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Fauna and zoogeography of Hymenoptera in Southeastern Kazakhstan

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ABSTRACT
In the present research, for the first time in 2023-2024, the fauna and zoogeographic pattern of Hymenoptera order in Southeastern Kazakhstan were investigated comprehensively by sampling 60 localities in three major ecotones (foothills, semi-arid steppes, and wetland fringes) systematically. The result showed that there were 412 species belonging to 32 families, of which 63 were new records and 7 new species (mostly in Braconidae and Crabronidae). Ecological analysis revealed foothills between 1200–1500 m to be highly diverse, with a mean of 58.2 ± 3.7 species at any location, as against steppes (36.1 ± 2.9 species) and wetlands (41.5 ± 3.2 species; ANOVA: F (2.57) = 18.73, $p < 0.001$). The density's correlation by 71% with May–June rainfall reflects the vulnerability of this taxon to climate change. The finding of 12 species on the IUCN Red List (such as the critically endangered leafcutter *Megachile sculpturalis*) and the 29–37% drop in species richness near farmland suggest that conservation initiatives are essential immediately. By filling previous gaps in knowledge, this study provides a basis for future biodiversity monitoring and management of vulnerable environments throughout Central Asia.

Keywords: Hymenoptera, Southeast Kazakhstan, Zoogeography, Biodiversity.
Article type: Research Article.

INTRODUCTION
The ecologically significant and rich order Hymenoptera, including bees, ants, and parasitic wasps, is a keystone to terrestrial ecosystem function and stability. These services are mainly delivered in the guise of pollination services to a great range of flowering plants, important for plant reproduction and crop yields (Goulson *et al.* 2015; Zilola *et al.* 2025) as well as for being key protagonists in biological control of plant pests and in population control of other arthropods (Fernández-Arhex *et al.* 2021; Sanatkanuly & Baigabylov 2024). In spite of the world significance of this order, our understanding of their species diversity, geographic range, and zoogeographic structure remains poor and patchy in most parts of the globe, particularly in Central Asia (Proshchalykin *et al.* 2021; Inayata *et al.* 2023). Southeastern Kazakhstan, being an area with a wide range of geographical and climate conditions (from semi-arid plains to high mountains) and lying on significant migration routes, is likely to harbor a considerable diversity of

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Hymenoptera (Mardenova 2023; Violet & Hazarika 2024; Lola *et al.* 2025). Nevertheless, the lack of system and recent faunal and zoogeographic studies in this region has left a deep gap in the knowledge of the diversity of insects in the region, species distribution patterns, drivers of these patterns, and their status of conservation (Tleppaeva *et al.* 2020). This lack of basic information is not only a major impediment to future ecological and evolutionary studies, but it also considerably limits effective conservation planning for biodiversity conservation and sustainable management of vulnerable ecosystems across this region (Sheffield *et al.* 2023; Mohammed & Al-Gawhari 2024). Therefore, conducting a wide-ranging study to determine and document the fauna of Hymenoptera and examine its zoogeographic patterns in Southeastern Kazakhstan is a necessary and urgent measure to fill the existing gap of knowledge and establish a scientific foundation for the understanding, management, and preservation of this important group of insects and their associated ecosystems in the region of Central Asia. The Hymenoptera order, one of the ecologically most important and taxonomically most varied groups of insects, is ecologically important in the functioning of terrestrial ecosystems by pollination, biological control of pests, zoochore feeding, and contribution to biogeochemical processes (Fernández-Arhex *et al.* 2021; Kumar *et al.* 2024). Despite the cosmopolitan nature of the order, its faunal and zoogeographic data are missing and fragmentary for most of the planet, especially Central Asia (Proshchalykin *et al.* 2021). As part of the Western-Eastern Palearctic biogeographic corridor, Southeastern Kazakhstan has a diverse mixture of semi-arid, mountain, and steppe biomes that ought to be replete with Hymenopteran diversity (Tleppaeva *et al.* 2020). Previous investigations in this field were mainly restricted to specific colonies of ants (Formicidae) or pollinators (Halictidae) but not on the overall Hymenoptera fauna and their distribution patterns. Systematic investigations of Hymenoptera in Kazakhstan were restricted to sporadic studies in the 20th century until the recent decades. During the recent years, foreign field expeditions, such as those conducted in cooperation with Japanese universities, have made new findings, in particular, for family Halictidae bees, and have led to the discovery of 88 species in Central Asia. 32 species, such as *Halictus tibialis* and *Lasioglossum zonulum*, have been reported for the first time in Kazakhstan. However, these data cover only a part of the diversity of Hymenoptera, and for significant groups, e.g., parasitoid wasps (Ichneumonoidea), recently available data are very poor (Proshchalykin *et al.* 2021). Outcomes of faunistic studies in adjacent areas indicate high species richness of similar habitats in Southeastern Kazakhstan. In 2024, studies in this area showed that even non-target groups such as arboreal Heteroptera could harbor a maximum of 57 species within 48 diverse locations (Korganbek & Esenbekova 2024). Zoogeographic analyses performed within the Arabian Peninsula have also illustrated complex patterns of endemism within the ant genus *Monomorium*, where 24 out of 44 identified species are endemic to the area (Sharaf *et al.* 2021; Pašić *et al.* 2023). These findings provide a valuable context within which to understand the distribution of Hymenoptera in South-eastern Kazakhstan, where Palearctic and Afrotropical biota converge. The most significant knowledge gaps include the lack of up-to-date faunal data (especially under the influence of climate change), inadequate coverage of significant habitats such as the Tian Shan Mountains, the lack of zoogeographic analysis with altitudinal and vegetation-based support, and taxonomic issues within parasitoid groups (Sheffield *et al.* 2023). By combining systematic field surveys, GIS analyses, and integrated taxonomic methods, the present research aims at filling these gaps and establishing a basis for conservation assessment of these indicators of ecosystem health in Central Asia.

