistical analyses

Statistical analyses were conducted to better understand the influence of environmental conditions on the structure and distribution of terrestrial gastropod communities in the studied sites. The relationships between environmental variables and biological parameters of gastropods (species richness, abundance, biometric parameters, and mortality rate) were explored using Pearson's correlation coefficient to identify the most significant linear associations. Calculations were performed in R, with a significance level set at $p < 0.05$. Spatial and seasonal variations of climatic parameters (temperature, relative humidity, and rainfall), individual abundance (live and empty shells), and biometric characteristics and mortality rate were tested using analysis of variance (ANOVA). When multiple factors were considered simultaneously, multifactorial models were used. The significance level retained was $p < 0.05$. Finally, multivariate analyses were used to explore the main gradients structuring the spatial distribution of communities. Principal Component Analysis (PCA) was used to highlight the relationships between species and environmental variables, while Correspondence Analysis (CA) was used to examine the associations between gastropods and physicochemical parameters of soils. All these analyses were performed in R.

RESULTS

Typology of sample surfaces based on abiotic parameters

Principal Component Analysis (PCA) performed on environmental data allowed grouping the sample surfaces based on their physical similarities. This classification is made based on the values average of each environmental variable. For the ordination of variables and sample surfaces, the first two axes (F1: 65.31% and F2: 24.16%) were selected as they represent 89.47% of the information contained in the data matrix (Fig. 3). The correlation circle (Fig. 3A) shows a positive correlation of Humidity, Fe^{2+}, K^+, Mg^{2+}, pH and Si, while Litter size, Temperatures and Ca^{2+} show a negative correlation with this axis. As for axis F2, it shows a positive correlation with temperatures, Ca^{2+}, Fe^{2+}, K^+ and Mg^{2+}. Fig. 3B illustrates the factor map of the distribution of the twenty sample surfaces according to their environmental characteristics. Group I (sample surfaces S1, S2, S6, S5, S9, S10, S11, S13, and S17) is discriminated by axis F1 in its positive part, while groups II (sample surfaces S3, S4, S7 and S8) and groups III (sample surfaces S7, S12, S14, S15, S16, S18 and S19) are located in the negative part of this axis. According to axis F1, the sample surfaces of group I show a positive correlation with high values of temperature, Mg^{2+}, K^{+}, Fe^{2+}, and Ca^{2+} at the sampling points. There is a negative correlation between the sample surfaces of groups II and III with high values of air humidity and Si. Axis F2 shows a positive correlation for the sample surfaces of group III with high values of pH and Mg^{2+}. However, the sample surfaces of groups I and II are negatively correlated with high values of temperature and litter size.

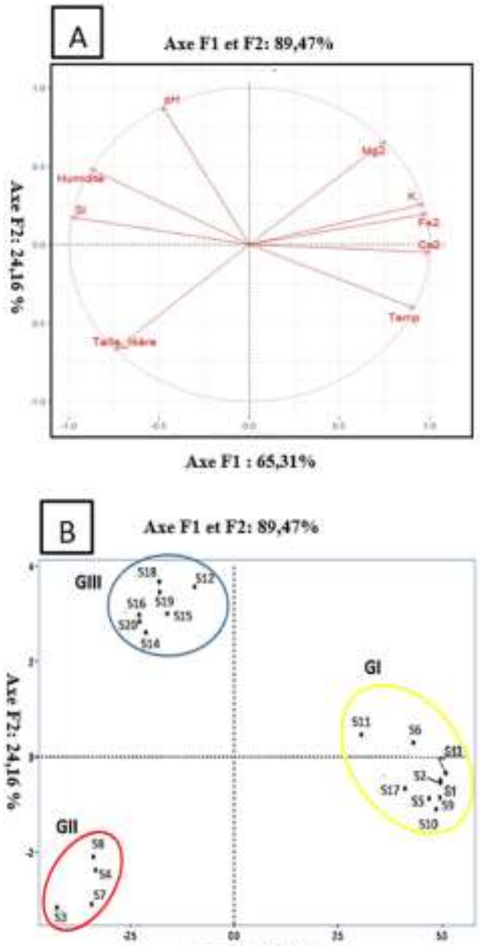

Fig. 3. Analyse en composantes principales réalisée sur la base des paramètres abiotiques

