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Assessing Coleoptera diversity in the chestnut (*Castanea sativa* Mill.) forests of Bursa, Türkiye: a multi-trap approach to evaluate the sampling efficiency and assemblage structure

Oğuzhan Sarikaya, İsmail Şen and Tutku Gencal

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Chestnut (*Castanea sativa* Mill.) forests represent structurally complex ecosystems that sustain high levels of insect diversity, yet the coleopteran assemblages in these habitats remain poorly documented in Türkiye. We assessed the beetle diversity and trap efficiency using a multi-trap approach (window, pitfall and red sticky traps) across coastal (Karacabey, 0-300 m), mid-elevation (Yıldırım, 300-600 m) and high-elevation inland (Osmangazi, 600-900 m) chestnut stands in Bursa Province during 2024. A total of 2,244 individuals representing 188 species belonging to 144 genera and 33 families were recorded. The trap type significantly affected the species richness, diversity and evenness (generalised linear mixed models, $p < 0.001$ in each case), although not the abundance, and explained 50.3% of the variation in the assemblage composition (PERMANOVA, pseudo-$F = 14.77$, $p = 0.0001$) compared with 12.3% for the study site. Window traps yielded the highest richness (127 species; Shannon $H' = 4.49$), while pitfall and sticky traps captured distinct subsets of ground-dwelling and trunk-associated taxa. All three of the trap types differed significantly from one another in their composition, and 35 species proved to be significant indicators of a single method. The most effective single method recovered only 67.6% of the total observed richness, so a reliance on one trap type would have missed approximately one third of the species present. Diversity patterns varied with the forest structure: open-canopy coastal stands supported a higher aerial diversity; whereas over-mature inland stands promoted saproxylic and ground-active assemblages. Because each altitudinal zone was represented by a single forest, differences among the sites were reported as case-specific patterns rather than as general altitude-diversity relationships. Our findings demonstrate that no single method adequately represents the beetle diversity in chestnut forests; instead, a multi-trap strategy is essential. From a management perspective, maintaining structural heterogeneity, including canopy variability, mature stands and deadwood resources, is critical for sustaining biodiversity in temperate deciduous ecosystems.

Key words: alpha diversity, beta diversity, PERMANOVA, window traps, pitfall traps, red-coloured sticky traps.

Oğuzhan Sarikaya✉, Tutku Gencal, Bursa Technical University, Faculty of Forestry, Department of Forest Engineering, Bursa, Türkiye.
E-mail: oguzhan.sarikaya@btu.edu.tr
İsmail Şen, Isparta University of Applied Sciences, Faculty of Technology, Department of Biomedical Engineering, Isparta, Türkiye.

Türkiye is located at the intersection of the Euro-Siberian, Mediterranean and Irano-Turanian biogeographical regions, and is characterised by pronounced geological and topographical heterogeneity, diverse climatic regimes and a wide range of microhabitat conditions. This environmental complexity supports exceptionally high levels of species richness and endemism across plant and animal taxa (Şekercioğlu *et al*. 2011; Zohary 1973; Avcı 2005). Forest ecosystems, in particular, harbour high levels of biodiversity and complex species interactions, while providing essential ecosystem services, in-

cluding carbon regulation, climate stabilisation, habitat provision and biodiversity conservation (Lindenmayer & Franklin 2002; FAO 2020; Pan *et al*. 2011).

The effective conservation of forest biodiversity requires comprehensive faunistic and systematic research to accurately document the species diversity and inform management strategies (Cardoso *et al.* 2011; Egorov *et al*. 2024). Insects constitute more than half of all known species and represent the most diverse terrestrial group (Stork 2018; Zhang 2011), yet their community dynamics across forest stand types remain insufficiently understood in many regions (Nieto & Alexander 2010; Didham *et al.* 2020). Among them, Coleoptera, with approximately 400,000 described species, play key ecological roles in decomposition, nutrient cycling and energy flows (Slipinski *et al.* 2011; Stork 2018; Parisi *et al.* 2020). In Türkiye, this order is represented by approximately 13,396 species (Tezcan 2024). Their ecological importance is particularly evident in deciduous forests, where deadwood resources provide critical feeding and breeding substrates (Grove 2002; Seibold *et al.* 2015).

The sweet chestnut (*Castanea sativa* Mill.) is a major component of Türkiye's natural vegetation that holds both ecological and economic importance (Soylu 2004; Cedano Giraldo & Mumcu Küçüker 2023). Chestnut forests, typically found in humid broad-leaved ecosystems, offer suitable habitats for diverse insect communities due to their well-developed understories and abundant deadwood (Soylu 2004). Although the ecological significance of chestnut forests has been well documented in Europe (Zlatanov *et al.* 2013; Parisi *et al.* 2020), studies of the beetle communities in Turkish chestnut stands remain limited (Kaplan & Turanlı 2016; Sürgüt & Varlı 2023). The existing research has largely focused on specific taxonomic groups, while comprehensive assessments of Coleoptera assemblages across different stand structures and altitudinal gradients are still lacking.

A reliable assessment of the beetle diversity in structurally complex forests depends not only on field sampling but also on a selection of the appropriate methodologies (Egorov *et al.* 2024; Ruchin *et al.* 2021). Trap-based methods are widely used; however, each trap type samples a distinct component of the fauna. Window traps effectively capture saproxylic and flying species (Hyvärinen *et al.* 2006), while pitfall traps target ground-dwelling taxa (Woodcock 2005; Skvarla & Dowling 2017) and sticky traps represent one of several methods used to sample bark and ambrosia beetles, alongside multi-funnel, intercept panel, bottle and window traps (Dodds *et al.* 2024). Previous studies have shown that these methods exhibit a low overlap in the captured assemblages, indicating that single-method approaches underestimate the total diversity (Egorov *et al.* 2024; Musthafa *et al.* 2022).

Bursa Province represents a suitable model system for such investigations, as it hosts extensive chestnut forests across a pronounced altitudinal gradient (Akilli 2012; Gencal & Sarikaya 2023a). This gradient encompasses substantial variations in stand structures and environmental conditions, providing an opportunity to evaluate both the beetle assemblage patterns and the sampling efficiency within a single framework (Parisi *et al.* 2020; Sürgüt & Varlı 2023). This study aims to: (i) compare the effectiveness of window, pitfall and red sticky traps in sampling Coleoptera diversity; (ii) characterise the beetle assemblages across different altitudinal zones; and (iii) identify the environmental drivers shaping these patterns. We hypothesised that each trap type would target a functionally distinct component of the beetle fauna, and that no single method would be sufficient to capture the full extent of the coleopteran diversity in structurally complex forest ecosystems.

Materials and Methods

1. Study sites

Bursa Province is geographically situated in the southern Marmara Region (Türkiye); specifically, between 40°12′N latitude and 29°04′E longitude. Serving as a strategic bridge between the Marmara Region and both Central and Western Anatolia, the province is bordered by the Sea of Marmara to the north, Kütahya to the south, Bilecik to the east and Balıkesir to the west (Gencal & Sarıkaya 2023b). The total forest area of the province is 553,214 ha (Sönmez & Gencal 2019), while sweet chestnut trees cover a total area of 11,580.5 ha within the boundaries of the Bursa Regional Directorate of Forestry (Büber 2021). The study was conducted across three distinct experimental sites in Bursa Province, representing key chestnut (*C. sativa*) forest ecosystems (Table 1, Figure 1).

