Postprint: Meta-Analysis of Soil Fauna Community Characteristics in Southwest China Karst Region

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Abstract

The karst regions of southwestern China are characterized by low environmental capacity, high sensitivity to ecosystem variation, and low disaster bearing capacity, representing typical ecologically vulnerable areas. Soil fauna constitute an important component of terrestrial ecosystems and are of great significance to ecosystem function and stability. Through Meta-analysis of soil fauna community characteristics in southwestern karst regions, the following results were obtained: soil fauna in this region belong to 5 phyla, 15 classes, and 31 groups; the average density of meso- and micro-soil fauna is 6.0×10^{3}–1.9×10 m ^{2}; the density and number of taxa of meso- and micro-soil fauna exhibit a pattern of being higher in summer and autumn and lower in winter and spring, with pronounced surface aggregation of soil fauna; karst rocky desertification significantly reduces the density and number of taxa of meso- and micro-soil fauna. The results of this study indicate that the number of soil fauna taxa in southwestern karst regions of China is relatively rich, while individual density is low but may be underestimated. In future work on biodiversity conservation and restoration of fragile ecosystems in karst regions, relevant research on soil fauna communities should be emphasized.

Full Text

Preamble

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Characteristics of Soil Fauna Communities in the Karst Region of Southwest China Based on Meta-Analysis

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Abstract

The karst region in Southwest China is characterized by low environmental capacity, high sensitivity to ecosystem variation, and low resilience to catastrophic disturbances, making it a typical ecologically vulnerable zone. Soil fauna are important components of terrestrial ecosystems and play significant roles in maintaining ecosystem functions and stability. Based on meta-analysis, this study evaluated soil fauna community characteristics in the karst region of Southwest China by analyzing species composition, vertical distribution patterns, and the influence of rocky desertification on soil fauna density and group numbers. Publications related to soil fauna ecology in the karst region of Southwest China, published between January 1, 1990 and October 31, 2016, were retrieved from the Web of Science and China Knowledge Resource Integrated Database (CNKI) using keywords including soil fauna, soil animal, soil invertebrates, soil micro-arthropods, and karst in both Chinese and English. A total of 34 publications were selected for meta-analysis after literature filtering and quality evaluation. Results showed that soil fauna belonged to 5 phyla, 15 classes, and 31 groups (classes or orders) in the karst region of Southwest China. Soil macro-fauna were dominated by Hymenoptera and Coleoptera, while soil micro-fauna and meso-fauna were dominated by soil mites and collembolans. The density of soil micro-fauna and meso-fauna ranged from 6.0×10^3 to 1.9×10 individuals/m^2. Soil fauna density and group numbers were significantly higher in summer and autumn than in winter and spring, showing obvious surface accumulation. Rocky desertification in the karst region of Southwest China significantly decreased soil fauna density ($P < 0.01$, MD = -7799.6, 95% CI: -10822.24 to -4776.99) and group numbers ($P < 0.01$, MD = -1.9, 95% CI: -2.89 to -1.09). Soil fauna individuals significantly decreased with soil depth ($P < 0.01$, MD = -23.4, 95% CI: -0.31 to -0.16), showing an obvious phenomenon of soil surface layer accumulation. These results indicate that soil fauna group numbers were high in Southwest China, while density was low but possibly underestimated due to the lack of soil nematodes data in most retrieved original publications. Because of the importance of soil fauna in ecosystems, greater attention should be paid to soil fauna communities and their ecological functions, especially for biodiversity protection and the recovery of vulnerable ecosystems in the karst

region of Southwest China.

Keywords: karst; soil fauna; community characteristic; meta-analysis; rocky desertification

Introduction

Soil fauna are important components of terrestrial ecosystems, widely distributed and playing crucial roles in maintaining material cycling and energy flow through their interactions with biotic and abiotic factors. As an important part of the belowground food web, they regulate litter decomposition, modify soil microenvironments, and influence soil microbial communities, thereby promoting litter decomposition and nutrient release. Soil fauna can accelerate the decomposition of more than 60% of litter and influence global carbon and nitrogen cycles. Changes in soil fauna community composition and functional groups are important driving factors of ecosystem functions.

