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Microhabitat and seasonal influences on terrestrial mollusc communities in a reforested secondary forest, south-eastern Côte d'Ivoire

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ABSTRACT

Terrestrial mollusks play a key role in litter decomposition and are also excellent bioindicators of environmental quality. The aim of this study was to investigate variation in microhabitats and seasonal changes in terrestrial molluscs. Sampling was used using the quadrat methode. The different strata were microhabitats such as in the soil (IS), on the sol and/or in litter (S/L), on wood or tree trunks (W/T) and on leaves (L). Results showed that species richness was highest in S/L (1-15 species) and IS (1-11 species), while it remained low on leaves (1-2 species). Communities were relatively even in DS and S/L, with median equitability values exceeding 0.8. Most microhabitats were dominated by Subulinidae, in DS, S/L and W/T, with abundances of 85.48% in IS, 76.51% in S/L and 93.50% in W/T. Taxonomic richness was high in S/L and IS in all seasons. In S/L microhabitats, the equitable distribution of molluscs was greater in all seasons except the dry season, when it was greater on leaves. This study shows that the type of microhabitat and the season have a considerable influence on the composition and diversity of molluscs. Therefore, in order to maintain this diversity, it is important to protect these microhabitats through forest conservation.

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INTRODUCTION

Terrestrial molluscs play a fundamental role in the functioning of forest ecosystems. In this way, they contribute to the decomposition of litter either directly or indirectly (Meyer *et al.*, 2013). Their ecological importance is also reflected in their position within the trophic network, as they constitute a food source for numerous birds and small mammals (Jordan and Black, 2012). Additionally, empty shells serve as secondary microhabitats for various invertebrates, thereby enhancing the ecological complexity of forest soils (Jordan and Black, 2012).

Beyond their functional roles, terrestrial molluscs are widely recognized as excellent bioindicators of environmental quality due to their sensitivity to variations in both abiotic and biotic conditions (Oehlmann and Schulte-Oehlmann, 2003; Salih *et al.*, 2021). Their diversity and distribution are strongly influenced by several environmental factors, including the type and structure of forest habitats (Wronski *et al.*, 2014; Memel *et al.*, 2009; Oke and Chokor, 2009; Amani *et al.*, 2018), the characteristics of microhabitats (Kemencei *et al.*, 2014; Gheoca *et al.*, 2021), relative soil and litter humidity, and litter depth (Kemencei *et al.*, 2014; N'Dri *et al.*, 2020). Climate and seasonality also constitute major determinants that modulate gastropod activity and presence (Nunes and Santos, 2012; Amani *et al.*, 2018).

In Côte d'Ivoire, however, research on terrestrial mollusks remains limited. Studies conducted in Banco National Park (Memel *et al.*, 2009) and in urban secondary forests (N'Dri *et al.*, 2019; 2020) have demonstrated the importance of microhabitats in species distribution. Other investigations, such as those by Amani *et al.* (2016; 2018), have examined the composition and distribution of mollusks in different types of forest habitats, including dense, secondary, and reforested stands. Nevertheless, no research has specifically focused on the spatial and temporal dynamics of terrestrial mollusks within microhabitats of a reforested secondary forest, despite the fact that these microhabitats strongly influence species richness, abundance, and gastropod activity (N'Dri *et al.*, 2019; Gheoca *et al.*, 2021; 2023). The aim of this study is to investigate the influence of microhabitats and climatic seasons on the dynamics of terrestrial molluscs within a reforested secondary forest.

MATERIALS AND METHODS

Study site

Our study site is located within the Yapo Forest Reserve, situated in the south-east of Côte d'Ivoire between latitudes 5° 40' 02'' and 5° 47' 32'' north and longitudes 30° 57' 02'' and 40° 11' 37'' west (Fig. 1). It lies 25 km south of Agboville, 8 km north of Azaguié, and 50 km northeast of Abidjan.