Global species richness of gastropod mollusc assemblages in Taï national park

The inventory of the malacofauna of TNP allowed us to collect a total of 13 species with 7 families and 10 genera in the different habitats prospected (Table 1). The Achatinidae family is the most diverse with a specific richness of 5 species: *Achatina fulica*, *Achatina achatina*, *Archachatina ventricosa*, *Archachatina ventricosa albinos* and *Archachatina marginata*. The Ariophantidae family has 2 species: *Macrochlamys* sp 1 and *Macrochlamys* sp 2. The Subulinidae family has 2 species: *Allopeas johanninus* and *Striosubulina striatella*. Four families are represented by only one species: Turritelidae with *Turritella communis*, Streptaxidae with *Pseudelma incisa*, Euconulidae with *Euconulidae* sp and Uniomidae comprising the species *Unio mancus*.

Specific and family abundance of molluscs collected in TNP

Fig. 4 presents the distribution of the relative abundance of gastropod mollusc species inventoried in Taï National Park. This pie chart highlights the specific structure of the malacofauna, emphasizing both dominant species and those with low relative contributions, thus reflecting the ecological organization of the studied community. The results show a strong dominance of *Achatina achatina*, which represents 26% of the total abundance. This species appears to be the most abundant in the assemblage, which can be attributed to its high ecological plasticity, its ability to adapt to different forest micro-habitats, and its high reproductive potential.

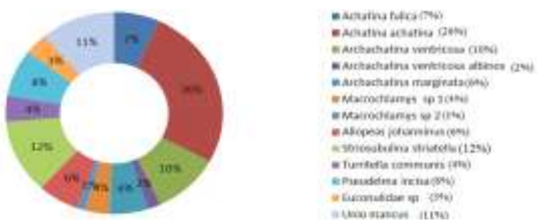

Fig. 4. Relative abundance (%) of gastropod mollusc species inventoried in Taï national park

This dominance confirms the central role of *Achatina achatina* in the trophic functioning and population dynamics of terrestrial gastropods in humid forest environments. The second most represented species is *Striosubulina striatella* (12%), followed by *Archachatina ventricosa* with 10% and *Unio mancus* (11%). The notable presence of these species indicates a significant functional diversity, associated with varied ecological preferences, ranging from humid substrates of forest litter to more open areas rich in organic matter. Species of the genus *Macrochlamys* (sp. 1: 4%; sp. 2: 1%) as well as *Allopeas johanninum* (6%) and *Pseudelma incisa* (8%) show intermediate to low abundances. These species, often small, are generally less detectable during inventories, which may explain their low relative contribution. Their presence nonetheless remains ecologically significant, as they contribute to the decomposition of organic matter and the structuring of soil microfauna. Species with very low abundance, such as *Euconulidae* sp. (3%) and *Turritella communis* (4%), reflect a more restricted distribution or low local density, probably linked to specific ecological requirements or a low dispersal capacity in this forest environment. The least abundant families are Turritelidae (8.38%), Streptaxidae (7%) and Euconulidae (5%) (Fig. 5). In addition, the species *Achatina achatina* (26%) is the majority in the gastropod mollusc population of TNP. A notable presence of species such as *Striosubulina striatella* (12%), *Unio mancus* (11%) and *Archachatina ventricosa* (10%) is observed. *Pseudelma incisa* (8%), *Achatina fulica* (7%), *Allopeas johanninus* (6%), *Macrochlamys* sp 1 (4%), *Turritella communis* (4%), *Euconulidae* (3%), *Archachatina ventricosa albinos* (2%) and *Macrochlamys* sp 2 (1%) are the least represented species (Fig. 5). The study of fluctuations in the relative abundances of gastropod mollusc families reveals that the Achatinidae family (41.18%) is the most epresentative. It is followed by Subulinidae (14.86%), Ariophantidae (11.27%) and Uniomidae (10.05%).

