

BIODIVERSITY CONSERVATION IN AGRICULTURAL LANDSCAPES: AN ECOLOGICAL OPPORTUNITY FOR COAL MINING SUBSIDENCE AREAS

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Abstract. Rapid population growth and economic development increase energy and grain demands. However, in the high-groundwater coal basins where coal seams and agricultural production overlap, mining subsidence destroys much arable land, causing a series of environmental and social issues. This study investigated plants, beetles, spiders and birds in typical intensive farmlands and farmlands containing mining subsidence mosaics (i.e., mosaic farmlands) in North China. The species composition of these four taxonomic groups differed significantly between the intensive farmlands and mosaic farmlands, with 271 plant, 17 spider, 49 beetle and 138 bird species in the mosaic farmlands and 76, 12, 35 and 30 such species in the intensive farmlands, respectively. The mosaic farmlands hosted more and different species than the intensive farmlands. Additionally, these four taxonomic groups, especially plants and birds, showed a higher abundance and diversity in mosaic farmlands than in intensive ones. These mosaics thus have increased biodiversity conservation value. We emphasize that attention should be paid not only to the environmental damage and human property loss caused by coal mining subsidence but also to the ecological opportunities from the formation of such new habitats. These post-mining habitats represent a new ecological landscape that should be a part of natural conservation.

Keywords: *landscape mosaic, plant, bird, beetle, spider*

Introduction

Natural and semi-natural habitats are considered the main source of biodiversity in agricultural landscapes (Duflo et al., 2015). While there is growing recognition of the need for their conservation, natural and semi-natural habitats continue to be lost throughout the world (Myers et al., 2000; He et al., 2014). Furthermore, rapid population growth and economic development worldwide have resulted in an increased demand for grain and energy. This further requires people to expand the scale of arable land and mining. In this context, agriculture has started to transform from traditional agriculture to intensive agriculture, and mining activities have also become more intense (Li, 2006; Meng et al., 2009). More than 92% of the total coal supply comes from underground mining, which often leads to serious surface subsidence (Xiao et al., 2018).

Most high-groundwater coal basins overlap with coal seams and agricultural production areas commonly have multiple and thick coal seams, a high groundwater table and flat terrain (Xiao et al., 2018). Underground mining compromises the stability of overlying rock, causing surface distortion, subsidence and eventually the formation

of water patches of various sizes (Hu et al., 2012). In China, subsidence areas are expected to increase by 2,104 ha annually (Hu and Xiao, 2013), and coal mining poses challenges that threaten the environment and human property (destruction of roads, farmland, buildings, etc.) (Xie et al., 2013; Xu et al., 2014; Xiao et al., 2018) and is traditionally perceived as a form of secondary geological disaster (Bell et al., 2000; Ju and Xu, 2015; Zhang et al., 2019b). Thus, coal mining subsidence is one of the most prominent environmental and social issues (Xu et al., 2014).

At present, most studies have reported the negative effects of coal mining subsidence. Many countries and regions recommend that measures such as reclamation and restoration must be adopted to address coal mining subsidence (Lokhande et al., 2005; Xu et al., 2014; Rola et al., 2015). However, recent studies have shown that after a period of development, mining subsidence sites can demonstrate typical features of a wetland ecosystem, such as a submerged environment, soil gleying and typical wetland vegetation (Harabiš et al., 2013; Harabiš, 2016; Zhang et al., 2019a), and some post-mining sites provide high biodiversity (Lewin et al., 2015; De Lucca et al., 2018; Moradi et al., 2018b; Błońska et al., 2019). This seems to indicate that a new ecological landscape is emerging and that some of the most degraded lands could be designed and used as ecologically very valuable habitats.

The characteristics and influencing factors of biodiversity in these newly formed landscapes have not been sufficiently studied. Therefore, assessing the ecological significance of mining subsidence sites from the perspective of biodiversity would not only shed light on the impact of mining subsidence on local biodiversity but also provide a basis for biodiversity management, utilization, protection and restoration. This study focuses on plant, beetle, spider and bird communities in typical intensive farmlands and farmlands containing mining subsidence mosaics in North China (a typical area in which agricultural activity overlaps with coal mining). We tested whether and how differences in the species composition, abundance and diversity of these four taxonomic groups occurred between these two types of landscapes.

Materials and methods

Study area

The Yanzhou coalfield (116°50'–116°55'E, 35°30'–35°25'N) is one of the most important coal production regions in China, where coal mining has been practised for more than 40 years (Xiao et al., 2018). The study area is located in the eastern part of the North China Plain and belongs to the temperate monsoon climate zone. This area has a long history of agriculture and the annual double-crop rotation system, wheat and corn, is the most popular planting pattern. Mining led to a noticeable shrinking of arable land from 18,652.84 ha in 1985 to 12,042.67 ha in 2015, a decrease of 6,610.17 ha; however, the area of water bodies increased from 474.47 ha in 1985 to 1,471.23 ha in 2015 (Xiao et al., 2018). The area of the mining subsidence is expected to reach 30,000 ha by 2020.

The main type of land use in this area was dry farmland in the pre-mining stage. However, once mining subsidence took place, the surface began to show different habitat types due to different historical subsidence features, such as abandoned agricultural fields, puddles, swales, and ponds. In this context, typical “mining subsidence wetlands” with soaked soils and hydrophilic plants were formed under waterlogging conditions. These wetlands were isolated in the agricultural landscape, as

they are characterized by a short formation history and no hydrological connections with other water bodies. Most of these water bodies are abandoned. They are disturbed to a very small degree and have a near-natural development process.

Sampling procedure

The study was conducted in 2 types of landscape. One (intensive farmland) is a typical intensive agricultural landscape and has few non-cropped elements (*Table 1*). The other (mosaic farmland) exhibited a newly formed agricultural landscape that included landscape mosaics (including features such as abandoned agricultural fields, puddles, swales, and ponds) formed by coal mining subsidence and dry farmland. Each type of agricultural landscape has 6 sites (*Fig. 1*). The area of each site was 0.5 km², and they were spaced at least 500 m apart. The crops in these 12 sites were planted almost simultaneously, with corn (*Zea mays*) from May to October and wheat (*Triticum aestivum*) in the rest of the year.

The plants, spiders, beetles and birds at these 12 sites were sampled during April, July and October 2017. An additional survey of birds in January 2018 was performed, as this area was located on the migration route of East Asian-Australian migratory birds. Samples from 9 herbaceous quadrats (1 m × 1 m) (Fang et al., 2009), 6 beetle and spider pitfall traps (Brown and Matthews, 2016), and 5 bird sites (Marsden, 1999) were collected randomly at each site. A qualitative survey of these four taxonomic groups was conducted based on spot investigation. A total of 324 plant samples, 216 beetle and spider samples, and 240 bird samples were obtained over the course of the study. Beetles and spiders were identified to the lowest possible classification unit using a binocular stereomicroscope in the laboratory.

