

Plant Diversity Is More Important than Climate Factors in Driving Insect Richness Pattern along a Latitudinal Gradient

Yanling Peng ¹, Jie Gao ^{2,*} and Xing Zhang ^{3,*}

¹ Department of Science and Technology, Southwest Forestry University, Kunming 650224, China; pyling0909@163.com

² College of City and Environment, Peking University, Beijing 100683, China

³ Qinhuangdao Key Rural Laboratory, Hebei University of Environmental Engineering, Qinhuangdao 066102, China

* Correspondence: jiegao72@gmail.com (J.G.); zxyybh@163.com (X.Z.)

Abstract: The insect data of 93 national nature reserves in China was used to identify the underlying drivers' potential for species richness along geographical gradients. We assessed the correlations between predictors (climate and soil) and response variables (insect richness). We found that the following: insect diversity decreased significantly at higher latitudes. The latitudinal variation in insect richness seems to be driven by climate and soil variations and also the diversity of other biota. Among all the tested predictors, plant diversity explained the most latitudinal patterns of insect richness ($R^2 = 0.498$). Insect richness showed a positive correlation with the diversity of other biota and climate factors (mean annual temperature and mean annual precipitation) and was negatively associated with soil pH. Overall, the interspecific relationship between organisms was the main driver of insect diversity's latitudinal pattern. However, the effects of climate and soil factors cannot be ignored.

Keywords: insect richness; latitude; climate change; soil factor



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1. Introduction

Pattern variations in species richness is still a fundamental challenge in biodiversity conservation [1–4]. Most of these studies are explicitly focused on understanding the drivers of the latitudinal gradient in species richness [5]. Changes in species richness along latitudinal gradients have proven to be valuable platforms to research the effects of environmental change on biodiversity [6]. As a group with high species richness and wide geographical distribution, insects play a critical role in driving multiple ecosystem functions and services, including nutrient cycling and food production [7]. It is of great ecological significance to understand the latitudinal distribution patterns of insects and the controlled environmental factors that affect them in order to protect biodiversity and the maintenance of ecosystem balance.

Climate change alters species' richness and distributions worldwide [4,8]. Many hypotheses related to the geographical gradient in species richness and distribution focus on the role of climatic drivers [5]. Generally speaking, precipitation and temperature, particularly, are highly correlated with geographical factors [5] and are thus expected to underlie these relationships. With the increase in temperature and rainfall, the available resources also increase, and higher species diversity can be ensured [4,5]. However, rising or too low temperatures may lead to reduced activity and fitness of cold-blooded species, and hence reduced their richness. Changes in other climate variables, such as precipitation and water availability, may likewise affect species' richness patterns [9].

Soil pH is one of the main factors affecting species richness [5]. Different plants have different survival strategies [10]. However, in general, the litter leaves produced by plants growing in nutrient-rich soils also have higher nutrients, which release large amounts of

nutrients after decay, thus maintaining a higher soil fertility level [5]. Some insects live on plants (or feed on plants), and some insects live directly in the soil. Therefore, as direct or indirect factors affect insect life, soil factors may be closely related to insect diversity. However, how the soil factors affect insect richness is still unclear.

In addition to the abiotic environment (climate and soil factors), biotic interactions are likely to be essential factors driving insect richness. In the process of long-term survival and development, insects and plants have formed complex interdependencies and mutualistic relationships. Plants provide resources that many insects depend on for their survival and reproduction. Likewise, many insects provide essential pollination services for plants [1].

The primary purpose of our study was to elucidate the relationships between climate, soil, and plant richness variables and to identify the critical factors affecting the distribution of insect richness along latitudinal gradients. We aim to answer the following questions: (i) Is the richness pattern of insects in latitudinal gradients is significant? (ii) Are diversity patterns relating to latitude correlated with climatic, soil, and plant richness variables? Additionally, (iii), what is the relative contribution of biotic and abiotic factors in driving the latitudinal pattern of insect diversity?

