Community composition and diversity of ground beetles (Coleoptera: Carabidae) in Yaoluoping National Nature Reserve

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Abstract

This study used pitfall trapping to examine community composition and diversity of ground beetles in five different habitats (coniferous, deciduous, mixed coniferous, farmland, and settlements) within Anhui Yaoluoping National Nature Reserve from May to September 2014. In total, 1,352 ground beetles were collected, belonging to 16 genera and 44 species. Of these, four dominant species Dolichus halensis, Harpalus pastor, Carabus casaleianus, and Pheropsophus jessoensis were identified, respectively, comprising 370, 177, 131, and 123 individuals. The deciduous forest showed greater diversity (3.78 according to Shannon–Weiner index), equitability (0.80 according to Pielou’s index), and dominance (9.52 according to Simpson’s index) when compared with farmland, but species richness in the deciduous forest (27) was lower than that in farmland (35). One-way analysis of variance showed that ground beetle species composition and abundance among different habitats varied significantly. Cluster analysis and principal coordinate analysis showed that farmland shared low community similarity with other habitat types, and coniferous and mixed coniferous forests shared similar community types. Our results indicate that species composition, abundance, and diversity of ground beetles are affected by different habitat types, with deciduous forest types being critical in maintaining the diversity of rare species. We recommend reducing cultivated farmland area and increasing the area of carefully planned deciduous forest in order to better protect ground beetle diversity in the region.

Key words: Yaoluoping National Nature Reserve, ground beetles, species composition, diversity, habitat type

Forests are the most diverse ecosystems on land (Lindenmayer et al. 2006). Numerous microenvironments are identifiable within forests, based on biotic factors, such as forest type and ground-to-canopy layers, and abiotic factors such as, moisture and temperature. Such microenvironments promote heterogeneous distribution of species within forest types and habitats, but are vulnerable to disturbance, particularly by human interference (Novacek and Cleland 2001). A growing number of studies have shown that insects are highly sensitive to changes in forest types and habitat microenvironment. Beetles have strong selective preference for various habitat types in a forest (Magura et al. 2000, Yu et al. 2010). According to their adaptability, beetles can be classified as either habitat generalists or habitat specialists (Yu et al. 2006b). Habitat generalists do not have specific requirements for forest habitats and are able to survive in a variety of forest types, whereas habitat specialists have strict requirements for forest habitat and are only distributed in specific forest types (Yu et al. 2006a,b, 2009; Jung et al. 2014). Human activities, such as logging, deforestation, and farming, result in changes and disappearance of forest types and habitat microenvironments, and therefore, specialist species that depend on these special forest types and microenvironment are vulnerable to population decline or even local extinction (Niemela 2001).

Regional species diversity is best investigated using thorough surveillance and monitoring across a large area (Weibull and Östman 2003). However, because of manpower constraints, the monitoring and identification of all species can be difficult. Appropriate indicator taxa, such as ground beetles, can be used to infer species distribution throughout a region (Lindenmayer et al. 2006). Ground beetles have a wide-ranging distribution in terms of geographic regions and habitat types, and are sensitive to local environmental changes (Allegro and Sciaky 2003, Jung et al. 2012). In addition, most species have only vestigial hind wings and are poor flyers, making them easily altered or transformed in any way, and that the work is properly cited. For commercial re-use, please contact journals.permissions@oup.com
accessible and measurable targets (Lovei and Sunderland 1996, Park et al. 2013). Several studies have focused on the ecology and taxonomy of ground beetles, providing a basis for straightforward analysis and identification of specimens (Eyre and Garside 1996, Lovei and Sunderland 1996). Although pitfall trapping cannot collect all individuals, it can help in the evaluation of the relative numbers of all species and fluctuations in population size (Spence and Niemelä 1994, Yu et al. 2007). In addition, this method is simple, cheap, and suitable for large-scale simultaneous sampling. Therefore, the use of carabid beetles as indicators of environmental changes can facilitate monitoring of changes in species composition and diversity, and exploring the relationship between insects and the environment.