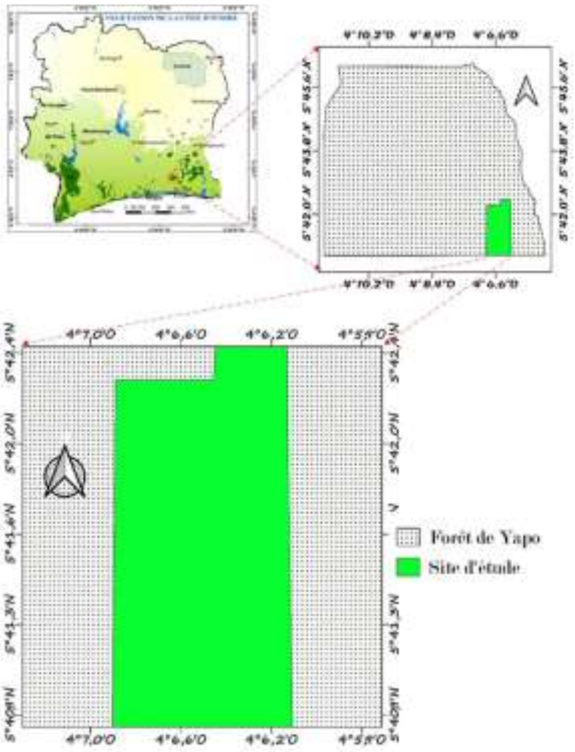

Fig. 1. Location of the study site in the Yapo classified forest

The area concerned by this study covers 355.929 hectares. It is characterized by a reforested forest composed of broadleaf tree species, a moderately dense forest structure, a moderately dense understory, and a litter layer approximately 6.5 cm thick (Amani, 2018). The relief is slightly undulating, with slopes below 5%. The Yapo

Classified Forest lies within a humid evergreen dense forest climax typical of the ombrophilous sector of the Guinean biogeographical zone. The Abgoville department, which includes our study area, is characterised by four seasons : a long dry season (December to February), a long rainy season (March to June), a short dry season (July to August) and a short rainy season (September to November) (SODEXAM 2010). The average annual temperature is around 27°C (SODEXAM 2010) and the average annual rainfall is 1400 mm. The vegetation consists of trees such as *Dacryodes klaineana*, *Drypetes aylmeri*, *Heritiera utilis*, *Funtumia africana* et *Trichilia monadelpha* (Konan *et al.*, 2015).

Methods

The sampled molluscs constituted the biological material. For sampling, 10 plots measuring 60 m x 40 m were established. A total of 24 quadrats to 10 m² were set up by subdividing the pre-established plots. Thus, over a period of 24 months, sampling was carried out at a rate of one sample per quadrat per month. Quadrats were randomly selected during every sampling campaign. Mollusc collection combined direct observation with litter and soil sampling, following the methods of Tatterfield *et al.* (2001), Oke and Chokor (2009), Oke (2013), and Wronski *et al.* (2014).

Across all sites, an exhaustive search was carried out in microhabitats favorable to mollusks (Amani *et al.*, 2018). Each quadrat was inspected for one hour. During each sampling event, litter was collected from a 1 m² surface (1 m × 1 m), and approximately 5 liters of soil were taken from within the quadrat (Amani *et al.*, 2018). These samples were sieved, and mollusks were searched for visually in the retained fractions and using a handheld magnifying lens for the soil material that passed through the mesh (Amani *et al.*, 2016). For every specimen encountered, the occupied microhabitat was recorded (IS= In Soil; S/L= On Soil and/or In Litter; W/T= On Wood and/or Trunk; L= On Leaves).

Identification of molluscs

The morphological descriptions and images observed in the works of Bequaert (1950), Daget (2003), Rowson (2009) and Oke (2013) were used to identify the sampled specimens.

Reporting of results

The data collected was used to calculate the Shannon-Weaver Diversity Index (H'), Equitability index (E) and relative abundance using the following formulas:

$H' = -\Sigma\, pi \log2\, pi$ with i = 1 to S (Shannon, 1948)

With pi = ni/N is the relative frequency of species i, i.e. the probability of species i (ni) appearing in the total number of individuals (N), and S is the number of species.

$E = (H'/ H'_{max}) \times 100$ (Shannon, 1948)

$H'_{max} = \log_2 S$ (S = number of species)

H'= Diversity index expressed in bits; H'max= Maximum diversity expressed in bits

$R_{abu\ 1} = (N_a/\ N_a + N_b + N_c + N_{...}) \times 100$ (Damerdji, 2022)

R_{abu} is the relative abundance of the species under consideration. Na, Nb, Nc are the numbers of individuals of species a, b, c.