2. Materials and Method

2.1. Study Site and Data Collection

We used insect data obtained from 93 national nature reserves (Table S1) in China. The data on insect richness comes from the newly published scientific investigation reports and are by far the most comprehensive documentation of insects in China in the national nature reserves. Insect richness, plant richness (gymnosperms, angiosperms, and ferns), bird richness, mammal richness, area, longitude, and latitude were also clearly obtained from these publications.

Across all the national nature reserves, mean annual precipitation (MAP) ranges from a low of 40 mm to a high of 3200 mm, and mean annual temperature (MAT) ranges from a low of -12°C to a high of 27°C . This sampling gradient also spans the following four major forest types: temperate broad-leaf forest, temperate coniferous forest, tropical/subtropical forest, and grasslands.

2.2. Environmental Predictor Variables

Because climate and soil factors are closely related to latitude [6], we used climate and soil factors to explain the geographic pattern of insect richness. Strong multicollinearity can result in the exclusion of causal ecological variables from examined models. Reducing the number of predictors can improve the accuracy of the model [11]. Mean annual temperature (MAT) and mean annual precipitation (MAP) obtained from the WorldClim database (<http://www.worldclim.org/>) (accessed on 31 December 2020) [12] using a 10 km spatial resolution [5], were selected as climate factors. Soil pH obtained from the scientific reports and the harmonized world soil database was chosen as a soil factor.

2.3. Analyses

Our primary interest was determining which environmental factors were significantly correlated with variation in insect richness across the sampling national nature reserves in China. We tested the normality of all environmental factors, and they were all normal. Then correlations between predictor (geographical and environmental factors) and response (insect richness) factors were assessed using general linear models (GLMs). Insect richness was regressed against latitude and longitude, and the GLM models were chosen using AIC. R^2 was used to evaluate the explanatory power of the climate, soil pH, and biotic richness on insect richness along latitude. Multiple regression model was used to test the degree of explanation of all factors for insect diversity. Because the area of the reserve has a significant impact on insect richness (Figure S1). We divided the number of insect species by the area of the reserve as the insect richness.

3. Results

We observed a wide variation in insect richness, which was significantly correlated with latitude (Figure 1). Latitude alone explained 17.6% of the variation in insect richness ($p < 0.001$).

