Postprint: Response of Forest Floor Coleoptera Adults to Disturbance Gradients in the Lesser Khingan Mountains

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Abstract

To investigate the response of ground-dwelling Coleoptera adult communities to different anthropogenic disturbance gradients in the forest ecosystem of Liangshui Nature Reserve in the Lesser Khingan Mountains, sampling surveys were conducted in July, August, and October 2015 across six forest types under light disturbance [primary broadleaf-Korean pine forest (KY) and valley spruce-fir forest (YL)], moderate disturbance [broadleaf-Korean pine selective cutting forest (ZF) and secondary birch forest (BH)], and heavy disturbance [larch plantation (RL) and Korean pine plantation (RHS)]. The results showed that: (1) A total of 879 ground-dwelling Coleoptera adults were captured throughout the sampling period, belonging to 9 families and 44 species; among them, light disturbance habitats captured 6 families, 29 species, and 251 individuals (KY captured 5 families, 21 species, and 150 individuals; YL captured 4 families, 20 species, and 101 individuals), moderate disturbance habitats captured 6 families, 27 species, and 276 individuals (ZF captured 3 families, 20 species, and 144 individuals; BH captured 6 families, 23 species, and 132 individuals), and heavy disturbance habitats captured 6 families, 29 species, and 352 individuals (RL captured 4 families, 22 species, and 232 individuals; RHS captured 5 families, 17 species, and 120 individuals). (2) Carabidae and Silphidae dominated in terms of abundance in July and August, while the abundance of Carabidae and Silphidae adults decreased significantly in October and Staphylinidae became dominant; the total species number and total individual number of ground-dwelling Coleoptera adults in different forest types and disturbance gradients showed a decreasing trend in July, August, and October, and community diversity also decreased to varying degrees. (3) Forest type and month had significant effects on the community structure of ground-dwelling Coleoptera adults, while disturbance gradient had no significant effect; there were significant differences in the individual numbers of ground-dwelling Coleoptera adults among the six forest types, but no significant differences in species composition; there were no significant differences in individual numbers and species numbers of ground-dwelling Coleoptera adults among different disturbance gradients, and there was no obvious gradient pattern with changes in disturbance gradient; similarity coefficient and cluster analysis indicated that the two forest types belonging to the same disturbance gradient did not show high similarity. This study demonstrates that disturbance gradient is not the main factor determining the differences in community diversity of ground-dwelling Coleoptera adults among forest types, the response of ground-dwelling Coleoptera adults to different disturbance gradients in the Liangshui forest ecosystem does not conform to the Intermediate Disturbance Hypothesis, and forest type and time are significant factors affecting the community composition of ground-dwelling Coleoptera adults. This experiment provides data support for ground biodiversity conservation and forest ecosystem management.

Full Text

Preamble

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Responses of Ground Coleoptera Adults to Different Disturbance Gradients in the Forest Ecosystem of the Xiaoxing' an Mountains

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Abstract

To investigate the responses of ground-dwelling Coleoptera adult communities to different anthropogenic disturbance gradients in the forest ecosystem of Liangshui Nature Reserve in the Xiaoxing' an Mountains, we conducted pitfall trap surveys in six forest habitats representing three disturbance levels: mild disturbance [virgin mixed broadleaved-Korean pine forest (KY) and valley spruce-fir forest (YL)], intermediate disturbance [selectively cut mixed broadleaved-Korean pine forest (ZF) and secondary birch forest (BH)], and severe disturbance [Dahurian larch plantation (RL) and Korean pine plantation (RHS)]. Sampling was performed in July, August, and October 2015. Statistical analyses included one-way ANOVA, three-way ANOVA, and clustering analysis to address three key questions: (1) whether abundance (individual number), richness (species number), and diversity indices of ground Coleoptera communities differed significantly among the six forest habitats and three seasons; (2) whether these metrics changed gradually across the disturbance intensity gradient; and (3) whether the diversity patterns supported the intermediate disturbance hypothesis.

The results showed that: (1) A total of 879 ground Coleoptera adults were captured across all habitats, belonging to nine families and 44 species. Mildly disturbed habitats yielded 251 individuals (150 in KY and 101 in YL) from six families and 29 species. Intermediately disturbed habitats yielded 276 individuals (144 in ZF and 132 in BH) from six families and 27 species. Severely disturbed habitats yielded 352 individuals (232 in RL and 120 in RHS) from six families and 29 species. (2) In July and August, Carabidae and Silphidae beetles were numerically dominant, while in October, Staphylinidae became dominant as Carabidae and Silphidae abundance decreased. All forest habitats showed a decreasing trend in total Coleoptera abundance from July to October, with community diversity indices also declining to varying degrees. (3) Three-way ANOVA revealed that forest habitat and month had significant main effects on community composition, while disturbance gradient had no significant effect. Beetle abundance differed significantly among the six forest habitats, but species richness did not. No significant differences in abundance, richness, or diversity indices were detected among mild, intermediate, and severe disturbance habitats, indicating no gradual change across the disturbance gradient. Furthermore, similarity coefficients and clustering analyses showed that communities classified within the same disturbance gradient did not exhibit high similarity. These findings suggest that disturbance gradient was not a primary driver of community composition differences among habitats in Liangshui Nature Reserve, and the intermediate disturbance hypothesis was not supported for ground Coleoptera adults. Instead, forest type and seasonal dynamics were identified as important factors structuring these communities. This study provides data support for ground biodiversity conservation and forest ecosystem management.

