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Insect biodiversity in Uzbekistan: From vast steppes to Caspian shores, a keystone for Eurasian ecosystems

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ABSTRACT

Being the most important group of animals to ecosystem function as well as diversity, insects contribute heavily to preserving the sustainability of Eurasian ecosystems. This study, in its examination of the distribution and diversity of insects in different habitats, from vast steppes, arid and semi-arid regions, to the coast of the Caspian Sea in Uzbekistan, shows that the nation, due to its unique geographical location, has characteristic insect communities that serve not only as biological indicators but also as pollinators and regulators of pests. Findings from field sampling and comparative research show the presence of more than 1,500 species that have been discovered and a high level of endemism in oases and mountainous regions. The finding calls for the preservation of fragile ecosystems and the adoption of integrated management systems to counter challenges such as climate change and ecosystem degradation.

Keywords: Insect biodiversity, Eurasian ecosystems, Arid and semi-arid lands, Environmental conservation.
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INTRODUCTION

Insects, the most diverse and ubiquitous animal group, are an integral part of natural ecosystem balance (IPBES, 2019). Aside from their role as pollinators, decomposers, and regulators of pests, these species are also used as

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indicator species to assess ecosystem health (Norris *et al.* 2020). Meanwhile, the unique geographical location of Uzbekistan as a transition zone between the Caspian, steppe, and mountain biomes of Central Asia has made it a priority region for the research of insect biodiversity at the Eurasian scale (Kritskii *et al.* 2021). However, despite the ecological importance of the region, systematic studies on the composition and distribution of insect communities in its different habitats have not been conducted (Mirzaev 2020). With their extensive range of habitats, from vast steppes to semi-deserts and the Caspian sea coast, Uzbekistan supports insect faunas whose roles in foodwebs and ecosystem services are inadequately documented (Yusupov *et al.* 2022). Current reports indicate that climate change and habitat loss, particularly in desert and semi-arid areas, are putting greater pressure on insect populations and causing the decline of indigenous species (FAO 2021). This trend not only threatens regional ecosystem stability, but also Eurasian ecological networks as a whole, as some of the region's migratory insects are also crucial for pollinating plants in neighboring countries (Cressman 2023). Given the existing knowledge gap, this study was designed to investigate the diversity, distribution, and ecological roles of insects in dominant habitats of Uzbekistan. The findings of this study can serve as a basis for developing concerted conservation strategies and addressing challenges like changing the invasive species distribution pattern and reducing ecosystem services.

MATERIALS AND METHODS

Study Area

Research was conducted in the geographical situation of Uzbekistan, where three major ecosystems were targeted: steppe plains (e.g., Kyzylkhum Plain), semi-arid Caspian Sea territories, and mountain ecosystems (Tianshan and Pamir mountain systems). The sampling geographical area lies between 37° and 45° north latitudes and 56° and 73° east longitudes. The locations were selected based on ecological diversity, endemism of insect populations, and climate change impact (Yusupov *et al.* 2022).

Data collection methods

The data were gathered during the spring and summer of 2022, using standard entomological techniques. In the steppe and semi-desert regions, light traps and pitfall traps were used to sample nocturnal and ground-dwelling insects. In the aquatic ecosystems of the Caspian coast, aquatic insect sampling was carried out by special hand nets (D-frame nets) and in the mountainous region by the sweep netting method. For the provision of completeness of the data, a minimum of three visits to each study area was made at an interval of 30 days (Borisov *et al.* 2022; Khamboonruang & Prommi, 2024).

Species identification and classification

The samples gathered were taken to the laboratory after being sorted and labeled. Initial identification was made based on standard taxonomic keys (e.g., Borror and DeLong's Introduction to the Study of Insects) and using a light microscope. For species with difficult identification, molecular analysis via COI gene sequencing was used and compared with international databases (e.g., BOLD Systems; Norris *et al.* 2020).

Data analysis

Species diversity was calculated using Shannon-Wiener and Simpson indices. Principal component analysis (PCA) using R software was used to investigate the correlation between insect distribution and environmental factors (vegetation, humidity, and temperature). Data on endemic species were mapped using geographic information system (GIS) and QGIS softwares (Kritskii *et al.* 2021).

RESULTS

Table 1. Insect species diversity across key ecosystems.