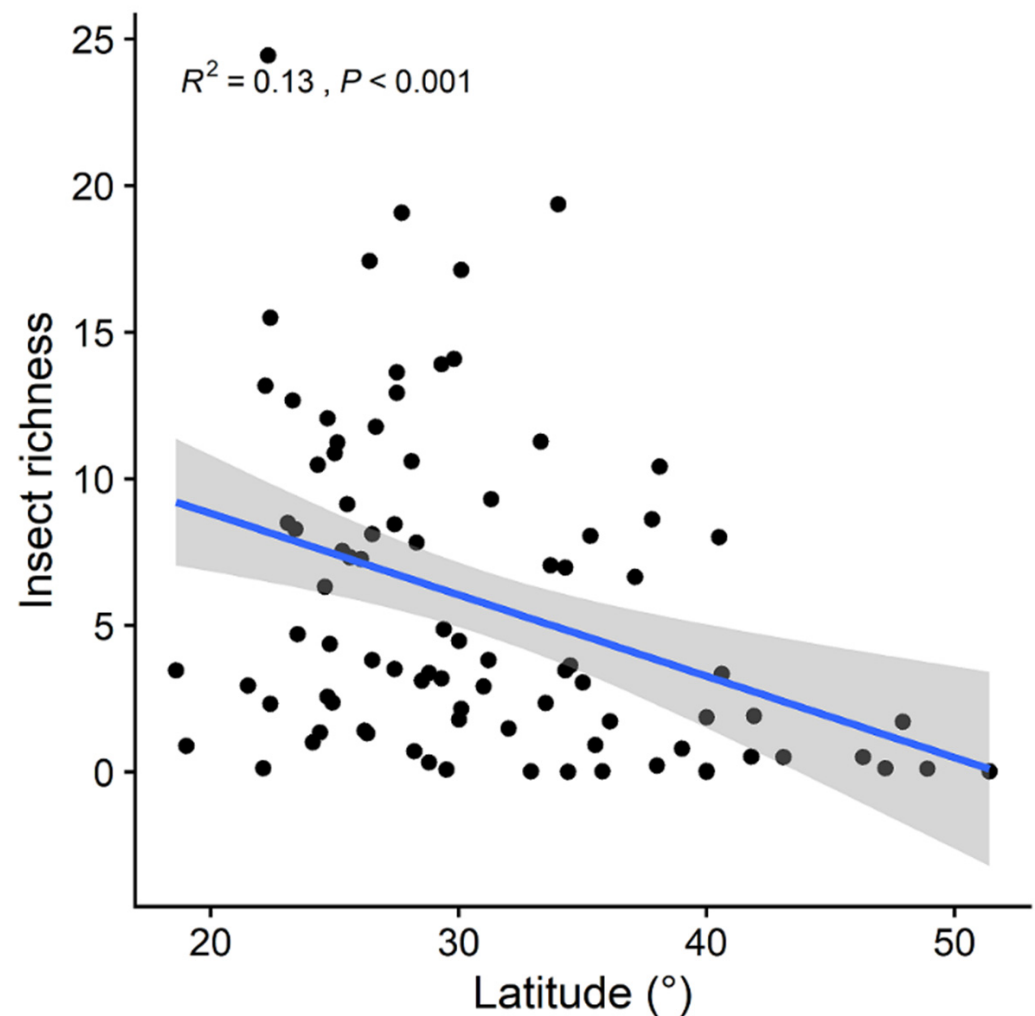


Figure 1. Latitudinal gradient in insect richness in China. R^2 was used to estimate the explanatory power of the regression models.

The latitudinal variation in insect richness that we observed appears to be affected by variation in climate. The insect richness was significantly correlated with both MAT and MAP (Figure 2). Among all the climate factors, the interpretation of MAT explained most of the latitudinal pattern of insect richness ($R^2 = 0.0726$). The variation in soil pH and plant richness was also significant (Figures 3 and 4). There was a strong positive correlation between plant richness, bird richness, mammal richness, and insect richness ($p < 0.001$) (Figures 3 and 5). In contrast, the soil pH was significantly negatively associated with insect richness (i.e., higher richness in more basic soils) (Figure 4).

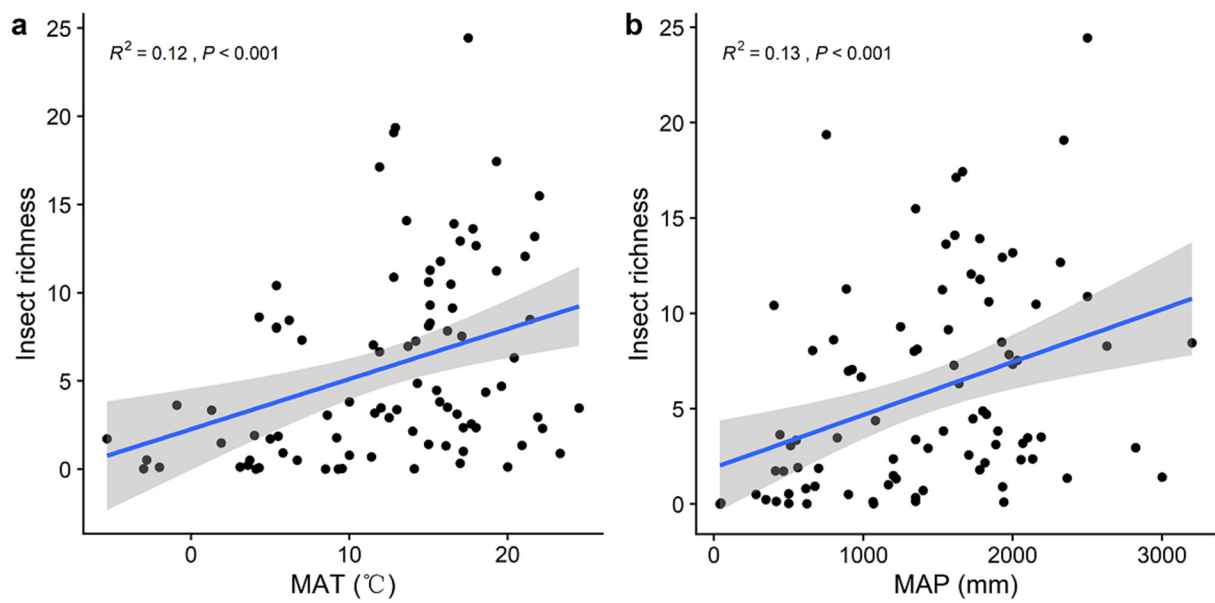


Figure 2. Relationships between the MAT (mean annual temperature) (a), MAP (mean annual precipitation) (b), and insect richness. R^2 was used to estimate the explanatory power of the regression models.

