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Diurnal insect pollinators of legume forage crops in Southeastern Kazakhstan

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Abstract
Principal pollinators of commercial legume forage crops (principally alfalfa and soybeans, plus minor crops of sainfoin, trefoil, and clovers) in south eastern Kazakhstan include 82 species of insects in 14 families and 3 orders. Hymenoptera species were the most frequently recorded. Lepidoptera and Diptera were less frequently encountered and carried little evident pollen, suggesting they were relatively unimportant as pollinators. Field data for Hymenoptera, supplemented with data from traps and artificial nesting sites, showed that 8 species of pollen carrying solitary bees (*Anthidium cingulatum, Hoplitis parvula, Megachile rotundata, Metallinella leucogastra, Osmia coerulescens, O. parvula, O. rufa,* and *Ceratina cyanea*) were the most frequent visitors, and thus the most important pollinators, of forage legumes in southeastern Kazakhstan. Zoogeographically, the identified pollinators were dominated by Holarctic, Trans- Palearctic, Western Palearctic, and Central Asian species.

Keywords: pollinators, hymenoptera, solitary bees, legume forage crops, Kazakhstan

Introduction
Insect pollinators are essential to maintain the productivity of legume forage crops such as alfalfa (*Medicago* sp.), clover (*Trifolium* sp.), and other forage legumes such as soy and others (e.g. *Melilotus* sp.). Alfalfa flowers, in particular, need specialist pollinators because the flowers must be tripped by specially adapted pollinators for pollen release [1, 2]. Of these, the most important are Hymenoptera, especially various solitary bee species and domestic honey bees (*Apis* sp.). For insect-pollinated crops such as alfalfa, clover and other forage legumes, domestic bees are not the most effective pollinators and other species, especially solitary bees, are much more important for pollination [3, 4].

In the North America, solitary alfalfa leafcutter bees *Megachile rotundata* (Fabricius) and *Anthidium manicatum* (Linnaeus) are much more effective pollinators of alfalfa than domestic bees [1, 5, 6, 7], leading to their widespread use in alfalfa production worldwide [7]. However, recent research [8] suggests that native solitary bee species are even more effective pollinators of alfalfa than either domestic bees or alfalfa leaf cutter bees. As a result, species composition, biology and approaches to conservation and artificial breeding of solitary bee species have been intensively studied worldwide [9, 10, 11], including Central Asia [12, 13, 14].

Research on crop pollinators of Central Asia, begun in the Soviet era, continued in the post-Soviet states of Russia, Uzbekistan and other republics [15, 16, 17, 18, 19, 20], as well as in Kazakhstan [21, 22, 23, 24, 25, 26]. However, much of this research focused largely on pollinators of fruits or other food crops, providing little information on the identity and roles of forage crop pollinators in the post-Soviet republics.

Current research in the region on pollinators of legume forage crops are limited to work in the Russian Federation [27, 28]. Recently, in response to the increase in beef and dairy cattle production in the country, the acreage devoted to legume forage crops in Kazakhstan has expanded rapidly. However, producers are unfamiliar with the management of newly expanding legume forage crops [29], including the importance of pollinators. In response, the Kazakh Scientific Research Institute of Plant Protection and Quarantine has begun research on this important group of pollinators.

This qualitative study was designed to identify the suite of pollinators of a legume forage crops in southeastern Kazakhstan, and to identify species, particularly Hymenoptera, whose populations could be increased through population enhancement or propagation. This research also contributes to a better understanding of the agricultural ecosystem associated with legume forage crops to develop integrated pest management practices (IPM) that will improve pollination and yields [30].

Materials and Methods
This research was part of larger Kazakh Ministry of Agriculture funded project to develop environmentally friendly method for increasing yields of forage and industrial crops. The study collected baseline data to be used in the design of field trials that test various Integrated Pest Management (IPM) practices for legume forage crops [30]. One component of the research was to identify legume forage crop pests and their predators and, for insect pollinated crops, to identify pollinator species as well. The project was located within the legume forage crop fields of "Agro Bayserke ", a commercial farm located in the Panfilov district of south-eastern Kazakhstan. Commercial acreage was planted in soybeans (*Glycine max*, 492 ha) and alfalfa (*Medcago*, 700 ha), with additional acreage in corn (240 ha) and triticale (350 ha). Strips of forage legumes - sainfoin (*Onobrychis* sp.), birds-foot trefoil (*Lotus corniculatus*), white and red clover (*Trifolium repens,*

T. pratense), intermixed with milk vetch (*Astragalus*) and vetch (*Vicia sativa*), were planted at the edges of alfalfa and soybean fields. We set up sampling sites, one each the edges of adjacent soybean and alfalfa fields, and in each of the adjoining forage legume strips, each with a different trial.

We used established entomology and plant protection research protocols for field work and specimen collection [31, 32, 33], as well as modified methods used for sampling artificially propagated and released pollinators and predator species [34]. Insects were collected from crop fields twice a week, with morning and afternoon collections (9-noon and 3-5 pm) from May 1 to September 1, covering most of the flowering season for the legume forage crops involved in the study. Specimens were collected by netting insects observed by the researchers on flowers of legume forage crops and on weeds and wildflowers in the crop fields. Targeted collections were augmented by sweep netting. Collections made by the authors in other regions of southeastern Kazakhstan during 2010-2015 supplemented the field collection data. Representative samples of specimens collected directly from legume forage crop flowers were examined with a hand lens or low power light microscope for evidence of a pollen load. Where possible, we tracked the movements of species were sampling to determine if they visited 5 or more flowers of the same plan in sequence. The evidence of noticeable pollen on collected individuals, combined with repeated visits to flowers of the same plants, led us to qualitatively define these as likely pollinators of that plant.

All specimens were identified to species. Collected Hymenoptera and Lepidoptera were added to the national entomological collections, stored at the Institute of Zoology of Kazakhstan; other collected specimens are held at the Kazakh Research Institute of Plant Protection and Quarantine, within the Ministry of Agriculture. Information on the recorded legume forage crops pest species and their predators has been previously published [34, 35, 36, 37].

Results

Below is an annotated list of species of Lepidoptera, Diptera and Hymenoptera found visiting flowers of legume forage crops in the study area. The Hymenoptera, identified as the primary legume forage crop pollinators, are listed in Table 1. The notes below describe known food species (host plants for Lepidoptera, and the preferred flowers for Hymenoptera and Diptera), habitats, overwintering, economic value and distribution of the species. Images of some of pollinating insects from different orders are shown in Figures 1-3.

Table 1: Hymenoptera collected from Agro Bayserke legume forage crop fields, 2015. X indicates the forage legume flowers it was collected from.

Taxon	**Legume Forage Crop**					
	Medicago	***Trifolium***	***Glycinde***	***Onobrychis***	***Lotus corniculatus***	***Vicia*/*Astrogalus***
Hymenoptera						
Hylaeus arenarius						
Hylaeus confusus						
Hylaeus turanicus						
Hylaeus vulgaris						
Andrena atrata	x					
Andrena chrysopyga				x		
Andrena cineraria						
Andrena cordialis	x	x	x		x	
Andrena flavipes	x					
Andrena labialis	x					
Melliturga clavicornis	x			x		
Halictus eurygnathus	x	x				
Halictus pollinosus	x			x	x	
Halictus quadricinctus	x				x	
Halictus sexcinctus	x			x		
Halictus subauratus	x			x		
Halictus tumulorum	x	x	x			
Lasioglossum calceatum	x					
Nomia diversipes	x			x		
Rophitoides canus	x		x			
Melitta leporina		x	x	x	x	
Anthidium cingulatum	x	x	x		x	
Anthidiellum strigatum			x	x		
Hoplitis leucomelaena	x		x	x	x	
Hoplitis parvula		x	x		x	
Megachile apicalis		x	x	x		
Megachile argentata	x		x	x	x	
Megachile centuncularis	x	x	x		x	
Megachile rotundata	x					
Metallinella leucogastra	x	x	x			
Osmia jagnobensis			x			
Osmia coerulescens	x		x			
Osmia parvula	x					
Osmia rufa	x					
Stelis phaeoptera	x			x		

Anthophora borealis		x	x			
Anthophora pedata	x	x	x			
Anthophora radoszkowskyi	x	x	x			
Ceratina cyanea	x	x				
Nomada ruficornis	x	x	x			
Pasites maculatus	x		x			
Xylocopa valga	x	x	x			
Xylocopa turanica	x		x			
Apis mellifera		x	x	x	x	x
Bombus alticola	x	x	x			
Bombus pascuorum	x	x	x	X		x
Bombus laesus	x	x	x	x		x
Bombus lucorum	x	x	x			

Order Lepidoptera

Family Papilionidae Latreille.

