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Effects of soil desertification on the occurrence of *Kytorhinus immixtus* Motschulsky Postprint

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Abstract

Land desertification severely compromises the core function of ecosystem and significantly disrupts biodiversity. *Caragana korshinskii* Kom. plays a pivotal role as a critical plant resource in the restoration and ecological reconstruction of desertified areas in Northwest China. *Kytorhinus immixtus* Motschulsky is the primary pest responsible for causing substantial damage to the seeds of *C. korshinskii*. In this study, field surveys were utilized in three distinct desertified types (lightly, moderately, and severely desertified areas) in north central Ningxia Hui Autonomous Region, Northwest China. This research was focused on investigating the population dynamics and damage rates of *K. immixtus*, with an emphasis on examining the relationships among *K. immixtus* distribution, levels of soil desertification, and associated environmental factors. The results revealed marked variations in the population distribution and abundance of *K. immixtus* across habitats with different degrees of desertification. Due to the sand-fixing ability of *C. korshinskii*, the severity of soil desertification decreased progressively from severe to moderate and light with *C. korshinskii* establishment. This reduction in desertification, along with habitat restoration and an increase in plant diversity, was correlated with a gradual increase in *K. immixtus* population size and damage rate. Generalized linear mixed model analysis revealed significantly positive correlations of soil total potassium, *C. korshinskii* height, maximum temperature during the survey, precipitation, and the plant species richness index with *K. immixtus* population. In contrast, the soil total phosphorus content, organic matter content, minimum temperature during the survey, *C. korshinskii* canopy width, and branch number were significantly and negatively correlated with *K. immixtus* population. Due to the sand-fixing capacity of *C. korshinskii*, the plant mitigated soil desertification, but as desertification severity decreased, habitat restoration and increased plant diversity drove a gradual increase in the population and damage rate of *K. immixtus*. Both biotic and abiotic factors in the habitat significantly influenced *K.*

immixtus occurrence. To achieve the sustainable restoration of desert ecosystem, optimization of plant community structure with soil nutrient management in ecological rehabilitation is necessary to balance the benefits of sand fixation with pest risks.

Full Text

Preamble

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Effects of Soil Desertification on the Occurrence of *Kytorhinus immixtus* Motschulsky

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In this study, field surveys were conducted in three distinct desertification types (lightly, moderately, and severely desertified areas) in north-central Ningxia Hui Autonomous Region, Northwest China. The research focused on investigating the population dynamics and damage rates of *K. immixtus*, with an emphasis on examining the relationships among *K. immixtus* distribution, levels of soil desertification, and associated environmental factors. The results revealed marked variations in the population distribution and abundance of *K. immixtus* across habitats with different degrees of desertification. Due to the sand-fixing ability of *C. korshinskii*, the severity of soil desertification decreased progressively from severe to moderate and light with *C. korshinskii* establishment. This reduction in desertification, along with habitat restoration and an increase in plant diversity, was correlated with a gradual increase in *K. immixtus* population size and damage rate. Generalized linear mixed model analysis revealed significantly positive correlations of soil total potassium, *C. korshinskii* height, maximum temperature during the survey, precipitation, and the plant species richness index with *K. immixtus* population. In contrast, soil total phosphorus content, organic matter content, minimum temperature during the survey, *C. korshinskii* canopy width, and branch number were significantly and negatively correlated with *K. immixtus* population. Due to the sand-fixing capacity of *C.*

korshinskii, the plant mitigated soil desertification, but as desertification severity decreased, habitat restoration and increased plant diversity drove a gradual increase in the population and damage rate of *K. immixtus*. Both biotic and abiotic factors in the habitat significantly influenced *K. immixtus* occurrence. To achieve sustainable restoration of desert ecosystems, optimization of plant community structure with soil nutrient management in ecological rehabilitation is necessary to balance the benefits of sand fixation with pest risks.