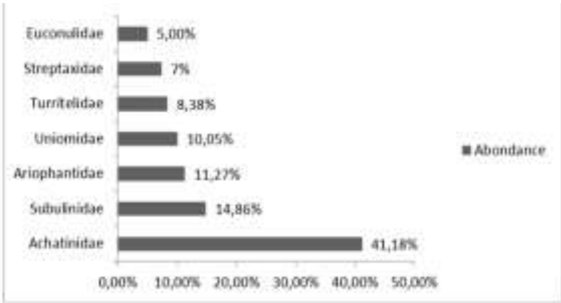

Fig. 5. Relative abundance of snail families in TNP

Table 1. Diversity of gastropod molluscs sampled in TNP

Family	Genus	Species
Achatinidae	*Lissachatina*	*Achatina fulica*
	Achatina	*Achatina achatina*
	Archachatina	*Archachatina ventricosa*
	Archachatina	*Archachatina ventricosa albinos*
	Archachatina	*Archachatina marginata*
Ariophantidae	*Macrochlamys*	*Macrochlamys* sp 1
	Macrochlamys	*Macrochlamys* sp 2
Subulinidae	*Allopeas*	*Allopeas johanninus*
	Striosubulina	*Striosubulina striatella*
Turritellidae	*Turritella*	*Turritella communis*
Streptaxidae	*Pseudelma*	*Pseudelma incisa*
Euconulidae	*Afroconulus*	*Euconulidae* sp
Unionidae	*Unio*	*Unio mancus*

Table 2. Relative abundance of gastropods from FMSF habitats in TNP

Family/Species	Abundance in the FMSF environment (%)	
Total (N=701)	Species (%)	Family (%)
Achatinidae		36,23
Achatina achatina	23,10	
Archachatina ventricosa	9,14	
Archachatina marginata	3,99	
Subulinidae		63,77
Allopeas johanninus	22,54	
Striosubulina striatella	41,23	

Spatial abundance of molluscs collected in TNP

Variations in the relative abundances of gastropod families and species from the FMSF habitat are presented in Table 2. For all sample surfaces, the relative abundance of the Subulinidae family (63.77%) is higher than that observed for the Achatinidae (36.23%). Regarding taxonomy, the most predominant species is *Striosubulina striatella* (41.23%). Observations reveal that *Achatina achatina* (23.10%) and *Allopeas johanninus* (22.54%) are the most frequent species.

Table 3. Relative abundance of gastropods from FMSO habitats in TNP

Family/Species	Abundance in the FMSO environment (%)	
Total (N=1735)	Species (%)	Family (%)
Achatinidae		50,47
Achatina fulica	12,68	
Achatina achatina	25,07	
Archachatina ventricosa	7,49	
Archachatina ventricosa albinos	2,03	
Archachatina marginata	3,20	
Ariophantidae		22,33
Macrochlamys sp 1	12,72	
Macrochlamys sp 2	9,61	
Turritellidae		14,47
Turritella communis	14,47	
Streptaxidae		12,91
Pseudelma incisa	12,91	

Table 4. Relative abundance of gastropods from FSHD habitats in TNP

Family/Species	Abundance in the FMHD environment (%)	
Total (N=1073)	Species (%)	Family (%)
Achatinidae		42,9
Achatina achatina	22,76	
Archachatina ventricosa	12,02	
Archachatina ventricosa albinos	1,30	
Archachatina marginata	6,82	
Euconulidae		32,23
Euconulidae sp	32,23	
Unionidae		24,87
Unio mancus	24,87	

The species *Archachatina ventricosa* (9.14%) and *Archachatina marginata* (3.99%) are the least common in the habitat. Table 3 illustrates the fluctuations in the relative abundances of malacological families and species encountered in the FMSO environment. The majority of these habitats are dominated by the Achatinidae family (50.47%) and the Ariophantidae (22.33%).

Turritelidae (14.47%) and Streptaxidae (12.91%) are families with relatively high proportions. In terms of taxonomy, the species *Achatina achatina* (25.07%) clearly predominates in the gastropod mollusc community. We observe that *Turritella communis* (14.47%), *Pseudelma incisa* (12.91%), *Macrochlamys* sp 1 (12.78%) and *Macrochlamys* sp 1 (9.61%) are the most frequent species, while *Archachatina ventricosa* (7.49%), *Archachatina marginata* (3.2%) and *Archachatina ventricosa albinos* (2.04%) are the least widespread. Table 4 presents the relative prevalence of gastropod mollusc species in FSHD habitats. In most of these habitats, the Achatinidae family (42.9%) is dominant, followed by the Euconulidae family (32.23%). The rate for the Uniomidae family (24.7%) is lower. For taxonomic classification, the species *Euconulidae* sp (32.23%) largely dominates the mollusc population gastropods. We observe that *Unio mancus* (24.87%), *Achatina achatina* (22.76%) and *Archachatina ventricosa* (12.02%) are the most frequent in this habitat. The species *Archachatina marginata* (6.82%) and Archachatina ventricosa albinos (1.3%) are the rarest.