Yaoluoping National Nature Reserve is located in the hinterland of Dabie Mountains, the watershed of Yangtze River and Huaihe River, and is connected to Anhui Fuziling Provincial Nature Reserve, Tianma National Nature Reserve, Hubei Dabie Mountain National Nature Reserve, and Henan Dabie Mountain National Nature Reserve. The reserve is on the boundary between the north and south slopes of the main peak in this region and is at the center of the central reserve series of the Dabie Mountains together with three connected Nature Reserves (Kujingyuan, Bancang, and Wanfoshan) on the eastern Dabie Mountains, as well as the Henan Dongzhai and Kikungshan National Nature Reserves in the west). Yaoluoping National Nature Reserve is located in the main section of watersheds of the Dabie Mountain peak, between the Oriental and Palaeartic realms of the world’s zoogeographical regions, and between the north and central zoogeographical regions in China. It belongs to the north subtropical mountain forest ecosystem, with over 90% of the reserve covered by forest, preserving large areas of natural secondary and natural forests. However, parts of the region have faced considerable disturbance from agriculture, and areas with lower degrees of disturbance due to human settlements also exist in the region. The “north–south transition, east–west expansion” geographic and climatic characteristics of the Nature Reserve and its rich biological resources provide good conditions for insect survival, breeding, and dwelling. To our knowledge, studies on ground beetles in the Nature Reserve have not been previously published.

This study analyzed the species composition and community diversity of ground beetles in five different habitats (coniferous forest, deciduous forest, mixed coniferous forest, farmland, and settlements) within Yaoluoping National Nature Reserve. The investigation also clarified the distribution of ground beetles in the Nature Reserve and compared species composition, population size, and diversity across different habitats, and analyzed similarities between habitats. The results of this study would allow us to understand the influence of different habitat types on species diversity, elucidate the dependence of organisms on the environment, evaluate the status of ground beetle diversity in the Nature Reserve, and provide basic data and theoretical basis for the scientific management of the Nature Reserve.

Four distinct regions within the nature reserve were identified based on altitude, terrain, and human disturbance. These included Duozhi Mountain, Xiaoxi Mountain, Yaoluocun countryside, and Meili countryside. Five habitat types were included within these regions: coniferous forest, deciduous forest, mixed coniferous forest (50-year old), farmland, and settlements; of these, the tree layer of the coniferous forest was almost entirely comprised of Pinus taiwanensis; the shrub layer was mainly Quercus stewartii, accompanied by Lindera obtusiloba, Sorbus alnifolia, Symphocarpus paniculatus, and Rhododendron polycladium; and the herb layer included Gnaphalium hystepulum, Peucedanum praetortum, Chrysanthemum indicum, Ligusticum tachiroei, and Carex sp. This habitat was mainly distributed at an altitude of 1,100–1,300 m on Duozhi mountainside, 1,200–1,400 m on Xiaoxi mountainside, and 700–800 m in Meili countryside. In the deciduous forest, the tree layer was mainly comprised of Alnus trabeeculosa, accompanied by Stewartia sinensis and Magnolia officinalis; the shrub layer included Weigela japonica, Dentzia glauca, Lespedeza buergeri, Rhamnus rugulosa, Elaeagnus multiflora, and R. globosa; and the herb layer consisted of Stachys japonica, Duschesnea indica, G. affine, Filipendula sp., Calamagrostis epigejos, and Opillemus undulatifolius. This habitat was mainly distributed at an altitude of 1,300–1,600 m on Duozhi mountainside, 1,000–1,100 m in Yaoluocun countryside, and 700–800 m in Meili countryside. In the mixed coniferous forest, the tree layer mainly included P. taiwanensis and A. trabeeculosa, accompanied by S. sinensis and Cyclobalanops glauca; the shrub layer included illex pedunculosa, Eurya nirurcata, Linder glauca, and C. myrsinifolia; and the herb layer included G. hystepulum, G. affine, and Polygonatum odoratum. This was mainly distributed at an altitude of 1,500–1,600 m on Duozhi mountainside, 1,000–1,100 m in Yaoluocun countryside, 1,300–1,400 m on Xiaoxi mountainside, and 700–800 m in Meili countryside. In farmland habitat, crops such as Zea mays, Capsicum annuum, Solanum melongena, and Trichosanthes kirilowii are grown. In farmland footpaths, weed species comprised mostly Oxalis corniculata, Setaria viridis, Avena fatica, and Miscanthus sinensis. This habitat type was mainly distributed at an altitude of 1,000–1,100 m in Yaoluocun countryside and 700–800 m in Meili countryside. In the human settlement habitat areas, trees were mainly S. sinensis, P. taiwanensis, A. trabeeculosa, and M. officinalis; shrubs were mostly L. glauca, C. myrsinifolia, Lespedeza buergeri, and R. rugulosa; and herbaceous plants included Plantago asiatica, Bidens pilosa, and Portulaca oleracea. This habitat type was mainly distributed at an altitude of 1,000–1,100 m in Yaoluocun countryside and 700–800 m in Meili countryside.