These sites were categorised according to their altitudinal ranges, with each comprised of three sampling stations identified by specific site codes (KB1–KB3, YL1–YL3 and OG1–OG3). The sampling stations were established with a minimum distance of 200 m between them to reduce the spatial dependence and to represent local environmental variability

Table 1

Structural characteristics of the study sites across different altitudinal ranges in Karacabey (KB), Yıldırım (YL) and Osmangazi (OG). Altitudes are expressed in metres above sea level (m a.s.l.). DBH: Diameter at Breast Height; TAR: Tree Age Range

Site	Stand Code	Altitude	Dominant Tree Species	Development Stage of the Stand (DBH)	TAR (years)	Crown Closure
KB	Ksb1	0-300	*C. sativa*	Medium diameter (8-19.9 cm DBH)	15-35	Low closure (11-40%)
KB	KsDfa	0-300	*C. sativa*, *L. nobilis*	Small diameter (0-7.9 cm DBH)	1-15	Open/Sparse (<10%)
YL	KnKsbc3	300-600	*F. orientalis*, *C. sativa*	Medium-large diameter (8-35.9 cm DBH)	35-80	High closure (71-100%)
OG	Ksd2	600-900	*C. sativa*	Very-large diameter forest (> 36 cm)	80-120+	Moderate/Medium closure (41–70%)

within each study site. **Site 1:** Karacabey-Kurşunlu (KB): Situated at an altitudinal range of 0-300 m, this site falls under the Karacabey Forest Operation Directorate, Yeniköy Forest Operation District (Compartment No. 4) (Table 1). Located within a coastal/marine-influenced ecosystem, the area is characterised by two distinct stand types: Ksb1, consisting of a chestnut forest in the medium diameter class with a low crown closure; and KsDfa, a chestnut-dominated and laurel-mixed (with *Laurus nobilis* L.) successful regeneration area where the canopy closure has not yet formed. The sampling stations

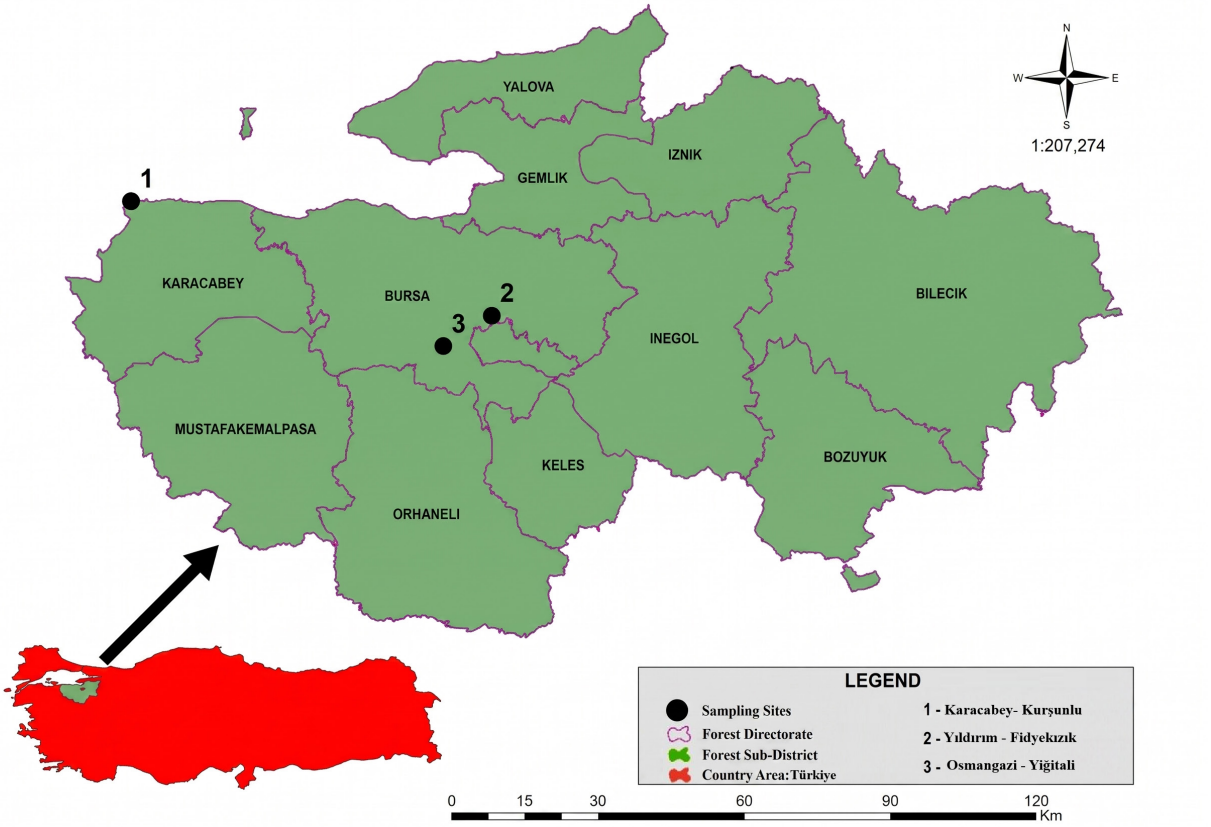

Fig. 1. Location of the three study sites within Bursa Province, north-western Türkiye. 1: Karacabey-Kurşunlu (KB), Karacabey Forest Operation Directorate, Yeniköy Forest Operation District (0-300 m a.s.l.); 2: Yıldırım-Fidyekızık (YL), Yıldırım Forest Operation District (300-600 m a.s.l.); 3: Osmangazi-Yiğitali (OG), Bursa-Merkez Forest Operation District (600-900 m a.s.l.). Green shading indicates the area administered by the Bursa Regional Directorate of Forestry; the inset shows the position of the province within Türkiye.

within this site were coded as KB1, KB2 and KB3. **Site 2:** Yıldırım-Fidyekızık (YL): Located at an altitudinal range of 300-600 m, this area is managed by the Yıldırım Forest Operation District (Compartment No. 5) (Table 1). This site is situated within an inland terrestrial ecosystem. The dominant forest structure has been identified as the KnKsbc3 stand type, which consists of a mixed beech and chestnut forest (*Fagus orientalis* and *Castanea sativa*) in the medium and large diameter classes with a high crown closure. The sampling stations were identified as YL1, YL2 and YL3. **Site 3:** Osmangazi-Yiğitali (OG): Situated at the highest altitudinal range of 600-1000 m, this site lies within the Bursa-Merkez Forest Operation District (Compartment No. 19) (Table 1). Located in an inland terrestrial ecosystem, the forest structure is characterised by the Ksd2 stand type. This area consists of a chestnut forest (*Castanea sativa*) in the very-large diameter class with a moderate crown closure. The sampling stations within this site were coded as OG1, OG2 and OG3.

2. Sampling design and biological sampling

Three sampling stations were established in each study site, giving nine stations in total. Window traps, pitfall traps and red sticky traps were used to capture the taxonomic and functional diversity of the Coleoptera fauna in the chestnut stands of Bursa Province (Figure 2). Window traps: To sample high-flying and saproxylic species, window traps consisting of a transparent plexiglass plate (30x50 cm) and a metal collecting container (15x15x30 cm) were used. These were suspended from trees at heights ranging from 1.5 to 5 m above ground level (Sürgüt & Varlı 2023). Pitfall traps: For monitoring ground-dwelling and nocturnal arthropods, plastic containers (12.5 cm diameter, 13 cm depth) were embedded in the forest floor. Each trap was filled to a two-thirds capacity with a glycol-water solution at a ratio of (1:2) to preserve the captured specimens (Skvarla & Dowling 2017). The trap dimensions followed the range most widely used in forest carabid and saproxylic beetle surveys, and were chosen to remain comparable with the earlier work in Turkish forest ecosystems. Red sticky traps: The trap colour is an important component of trapping efficiency because visual responses differ among bark- and ambrosia beetle species. Previous studies have shown that although black and green traps are generally effective for many Scolytinae species, certain taxa respond more strongly to alternative colours, including red, purple and blue, indicating that no single trap colour is universally attractive (Cavaletto *et al.* 2020; Marchioro *et al.* 2020). Consequently, red sticky traps were selected in the present study as one of the standard sampling methods for trunk-associated Coleoptera, recognising that the trap colour may influence the representation of individual taxa. To target bark beetles and secondary pests via visual and chemical cues, red sticky traps were deployed at heights of 2-2.5 m. The traps were baited with a mixture of 96% ethanol and 1% toluene, following a previously validated trapping protocol for bark beetles. Ethanol is a well-established host-derived kairomone released by physiologically stressed or recently dead trees, and is widely used to attract bark, ambrosia and other wood-associated beetles (Miller & Rabaglia 2009). The addition of 1% toluene was adopted because previous studies have demonstrated that diluting 96% ethanol with 1% toluene improved the performance of sticky traps for capturing bark beetles compared with those baited with ethanol alone (Ak *et al.* 2014; Aker 2022).