***Papilio machaon* Linnaeus.**

Flight: April-November. It inhabits a variety of landscapes from deserts to high mountains, including cultivated areas. Host plants include *Artemisia dracunculus* (Asteraceae), *Prangos pabularia*, *Ferula* spp. (Apiaceae), *Haplofillum latifolium* (Rutaceae), and *Horaninovia ulucina* (Chenopodiaceae). Winters as pupa. Occasionally a pest of umbelliferous crops - carrots, dill, celery, cumin and others.

Family Pieridae Duponchel.

***Anthocharis cardamines* (Linnaeus).**

Flight: April-July. Ubiquitous except for deserts and semi-deserts. Meadows, woody scrub, forest edges, river valleys, gorges and forb-dominated slopes at altitudes up to 3000 m. Host plants include *Cardamine, Turritis, Sisymbrium, Brassica* and other Brassicaceae. Winters as pupa.

***Aporia crataegi* (Linnaeus).**

Flight: May-July. Ubiquitous except for deserts and semi-deserts. Steppe habitats with shrubs (*Spiraea*, *Caragana*), river valley plains, and in the mountains, at altitudes of 700-2500 m. Host plants include various species of Rosaceae and Vacciniaceae. Become pests of fruits and ornamental plants when populations erupt periodically. Overwinters as an instar.

***Colias hyale* Linnaeus.**

Flight: mid-May to October, in two or three generations. Distribution: Jungar Alatau, Northern Tien Shan. It occurs in steppe habitats, but there are also on various types of meadows, on vacant lots, and in urbanized areas; in the mountains it has been recorded up to the alpine zone (3300 m in Tien Shan), but only infrequently at such altitudes. Host plants include *Medicago, Vicia, Melilotus, Trifolium, Coronilla, Chamaecytisus*, *Lotus*, and others (Fabaceae). Overwinters as an instar.

***Colias erate* (Esper).**

Flight: from April to early November, in two or three generations. Deserts, grasslands, wastelands, cultivated landscapes, and in a variety of habitats in the mountains up to 3300 m. Host plants include *Medicago, Caragana, Trifolium, Onobrychis, Trigonella* (Fabaceae). Overwinters as both as a pupa and as an instar.

***Gonepteryx rhamni* (Linnaeus).**

Flight: March-October. Ubiquitous except for deserts. Most common in gorges of Mountain Rivers, shrub-dominated slopes, mixed forests at altitudes of 800-2500 m. Host plants in the Tien Shan include *Rhamnus catharica, Frangula alnus* (Rhamnaceae) and *Padus avium* (Rosaceae).

***Leptidea sinapis* (Linnaeus).**

Flight: from the end of April to August in two generations. Ubiquitous except for deserts and semi-deserts. Common in grasslands of various types, especially those with shrubs, the edges of mixed forests, river valleys and ravines at altitudes up to 2000 m. Host plants include *Vicia*, *Astragalus, Lotus, Medicago, Trifolium* (Fabaceae). A pest of legumes. Winters as a pupa.

***Pontia daplidice* (Linnaeus).**

Flight: April-October, in two or three generations. Found in different types of dry open landscapes - deserts, steppes, river valleys, cultivated land, and in the sharp, often stepped flat surfaced cliffs typical of Tien Shan and Alatau foothills up to 3000 m. Host plants include *Allysum, Arabis, Berteroa, Erysimum, Sisimbrium, Thlaspi, Turritis* (Brassicaceae), *Reseda lutea* (Resedaceae) and *Vicia, Lathyrus, Pisum, Trifolium* (Fabaceae), а также as well as *Miniocus*. The caterpillars live in groups or singly, and are a pest on crucifers and legumes. Winters as a pupa.

***Pieris brassicae* (Linnaeus).**

Flight: April-September in two or three generations. Ubiquitous except for deserts. Common in agricultural and urban landscapes, river valley meadows and in forested and open slopes of the subalpine zone to altitudes of 2800 m. Host plants include *Brassica, Lepidium, Sinapis, Raohanus, Rorrippa, Nasturtium* (Brassicaceae), *Reseda lutea* (Resedaceae). A pest of crucifers. Winters as a pupa.

***Pieris napi* (Linnaeus).**

Flight: April-September, in two or three generations. Ubiquitous except for deserts and semi-deserts. Grasslands of various types, usually in river valleys, including anthropogenic landscapes to altitudes of 2800 m. Host plants include *Brassica, Cardamine, Allysum, Arabis, Barbarea, Descurainia, Erysimum, Sisimbrium, Thlaspi, Draba, Lepidium* (Brassicaceae), *Reseda lutea* (Resedaceae). A pest of crucifers. Winters as a pupa.

***Pieris rapae* (Linnaeus).**

Flight: April-September, in two or three generations. Ubiquitous, except for deserts. Open prairie and meadow landscapes and clearings in mountain forests, wastelands and cultivated land in the mountains up to 3000 m. Host plants

Cardamine, Arabis, Barbarea, Raphanus, Turritis, Brassica, Alliaria, Descurainia, Erysimum, Hesperis (Brassicaceae), *Reseda lutea* (Resedaceae). A pest of crucifers. Winters as a pupa.

Family Satyridae Boisduval.

***Chazara briseis* (Linnaeus).**

Flight: from June to September. Ubiquitous, except for deserts. Prefers stony and clay slopes with grassy vegetation at altitudes of 700-2500 m. Host plants include *Festuca, Stipa, Sesleria, Poa* (Poaceae). Overwinter as an early instar larva.

***Chazara enervata* (Alpheraky).**

Flight: May-August. Found in the deserts of the Semirechye region, in the Ile Alatau, Alatau Kungei, Terskey Alatau ranges, and the Ketmen system ranges of the Jungar Alatau. Prefers sand and clay deserts, semi-arid stony-clay dry gorges and canyons with a predominance of grassy vegetation at altitudes of 500-2900 m. Host plants limited to the Poaceae. Overwinters as a larva of different instars

***Coenonympha pamphilus* (Linnaeus).**

Flight: May to August in two generations. Ubiquitous, except for deserts. Prefers meadow and steppe habitats, heaths, and cultivated landscapes in the mountains up to 2000 m. Host plants include *Poa, Anthoxanthum, Cynosurus, Dactylis, Festuca, Nardus* (Poaceae). Overwinters as a larva.

***Erebia turanica* Erschoff.**

Flight: May-July. Distribution: Ile Alatau and Kungei Alatau ranges, as well as in the Ketmen, Jungar Alatau and ridges of the Toksanbay and Tyshkantau. Wet meadows on the slopes of different exposures and in mountain river valleys at altitudes of 1200-3000 m. Host plants limited to Poaceae.