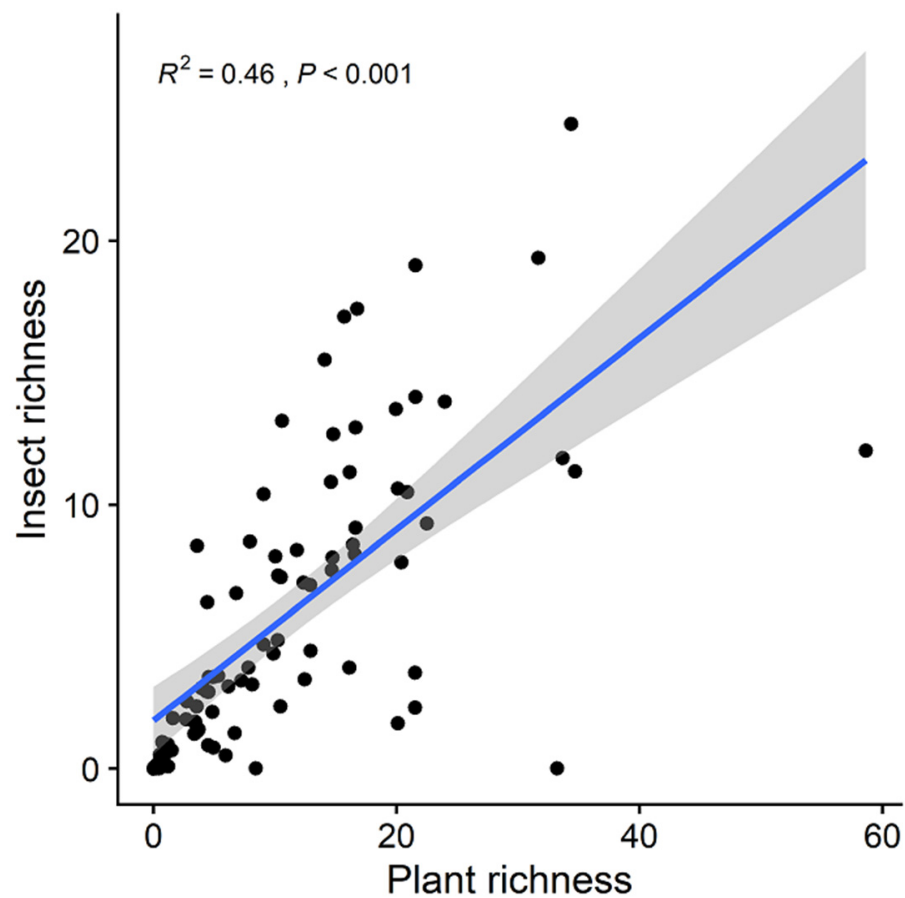


Figure 3. Relationships between insect richness and plant richness. R^2 was used to estimate the explanatory power of the regression models.