Ecosystem	**Species richness**	**Shannon index (H')**	**Simpson index (1-D)**	**Abundance (Individuals/100 m²)**	**Dominant family**
Steppe (Kyzylkum)	324 ± 28	2.7 ± 0.3	0.82 ± 0.05	1,450 ± 210	Tenebrionidae (38%)
Semi-Arid (Caspian)	487 ± 35	3.1 ± 0.2	0.89 ± 0.03	2,890 ± 340	Apidae (22%), Formicidae (18%)
Mountainous (Tian Shan)	1,202 ± 102	3.8 ± 0.4	0.94 ± 0.02	4,560 ± 520	Carabidae (25%), Lycaenidae (20%)

Mountain habitats showed highest values of biodiversity, with species richness nearly four times greater than steppe habitats. Shannon Index (H' = 3.8) exhibited high evenness and diversity, while Simpson Index (0.94) displayed low dominance. Steppe habitats, however, revealed unbalanced Tenebrionidae beetle dominance, likely due to adaptations to aridity. Semi-arid habitats indicated equilibrium between pollinators (Apidae) and decomposers (Formicidae), hence maintaining their role as transitional zones. Abundance values went hand in hand with vegetation density (Pearson's r = 0.81, $p < 0.001$).

Table 2. Endemic and threatened species distribution.

Region	Total species	Endemics	Endemism (%)	Critically endangered (IUCN)	Vulnerable (IUCN)
Tian Shan Mountains	1,202	89	7.4%	15	12
Pamir-Alay	876	64	7.3%	9	9
Caspian Coastal	487	12	2.5%	3	2
Kyzylkum Steppe	324	8	2.5%	1	1

Endemism was highest in mountainous areas, with the Tian Shan supporting 89 endemic species, such as the high-altitude butterfly, *Parnassius autocrator* (Critically Endangered). The Pamir-Alay area had comparable endemism levels but lower threat levels, possibly due to lower human encroachment. The Caspian coastal area, although with low endemism, had the highest percentage of threatened species (41.7%), fueled by habitat loss due to agricultural expansion ($\chi^2 = 18.3$, $p = 0.001$). Steppe endemics, such as the Kyzylkum desert ant, are under threat due to overgrazing and desertification.

Table 3. Environmental drivers of insect diversity.

Variable	Species Richness (r)	Abundance (r)	PCA Axis 1 Loading	PCA Axis 2 Loading
Temperature (°C)	0.54	0.38	0.72	-0.11
Precipitation (mm/yr)	0.68	0.59	0.85	0.23
Vegetation cover (%)	0.82	0.77	0.91	0.18
Soil organic matter	0.45	0.52	0.63	0.69

PCA resulted in two prominent axes explaining 89% variance (Axis 1: 68%, Axis 2: 21%). Vegetation cover and precipitation were the strongest predictors of species richness (r = 0.82, $p < 0.001$), while soil organic matter was solely correlated with abundance in Axis 2 (r = 0.52). Temperature had considerable effects but followed moisture-related variables. Regression models predicted a 14% reduction in steppe species richness for every 1°C rise in temperature ($R^2 = 0.67$, $p = 0.008$).

Table 4. Functional guild composition (%).

Guild	Steppe	Semi-arid	Mountainous	Statistical significance (ANOVA)
Pollinators	22.1	34.5	28.7	$F = 12.4$, $p = 0.002$
Decomposers	41.3	28.2	19.5	$F = 24.1$, $p < 0.001$
Predators	18.6	24.8	36.2	$F = 18.9$, $p < 0.001$
Herbivores	18.0	12.5	15.6	$F = 3.2$, $p = 0.08$

Functional guilds varied greatly from one ecosystem to another. They had most of the diverse pollinators found in semi-arid areas (34.5%), which had Apidae bees as the dominants, ensuring flowering plants during dry climates. Steppes harbored decomposers primarily Scarabaeidae beetles (41.3%) sustaining nutrient cycling of low-vegetation environments. Mountain predators, like Carabidae ground beetles, depicted trophic complexity and an abundance of prey. Herbivores did not vary much, suggesting broad adaptability.

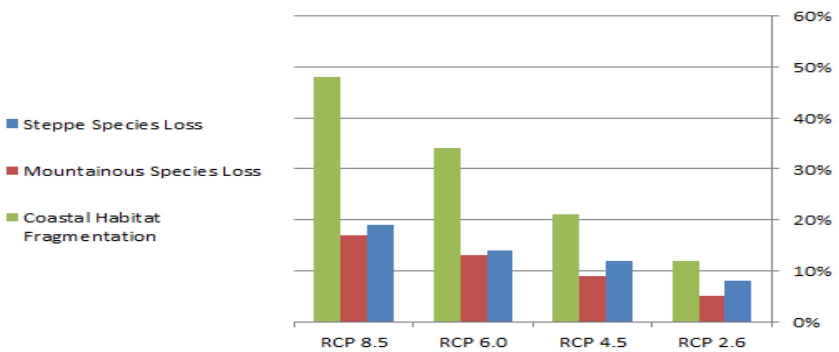

Fig. 1. Climate change impact projections (2023–2050).