***Melanargia russia* (Esper).**

Flight: June-July. Distribution in Kazakhstan: the entire steppe zone, and in the mountains of the Northern Tien Shan to Altai. Meadow and steppe habitats in the mountains up to 2500 m. Host plants include *Stypa, Brachipodium, Bromus, Elytrigia, Phleum, Poa* (Poaceae). Overwinters as a larva.

Family Nymphalidae Rafinesque.

***Argynnis pandora* (Denis et Schiffermuller).**

Flight: May-September, with two generations in the southern part of the range. Distribution: Tien Shan and Jungar Alatau Mountains. Found in meadows and steppe areas in forests of different types, on the slopes at an altitude of 2500 m. Host plants are various species of *Viola* (Violaceae). Winters as larva.

***Issoria lathonia* (Linnaeus).**

Flight: April - October, in two or more generations. Ubiquitous, and locally in deserts. Inhabit all kinds of landscapes, from lowlands to the subalpine zone up to 2900 m. Host plants - different species of *Violaceae*; *Rubus* (Rosaceae), *Onobrychis* (Fabaceae). Winter in all life stages.

***Melitaea didyma* (Esper).**

Flight: May-September, in two or more generations. Prefers dry, open landscapes of deserts, steppe areas, gorges, valleys and rocky slopes at elevations up to 2500 m. Host plants include various species of Lamiaceae, Plantaginaceae, Scrophulariaceae, Fabaceae and Asteraceae. Winters as larva.

Neptis rivularis (Scopoli).

Flight: June-August, with two generations in the southern part of its range. Distribution: Tien Shan and Jungar Alatau Mountains. Found in river valleys and along streams, on dry shrub-covered (*Spiraea*) slopes of the foothills and mountains to altitudes of 1800 m. Host plants limited to *Spiraea* spp. (Rosaceae). Winters as larva.

***Inachis io* (Linnaeus).**

Flight: March-September. Distribution: Tien Shan and Jungar Alatau Mountains. Common in open landscapes in forest and forest-steppe regions, including urban and agricultural areas, from plains to mountains up to 3200m altitude. Host plants are *Urtica dioica* (Urticaceae) *и Humulus lupulus* (Cannabaceae). Winters as larva.

***Nymphalis urticae* (Linnaeus).**

Flight: March-October. Ubiquitous, except for deserts. Host plants are *Urtica* spp. (Urticaceae). Winters as imago.

***Nymphalis xanthomelas* (Esper).**

Flight: March-October. Distribution: Northern Tien Shan, Jungar Alatau Mountains. Occurs locally in desert areas, otherwise prefers mixed floodplain forests and in willow groves in gorges with springs at altitudes up to 2700 m. Host plants *Populu*s spp., *Salix* spp. (Salicaceae); *Ulmus* sp. (Ulmaceae). Winters as imago.

***Vanessa cardui* (Linnaeus).**

Flight: March-October, sometimes two generations. Ubiquitous. Occurs in a variety of open landscapes, from deserts to high mountains. Host plants vary through different parts of the range: *Carduus, Cirsium, Achillea, Arctium, Artemisia, Centaurea, Heliantus, Senecio, Serratula, Tanacetum, Xantium Cusinia, Helichrysum arenarium* (Asteraceae); *Urtica* (Urticaceae); *Plantago* (Plantaginaceae); *Zea mays* (Poaceae); *Rumex* (Polygonaceae); *Altea, Malva* (Malvaceae); *Medicago, Trifolium* (Fabaceae); *Menta, Sativa, Stachus* (Lamiaceae); *Frangaria, Prunus* (Rosaceae); *Rhamnus* (Rhamnaceae). Winters as imago.

Family Lycaenidae Leach.

***Everes argiades* (Pallas).**

Flight: May-June and July-September, in two generations. Distribution: Jungar Alatau and Tien Shan mountains. Various meadow habitats, usually in the lower mountain elevations to the mixed forest zone (1800 m). Host plants are members of Fabaceae; in the Ile Alatau reported to be *Trifolium pratense*.

*Lampides boeticus (*Linnaeus).

Flight: May-October, 2-4 generations, depending on local conditions. Locally abundant throughout range. Occupies different habitats in the plains and in the foothills, in addition to cultivated landscape, ranges to 2500 m in the mountains. Host plants include various Lamiaceae, as well as *Pisum, Phaseolus, Cicer, Medicago, Alhagi, Colutea persica, C. paulsenii,* and *Astragalu*s sp. (Fabaceae).

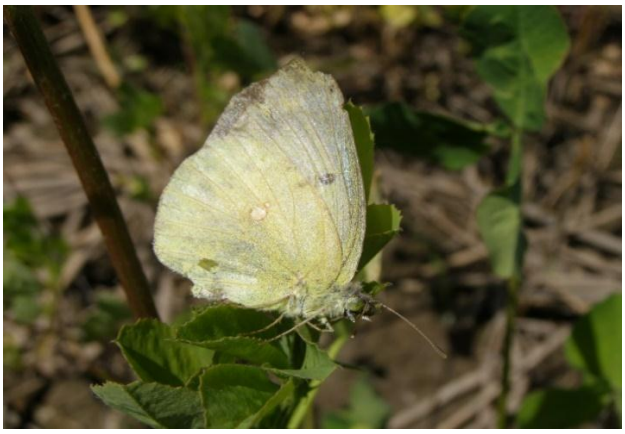
***Polyommatus icarus* (Rottemburg).**

Flight: May-September, in 1-2 generations, depending on environmental conditions. Ubiquitous throughout the entire

region, except for deserts. Prefers various types of mixed grass meadows up to 2000 m. Host plants include herbaceous Fabaceae: *Trifolium*, *Medicago*, *Genista*, *Lotus*, *Melilotus*, *Onosis* and others.

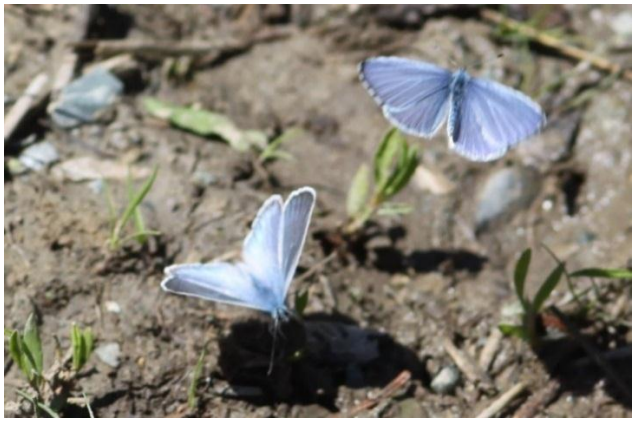
***Thersamonia thersamon* (Esper).**
Flight: April-October, in 1-4 generations, depending on specific conditions. Ubiquitous throughout the entire region, except only locally in the desert zone). Found in various types of meadows, grasslands, semi-deserts, cultivated landscapes, and in the sharp, stepped, flat surfaced cliffs of the Alatau foothills, typically up to 2000 m. Forage plants include different species of families Polygonaceae, Limoniaceae and Fabaceae.

Family Hesperiidae Latreille.
Eogenes alcides (Herrich-Schaffer).
Flight: May-June. Found in the deserts of the Semirechye region. Occurs in reed meadows (*Phragmites australis*, Poaceae) near water.