Southwest China contains the world' s largest, most concentrated contiguous karst region, which also suffers from the most severe rocky desertification. This region is characterized by rugged terrain, frequent drought and flood disasters, poor ecological stability, weak disaster resistance, and vulnerability to damage with slow recovery. Vegetation destruction and habitat degradation in karst areas affect soil fauna communities, while changes in soil fauna communities also influence soil physicochemical properties and microhabitat alterations. As an important component of terrestrial ecosystems, soil fauna communities should receive adequate attention in ecological restoration efforts in karst regions. To comprehensively evaluate soil fauna community characteristics in karst areas, this study summarizes previous research and compares them with other regions to provide basic materials for biodiversity protection and comprehensive prevention and restoration of fragile karst ecosystems.

This study proposes the following hypotheses: (1) Soil fauna group numbers are low in Southwest China karst region, and (2) rocky desertification will reduce species numbers and individual density.

1 Data Acquisition

Publications were retrieved from the Web of Science and CNKI databases without time restrictions using search terms: "soil fauna / microarthropods / soil organisms / soil animal / Karst / China" . The final retrieval date was October 31, 2016. Literature with non-soil animal study objects was excluded. Data in tables were directly extracted, while data in figures from original literature were obtained using GetData software.

2 Data Processing

Because different studies used inconsistent classification levels (mostly to class or order), original data were reclassified according to *China Soil Fauna Identifi-*

cation Atlas and unified to class or order. Study methods included hand picking (H), pitfall traps (X), Tullgren funnels (T), and Baermann funnels (B). The acquired data were divided into macro-fauna and micro/meso-fauna for separate analysis. Since quantitative standards for macro-fauna using hand picking and pitfall traps were not uniform, only community composition was analyzed. For micro/meso-fauna, original data were converted to density (individuals/m^2) based on sampling area to enable comparison among different studies.

Analysis Requirements

Data were organized and analyzed to establish a database. Due to inconsistent representation of individual numbers in vertical distribution among studies, data were uniformly divided into 0-5 cm, 5-10 cm, and 10-15 cm layers for statistics, with mean and standard deviation calculated for each layer. According to plot descriptions in literature, habitats were divided into two levels: rocky desertification and non-desertification, and individual density and species numbers of soil fauna were statistically analyzed for both habitat types. The percentage of between-study variation in total variation was used as a heterogeneity test index (I^2). A fixed-effects model was used to combine results when $I^2 < 0.25$, while a random-effects model was used when $I^2 > 0.25$ or when data needed verification, subgroup analysis, or sensitivity analysis. Funnel plot method and Begg' s test were used for bias assessment. The "meta" and "vegan" packages in R were used for statistical analysis and plotting. Significance level was set at $= 0.05$.

1 Species Composition

Soil fauna in Southwest China karst region totaled 31 groups, belonging to 5 phyla and 15 classes. Soil nematodes accounted for only 2.3% of the total. Macro-fauna dominant groups were Hymenoptera (42%) and Coleoptera (20%). Mites and collembolans were dominant in micro/meso-fauna, accounting for 41.6% and 39% respectively .

2 Seasonal Distribution Characteristics

Karst micro/meso-fauna showed distinct seasonal distribution patterns. Soil fauna density was significantly higher in summer (16,035 individuals/m^2) and autumn (7,270 individuals/m^2) than in winter ($P < 0.05$). Although differences in micro/meso-fauna density among other seasons were not significant, the overall trend showed higher values in summer and autumn than in spring and winter. Group numbers also showed a summer-autumn > spring-winter trend (12-19 groups), but differences among seasons did not reach significant levels ($P > 0.05$) [Figure 1: see original paper].

3 Vertical Distribution Characteristics

Karst soil fauna numbers decreased with increasing soil depth, showing obvious surface accumulation. Individuals in the 0-5 cm soil layer accounted for 61.5% of the total, while those in the 10-15 cm layer accounted for 38.5%. The mean difference was -0.23 (95% CI: -0.31 to -0.16, $P < 0.05$). Begg' s test results showed good funnel plot symmetry ($P > 0.05$), indicating low publication bias in selected literature [Figure 2: see original paper].