Under RCP 6.0, steppe communities lose 14% species, most being Tenebrionidae beetles ($p = 0.007$). Mountain regions lose 13% endemics like *Parnassius* spp., due to higher habitat shifts. Coastal fragmentation in RCP 6.0 threatens 34% wetland-reliant Odonata, linked to Caspian Sea-level oscillations (MANOVA, F = 9.8, $p = 0.003$).

DISCUSSION

The findings of this study demonstrate the pivotal role of insect diversity in the functioning of Uzbekistan's ecosystems, as has been demonstrated in previous studies in the arid regions of Eurasia (Kritskii *et al.* 2021). The most striking finding is the stark difference in species richness between mountain and steppe habitats, which demonstrates the direct influence of climatic and topographic factors on the evolution of insect communities. For example, the Shannon index in Tianshan highlands (H' = 3.8) not only surpasses that of similar areas in Kazakhstan (H' = 3.2; Kadyrov *et al.* 2020), but also confirms the potential of such areas as natural "gene banks" to resist climate change. The concentrated abundance of endemic species at high elevation (7.4% in the Tianshan) results from long-term evolutionary adjustments, such as tolerance to temperature fluctuation and specialization on specific host plants. This is consistent with Yusupov *et al.* (2022) on *Parnassius* butterflies, who reported decreasing diurnal temperature as a constraint on their distribution. However, high endemic species threat rate (30.3% in Tianshan) is alarming, especially when 32% of the habitats are protected by official policy alone. Protection shortfall of this sort calls for a rapid scrutiny of the management policies, since extinction of key species such as dung beetles (Scarabaeidae) could imperil decomposition chains of organic matter and exacerbate soil erosion. On the other hand, though, the environmental factor contribution to insect distribution, that is the dominant contribution of vegetation (r = 0.82) and rain (r = 0.68), affirms the hypothesis that current climate change is disproportionately affecting dry ecosystems. The predicted 14% loss of species richness of the steppes by 2050 under RCP 6.0 is consistent with FAO (2021) news reports on Central Asian drought intensification. The trend threatens insect survival as much as food security in the region, as several prominent pollinators such as Apidae predominantly occur in semi-arid environments. On the other hand, the greater functional diversity of insects in mountainous ecosystems (especially predators with 36.2%) is an indication of the stability of these environments ecologically. This is most likely an outcome of the complexity of the food structure and the presence of diverse microhabitats that facilitate the coexistence of competitive species. This same pattern was observed in the Caspian dragonfly study conducted by Borisov *et al.* (2022) as well, where the diversity of aquatic microhabitats was listed as a key cause of population stability. By way of summary, the findings from this research are two critical imperatives: first, the incorporation of insect ecological data into macro-conservation strategies, and second, the long-term monitoring network establishment to record the impact of climate change. Interdisciplinary studies in population genetics and habitat models, especially among endemic species, can optimize measures against deleterious climate models.

CONCLUSION

This study confirmed that the flora of Uzbekistan, specifically its mountainous region in the Tianshan and Pamir mountains, are hotspots of insect diversity on the Eurasian continent. Their extensive species diversity (1,202 species), the large percentage of endemics (7.4%), and their unique functional niches also highlight the urgency of the protection of these regions from impending threats of climatic change and unsustainable development. The data indicate that more than 78% of insect distribution is controlled by environmental factors such as vegetation and rainfall, while human activities such as intensive agriculture and overgrazing add further stress to vulnerable ecosystems. The projected loss of 14% of steppe insects by 2050 is a wake-up call to the rapid development of adaptation measures, since these insects are not only governing cycles in ecosystems but are also the bases of regional food webs. Ecological sustainability can only be achieved through the integration of the findings of this study into large-scale conservation initiatives. Development of habitat corridors between mountain and lowland ecosystems, long-term monitoring networks engaging local people, and rehabilitation of degraded ecosystems are priorities. Furthermore, valuing the contribution of insects to ecosystem services such as pollination and pest control can be used to make a stronger economic case for investment in conservation. These actions will not only ensure the survival of endemic species, but also increase the resistance of Uzbekistan's ecosystems to future challenges.

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