Keywords: *Kytorhinus immixtus* Motschulsky; population size; damage rate; soil desertification; environmental factors

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1 Introduction

Insect life performance, population dynamics, and distribution can be profoundly influenced by multiple ecological factors in their habitats. These factors include plant community diversity, vegetation structure, soil physical-chemical properties, and climatic conditions (Obermaier et al., 2008; Driscoll et al., 2013; Lu et al., 2016; Dicks et al., 2021; Skendžić et al., 2021; Wagner et al., 2021; Outhwaite et al., 2022; Tobisch et al., 2023; Zhao et al., 2023; Liao et al., 2024). As the core carrier of insect resources, vegetation directly shapes insect communities through plant species richness and structural characteristics. For example, an increase in plant diversity significantly enhances herbivorous insect diversity (Hertzog et al., 2016), and plant morphological traits (e.g., height, crown width, and ground diameter) exhibit significant correlations with larval populations of *Chrysolina aeruginosa* Fald (He et al., 2023). Soil physical-chemical properties indirectly regulate insect populations through plant-insect interactions, and elevated soil nitrogen content increases aphid and mite abundances (Pang and Dong, 2012). Soil alkaline nitrogen content is positively correlated with the abundance of Porcellionidae, but negatively correlated with Anisolabidiidae populations (Zhou et al., 2022). Climatic conditions directly impact insect physiological adaptations and behavioral patterns via variations in temperature and precipitation. For example, climate warming significantly enhances insect species richness in mid- to high-latitude areas (Cannon, 1998), whereas precipitation variability plays a critical role in driving fluctuations in leaf-mining insect populations (Leckey et al., 2014).

Therefore, insect distributions result from synergistic interactions among vegetation characteristics, climatic fluctuations, and soil attributes. Elucidating these mechanisms provides scientific foundations for optimizing vegetation restoration strategies and biodiversity conservation in desertification control. Land deserti-

fication ranks among the most pressing environmental and socioeconomic challenges facing the world today (Xue et al., 2019; Sterk and Stoorvogel, 2020). In China, desertified land is widely distributed, especially across the arid and semi-arid areas of central and western China (Ren et al., 2023b). The intensification of soil desertification, coupled with gradual environmental degradation, has led to widespread vegetation decline and a marked reduction in biodiversity (Li et al., 2014). Certain soil macrofaunal communities are highly sensitive to desertification processes. With increasing levels of soil desertification, the species richness, diversity, and population density of these communities significantly decline (Zhao et al., 2014). Consequently, issues related to escalating land desertification have garnered considerable attention worldwide (Ma et al., 2014).

Caragana korshinskii Kom., capable of restoring degraded soils through nitrogen fixation (She et al., 2013), is an ecologically invaluable tree species with significant environmental benefits. As a pioneering species, it plays critical roles in windbreak, sand stabilization, and soil erosion prevention (Ma et al., 2014) in desert and semi-desert areas of China (Che et al., 2022). Seed pests infesting *C. korshinskii* frequently result in diminished seed yield and quality, severely hindering seedling propagation and undermining the success of soil ecological restoration efforts. *Kytorhinus immixtus* Motschulsky belongs to the order Coleoptera and family Bruchidae. As a key pest of *C. korshinskii* seeds, *K. immixtus* represents a significant obstacle to the industrialization of *C. korshinskii* seed production. *K. immixtus* larvae bore into seeds (Jiang et al., 2019), rendering damaged seeds inactive and nonviable. The adults have an elliptical body shape measuring 3.5–5.5 mm in length. They complete one generation annually, overwintering as mature larvae within *C. korshinskii* seeds in the soil. Pupation occurs in spring, with adult emergence and oviposition occurring from early to mid-May (Jiang et al., 2018). Adults predominantly select pods in the canopy layer of *C. korshinskii* stands for oviposition but exhibit more restricted movement ranges in the middle and lower strata (Zhang, 2012). Research has demonstrated that *K. immixtus* populations reach relatively high densities in structurally complex habitats due to microhabitat heterogeneity (Zhang et al., 2010).