4 Effects of Rocky Desertification on Soil Fauna Density and Group Numbers

Micro/meso-fauna density and group numbers were greater in non-desertification areas than in desertification areas, with densities of 16,266.8 individuals/m² and 8,466.2 individuals/m² respectively, and group numbers of 19 and 12 respectively. Rocky desertification significantly reduced micro/meso-fauna density and species numbers. The mean differences between desertification and non-desertification areas were -7,799.6 (95% CI: -10,822.24 to -4,776.99, $P < 0.01$) for density and -1.9 (95% CI: -2.89 to -1.09, $P < 0.01$) for group numbers. Begg' s test showed good funnel plot symmetry ($P > 0.05$), indicating low publication bias [TABLE:2, TABLE:3].

3 Discussion

Contrary to our first hypothesis, Southwest China karst region has relatively high soil fauna group numbers, comparable to those in Northeast, East, and other regions. The study area features varied topography, forming rich ecosystem types, lakes, and karst caves, which create complex and diverse microhabitats. Previous studies have shown that more complex ecosystems support higher biodiversity. Although Southwest China karst is a typical ecologically vulnerable region, its diverse environmental types and high habitat diversity result in relatively rich soil fauna group numbers.

However, despite high group numbers, micro/meso-fauna density in Southwest China karst region is low, far below densities in forest and grassland ecosystems in Northeast, East, and Sichuan regions, and only higher than that in Songnen sandy land (6.0×10^3 to 1.9×10 individuals/m²). Compared with literature from other regions, most studies in this region did not include soil nematode data, while nematodes are one of the high-density groups in soil fauna with densities up to 8.1×10 to 3.0×10 individuals/m². Therefore, soil fauna individual density in this region may be underestimated.

Seasonal dynamics of soil fauna are influenced by seasonal precipitation, temperature, and vegetation differences. Seasonal dynamics of soil fauna diversity vary across regions. Studies in Ruoergai alpine meadows showed negative correlations between soil fauna group numbers/density and air/soil temperature, while hilly regions in Changbai Mountains showed positive correlations with soil tempera-

ture. Yang et al. found that soil fauna group numbers, individual numbers, and diversity were lowest during rainy seasons. Research in jujube forests in Northern Shaanxi showed positive correlations between soil fauna density and soil water content. In mid-temperate and cold-temperate regions, soil fauna density peaks in July, while in tropical regions it generally peaks in late autumn and early winter. In regions with concurrent heat and precipitation, soil fauna community numbers and diversity are high in summer and autumn but relatively low in winter and spring. This region belongs to the subtropical zone, where soil fauna density and group numbers are high in summer and autumn [Figure 2: see original paper], consistent with temperature and precipitation patterns. Soil fauna communities in Southwest China karst region are also affected by extreme climates, such as drought reducing group numbers, dominance, and richness indices.

Consistent with other regions, karst soil fauna vertical distribution shows obvious surface accumulation, with individual density and species numbers decreasing with soil depth. This pattern is closely related to vertical distribution of soil physicochemical properties such as organic matter content and soil porosity. Due to plant root activity, surface soil is relatively loose, and soil fauna distribution varies among different groups and soil environments, also showing seasonal fluctuations influenced by climate. Additionally, distribution is affected by natural disasters and external disturbances. Horizontal distribution of soil fauna is influenced by vegetation structure complexity, vegetation coverage, and litter quality. Aboveground and belowground ecosystems are coevolutionary communities, where changes in aboveground vegetation directly or indirectly affect soil fauna community structure. With habitat degradation, soil fauna density, group numbers, and community evenness show decreasing trends. Rocky desertification destroys system structure, reduces vegetation coverage, degrades soil quality, and deteriorates habitat conditions for soil fauna. Both soil fauna density and group numbers are affected by human disturbance and natural conditions, being higher in forest land and non-desertification areas, and significantly decreasing with rocky desertification intensity, supporting our second hypothesis. Ecological restoration helps recover soil fauna communities, as group numbers, individual density, and diversity significantly increase with environmental improvement. Therefore, soil fauna community changes should be considered in biodiversity protection and restoration efforts in karst regions.

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