Statistical analyses

The average Shannon and equitability indexs between different microhabitats and across seasons were compared using the Mann-Whitney test. The significance threshold was set at 5%. STATIATICA version 7.1 software was used for this purpose.

RESULTS

Influence of microhabitats

Taxonomic richness

Taxonomic richness varied differently depending on the microhabitat (Fig. 2). It ranged from 1 to 5 species on S/L and 1 to 2 species on leaves. Microhabitats W/T and IS recorded intermediate values of 1 to 6 species and 1 to 11 species, respectively. These variations were significant in the Mann-Whitney test.

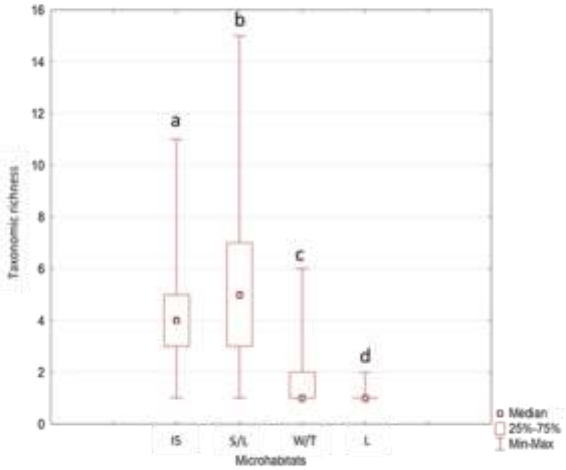

Fig. 2. Variation in the taxonomic richness of gastropods in microhabitats

The values assigned to the same letters do not differ significantly (Mann-Whitney test significant; $p < 0.05$); IS= In the Soil, S/L= on the soil and/or litter, W/T= wood and/or trunk, L= leaf

Shannon diversity index (H)

The Shannon diversity index varied significantly (Mann-Whitney test significant; $p<0.05$) from one microhabitat to another (Fig. 3). It had a high value in IS and S/L with medians above 1.1 and a very low value on W/T and L with medians around 0.001.

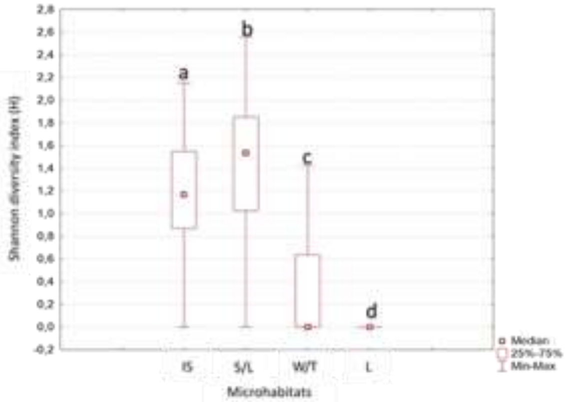

Fig. 3. Variation in Shannon diversity index (H) in microhabitats

Equitability index

Like the Shannon diversity index, the Equitability index also varied (Mann-Whitney test significant ; $p < 0.05$) from one microhabitat to another (Fig. 4). This index was high at DS and S/L with medians above 0.8, while it was low at B/T and F with a median of approximately 0.001.

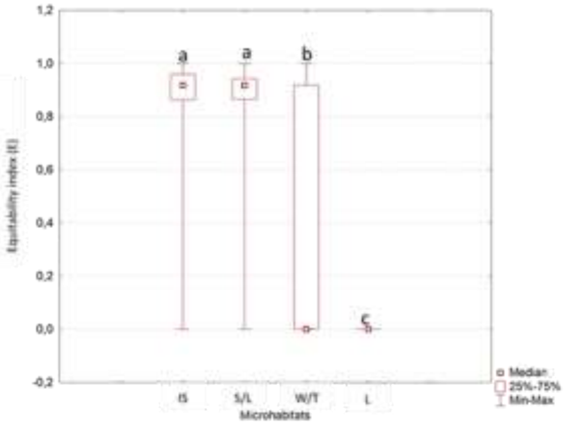

Fig. 4. Spatial variation of Equitability index (E) in microhabitats

The median values assigned to the same letters do not differ significantly (Mann-Whitney test significant; $p < 0.05$) ; IS= in the soil, S/L= on the soil and/or litter, W/T= wood and/or trunk, L= leaf.