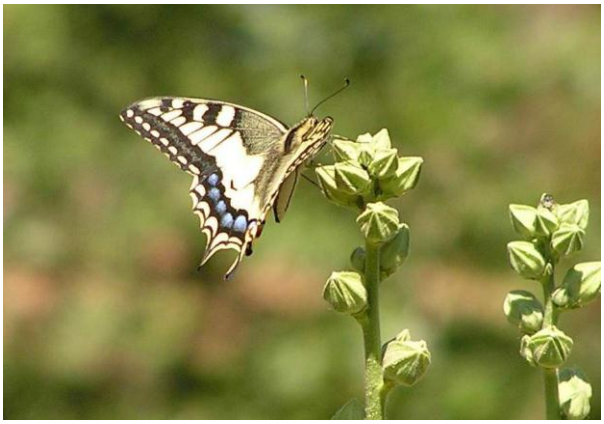


Colias erate (Esper) (photo P. A. Esenbekova),

Inachis io (Linnaeus) (photo I.I. Temreshev)

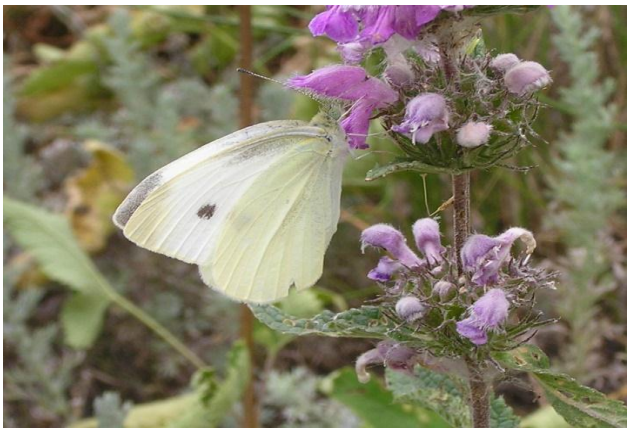


Polyommatus icarus (Rottemburg) (photo I.I. Temreshev)



Papilio machaon Linnaeus (photo V. L. Kazenas)

Pontia daplidice (Linnaeus) (photo I. I. Temreshev)



Pieris rapae (Linnaeus) (photo V. L. Kazenas)

Fig 1: Some lepidopteran pollinators of forage crops in South-East Kazakhstan

Order hymenoptera Linnaeus.
Family Colletidae Lepeletier.

***Hylaeus arenarius* Morawitz.**
Foothills of the Ile Alatau Mountains. It occupies man-made bee shelters.

***Hylaeus confusus* Nylander.**
Foothills of the Ile Alatau Mountains. Frequents man-made bee shelters.

***Hylaeus turanicus* (Morawitz).**
A Central Asian species. Found in the foothills of the Ile Alatau. Populations can be maintained in reed bee shelters. Reported from the foothills around the city of Almaty and in the Malaya Almatinka Gorge, up to a height of 1700 m.

***Hylaeus vulgaris* (Morawitz).**
Foothills of the Ile Alatau. Readily frequents man-made bee shelters. Also known from Kyrgyzstan.

Family Andrenidae Latreille.
Andrena atrata Friese.
Characteristic Mediterranean-Central Asian species. Foothills of the Ile Alatau. Pollinator of alfalfa. Found in June on *Hyoscyamus niger* and in July on *Onobrychis viciaefolia*.

***Andrena chrysopyga* Schenck.**
Widely distributed in Europe, but rare in Kazakhstan. Noted on *Onobrychis viciaefolia, Barbarea vulgaris*. It can be found in meadows with lucerne (*Medicago falcata*), burclover (*Medicago* sp.) and sainfoin (*Onobrychis*) and is used as a commercial pollinator. Numbers are reduced due to the conversion of natural meadows to agriculture.

***Andrena cineraria* (Linnaeus).**
Inhabits the sandy desert to an altitude of 2000 m in Ile Alatau mountains of south-east of Kazakhstan. Found also in the foothills around Almaty from May to July, on flowers of *Potentilla sibirica, Thymus marschianus, Heliotropium arguzioides, Taraxacum officinale, Glycyrrhiza uraliensis, Salix*. Important pollinator of fruit crops.
Andrena cordialis Morawitz.
Foothills of the Ile Alatau. Pollinator of alfalfa (*Medicago* sp.), and bird's-foot trefoil (*Lotus corniculatus*); also observed visiting clover (*Trifolium* sp.), soybeans (*Glycine max*), and chamomile (*Matricaria* sp.).

***Andrena flavipes* Panzer.**
Widespread species that visits a broad range of flowers. Noted in June-July on rocky ledges in the vicinity of the city of Almaty, in the Aksai Gorge on *Ziziphora* sp. flowers, and in the Malaya Almatinka Gorge on flowers of *Inula helenica*. Nectars on dandelion (*Taraxacum sp.*) and yellow lucerne (*Medicago falcata*).

***Andrena labialis* Kirby.**
Visits a broad range of flowers. In Central Asia it is confined to legumes. Reported from the foothills around Almaty and in the Turgen Gorge at an altitude of about 1300 m on flowers *Mentha asiatica*, *Inula britannica*, and *Achillea*. Nectars on dandelion (*Taraxacum*) and yellow lucerne (*Medicago falcata*).

***Melliturga clavicornis* (Latreille).**
A widespread Palearctic species. Reported from the foothills of the Ile Alatau. Pollinator of alfalfa (*Medicago* sp.) and sainfoin (*Onobrychis*).

Family Halictidae Thomson.
***Halictus eurygnathus* Blüthgen.**
Mediterranean-Central Asian species. Recorded from *Astragalus arbuscula, Trifolium, Salvia stepposa, Onopordon acanthium*, and *Oryganum*. In East Kazakhstan it visits *Medicago*. Found in the Ile Alatau (Karta-Bulak Gorge), in the foothills near Almaty, and in the middle reaches of the river Ili (Kara-Chingil, Kapchagai). It is a pollinator of alfalfa (*Medicago* sp.) and orchard crops.

***Halictus pollinosus* Blüthgen.**
Mediterranean-Central Asian species. Visits a broad range of flowers. Reported from the Ile Alatau foothills around Almaty and in Kaskelen, in in July on flowers of *Echium vulgare, Achilleum, Inula, Acroptilon, Medicago* and *Salvia*. It is also found in meadows on alfalfa, yellow lucerne (*M. falcata*), other *Medicago* sp., bird's-foot trefoil (*Lotus corniculatus*) and other *Lotus* sp., and sainfoin (*Onobrychis*).

***Halictus quadricinctus* (Fabricius).**
Holarctic species, widespread, visits a broad range of flowers. In the foothills of the Ile Alatau it is a pollinator of bird's-foot trefoil (*Lotus corniculatus*), alfalfa (*Medicago* sp.) and fruit crops. Females have been observed in the vicinity of Kaskelen, Almaty, and Talgar, and in the mountains up to 1700 m in the valleys of the Bolshaya and Malaya Almatinka rivers, in the Kaskelen and Talgar Turgen gorges. They have been recorded from May to September on the flowers of plants seven different families. Generally occupy isolated, solitary ground burrows, but a small colony has been reported from the sharp, stepped shelf-like cliffs at the mouth of the Kaskelen Gorge.

***Halictus sexcinctus* Fabricius.**
A widely distributed species that flies from mid-April to late September, likely with two generations per year. Reported to visit a broad range of flowers, but we observed that females visited mostly Asteraceae to collect pollen. It nests in the ground, forming small colonies. Reported in the foothills of the Ile Alatau in the vicinity of Almaty, where it is common in meadows with lucerne (*Medicago falcata* and other species) and sainfoin (*Onobrychis*), and in the Boguty Mountains. It is also found around Bartagoy Lake on *Salvia stepposa*, and along the middle reaches of the river Illi.

***Halictus subauratus* Rossi.**
Two generations annually. Prefers flowers of the Asteraceae, Fabaceae, Lamiaceae and Chenopodioídeae. Found in the outskirts of Almaty on *Trifolium repens, Rubus caesius*; *Achillea millefolium*, in the Bolshaya Almatinka Gorge on *Taraxacum officinale*, on the spurs of Jungar Alatau Mountains near Pokatilovka village, in the Syugaty Mountains on *Mentha asiatica*, near the Ili River salt lakes around Kapchagay on *Limonium gmelini*. Pollinator of alfalfa (*Medicago* sp.).