The trap heights were adopted from previous studies rather than optimised for this work. Window traps were suspended between 1.5 and 5 m, which is the range used by Sürgüt and Varlı (2023) in comparable broad-leaved stands, because flight-intercept traps set at this height sample both understorey and lower-canopy flight activity. Red sticky traps were placed at 2 to 2.5 m, corresponding to the trunk zone where bark and ambrosia beetles typically land and where sticky traps have been used in earlier surveys of these taxa (Sarıkaya & Sayın 2016). We do not claim that these heights are optimal for either method, and we made no attempt to separate the effect of the height from other design features; this limitation is addressed explicitly in Section 4.5.

The sampling effort differed among the trap types: three window traps, five pitfall traps and five red sticky traps were deployed at each of the nine sampling stations, giving 27 window traps, 45 pitfall traps and 45 red sticky traps in total. Within a station, the pitfall traps were spaced 10 m apart, window traps 20 m apart and red sticky traps 25 m apart. For each station, the catch of all the traps of a given type was pooled, yielding 27 station-by-trap-type samples (nine stations x three trap types), which formed the units of the analysis. The traps remained in the field from March to October 2024 and were checked at 21-day intervals, at which stage the catch was removed, the preservative fluid renewed and the traps replaced. No trap was found flooded or containing a decomposed catch during the sampling period. The specimens collected from the traps were transferred to storage containers and preserved in the laboratory.

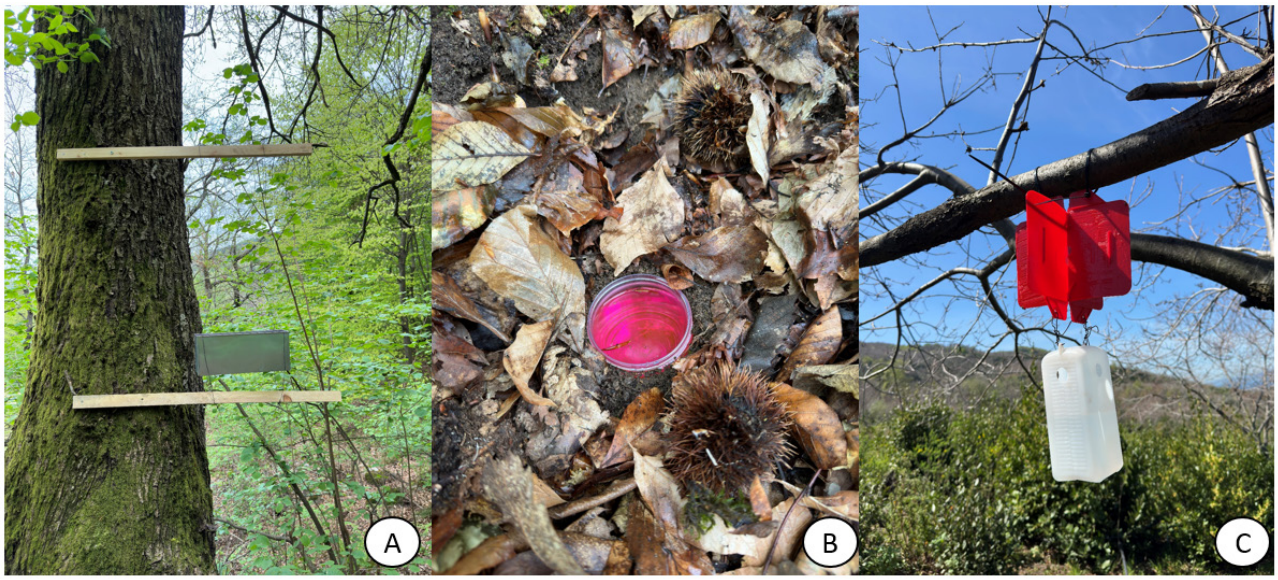

Fig. 2. The trap types used in the study: A – Window trap, B – Pitfall trap, C – Red-coloured sticky trap.

The three trap types were deployed together at every sampling station, so that each station received the complete set of treatments. The design is therefore a randomised complete block design in which the sampling station serves as the block, and comparisons among the trap types were made within stations rather than across them. The trap positions within a station were assigned so as to maintain the specified spacing while avoiding local features such as gaps, tracks and watercourses. The positions were not randomised within this constraint, and the station was therefore treated as a blocking factor rather than individual traps as independent units.

3. Preparation and preservation of specimens

Specimens were sorted to the family level under a stereomicroscope and forwarded to the relevant specialists for identification. The taxa were allocated as follows: Carabidae were identified by Assoc. Prof. Rumyana Kostova (Faculty of Biology, Sofia University); Scolytinae were identified by Dr Miloš Knížek and Dr Petr Zahradník (Forestry and Game Management Research Institute, Prague) and Dr Michail Mandelshtam (St Petersburg State Forest Technical University); Tenebrionidae by Prof. Bekir Keskin (Faculty of Science, Ege University); Cerambycidae by Dr Luis Miguel Torres-Vila (Institute for Plant Health, Extremadura); Elateridae by Dr Nilay Gülperçin (Faculty of Agriculture, Ege University); and the remaining saproxylic families by Dr Hakan Sürgüt and Dr Aylin Tüven (Faculty of Arts and Sciences, Balıkesir University).

All of the identified specimens were returned to the authors and deposited in the Entomology Laboratory, Department of Forest Engineering, Faculty of Forestry, Bursa Technical University.

4. Data analysis

All of the analyses were performed in R 4.4.1. Each of the nine sampling stations received all three trap types, yielding 27 trap-by-station samples, which were analysed as a randomised complete block design with the sampling station as the blocking unit.

The alpha diversity was quantified for each sample as: species richness (S), abundance (N), the Shannon-Wiener index (H′), the Simpson index (1-D) and Pielou's evenness (J′). Values were reported as the mean ± standard error across the nine sampling stations. Pooled trap-level indices, calculated on the assemblage combined across all stations, were reported separately, since the two are not directly comparable.

The effect of the trap type on S and N was tested with generalised linear mixed models. A Poisson error structure was used where the Pearson dispersion statistic was close to unity (S: $\varphi = 1.22$), and a negative binomial structure was used where it was not (N: $\varphi = 3.59$). The sampling station was included as a random effect to account for the hierarchical structure of the design. H′, 1-D and J′ were analysed with linear mixed models under the same random structure. Because nine blocks provide limited power for parametric assumptions, all the trap-type effects were additionally verified with Friedman tests blocked by

the sampling station, followed by Wilcoxon signed-rank post-hoc comparisons with a Holm correction. The effect of the study site was tested with trap types pooled and the sampling stations used as replicates. The same approach was applied to the six most species-rich families. Because the number of traps per station differed among the trap types, all comparisons were made on the pooled catch per station and per trap type, and richness comparisons were additionally standardised by individual-based rarefaction.

The assemblage composition was compared using a permutational multivariate analysis of variance (PERMANOVA, 9,999 permutations) on Bray-Curtis dissimilarities computed from the relative abundances, which controls for unequal capture totals among the trap types, and on Jaccard distances derived from presence-absence data. The trap type and site were entered as factors. The homogeneity of multivariate dispersion was assessed with PERMDISP and pairwise contrasts among the trap types were Holm-corrected. Compositional patterns were visualised by non-metric multidimensional scaling (NMDS) on the same Bray-Curtis dissimilarity matrix. The species characteristic of each trap type were identified by an indicator species analysis (IndVal, 999 permutations) with a Benjamini-Hochberg correction of the false discovery rate. The sampling completeness was evaluated with an individual-based rarefaction and Chao1 richness estimation. Compositional similarity among the sites was additionally summarised with the Sørensen and Jaccard indices and UPGMA clustering.

To test whether carrion-attracted Silphidae influenced the outcome, all trap-type analyses were repeated with this family excluded as a sensitivity check.

The analyses used the vegan (Oksanen *et al.* 2007) package for PERMANOVA, PERMDISP, NMDS and rarefaction, lme4 (Bates *et al.* 2015) and glmmTMB (Brooks *et al.* 2017) for the mixed models, and indicspecies (De Cáceres & Legendre 2009) for the indicator species analysis.