Table 1. Main environmental characteristics of the mosaic farmlands and intensive farmlands

| Characteristic | | Mosaic farmlands | Intensive farmlands |
|--------------------------|-------------------------------------|-------------------------|----------------------------|
| Environmental conditions | Slope (°) | 5.61-29.80 | 0.02-1.00 |
| | Subsidence history (year) | 3-20 | - |
| | Water area (ha) | 0.003-15 | - |
| | Water depth (m) | 0.10-1.30 | - |
| | Water temperature (°C) | 18.66-31.73 | - |
| | Soil temperature (°C) | 25.54-33.58 | 26.92-33.89 |
| | Soil moisture (g kg ⁻¹) | 0.15 -0.97 | 0.08-0.26 |
| | Air temperature (°C) | 26.31-34.2 | 26.70-33.9 |
| | Air humidity (%) | 58-77 | 53-73 |

Data analysis

The richness, rarefied richness, abundance and Shannon diversity of plants, spiders, beetles and birds in mosaic farmlands and intensive farmlands were calculated by using Estimate S (Colwell, 2005). Nonmetric multidimensional scaling (NMDS) was performed in CANOCO 5.0 to visualize the variation in community composition between mosaic farmlands and intensive farmlands based on the Bray-Curtis

dissimilarity index, which was calculated from the $\log(x + 1)$ -transformed abundance data for beetle, spider, and bird communities and data averaged by the relative height, abundance and coverage of plant communities (Ter Braak and Smilauer, 2001). Primer 5.0 was used to analyse the Bray-Curtis similarity of the species composition of these four groups between sites (Clarke and Gorley, 2001). Rarefaction was used in Estimate S to compare cumulative species richness between mosaic farmlands and intensive farmlands over the sampling periods (Colwell, 2005). One-way analysis of variance (ANOVA) performed in IBM SPSS 20.0 was used to test for differences in species richness, rarefied richness, abundance, and the diversity index of these four taxonomic groups between mosaic farmlands and intensive farmlands. The data from all samples from each site were averaged by season.

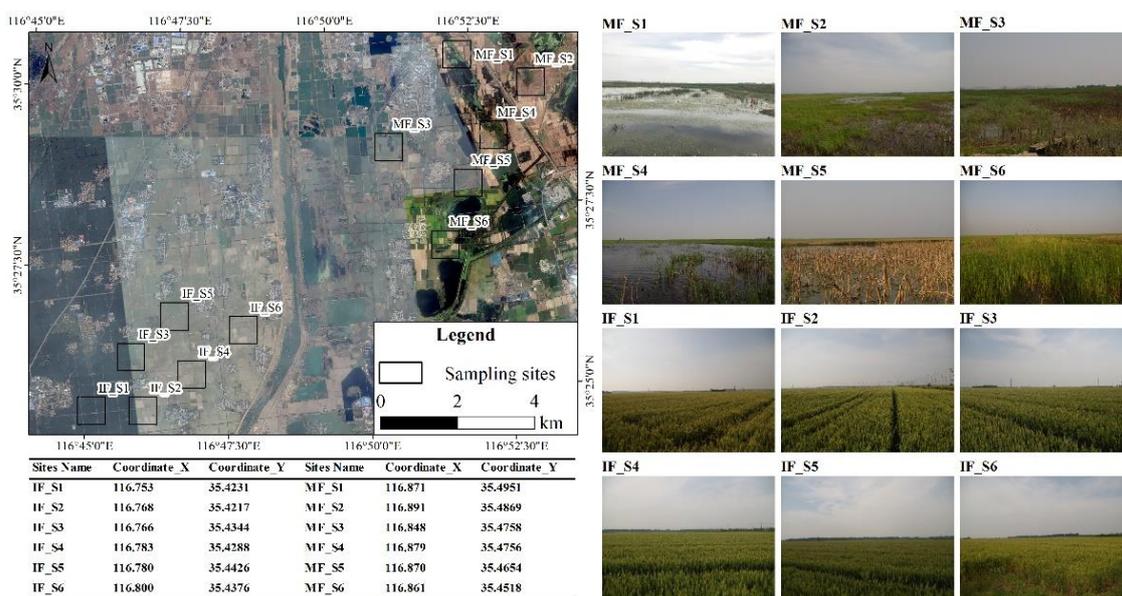


Figure 1. Location of mosaic farmland (MF) sites and intensive farmland (IF) sites

Results

Species composition of plant, spider, beetle and bird communities

A total of 271 species of plants, 17 species of spiders, 49 species of beetles and 138 species of birds were collected in mosaic farmlands, and 76 plant, 12 spider, 35 beetle and 30 bird species were collected in intensive farmlands (Appendix).

The results of PERMANOVA showed that most samples from mosaic farmlands were separated from those of intensive farmlands, indicating significant differences in plant, spider, beetle and bird species composition between these two types of landscape ($R^2 = 0.2025$, $p = 0.01$; $R^2 = 0.1249$, $p = 0.01$; $R^2 = 0.2752$, $p = 0.01$; and $R^2 = 0.2734$, $p = 0.01$, respectively; Fig. 2). The result of Bray-Curtis similarity analysis showed differences in the species composition of these four groups between sites (Tables 2–5), especially in plants, beetles, and birds. From an overall perspective, the lowest similarity was between mosaic farmland sites and intensive farmland sites, followed by the change between mosaic farmland sites, and the most similar were between intensive farmland sites.