***Halictus tumulorum* (Linnaeus).**
Reported visiting a variety of flowers. Found in the Malaysary range near Bakbakty on *Tamarix ramosissima*; in Dzhingil-Su on *Mentha asiatica*; vicinity of Bartagoy Lake, in the Syugatinckoy Valley on *Inula britanica, Medicago sp.*, Centaurea. Pollinator of alfalfa (*Medicago* sp.), we also noted it visiting soybean (*Glycine max*) and clover (*Trifolium*).

***Lasioglossum calceatum* (Scopoli).**
Visits a broad range of flowers. Reported from the Jungar Alatau and Ile Alatau Mountains, the Agano-Kata Gorge, the Alakul plain near Uch-Aral, the salt lakes in the middle reaches of the Ili River, and in the loess desert near the village of Baschi. In the Ile Alatau mountains specimens were collected on flowers of *Vicia, Centaurea, Lotus, Cousinia, Trifolium, Cichorium, Taraxacum, Gheranium, Malus* and others. A pollinator of alfalfa (*Medicago* sp.) and fruit crops, the species is social and has 2 generations per year.

***Nomia diversipes* (Latreille).**
A widespread Palearctic species. Found near Almaty, in the foothills of the Ile Alatau, in meadows with lucerne (*Medicago falcata*) and sainfoin (*Onobrychis*). Flies in the summer, from late June to early September. The species is reported to visit a broad array of flowers, but in Central Asia it is confined mainly to the Fabaceae. It is one of the important alfalfa pollinators. It nests in the ground, sometimes in alfalfa fields.

***Rophitoides canus* (Eversmann).**
A Trans-Palearctic species. Often found on flowers of legumes (Fabaceae), including soybeans, it one of the main pollinators of alfalfa. It nests colonially in the ground. Reported in June and July on the flowers of alfalfa, yellow lucerne and other *Medicago* sp. in the piedmont plain and the foothills of the Ile Alatau. Because it often nests in alfalfa fields, plowing under flowering cover crops of alfalfa destroys both the nests and the food sources of the bees.

Family Melittidae Michener.
***Melitta leporina* (Panzer).**
Trans-Palearctic species known from the Caspian and Eastern regions of Kazakhstan. Visits a wide variety of flowers, but noted for its affinity to legumes. Reported in the foothills of the Ile Alatau, around the southwestern city of Kaskelen, on sainfoin (*Onobrychis*) flowers in June. Pollinator of alfalfa (*Medicago* sp.), bird's-foot trefoil (*Lotus corniculatus*), and sainfoin (*Onobrychis*). We noted it on soybean and clover crops.

Family Megachilidae Latreille.
***Anthidium cingulatum* Latreille.**
A widespread Mediterranean-Central Asian species. Reported most commonly on flowers of legumes (Fabaceae) and deadnettle (Lamiaceae). In Kazakhstan found June-August everywhere on piedmont plains, foothills and lower mountain belt of the Ile Alatau. Visits flowers of alfalfa (*Medicago* sp.), yellow lucerne (*M. falcata*), sage (*Salvia* sp.), birds-foot trefoil (*Lotus corniculatus*), *Dodartia orientalis*, and various genera of Asteraceae. Also occurs in loess and rocky deserts, and reported on common sage (*Salvia officinalis*) in the Syugatinskoy valley of the Boguty Syugaty Mountains. We noted it on soybeans (*Glycine max*), red and white clover (*Trifolium* sp.), and chamomile (*Matricaria* sp.).

***Anthidiellum strigatum* (Panzer).**
Widespread, reported in July and August from flowers of *Lotus corniculatus, Hippocrepis comosa, Scabiosa columbaria, Sophora* sp., and lucerne (*Medicago falcata*). Rare in Western and Northern Kazakhstan, primarily found in the foothills of the Ile Alatau Mountains, as well as in different types of deserts in the Arkharly, Boguty and Syugaty mountains. We recorded it June-August on soybeans (*Glycine max*), dandelions (*Taraxacum* sp.), and on various umbelifers (Apiaceae).
Hoplitis leucomelaena Kirby.
In Kazakhstan reported from stepped cliffs and ledges in the outskirts of Almaty in May-July, on flowers of borage (*Echium* sp.), clover (*Trifolium* sp.), birds-foot trefoil (*Lotus corniculatus*), sainfoin (*Onobrychis*), thistle (*Onopordum acanthium*), and cornflower (*Centaurea cyanus*); also in the Malaya Almatinka Gorge at an altitude of 900-1600 m on flowers of *Inula helenica, I. britannica, Echium rubrum, Vicia tenuifolia, Lathyrus pratensis, Medicago sativa, M. falcata, Lotus corniculatus.* We noted on soybeans (*Glycine max*), chamomile (*Matricaria*) and dandelion (*Taraxacum* sp.).

***Hoplitis parvula* (Dufour & Perris).**
Species is known from Central Europe through Central Asia. Individuals were noted in July in Aksai and Malaya Almatinka Gorges at an altitude of 1000-1300m on the flowers of oregano (*Origanum*), yarrow (*Achillea*), and thistle (*Onopordum acanthium*). In the foothills of the Ile Alatau it visits flowers of birds-foot trefoil (*Lotus corniculatus*). We noted it on soybeans (*Glycine max*) and clover (*Trifolium* sp.). It occupies man-made bee shelters.

***Megachile apicalis* Spinola.**
Known from Central and Southern Europe through Central Asia. Breeds in rocky desert of the Boguty Mountains, and in the foothills of the Ile Alatau, 15-20 km west of the village of Kamenka, in the outskirts of Almaty. Pollen collected from the female flowers of *Onopordon acanthium*. The species is also known from the lower reaches of the river Charyn in Tugay, found in June on flowers of *Acroptilon repens*, and from the Ile Alatau foothills near the city of Almaty, in July on the flowers of yellow lucerne (*Medicago falcata*), and other *Medicago* sp., and on sainfoin (*Onobrychis*). We noted it on soybeans (*Glycine max*) and clover (*Trifolium* sp.).

***Megachile argentata* (Fabricius).**
A widespread and common species. Reported from a variety of flowers, it apparently prefers flowers of Fabaceae. In the Almaty region it is recognized as one of the main pollinators of alfalfa. Found in the Ile Alatau foothills near the city of Almaty on borage (*Echium),* cornflower (*Centaurea*), lucerne (*Medicago* sp.) and on crops of alfalfa (*Medicago* sp.), birds-foot trefoil (*Lotus corniculatus*) and sainfoin (*Onobrychis*) in July. It has also been reported from the lower reaches of the river Ili, in loess desert 40 km above village of Bakanas, in June on rue (*Peganum harmala*). We noted on soybeans (*Glycine max*) and cow parsnip (*Heracleum* sp.).
Megachile centuncularis (Linnaeus).
A widespread species. Found around Almaty and in the foothills of the Ile Alatau, in meadows with lucerne (*Medicago* sp.) and sainfoin (*Onobrychis*). Settles in a broad range of

habitats: under stones in the soil, in stems of sumac (*Rhus*) and reed (*Phragmites*), in holes bored in the wood, in cardboard tubes and in crevices of buildings. Reported from the piedmont plain and the foothills of the Ile Alatau in June-August on alfalfa (*Medicago falcata*), birds-foot trefoil (*Lotus corniculatus*), borage (*Echium* sp.), cranesbill (*Geranium* sp.), chicory (*Cichorium* sp.), chamomile (*Matricaria* sp.), and thistles (*Onopordum acanthium* and *Cousinia* sp.). Found also along the Ili River: in the lower reaches in late May on the flowers *Halimodendron* in the loess desert of the Malaysary Mountains, and in mid- September the middle reaches near Chilik (Bartogay Mountains). We noted on soybeans (*Glycine max*) and clover (*Trifolium* sp.). It occupies man-made bee shelters.