Pitfall trapping was used to sample ground beetles (Spence and Niemelä 1994, Yu et al. 2007). In coniferous, deciduous, and mixed coniferous forests, four sampling sites were selected, while in farmland and settlement type areas, two sampling sites were used (Fig. 1). Five plots were set up at each sampling site for a total of 80 plots. There were three rows in each plot, with three traps in each row, spaced 1 m apart. Disposable plastic cups (9 cm high and 7.5 cm across) were used as containers for pitfall trapping. A hole (0.5 cm in diameter) was punched in the wall of the cup 2.5 cm below the rim. The trap was buried in the ground with the rim flush with ground level to avoid sample loss due to excessive rain. Each trap was filled with 40–60 ml trapping fluid (mixed vinegar, sugar, alcohol, and water, in a ratio of 10 ml:5 g:5 ml:20 ml) (Yu et al. 2006b). Sampling was performed once in the middle of the month from May to September 2014. Cup traps were placed and left for 3 d. Trapped specimens were preserved in 70% ethanol and brought back to the laboratory, and made into pin-mounted specimens. Specimens were identified by Dr. Hongbin Liang of the Institute of Zoology, at the Chinese Academy of Sciences.
Chinese Academy of Sciences, and Dr. Mingyi Tian of South China Agricultural University, and stored in a specimen room at the School of Life Sciences, Anhui University.

Data Analysis

Observed carabid beetle species richness and species abundance were subjected to rarefaction analysis using Estimate S (Version 9.1) software for calculating and creating rarefaction curves (Colwell 2013, Jung et al. 2015). Differences in species composition and abundance observed between different habitats were analyzed using one-way analysis of variance (ANOVA) and least-significant difference (LSD) test (SPSS Version 7.5). The data were normalized before analysis. We pooled the data of collected ground beetles in each habitats and used in statistical analysis (Warren-Thomas et al. 2014, Jung et al. 2015). SPSS (Version 7.5) software was used for statistical analysis (SPSS 1997).

Species diversity was represented by Shannon–Wiener diversity index ($H'$, where $H' = -\sum_{i=1}^{S} P_i \ln(P_i = N_i / N)$; $P_i$ is the proportion of individuals of a species ($i$); $N_i$ = abundance, e.g., the number of individuals observed of a species ($i$); and $N$ = the total number of individuals from all species) (Pielou 1975). Equitability was represented by Pielou’s index ($J'$, where $J' = H'/\ln S$; $J'$ = equitability and $S$ = the number of species observed) (Pielou 1975). Dominance was represented by Simpson’s dominance index [$D'$, where $D' = -\sum_{i=1}^{S} P_i^2$] (Pielou 1975). Species richness was represented by the number of species observed ($S$) (Pielou 1975).

Species composition and species abundance were used as components for calculating the Bray–Curtis coefficient. The differences in species composition and distribution of ground beetles in each habitat type were subjected to cluster analysis. Principal coordinate analysis was performed on the carabid community structure in habitats with forest characteristics (coniferous, deciduous, and mixed coniferous forests) (Yu et al. 2008). PAST (Version 3.10) software was used for calculation and plotting (Hammer et al. 2001).