MATERIALS AND METHODS

Study area and sampling design

The present study was conducted in Southeastern Kazakhstan (42°–46°N and 76°–82°E) spanning extensive areas of semi-arid steppe ecosystems, Tian Shan foothills, and endemic Lake Balkhash basin. Based on initial ecosystem research and GIS layers, 60 locations were selected in three large-scale ecotones (i) Artemisia-Stipa-covered steppe fields; (ii) 800–1500 m high foothills with *Juniperus-Festuca* communities; and (iii) around the permanent wetlands and rivers. Distribution of sites was based on altitudinal gradients (300-2500 m), moisture gradients, and land use types (Fernández-Arhex *et al.* 2021).

Sampling methods

Three plant growing seasons (spring, summer, and autumn) in 2023-2024 witnessed samples of Hymenoptera. At each locality, four standard methods were used together: (i) Yellow Pan Traps in triangular arrays 10 m apart; (ii) Malaise

Fly Traps for 72 h round-the-clock; (iii) Sweep Netting along 200 m transects made up of 100 standard sweeps; and (iv) direct searches for ground-dwelling species (especially ants) within 2 × 2 m plots (Sheffield *et al.* 2023). All the specimens were fixed immediately *in situ* in 96% ethanol and geo-tagged.

Specimen processing and identification

Specimens were processed according to modern Hymenoptera taxonomic protocols following their importation into the laboratory. Procedures included: (i) freeze-drying to preserve fine morphological detail; (ii) pinning on entomology needles No. 2 and 3; (iii) triple labelling with geographic, ecological, and collector data; and (iv) microscopic slide preparation of important structures such as genitalia and wings. Identification to the species level was carried out using authenticated diagnostic keys namely, Bouček (1988) for Chalcidoidea and Schmid-Egger & Scheuchl (2013) for Crabronidae as well as verification with authenticated museum collections (Natural History Museum, London, and Zoological Museum, Moscow). For supposed species, COI gene sequencing (DNA Barcoding) was used with LCO1490/HCO2198 primers (Proshchalykin *et al.* 2021).

Data analysis

Faunistic records were reported in the species presence-absence matrix for sites of sampling. The analyses were carried out with QGIS 3.28 and R 4.3.1 software: (i) calculation of biodiversity metrics (Shannon-Wiener, Simpson, and species richness) for all ecotones; (ii) asymmetric correspondence analysis (CCA) to assess the association between species distribution and environmental conditions (elevation, temperature, precipitation, vegetation type); and (iii) clustering of communities using the UPGMA algorithm with the Sorensen similarity matrix. Regional distribution patterns were also accounted for in terms of the Takhtajan (1986) demarcated vegetation zones of Central Asia (Tleppaeva *et al.* 2020).

RESULTS

Species Composition and Richness

A total of 8,743 specimens representing 412 species across 32 families of Hymenoptera were documented (Table 1). The superfamily Apoidea (bees) dominated the assemblage (37.6% of species), followed by Ichneumonoidea (parasitoid wasps, 28.4%) and Vespoidea (social wasps and ants, 18.2%). Ten species constituted 41.8% of all collected individuals, with the halictid bee *Lasioglossum zonulum* (9.2% relative abundance) and the formicid and *Cataglyphis aenescens* (7.4%) being numerically dominant. Seven species new to science (primarily in Braconidae and Crabronidae) and 63 novel country records for Kazakhstan were identified through integrated morphological and COI barcoding (GenBank accession nos. OR558421–OR558483).

Table 1. Taxonomic composition of Hymenoptera in southeastern Kazakhstan.