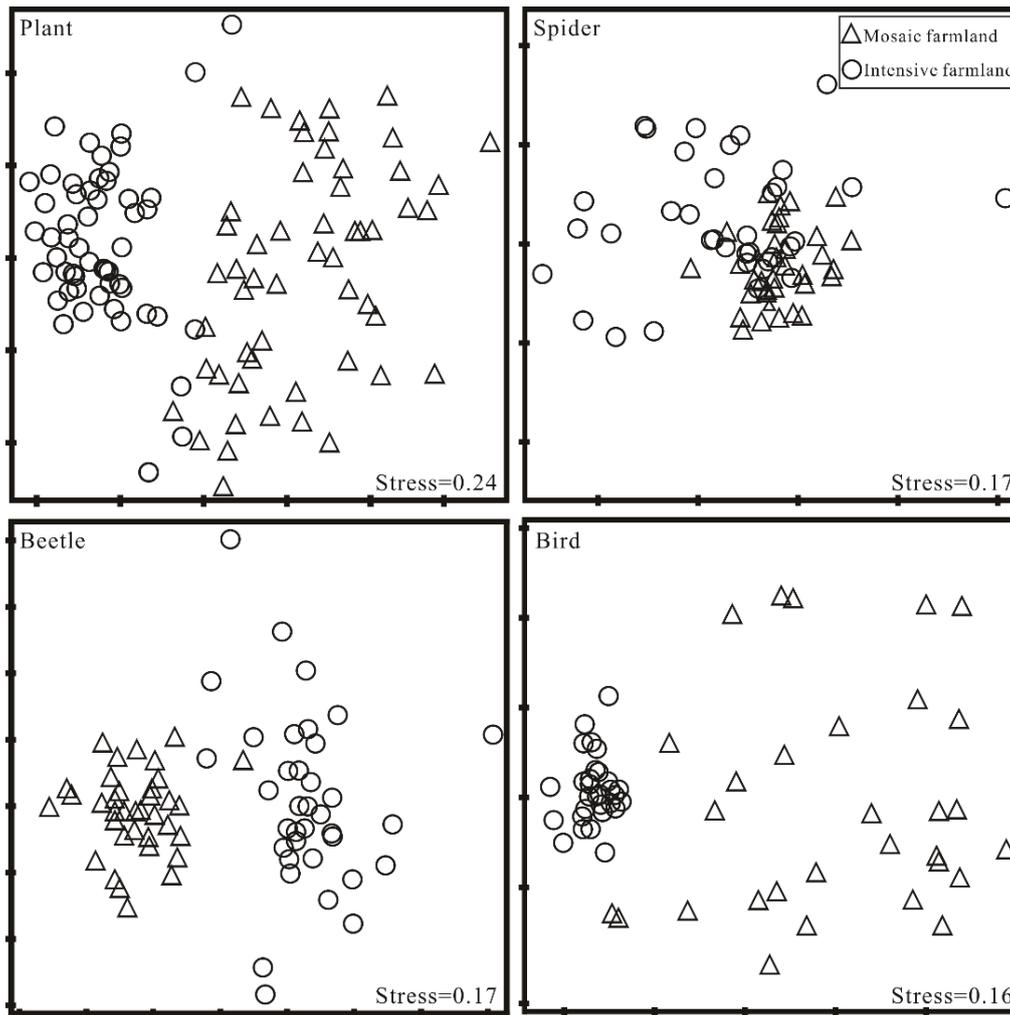


Figure 2. Nonmetric multidimensional scaling ordination of variation in the community composition of plant, spider, beetle and bird species between mosaic farmlands and intensive farmlands based on Bray-Curtis dissimilarities

Table 2. Bray-Curtis similarity analysis of species composition of plant communities in mosaic farmland sites (MS) and intensive farmland sites (IS)

| | MS1 | MS2 | MS3 | MS4 | MS5 | MS6 | IS1 | IS2 | IS3 | IS4 | IS5 | IS6 |
|------------|------|------|------|------|------|------|------|------|------|------|------|-----|
| MS1 | 1 | | | | | | | | | | | |
| MS2 | 0.51 | 1 | | | | | | | | | | |
| MS3 | 0.52 | 0.46 | 1 | | | | | | | | | |
| MS4 | 0.39 | 0.47 | 0.45 | 1 | | | | | | | | |
| MS5 | 0.45 | 0.41 | 0.57 | 0.51 | 1 | | | | | | | |
| MS6 | 0.50 | 0.40 | 0.50 | 0.50 | 0.57 | 1 | | | | | | |
| IS1 | 0.26 | 0.27 | 0.25 | 0.20 | 0.19 | 0.23 | 1 | | | | | |
| IS2 | 0.33 | 0.32 | 0.31 | 0.22 | 0.21 | 0.26 | 0.60 | 1 | | | | |
| IS3 | 0.31 | 0.31 | 0.30 | 0.21 | 0.28 | 0.34 | 0.39 | 0.47 | 1 | | | |
| IS4 | 0.28 | 0.25 | 0.31 | 0.17 | 0.28 | 0.25 | 0.57 | 0.50 | 0.48 | 1 | | |
| IS5 | 0.38 | 0.34 | 0.36 | 0.26 | 0.30 | 0.34 | 0.55 | 0.57 | 0.51 | 0.72 | 1 | |
| IS6 | 0.29 | 0.29 | 0.30 | 0.20 | 0.23 | 0.24 | 0.61 | 0.56 | 0.43 | 0.66 | 0.73 | 1 |

Table 3. Bray-Curtis similarity analysis of species composition of beetle communities in mosaic farmland sites (MS) and intensive farmland sites (IS)

| | MS1 | MS2 | MS3 | MS4 | MS5 | MS6 | IS1 | IS2 | IS3 | IS4 | IS5 | IS6 |
|------------|------|------|------|------|------|------|------|------|------|------|------|-----|
| MS1 | 1 | | | | | | | | | | | |
| MS2 | 0.62 | 1 | | | | | | | | | | |
| MS3 | 0.77 | 0.49 | 1 | | | | | | | | | |
| MS4 | 0.74 | 0.46 | 0.90 | 1 | | | | | | | | |
| MS5 | 0.55 | 0.79 | 0.44 | 0.41 | 1 | | | | | | | |
| MS6 | 0.53 | 0.76 | 0.44 | 0.43 | 0.79 | 1 | | | | | | |
| IS1 | 0.10 | 0.17 | 0.09 | 0.07 | 0.14 | 0.10 | 1 | | | | | |
| IS2 | 0.11 | 0.24 | 0.10 | 0.09 | 0.19 | 0.17 | 0.33 | 1 | | | | |
| IS3 | 0.10 | 0.21 | 0.09 | 0.08 | 0.17 | 0.12 | 0.73 | 0.55 | 1 | | | |
| IS4 | 0.12 | 0.27 | 0.11 | 0.09 | 0.22 | 0.15 | 0.36 | 0.57 | 0.40 | 1 | | |
| IS5 | 0.09 | 0.20 | 0.10 | 0.07 | 0.17 | 0.12 | 0.52 | 0.68 | 0.74 | 0.48 | 1 | |
| IS6 | 0.09 | 0.20 | 0.09 | 0.07 | 0.15 | 0.12 | 0.54 | 0.62 | 0.75 | 0.46 | 0.81 | 1 |

Table 4. Bray-Curtis similarity analysis of species composition of spider communities in mosaic farmland sites (MS) and intensive farmland sites (IS)

| | MS1 | MS2 | MS3 | MS4 | MS5 | MS6 | IS1 | IS2 | IS3 | IS4 | IS5 | IS6 |
|------------|------|------|------|------|------|------|------|------|------|------|------|-----|
| MS1 | 1 | | | | | | | | | | | |
| MS2 | 0.77 | 1 | | | | | | | | | | |
| MS3 | 0.65 | 0.63 | 1 | | | | | | | | | |
| MS4 | 0.80 | 0.85 | 0.71 | 1 | | | | | | | | |
| MS5 | 0.58 | 0.68 | 0.63 | 0.72 | 1 | | | | | | | |
| MS6 | 0.66 | 0.72 | 0.77 | 0.78 | 0.78 | 1 | | | | | | |
| IS1 | 0.16 | 0.21 | 0.15 | 0.20 | 0.27 | 0.25 | 1 | | | | | |
| IS2 | 0.50 | 0.60 | 0.59 | 0.62 | 0.63 | 0.65 | 0.30 | 1 | | | | |
| IS3 | 0.46 | 0.56 | 0.64 | 0.54 | 0.58 | 0.70 | 0.28 | 0.78 | 1 | | | |
| IS4 | 0.26 | 0.31 | 0.24 | 0.30 | 0.33 | 0.32 | 0.42 | 0.38 | 0.38 | 1 | | |
| IS5 | 0.38 | 0.49 | 0.41 | 0.46 | 0.51 | 0.47 | 0.35 | 0.69 | 0.56 | 0.49 | 1 | |
| IS6 | 0.50 | 0.60 | 0.65 | 0.61 | 0.69 | 0.74 | 0.29 | 0.84 | 0.77 | 0.34 | 0.63 | 1 |