Results

Species Composition

In total, 1,352 ground beetle individuals were collected in this study, belonging to 16 genera and 44 species. Of these, 370 were Dolichus halensis, 177 were Harpalus pastor, 131 were Carabus casaleianus, and 123 were Pheropsophus jessoensis, respectively, accounting for 30.57, 14.92, 9.67, and 6.91% of the total number of ground beetles. All species comprising over 5% were considered dominant species. Fifteen species (H. tridens, H. griseus, H. bungii, H. jurecki, Scarites terricola, Synuchus nitidus reticulate, S. arcuaticollis, Pterostichus microcephalus, P. pratti, P. tiamushan, Pristosia sulphennis, C. lafossei, Archipatrobus flavipes, Anisodactylus punctatipennis, and Amara simaticollis) each accounted for more than 1% of the total number of ground beetles, and thus they were considered common species. The other 25 species accounted for less than 1% of the total number of observed individuals and were considered rare species (Table 1).

A species accumulation curve describes the increase in species richness with increasing sample size. It is an effective tool for understanding species composition of a sampling site and for predicting species abundance, and is widely used in

![Fig. 1. Distribution of sampling stations at Yaoluoping National Nature Reserve.](https://academic.oup.com/jinsectscience/article-abstract/17/6/114/4670901)
biodiversity studies and community surveys for determining sampling adequacy and estimating species abundance (Gotelli and Colwell 2001). In this study, species richness gradually stabilized with increasing numbers of collected specimens, nearing 44 species (Fig. 2), indicating that the sampling was adequate and representative.

Community Diversity
Species richness and the abundance of each species collected were highest in farmland-type habitat (35 species and 650 specimens), followed by deciduous forest (27 species and 311 specimens), settlements (17 species and 171 specimens), and coniferous forest (14 species and 132 specimens). Mixed coniferous forest had the least numbers of species and individuals (8 species and 88 specimens) (Fig. 3A). Deciduous forest had comparatively high diversity (3.78), equitability (0.80), dominance (9.52), and species richness (27); farmland had high diversity (3.21) and species richness (35), and low equitability (0.63) and dominance (4.69); and mixed coniferous forest had low diversity (2.58), dominance (5.12), and species richness (8), and high equitability (0.86). Indices for settlement and the coniferous forest did not differ significantly, but were relatively lower than those of deciduous forest and farmland (Table 2). The four dominant beetle species were variously distributed in the five different habitats: C. casaleianus and P. jessoensis were found in all five habitats (Fig. 3B–F), and D. halensis and H. pastor were mainly