Keywords: Coleoptera adults; community composition; diversity; disturbance gradient; Xiaoxing' an Mountains

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Introduction

Human activities influence species dynamics by altering biological habitats, thereby affecting biodiversity patterns. With increasing anthropogenic and natural disturbances, research on biodiversity responses to varying disturbance intensities has become increasingly relevant. Disturbance theory constitutes an important component of ecology, with the intermediate disturbance hypothesis receiving particular attention. This hypothesis proposes that intermediate levels of disturbance can maintain high biodiversity and has been validated across various communities. However, whether soil animal communities in forest ecosystems support this hypothesis remains unclear. While some studies have examined soil animal responses to human disturbance intensity in grassland, farmland, and wetland ecosystems, research on ground-dwelling soil animals in forest ecosystems is scarce.

Liangshui Nature Reserve in the Xiaoxing'an Mountains presents a complete disturbance gradient from primary forest to secondary forest to plantation forest, providing an ideal platform for investigating soil animal community responses to different disturbance intensities. This study selected six forest types representing different disturbance gradients: virgin mixed broadleaved-Korean pine forest (KY), valley spruce-fir forest (YL), selectively cut mixed broadleaved-Korean pine forest (ZF), secondary birch forest (BH), Dahurian larch plantation (RL), and Korean pine plantation (RHS). Pitfall trapping was conducted in July, August, and October to address: (1) whether individual numbers, species composition, and community diversity differ significantly among forest types and seasons; (2) whether these metrics show gradient patterns along the disturbance intensity gradient; and (3) whether the diversity patterns support the intermediate disturbance hypothesis.

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1. Study Area

The study area is located in Liangshui Nature Reserve, Dailing District, Yichun City, Heilongjiang Province (47°10 50 N, 128°53 20 E), on the eastern slope of the Dailing branch of the Xiaoxing' an Mountains at elevations of 280–707 m. The region features typical low mountain-hilly terrain and a temperate continental monsoon climate with rainy summers. Long-term cold, dry winters and rapid autumn cooling characterize the climate. The zonal soil is dark brown forest soil, with non-zonal soils including meadow soil, swamp soil, and peat soil. The reserve preserves intact, typical zonal climax communities and natural landscapes, with complex and diverse vegetation. The zonal vegetation is temperate coniferous-broadleaved mixed forest dominated by Korean pine (*Pinus koraiensis*), providing a complete gradient of primary forest, secondary forest, and plantation forest ecosystems.

Six forest types were selected as experimental plots representing different disturbance gradients: - **Mild disturbance**: Virgin mixed broadleaved-Korean pine forest (KY, ~300 years) and valley spruce-fir forest (YL, ~300 years) - **Intermediate disturbance**: Selectively cut mixed broadleaved-Korean pine forest (ZF, ~200 years) and secondary birch forest (BH, ~60 years) - **Severe disturbance**: Dahurian larch plantation (RL, ~63 years) and Korean pine plantation (RHS, 62–63 years), established after clear-cutting

Detailed information on site conditions and species composition is provided in reference [13].

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2. Sampling Design and Specimen Collection

Within each of the six forest types (KY, YL, ZF, BH, RL, RHS), three 20 m × 30 m replicate plots were established. Pitfall traps were used to collect ground-dwelling soil animals. At each plot, three sampling points were randomly selected from the four vertices. At each point, a cylindrical pit (7 cm diameter, 14 cm depth) was dug, and a plastic cup containing approximately 2/3 volume of preservative was placed flush with the ground surface. A disposable plate was positioned ~5 cm above the cup opening to prevent litter and rainwater contamination. Traps were left in the field for 7 days.

Sampling was conducted in July, August, and October 2015, yielding 54 samples total (6 forest types × 3 plots × 3 months). Collected Coleoptera adults were sorted by hand, preserved in medical alcohol, and identified to species under a stereomicroscope (Motic SMZ168) using *Illustrated Guide to Soil Beetles of Northeast China* [16, 17], *Illustrated Key to Soil Animals of China* [18], and *Study on Silphidae of Northeast China* [19].