Relative abundance

The distribution of molluscs among microhabitats is presented in Table 1. Subulinidae were the most abundant group in IS (85.48%), S/L (76.51%), and W/T (93.50%), followed by Streptaxidae in these three microhabitats. On L, however, Streptaxidae were most represented (50%). In IS, six taxa belonging to the genera *Curvella* and *Pseudopea* were found at abundances >12%. *Gullela io* represented 5.89%. In S/L, dominant species included *Curvella* sp. 2, *Curvella* sp. 3, *Curvella* sp. 4, and *Pseudopeas* sp. 1 with relative abundances ranging from 10.80% to 11.71%. *Subulona* sp. 1, *Gullela* io, *Pseudopeas* sp. 2, and *Curvella* sp. 1 displayed intermediate abundances (6-8%). In W/T, the most abundant taxa belonged to the genus *Subulona* more than 50% and *Striosubulina* with 33% abundance. On L, these taxa were replaced by *Edentoulina* sp. (18.19%) and *Gonaxis* sp. 1 (22.73%), along with *Curvella* sp. 3, *Pseudopeas* sp. 1, and *Pseudopeas* sp. 2 (9-11.41%). In this microhabitat, the taxa dominant in W/T (>60%) were thus replaced by leaf-associated taxa.

Table 1. Abundance of families and taxa of molluscs in microhabitats

Species	Individuals	Abon. IS (%)	Individuals	Abon. S/L (%)	Individuals	Abon. W/T (%)	Individuals	Abon. L (%)
Achatinidae		-		0,67		3,25		4,55
Achatina achatina	-	-	3	0.07	-	-	-	-
Archachatina ventricosa	-	-	3	0.07	6	0.81	-	-
Lignus sp.	-	-	15	0.33	9	1.22	-	-
Limicolaria flammea	-	-	6	0.13	10	1.22	2	4.55
Ferussaciidae		4.26		4.86		-		-
Cecilioides sp.	102	4.26	219	4.86	-	-	-	-
Subulinidae		85.48		76.51		93.50		22.73
Subulona sp. 1	15	0.63	303	6.72	288	39.02	6	9.09
Subulona sp. 2	9	0.38	183	4.06	150	20.73	-	-
Striosubulina striatella	6	0.25	216	4.79	252	33.74	10	15.16
Curvella sp. 1	324	13.52	381	8.52	-	-	-	-
Curvella sp. 2	318	13.27	528	11.71	-	-	-	-
Curvella sp. 3	333	13.89	504	10.80	-	-	-	-
Curvella sp. 4	429	17.9	501	11.24	-	-	-	-
Pseudopeas sp. 1	294	12.14	513	11.37	-	-	-	-
Pseudopeas sp. 2	324	13.52	33	7.39	-	-	-	-
Streptaxidae	-	10.26	-	17.83	-	3.25	-	50
Edentoulina sp.	-	-	189	4.19	-	-	12	18.19
Gonaxis sp. 1	3	0,13	162	3.59	21	2.85	15	22.73
Gonaxis sp.2	-	-	37	0.8	3	0.41	5	9.04
Gonaxis sp. 3	-	-	6	0.13	-	-	-	-
Gullela io	141	5.89	315	6.99	-	-	-	-
Gullela sp. 1	93	1.63	15	0.33	-	-	-	-
Gullela sp. 2	27	1.13	33	0.73	-	-	-	-
Gullela cf *opoboensis*	36	1.50	48	1.06	-	-	-	-
Urocyclidae	-		-	0.13	-	-	-	22.73
Trochozonites talcosus	-	-	6	0.13	-	-	-	-
Verucarion sp. 1	-	-	-	-	-	-	8	12.12
Verucarion sp. 2	-	-	-	-	-	-	6	9.09

Abun= abundance, IS= in the soil, S/L= on the soil and/or litter, W/T= wood and/or trunk, L= leaf.