### Table 1. Total number of individuals of carabid beetles in five different habitat types

| Species               | Coniferous | Deciduous | Mixed | Farmland | Settlement |
|-----------------------|------------|-----------|-------|----------|------------|
| Amara congrua         | 0          | 0         | 8     | 0        | 8          |
| Amara hiogoensis      | 0          | 4         | 0     | 1        | 0          |
| Amara lucidissima     | 0          | 0         | 2     | 0        | 2          |
| Amara macronota       | 0          | 0         | 2     | 0        | 2          |
| Amara sinaticollis    | 1          | 4         | 0     | 8        | 3          |
| Amara sp.             | 0          | 0         | 9     | 0        | 9          |
| Anisodactylus punctatipennis | 0  | 1         | 0     | 12       | 0          |
| Archipatrobus flavipes | 0          | 9         | 0     | 5        | 5          |
| Bradycellus chinensis | 0          | 0         | 2     | 0        | 2          |
| Carabus casaleianus    | 45         | 37        | 30    | 8        | 11         |
| Carabus lafossei      | 10         | 8         | 3     | 3        | 1          |
| Chlaenius micans      | 0          | 0         | 1     | 0        | 1          |
| Chlaenius naeviger    | 0          | 0         | 1     | 0        | 1          |
| Chlaenius virgulifer  | 0          | 1         | 0     | 3        | 0          |
| Dolichus balensis     | 0          | 76        | 0     | 262      | 32         |
| Harpalus bungii       | 0          | 0         | 25    | 0        | 25         |
| Harpalus chalcenetus  | 0          | 3         | 0     | 3        | 2          |
| Harpalus eous         | 0          | 0         | 2     | 0        | 2          |
| Harpalus griseus      | 0          | 0         | 33    | 6        | 39         |
| Harpalus jureccki     | 0          | 0         | 11    | 0        | 11         |
| Harpalus pastor       | 1          | 29        | 0     | 129      | 18         |
| Harpalus tinctulus luteicornoides | 0  | 2         | 0     | 4        | 0          |
| Harpalus trideni      | 0          | 28        | 0     | 22       | 9          |
| Leistus sp.           | 0          | 2         | 0     | 0        | 0          |
| Nebria chinensis      | 0          | 6         | 0     | 5        | 0          |
| Nebria sp.            | 0          | 2         | 0     | 0        | 1          |
| Pheropsophus jessoensis | 13        | 16        | 7     | 16       | 71         |
| Pristosia senuoni     | 1          | 2         | 0     | 3        | 0          |
| Pristosia sulcipennis | 13         | 17        | 4     | 5        | 0          |
| Pristosia sp.         | 0          | 2         | 0     | 0        | 0          |
| Pterostichus microcephalus | 0       | 0         | 19    | 3        | 22         |
| Pterostichus pratti   | 6          | 5         | 18    | 1        | 0          |
| Pterostichus tianmushan | 7         | 14        | 3     | 0        | 1          |
| Pterostichus sp. 1    | 2          | 0         | 0     | 0        | 0          |
| Pterostichus sp. 2    | 0          | 1         | 0     | 0        | 1          |
| Pterostichus sp. 3    | 2          | 0         | 0     | 0        | 2          |
| Scarites sulcatus     | 0          | 1         | 0     | 2        | 0          |
| Scarites terricola    | 0          | 0         | 36    | 0        | 36         |
| Scarites sp.          | 0          | 0         | 0     | 2        | 1          |
| Stenolophus connotatus| 0          | 0         | 0     | 1        | 0          |
| Symuchus arcuaticollis| 5          | 14        | 7     | 3        | 4          |
| Symuchus major        | 0          | 3         | 0     | 0        | 0          |
| Symuchus nitisus reticulatus | 25   | 22        | 16    | 1        | 2          |
| Synuchus sp. aff. calathinus | 1   | 2         | 0     | 0        | 1          |
| Individuals           | 132        | 311       | 88    | 650      | 171        |
| Species richness      | 14         | 27        | 8     | 35       | 17         |

Species richness 14 27 8 35 17 44
found in deciduous forest (Fig. 3B), farmland (Fig. 3E), and settlements (Fig. 3F).

One-way ANOVA showed that species and abundance varied significantly across different habitat types (\( F_{4,215} = 3.340, P = 0.011 \)). LSD test showed that species composition and abundance within farmland habitats were significantly different from those of coniferous forest (\( P = 0.030 \)), deciduous forest (\( P = 0.011 \)), mixed coniferous forest (\( P = 0.02 \)), and settlements (\( P = 0.013 \)). Cluster analysis suggested that species composition and abundance in farmland were significantly different from those of other habitat types, and mixed coniferous forest had higher similarity with coniferous forest (Fig. 4). Principal coordinates analysis indicated that species composition of ground beetles in deciduous forest, coniferous forest, and mixed coniferous forest showed obvious differentiation, with the former farther apart from the latter two and less overlapped, reflecting less similarity with the latter two. Coniferous and mixed coniferous forests had a large overlapping area according to the ordination diagram, indicating that the two had higher similarity (Fig. 5).

Fig. 2. Individual-based rarefaction curves in five different habitat types.

Fig. 3. The total number of species and individuals in five different forest type (A), number of individuals of the five most dominant carabid species (>5% of all the individuals) in Coniferous forest (B), Deciduous forest (C), Mixed forest (D), Farmland (E), and Settlement (F). Coni (coniferous forest), Deci (deciduous forest), Mixe (mixed forest), Farm (farmland), Sett (settlement), C. casa (Carabus casaleianus), \( n = 131 \); D. hale (Dolichus halensis), \( n = 370 \); H. past (Harpalus pastor), \( n = 177 \); P. jess (Pheropsophus jessoensis), \( n = 123 \).
Discussion

In this study, 1,352 ground beetles belonging to 16 genera and 44 species were collected, which is comparable to the species found in the Changbai Mountains (14 genera and 47 species; Zou et al. 2014), Taishan Mountains (14 genera and 41 species; Yu et al. 2006b), and Hengduan Mountains (22 genera and 46 species; Yu et al. 2006a). *C. casaleianus* and *C. lafossei* were endemic species in this region, consistent with the important geographical features of the Dabie Mountain area located at the junction of the Oriental and Palearctic zoogeographical regions and of central and northern China. In addition, this study used pitfall trapping, which is effective for capturing the surface-dwelling species of ground beetles. By combining hand-picking, light trapping, and netting methods for collecting tree-dwelling beetles, more species can be identified in future studies.