Abundance of collected species according to seasons in TNP

Fig. 6 presents the temporal variation of the abundances of malacological species recorded in the habitats visited in TNP. The dominance of molluscs varies across different sampling periods in each habitat. Fig. 6a reveals the fluctuations in the occurrences of different mollusc species collected in the FMSF habitat in TNP. The species *Achatina achatina* (63.33%) is the most abundant during the long rainy season, while the species *Archachatina ventricosa* (20.57%) shows a higher dominance during the long dry season.

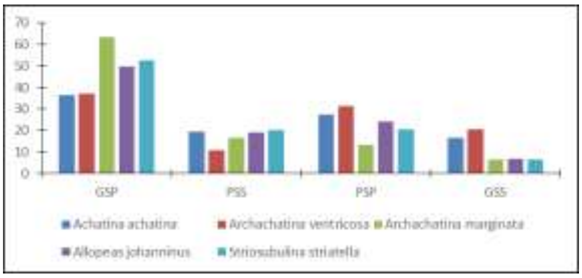

Fig. 6a. Seasonal variation of the abundance of gastropod molluscs collected in the FMSF habitat of TNP

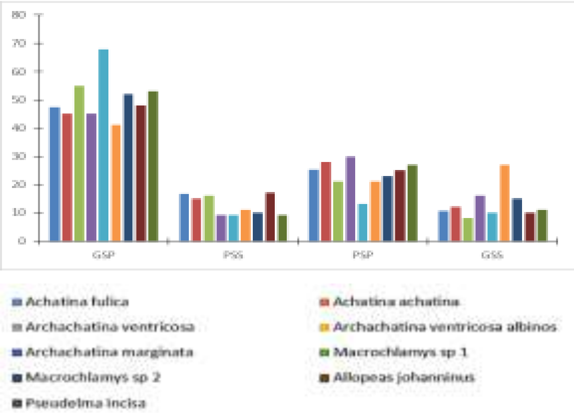

Fig. 6b. Seasonal variation of the abundance of gastropod molluscs collected in the FMSO habitat of TNP

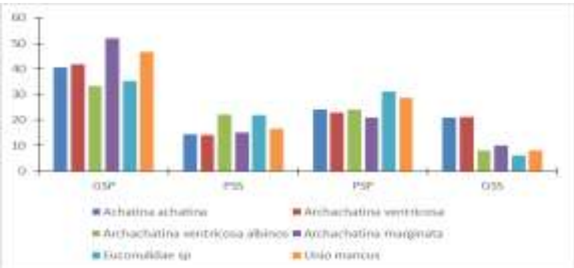

Fig. 6c. Seasonal variation of the abundance of gastropod molluscs collected in the FSHD habitat of TNP

Fig. 6b illustrates a variation in the occurrences of mollusc species observed in the FMSO habitat within TNP. During the long rainy season, the species *Achatina fulica* is the most represented with a rate of 68%, while the species *Macrochlamys* sp reaches a more significant predominance during the long dry season, estimated at 27%. The graph illustrated by Fig. 6c shows the fluctuations in the abundances of different species observed in the FSHD environment in TNP. During the long rainy season, the species *Achatina marginata* is the most prevalent with a rate of 52%, whereas during the long dry season, the species *Archachatina ventricosa* shows a more significant predominance with a percentage estimated at 21.25%.

Spatial variations of Shannon index and evenness Shannon index

Spatial variations of the Shannon index

Fig. 7 presents the variations of the Shannon diversity index (H') of the mollusc community in the different habitats explored in TNP. The Shannon diversity index ranges from a minimum of H' = 2.3 bits (FMSF habitat) to a maximum value of H' = 3 bits (FMSO habitat). In the FMSF environment, the minimum value recorded was H' = 1.2 bits and the maximum value H' = 2.4 bits. This index varies from 1.5 to 3 bits in the FMSO habitat. In the FSHD environment, the Shannon index indicates a minimum value of 1.8 bits and a maximum value of 2.7 bits. The Shannon diversity index (H') shows a significant variation from one environment to another (Kruskal-Wallis test, *p*-value < 0.05).