***Megachile rotundata* Fabricius.**
A widespread species. Artificially propagated to pollinate alfalfa, including North America. Found in the middle reaches of the Ili River. Nesting burrow is dug in the thick loess soil by the female, and the cells are lined with oleaster (*Elaeagnus*) leaves. Good prospect for alfalfa propagation in Kazakhstan.
Metallinella leucogastra Morawitz.
Rare. Found from mid-May to July in the Ile Alatau foothills and in river valleys, visiting flowers of clover (*Trifolium*), lupine (*Lupinus*), yellow lucerne (*Medicago falcata*), and borage (*Echium*). They utilize artificial nests drilled into a piece of poplar. Promising pollinator of commercial alfalfa, and amenable to domestication. We noted on soybeans (*Glycine max*) and mallow (*Malva* sp.).

***Osmia jagnobensis* Morawitz.**
A Central Asian species found in the foothills of the Ile Alatau. They nest colonially in loess cliffs, burrow cells are lined with flower petals. Known to visit flowers of 6 families of plants, but prefer legumes (Fabaceae) and mints (Lamiaceae). We noted on soybeans (*Glycine max*).

***Osmia coerulescens* (Linnaeus).**
A wide ranging species. In Kazakhstan it inhabits man made bee shelters in the foothills of the Ile Alatau. Uses cavities and holes in a wide variety of materials and habitats for building nests, and is frequent user of artificial nests. It has promise as a pollinator of alfalfa, since it readily visits flowers of legumes. We noted it on soybeans (*Glycine max*), mallow (*Malva* sp.) and marshmallow (*Althea* sp.).

***Osmia parvula* (Dufour & Perris).**
Found in the foothills of the Ile Alatau. It readily occupies artificial nests. A prospective species for commercial alfalfa and other forage crop propagation.

***Osmia rufa* (Linnaeus).**
Found in the foothills of the Ile Alatau. It readily occupies artificial nests. An important pollinator of fruit crops and alfalfa. A prospective species for commercial alfalfa and other forage crop propagation.

***Stelis phaeoptera* Kirby.**
A Central Asian species found in meadows with yellow lucerne (*Medicago falcata*) and sainfoin (*Onobrychis*) outside the city of Almaty. A kleptoparasite on *Osmia leiana* and possibly on other megachilid bee species.

Family Apidae Linnaeus.
***Anthophora borealis* Morawitz.**
A West Palearctic species. Found June-August in the foothills of the Ile Alatau Mountains on *Lamium album*, *Salvia stepposa*, and *Medicago* sp. Also reported from the Syugatinskaya valley loess desert in June, on common sage (*Salvia officinalis*). We noted one instance of this species visiting clover (*Trifolium* sp.) and soybeans (*Glycine max*).

***Anthophora pedata* Eversmann.**
A Palearctic species with the steppe zone forming the northern boundary of its range. It shows a clear preference for legumes (Fabaceae). A common spring species found in the foothills of the Trans-Ili Alatau. Reported from the vicinity of Almaty, Kaskelen and Talgar in April - May, on flowers of *Gagea minima*, *Fumaria*, and *Crocus*. A pollinator of fruit crops, we noted on soybeans (*Glycine max*), clover (*Trifolium* sp.), and alfalfa (*Medicago* sp.) and chamomile (*Matricaria* sp.).

***Anthophora radoszkowskyi* Fedtschenko.**
Foothills of the Ile Alatau. A pollinator of alfalfa and fruit crops, we noted on soybeans (*Glycine max*) and clover (*Trifolium* sp.).

***Ceratina cyanea* Kirby.**
The species is distributed from Central and Southern Europe through Central Asia. Found on the piedmont plain, in the foothills and mountains of the middle belt of the Ile Alatau, from late April to mid-September on fruit crops (apple, apricot, pear, cherry, raspberry) on borage (*Echium* sp.), clover (*Trifolium* sp.), alfalfa (*Medicago sativa*), yellow lucerne (*Medicago* sp.) and various Asteraceae. It nests in plant stems. A prospective species for artificial propagation as a crop pollinator.

***Nomada ruficornis* Linnaeus.**
A Southwest Palearctic species. It is a nest parasite on other solitary bees. Found in the foothills of the Ile Alatau, it is a pollinator fruit crops and alfalfa. We noted on dandelions (*Taraxacum* sp.), mallow (*Malva* sp.), soybeans (*Glycine max*), clover (*Trifolium* sp.), and on various umbelifers (Apiaceae).

***Pasites maculatus* Jurine.**
A Central Asian species, found in the foothills of the Ile Alatau. It is a pollinator of commercial alfalfa crops. It parasitizes the nests of other solitary bees. We noted it on soybeans (*Glycine max*), chamomile (*Matricaria* sp.), thistles (*Onopordum acanthium* and *Cousinia* sp.), cow parsnip (*Heracleum* sp.) and dandelions (*Taraxacum* sp.).

***Xylocopa valga* Gerstäcker.**
A species reported from a wide variety of lower species. Found in the foothills and low mountains up to 2000 m in south-eastern Kazakhstan from May to September. It prefers loess cliffs for its burrows. This species readily adapts to anthropogenic environments, and is common around settled areas in the countryside, nesting in adjacent wooded areas. We noted on clover (*Trifolium* sp.), alfalfa (*Medicago* sp.), soybeans (*Glycine max*), and dandelions (*Taraxacum* sp.).

***Xylocopa turanica* Morawitz.**
This species is distributed from the Caucasus and Iran west to

the Central Asian mountains, to the steppes of central Kazakhstan in the north and south to the Hindu Kush. Found from the end of April to September in the foothills and mountains of the Ile Alatau and Jungar Alatau ranges. Restricted to legumes (Fabaceae). It was noted in nesting in stalks of corn, umbelifers (Apiaceae) and burdock (*Arctium*). We noted an individual visiting flowering soybeans (*Glycine max*) and alfalfa (*Medicago* sp.).

***Apis mellifera* Linnaeus.**
Cosmopolitan worldwide species. A pollinator of birds-foot trefoil (*Lotus corniculatus*) and many other food and fodder crops (including clover, vetch and soybeans). In Kazakhstan it is ubiquitous. It can be used for pollination of alfalfa but requires special field preparation and management to be successful.

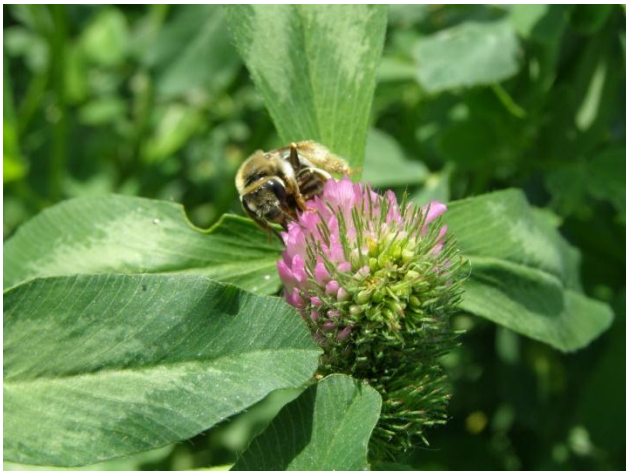
***Bombus alticola* (Kriechbaum).**
A widespread western Palearctic species. Found in the foothills of the Ile Alatau. A pollinator of commercial alfalfa crops. We noted it on clover (*Trifolium* sp.), soybeans (*Glycine max*), and dandelions (*Taraxacum* sp.).