Results

1. Taxonomic composition and species dominance

A total of 2,244 Coleoptera individuals were collected across the three chestnut forest sites. The identification revealed 188 species belonging to 144 genera and 33 families. The most species-rich families were Cerambycidae (34 species, 18.1%), Curculionidae (26 species, 13.8%) and Elateridae (24 species, 12.8%), which together accounted for almost half of the recorded fauna. The same pattern held at the site level, with Cerambycidae being the most species-rich family at KB and OG, while Curculionidae took that position at YL.

The dominant species across the study area, by number of individuals, were *Xyleborinus saxesenii* (119 individuals; 5.30%), *Trichodes apiarius* (99; 4.41%) and *Anisandrus dispar* (84; 3.74%), followed by *Nicrophorus investigator* (79; 3.52%) and *Scobicia chevrieri* (71; 3.16%).

The composition of the catch differed markedly among the methods, and these differences were significant for every dominant family (Table 2). The red sticky traps were strongly selective for Curculionidae; in particular, the ambrosia and bark beetles *X. saxesenii*, *Taphrorychus villifrons* and *A. dispar*, capturing on average 44.0 individuals of this family per sampling station compared to 8.9 in the window traps. The pitfall traps were selective for ground-associated families, notably Carabidae, Silphidae and Staphylinidae, while neither Carabidae nor Scarabaeidae were recorded in the sticky traps at all. The window traps covered the broadest taxonomic spectrum, sampling flight-active and xylophagous species simultaneously.

The indicator species analysis confirmed this partitioning (Table 3). Thirty-five of the 188 species were significant indicators of a single trap type: 13 for the window traps, including *Cerambyx cerdo*, *Cetonia aurata* and *Capnodis tenebricosa*; 10 for the pitfall traps, including *Nicrophorus investigator*, *Carabus coriaceus* and *Mordella aculeata*; and 12 for the sticky traps, which were almost all Scolytinae, among them *Xyleborinus saxesenii*, *Anisandrus dispar*, *Scolytus rugulosus* and *Taphrorychus villifrons*. The ecological affiliations of these indicator species correspond closely to the stratum that each method samples.

Within the window trap data, KB reached the highest species richness with 72 species and 350 individuals, followed by OG (59 species, 254 individuals) and YL (51 species, 218 individuals). *Scobicia chevrieri* was the most dominant species at both KB and YL (4.57% and 7.80%, respectively), whereas *Melolontha melolontha* ranked first at OG (4.72%).

2. Trap efficiency and community metrics

The trap performances varied significantly in terms of species richness but, unexpectedly, not in terms of abundance (Tables 4 and 5). Window traps were the most effective method overall, returning the highest species richness, the largest catch and the

Table 2

Abundance of the six most species-rich families across the trap types, with Friedman tests blocked by the sampling station. Values are the mean ± SE individuals per sampling station. S: number of species in the family, with its percentage of the total 188 species in parentheses; N: total number of individuals; χ^2: Friedman test statistic

Family	S (%)	N	χ^2	p	Window	Pitfall	Sticky
Cerambycidae	34 (18.1)	215	14.89	0.0006	16.3 ± 1.7	5.0 ± 1.0	2.6 ± 1.0
Curculionidae	26 (13.8)	510	13.56	0.0011	8.9 ± 3.0	3.8 ± 0.8	44.0 ± 2.6
Elateridae	24 (12.8)	187	14.22	0.0008	12.9 ± 1.0	1.2 ± 0.4	6.7 ± 1.1
Carabidae	15 (8.0)	105	16.71	0.0002	0.8 ± 0.4	10.9 ± 1.2	0.0 ± 0.0
Ptinidae	11 (5.9)	148	14.00	0.0009	8.0 ± 1.4	6.2 ± 1.1	2.2 ± 0.9
Scarabaeidae	11 (5.9)	140	15.94	0.0003	9.1 ± 1.1	6.4 ± 0.7	0.0 ± 0.0

Table 3

Species identified as significant indicators of a single trap type (IndVal, 999 permutations, Benjamini-Hochberg FDR < 0.05). The five species with the highest IndVal are listed for each method; 35 species were significant, in total

Trap type	Indicator species	IndVal	N	p (FDR)
Window	*Cetonia aurata*	2.67	17	0.015
Window	*Capnodis tenebricosa*	2.00	20	0.020
Window	*Gonodera jureceki*	2.00	13	0.015
Window	*Melanotus fusciceps*	2.00	14	0.020
Window	*Pseudocistela ceramboides*	1.79	42	0.035
Pitfall	*Nicrophorus investigator*	3.00	79	0.015
Pitfall	*Mordella aculeata*	2.79	43	0.015
Pitfall	*Agrilus relegatus alexeevi*	2.67	17	0.015
Pitfall	*Hylastes linearis*	2.00	16	0.026
Pitfall	*Carabus coriaceus*	1.77	26	0.020
Red sticky	*Phyllobius arborator*	3.00	38	0.015
Red sticky	*Xyleborinus saxesenii*	2.62	119	0.015
Red sticky	*Anisandrus dispar*	2.50	84	0.015
Red sticky	*Taphrorychus villifrons*	2.49	59	0.015
Red sticky	*Scolytus rugulosus*	2.00	32	0.020

Table 4

Coleoptera species and individuals collected by trap type. Mean ± SE was calculated across the nine sampling stations; totals and pooled indices were calculated on the assemblage combined across the stations. S: species richness; N: individuals; H′: Shannon-Wiener; 1-D: Simpson; UniqS: species recorded in that trap only

Trap type	S (mean ± SE)	N (mean ± SE)	H′ (mean ± SE)	1-D (mean ± SE)	S tot	N tot	UniqS	H′ pooled	1-D pooled
Window	42.11 ± 3.23	91.33 ± 8.30	3.58 ± 0.07	0.968 ± 0.002	127	822	77	4.49	0.98
Pitfall	26.33 ± 1.68	74.67 ± 3.30	3.05 ± 0.08	0.940 ± 0.006	67	672	31	3.70	0.96
Red sticky	22.89 ± 1.10	83.33 ± 4.96	2.88 ± 0.04	0.930 ± 0.003	55	750	25	3.44	0.95

Table 5

Effect of the trap type on the community metrics. Generalised linear mixed models with the sampling station as a random effect; Window is the reference level. S: species richness; N: individuals; H': Shannon-Wiener; 1-D: Simpson index; J': Pielou's evenness

Response	Model	Omnibus χ^2	p	Pitfall vs Window	Sticky vs Window
S	GLMM (Poisson)	133.90	< 0.001	$\beta = -0.470$, $p < 0.001$	$\beta = -0.610$, $p < 0.001$
N	GLMM (neg. binom.)	8.48	0.014	$\beta = -0.202$, $p = 0.005$	$\beta = -0.092$, $p = 0.137$
H′	LMM	128.28	< 0.001	$\beta = -0.533$, $p < 0.001$	$\beta = -0.695$, $p < 0.001$
1-D	LMM	62.39	< 0.001	$\beta = -0.026$, $p < 0.001$	$\beta = -0.037$, $p < 0.001$
J′	LMM	33.01	< 0.001	$\beta = -0.027$, $p < 0.001$	$\beta = -0.038$, $p < 0.001$

greatest number of unique species, while also providing the highest richness at every site. The pitfall traps ranked second in richness, while the red sticky traps captured the fewest species but a high number of individuals, most of them bark and ambrosia beetles. The full values are given in Table 4.

Generalised linear mixed models with the sampling station as a random effect confirmed a significant effect of the trap type on the richness ($\chi^2 = 133.90$, $p < 0.001$), Shannon diversity ($\chi^2 = 128.28$, $p < 0.001$), Simpson diversity ($\chi^2 = 62.39$, $p < 0.001$) and the Pielou evenness ($\chi^2 = 33.01$, $p < 0.001$). The window traps differed significantly from both the pitfall and sticky traps for each of these metrics (Holm-adjusted $p = 0.012$), whereas the pitfall and sticky traps did not differ from one another. Abundance behaved differently: the omnibus effect was weak ($\chi^2 = 8.48$, $p = 0.014$) and the non-parametric test found no significant difference at all (Friedman $\chi^2 = 3.06$, $p = 0.22$). Red sticky traps therefore capture many individuals belonging to comparatively few species, a distinction that a comparison of the totals alone would obscure.

