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Effects of Habitat Loss on Tenebrionidae in Gravel–Sand Mulching Areas of Desert Steppe in Ningxia, China

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Abstract: The desert steppe in Ningxia is the largest natural steppe type in the region, characterized by a fragile ecological environment and low carrying capacity. Gravel–sand mulching, a local agricultural practice, involves using a sand and gravel covering layer to maintain soil warmth and moisture. However, this method has led to ecological problems, such as habitat loss and biodiversity loss. Tenebrionidae, one of the most widely distributed beetle families, is commonly used to indicate habitat degradation and is a significant steppe pest in desert steppe areas. This study, conducted in the gravel–sand mulching areas of Shapotou District, Zhongwei City, Ningxia, classified the habitat loss from low to high in these areas into five grades (I-V) and examined the effects of habitat loss on Tenebrionidae. We collected 6565 Tenebrionidae, with *Blaps femoralis*, *Anatolica nureti*, and *Pterocoma vittata* being the dominant species. The findings reveal that habitat loss grade I had the highest abundance, diversity index, and evenness index of Tenebrionidae, significantly higher than those of grades II–IV. Habitat loss had a significant negative effect on Tenebrionidae abundance, a significant positive effect on the richness index, no significant effect on the vegetation diversity index, a significant positive effect on soil available potassium (APP), and a significant negative effect on soil total phosphorus (TP). Redundancy analysis indicated a positive correlation between Tenebrionidae abundance and the vegetation diversity index; a negative correlation between Tenebrionidae richness, the diversity index, and vegetation indices; a positive correlation between Tenebrionidae abundance and soil TP; and a negative correlation between the Tenebrionidae diversity index and soil TP and soil APP. These findings will contribute to biodiversity conservation and ecological restoration and provide a theoretical basis for steppe management, sustainable agricultural development, and pest monitoring in desert steppe environments.

Keywords: desert steppe; habitat loss; Tenebrionidae; biodiversity; China

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1. Introduction

The steppe ecosystem is one of the largest terrestrial ecosystems globally, covering approximately 24% of the earth's land area. The steppe is characterized by a semi-humid and semi-arid climate, where xerophytic herbaceous species are predominant. It is also the largest terrestrial ecosystem in China, accounting for 40.90% of the country's total land area [1]. In Ningxia, located in northwest China, a variety of steppe types are found, with desert steppe comprising 55% of the total steppe area in the region, making it the predominant type of natural steppe in Ningxia [2]. Due to its unique geographical location and climatic conditions, the desert steppe in Ningxia is characterized by a fragile ecological environment and low carrying capacity [3,4]. Furthermore, human activities and climate change have significantly impacted the desert steppe, leading to pronounced habitat loss [5,6].

In the Xiangshan area of Shapotou District, Zhongwei City, Ningxia, sand compaction planting is a specialized agricultural technique used in the warm desert steppe. This method involves applying a sand or sand–gravel mixture as a surface cover layer for dry farming [7,8]. This covering helps retain soil heat, moisture, and water [9]. While watermelon cultivation in gravel–sand mulching areas was once a leading local industry, it has led to several ecological issues, including habitat loss, biodiversity loss, vegetation destruction, and soil desertification [10]. These problems are significant contributors to habitat loss in the desert steppe of this region.

Habitat loss is one of the main reasons for biodiversity reduction and species composition changes [11], which refers to the reduction in the overall habitat area and the loss of some habitats and is an independent ecological process [12–14]. In recent years, the impact of habitat loss on biodiversity has become a prominent topic in ecological research [15,16]. Numerous studies have investigated this issue, revealing that habitat loss can positively and negatively affect biodiversity [17–19]. The response of different species to habitat loss varies, largely depending on their biological characteristics and the landscape structure [20]. Generally, species sensitive to regional changes or with narrow dietary requirements tend to decline or disappear with habitat loss [21]. In contrast, widespread and common species may show little change or even an increase in distribution and population [22]. Predatory insects at a higher trophic level are typically more affected by habitat loss than phytophagous insects at lower trophic levels [23,24], primarily due to the impact on their predation behavior and aggregation [25,26].

The Tenebrionidae family of beetles, characterized by its wide distribution and high species richness, plays a crucial role in the desert steppe ecosystem. These beetles are highly adaptable, and their presence is recorded across diverse ecosystems, including tropical rainforests, deserts, coastal sand dunes, and mountain summits, spanning various altitudinal ranges. [27]. They are considered indicators of habitat degradation [28]. In desert steppe areas, Tenebrionidae larvae typically feed on plant roots, while adults consume plant stems, leaves, etc., and also feed on dead leaves and branches on the surface, making them important pests in steppe environments [29]. As a key component of the desert steppe food web, Tenebrionidae are vital for maintaining biodiversity and ecosystem stability [30]. This study investigated the impact of landscape loss on Tenebrionidae in gravel–sand mulching areas of the desert steppe, addressing the following research questions: (1) How does habitat loss affect Tenebrionidae in the desert steppe? (2) What mechanisms underlie the effects of habitat loss on Tenebrionidae?

2. Materials and Methods

2.1. Overview of the Study Area

The research area was located in Shapotou District (104°17′~106°10′ E, 36°06′~37°50′ N), Zhongwei City, Ningxia, China. This region features a fragile ecological environment, situated in the middle arid zone of Ningxia and on the southern edge of the Tenggali Desert. The altitude ranges from 1100 to 2300 m, with an average annual temperature of 10 °C. The region experiences an average annual frost-free period of 167 days and receives approximately 200 mm of annual precipitation, characterizing it as having a typical temperate continental climate. This area is representative of gravel–sand mulching, where the natural desert steppe has been artificially transformed into watermelon fields [31] (Figure 1). In contrast, the regions not subjected to gravel–sand coverage are characterized by natural herbaceous vegetation, predominantly featuring *Stipa capillata* and *Ajania achilleoides* as the main dominant species.

Figure 1. (**a**) Gravel–sand mulching fields, (**b**) watermelon cultivation on gravel–sand mulching fields, and (**c**) semi-natural steppe habitat.

2.2. Methods

2.2.1. Classification of Habitat Loss Levels

This study utilized ArcGIS 10.2 (ESRI, Redlands, CA, USA) to extract area data for the study region to classify habitat loss levels. The fragmentation gradient was assessed using remote-sensing images and combining grid (raster) and concentric circle methods [32]. The distance from a standard ground scale and the range of distance around the central point were integrated into the analysis. Circular areas with a radius of 1 km centered on each grid cell were used as standard sites. A total of 24 standard sites with fixed boundaries were identified in the study area. Each site was quantified based on the percentage of gravel–sand mulching (*PLAND*, %). The *PLAND* was calculated using the following formula: $PLAND = (s/S) \cdot 100\%$, where *PLAND* denotes the landscape percentage, s denotes the area of gravel–sand mulching, and S denotes the total area. The *PLAND* approaches 0 as the sand compaction area diminishes in the habitat, and *PLAND* = 100 when the entire landscape consists of a single gravel–sand mulching site.