2.1. Diversity Indices

Abundance classification: Based on Raunkiaer's frequency index [19], species with >10% of total individuals were classified as dominant, 1.0%-10.0% as common, and <1.0% as rare.

Diversity indices: Shannon-Wiener index ($H' = -\sum P_i \ln P_i$), Pielou' s evenness index ($J = H'/\ln S$), and Simpson' s dominance index ($D = \sum P_i^2$) were calculated, where S is species number and P_i is the proportion of individuals of species i.

Density-Group index: $DG = \sum(D_i C_i / D_i C)$, where D_i is individual number of species i, C_i is occurrence frequency, C is maximum individual number of species i across communities, and g is species number.

Community similarity: Jaccard similarity coefficient ($q = c/(a + b - c)$) and Gower coefficient ($S_g = 1 - \frac{1}{n}\sum |X_{ij} - X_{ik}|/R_i$) were used, where a and b are total species numbers in two plots, c is shared species number, X_{ij} and X_{ik} are individual numbers of species i in communities j and k, and R_i is the range of species i across communities. Similarity was interpreted as: 0.75-1.00 (highly similar), 0.50-0.74 (moderately similar), 0.25-0.49 (moderately dissimilar), and 0.00-0.24 (extremely dissimilar).

2.2. Statistical Analysis

Data normality was tested using Q-Q plots. Non-normal data were square-root transformed. Three-way ANOVA tested main and interactive effects of disturbance gradient, forest type, and month on individual numbers, species numbers, and diversity indices. One-way ANOVA compared differences among forest types within the same month and among months within the same forest type. Multiple comparisons used least significant difference (LSD) method. Cluster analysis based on squared Euclidean distance was performed to assess similarity among forest types. All analyses were conducted in SPSS 21.0, Origin 8.6, and Excel 2007.

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3. Results and Analysis

3.1. Species Composition and Abundance Characteristics

A total of 879 ground Coleoptera adults were captured, belonging to nine families and 44 species. Carabidae, Silphidae, and Staphylinidae were the dominant families, comprising 39.81%, 35.16%, and 10.35% of total individuals, respectively. Three dominant species accounted for 42.43% of total captures: *Phosphuga atrata* (Silphidae, 23.54%), *Nicrophorus tenuipes* (Silphidae, 21.96%), and *Aulonocarabus canaliculatus* (Carabidae, 14.56%). Common species comprised 10.69% of individuals, while 29 rare species (65.91% of total species) accounted for only 1.94% of individuals.

Dominant and common species showed wide distributions across forest types. All three dominant species occurred in multiple forest types and disturbance gradients. Frequency analysis revealed that species in Raunkiaer' s classes A (>80% frequency) and B (60–80%) were most numerous, indicating that low-frequency species outnumbered high-frequency species—a typical pattern where most species have restricted distributions.

Across forest types, individual numbers ranked: RL (232) > KY (150) > ZF (144) > RHS (120) > YL (101) > BH (98). RL differed significantly from all other types ($P < 0.05$), while other pairwise comparisons showed no significant differences. Species richness ranked: BH (23) > RL (22) > KY (21) > ZF (20) > YL (20) > RHS (17), with no significant differences among forest types.

Mild, intermediate, and severe disturbance habitats captured 251, 276, and 352 individuals, respectively, with no significant differences among disturbance levels. Three-way ANOVA showed that forest type ($F = 31.441$, $P < 0.05$) and month ($F = 60.454$, $P < 0.05$) significantly affected individual numbers, while disturbance gradient did not. Forest type significantly affected species richness ($F = 6.088$, $P < 0.05$), but month and disturbance gradient did not. No significant interactions were detected.

Seasonally, July and August captures were dominated by Carabidae and Silphidae, while October was dominated by Staphylinidae. Total individuals and species numbers declined from July to October across all forest types, with diversity indices also decreasing.

3.2. Horizontal Distribution and Seasonal Dynamics

In July, RL had significantly higher individual numbers than all other forest types except ZF ($P < 0.05$). KY and ZF showed moderate abundances, while YL, BH, and RHS had the lowest numbers. In August, RL again had the highest abundance, significantly different from all types except ZF ($P < 0.01$). KY and ZF were moderately abundant, while BH and RHS were lowest. In October, all forest types showed low captures, with RL and KY significantly higher than ZF ($P < 0.05$).

Species richness varied seasonally within forest types. In KY, species numbers differed significantly between July and October ($P < 0.05$). In YL, ZF, and BH, species richness declined from July to August and further to October, with significant differences between July and October ($P < 0.05$). In RL, species numbers in July and August were significantly higher than in October ($P < 0.05$). In RHS, July and August species numbers were significantly higher than October ($P < 0.05$).