The superiority of the window traps is not an artefact of the catch size. When rarefied to the smallest trap total (N = 672), the window traps still yielded 125.1 species against 67.0 for the pitfall traps and 54.8 for sticky traps. Chao1 estimates (127.2, 67.7 and 55.0, respectively; and 188.6 for all traps combined) indicate that each method approached its asymptote. The window traps alone recovered 127 of the 188 species observed, or 67.6%, so a reliance on the single most effective method would still have missed roughly a third of the fauna.

The similarity among the assemblages captured by the three methods was low throughout. The window and pitfall traps formed the most similar pair (Sørensen 0.32; Jaccard 0.19), followed by the window and sticky traps (0.28; 0.16), while the pitfall and sticky traps showed the least amount of overlap (0.18; 0.10). Only six of the species were recorded by all three methods.

This superiority was achieved with a lower sampling effort. Window traps accounted for 27 of the 117 traps deployed, against 45 each for pitfall and sticky traps, yet returned the highest species richness and the highest catch per trap (30.4 individuals per trap, compared to 14.9 for the pitfall and 16.7 for the sticky traps). Any bias arising from an unequal effort therefore acts against window traps, and the difference reported here is (if anything) conservative.

3. Assemblage composition across trap types and sites

The PERMANOVA on the 27 trap-by-station samples showed that the trap type was by far the strongest determinant of the assemblage composition (Table 6). Using Bray-Curtis dissimilarities computed from relative abundances, the trap type accounted for 50.3% of the compositional variation (pseudo-F = 14.77, p = 0.0001), whereas the study site accounted for 12.3% and did not reach significance (p = 0.066). The same analysis on Jaccard distances gave a comparable result for the trap type (39.1%, p = 0.0001) and a significant but much smaller effect of the site (17.2%, p = 0.0011).

All three trap types differed significantly from one another in a pairwise comparison (Holm-adjusted p = 0.0003 throughout). The strongest separation was between the pitfall and sticky traps ($R^2 = 0.535$), followed by the window versus sticky traps ($R^2 = 0.402$) and the window versus pitfall traps ($R^2 = 0.351$). This ordering follows the vertical strata that the methods sample: the soil surface and the tree trunk lie furthest apart, while window traps intercept an intermediate, flight-active fauna.

The NMDS ordination (Figure 3) shows the same structure. The three trap types form clearly separated

Table 6

PERMANOVA of the Coleoptera assemblage composition across 27 trap-by-station samples (9,999 permutations)

Distance measure	Factor	pseudo-F	R^2	p
Bray–Curtis (relative abundance)	Trap type	14.77	0.503	0.0001
Bray–Curtis (relative abundance)	Site	3.60	0.123	0.066
Jaccard (presence/absence)	Trap type	9.84	0.391	0.0001
Jaccard (presence/absence)	Site	4.33	0.172	0.0011

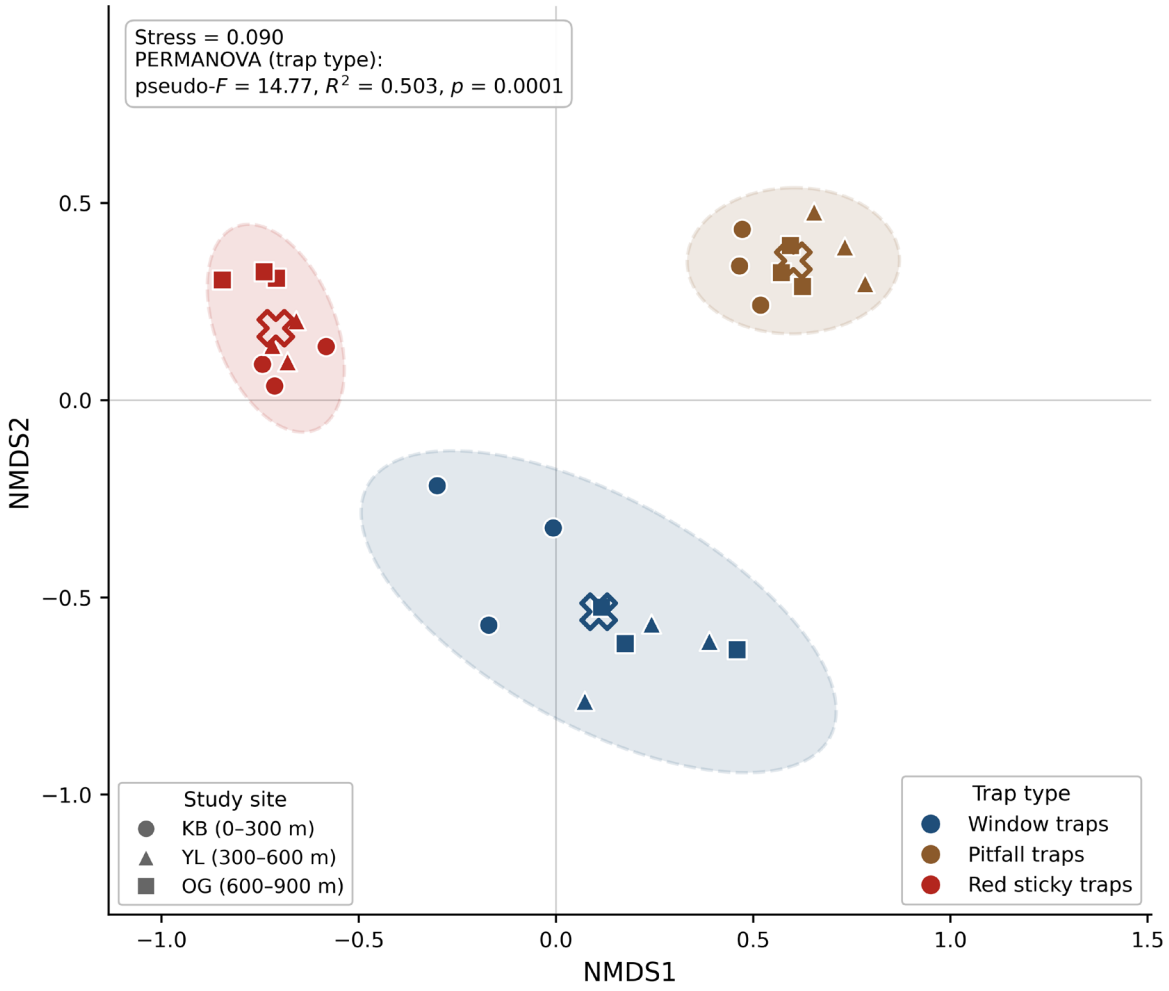

Fig. 3. Non-metric multidimensional scaling (NMDS) ordination of the Coleoptera assemblages across 27 trap-by-station samples, based on Bray-Curtis dissimilarities calculated from relative abundances (stress = 0.090). Colours denote the trap type and symbols denote the study site. Dashed ellipses show 95% confidence regions for each trap type and crosses mark group centroids. The trap type explained 50.3% of the variation in the assemblage composition (PERMANOVA, pseudo-F = 14.77, p = 0.0001), compared with 12.3% for the study site.

clusters whose 95% confidence ellipses barely overlap, while samples from the three study sites are distributed within each trap cluster rather than forming clusters of their own. The sampling method, and not the location, is the dominant axis of variation in this data.

Multivariate dispersion was heterogeneous among the trap types (PERMDISP, F = 15.85, p = 0.0001) and among the sites (F = 8.02, p = 0.0001). Part of the PERMANOVA signal therefore reflects differences in within-group variability as well as in the centroid

position, and this should be borne in mind when interpreting the result. The window traps showed the greatest within-group dispersion, which is consistent with their broader taxonomic coverage. Given the magnitude of the trap effect, however, dispersion is unlikely to account for this result on its own.