Remote-sensing data were calibrated with field investigations to classify loss grades accurately. The 24 standard plots were categorized into five habitat loss grades according to the landscape percentage: grade I ($0 \leq PLAND < 1\%$, 7), grade II ($1\% \leq PLAND < 5\%$, 6), grade III ($5\% \leq PLAND < 20\%$, 5), grade IV ($20\% \leq PLAND < 40\%$, 4), and grade V ($40\% \leq PLAND < 100\%$, 2). Grade I represents primitive steppe.

2.2.2. Collection of Tenebrionidae

In the spring, summer, and autumn of 2023, Tenebrionidae were collected from the 24 standard sites using the following trap method [33]. A random five-point sampling method was employed to collect Tenebrionidae. Five sampling points were established at each standard site, spaced approximately 150 m apart. At each sampling point, five traps were arranged in a group, with a spacing of approximately 5 m between traps. A disposable plastic cup, with a diameter of 7.5 cm and a height of 9 cm, was used as the trap and buried in the soil so that the rim of the cup was level with the surface. The traps were filled to one-third of their height with a liquid mixture of ethylene glycol and water (with a volume ratio of 1:2). The pitfall traps were placed in surviving patches of semi-natural vegetation. The Tenebrionidaes in the cups were collected every 10 d and preserved in anhydrous ethanol. These samples were returned to the laboratory for species identification, and we counted the number of individuals for each species. Dominant species were determined based on the proportion of individual insects of each species relative to the total number of individuals in the community. Species with a proportion of less than 1% were classified as rare, those with a proportion between 1% and 10% were classified as common, and those with a proportion of 10% or more were classified as dominant [34].

2.2.3. Collection of Vegetation

A 1 m × 1 m plot was selected for vegetation sampling at each insect sampling site, resulting in five sampling plots. When the vegetation biomass reached its peak in 2023, the species richness, abundance, and coverage of vegetation were recorded; meanwhile, the dry weight of all the vegetation within the sample plot was measured and recorded as the vegetation biomass. All vegetation was identified at the species level.

2.2.4. Soil Collection and Physicochemical Property Measurement

Soil samples were collected from five points within each standard site, corresponding to the Tenebrionidaes sampling points. The soil samples were taken from the top 0–20 cm layer using a five-point sampling method, with surface sand removed prior to sampling. Large-grained soil clods and weeds were removed through a 2 mm sieve. The physical and chemical properties of the soil were then analyzed, including nine indicators: available potassium (APP, mg/kg), available phosphorus (APK, mg/kg), total potassium (TK, mg/kg), total phosphorus (TP, mg/kg), total nitrogen (TN, mg/kg), alkaline hydrolysis nitrogen (AHN, mg/kg), soil organic matter (OM, g/kg), electrical conductivity (EC, μs/cm), and pH.

2.2.5. Diversity Index Calculation

Insect and vegetation diversity was assessed using four indices: Margalef's richness index (*d*) is primarily employed to assess and compare species diversity across various ecological communities. The Shannon–Wiener diversity index (H') is mainly used to study the completeness of a sample; the index is based on the number of species and reflects the degree of species diversity in a community, which can be used to judge the stability of an ecosystem. The Simpson dominance index (λ) measures the proportion of the most abundant species within a community, with higher values indicating reduced diversity. Pielou's evenness index (*E*) specifically measures the degree of even distribution of species abundance in a community and is a derived index from the Shannon–Wiener diversity index. The formulas for these indices are as follows [35]:

Margalef's richness index $d = (S-1)/\ln N$, where S is the number of species, and N is the sum of the number of individuals of all species.

The Shannon–Wiener diversity index $H' = -\sum P_i \ln P_i$, where P_i is the proportion of the i-th individual in a monitoring area to the total number of individuals in the monitoring area.

The Simpson dominance index $\lambda = \sum N_i\ (N_i-1)/N\ (N-1)$, where N_i is the sum of the number of species individuals in the i-th monitoring area.

Pieloun's uniformity index $E = H'/\ln S$.

2.3. Data Analysis

The experimental data were organized using Microsoft Excel 2021. Duncan's new complex range test, based on one-way analysis of variance, was used to examine the differences in diversity between fragmentation grades I–V. Linear regression analysis assessed the effects of habitat fragmentation on Tenebrionidae diversity, vegetation diversity, and soil physicochemical properties. The "iNEXT" package in R (4.2.3) was used to estimate differences in the composition of the insect community diversity across various fragmentation levels [36]. Detrended correspondence analysis was conducted using the "decorana" function in the vegan package to analyze dominant species and Tenebrionidae diversity. Redundancy analysis (axis lengths < 3.0) or canonical correspondence analysis (axis lengths > 4.0) [37] were performed using the "rda" or "cca" functions in the vegan package for the dominant species, Tenebrionidae diversity, vegetation diversity, and soil physicochemical properties. Graphs were constructed using the "ggplot2" package in R (4.2.3) and GraphPad Prism 9.5.0.

3. Results

3.1. Diversity of Tenebrionidae Across Different Habitat Loss Grades

A total of 6565 Tenebrionidaes were collected, representing 18 species. Among these, *B. femoralis*, *A. nureti*, and *P. vittata* were the dominant species, accounting for 56.69%, 13.39%, and 10.62% of the total, respectively (Table 1). Extrapolated analyses based on the individual numbers and species richness at different fragmentation levels are shown in Figure 2. The insect richness collected under each loss grade exceeded the minimum value of habitat species estimated by extrapolation (Figure 2a), and the sample coverage curve indicated that coverage was above 99% across the five fragmentation grades (Figure 2b). If the sparse curve converges toward a specific value as the sampling effort increases, it indicates that the sample sizes are adequate.

Table 1. Number of individuals of Tenebrionidaes in habitat loss grades.