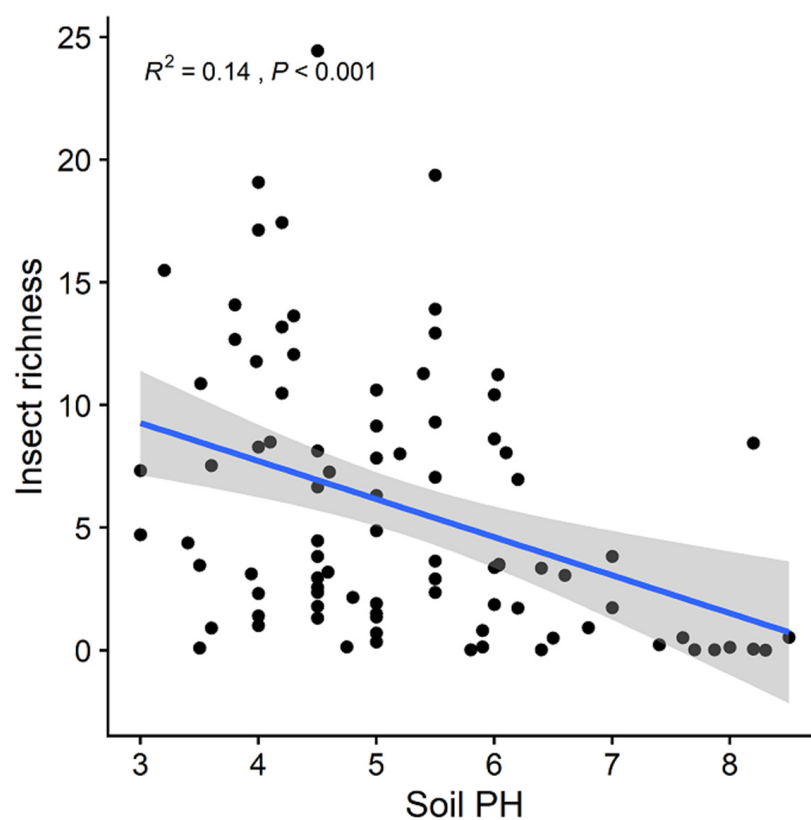


Figure 4. Relationships between soil pH and insect richness. R^2 was used to estimate the explanatory power of the regression models.

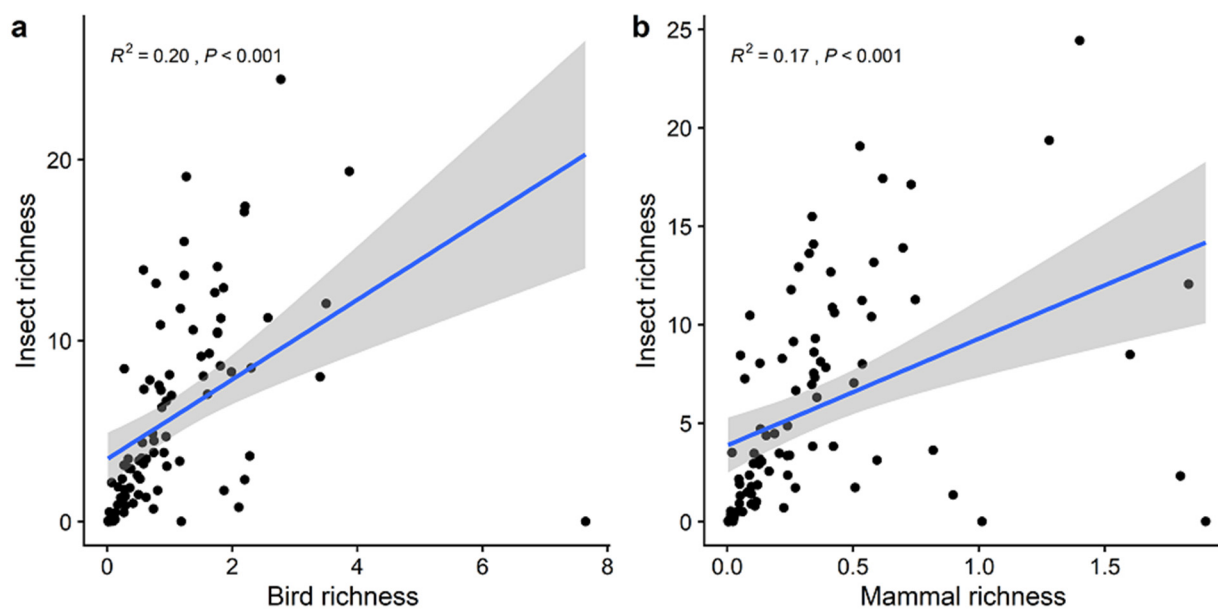


Figure 5. Relationships between bird (a), mammal (b), and insect richness. R^2 was used to estimate the explanatory power of the regression models.