***Bombus pascuorum* Scopoli.**
A widespread western Palearctic species. Found in the foothills of the Ile Alatau. Around Almaty it occurs in crop fields of alfalfa (*Medicago* sp.) and sainfoin (*Onobrychis*). We also noted it on soybeans (*Glycine max*), vetch (*Vicia* sp.) and clover (*Trifolium* sp.).

***Bombus laesus* Morawitz.**
A Central Asian species. Found in the vicinity of Almaty in crop fields of alfalfa (*Medicago* sp.) and sainfoin (*Onobrychis*). We noted it on clover (*Trifolium* sp.), soybeans (*Glycine max*), dandelions (*Taraxacum* sp.) and milkvetch (*Astragalus* sp.).

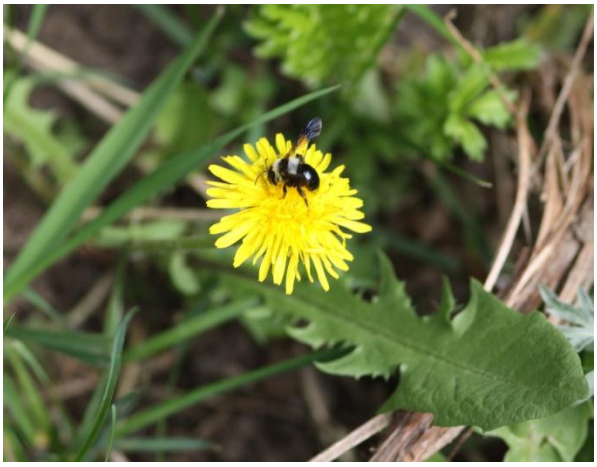
***Bombus lucorum* Linnaeus.**
A widespread Palearctic species. It occurs in the foothills of the Ile Alatau and around Almaty during the summer. We noted it on a variety of flowers, including clover (*Trifolium* sp.), soybeans (*Glycine max*), and alfalfa (*Medicago* sp.).

Anthidium cingulatum Latreille (photo V. L. Kazenas),



Osmia coerulescens (Linnaeus)(photo P. A. Esenbekova)

Melitta leporina (Panzer1799) (photo P. A. Esenbekova),



Andrena cineraria (Linnaeus) (photo I. I. Temreshev)

Fig 2: Some Hymenoptera pollinators of forage crops in Southeastern Kazakhstan.

***Order diptera* Linnaeus.**
Family Syrphidae Rondani.

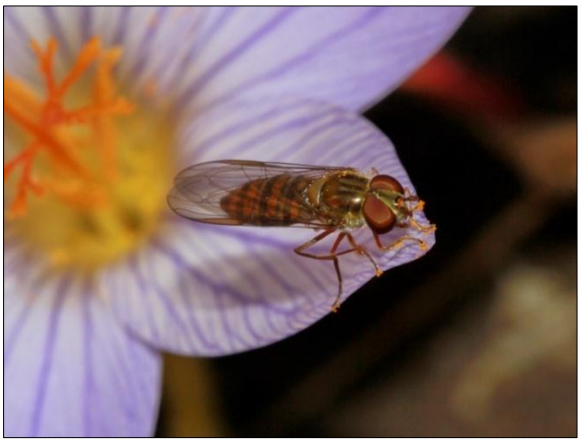
***Syrphus ribesii* (Linnaeus).**
A widespread Trans-Palearctic species. Larvae prey on many species of aphids. It has is a pollinator of a wide variety of plants. We noted on alfalfa (*Medicago* sp.), umbelifers (Apiaceae), clover (*Trifolium* sp.), soybeans (*Glycine max*), and dandelions (*Taraxacum* sp.).

***Episyrphus balteatus* (De Geer).**
Flies from June to October. Occurs primarily in heaths and meadows. The larvae are predators of aphids (Aphididae). Adult flies feed primarily pollen, less so on nectar. They feed on the flowers of many species of the family Asteraceae, and *Galeopsis tetrahit*, *Teucrium scorodonia*, *Succisa pratensis*, *Hypericum maculatum*, *Epilobium angustifolium*, *Digitalis purpurea*, *Calystegia sepium*, *Rumex obtusifolius*, *Chenopodium album*, *Filipendula ulmaria*, *Heracleum sphondylium*, *Rubus fruticosus*, *Campanula rotundifolia*, *Malva moschata*, *Eleocharis palustris*, *Calluna vulgaris*, *Origanum vulgare*, and *Galatella* sp. We noted on clover (*Trifolium* sp.), soybeans (*Glycine max*), and alfalfa (*Medicago* sp.).

***Eristalis tenax* (Linnaeus).**
Flies from May to October. A cosmopolitan species introduced into different parts of the world. Larva are aquatic, equipped with a special breathing appendage at the distal end of the body. Pollinator of a wide variety of plants. We noted it on soybeans (*Glycine max*), clover (*Trifolium* sp.), and crops of carrot (*Daucus carota*), as well as flowers of *Bunias orientalis*, *Galatella* sp., *Delphinium elatum*, and *Ajania* sp.

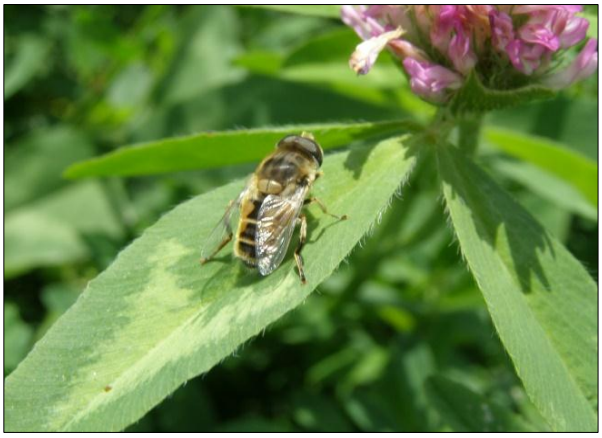
***Scaeva pyrastri* (Linnaeus).**
It occurs in meadows, fields and vacant lots. The larvae are predators that feed mainly on aphids. Adult flies feed on nectar and pollen of Asteraceae, and *Heracleum sphondylium* and *Rumex obtusifolius*. We observed on alfalfa, (*Medicago* sp.), soybeans (*Glycine max*), dandelions (*Taraxacum* sp.), clover (*Trifolium* sp.), and sweet pea (*Lathyrus* sp.).
Family Tachinidae Robineau-Desvoidy.

***Exorista larvarum* (Linnaeus).**
A widespread species. The adults have some importance as crop pollinators. The larva is a parasite on caterpillars of various moths (Lymantriinae, Saturniidae, Noctuidae, Arctiidae, and others). We observed on alfalfa, (*Medicago* sp.), soybeans (*Glycine max*), clover (*Trifolium* sp.), and umbelifers (Apiaceae).