Name	Grade					Proportion (%)
	I	II	III	IV	V	
Blaps femoralis (Fischer von Waldheim, 1844)	1783	908	451	411	169	56.69%
Anatolica nureti Schuster et Reymond, 1937	172	340	239	118	10	13.39%
Pterocoma vittata Frivaldszky, 1889	360	101	202	28	6	10.62%
Trigonocnera pseudopimelia (Reitter, 1889)	325	23	6	7	3	5.54%
Microderakroatzi alashanica Skopin, 1964	231	46	64	8	9	5.45%
Blaps variolosa Faldermann, 1835	39	51	9	7	6	1.71%
Pterocoma reitteri Frivaldszky, 1889	76	13	10	1	8	1.65%
Penthicus alashanicus (Reichardt, 1936)	41	22	17	11	7	1.49%
Blaps opaca (Reitter, 1889)	20	8	9	14	4	0.84%
Scleropatrum horridum Reitter, 1898	23	13	8	1	0	0.69%
Microdera mongolica (Reitter, 1889)	0	6	6	12	16	0.61%
Anatolica potanini Reitter, 1889	2	8	18	1	0	0.44%
Platyscelis hauseri Reitter, 1889	1	3	6	11	4	0.38%
Cyphogenia chinensis (Faldermann, 1835)	6	2	0	4	6	0.27%
Blaps medusula Kaszab, 1968	1	0	5	2	0	0.12%
Platyscelis gebieni Schuster, 1915	0	0	0	5	0	0.08%
Prosodes kreitneri Frivaldszky, 1889	1	0	0	0	0	0.02%
Sternoplax szechenyi (Frivaldszky, 1889)	1	0	0	0	0	0.02%
Total	3082	1544	1050	641	248	100%

Note: proportion (%); rare species (<1%); common species (1–10%); dominant species (>10%).

Different habitat loss levels in the desert steppe showed variations in diversity indices (Figure 3). No significant difference in species richness was observed between the five loss grades (Figure 3a). However, the number of individuals, Shannon–Wiener diversity index, and Pielou's evenness index in loss grades II, III, IV, and V were significantly lower than those in loss grade I ($p < 0.05$) (Figure 3b,d,f). Additionally, the number of individuals decreased progressively with an increase in the loss grade. The Margalef richness index was the highest in grade IV and significantly higher than in grade II ($p < 0.05$) (Figure 3c). In comparison, the Simpson dominance index was the highest in grade V and significantly higher than in grades I and III ($p < 0.05$) (Figure 3e).

3.2. Effects of Habitat Loss on Tenebrionidae Diversity

In fragmented landscapes, the degree of habitat loss was positively correlated with the richness of Tenebrionidae, the Margalef richness index, and the Simpson dominance index but had no significant effect on species richness and the Simpson dominance index. A significant positive correlation was observed with the Margalef richness index ($p < 0.05$) (Figure 4a,c,e). Conversely, the habitat loss degree was negatively correlated with abundance, the Shannon–Wiener diversity index, and the Pielou evenness index, with a significant negative correlation with abundance ($p < 0.001$) (Figure 4b,d,f). There was no significant effect on the Shannon–Wiener diversity index and Pielou evenness index.

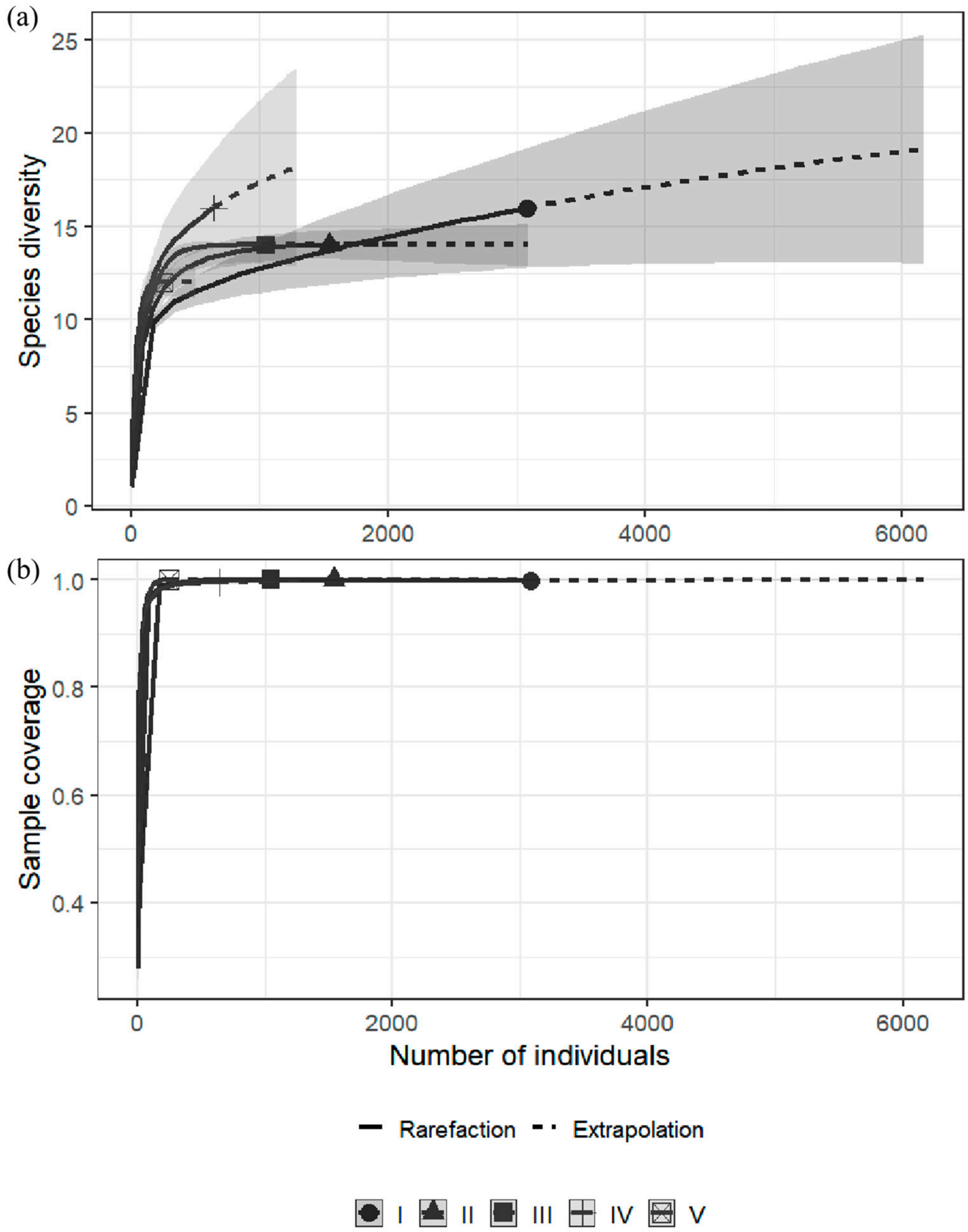

Figure 2. Estimation of Tenebrionidae community diversity across different habitat loss grades using dilution extrapolation analysis. Note: (**a**) sample-based sparse/extrapolation curves; (**b**) sample integrity curve. The solid lines are drawn based on interpolation, and the dotted lines are drawn based on extrapolation.