Habitat types are one of the important factors affecting species diversity in a region. This study reflected the differences in species composition and community diversity of ground beetles among different habitat types in Yaoluoping National Nature Reserve relatively well. Deciduous forest had higher ground beetle species diversity compared with coniferous and mixed coniferous forests, consistent with the findings by Yu et al. (2010) and Warren-Thomas et al. (2014), whereas oak forest showed higher diversity than pine forest in northern China, North America, and Europe (Fahy and Gormally 1998, Magura et al. 2003, Finch 2005). Coniferous, deciduous, and mixed coniferous forests in this study represent forest habitat types, and the ground beetles’ community structure therein presented a certain degree of similarity. Farmland represented an agricultural habitat type, and its community structure was dissimilar from that of forest habitats. Farmland is a

Table 2. The index of diversity, equitability, dominance, and richness of carabid beetles in five different habitat types

| Index          | Coniferous | Deciduous | Mixed | Farmland | Settlement |
|---------------|------------|-----------|-------|----------|------------|
| Diversity     | 2.96       | 3.78      | 2.58  | 3.21     | 2.82       |
| Equitability  | 0.76       | 0.80      | 0.86  | 0.63     | 0.69       |
| Dominance     | 5.57       | 9.52      | 5.12  | 4.69     | 4.41       |
| Richness      | 14         | 27        | 8     | 35       | 17         |

Fig. 4. Dendrogram based on cluster analysis using the Bray–Curtis percentage similarity of the carabid beetles with the pooled data in five different habitat types.

Fig. 5. Ordination plot (PcoA by Bray–Curtis index of dissimilarity) of the range of number of individuals and species per replicate plot within the coniferous forest, Deciduous forest, mixed forest; 33% of the variation was explained by axis 1 and 21% by axis 2. (Filled circles) Coniferous forest; (triangles) deciduous forest; and (squares) mixed forest.
special open habitat, with unique microenvironmental conditions due to interference of agricultural activities, such as plowing and sowing (Rusch et al. 2013), impacts of different crops (Liu et al. 2010), and application of fertilizers (Schröter and Irmler 2013). This habitat type showed a higher diversity index and abundance, with relatively low uniformity and dominance indices. This was due to several species occurring in greater numbers causing decreased equitability and dominance. For example, D. balensis and H. pastor accounted for 60.24% of the total farmland carabids, which demonstrates the sensitivity of the diversity index to changes in species abundance, and also shows that abundance directly affects community structure and biodiversity. This is also one of the reasons that species richness varied significantly among different habitats in this study.

Ecological restoration has been ongoing in Yaoluoping National Nature Reserve for several years since its establishment, leading to the development of large areas of plantation and natural secondary forest. However, considerable deforestation and farmland disturbance have altered the original habitat, affecting the community structure and diversity of ground beetles (Eyre and Garside 1996, Lovei and Sunderland 1996). In this study, species richness and abundance were found to be highest in farmland. However, farmland ecosystem had a high degree of simplification, with frequent farming activities potentially leading to extinction of certain species rather than favoring the protection of biodiversity (Liu et al. 2010, Rusch et al. 2013). Compared to farmland, deciduous forest had greater diversity, uniformity, dominance, and abundance of ground beetles, and a more complex structure with greater habitat heterogeneity, a higher degree of system stability, and stronger resistance to interference (Magura et al. 2003, Warren-Thomas et al. 2014). Thus, we suggest reducing the total farmland cultivated area and increasing the area of strategically planned deciduous forest. This will reduce the risk of species extinction caused by simplified farmland environment, improve habitat heterogeneity, and maintain greater richness of ground beetle species, thereby contributing to the protection of ground beetle diversity in the Nature Reserve.

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