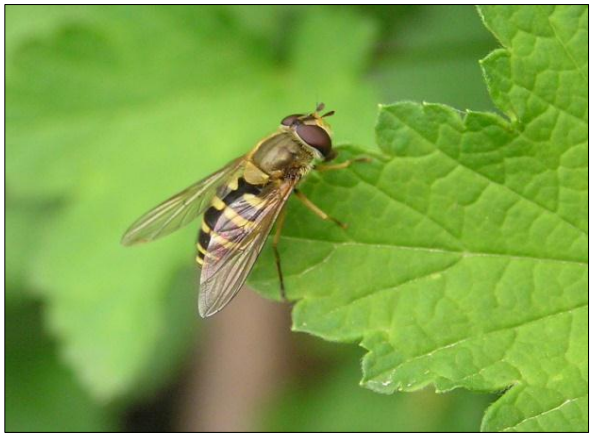


Episyrphus balteatus (De Geer) (photo V. L. Kazenas)

Scaeva pyrastri (Linnaeus) (photo V. L. Kazenas)



Eristalis tenax (Linnaeus) (photo P. A. Esenbekova)



Syrphus ribesii (Linnaeus) (photo V. L. Kazenas)

Fig 3: Some Diptera pollinators of forage crops in Southeastern Kazakhstan

Conclusions and Discussion

Legume forage crops have to be cross pollinated to produce seed. In legumes, nectar is produced at the bottom of the flower, so pollinators must force open the flower to access the nectar, coming in contact with pollen as they pass by the flower parts to access the nectar [38]. Solitary bees are highly adapted to the task and are the principal pollinators of legume forage crops worldwide [2, 6, 11, 30, 38]. This study involved primarily bee-pollinated alfalfa or lucerne (*Medciago sativa*.), with lesser amounts of birds-foot trefoil (*Lotus corniculatus*), clovers (*Trifolium pratense*, *T. repens*), sainfoin (*Onobrychis*), milkvetch (*Astragalus*) and vetch (*Vicia sativa*). While soybeans (*Glycinde max*), the other principal forage crop in the trials, are both self-pollinating and bee pollinated.

We recorded 82 species of insects, belonging to 14 families in 3 orders as pollinators of the legume forage crops in the trials. Not surprisingly, the largest number of species and families of forage crop pollinators were in the order Hymenoptera, with 6 families and 47 species. Anecdotally, bees and bumblebee were the most abundant insect group in the test plots.

A summary of the Hymenoptera collected in the study is listed in Table 1, indicating the forage legume flower is was collected from. We made no association among any *Hylaeus* species and a particular legume forage crop flower. *Hylaeus* females lack pollen-carrying scopae and instead carry pollen and nectar back to the nest in their crop. This foraging behavior made it difficult to either determine pollen loads or their role or importance in legume forage crop pollination. *Hylaeus* are suspected of being foraging generalists. While they have short tongues, their small size allows them to access deep flowers [19]. Regardless, they may be ineffective pollinators [39].

Second in number of species was the Lepidoptera, with 6 families and 29 species. Only 4 species in 2 families of Diptera were identified as likely pollinators of the forage crops involved in this study. Other groups, including beetles (Coleoptera), lacewings (Neuroptera), true bugs (Heteroptera), and grasshoppers and crickets (Orthoptera), observed at times in large numbers in forage crop fields, did not carry noticeable amounts of pollen. We concluded they did not play a role in forage crop pollination. Previous studies of legume forage crops in Central Asia [16, 18, 26] found that these insects contributed little to pollination of forage legumes.

The Lepidoptera and Diptera we examined had only small amounts pollen, suggesting they contribute little to the pollination of legume forage crops. Lepidoptera, although diverse and numerous, are less effective and of lesser importance as legume forage crop pollinators than are Hymenoptera. Lepidoptera and Diptera are generalist pollinators that visit both unspecialized flowers and specialized bee and bumblebee flowers, able to feed on nectar while bypassing the pollen dispersal or "tripping" mechanism [38, 40]. In addition, many lepidopteran larvae can cause considerable damage to legume forage crops [30], offsetting any pollinator value. Most syrphid flies visit flowers to collect nectar only, and contribute little to pollination. Much more important is the role that the larval stages play as predators of aphids.

Research in Russia [41] suggests that the numbers and diversity (30-40 species) of solitary bee species in alfalfa fields in southwestern Russia is sufficiently high that artificial enhancement of pollinator species such as *Megachile rotundata or Nomia diversipes* is not needed. The high density of the diverse group of native solitary soil bees ensures the complete pollination of alfalfa flowers. This finding is directly applicable to Kazakhstan for the forage crops studied in these trials. The diversity and abundance of local solitary bee species that we report may provide all of the needed pollinators for forage crop production.

Intensive modern management practices appear to greatly reduce the abundance and diversity of bees other than managed species (*M. rotundata*, *Nomia melanderi* and *Apis mellifera*) from alfalfa fields. Early research on alfalfa production in the US [42] and Europe [43, 44] reported numerous solitary bee species foraging in alfalfa fields. However, the increase in alfalfa acreage worldwide since the 1950s has been accompanied by rapid increases in field size, increased use of mechanical weed control along road and field edges, and the increased use of herbicides. These changes have had effects, both positive and negative, on native solitary bee populations in Europe and North America [30, 43, 45, 46]. In addition, the high *Megachile rotundata* populations maintained by most alfalfa growers [7] in North America may also displace native solitary bee species in and around agricultural areas [47, 48]. When *M. rotundata* is very abundant (~100,000 bees per ha), they monopolize the alfalfa flower resources and prevent other bee species from becoming established [7, 49].

Intensification of agriculture may also be a contributing factor in the decline of native solitary bee species [46], including forage crops [50]. Cultivation to add fertilizer, for weed control or to thin alfalfa may also disrupt bee nests located within the field. This can be particularly disruptive to native species when cultivation does not affect the introduced pollinators: *Megachile rotundata* in artificial nests and *Nomia melanderi* nesting in bare ground adjacent to the fields. Rapid rotation between alfalfa forage and cash crops greatly reduces the time for solitary ground nesting bees to establish themselves. Increasing field size, reliance on a single forage crop and conversion of adjacent lands to increase plantings of a single crop can all contribute to reduced rates of pollination by native bees and lower seed yields in alfalfa. The increase in distance from field edges (the result of increased field size) and the loss of nearby wildflowers has been shown to negatively affect alfalfa seed production [51].

Climate may also play a role in managing for native bee species for adequate pollination [52]. Crops in dry steppe and semi-desert brush habitat, identified as prime target areas for expansion of forage crops in Kazakhstan [53], have a diverse fauna of solitary bee species, but natural bee populations are low. As crops become established, native species may not expand sufficiently rapidly to adequately pollinate the crops, in part because of low initial numbers and in part because there will be very little in bloom in mid-summer. The lack of sufficient numbers of pollinators will affect seed yields, and the time that it takes to pollinate the fields. Growers may press to introduce large numbers of one or two bee species for short periods, potentially further depressing the native bee fauna that is also facing challenges in becoming established. Irrigation, promoting the growth of other flower resources and planting a mixture of crops to expand the flowering season may help promote the more rapid growth of native bee species populations.

The main factor identified in maintaining native bee populations is the landscape mosaic of cultivated fields interspersed with meadows, non-tilled plots with poor soils or broken relief, and remnant natural plant communities in

ditches, along road and woodland edges [50]. This creates a system of untilled and less disturbed refuges interspersed with crop fields that provide rich nutrient sources for native bees. Less intensive management practices and maintaining a mosaic landscape will contribute to the development of a diverse and abundant pollinator population.

The expansion of forage crops in Kazakhstan will require the agricultural community to support the development of a diverse population of native solitary bees in the forage crop region. This can be accomplished by improved management of crop fields (changing rotation and tilling practices, planting other forage besides alfalfa, reduced pesticide use), maintaining a mosaic of cultivated and uncultivated land, and expanding the use of native solitary bees that readily use man-made shelters. These practices can successfully increase native solitary bee populations, a necessary prerequisite for the successful and sustainable expansion of legume forage crop production in the country.

Agricultural diversification and expansion in Kazakhstan requires a detailed knowledge of the ecology of solitary bees and other pollinator. This is essential to develop management protocols for native solitary bee species that pollinate clover and alfalfa as well as other legume forage crops in Central Asia. Improved knowledge will permit increased utilization of native solitary bee pollinators. To both improve crop yields and support healthy populations of pollinators and beneficial predatory species, more research is needed to better understand how crop productivity is related agricultural and undisturbed natural ecosystems.

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