3.3. Effects of Habitat Loss on Vegetation Diversity

In fragmented landscapes, the degree of habitat loss was positively correlated with vegetation richness, the Shannon–Wiener diversity index, and the Simpson dominance index, although this correlation was not statistically significant (Figure 5a–c). However, it was negatively correlated with the vegetation Pielou evenness index, although this correlation was not statistically significant (Figure 5d). It was significantly negatively correlated with vegetation biomass ($p < 0.01$; Figure 5e) and vegetation coverage ($p < 0.001$; Figure 5f).

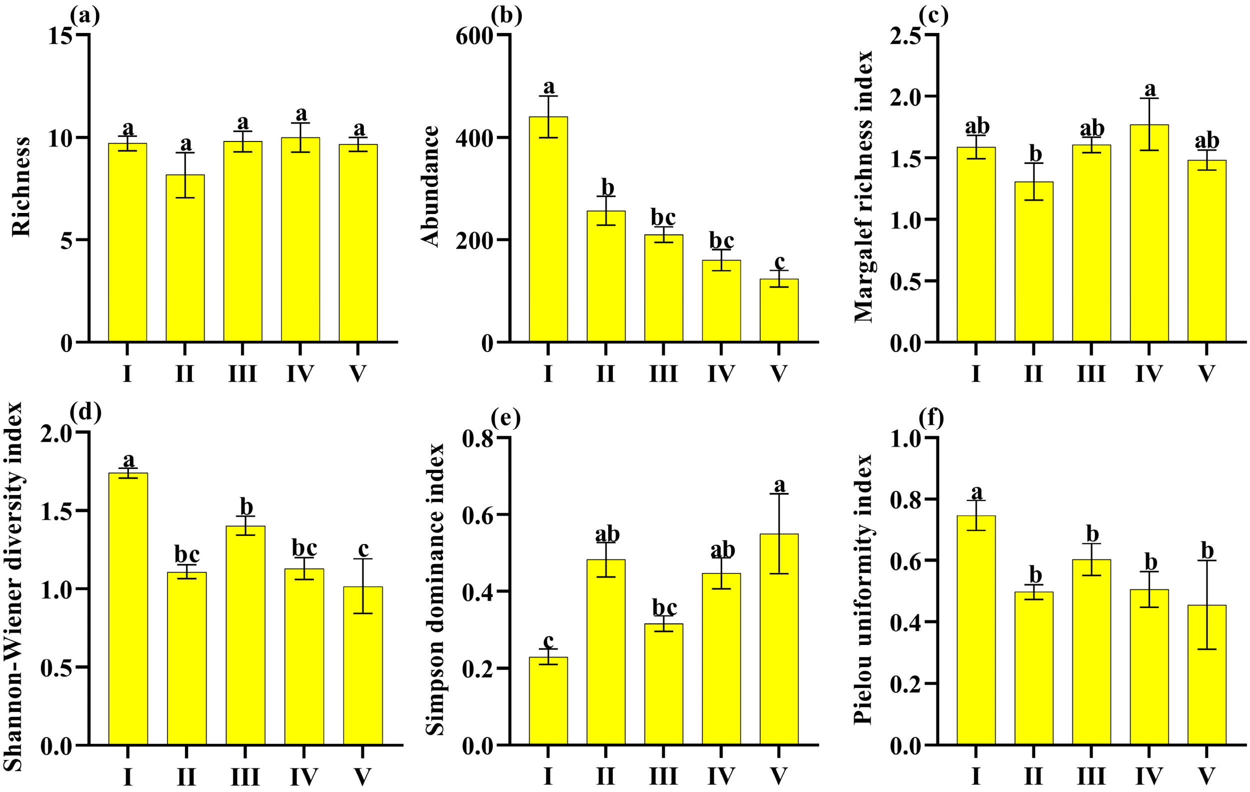

Figure 3. Diversity of Tenebrionidae across different habitat loss grades. Note: (**a**) Tenebrionidae richness, (**b**) Tenebrionidae abundance, (**c**) Tenebrionidae Margalef richness index, (**d**) Tenebrionidae Shannon–Wiener diversity index, (**e**) Tenebrionidae Simpson dominance index, and (**f**) Tenebrionidae Pielou uniformity index. The data in the figure represent the means ± standard error. Different lowercase letters indicate that there is a significant difference ($p < 0.05$) between each fragmentation grade according to Duncan's new multiple-range test (DMRT), while the same lowercase letters indicate no significant difference.