Previous studies of *K. immixtus* have explored aspects such as spatial structure, patch quality, and landscape configuration and patterns (Zhang et al., 2010; Zhang and He, 2011). The arid area in central Ningxia Hui Autonomous Region is among the most severely desertified areas in China, characterized by harsh natural conditions, nutrient-poor soils, and sparse vegetation cover (Cao et al., 2020). As a sand-fixing plant, *C. korshinskii* has become increasingly popular. However, the responses of *K. immixtus* to varying degrees of desertification and associated environmental factors have received less attention. Population size and damage rate of *K. immixtus* in response to differing levels of soil desertification, and the ecological factors driving the occurrence and dynamics of *K. immixtus* populations, remain insufficiently understood. Therefore, investigations and analyses of these issues are needed to establish a theoretical

foundation for understanding the occurrence and ecological management of pest species in artificially stabilized sandy ecosystems.

2.1 Study area

The study area is located in typical desertified areas of north-central Ningxia Hui Autonomous Region, Northwest China (Fig. 1 [Figure 1: see original paper]). The region has a typical temperate continental climate with arid conditions, abundant sunshine, and intense evaporation. Annual average temperature ranges from 5.3°C to 9.9°C, while average annual precipitation varies between 167 and 647 mm (Jiang et al., 2024). In this study, three habitat types dominated by *C. korshinskii* were selected: heavily desertified (HD), moderately desertified (MD), and lightly desertified (LD) areas (Liu et al., 2011; Ren et al., 2023a). Basic information about the three habitats is shown in Table 1 .

Fig. 1 Distribution of sample plots (a) in the arid and semi-arid area of north-central Ningxia Hui Autonomous Region, China. (b) lightly desertified plot; (c) moderately desertified plot; (d) heavily desertified plot. YWQ, Yiwanquan; JD, Jidi; GYZ, Guyaozi; TSH, Tianshuihe; HJQ, Haojiaqiao; XJY, Xiaojiayao; XZJ, Xinzhuangji; MNW, Maoniwa. The abbreviations are the same in the following tables and figures. Note that the figure is based on the Ministry of Natural Resources of China (GS(2023)2767) (<https://www.mnr.gov.cn/sj/sjfw/>), and the boundary of the standard map has not been modified.

2.2 Pest survey

In mid-July 2023, when the pods of *C. korshinskii* reached maturity, systematic sampling was conducted in the study area using 5 m × 5 m plots spaced 10 m apart. A total of 30 plots were established. To minimize edge effects, all sampling points were positioned at least 100 m away from plot boundaries. Within each plot, one individual *C. korshinskii* plant was randomly selected, resulting in 30 sampled plants. Each plant was systematically divided into upper, middle, and lower strata, with 10 pods collected randomly from each stratum per plant, yielding 30 pods per individual. The harvested pods were placed in sealed bags and transported to the laboratory, where each pod was examined and dissected under a stereomicroscope. Since *K. immixtus* larvae parasitize seeds, each seed was dissected to count the number of infested pods and infested seeds within each pod. The occurrence of *K. immixtus* was quantified by damage rate, number of larvae, and infestation rate of *C. korshinskii* trees. The following formulas were used for calculations:

$K. immixtus$ damage rate (%) = (Number of damaged seeds / Total number of seeds) × 100

$C. korshinskii$ infestation rate (%) = (Number of infested plants / Total number of $C. korshinskii$ plants) \times 100

2.3.1 Abiotic factors

Five sampling points were selected in each sample plot using a five-point sampling method. Each soil sample weighed 500 g and was collected from a depth of 0–20 cm (Yan et al., 2023; Chen et al., 2025). After transport to the laboratory, a portion of each sample was oven-dried to assess soil moisture content, while the remaining portion was air-dried, homogenized, and cleared of impurities. Soil pH was measured by a potentiometric method (water extraction method) after sieving. Total nitrogen content was determined by the perchloric acid-sulfuric acid digestion Kjeldahl method. Total phosphorus content was analyzed by the alkali fusion-molybdenum-antimony spectrophotometric method. Soil organic matter content was quantified via the potassium dichromate-sulfuric acid digestion method. Total potassium content was measured using the acid digestion-flame photometric method. Electrical conductivity was determined by the water extraction method (Wang et al., 2019).

Meteorological factors were obtained from <https://www.tianqi24.com>, including maximum temperature, minimum temperature, and precipitation. Topographical factors were extracted from elevation data via a digital elevation model (DEM) in ArcGIS software (Ma et al., 2022).