Table 5. Bray-Curtis similarity analysis of species composition of bird communities in mosaic farmland sites (MS) and intensive farmland sites (IS)

| | MS1 | MS2 | MS3 | MS4 | MS5 | MS6 | IS1 | IS2 | IS3 | IS4 | IS5 | IS6 |
|------------|------|------|------|------|------|------|------|------|------|------|------|-----|
| MS1 | 1 | | | | | | | | | | | |
| MS2 | 0.56 | 1 | | | | | | | | | | |
| MS3 | 0.69 | 0.51 | 1 | | | | | | | | | |
| MS4 | 0.67 | 0.55 | 0.57 | 1 | | | | | | | | |
| MS5 | 0.35 | 0.49 | 0.20 | 0.37 | 1 | | | | | | | |
| MS6 | 0.53 | 0.59 | 0.41 | 0.52 | 0.51 | 1 | | | | | | |
| IS1 | 0.15 | 0.23 | 0.09 | 0.28 | 0.33 | 0.29 | 1 | | | | | |
| IS2 | 0.13 | 0.20 | 0.09 | 0.27 | 0.36 | 0.28 | 0.79 | 1 | | | | |
| IS3 | 0.15 | 0.22 | 0.08 | 0.26 | 0.35 | 0.30 | 0.71 | 0.72 | 1 | | | |
| IS4 | 0.14 | 0.21 | 0.10 | 0.28 | 0.35 | 0.30 | 0.71 | 0.72 | 0.71 | 1 | | |
| IS5 | 0.18 | 0.23 | 0.09 | 0.27 | 0.34 | 0.36 | 0.73 | 0.74 | 0.68 | 0.71 | 1 | |
| IS6 | 0.14 | 0.19 | 0.08 | 0.25 | 0.32 | 0.27 | 0.66 | 0.69 | 0.81 | 0.71 | 0.61 | 1 |

The dominant species of plants in the mosaic farmlands were *Phragmites australis*, *Digitaria sanguinalis* and *Bromus japonicus*, while *Aegilops tauschii*, *Galium aparine* and *Descurainia sophia* were the dominant plant species in the intensive farmlands. In the mosaic farmlands, the dominant species of beetles were *Pheropsophus jessoensis* (73.37%, relative abundance), *Chlaenius micans* (4.52%) and *Phacophallus japonicus* (3.58%), but *Chlaenius micans* (54.30%), *Atholus depistor* (24.89%) and *Atomaria lewisi* (3.62%) were the dominant beetle species in the intensive farmlands. Furthermore, the dominant species of spiders in the mosaic farmlands were *Pardosa astrigera* (42.10%), *Pardosa* sp. (17.77%) and *Trochosa ruricola* (13.58%), while *Erigone prominens* (26.11%), *Pardosa astrigera* (24.18%) and *Trochosa ruricola* (15.47%) were the dominant spider species in the intensive farmlands. The dominant species of birds in the mosaic farmlands were *Fulica atra* (21.58%), *Anas crecca* (7.95%) and *Tachybaptus ruficollis* (7.92%), while *Passer montanus* (42.70%), *Pica pica* (21.66%) and *Hirundo rustica* (14.36%) were the dominant bird species in the intensive farmlands.

Species accumulation curves showed that the mosaic farmlands supported more species than the intensive farmlands (Fig. 3). A total of 196 species of plants (such as *Rumex dentatus*) (Table 6; Appendix), 5 species of spiders (such as *Asianellus* sp.), 23 species of beetles (such as *Harpalus pallidipennis*) and 109 species of birds (such as *Himantopus himantopus*) were exclusively found in the mosaic farmlands, while *Veronica persica*, 9 species of beetles (such as *Oenopia conglobata*) and *Corvus corone* were exclusively found in the intensive farmlands.

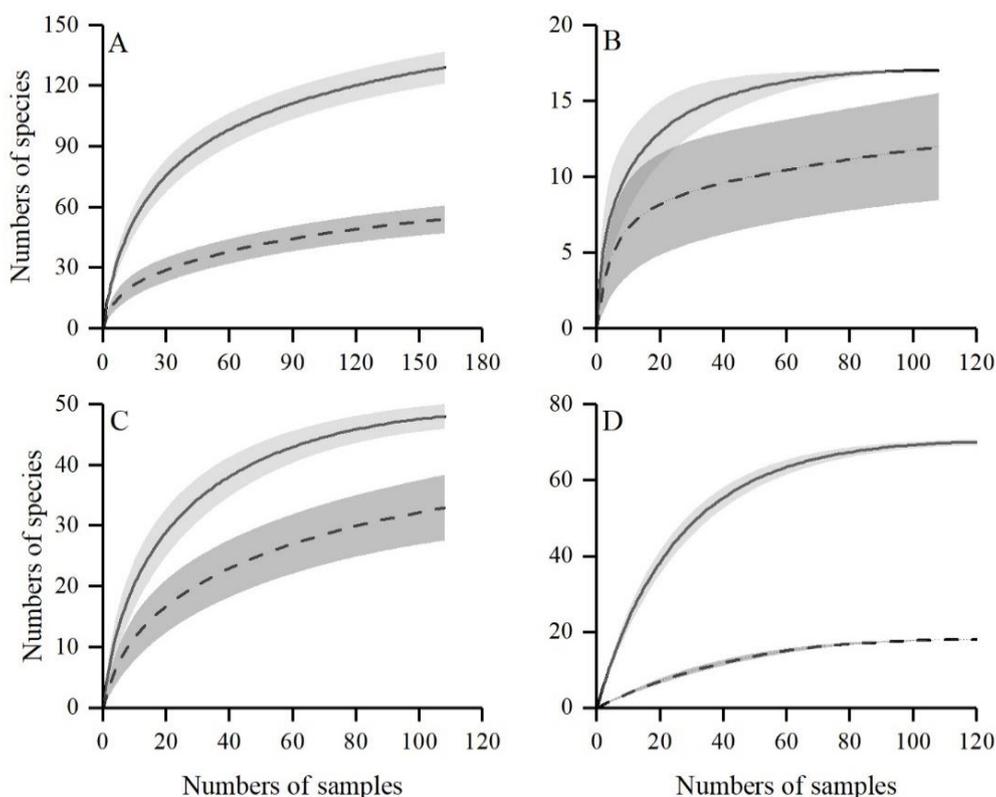


Figure 3. Species accumulation curves for plants (A), spiders (B), beetles (C) and birds (D). The solid line represents the mosaic farmlands, and the dotted line represents the intensive farmlands. Shading indicates the 95% confidence interval

Table 6. Comparison of the species compositions of plant, spider, beetle and bird communities between mosaic farmlands and intensive farmlands

| Taxonomic group | Mosaic farmlands | | Intensive farmlands | | Mutual species |
|-----------------|------------------|----------------|---------------------|----------------|----------------|
| | Total species | Unique species | Total species | Unique species | |
| Plant | 271 | 196 | 76 | 1 | 75 |
| Spider | 17 | 5 | 12 | 0 | 12 |
| Beetle | 49 | 23 | 35 | 9 | 26 |
| Bird | 138 | 109 | 30 | 1 | 29 |

Furthermore, most of the unique species of plants in the mosaic farmlands were hydrophytic (52 species) and aquatic plants (28), while only 5 hydrophytic species were recorded in the intensive farmlands (*Appendix*). Similarly, 59 species of waterfowl and 23 species of beetles were found in only the mosaic farmlands (*Appendix*).