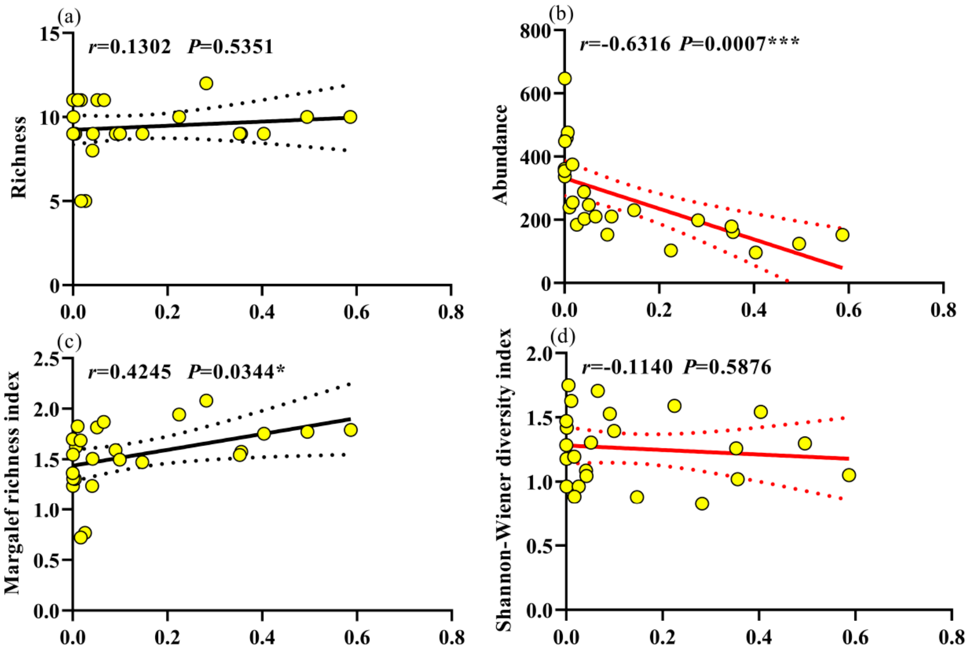

Figure 4. *Cont.*

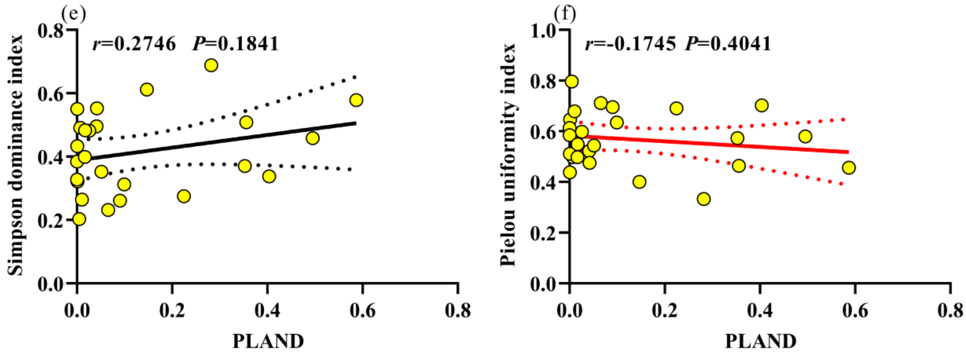

Figure 4. Relationship between habitat loss grades and Tenebrionidae diversity. Note: (**a**) Tenebrionidae richness, (**b**) Tenebrionidae abundance, (**c**) Tenebrionidae Margalef richness index, (**d**) Tenebrionidae Shannon–Wiener diversity index, (**e**) Tenebrionidae Simpson dominance index, and (**f**) Tenebrionidae Pielou uniformity index. The black lines indicate a positive relationship, the red lines indicate a negative relationship, and the area between the dashed lines represents the 95% confidence interval. *** = $p < 0.001$; * = $p < 0.05$.

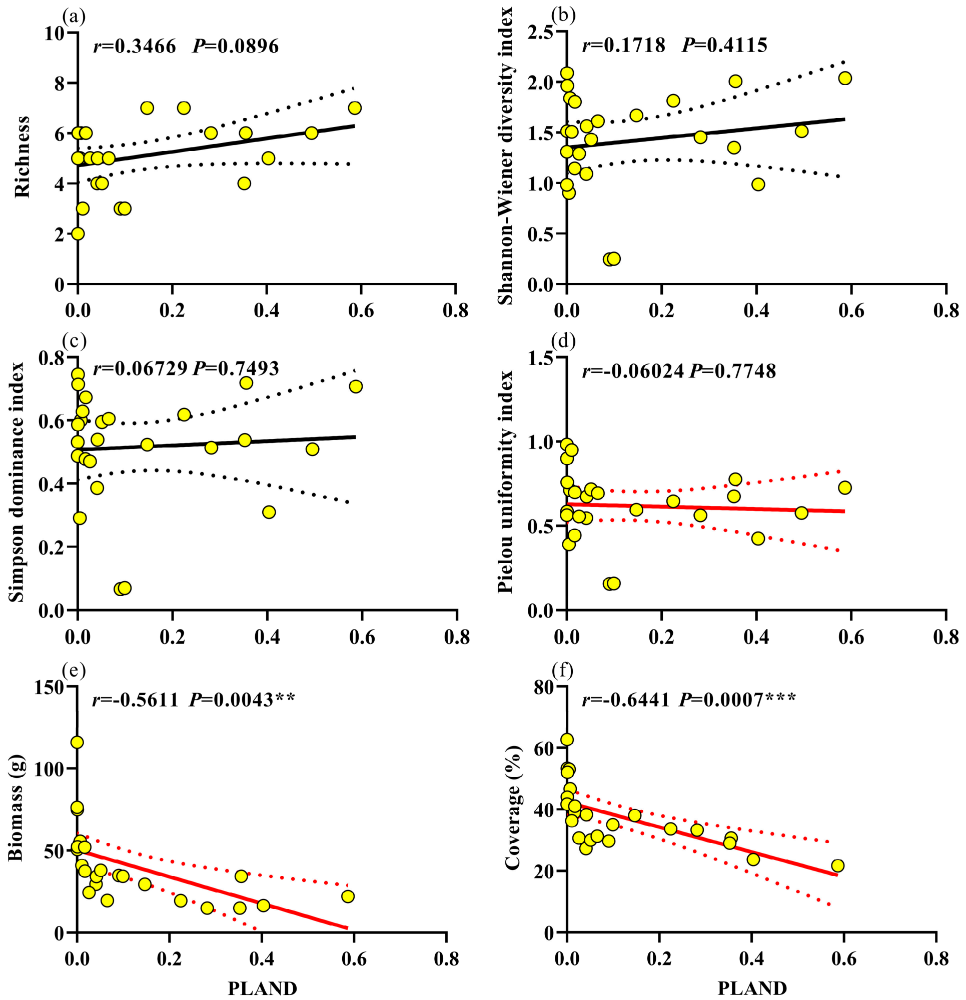

Figure 5. Relationship between habitat loss grades and vegetation diversity. Note: (**a**) vegetation richness, (**b**) vegetation Shannon–Wiener diversity index, (**c**) vegetation Simpson dominance index, (**d**) vegetation Pielou uniformity index, (**e**) vegetation biomass, and (**f**) vegetation coverage. The black lines indicate a positive relationship, while the red lines indicate a negative relationship, and the area between the dashed lines represents the 95% confidence interval. *** = $p < 0.001$; ** = $p < 0.01$.

3.4. Effects of Habitat Loss on Soil Physicochemical Properties

In fragmented landscapes, the degree of habitat loss was significantly positively correlated with soil APP ($p < 0.05$) (Figure 6a). It was positively correlated with APK, AHN, and soil pH, though these correlations were not significant (Figure 6d,e,i). The habitat loss degree was negatively correlated with soil TP ($p < 0.05$) (Figure 6c) and with soil TK, EC, TN, and OM. However, these correlations were not significant (Figure 6b,f,g,h).