Table 2. Seasonal variation in the taxonomic richness of gastropods in microhabitatst

Seasons	Microhabitats			
	IS	S/L	W/T	L
LRS	3.66 ± 2.27 ^{a}	6.97 ± 3.22 ^{b}	1.21 ± 1.01 ^{c}	0.17 ± 0.38 ^{d}
SDS	3.64 ± 2.13 ^{a}	6.64 ± 3.73 ^{b}	1.50 ± 1.16 ^{c}	0.07 ± 0.27 ^{d}
SRS	4.14 ± 2.69 $^{a\,b}$	5.57 ± 3.06 ^{b}	1.52 ± 1.50 ^{c}	0.33 ± 0.58 ^{d}
LDS	4.19 ± 2.04 ^{a}	2.38 ± 1.56 ^{b}	0.48 ± 0.60 ^{c}	0 ^{d}

The values of the lines assigned the same letters do not differ significantly (Mann-Whitney test significant; $p< 0.05$). IS= in the soil, S/L= on the soil and/or litter, W/T= wood and/or trunk, L= leaf.

Seasonal variation

Taxonomic richness

Mean taxonomic richness varied significantly among microhabitats across seasons (Mann–Whitney test; $p<0.05$), except during the Short Rainy Season (SRS), where no significant differences were observed between IS and S/L (Table 2). During the Long Rainy Season (LRS), the highest mean number of taxa (6.97 ± 3.22) was recorded on S/L, while the lowest (0.17 ± 0.38) was observed on L. A similar pattern occurred during the Short Dry Season (SDS), with values of 6.64 ± 3.73 on S/L and 0.07 ± 0.27 on L. In contrast, during the Long Dry Season (LDS), richness peaked in IS (4.19 ± 2.04), while no species were recorded on L.

During the SRS, richness was 0.33 ± 0.58 on L and 5.57 ± 3.06 on S/L. Except for richness values in IS and S/L during SRS, all other seasonal comparisons showed significant differences (Mann-Whitney test; $p<0.05$).

Shannon diversity index (H)

Mean values of Shannon diversity across microhabitats and seasons are presented in Table 3.

Except during LDS, the highest values were consistently recorded on S/L. In LRS, H ranged from 0.001 ± 0.00 (L) to 1.74 ± 0.38 (S/L). In SDS, H ranged from 0.001 ± 0.00 (L) to 1.68 ± 0.49 (S/L). In SRS, values ranged from 0.001 ± 0.00 (L) to 1.36 ± 0.62 (S/L). During the LDS, however, Shannon diversity reached its maximum in IS (1.16 ± 0.53) and was zero on L. According to the Mann–Whitney test Significant differences were observed between IS and S/L during LRS and SDS ($p< 0.05$). In SRS, H was significantly lower on L than in all other microhabitats. During LDS, the value on W/T differed significantly from those recorded in IS and S/L.

Table 3. Seasonal variation in the average Shannon diversity index (H) in microhabitats

Seasons	Microhabitats			
	IS	S/L	W/T	L
LRS	1.16 ± 0.52 ^{a}	1.74 ± 0.38 ^{b}	0.25 ± 0.37 ^{c}	0.001 ± 0.00 ^{c}
SDS	1.18 ± 0.54 ^{a}	1.68 ± 0.49 ^{b}	0.49 ± 0.49 ^{c}	0.001 ± 0.00 $^{a\,b\,c}$
SRS	1.09 ± 0.64 ^{a}	1.36 ± 0.62 ^{a}	0.38 ± 0.45 $^{b\,c}$	0.001 ± 0.00 ^{c}
LDS	1.16 ± 0.53 ^{a}	0.69 ± 0.51 ^{b}	0.05 ± 0.14 ^{c}	-

The values of the lines assigned the same letters do not differ significantly (Mann-Whitney test significant ; p < 0.05) ; IS= in the soil, S/L= on the soil and/or litter, W/T= wood and/or trunk, L= leaf, LRS= long rainy season, SDS= short dry season, SRS= short rainy season, LDS= long dry season.