Notably, 134 species of birds were on the International Union for Conservation of Nature (IUCN) Red List (*Appendix*). Six bird species are near-threatened (such as *Emberiza yessoensis*, *Paradoxornis heudei*, *Anas falcata* and *Coturnix japonica*), and *Aythya baeri* is critically endangered, all of which were observed in only mosaic farmlands.

These observations indicated that compared to the intensive farmlands, the mosaic farmlands hosted more and different species.

Community structure of plants, spiders, beetles and birds

ANOVA showed that the richness and abundance of plants, spiders, beetles and birds in the mosaic farmlands were significantly higher than those in intensive farmlands ($p < 0.05$) (*Fig. 4; Appendix*). Similarly, the rarefied species richness and Shannon diversity of plants and birds in mosaic farmlands were significantly higher than those in intensive farmlands ($p < 0.05$). Despite none of the other comparisons being significant ($p > 0.05$), the indexes increased in mosaic farmlands. These observations indicate that the abundance and diversity of these taxonomic groups in mosaic farmlands were higher than those in intensive farmlands, especially for plants and birds.

Discussion

Understanding patterns of biodiversity during landscape change is one of the central pursuits of community ecology and relevant for improved conservation theory (Soykan et al., 2012). The mosaic farmlands showed higher biodiversity than the intensive farmlands, suggesting that such mosaics represent important supplements to the agricultural landscape. Studies have shown that natural and semi-natural habitats in agricultural landscapes can provide valuable habitats for communities in China (Liu et al., 2010; De-Jun et al., 2011; Toral et al., 2011; Zhao and Zhou, 2018) and in other regions such as Japan (Amano et al., 2008; Katayama et al., 2015), Europe (Ma, 2008; Frenzel et al., 2016; Lewis-Phillips et al., 2019) and North America (Elphick, 2000).

Biodiversity in mosaic farmlands and intensive farmlands

The communities of plants, spiders, beetles and birds exhibited significant differences in species composition between the mosaic farmlands and intensive

farmlands (Fig. 2). The mosaic farmlands hosted more and different species than the intensive farmlands (Table 6). Furthermore, the mosaic farmlands showed a higher abundance and diversity of these taxonomic groups than the intensive farmlands did, while the rarefied richness and Shannon diversity of beetles and spiders did not show a similar pattern (Fig. 3). These results are consistent with those of other studies (Duelli and Obrist, 2003; Ma, 2008; Nagy et al., 2017; Lee and Goodale, 2018; Li et al., 2018; Šálek et al., 2018), especially for plants (Bratli et al., 2006; Ma, 2008), beetles (Gioria et al., 2010; Li et al., 2018), spiders (Knapp and Řezáč, 2015) and birds (Giralt et al., 2008; Wuczyński et al., 2014; Morelli, 2018). Studies have shown that the impact of habitats and landscape features on beetles and spiders is limited (Jeanneret et al., 2003). However, a direct positive effect of mosaic farmlands was found for waterfowl and migratory birds, suggesting that the mosaic farmlands supply food or breeding facilities not provided by intensive farmlands (Appendix). These resources could be provided because these newly formed mosaics differ from traditional intensive farmlands, as they do not experience crop rotation and agricultural practices such as mowing, fertilization and oversowing with seeds of desirable plants. These practices are known to affect plants and birds (Gaujour et al., 2012; Frenzel et al., 2016; Nagy et al., 2017) and probably also affect arthropods, including carabids and spiders (Cerezo et al., 2011; Knapp and Řezáč, 2015). In other respects, the hydrological conditions of the newly formed mosaics can provide many species with adequate moisture and moist soil (Mathias and Moyle, 1992; Duelli, 1997; Bornette and Puijalon, 2011; Xu et al., 2019). Studies have reported that coal mining subsidence can be characterized as an intermediate disturbance to plant communities in semi-arid areas: changes in the functioning of local ecosystems and the number of plant species are limited after coal mining subsidence (Czaja et al., 2014; He et al., 2017). However, our results indicate that in high-groundwater coal basins, mining subsidence mosaics increase the plant diversity of the local landscape. The appearance of some unique species may be promoted by an increase in subsidence cracks, which trap seeds transported by the wind and participate in increasing plant richness (He et al., 2017). It is also possible that the surface upheavals and cracks caused by coal mining subsidence offer conditions for the germination of seeds, especially those with seeds buried in the soil for a long time. A soil seed bank is considered a potential contributor to plant diversity, as it can take part in the renewal and succession of the surface vegetation (De Villiers et al., 2001; Szarek-Lukaszewska et al., 2007; Liu et al., 2016), especially after natural or human intervention (Bell et al., 1993). Furthermore, the higher plant diversity may also be due to the dispersal mechanism of plant propagules (Moran et al., 2004; Cramer et al., 2007; Brudvig et al., 2009); with the assistance of the wind and animals (especially birds), some plant propagules were introduced into the coal mining subsidence area, further enriching the regional species pool.

In stark contrast to the formation processes that occur in valuable habitats such as natural habitats, mining subsidence was the main driver of the mosaic farmlands, and it often changes the original landscape patterns, imposing great pressure on environmental recovery; in addition, land use transformations have usually been fast, with uncertain consequences (Zhang et al., 2019a). There is a temporal component of this study obtained by comparing current mosaic farmlands and intensive farmlands. The hypothesis was that the biodiversity changed and increased after these mosaics formed. Similar to the results above, in limestone quarries in the Bohemian Karst, Czech Republic, 153 species of vascular plants were found (Tropek et al., 2010); likewise, in

post-mining sites in the Sokolov district, western Czech Republic, 380 species of arthropods were found (Moradi et al., 2018a). These studies suggest that the high diversity in post-mining areas is not random but may be caused by their particular origin and subsequent environmental changes. Therefore, in our study, the environmental changes that occurred after these mosaics formed must be considered to explain the change in the diversity of plants, beetles, spiders and birds.