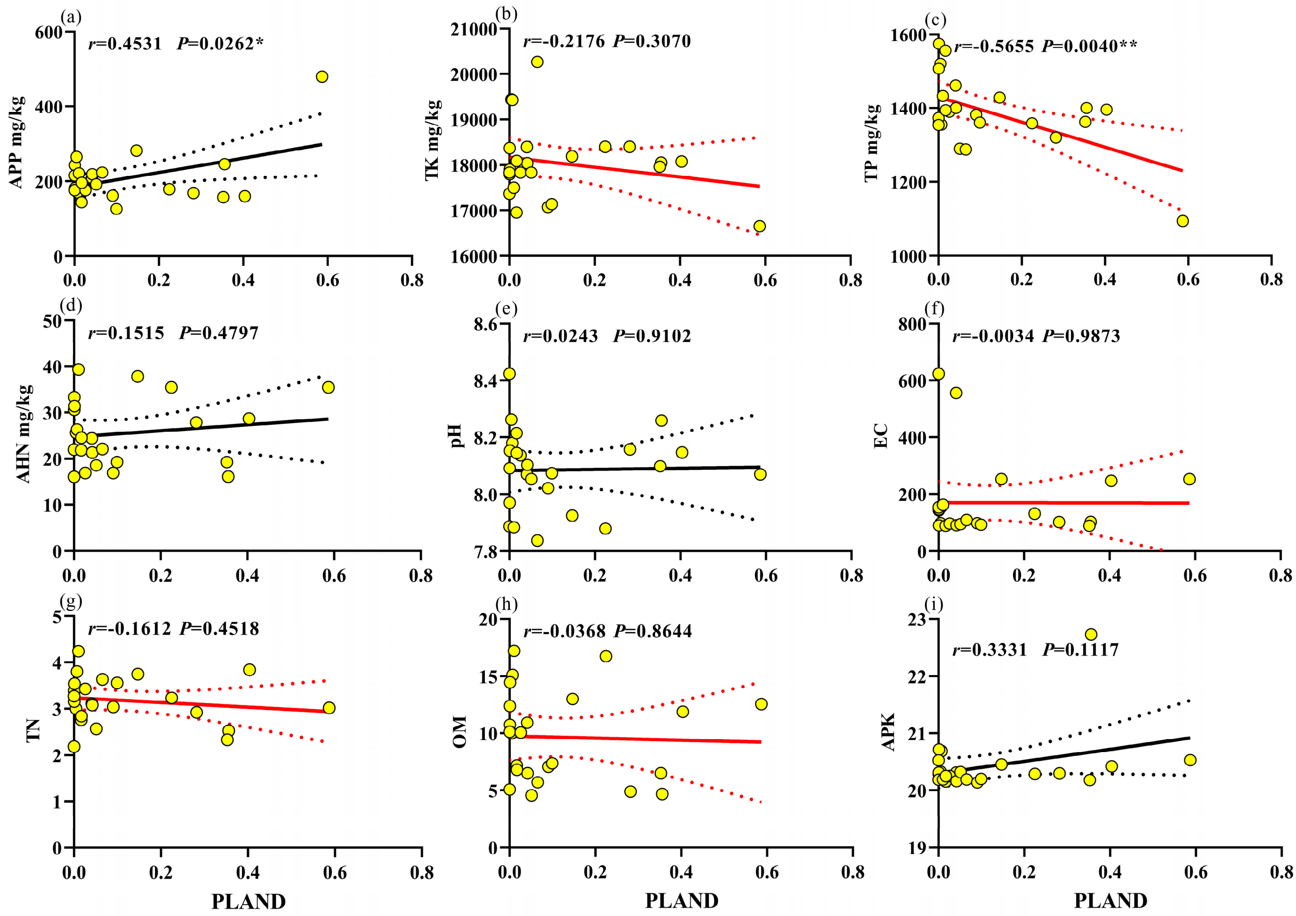

Figure 6. Relationship between habitat loss grades and soil physicochemical properties. Note: (**a**) available potassium, (**b**) total potassium, (**c**) total phosphorus, (**d**) alkaline hydrolysis nitrogen, (**e**) pH, (**f**) electrical conductivity, (**g**) total nitrogen, (**h**) organic matter, and (**i**) available phosphorus. The black lines indicate a positive relationship, the red lines indicate a negative relationship, and the area between the dashed lines represents the 95% confidence interval. ** = $p < 0.01$; * = $p < 0.05$.

3.5. Redundancy Analysis of Tenebrionidae and Vegetation

RDA revealed that the sequence of vegetation indices influencing Tenebrionidae, ranked in descending order, was V_Simpson > V_Pielou > V_Shannon > V_Coverage > V_Biomass > V_Margalef. Blfa showed a positive correlation with all vegetation indices, Annu showed a negative correlation with all vegetation indices, and Ptvi showed a negative correlation with V_Simpson, V_Pielou, V_Shannon, and V_Margalef. T_Number was positively correlated with V_Coverage and V_Biomass, and T_Species and T_Shannon were negatively correlated with V_Coverage and V_Biomass (Figure 7).