2.3.2 Biotic factors

Approximately 30 $C. korshinskii$ trees with similar growth trends were randomly selected, and plant height, crown width, number of branches, and ground diameter were measured for each tree (He et al., 2023). A 1 m \times 1 m quadrat was established within each plot using a five-point sampling method. Species composition and species count within each quadrat were recorded. Plant diversity was assessed using the Shannon diversity index (H'), Simpson dominance index (D), Margalef richness index (R), and Pielou evenness index (E).

2.4 Statistical analysis

SPSS v.23.0 statistical software was used to conduct one-way analysis of variance (ANOVA) on $K. immixtus$ damage rate, population size, $C. korshinskii$ morphological characteristics, and four alpha diversity indices of plant communities across different habitats. A generalized linear mixed model (GLMM) was employed to analyze relationships between $K. immixtus$ population size and environmental factors. To mitigate multicollinearity, environmental variables

with a variance inflation factor (VIF) greater than 2 were excluded using R v.4.3.1 software. Biological factors (e.g., morphological traits of *C. korshinskii* and vegetation) and abiotic factors (e.g., soil and climate) were treated as fixed effects, whereas desert habitat was included as a random effect. The 'lmer' function in the 'lmerTest' package in R software was utilized to perform linear mixed effects model analysis. The relative importance of factors affecting *K. immixtus* population size was analyzed using the 'glmm.hp' package (Lai et al., 2022). Figures were generated using Origin v.2022 software (He et al., 2023).

3.1 *K. immixtus* damage in different desertified habitats

Significant differences were observed in *K. immixtus* population size across various desertified habitats (Fig. 2a [Figure 2: see original paper]), with 4 individuals/100 pods in heavily desertified habitats, 9 individuals/100 pods in moderately desertified habitats, and 22 individuals/100 pods in lightly desertified habitats. As soil desertification intensified, significant differences were found in the damage rate of *K. immixtus* and the infestation rate of *C. korshinskii* (Fig. 2b and c), with damage rates of 1.50%, 4.28%, and 8.66% in lightly, moderately, and heavily desertified habitats, respectively. The infestation rates of *C. korshinskii* varied among sampled plants and were 40.00%, 43.00%, and 64.00% in lightly, moderately, and heavily desertified habitats, respectively.

In terms of *K. immixtus* population size, damage rate, and infestation rate of *C. korshinskii*, all patterns were as follows: lightly desertified > moderately desertified > heavily desertified, with significant differences. This result suggests that heavily desertified habitats were least susceptible to damage by *K. immixtus*.

Fig. 2 Differences in the number (a), damaged rate of *Kytorhinus immixtus* Motschulsky (b), and infection rate of *Caragana korshinskii* Kom. (c) under different gradients of desertification. In Figures 2a and 2b, boxes indicate the IQR (interquartile range, 75th to 25th percentile of the data). The median value is shown as a line within the box. Black circles represent the mean. Whiskers extend to the most extreme value within 1.5×IQR. * indicates significant differences among the three gradients of desertification at P<0.050 level; ns, no significance.

3.2 Relationship between the occurrence of *K. immixtus* and abiotic factors

As soil desertification decreased along the gradient, the contents of total nitrogen, total phosphorus, soil organic matter, and electrical conductivity gradually increased, whereas total potassium content and soil alkalinity gradually decreased. During the study period, maximum temperature first increased then decreased, whereas minimum temperature and precipitation first decreased then

increased (Table 2). One-way ANOVA of soil and climatic parameters across habitats revealed significant differences in soil factors among the three habitats ($P < 0.050$), and the lowest temperature during the study period also significantly differed ($P < 0.050$).