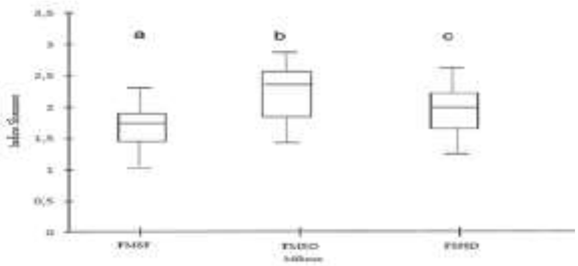

Fig. 7. Variation of the Shannon diversity index in the visited environments in TNP FMSF = Closed Understory Mixed Forest, FMSO = Open Understory Mixed Forest, FSHD = Mixed Forest on Hydromorphic Soils; values affected by the same letter (a or b) differ significantly (Kruskal-Wallis test, *p*-value < 0.05)

Spatial variations of the evenness index

The spatial variations of Pielou's Evenness calculated for mollusc species observed in the visited habitats are illustrated in Fig. 8. During the sampling period, Pielou's Evenness values ranged from 0.82 to 0.65 in the FMSF environment. In the FMSO habitat, Evenness fluctuated between 0.68 and 0.93. This index oscillated between 0.58 and 0.90 for the FSHD environment. Pielou's Evenness shows a significant variation from one environment to another (Kruskal-Wallis test, p-value < 0.05).

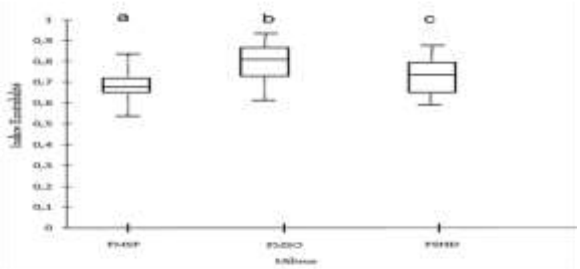

Fig. 8. Variation of evenness in the visited environments in TNP. FMSF = Closed Understory Mixed Forest, FMSO = Open Understory Mixed Forest, FSHD = Mixed Forest on Hydromorphic Soils; values affected by the same letter (a or b) differ significantly (Kruskal-Wallis test, p-value < 0.05)

Seasonal variations of the Shannon index and evenness

Table 5 indicates the seasonal variations of the Shannon index in the different sampled habitats. The FMSO habitat recorded a minimum value (1.64 ±0.18) in the dry season and its maximum value (2.53 ±0.21) in the rainy season. During the dry season, the Shannon diversity index fluctuated between 1.49 ±0.21 bits (FMSF) and 1.52 ±0.14 bits (FSHD), whereas during the rainy season it ranged between 1.97 ±0.17 bits (FMSF) and 2.34 ±0.11 (FSHD).

Table 5. Seasonal variations of the mean Shannon diversity index in the visited environments in TNP

Habitats	Seasons	
	Rainy season	Dry season
Habitat FMSF	1,97 ±0,17^{c}	1,49 ±0,21^{a}
Habitat FMSO	2,53 ±0,21^{ab}	1,64 ±0,18^{b}
Habitat FSHD	2,34 ±0,11^{ab}	1,52 ±0,14^{b}

Values in rows affected by the same letter (a or b) do not differ significantly (Mann-Whitney Test, p < 0.05)

Table 6 presents the seasonal variations of evenness in the visited habitats of TNP. For the FMSF habitat, evenness reached its lowest level (0.73±0.011) during the dry season and its highest value (0.84 ± 0.006) during the rainy season. In the FMSO environment, the minimum (0.78±0.002) and maximum (0.92 ± 0.016) values were recorded during the dry season and rainy season, respectively. In the FSHD habitat, the lowest evenness value (0.71± 0.003) was noted in the dry season, while the highest value (0.83 ± 0.007) was obtained in the rainy season.

Table 6. Seasonal variations of evenness in the visited environments in TNP

Habitats	Seasons	
	Rainy season	Dry season
Habitat FMSF	0,84 ± 0,006^{c}	0,73±0,011^{a}
Habitat FMSO	0,92 ± 0,016^{ab}	0,78±0,002^{b}
Habitat FSHD	0,83 ± 0,007^{c}	0,71± 0,003^{a}

Values in rows affected by the same letter (a or b) do not differ significantly (Mann-Whitney Test, p < 0.05).