3.3. Community Diversity

Diversity indices (H', J, C, DG) showed no significant differences among forest types within the same month. However, within the same forest type, significant temporal differences were observed. For example, KY' s DG index differed significantly across all three months ($P < 0.05$). ZF's DG index differed between July and October ($P < 0.05$). BH' s H' index differed significantly between July and both August and October ($P < 0.05$). RL' s DG index differed between July and October ($P < 0.05$), while RHS' s DG index differed between July and August ($P < 0.05$).

Three-way ANOVA revealed that month had significant main effects on diversity indices ($F = 26.372$, $P < 0.05$ for DG; $F = 48.123$, $P < 0.05$ for H'; $F = 25.714$, $P < 0.05$ for J), while forest type and disturbance gradient did not. No significant interactions were found.

3.4. Community Similarity and Cluster Analysis

Jaccard similarity coefficients (q) among forest types ranged from 0.125 to 0.688, while Gower coefficients (S_g) ranged from 0.052 to 0.452, indicating greater heterogeneity in individual numbers than in species composition. In July, KY-YL showed the highest similarity ($q = 0.688$), while RL-RHS showed the lowest ($q = 0.125$). In August, ZF-KY were most similar ($q = 0.643$), and RL-RHS remained most dissimilar ($q = 0.267$). In October, RL-RHS similarity increased ($q = 0.500$), while KY-YL became most dissimilar ($q = 0.125$).

Cluster analysis based on squared Euclidean distance showed that forest types with the same disturbance gradient did not cluster together. Instead, clustering patterns varied by month, with no consistent grouping by disturbance level. For example, in July, RL and RHS (both severe disturbance) were separated, while in October, they showed some similarity. This indicates that disturbance gradient was not a primary determinant of community similarity.

shows detailed comparisons of individual and species numbers among forest types, disturbance gradients, and months. [Figure 1: see original paper] illustrates seasonal dynamics of individual and species numbers for each forest type. [Figure 2: see original paper] presents clustering dendrograms for each month.

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4. Discussion

The intermediate disturbance hypothesis was not supported in this study. Ground Coleoptera community diversity in Liangshui forest ecosystem did not show the predicted peak at intermediate disturbance levels. Instead, forest type and seasonal dynamics emerged as the primary factors influencing community structure, while disturbance gradient had no significant direct effect.

Several mechanisms may explain these patterns. The valley spruce-fir forest (YL), despite being mildly disturbed, had low diversity due to its topographic position in low-lying areas that experience periodic waterlogging, creating suboptimal conditions for soil arthropods. The virgin mixed broadleaved-Korean pine forest (KY) showed moderate diversity, possibly due to minor anthropogenic impacts such as tourist trails that caused localized vegetation damage.

The secondary birch forest (BH) and selectively cut forest (ZF), representing intermediate disturbance, showed divergent diversity patterns despite similar disturbance classifications. This likely reflects differences in microhabitat conditions, vegetation structure, and soil moisture regimes between these forest types. The larch plantation (RL), a severely disturbed habitat, unexpectedly exhibited high beetle abundance and diversity. This may be attributed to its location on sunny slopes with good soil drainage, abundant understory vegetation, and rich litter resources, creating favorable microenvironments for soil fauna. In contrast, the Korean pine plantation (RHS) had lower diversity, possibly due to sparse ground cover and exposed soil surfaces.

Seasonal dynamics strongly influenced community composition. The shift from Carabidae/Silphidae dominance in summer to Staphylinidae dominance in October reflects temperature-driven changes in beetle activity and resource availability. The significant decline in diversity indices across months underscores the importance of seasonal variation in structuring these communities.

The high proportion of rare species (65.91% of species but only 1.94% of individuals) confirms that community heterogeneity is pronounced in this system, with most species having narrow distributions and low abundances. This pattern aligns with findings from other soil fauna studies showing that rare taxa contribute disproportionately to regional diversity.

Similarity analyses revealed that forest types with identical disturbance histories did not form coherent groups. The Jaccard coefficients, which consider only species presence/absence, were consistently higher than Gower coefficients, which incorporate abundance data. This indicates that while some species were shared among habitats, their abundances varied dramatically, contributing to community differentiation.

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5. Conclusion

This study demonstrates that ground Coleoptera adult communities in Liangshui Nature Reserve do not conform to the intermediate disturbance hypothesis. Community composition, individual numbers, and diversity indices did not show gradient patterns corresponding to disturbance intensity. Instead, forest type and seasonal dynamics were the primary factors influencing community structure. The lack of significant differences among disturbance gradients indicates that other factors—such as microclimate, vegetation structure, soil conditions, and historical land-use patterns—play more important roles in shaping ground beetle communities. These results provide important baseline data for biodiversity conservation and forest ecosystem management in temperate forest ecosystems.

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Note: Figure translations are in progress. See original paper for figures.