4. Diversity patterns across the study sites

The Shannon-Wiener (H') and Simpson (1-D) indices (Table 7) indicated that the Coleoptera diversity values were numerically high across all study sites and trap types. For the window traps, the Shannon index values ranged from 3.299 to 3.982, while the Simpson index values ranged from 0.958 to 0.978 (Table 7). The highest recorded Shannon value (3.982) was observed at KB2, while the other stations showed comparable values with relatively limited variation. For the pitfall traps, the Shannon index values ranged from 2.655 to 3.390, and the Simpson index values ranged from 0.907 to 0.960 (Table 7). The highest Shannon value (3.390) was recorded at OG2, with the other stations exhibiting values within a similar range. For the red sticky traps, the Shannon index values varied between 2.626 and 3.034, and the Simpson index values ranged from 0.917 to 0.942 (Table 7). The highest Shannon value (3.034) was observed at KB3, while the remaining stations showed relatively comparable values. Across all trap types, the diversity index values displayed overlapping ranges among the study sites, with variation occurring at the station level.

With the trap types pooled and the sampling stations used as replicates, the study site had a significant effect on the species richness ($p = 0.019$) and abundance ($p < 0.001$), but not on the Shannon ($F = 4.31$, $p = 0.069$) or Simpson diversity ($F = 3.52$, $p = 0.097$). Within individual trap types, the site effect on the Shannon diversity was significant only for the pitfall traps ($F = 9.12$, $p = 0.015$), where OG showed the highest values, and was not significant for the window traps ($p = 0.074$) or sticky traps ($p = 0.103$). The mean Shannon values by site were 3.25 ± 0.13 for KB, 3.25 ± 0.10 for OG and 3.01 ± 0.11 for YL. Because each altitudinal zone is represented by a single forest, these differences cannot be attributed to the altitude specifically, and they are reported here as case-specific patterns rather than as evidence of a general relationship.

5. Similarity patterns of Coleoptera assemblages across the study sites

The similarity in species composition among the KB, OG and YL study sites was analysed using the Sørensen and Jaccard indices based on the determined Coleoptera species. Cluster analyses (UPGMA) revealed that both indices yielded consistent and mutually supportive results across all three trap types (Figure 4). Regarding the data obtained from the window traps, the OG and YL sites were identified as the most similar in terms of the species composition. Both indices indicated a markedly higher degree of similarity between these two localities compared to the others, a trend that is clearly illustrated in the corresponding dendrograms (Figure 4 a-b). A similar pattern was observed in the pitfall trap data, where the highest similarity rate was again recorded between the OG and YL sites. This substantial overlap in species composition was further corroborated by a consistent clustering tendency in both index frameworks (Figure 4 c-d). In contrast, the analysis of the red sticky trap data revealed a distinct distributional pattern. For this trap type, the highest similarity in the species composition was determined to be between the KB and YL study sites. The Sørensen and Jaccard index results, along with the associated similarity diagrams (Figures 4 e-f), confirmed that

Table 7

Shannon-Wiener (H′) and Simpson (1-D) diversity indices for each sampling station, by trap type. H′ weights common and rare species equally and increases with both the richness and evenness; while 1-D expresses the probability that two individuals drawn at random belong to different species, and is most sensitive to changes among the abundant species. The stations are coded by site as follows: KB (coastal, 0-300 m), OG (inland, 600-900 m), YL (mid-elevation, 300-600 m)

Trap type	Indices	KB1	KB2	KB3	OG1	OG2	OG3	YL1	YL2	YL3
Window traps	H′	3.73	3.98	3.55	3.60	3.67	3.48	3.47	3.45	3.30
	1-D	0.97	0.98	0.97	0.97	0.97	0.97	0.96	0.96	0.96
Pitfall traps	H′	2.92	3.15	2.96	3.28	3.39	3.20	2.94	2.94	2.66
	1-D	0.92	0.95	0.93	0.96	0.96	0.95	0.94	0.94	0.91
Sticky traps	H′	2.94	3.00	3.03	2.86	3.03	2.79	2.63	2.83	2.85
	1-D	0.94	0.93	0.94	0.93	0.94	0.92	0.92	0.92	0.93

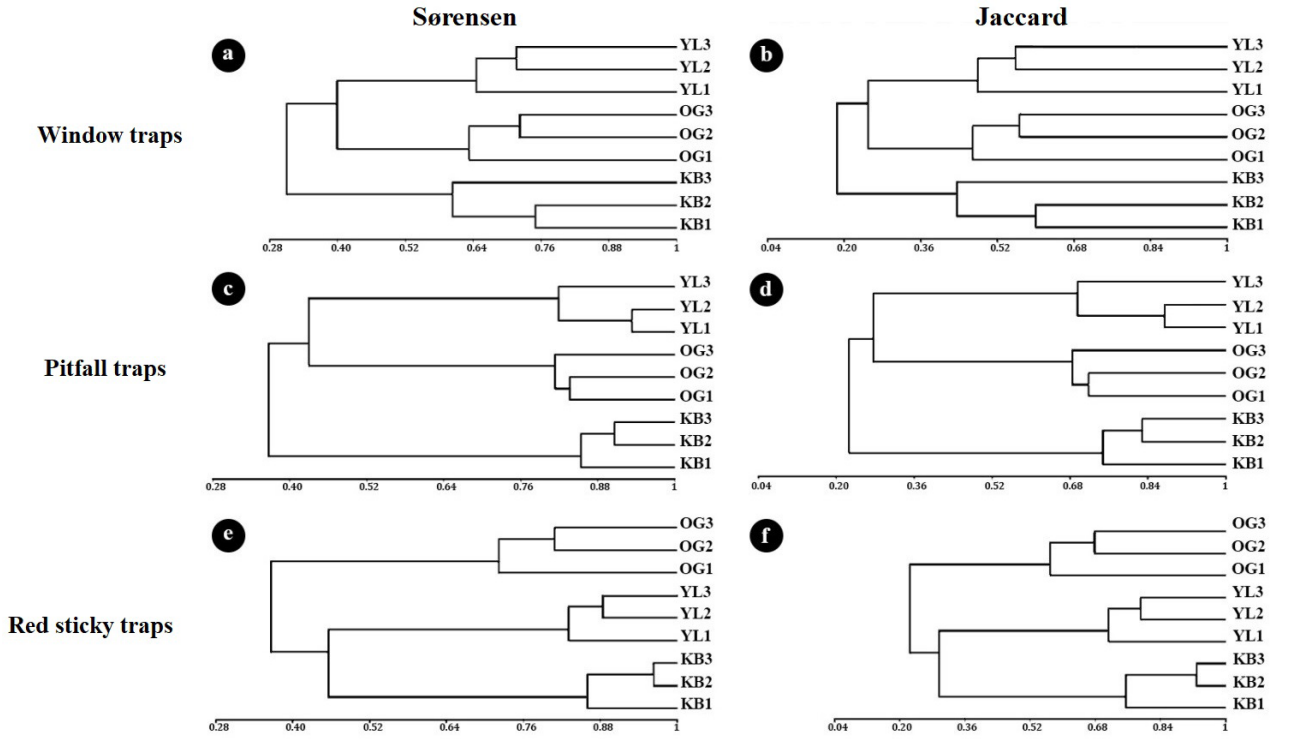

Fig. 4. Dendrograms representing the similarity of Coleoptera communities among the study sites based on Sørensen and Jaccard indices (respectively) for the window traps (a-b), pitfall traps (c-d) and red sticky traps (e-f).

KB and YL were the most closely related localities regarding the Coleoptera assemblages sampled via the sticky traps.

6. Sensitivity analysis

Because Silphidae are attracted to carrion rather than being generalist forest-floor taxa, we repeated all the trap-type analyses with this family excluded, in order to confirm that the results were not driven by their abundance in the pitfall traps. The conclusions were unchanged (Friedman on H′: $\chi^2 = 14.89$, $p = 0.0006$; mean H′ 3.58 for window, 3.01 for pitfall and 2.87 for sticky traps). *Nicrophorus* was recorded at all nine pitfall stations, with between 6 and 18 individuals per station, and accounted for 15.0% of the pitfall catch. No Nicrophorus were recorded in the window traps, which also employ a liquid-filled collecting container.