Table 4. Seasonal variation in average equitability index in microhabitats

Seasons	Microhabitats			
	IS	S/L	W/T	L
LRS	0.84 ± 0.26 ^{a}	0.91 ± 0.04 ^{a}	0.32 ± 0.45 ^{b}	0.001 ± 0.01 ^{b}
SDS	0.87 ± 0.25 ^{a}	0.91 ± 0.05 ^{a}	0.51 ± 0.48 ^{b}	0.001 ± 0.00 ^{b}
SRS	0.78 ± 0.33 ^{a}	0.80 ± 0.27 ^{a}	0.44 ± 0.47 $^{a\,b}$	0.001 ± 0.00 ^{b}
LDS	0.81 ± 0.29 ^{a}	0.69 ± 0.43 ^{a}	0.07 ± 0.20 ^{b}	-

The values of the lines assigned the same letters do not differ significantly (Mann-Whitney test significant; $p <$ 0.05) ; IS= in the soil, S/L= on the soil and/or litter, W/T= wood and/or trunk, L= leaf, LRS= long rainy season, SDS= short dry season, SRS= short rainy season, LDS= long dry season.

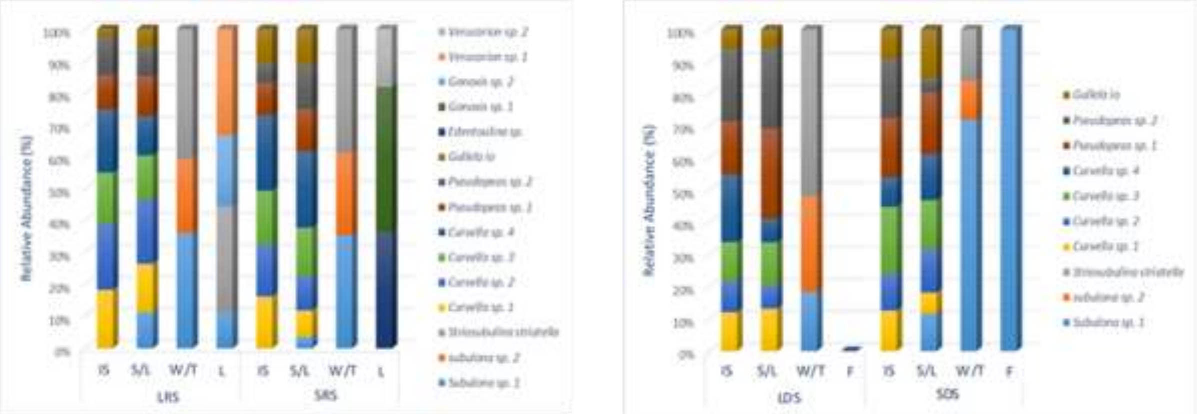

Fig. 5. Seasonal variation of the main species of gastropods in microhabitats. IS= in the soil, S/L= on the soil and/or litter, W/T= wood and/or trunk, L= leaf, LRS= long rainy season, SDS= short dry season, SRS= short rainy season, LDS= long dry season (at least 5% of overall abundance in each microhabitat).

Equitability (E)

Seasonal mean values of E are shown in Table 4. Overall, equitability was highest on S/L and lowest on L, except during LDS where the highest value was recorded in IS, whereas L showed no measurable equitability. According to the Mann–Whitney test In LRS and SDS, equitability on W/T and L differed significantly from that in IS and S/L ($p<0.05$).

During SRS, equitability on L differed significantly from IS and S/L, while W/T differed from both IS and S/L during LDS.

Relative abundance

Seasonal changes in relative abundance across microhabitats are shown in Fig. 5. There are four dominant taxa together accounting for more than 60% in LRS (*Curvella* sp. 1, *Curvella* sp. 2, *Curvella* sp. 3, *Curvella* sp. 4) in IS. In the S/L microhabitat, this distribution was between the four previous taxa and two other species (*Subulona* sp. 1, *Pseudopeas* sp. 1).