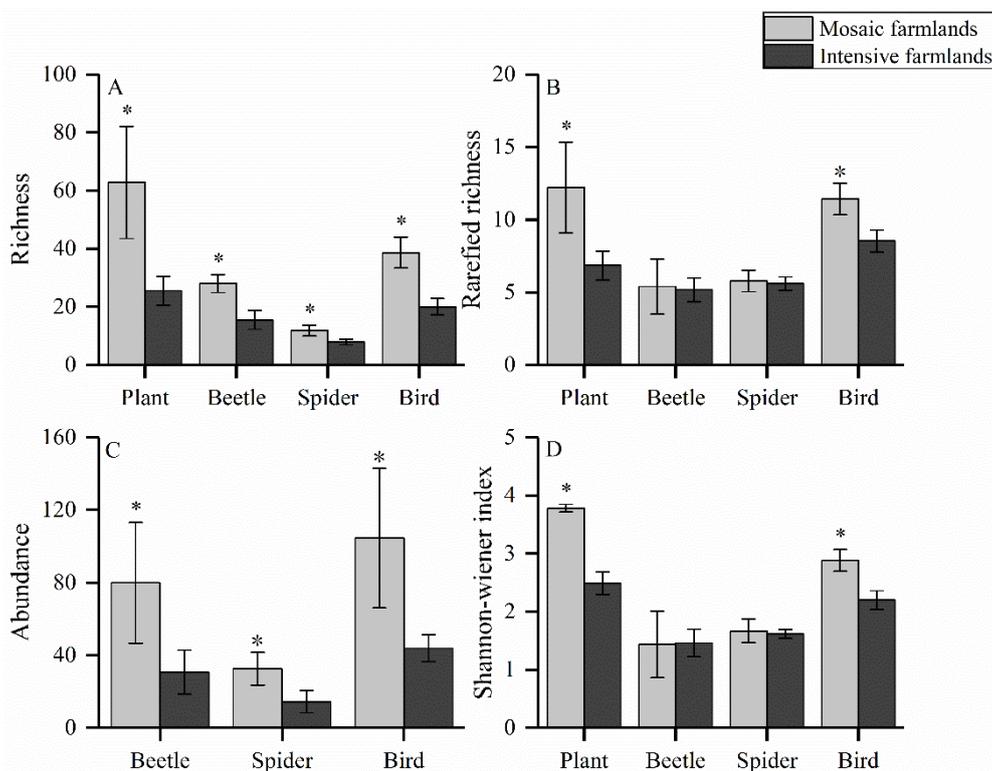


Figure 4. Mean species richness, rarefied richness, abundance, and Shannon diversity of plants, spiders, beetles and birds in mosaic farmlands and intensive farmlands. * means $p < 0.05$. Standard error is represented by the vertical bars

Generally, landscape modification can not only directly impact local biodiversity (Cerezo et al., 2011) but also indirectly affect local biodiversity by changing environmental conditions (Dolný and Harabiš, 2012; Li et al., 2019), such as water, soil and the microclimate (Mantyka-Pringle et al., 2012; Růžicka et al., 2012; Huang et al., 2019; Oishi, 2019). Studies have reported that environmental conditions significantly affect plants and arthropods in certain cases (Lindenmayer et al., 1999; Lundholm and Larson, 2003; Joern and Laws, 2013), while site-level conditions may be more important for highly mobile species such as birds (Lindenmayer et al., 2010). A previous study in the same area confirmed the positive effect of the newly formed mosaics on local landscape heterogeneity: compared to the mosaics, the surrounding landscapes were almost homogeneous habitats, while the mosaics were the more diverse habitats (Xiao et al., 2018). Due to differences in subsidence history, newly formed mosaics with different shapes, sizes and water depths were created, including features such as puddles, swales, ponds, and even shallow lakes, which are different from the surrounding landscapes and increase the local water area and heterogeneity of water

characteristics such as its area, depth and temperature (*Table 1*) but are capable of providing important habitats for more and different species than homogeneous landscapes (Frouz et al., 2018). Non-cropped elements (such as the mosaics in this study) represent high-quality habitats for various taxa, and their positive impact on biodiversity in agricultural landscapes has been previously documented in studies on plants and animals (Chiron et al., 2010; Ma and Herzon, 2014; Kirk and Lindsay, 2017). In accordance with traditional gradient theories (Austin, 1999; Gaston, 2000; Reynolds, 2002; Telesh et al., 2013), an increase in water heterogeneity will create additional ecological niches and allow the coexistence of an increased number of species, especially wetland specialists (Pollock et al., 1998). For example, 59 waterfowl species were found in the mosaic farmlands but not in the intensive farmlands (*Appendix*). Similarly, 28 species of aquatic plants were collected in only the mosaic farmlands, including submerged plants such as *Potamogeton crispus* and *Ceratophyllum demersum*, floating-leaved plants such as *Euryale ferox* and *Nymphoides peltata*, and emergent plants such as *Phragmites australis* and *Typha angustifolia*.

Studies have shown that mining subsidence can change local soil conditions (Quadros et al., 2016; Hu et al., 2017; Willscher et al., 2017) such as moisture, temperature and nutrient levels. Plants and animals are sensitive to soil conditions; for example, in temporary wetlands in agricultural landscapes in northeastern Germany, an increase in soil moisture increased the diversity of arthropods (Brose, 2001, 2003a, b). An increase in soil moisture can also help improve habitat quality and subsequently improve the survival rate of eggs and larvae (Huk and Kühne, 1999). In our study, 94 xerophytic, 92 mesophytic, 56 hygrophytic and 28 aquatic species of plants were found in the mosaic farmlands (*Appendix*), while only 28 xerophytic, 42 mesophytic and 5 hygrophytic species were found in the intensive farmlands. Moreover, *Pheropsophus jessoensis* (73.37% relative abundance in mosaic farmlands), which prefers high soil moisture (Frank et al., 2009; Sugiura, 2018), was found in the mosaic farmlands but not in the intensive farmlands. Furthermore, changes in soil temperature, soil quality and soil nutrient conditions can also impact the biotic community (Iannone Iii and Galatowitsch, 2008; Sutton-Grier et al., 2011; Altenfelder et al., 2016; Hong et al., 2017).

Landscape change, such as the transformation from intensive farmlands to mosaic farmlands, can also influence aspects of the local microclimate (Bai et al., 2013; Mclaughlin and Cohen, 2013) such as air temperature and air humidity (*Table 1*). The temperature and insolation of microenvironments are important factors affecting nest site choice by Anatidae species because stable microclimatic conditions can improve the efficiency of heat transfer to eggs (Shutler et al., 1998). Research has reported that carabids are sensitive to ambient temperature changes (Niemelä, 2001; Allen, 2016). In our study, 19 Anatidae species and 18 carabid species were collected in the mosaic farmlands, while only 9 of these carabid species were collected in the intensive farmlands (*Appendix*). This difference may be because mosaic farmlands provide better microclimatic conditions for these species.