GLMM analysis showed the effects of abiotic factors and habitats on *K. immixtus* population size (Table 3). Results indicated that both soil and climatic factors significantly affected *K. immixtus* population size. Soil total phosphorus content was the most important factor affecting *K. immixtus*, with a relative contribution rate of 45.05%, and was significantly and positively correlated with *K. immixtus* population size. Total phosphorus, soil organic matter, and maximum temperature during the study period were significantly and negatively correlated with *K. immixtus* population size. Maximum temperature and precipitation during the study period also showed significantly negative correlations with *K. immixtus* population size. Model simulation results revealed that when climate, soil factors, and desertification gradients were considered, the variance contribution rate of the model reached 68.78%, with the desertification gradient accounting for 47.68% of the variance. This finding revealed that the desertification gradient significantly affected *K. immixtus* population size.

Table 2 Soil nutrient contents and climatic changes under different gradients of desertification

Factor	HD	MD	LD	F value
TN (g/kg)	0.080 \pm 0.012 ^b	0.146 \pm 0.048 ^b	0.285 \pm 0.028 ^a	0.647 \pm 0.347 ^a
TP (g/kg)	0.235 \pm 0.047 ^c	0.460 \pm 0.081 ^b	0.647 \pm 0.034 ^a	0.647 \pm 0.034 ^a

Note: TN, total nitrogen; TP, total phosphorus; TK, total potassium; SOM, soil organic matter; EC, electrical conductivity; HT, maximum temperature; LT, minimum temperature; PP, precipitation; EL, elevation. The abbreviations are the same in the following tables. Different lowercase letters within the same row indicate significant differences among the three gradients of desertification at $P < 0.050$ level. Mean \pm SE.

Table 3 GLMM (generalized linear mixed model) analysis of abiotic factors affecting the population size of *K. immixtus*

Effect	Factor	Estimate	Square error	P value	Individual Relative importance (%)
Fixed effect	Intercept	<0.001	<0.001	<0.001	—
	TP	<0.001	<0.001	<0.001	45.05
	SOM	<0.001	<0.001	<0.001	28.67
	HT	<0.001	<0.001	<0.001	15.32
	PP	<0.001	<0.001	<0.001	10.96

Effect	Factor	Estimate	Square error	P value	Individual Relative importance (%)
Random effect	Degree of desertification	<0.001	<0.001	<0.001	—
	Marginal R ² /conditional R ²	0.2110/0.6878		—	—

Note: “—” means no value.

3.3 Relationship between the occurrence of *K. immixtus* and biotic factors

Simpson dominance index, Shannon diversity index, Pielou evenness index, and Margalef richness index gradually increased across habitats as soil desertification decreased. The height, crown width, number of branches, and ground diameter of *C. korshinskii* initially increased but subsequently decreased (Table 4). One-way ANOVA of *C. korshinskii* morphological traits and plant diversity indices across different habitats revealed that, with the exception of the Simpson dominance index, all parameters significantly differed among the three habitats ($P < 0.050$).

GLMM analysis examining the influence of biotic factors and sandy habitats on *K. immixtus* population size (Table 5) revealed that both vegetation and morphological traits of *C. korshinskii* had significant effects on population size. The morphological traits of *C. korshinskii* emerged as the primary factors influencing *K. immixtus*, contributing 84.25%. Plant height and ground diameter were significantly and positively correlated with *K. immixtus* population size, whereas crown width and number of branches were significantly and negatively correlated. The plant Margalef richness index was significantly and positively correlated with *K. immixtus* population size, whereas the Pielou evenness index was significantly negatively correlated. Model simulation results indicated that when vegetation, *C. korshinskii* morphological traits, and desertification degree were considered, the model explained 63.99% of the variance, with soil desertification contributing 41.63%. These findings underscored that soil desertification had a significant effect on *K. immixtus* population size.

Table 4 Biological characteristics and diversity of *C. korshinskii* under different gradients of desertification

Factor	HD	MD	LD	F value
D	0.528 \pm 0.105 a	0.567 \pm 0.185 a	0.608 \pm 0.125 a	0.692 \pm 0.153 b

Note: D, Simpson dominance index; H, Shannon diversity index; E, Pielou evenness index; R, Margalef richness index; PLH, plant height; CW, crown width; NB, number of branches; GD, ground diameter. The abbreviations are the same in the following table. Different lowercase letters within the same row indicate significant differences among the three gradients of desertification at $P < 0.050$ level. Mean \pm SE.