A multiple regression model revealed that the most significant variation in richness was accounted for by plant richness. All these factors can explain 55.5% of the latitude variation of insect richness (Tables 1 and 2).

Table 1. Summary of the separate multiple regression models for the climate, biodiversity, and soil variables for insect richness. The model with the lowest AICc (Akaike information criterion) was selected as the best one.

Variables	Predictors Included in the Best Model (Standardized Coefficient)	Adjusted R^2	p -Value	AICc
Climate	MAT, MAP	0.127	<0.05	23.5
Biodiversity	Plant richness, Bird richness, Mammal richness	0.632	<0.01	19.6
Soil	Soil pH	0.141	<0.01	14.8

Table 2. Summary of the general linear models for the climate, biodiversity, and soil variables for insect richness. R^2 was used to estimate the explanatory power of the regression models. All variables passing the significance test level of 95% confidence interval are marked in bold. CI represents the confidence interval at the 95% level. The p value represents significance at the 95% level.

Insect Richness			
Predictors	Estimates	CI	p
(Intercept)	3.27	(−2.94, 9.48)	0.023
MAT	−0.01	(−0.17, 0.16)	0.063
MAP	0.02	(−0.02, 0.03)	0.101
Bird richness	1.08	(0.12, 2.04)	0.028
Mammal richness	−3.21	(−6.31, −0.11)	0.043
Plant richness	0.36	(0.23, 0.48)	<0.001
Soil pH	−0.59	(−1.42, 0.24)	0.159

4. Discussion

Insect richness is significantly lower with increasing latitude across China. From high latitude to low latitude, biological resources gradually increased, and the climate was also suitable for insect survival. Therefore, insect richness steadily increased. Lomolino [3] found that more complex environments foster higher species richness. Gao [5] also found that plant diversity showed a significant downward trend with the increase in latitude. This reflects that the variation laws of different species within biological groups along the latitude gradient are consistent.

Species–area relationship is an important scientific question in ecology, which studies the law that the number of species changes with the increase in sampling area [13]. With the increase in sampling area, habitat heterogeneity increases, so more species can be retained. Habitat heterogeneity provides more niches and increases the niche width, thus ensuring a high level of biodiversity [5].

Soil and plants serve as the immediate environment for insects to live [6]. The physical and chemical properties of soil and plant diversity significantly impact insect diversity [14]. A place with more plant species provides a higher ecological niche for insects and expands the insects' feeding and reproduction range [15]. Therefore, as the number of plant species increases, the number of insect species also increases. Soil pH represents an essential physical and chemical property of the soil. The smaller the soil pH, the greater the soil acidity, which is not suitable for the survival and reproduction of insects. Therefore, as soil acidity increases, insect diversity shows a downward trend. There is a predation relationship between birds and insects [16]. Therefore, there is a positive correlation between insect and bird diversity.

There are complex interspecific relationships between birds, mammals, and insects, such as predation and parasitism [5]. Most previous studies ignored the impact of interspecific relationships on the spatial pattern of biodiversity. Our study found that this kind of interspecific relationship often has a positive correlation [17–19].

Overall, the ability of plant diversity to shape the latitude pattern of insect richness is more vital than other environmental factors. The effects of soil on insect richness are often indirect, while climate factors are the dominant factors that determine the richness

of insects [20]. With global climate change, understanding the latitudinal pattern of insect diversity and controlling factors is of great significance to biodiversity conservation and can effectively help us understand the rules and progress of biological invasions.

5. Conclusions

Our study quantified the effects of the biological and abiotic factors on the spatial pattern of insect diversity. At a specific regional scale, the impact of interspecific interaction on insect diversity is greater than that of climate factors. This discovery is of great significance for us in understanding the spatial variation pattern of insect diversity.

Supplementary Materials: The following supporting information can be downloaded at: <https://www.mdpi.com/article/10.3390/ecologies3010004/s1>, Figure S1: Relationships between area (ha) and insect richness. R^2 was used to estimate the explanatory power of the regression models, Figure S2: Study points. Table S1: The studied areas.

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Soil Data: Harmonized World Soil Database v 1.2 Online.

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