Increases or decreases in diversity within a trophic level are highly relevant for the rest of the community because of an ecosystem's balance between ecological niche complementarity effects and community trophic cascades (Ives et al., 2005; Finke and Snyder, 2008; Schneider et al., 2016). For example, research has revealed that differences in vegetation among systems may lead to disparities in other communities (Davidowitz and Rosenzweig, 1998). Plants also provide food and habitats for arthropods and birds (Zimmer et al., 2000; Gucel et al., 2012), and high heterogeneity of

microhabitats is reciprocally related to the diversity of plants (Bogusch et al., 2016). Thus, in our study, the increase in plant diversity must also impact beetles, spiders and birds. In contrast, changes in animals can have effects on plants (Schemske et al., 2009; Stam et al., 2014). For example, *Podiceps cristatus* and *Fulica atra* build nests with branches of *Potamogeton crispus* or *Phragmites australis*, and the “floating nests” of these two bird species can be formed only with the support of the stems of emergent plants. Moreover, common bird species, such as *Acrocephalus orientalis* and *Cisticola juncidis*, are reported to inhabit both *Phragmites australis* and *Typha angustifolia* communities (Ueda, 1993; Katayama et al., 2015). Some waterfowl such as *Aythya baeri* and *Fulica atra* feed on the roots, stems, leaves and seeds of submerged plants (e.g., *Potamogeton crispus*). The structure of vegetation is also an important factor, affecting, for example, the presence and abundance of oviposition sites and potential predator–prey interactions of arthropods (Katayama et al., 2015; Li et al., 2018).

Implication for conservation

Many studies of biodiversity differences between landscapes generally focus on one taxonomic group, while we compared the biodiversity of mosaic farmlands with that of intensive farmlands from the perspective of four taxonomic groups, which makes our results more accurate. Our important result is that these newly formed mosaic farmlands can support higher biodiversity than the traditional intensive farmlands and host many unique species that are not present within the intensive farmlands, especially some endangered species, such as *Aythya baeri* (Appendix), of which fewer than 1,000 individuals remain worldwide (Wang et al., 2012). In fact, some species have difficulties migrating to newly emerging habitats, and there will always be a group of rare and threatened organisms with low migration ability or very specific habitat requirements, which can hardly be provided by newly formed habitats. However, for disturbance-dependent species, the mosaics (such as these post-mining sites) are nearly ideal. Importantly, the newly formed mosaics have been shown to be important intermediate stops on the migration route of East Asian–Australian migratory birds because the bird community contains a large number of migratory bird species that travel along the route, such as *Calidris ferruginea*, *Numenius arquata*, *Aythya nyroca*, *Aythya baeri* and *Vanellus vanellus*. These findings indicate that these mosaics are valuable habitats for plants and animals and can contribute to regional biodiversity conservation.

The traditional understanding of coal mining subsidence mainly involves its damage to the environment and human property (Bell et al., 2000; Bell and Genske, 2001; Yao and Gui, 2008; Hu et al., 2016; Yu et al., 2018). However, these newly formed mosaics are important supplements to the agricultural landscape and could help dampen the effects of intensive farming activities and landscape fragmentation because they provide additional refuges and overwintering habitats, hence enhancing the overall diversity in agricultural landscapes (Schmidt et al., 2005; Li et al., 2018). Importantly, with economic development and human population growth, natural habitats will continue to decrease due to intensification and urbanization (Erwin, 2008; Verburg et al., 2010; Mao et al., 2018). Intuitively, however, farmers are not willing to sacrifice large areas of arable land to create non-crop habitats. Although studies have shown the importance of non-crop habitats for the conservation of beneficial arthropod diversity in agricultural landscapes (Knapp and Řezáč, 2015; Li et al., 2018), the positive impact of the presence of non-crop habitats on pest control services cannot be replicated by crop rotation management (Rusch et al., 2013).

However, these newly formed ecosystems are unstable, and their occurrence, development and succession are prone to external influences due to their short period of development and immaturity. Although we do not know how the biodiversity of mosaic farmlands will change with succession in the future, our study can facilitate understanding and aid in biodiversity conservation in this area. We emphasize that attention should be paid not only to the environmental damage and human property loss caused by coal mining subsidence but also to the ecological opportunities brought about by the formation of such new habitats.

Conclusions

Mining subsidence mosaics situated inside arable land are important supplements to the agricultural landscape and host many unique species that are not present within surrounding arable land. These newly formed landscape mosaics have been strengthened due to the decreasing natural habitats and provide important habitats for plants and animals at different times of the year. We presume that the high diversity in mosaic farmlands is not coincidental and that these habitats comprise an important component from a nature conservation perspective. This paper demonstrates a path forward from some of the most destructive land uses. Please note that the paper is not encouraging mining but rather offers a potential utilization idea after mines have closed or moved to another location. Future studies should investigate (i) whether and how the species respond to subsidence, and (ii) a variety of habitats in agricultural landscape, including mining subsidence habitats (puddles, swales, and ponds), intensified and abandoned fields, to assess the value of these habitats and propose appropriate ‘win-win’ solutions for agricultural development and biodiversity conservation in agricultural landscape.

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APPENDIX

Descriptive statistics of the community structure of plants, spiders, beetles and birds between mosaic farmlands and intensive farmlands

| Taxonomic group | Variable | Mosaic farmlands (mean ± SD) | Intensive farmlands (mean ± SD) | F | p |
|-----------------|-------------------|------------------------------|---------------------------------|---------|-------|
| Plant | Richness | 62.83 ± 19.29 | 25.50 ± 5.01 | 21.051 | 0.001 |
| | Rarefied richness | 12.21 ± 3.13 | 6.85 ± 0.98 | 16.058 | 0.002 |
| | Shannon diversity | 3.78 ± 0.07 | 2.49 ± 0.20 | 223.093 | 0.000 |
| Beetle | Richness | 28.00 ± 3.16 | 15.50 ± 3.21 | 46.182 | 0.000 |
| | Rarefied richness | 5.39 ± 1.90 | 5.16 ± 0.82 | 0.000 | 0.996 |
| | Abundance | 78.89 ± 33.29 | 30.69 ± 12.07 | 14.24 | 0.004 |
| | Shannon diversity | 1.43 ± 0.57 | 1.46 ± 0.24 | 0.184 | 0.677 |
| Spider | Richness | 11.83 ± 1.83 | 7.83 ± 0.98 | 22.154 | 0.001 |
| | Rarefied richness | 5.78 ± 0.74 | 5.61 ± 0.45 | 0.252 | 0.627 |
| | Abundance | 32.53 ± 9.05 | 14.36 ± 6.10 | 16.631 | 0.002 |
| | Shannon diversity | 1.67 ± 0.20 | 1.62 ± 0.08 | 0.249 | 0.629 |
| Bird | Richness | 38.67 ± 5.32 | 20.00 ± 2.90 | 57.018 | 0.000 |
| | Rarefied richness | 11.42 ± 1.09 | 8.52 ± 0.76 | 28.491 | 0.000 |
| | Abundance | 104.47 ± 38.39 | 43.93 ± 7.31 | 24.002 | 0.001 |
| | Shannon diversity | 2.88 ± 0.19 | 2.20 ± 0.16 | 45.938 | 0.000 |