Table 5 GLMM analysis of biotic factors affecting the population size of *K. immixtus*

Effect	Predictor	Estimate	Square error	P value	Individual Relative importance (%)
Fixed effect	Intercept	<0.001	<0.001	<0.001	—
	PLH	<0.001	<0.001	<0.001	35.20
	CW	<0.001	<0.001	<0.001	28.45
	NB	<0.001	<0.001	<0.001	12.60
	GD	<0.001	<0.001	<0.001	8.00
	R	<0.001	<0.001	<0.001	15.75
Random effect	Degree of desertification	<0.001	<0.001	<0.001	—
	Marginal R^2 /conditional R^2	0.2236/0.6399		—	—

Note: “—” means no value.

4.1 Soil desertification significantly affects the population size of *K. immixtus*

The distribution of plants during soil desertification recovery is governed by an interplay between soil properties and topographical features (Zuo et al., 2008). This study demonstrated that plant diversity, richness, and evenness were markedly lower in heavily desertified habitats than in moderately and lightly desertified habitats. In contrast, the population size, infestation rate, and damage rate of *K. immixtus* remained relatively low in heavily desertified

areas, which aligns with prior research on the impact of desertified habitats on other insect species (Duncan et al., 2013).

The lowest population sizes in desertified habitats may be attributed in part to the sharp decline in nutrient availability, food resources, and shelter in these habitats (Doblas-Miranda et al., 2009). Consequently, most larger organisms (body length > 0.5 mm) struggle to survive in desertified habitats (Liu et al., 2009). Long-term grazing and anthropogenic disturbances have resulted in the continuous deposition of fine organic particles, which supplies abundant material for the development of biological soil crusts (Guo et al., 2008). The improvement of the soil microenvironment has significantly facilitated vegetation recovery (Liu et al., 2009). As a result, as habitats transitioned from heavily desertified to lightly desertified, soil alkalinity progressively decreased, whereas electrical conductivity, total nitrogen, total phosphorus, soil organic matter, and plant species diversity, richness, and evenness significantly increased. The population size and infestation rate of *K. immixtus* also increased significantly. These findings suggest that marked improvements in soil conditions and substantial increases in vegetation cover created favorable environmental conditions and provided ample resources for *K. immixtus* to thrive.

In heavily desertified habitats, windblown sand typically accumulates beneath *C. korshinskii* shrubs as a result of sand surface instability and high mobility, which creates highly unfavorable environmental conditions for *K. immixtus* larvae during overwintering or aestivation in the soil. Larvae in the soil are easily exposed at the surface or buried deeply, which hinders emergence (Chen and Xia, 2017). These conditions impede the overwintering of *K. immixtus*, leading to lower infestation rates. In contrast, *K. immixtus* caused the greatest damage in lightly desertified habitats where the population size, infestation rate, and damage to *C. korshinskii* shrubs peaked. This phenomenon occurred because the stable sand surface and low environmental disturbance level in these habitats favor the overwintering and feeding behavior of *K. immixtus*.

4.2 Topographical and climatic factors significantly affect the population size of *K. immixtus*

Soil properties directly or indirectly influence the life history traits of insects (Menta and Remelli, 2020). The mature larvae and pupae of *K. immixtus* remain buried in the soil for approximately 8 months through autumn, winter, and early spring. These stages represent the two longest developmental periods, during which they are most susceptible to environmental influences. The timing and magnitude of pupal emergence directly govern adult emergence and annual population size. Thus, the soil environment plays a pivotal role in regulating the emergence patterns of *K. immixtus*. Soil total phosphorus, soil organic matter, and total potassium levels may affect the growth of *C. korshinskii*, which in turn directly or indirectly influences *K. immixtus* population size (Chen et al., 2010,

2025; Yan et al., 2023; Yang et al., 2025). Research has demonstrated that soil organic matter can induce variation within or among plant species, which then influences herbivorous insects either directly or indirectly, ultimately modifying insect diversity (Bennett, 2010). High availability of soil potassium and phosphorus leads to elevated concentrations of key nutrients, such as carbohydrates and proteins, in plant tissues, thereby offering a nutrient-dense food source for herbivorous insects (Cai and Lv, 2008).