During the same season, *Striosubulina striatella* and *Subulona* sp. 1 were the most abundant in W/T. On leaves, a cumulative abundance of more than 60% of *Striosubulina striatella* and *Verucarion* sp. 1 was observed. The four species observed mainly in LRS in the soil represent more than 70% of organisms during the SRS. On the S/L, *Curvella* sp. 4 (18.01%) is the predominant taxon during this last season. It is followed by three other taxa (*Curvella* sp. 3, *Pseudopeas* sp. 1, *Pseudopeas* sp. 2) whose abundances range from 9% to 11.41%. On W/T, the two taxa (*Subulona* sp. 1, *Striosubulina striatella*) present in more than 60% of the samples were replaced by *Edentoulina* sp. and *Gonaxis* sp. 1 on the leaves. During the LDS, *Pseudopeas* sp. 1 and *Pseudopeas* sp. 2 were the most abundant in both IS and S/L, with *Curvella* sp. 4 also prominent in IS. On W/T, half of all individuals belonged to *Striosubulina striatella*. No organisms were recorded on L during this season.

In IS, four taxa (*Curvella* sp. 1, *Curvella* sp. 3, *Pseudopeas* sp. 1, *Pseudopeas* sp. 2) accounted for more than 60% of individuals during the SDS. On S/L, more than half of individuals belonged to five taxa (*Curvella* sp. 2, *Curvella* sp. 3, *Curvella* sp. 4, *Pseudopeas* sp. 1, *Gullela* io). *Subulona* sp. 1 dominated strongly in W/T (63.16%) and completely in L (100%).

DISCUSSION

Spatial variation

Taxonomic richness was highest on soil and/or within litter (S/L) and lowest on leaves, regardless of habitat type. The richness recorded on S/L was followed by that observed in soil (IS) across all habitats. The predominance of molluscs in these two microhabitats may be explained by their need to obtain certain nutrients directly from the soil (Jess, 1989; Forman *et al.*, 2021). Other studies have also confirmed this heterogeneity in species distribution (Patil *et al.*, 2012; Kayeye *et al.*, 2014).

The Shannon diversity index according to microhabitats is highest on S/L. This shows that this microhabitat is more favoured by molluscs, as it appears to be the most diverse. These results are consistent with those of Damerdji (2009) and N'Dri *et al.* (2020). This index is lower on leaves with a value close to zero. This means that there are few species on the leaves, or almost none at all in these two previous habitats. This low diversity may be attributed to the high exposure of leaves to direct sunlight, given their elevated position. As molluscs are highly sensitive to desiccation and generally attracted to humid environments, they tend to avoid canopy-level habitats and preferentially occupy lower strata. The canopy, therefore, remains particularly poor in species. Microhabitat type thus significantly influences species composition and distribution. For example, Thilakarathne *et al.* (2024) showed that in tropical montane forests, factors such as litter quantity, presence of dead wood, and fern and herb cover strongly shape species distribution patterns. Similarly, N'Dri *et al.* (2020) demonstrated that microhabitats such as the soil surface, beneath the litter, on top of litter, and under fallen logs are the most preferred by terrestrial mollusks.

Equitability (E) was markedly higher in IS and S/L, with median values above 0.8, while equitability remained extremely low on W/T and L (median = 0.001). These results indicate that molluscs communities are more evenly distributed in IS and S/L, whereas W/T and L are dominated by only three taxa of the genus *Verucarion* and *Pseudoveronicella*. This equitability value in our work is higher than those obtained by Guennoun *et al.* (2023), which ranged from 0.47 to 0.77 in Morocco. This could be linked to the difference in environment, as the latter worked in the dunes. This arid environment, compared to our study area, may have affected the distribution of molluscs. Subulinidae were particularly abundant in IS, S/L, and on W/T, irrespective of habitat type.

Species such as *Curvella* sp. 2, *Curvella* sp. 3, *Curvella* sp. 4, and *Pseudopeas* sp. 1 also displayed high densities in IS and S/L. The distribution of these species appears to be linked to canopy openness, less dense canopy cover tends to favor species in IS, on S/L and on W/T, which retain higher moisture levels. On the contrary, leaf receives more direct sunlight, is much drier and therefore less suitable for mollucs. The other microhabitats - DS, S/L, and B/T - are more shaded and offer better humidity, explaining mollusc preferences for these zones. Molluscs actively avoid hot and desiccating environments. Bloch and Stock (2014) demonstrated that molluscs exposed to open canopy conditions rapidly migrate toward areas with denser vegetation, where shade and moisture are more abundant. Open canopies receive greater solar radiation than closed canopies (Marthews *et al.*, 2008), making them less favorable for organisms susceptible to dehydration. Some species - such as *Archachatina ventricosa*, *Limicolaria flammea*, *Edentulina* sp., *Gonaxis* sp. 1, and *Striosubulina striatella* - occurred across all four microhabitats, suggesting broad ecological plasticity. However, the two species of the genus *Verucarion* and the species of the genus *Pseudoveronicella* found were almost exclusively found on W/T and L. Despite their small shell size, which could theoretically increase vulnerability to desiccation, these species likely withstand heat through substantial mucus production, which acts as a protective barrier. Their low calcium requirement, associated with reduced shell development, may also contribute to their affinity for these microhabitats. These species may thus be considered primarily arboreal.