Discussion

1. Coleoptera diversity and assemblage composition across trap types

Regarding the taxonomic efficiency and overlap of the sampling methodologies, only six species were commonly detected by all three trap types, indicating a profound functional divergence in the beetle captures. Window traps emerged as the most comprehensive method, with 127 species identified in total, 77 of which were captured exclusively by this technique.

In addition, the pitfall and red sticky traps collected 67 and 55 insect species. The number of overlaps of species between the different traps, which is the number of species found in two different traps, also highlighted their differences as there were 25 species shared by the window and pitfall traps, 19 that overlapped in both the window and sticky traps, and only 5 that overlapped in both the pitfall and sticky traps. This demonstrates that each trap type samples a very distinct functional group/ecological niche due to the large number of unique catches, with 31 species found only in the pitfall traps and 25 species found only in the red sticky traps.

The biodiversity indices confirmed this finding. The biodiversity was highest for the window traps, as evidenced by the highest values for the Shannon's H′ (4.49) and Simpson's index (1-D = 0.98) in all cases. This demonstrates the ability of the window trap to not only collect a high number of diverse species, but also to collect organisms that are evenly distributed throughout the sampled community. The pitfall traps had lower diversity than the win-

dow traps (H′=3.70), while the red sticky traps had even lower diversity values (H′=3.44), indicating that they collected samples from a limited number of ecological strata. In addition to the substantial difference in sampling between the pitfall and red sticky traps, the maximum Sørensen values (0.18-0.32) and virtually no overlap between the pitfall and red sticky traps (Jaccard = 0.10) indicates that these two trapping methods collected beetles from completely different ecological niches (i.e. the soil surface and the tree trunk). This interpretation was confirmed by the multivariate analysis: the trap type accounted for 50.3% of the variation in the assemblage composition (PERMANOVA, p = 0.0001), and all three methods differed significantly from one another in the pairwise comparison (p = 0.0003). From this, it can be deduced that the use of more than one trap type is necessary to successfully document the greatest extent of Coleoptera biodiversity in deciduous forest systems.

2. Taxonomic composition and species dominance

The dominance of Cerambycidae (18.1%), Curculionidae (13.8%) and Elateridae (12.8%) within the chestnut stands of Bursa Province reflects a characteristic faunal composition often observed in Turkish forest ecosystems. Although previous studies (e.g. Ünal & Küçük 2007; Avgın 2014; Gömlek 2018; Laz 2015; Platia *et al*. 2011) were conducted in diverse environments using varying methodologies, their findings have consistently highlighted these families as major components of the Coleoptera fauna. However, the results of the present study demonstrate that relying solely on canopy-associated or saproxylic life forms provides an incomplete ecological picture. Utilising a synergistic approach with pitfall traps, we have documented a highly active and diverse community inhabiting the forest floor. Silphidae dominates this active group, where the *Nicrophorus investigator* species alone makes up a total of 79 individuals in number. These are specialised carrion-attracted necrophages as opposed to generalist litter dwellers. The consistent presence of necrophages at every pitfall station across all three sites suggests an active carrion-recycling guild existing at all three sites. There were many scarabs (Scarabaeidae), particularly *Onthophagus taurus* and *Pentodon quadridens*, which indicates that coprophagous species play a significant role in nutrient cycling.

Ground-dwelling predators were well represented across the study area. Carabidae alone contributed 15 species from 9 genera, including *Carabus* (six species), *Ophonus*, *Notiophilus*, *Pterostichus*, *Poecilus*, *Chlaenius*, *Harpalus*, *Acupalpus* and *Trechus*. It is this breadth of predatory genera, rather than the abundance of any single one, that indicates a structurally complex and trophically diverse forest floor. The three most species-rich families are primarily found on woody plant materials, but because of the abundance of ground-active species found in the chestnut forest, it is apparent that chestnut forests have what can be called a vertically stratified fauna, with both wood-based and soil-based species being well-represented. The indicator species analysis examined the same station quantitatively: the taxa diagnostic of each trap type corresponded to distinct functional guilds rather than to arbitrary subsets of a single community.

3. Diversity patterns of Coleoptera assemblages across the study sites

The evaluation of the Coleoptera diversity using Shannon-Wiener (H') and Simpson (1-D) indices revealed consistently high alpha diversity across all study sites and trap types, indicating structurally complex and species-rich assemblages throughout the study area (Table 7). The window traps yielded the numerically highest diversity values overall (H': 3.30-3.98), suggesting that the aerial and dispersive components of the beetle fauna are particularly diverse. This pattern may reflect the high mobility of flying taxa and their capacity to integrate resources across habitat patches, leading to an elevated local richness.

Across the sites, the diversity values derived from the window traps remained uniformly high; contrary to expectations, there were only minor numerical variation among the locations. Although the KB site exhibited slightly higher diversity values than OG and YL, this difference was not statistically significant (p = 0.074), and it should therefore be interpreted as a descriptive pattern rather than a supported distinction. The relative separation of KB in the UPGMA dendrograms (Figures 4 a-b) suggests some degree of compositional differentiation, which may be associated with regional climatic conditions, including a maritime influence and favourable microclimates at lower altitudes (0-300 m) that can support thermophilic and dispersive species (Seibold *et al.* 2015; Müller *et al.* 2010). In addition to climatic factors, the stand structure likely contributed to the observed patterns. The relatively open canopy conditions in KB (Crown Closure: < 10-40%; Ksb1 and KsDfa stands) may increase light penetration and flight activity, potentially enhancing the detectability and encounter rates of heliophilic species in window traps (Bouget *et al.* 2008; Müller *et al.*

2010). Conversely, the relatively lower end of the diversity spectrum observed in YL, characterised by a high canopy cover (71-100%; KnKsbc3 stands), may indicate that closed-canopy conditions can limit the activity and vertical movement of light-dependent taxa, thereby reducing their representation in aerial samples.

The ground-dwelling assemblages sampled by pitfall traps also exhibited consistently high alpha diversity (H': 2.66-3.28; 1-D: 0.91-0.96) across all sites. In contrast to the window traps, the variation in diversity among the pitfall samples appears more closely associated with the forest floor characteristics and stand maturity. The relatively higher diversity observed in OG, particularly at the OG2 station, may be linked to the advanced developmental stage of these stands (80-120+ years, Table 1), which can increase habitat heterogeneity through the accumulation of litter, deadwood and fungal substrates. Such structural components increase the complexity of the forest floor, creating a more stable environment with reduced fluctuations in temperature and humidity (Koivula *et al*. 1999; Mazía *et al*. 2006). These conditions are known to enhance the resource diversity and promote niche differentiation among ground-dwelling arthropods (Müller *et al.* 2010; Schiegg 2000). While KB and YL also supported high diversity, the dendrogram patterns (Figure 4 c-d) indicate that KB is more compositionally distinct, potentially reflecting a combination of its coastal positioning and distinct stand characteristics, such as a lower canopy closure and younger age classes compared to the mature, inland terrestrial conditions of OG and YL. Consistent with this observation, the site effect on the Shannon diversity was significant for pitfall traps ($p = 0.015$) but not for window ($p = 0.074$) or sticky traps ($p = 0.103$), indicating that forest-floor assemblages respond more strongly to stand-level conditions than the aerial or trunk-associated fauna.

A similar pattern was observed for the trunk-associated assemblages sampled by sticky traps, where the diversity values (H': 2.63-3.03, 1-D: 0.92-0.94) indicated consistently rich communities. Despite broadly similar diversity values, the separation of OG in the dendrogram analyses (Figure 4 e-f) suggests that mature stand conditions may support distinct assemblages. The advanced developmental stage of the OG stands (80-120+ years) and the presence of very large-diameter trees (DBH > 35.9 cm) may contribute to increased bark complexity and the continuity of microhabitats relevant for saproxylic and host-associated beetles (Gossner *et al.* 2013; Thorn *et al.* 2016). In contrast, the relatively lower diversity values in YL and KB may be associated with younger stand structures (Table 1) and a reduced availability of specialised trunk microhabitats. Previous research has shown that younger stands often support less specialised and more homogenised assemblages due to limited habitat continuity and reduced microhabitat diversity (Schiegg 2000).