Taxonomic similarity

Table 7 presents the specific similarities between the visited habitats, highlighted by the Jaccard similarity index (J) values, calculated from their specific composition. For all habitats, the value of the Jaccard similarity index (J) between malacological species varies from 0.27 to 0.43 when compared pairwise. The FMSO and FSHD habitats [IJ = 0.43] show a greater similarity in their taxonomic composition compared to species affinities between other environments. Furthermore, the lowest Jaccard similarity index [IJ = 0.27] is observed between the FMSO and FMSF habitats. In addition, the comparison of species resemblance between FMSF and FSHD habitats reveals a similarity index estimated at 0.33.

Table 7. Jaccard index between sampling habitats

Jaccard	FMSO	FMSF	FSHD
FMSO		0,27	0,43
FMSF			0,33
FSHD			

DISCUSSION

The inventory of terrestrial gastropod molluscs in TNP conducted from March 2021 to February 2023 led to the identification of 13 species grouped into 7 distinct families: Achatinidae (*Achatina fulica*, *Achatina achatina*, *Archachatina ventricosa*, *Archachatina ventricosa albinos*, *Archachatina marginata*), Ariophantidae (*Macrochlamys* sp 1, *Macrochlamys* sp 2), Subulinidae (*Allopeas* *johanninus*, *Striosubulina striatella*), Turritelidae (*Turritella communis*), Streptaxidae (*Pseudelma incisa*), Euconulidae (*Euconulidae* sp) and Uniomidae (*Unio mancus*). The examined environment favors the growth of these species. This explains their presence in this environment.

This environment would offer the essential conditions for the life cycle of these species. This includes climatic conditions such as temperature and humidity, as well as edaphic conditions such as soil texture and mineralogical composition. The observed average temperatures vary between 34.51 °C and 22.07 °C. Furthermore, the average humidity levels vary between 91.54% and 76.87%. Our results are consistent with those of Otchoumou (2005), which indicate that beyond 30 °C and below 65% relative humidity, the growth and reproduction of Achatinidae would be hindered. Similarly, studies conducted by Memel (2009) in Banco National Park reveal that average annual temperatures between 23.2 ± 5 °C and 27.9 ± 0.3 °C and average annual relative humidities between 86.83 ± 1.6% and 94.1 ± 1.2% would probably be those that ensure better living conditions for Achatinidae. The abundance of terrestrial molluscs is often used as an indicator of the ecological health of natural environments. A significant decrease in their number can signal environmental problems, such as biodiversity loss, pollution of the soil, or the impact of climate change. The relative abundance of terrestrial gastropods shows notable variability depending on the sampling stations and observation periods. The FMSO habitat is distinguished by significantly higher abundance than those recorded in the FMSF and FSHD environments. These results are consistent with the work of Amani, 2016 carried out in the Yapo forest. This spatial variation can be attributed to environmental factors such as air humidity, vegetation cover structure, availability of food resources, and microhabitats.