Seasonal variation

Seasonal patterns revealed that taxonomic richness remained highest on S/L and in IS during all seasons except the long dry season (LDS). During LDS, no species were recorded on L across all habitat types. This absence is likely due to the strong sensitivity of mollusks to desiccation. Humidity plays a crucial role in triggering feeding and reproductive activities (Abdel El-Raheem *et al.*, 2023; Salvador and Tomotani, 2024). Consequently, mollusks move toward microhabitats that retain suitable moisture levels as seasonal conditions fluctuate. They occupy all microhabitats during humid periods (LRS, SDS, SDS), but avoid leaves during LDS because of excessive exposure and elevated dehydration risk. Kouadio *et al.* (2025) also noted this diversity of molluscs on the ground and litter in northern Côte d'Ivoire in their work. N'Dri *et al.* (2020) showed that litter depth promotes high species richness and abundance, as it provides both a food resource and a refuge under unfavorable conditions, while also offering protection against predators. Conversely, leaves are rarely preferred by terrestrial molluscs. The moisture content of litter is a determining factor in the distribution of molluscs (Książkiewicz-Parulska and Ablett, 2017). According to these authors, the abundance of most species increases with increasing litter moisture. Similar relationships between diversity and soil humidity were reported by Kagawa *et al.* (2024) and Thilakarathne *et al.* (2024).

Shannon diversity was highest on S/L during LRS, SDS, and SRS, and on IS during LDS. It remained extremely low (0.001) on L during all seasons except LDS, during which no individuals were observed in any habitat type. These microhabitats (S/L and IS) likely retain more humidity throughout the year, making them more favorable to molluscs. These findings corroborate those of Thilakarathne *et al.* (2024), who reported high gastropod diversity in moist litter environments in Sri Lanka. The elevated diversity on S/L during LRS and SRS may be linked to sustained humidity maintained by tree cover, which helps preserve suitable moisture levels for molluscs. Seasonal variation in species composition has also been documented in Brazil by Esteves *et al.* (2025). Likewise, Patil *et al.* (2012) demonstrated in India that species richness and density reach their maximum during the monsoon, while the lowest values occur during the hot dry season. During dry periods, mollusks tend to burrow into the soil to access more favorable microclimatic conditions and reduce dehydration risk.

These observations are consistent with those of Shukeran and Rahim (2024), who reported downward vertical migration of mollusks during dry periods.

Seasonal changes also influenced equitability (E). Generally, E was highest in S/L and lowest on L, except during LDS when IS exhibited the highest equitability and L showed no measurable value. These results indicate that mollusc communities respond differentially to seasonal climatic variations. Similar trends were reported by Memel *et al.* (2009) on their study on Achatinidae and Zaidi *et al.* (2021) regarding mollusk diversity in northeastern Algeria.

CONCLUSION

In conclusion, the present study shows that, at the microhabitat scale, soil and/or litter consistently support the highest levels of diversity across all seasons, except during the major dry season, during which maximum diversity is observed in soil. This microhabitat is also characterized by a relatively even distribution of mollusc communities. The taxa *Curvella* sp. 2, *Curvella* sp. 3, *Curvella* sp. 4, and *Pseudopeas* sp. 1 were particularly abundant in both IS and S/L. However, their abundance fluctuated according to seasonal climatic conditions.

These findings highlight the importance of microhabitat structure in shaping the diversity, distribution, and seasonal dynamics of terrestrial mollusks in reforested secondary forests.

Conducting a systematic study of these taxa would provide greater insight into their ecological roles and could help refine conservation and forest restoration strategies aimed at preserving malacological diversity.

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