4. Similarity patterns of Coleoptera assemblages across the study sites

The UPGMA dendrograms based on the Sørensen and Jaccard indices (Figure 4) revealed distinct clustering patterns that varied significantly depending on the sampling methodology, while consistently showing a strong within-site grouping of the sampling units. These clustering patterns are consistent with the PERMANOVA result, in which the trap type accounted for four times more compositional variation than the study site.

The similarity dendrograms of the Coleoptera species collected by the window traps revealed that the YL and OG clusters exhibited a higher degree of similarity when compared to KB (Figure 4 a, b). This clustering reflects their geographical proximity and shared ecological conditions, as both YL and OG represent higher-altitude inland chestnut ecosystems (300-900 m) with complex stand structures (KnKsbc3 and Ksd2). The presence of young to mature forests with medium-to-large diameter beech-chestnut mixtures in YL (TAR: 35-80 years) and over-mature, very large-diameter chestnut stands in OG (TAR: 80-120+ years) provides a heterogeneous canopy and abundant saproxylic niches, which are favourable habitats for high-flying and wood-associated beetles.

In contrast, the KB site (0-300 m) formed a distinct cluster, as highlighted in the dendrograms. This differentiation was likely driven by its coastal location and marine influence, resulting in a markedly different vegetation structure. The KB stands, which are dominated by younger chestnut and laurel regeneration with a sparse or low crown closure (Ksb1, KsDfa), lack the structural maturity and large-diameter deadwood components (DBH < 20 cm) that characterise the older stands of YL and OG. The relatively simple stand structure in KB may function as an environmental filter, potentially constraining the saproxylic beetle diversity in window trap samples. The dendrogram patterns are therefore consistent with an influence of the stand structure on the window trap assemblages, although the site effect did not reach significance in the multivariate analysis (PERMANOVA, $p = 0.066$) and should not be read as a general altitudinal relationship.

The similarity dendrograms of the Coleoptera species obtained from the pitfall traps showed that YL and OG were more similar to each other, while KB was compositionally more distinct. The separation of the KB site was particularly pronounced; its coastal location and lower altitude, together with leaf litter characteristics that differ from the deeper, more heterogeneous layers in YL and OG, create a forest floor environment distinct from the more humid inland conditions. This pattern highlights the role of litter heterogeneity as an environmental filter, alongside geographical isolation and coastal climatic factors, in driving community divergence.

The red sticky traps displayed a distinct clustering pattern in which the similarity between KB and YL was particularly pronounced, suggesting that these sites support comparable assemblages of wood-boring taxa, likely associated with developing and maturing stands (8-35.9 cm DBH). In contrast, the distinct composition observed in OG can be attributed to its substantially older (80-120+ years) and over-mature stand structure, characterised by large-diameter chestnut trees (> 36 cm DBH). This pattern is consistent with previous studies showing that older and larger-diameter trees offer more suitable niches for bark beetles (Curculionidae: Scolytinae) and secondary pest species, particularly owing to thicker phloem resources and structurally complex bark that enhance habitat heterogeneity (Hutchison & Reid 2022; Martikainen *et al.* 1999; Gossner *et al.* 2013; Percel *et al.* 2018; Thorn *et al.* 2016). Given that red sticky traps rely on both visual cues and host-related volatiles, the high availability of old wood in OG likely promotes a more specialised community of wood-boring taxa compared to the younger or maturing stands in KB and YL.

5. Methodological limitations

Three limitations of this study deserve an explicit statement.

First, no semiochemical lures were used beyond the ethanol-toluene mixture in the sticky traps. Generic multi-species pheromone blends, particularly when combined with host volatiles, have been shown to substantially increase both the abundance and the diversity of wood-associated beetles captured, including Cerambycidae, bark and ambrosia beetles, as well as Buprestidae (Roques *et al.* 2023). Our richness estimates for these groups were therefore likely to be conservative. We did not use such lures because the object of the study was to compare three passive trapping methods under identical conditions, and adding attractants to one method would have introduced a further difference among the very methods being compared. Future surveys aimed at maximum inventory completeness, rather than at a method comparison, would benefit from including them.

Second, the three trap types differed in several respects at once, including the deployment height, the presence or absence of bait, and the physical mechanism of capture. It is therefore not possible to attribute the observed differences to any single design feature, and we make no such claim. The trap type is treated here as an integrated sampling method, and the question addressed is whether three standard methods sample different components of the fauna, which the PERMANOVA and indicator species results showed that they do. The confounding of design features is in this sense inseparable from the complementarity we reported. The same reasoning applies to the dimensions of the pitfall traps. A trap's diameter and depth are known to influence capture rates, with larger and deeper traps generally retaining more individuals and a greater proportion of large-bodied taxa (Woodcock 2005; Skvarla & Dowling 2017). Because all the pitfall traps used here were of identical dimensions, this does not confound the comparisons we reported, but it does mean that our pitfall catches are not directly comparable in absolute terms with studies employing traps of a different size.

Third, and most importantly for the interpretation of the site effects, each altitudinal zone was represented by a single forest. The altitude was consequently confounded with the stand age, canopy closure, diameter distribution and maritime influence, and no analysis of the data can separate these factors. The trap comparison was unaffected, since all three trap types were deployed at every sampling station and the contrast was made within the stations, which is why the trap effect could be tested with confidence. The site comparison, however, rested on sampling stations that are pseudo-replicates with respect to site-level inference. Differences among the sites were accordingly reported as case-specific patterns and not as evidence of a general relationship between the altitude and beetle diversity. Establishing such a relationship would require studying several independent forests within each altitudinal band.

Conclusion

The results of this study demonstrate that Coleoptera diversity within the chestnut forest ecosystems of Bursa is governed by a complex interplay of envi-

ronmental drivers and forest stand characteristics. Our findings suggest that maritime microclimatic conditions at lower elevations (KB) are associated with a higher level of aerial and heliophilic beetle diversity, although this site-level difference was not statistically significant. In contrast, the forest maturity and structural complexity in inland sites (OG) promoted ground-dwelling and saproxylic assemblages by increasing microhabitat availability, such as large-diameter deadwood and deep litter layers. Furthermore, the canopy closure and stand composition appeared to modulate these diversity patterns by influencing light availability and the vertical mobility of species. From the multivariate analysis perspective, the principal factor influencing the composition of those communities was the way in which samples were taken: either by trap types or by location. It turned out that the trap types were responsible for 50.3% of the variation in the community composition, while the location contributed only about 12.3%. The YL and OG locations produced similar results since both are high-elevation locations, and their forest structures are similar, whereas the Karacabey location is home to a distinct set of animal species that exist primarily due to the coastal topography of the area. The pairwise PERMANOVA results further showed that all three trap types produced assemblages that were significantly different from each other ($p = 0.0003$), and 35 species strongly indicated only one of the trap types. This study highlights the fact that relying on a single sampling method provides an incomplete ecological picture; instead, the distinct effectiveness of window traps for overall richness, pitfall traps for surface-active species, and red sticky traps for specialised bark beetles underscores the functional complementarity of these techniques. Integrating climatic, structural and methodological factors is essential for a holistic assessment of forest biodiversity. These insights emphasise the need for conservation strategies that prioritise the preservation of both habitat heterogeneity and successional complexity, to sustain the biological network of these vital deciduous forest ecosystems.

This study provides baseline information on the Coleoptera fauna associated with the chestnut forests in Bursa and demonstrates the value of using complementary trapping methods to characterise beetle assemblages. Since there was only one site included with each environmental condition, the differences among all of the sites represents only the specific patterns of each site and should not be interpreted as the general ecological response of the beetles due to altitude or other environmental gradients. Future research will require multifold replicated sites within similar environments in order to corroborate the conclusions reached in this study and to be able to better understand what are the environmental factors that affect the community structures of beetles.

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Author Contributions

Research concept and design: O.S., I.S.; Collection and/or assembly of data: O.S., T.G.; Data analysis and interpretation: O.S., I.S., T.G.; Writing the article: O.S., I.S., T.G.; Critical revision of the article: O.S., I.S.; Final approval of article: O.S.

Conflict of Interest

The authors declare no conflict of interest.

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