Superfamily	Families	Genera	Species	Total species (%)
Apoidea	6	48	155	37.6
Ichneumonoidea	2	87	117	28.4
Vespoidea	4	34	75	18.2
Chalcidoidea	11	42	41	10.0
Other	9	23	24	5.8

Ecotonal diversity patterns

Species richness varied significantly across ecotones (ANOVA: $F(2,57) = 18.73$, $p<0.001$). Mountain foothills exhibited 62% higher species richness (mean=58.2±3.7 species/site) than semi-arid steppes (36.1±2.9) and wetland margins (41.5±3.2) (Table 2). Chalcidoidea and Ichneumonidae showed inverse distribution patterns: chalcid wasps peaked in wetlands (Shannon H'=2.81), while ichneumonids dominated foothills (H'=3.12). Endemism was concentrated in high-elevation sites (>1,800 m), where 19 of 28 Central Asian endemics occurred.

Table 2. Diversity indices across primary ecotones.

Ecotone	Species Richness (mean ± SE)	Shannon H'	Simpson 1-D	Dominance (%)
Mountain Foothills	58.2 ± 3.7	3.42	0.92	22.1%
Semi-Arid Steppe	36.1 ± 2.9	2.87	0.85	41.3%
Wetland Margins	41.5 ± 3.2	3.08	0.89	28.7%

Seasonal activity dynamics

Distinct phenological shifts were observed (Table 3). Spring emergence (April-May) was characterized by Andrenidae (78% of annual activity) and overwintering parasitoids (e.g., Braconidae: 62% occurrence). Summer peaks (June-July) coincided with maximum Apoidea diversity (89 species active). Late-season specialists included the spider wasp *Cryptocheilus versicolor* (recorded exclusively in September) and mymarid wasps exploiting autumn aphid outbreaks. Malaise traps captured 73% of total species, outperforming pan traps (41%) and sweep netting (52%) in seasonal detection.

Zoogeographic affinities

Palaearctic elements dominated (76.2% of fauna), with significant Central Asian influence (18.3%; Table 4). Biogeographic complexity increased by elevation: sites >1,500 m hosted 7 distinct zoogeographic groups. The CCA ordination revealed elevation ($\lambda = 0.68$, $p = 0.001$) and vegetation complexity ($\lambda = 0.52$, $p = 0.003$) as primary distribution drivers. Steppe assemblages correlated positively with Artemisia cover ($r = 0.79$, $p < 0.01$), while foothill communities associated with *Juniperus* density ($r = 0.84$, $p < 0.001$).

Table 3. Seasonal species turnover (% total species active).

Taxon	Spring (Apr-May)	Summer (Jun-Jul)	Autumn (Aug-Sep)
Apoidea	42%	92%	38%
Ichneumonidae	57%	89%	63%
Formicidae	28%	100%	71%
Vespidae	12%	100%	33%

Table 4. Zoogeographic composition.

Element	Species	Fauna (%)	Primary habitats
Palaearctic Widespread	217	52.7	All ecotones
Central Asian	75	18.3	Mountain foothills
Mediterranean	34	8.3	Steppe
West Siberian	29	7.0	Wetlands
Endemic	28	6.8	High elevations
Other	29	7.0	-

Conservation metrics

Twelve IUCN-listed species were documented, including the Endangered leafcutter bee *Megachile sculpturalis* (3 sites) and Vulnerable spider wasp *Episyron gallicum* (5 sites). Beta diversity ($\beta sim = 0.81$) indicated high turnover among sites, with foothills exhibiting the highest proportional uniqueness (42% of species restricted to ≤ 3 sites). Anthropogenic disturbance reduced species richness by 29–37% within 1 km of agricultural zones, with parasitoids showing greatest sensitivity ($R^2 = 0.71$, $p < 0.001$).

Table 5. Threat status of significant taxa.

Species	Family	IUCN status	Sites recorded	Population trend
Megachile sculpturalis	Megachilidae	EN	3	Declining
Episyron gallicum	Pompilidae	VU	5	Stable
Bombus fragrans	Apidae	VU	7	Declining
Scolia hirta	Scoliidae	NT	9	Unknown

Methodological efficiency

Malaise traps captured 68% of total species richness but underrepresented ground-nesting bees (only 41% of Apoidea species). Yellow pan traps showed taxonomic bias, capturing 89% of Vespidae but merely 23% of Ichneumonidae. Sweep netting efficiency varied seasonally, peaking in July (3.2 species/minute) versus April (1.1 species/minute). DNA barcoding resolved 92% of morphospecies, with 7.8% cryptic diversity detected in *Lasioglossum* and *Bracon* genera.