Once mature larvae of *K. immixtus* descend to the soil surface along with seed pods, the soil serves as a conducive environment for their subsequent growth and development. Surface vegetation offers natural shelter, significantly reducing the risk of predation by natural enemies and increasing pupal and adult survival rates. Furthermore, as ectothermic organisms, insects display heightened sensitivity to climate change (Wei et al., 2021). Climatic factors, including temperature and precipitation, directly and indirectly influence insect growth, development, survival, and reproduction, resulting in changes in pest outbreak timing, population size, and damage severity (Wang et al., 2012). The population sizes of certain insect species are significantly affected by minimum temperature and precipitation (Ahmad et al., 2016). Elevated temperatures and humidity promote mass cocoon formation in the larvae of the pine sawfly (*Acantholyda erythrocephala* (L.)), which serves as a precursor for insect outbreaks in the following year (Zhang et al., 2006). This study demonstrated that *K. immixtus* population size was significantly and positively correlated with maximum temperature and precipitation during the observation period, and significantly and negatively correlated with minimum temperature, confirming results from previous research (Ahmad et al., 2016).

4.3 Vegetation and host plant growth characteristics affect the population size of *K. immixtus*

Plant communities within habitats play a critical role in shaping insect population composition. Vegetation not only offers shelter and refuge to most insect species but also serves as a primary food source for herbivores. Key indicators such as species richness, plant height, cover, and biomass significantly influence insect populations (Hao et al., 2015). Previous research has demonstrated that thrips population size is strongly and positively correlated with cotton plant height (Khalil et al., 2017), whereas the height of *C. korshinskii* is significantly and positively correlated with *Agriopsis leucophaearia* (Denis & Schiffermüller) density (Chen and Xia, 2017), and major jute pest incidence is similarly correlated with jute plant height (Rahman and Khan, 2012). High plant diversity supports richer insect communities, whereas increased plant richness and cover provide additional food resources for insect populations (Maharning et al., 2009). Vegetation improves soil conditions, and increasing plant diversity mitigates soil desertification, thereby increasing insect diversity (Zhao et al., 2002). The morphological traits of host plants, including height, significantly influence plant re-

sistance to pest infestations (Khairnar and Patel, 2015). Pests are more readily attracted to plants with simpler stems (Obermaier et al., 2008), as host-finding success rates are higher in structurally simple plants than in more complex ones (Gingras et al., 2003).

In this study, *K. immixtus* population size was significantly and positively correlated with both the plant richness index and the height of *C. korshinskii*. After *K. immixtus* pupae emerged as adults, *C. korshinskii* served as their primary food source. The population size of *K. immixtus* exhibited a significantly negative correlation with both the number of branches and the canopy width of *C. korshinskii*. Thus, the growth status of *C. korshinskii* was a major factor influencing the infestation rate of *K. immixtus*.

5 Conclusions

This study revealed that due to the sand-fixation capacity of *C. korshinskii*, it effectively alleviated soil desertification. *K. immixtus* is a key pest of *C. korshinskii* seeds. However, as desertification decreases, habitat restoration and increased plant diversity lead to a significant increase in the population size and damage rate of *K. immixtus*. Analysis of environmental factors revealed that soil total potassium content, plant height of *C. korshinskii*, and plant richness index were significantly and positively correlated with *K. immixtus* populations, whereas soil total phosphorus content, soil organic matter content, crown width, and branch number of *C. korshinskii* were significantly and negatively correlated. Nevertheless, this study has spatiotemporal limitations: data collection was based solely on field surveys during a single growing season and did not incorporate the impacts of inter-annual climate fluctuations, and the research scope was confined to desertified areas in north-central Ningxia. Future studies should systematically evaluate the effects of landscape-scale factors on the dispersal capacity of *K. immixtus* and analyze the regulatory networks of their natural enemies. This study will clarify the multitrophic interaction mechanisms of “plant-pest” and provide a scientific basis for enhancing the ecological functions of *C. korshinskii* and implementing coordinated multifactor pest management during desertification control.

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