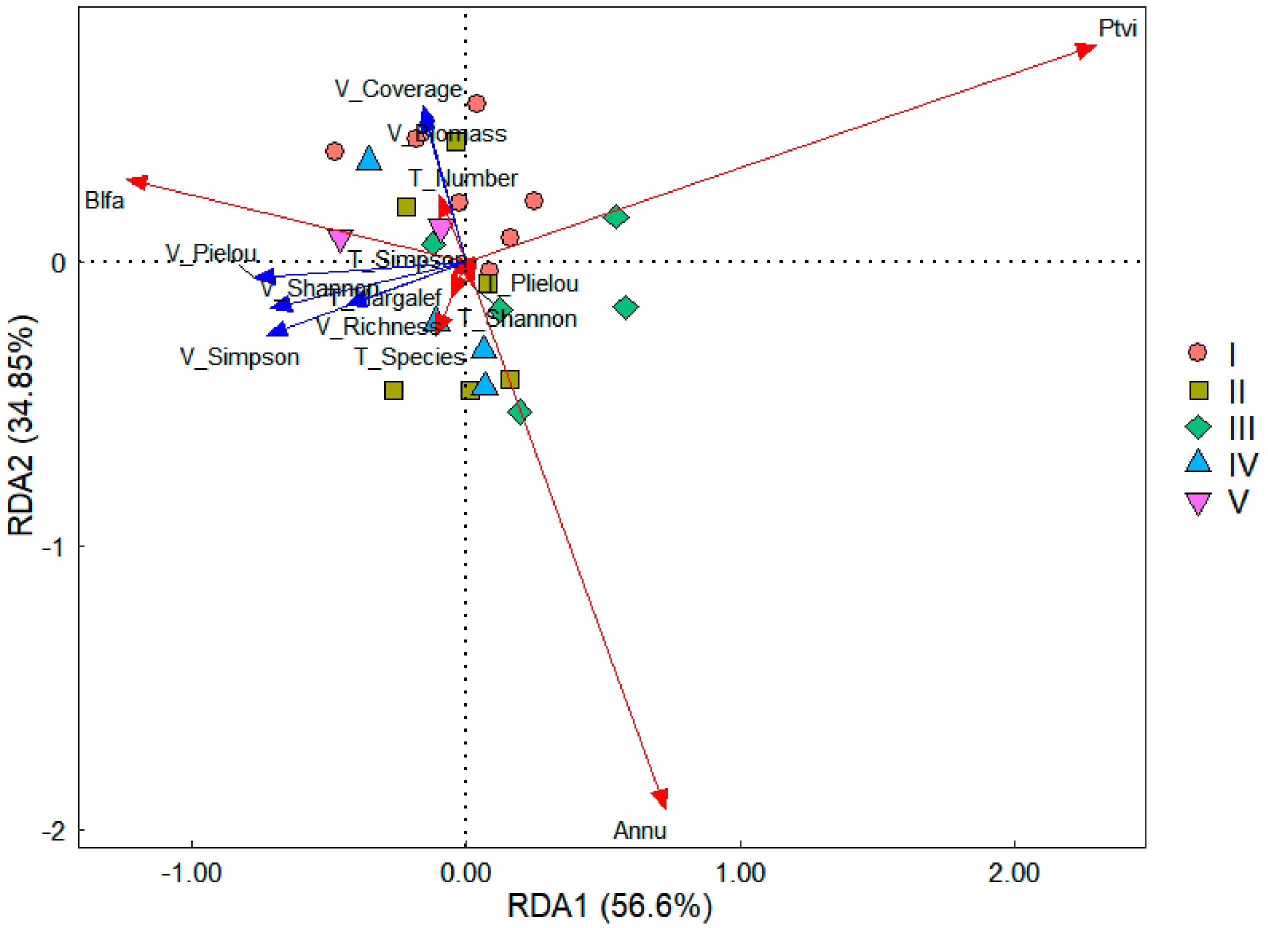

Figure 7. Redundancy analysis of Tenebrionidae and vegetation. Note: Blfa is Blaps femoralis number of individuals, Annu is Anatolica nureti number of individuals, and Ptvi is Pterocoma vittata number of individuals. T_Species is Tenebrionidae species, T_Number is Tenebrionidae number, T_Margalef is Tenebrionidae Margalef richness index, T_Shannon is Tenebrionidae Shannon–Wiener diversity index, T_Simpson is Tenebrionidae Simpson dominance index, and T_Pielou is Tenebrionidae Pielou uniformity index. V_Richness is vegetation richness, V_Shannon is vegetation Shannon–Wiener diversity index, V_Simpson is vegetation Simpson dominance index, V_Pielou is vegetation Pielou uniformity index, V_Biomass is vegetation biomass, and V_Coverage is vegetation coverage. The red arrow represents the diversity index of Tenebrionidaes, and the blue arrow represents the vegetation index. If the angle between two arrows is acute, they are positively correlated; if the angle is obtuse, they are negatively correlated.

3.6. Redundancy Analysis of Tenebrionidae and Soil

RDA revealed that the sequence of soil physicochemical properties influencing Tenebrionidae, ranking in descending order, was EC > APK > TP > APP > pH > TK > AHN > TN > OM. Blfa exhibited positive correlations with EC, pH, APP, APK, AHN, and OM; Annu exhibited positive correlations with APK and AHN; and Ptvi exhibited positive correlations with TK, TN, and TP. T_Number exhibited positive correlations with TK, TN, TP, EC, and pH. T_Species, T_Margalef, T_Simpson, and T_Shannon exhibited positive correlations with APK and AHN (Figure 8).