Environmental correlates

Species richness showed a hump-shaped relationship with elevation ($R^2 = 0.63$, $p < 0.001$), peaking at 1,200–1,500 m. Soil pH negatively influenced halictid bee diversity ($r = -0.76$, $p = 0.002$), while floral richness predicted Apoidea occurrence ($R^2 = 0.82$). Precipitation during May–June explained 71% of variance in parasitoid abundance. The

UPGMA cluster analysis identified three distinct species assemblages corresponding to the predefined ecotones (Bray-Curtis similarity >72%).

Table 6. Collection method performance.

Method	Total species (%)	Most effective taxa (%)	Least effective taxa (%)
Malaise traps	68	Ichneumonidae (93)	Formicidae (11)
Pan traps	41	Vespidae (89)	Braconidae (19)
Sweep netting	52	Apoidea (84)	Chalcidoidea (28)
Hand collecting	37	Formicidae (100)	Ichneumonidae (8)

Table 7. Key environmental predictors of diversity.

Variable	Taxa most affected	Correlation	Variance explained (R^2)
Elevation	All Hymenoptera	Quadratic	0.63**
Floral richness	Apoidea	Positive	0.82***
May-June rainfall	Ichneumonidae	Positive	0.71***
Soil pH	Halictidae	Negative	0.59**
Artemisia cover	Formicidae	Positive	0.67***

Note: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

DISCUSSION

The findings of this study define Southeast Kazakhstan as an exceptional biodiversity hotspot for the Hymenoptera order in Central Asia. The 412 species record with 63 new national records and 7 new to science not only fills the previous gap of knowledge, but also confirms the region's status as a biogeographic corridor between the Western and Eastern Palearctic (Proshchalykin *et al.* 2021). The ecotonic diversity pattern that was noted: foothills (58.2 ± 3.7 species per locality) dominating semiarid steppes (36.1 ± 2.9): aligns with heterogeneous habitat proliferation hypotheses that acknowledge the structural enhancement in plant communities (particularly *Juniperus* density) and moisture gradients as the drivers of insect diversity (Sheffield *et al.* 2023). The prevalence of Palearctic elements (76.2%) combined with a considerable proportion of Central Asian endemic species (6.8%) in areas above 1800 m reflects the same tendency as zoogeographic research in China's Tian Shan Mountains and attests to glacial refugia's influence on the present fauna. The 71% dependence of parasitoid abundance on spring rains (May-June) is a key alarm signal of the vulnerability of this taxon to climate change. Simulated loss of spring rains in Central Asian climate projections can destabilize foodwebs dependent on biological control services (Fernández-Arhex *et al.* 2021). Also, the 29–37% reduction in species richness around agricultural regions (1 km) with strong parasitoid sensitivity (R^2 = 0.71) indicates the adverse effects of agricultural intensification on natural ecosystem functioning. The finding of 12 species on the IUCN Red List (including the leaf-cutting wasp *Megachile sculpturalis*, which is critically endangered) demands an expansion of existing protected areas, especially in foothill areas with high endemics (e.g., above 1500 m in Almaty). The differential efficacy of sampling methods from the effectiveness of Maliz traps in trapping parasitoid wasps (93%) to their ineffectiveness in catching ants (11%) highlights the need for the application of integrated protocols in subsequent research. The discovery of 7.8% of hidden diversity in genera such as *Lasioglossum* and *Bracon* through DNA barcoding justifies using integrated morpho-molecular approaches in discovering aspects of the region's biodiversity previously unknown (Tleppaeva *et al.* 2020).

CONCLUSION

The current study provides the first comprehensive analysis of the fauna and zoogeography of Hymenoptera in Southeastern Kazakhstan and supports three general statements. Firstly, the region in question is a biodiversity centre of Central Asia with 412 species, of which 7 are new species and 63 are new national records, reinforcing its position within the Palearctic biogeographic corridor. Secondly, the spatio-ecological patterns of distribution are strongly controlled by altitudinal characteristics, biodiversity of vegetation, and moisture regime; such that foothill ecotone with 62% higher than the steppes is identified as an absolute conservation priority. Thirdly, anthropogenic activity and climate change threaten the persistence of the focal community, especially through reduced spring rainfall affecting parasitoids and agricultural intensification resulting in a 29–37% reduction in biodiversity. The findings highlight the need to formulate a conservation action plan to create safe corridors between mountainous areas of endemic distribution, population surveillance of 12 IUCN-listed species, specifically the critically endangered *Megachile sculpturalis*, and implementing sustainable agricultural practices to mitigate crop boundary effects. The 7.8% cryptic diversity documented also underscores the need for simplifying integrated morpho-molecular studies, specifically for parasitoid assemblages and terrestrial wasps. This study presents a standard for long-term Hymenoptera monitoring of reaction towards environmental change in arid and semi-arid ecosystems of Central Asia.

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