The semi-open enriched habitat offers favorable microclimatic conditions for survival: high humidity, moderate temperatures, abundance of organic matter and litter, promoting the activity and reproduction of molluscs (N'dri, 2021). Conversely, in FMSF habitats, a low density of terrestrial gastropods is observed. The data obtained concerning the abundance of terrestrial molluscs in this habitat diverge notably from observations reported by Memel (2009). This discrepancy could be explained not only by the high density of vegetation but also by the larger litter size, which would strongly limit snail activity, thus reducing abundance. This abundance is dominated by the Achatinidae family with 41.18%. This could be explained by the fact that Achatinidae are better adapted to tropical forests. Our results are consistent with those of N'dri (2021) at the National Floristic Center of the University of Cocody Abidjan. Memel (2009) observed that species like *Achatina fulica* and *Archachatina ventricosa* possess remarkable ecological plasticity. They are capable of surviving in environments with low humidity levels and can even withstand higher temperatures, making them ideal candidates for environments disturbed by human activities. Moreover, they colonize anthropized environments (Karamoko, 2009). These taxa are the most widespread and abundant in sub-Saharan African countries (Horsa, 2014). The seasonal variation in abundance is a characteristic feature of terrestrial mollusc populations. Our data indicate a notable increase in abundance during the rainy season (GSP and PSP), followed by a progressive decrease during the dry season (GSS and PSS) in each sampled habitat. This seasonal trend is attributable to the direct influence of water and climatic conditions on gastropod physiology. During the humid period, mollusc populations, particularly species like *Cornu aspersum* and *Succinea costaricana*, are more abundant, which corresponds to greater activity and increased reproduction. During the rainy season, high soil humidity and abundant organic matter create more favorable conditions for feeding, locomotion, and reproduction. Humidity helps prevent desiccation, a major physiological stress for these permeable-skinned organisms. Conversely, in the dry season, high temperatures and low humidity limit the activity of individuals, who often enter aestivation to reduce water loss. This reduction in activity results in a clear decrease in abundance observable in our surveys. Work by (Barker *et al.*, 1999) confirms that terrestrial gastropods show activity peaks during humid periods and troughs during dry periods, highlighting the crucial role of rainfall and humidity on life rhythms. Analyzing fluctuations in diversity through the Shannon index and evenness makes it possible to understand the effect of seasons and different habitats on the structure of the malacological communities of TNP. The FMSO habitat stands out with higher diversity and evenness indices, indicating an environment offering a mosaic of resources and relative ecological stability. Furthermore, the FSHD environment, although diversified, also shows a significant reduction in the dry season, suggesting that certain physical or anthropogenic characteristics of the environment amplify vulnerability to seasonal climatic changes. Moreover, the FMSF habitat appears to be the most sensitive to seasonal variations, with more pronounced decreases in the dry season. The Jaccard index (J), used in ecology to compare the composition of species between different habitats, allows measuring the similarity of species communities by taking into account common species. In this study, the Jaccard index values between malacological habitats vary from 0.27 to 0.43, reflecting the diversity and variations in the specific composition of observed species. The highest similarity index (J= 0.43) is observed between the FMSO and FSHD habitats. This high similarity suggests that these habitats share a favorable ecological environment for a number of malacological species. Amani N'Dri Saint-Clair *et al.* (2016) observed in their work that habitats with similar abiotic conditions, such as humidity and temperature, often favor the presence of common species. The fact that FMSO and FSHD share several species, such as *Achatina achatina*, *Archachatina ventricosa*, and *Archachatina marginata*, supports the idea of ecological homogeneity in these two habitats.

Conversely, the lowest similarity index (J= 0.27) is observed between the FMSO and FMSF habitats, indicating notable differences in species composition. This low index can be explained by ecological differences between these habitats, particularly in terms of substrate, vegetation, or resource availability. N'Dri Gérôme and Otchoumou Atcho (2021) showed that such divergences can result from the structure of habitats, which directly influence species communities. The differences between FMSO and FMSF are therefore likely linked to variations in local environmental conditions. The result of the comparison between FMSF and FSHD (J = 0.33) shows a moderate similarity, suggesting that these two habitats share certain ecological conditions while being distinct. Habib (2004) suggested that moderately similar habitats can harbor a common number of species while maintaining differences in their overall composition.

The presence of species such as *Achatina achatina*, *Archachatina ventricosa*, and *Archachatina marginata* in these two habitats indicates the ability of these species to adapt to varied ecological environments, as highlighted by Otchoumou Atcho *et al.* (1997).

CONCLUSION

At the end of this study on the spatial and temporal distribution of terrestrial molluscs in a protected natural environment, it appears that these organisms constitute true indicators of habitat ecological integrity. Their distribution, far from being random, responds closely to the abiotic gradients that structure the environment, particularly humidity and temperature. This strong dependence on environmental micro-conditions explains the preferential concentration of species in shaded and humid areas, where thermal variations are buffered and trophic resources remain more accessible. On the temporal level, seasonal fluctuations significantly influence activity, mobility, and the apparent density of populations. The humid season is distinguished by spatial expansion and intensification of biological interactions, while the dry season induces withdrawal and preservation strategies, translated by a contraction of distribution and a selective occupation of micro-refuges. These dynamics testify to the ecological plasticity of molluscs, but also to their vulnerability to changes in abiotic parameters. The results obtained confirm that the status of a protected area plays an essential role in preserving ecological niches favorable to molluscs.

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