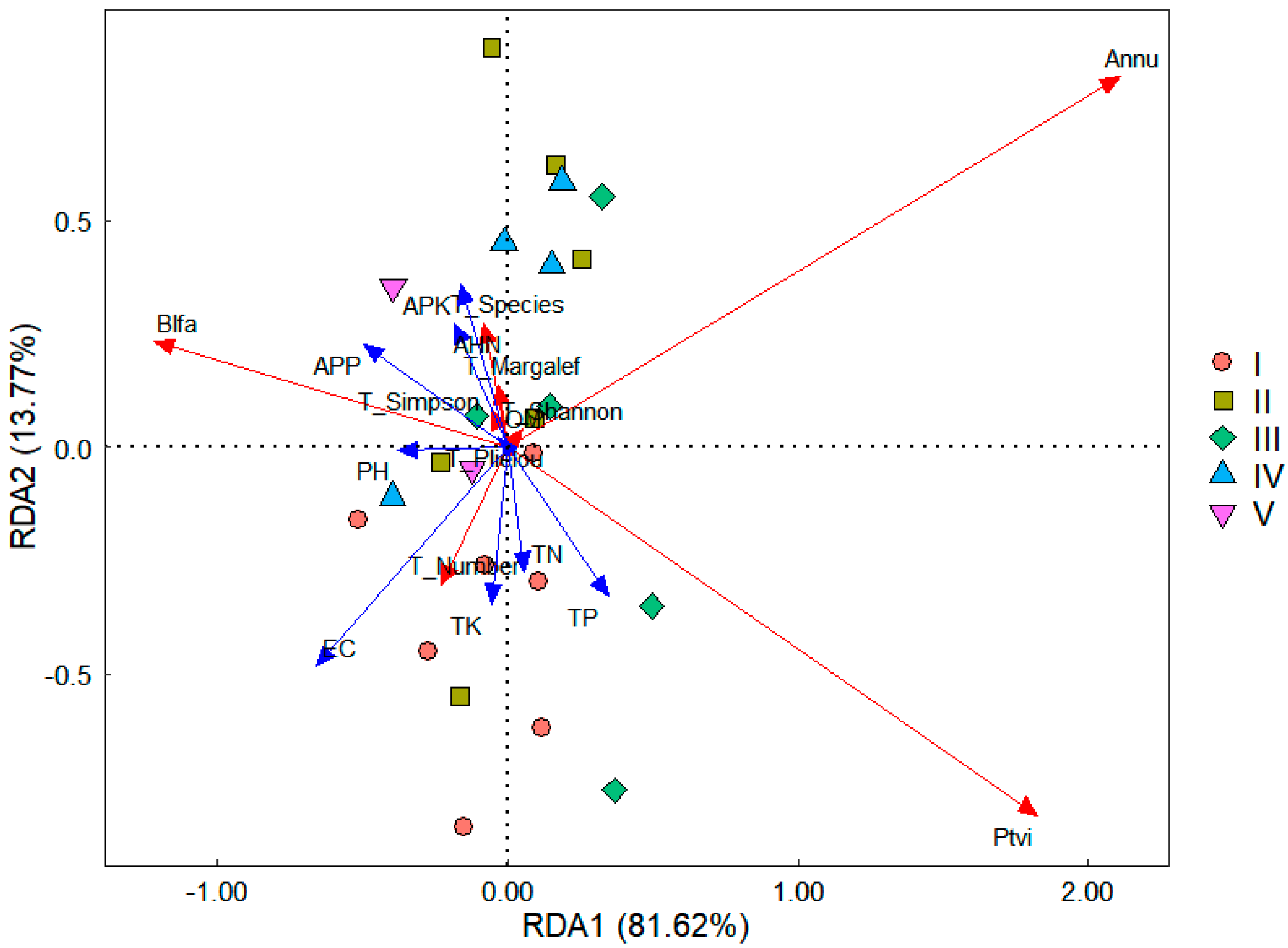

Figure 8. Redundancy analysis of Tenebrionidae and soil. Note: Blfa is Blaps femoralis number of individuals, Annu is Anatolica nureti number of individuals, and Ptvi is Pterocoma vittata number of individuals. T_Species is Tenebrionidae species, T_Number is Tenebrionidae number, T_Margalef is Tenebrionidae Margalef richness index, T_Shannon is Tenebrionidae Shannon–Wiener diversity index, T_Simpson is Tenebrionidae Simpson dominance index, and T_Pielou is Tenebrionidae Pielou uniformity index. APP is available potassium, TP is total potassium, TK is total phosphorus, AHN is alkaline hydrolysis nitrogen, pH is soil pH, EC is electrical conductivity, TN is total nitrogen, OM is organic matter, and APK is available phosphorus. The red arrow represents the diversity index of Tenebrionidaes, and the blue arrow represents the vegetation index. If the angle between two arrows is acute, they are positively correlated; if the angle is obtuse, they are negatively correlated.

4. Discussion

Understanding the spatial distribution of Tenebrionidae species diversity is crucial for conserving and stabilizing desert steppe ecosystems [38]. Previous studies have examined the effects of habitat loss on various insects, including pollinators [39] and steatophora [40]. This paper is the first to investigate changes in Tenebrionidae's diversity under different levels of habitat loss in the gravel–sand mulching areas of the Ningxia desert steppe. Our findings reveal significant differences in Tenebrionidae's diversity across the five habitat loss levels (I–V) in this region. We clarified the effects of habitat loss on Tenebrionidae's diversity, vegetation diversity, and soil physicochemical properties and elucidated the relationships between these factors in the Ningxia desert steppe.

Most studies indicate that habitat loss alters insect habitats, leading to a loss of diversity that is difficult to recover [41–43]. The degree of species recovery often depends on the extent of habitat loss [44]. In our study, habitat loss grade I exhibited the highest levels of abundance, diversity index, and evenness index, significantly higher than grades II–IV.

The gravel–sand mulching areas of grade V were the most extensive, with a dominance index significantly higher than those of grades I–IV, indicating a more pronounced presence of dominant species and a more balanced competition between species [45]. Grade I, representing a primitive steppe, offers a relatively intact habitat compared with grades II–V, thus providing more favorable conditions for Tenebrionidae growth and reproduction. This includes higher vegetation diversity, which ensures sufficient food resources [46], and suitable soil physical and chemical properties [47]. Insect abundance is particularly sensitive to habitat loss [48]. Our study found that habitat loss had a significant negative effect on the abundance of Tenebrionidae, a significant positive effect on their richness index, and no significant effect on other diversity indices. While this study focused on steppe habitat loss caused by gravel–sand mulching, previous research has shown that converting steppe to farmland significantly reduces the abundance of herbivorous insects [49], which was consistent with our findings.

As an important phytophagous insect group in the desert steppe, Tenebrionidae communities are closely influenced by vegetation diversity [50]. This study found that habitat loss did not significantly impact various vegetation diversity indices. This lack of impact may be attributed to the small scale of the standard ground areas, the homogenization of desert steppe habitats [51], similar habitat types, and the high overlap between established species and dominant planting types. Consequently, the distribution of vegetation groups is relatively simple, which affects the distribution of Tenebrionidae. The structure of dominant steppe pest species is crucial for controlling steppe pests and significantly impacts the stability of the overall community structure [52]. This study identified three dominant species: *B. femoralis*, *A. nureti*, and *P. vittata*. RDA analysis revealed that *B. femoralis* and *A. nureti* were positively correlated with various vegetation diversity indices, while *P. vittata* showed a negative correlation. This suggests that *B. femoralis* and *A. nureti* thrive in habitats with high vegetation diversity, whereas *P. vittata* prefers habitats with low vegetation diversity. These findings are consistent with previous studies on Tenebrionidae and vegetation in the desert steppe of northwest China [53]. The abundance and dominance index of Tenebrionidae were positively correlated with vegetation diversity, whereas the abundance and diversity indices were negatively correlated. This indicates that higher vegetation diversity corresponds to lower diversity and a more homogeneous species distribution in the desert steppe habitat. In the Ningxia desert steppe, most Tenebrionidae species are soil-dwelling. Adults lay their eggs in the soil, larvae complete their life cycle underground, and pupae remain in the deep soil, making their life history closely tied to soil conditions [27]. This study found that habitat loss had a significant positive effect on soil APP and a significant negative effect on soil TP. Steppe habitat loss alters soil heterogeneity and nutrient distribution [54], impacting the structure and function of steppe ecosystems. However, the effect of habitat loss on soil physical and chemical properties is influenced by multiple factors [55]. Different habitats experience varying impacts of loss on soil properties [56], and local environmental factors, such as elevation and precipitation, also play a role [57]. RDA analysis showed that *B. femoralis* had a positive correlation with soil APP and a negative correlation with soil TP. In contrast, *A. nureti* and *P. vittata* had positive correlations with soil TP and negative correlations with soil APP. This indicates that different dominant species have distinct relationships with soil physical and chemical properties. Additionally, Tenebrionidae's abundance was positively correlated with soil TP, which is consistent with some studies finding a positive correlation between soil total phosphorus and insect abundance [58]. However, the diversity index of Tenebrionidae was negatively correlated with soil TP and soil APP. This may be due to increased soil nutrients promoting better vegetation growth [59]. As previously mentioned, the negative correlation between Tenebrionidae diversity and vegetation diversity in the desert steppe contributes to these findings.

5. Conclusions

In this study, 6565 Tenebrionidae were collected from sand-covered areas in the desert steppe of Ningxia, representing 18 species. Three species were identified as dominant among these Tenebrionidae: *B. femoralis*, *A. nureti*, and *P. vittata*. This study categorized habitat loss into five levels (I–V) utilizing remote-sensing images and field investigations. Significant differences were observed in the diversity indices of Tenebrionidae species across these habitat loss levels. Habitat loss was found to have a significant negative impact on species abundance while positively affecting the richness index, and it had a significant negative impact on the vegetation biomass and coverage. Habitat loss also led to a significant positive effect on soil APP but a significant negative effect on soil TP. RDA revealed that increased soil nutrients led to better vegetation growth in desert steppe habitats, leading to higher vegetation diversity. However, this also decreased Tenebrionidae's diversity and a more homogeneous species distribution. This study investigated the response of Tenebrionidae's diversity to habitat loss in the sand compaction area of the desert steppe and identified the mechanisms through which habitat loss affects Tenebrionidae. The findings provide a theoretical basis for steppe management, sustainable agricultural development, pest monitoring, and early warning.

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