The species list of plants of mosaics farmlands (MF) and intensive farmlands (IF)

| Species list of plants | | | | Species list of birds | | | | |
|--|-----|----|----|-----------------------------------|----|----|------|-----------|
| Species | MFS | IF | WE | Species | MF | IF | ICUN | Migration |
| Salviniaceae | | | | Phasianidae | | | | |
| 1. <i>Salvinia natans</i> | + | | A | 1. <i>Coturnix japonica</i> | + | | NT | P |
| Equisetaceae | | | | 2. <i>Phasianus colchicus</i> | + | + | LC | R |
| 2. <i>Equisetum ramosissimum</i> | + | | M | Anatidae | | | | |
| Marsileaceae | | | | 3. <i>Anser fabalis</i> | + | | LC | W |
| 3. <i>Marsilea quadrifolia</i> | + | | A | 4. <i>Anser anser</i> | + | | LC | P |
| Azollaceae | | | | 5. <i>Anser albifrons</i> | + | | LC | P |
| 4. <i>Azolla imbricata</i> | + | | A | 6. <i>Cygnus columbianus</i> | + | | LC | W |
| Nymphaeaceae | | | | 7. <i>Tadorna ferruginea</i> | + | | LC | R |
| 5. <i>Nelumbo nucifera</i> | + | | A | 8. <i>Aix galericulata</i> | + | | LC | P |
| 6. <i>Euryale ferox</i> | + | | A | 9. <i>Anas strepera</i> | + | | LC | P |
| Ceratophyllaceae | | | | 10. <i>Anas falcata</i> | + | | NT | W |
| 7. <i>Ceratophyllum demersum</i> | + | | A | 11. <i>Anas crecca</i> | + | | LC | P |
| 8. <i>Ceratophyllum oryzetorum</i> | + | | A | 12. <i>Anas platyrhynchos</i> | + | | LC | W |
| 9. <i>Ceratophyllum</i> sp. | + | | A | 13. <i>Anas clypeata</i> | + | | LC | P |
| Ranunculaceae | | | | 14. <i>Anas querquedula</i> | + | | LC | W |
| 10. <i>Ranunculus chinensis</i> | + | | H | 15. <i>Anas formosa</i> | + | | LC | P |
| 11. <i>Ranunculus sceleratus</i> | + | | H | 16. <i>Anas zonorhyncha</i> | + | | LC | R |
| 12. <i>Ranunculus japonicus</i> | + | | H | 17. <i>Aythya ferina</i> | + | | LC | P |
| 13. <i>Semiaquilegia adoxoides</i> | + | | M | 18. <i>Aythya baeri</i> | + | | CR | W |
| Papaveraceae | | | | 19. <i>Aythya nyroca</i> | + | | NT | W |
| 14. <i>Dicranostigma leptopodum</i> | + | | X | 20. <i>Aythya fuligula</i> | + | | LC | W |
| Moraceae | | | | 21. <i>Mergellus albellus</i> | + | | LC | W |
| 15. <i>Humulus scandens</i> | + | + | M | 22. <i>Mergus squamatus</i> | + | | LC | P |
| Rubiaceae | | | | Podicipedidae | | | | |
| 16. <i>Galium aparine</i> | + | + | M | 23. <i>Tachybaptus ruficollis</i> | + | | LC | R |
| 17. <i>Galium bungei</i> | + | | M | 24. <i>Podiceps cristatus</i> | + | | LC | R |
| 18. <i>Rubia cordifolia</i> | + | | M | Ardeidae | | | | |
| Chenopodiaceae | | | | 25. <i>Nycticorax nycticorax</i> | + | | LC | S |
| 19. <i>Chenopodium album</i> | + | + | M | 26. <i>Ardeola bacchus</i> | + | | LC | R |
| 20. <i>Chenopodium serotinum</i> | + | + | M | 27. <i>Ardea cinerea</i> | + | | LC | R |
| 21. <i>Chenopodium ambrosioides</i> | + | | H | 28. <i>Ardea purpurea</i> | + | | LC | S |
| 22. <i>Chenopodium glaucum</i> | + | | M | 29. <i>Ardea alba</i> | + | | LC | R |
| 23. <i>Kochia scoparia</i> | + | | M | 30. <i>Egretta garzetta</i> | + | | LC | S |
| 24. <i>Salsola collina</i> | + | + | X | 31. <i>Botaurus stellaris</i> | + | | LC | S |
| Amaranthaceae | | | | 32. <i>Ixobrychus sinensis</i> | + | | LC | S |
| 25. <i>Alternanthera philoxeroides</i> | + | | H | 33. <i>Platalea leucorodia</i> | + | | LC | S |
| 26. <i>Alternanthera sessilis</i> | + | | H | Phalacrocoracidae | | | | |
| 27. <i>Amaranthus hybridus</i> | + | | M | 34. <i>Phalacrocorax carbo</i> | + | | LC | P |
| 28. <i>Amaranthus paniculatus</i> | + | | X | Pandionidae | | | | |
| 29. <i>Amaranthus caudatus</i> | + | | M | 35. <i>Pandion haliaetus</i> | + | | LC | P |
| 30. <i>Amaranthus polygonoides</i> | + | | M | Accipitridae | | | | |
| 31. <i>Amaranthus retroflexus</i> | + | + | M | 36. <i>Elanus caeruleus</i> | + | + | LC | P |
| 32. <i>Amaranthus spinosus</i> | + | + | M | 37. <i>Circus cyaneus</i> | + | | LC | P |
| 33. <i>Amaranthus viridis</i> | + | + | M | 38. <i>Circus spilonotus</i> | + | | LC | W |
| 34. <i>Amaranthus lividus</i> | + | | M | 39. <i>Buteo japonicus</i> | + | | LC | P |
| Polygonaceae | | | | 40. <i>Accipiter nisus</i> | + | | LC | P |
| 35. <i>Rumex dentatus</i> | + | | H | Falconidae | | | | |
| 36. <i>Rumex maritimus</i> | + | | H | 41. <i>Falco tinnunculus</i> | + | | LC | R |
| 37. <i>Rumex amurensis</i> | + | | H | 42. <i>Falco subbuteo</i> | + | | LC | P |
| 38. <i>Rumex patientia</i> | + | | H | 43. <i>Falco amurensis</i> | + | | LC | P |
| 39. <i>Fallopia multiflora</i> | + | | H | 44. <i>Falco peregrinus</i> | + | | LC | P |
| 40. <i>Polygonum aviculare</i> | + | + | M | Strigidae | | | | |
| 41. <i>Polygonum perfoliatum</i> | + | | H | 45. <i>Athene noctua</i> | + | + | LC | R |
| 42. <i>Polygonum longisetum</i> | + | | H | Rallidae | | | | |
| 43. <i>Polygonum hydropiper</i> | + | | H | 46. <i>Amaurornis phoenicurus</i> | + | | LC | S |
| 44. <i>Polygonum lapathifolium</i> | + | + | M | 47. <i>Gallinula chloropus</i> | + | | LC | S |

| | | | | | | | | |
|---------------------------------------|---|---|---|---------------------------------------|---|---|----|---|
| 45. <i>Polygonum plebeium</i> | + | | H | 48. <i>Fulica atra</i> | + | | LC | R |
| Caryophyllaceae | | | | 49. <i>Rallus indicus</i> | + | | LC | P |
| 46. <i>Dianthus chinensis</i> | + | | X | 50. <i>Porzana pusilla</i> | + | | LC | P |
| 47. <i>Dianthus superbus</i> | + | | X | Recurvirostridae | | | | |
| 48. <i>Silene firma</i> | + | | X | 51. <i>Himantopus himantopus</i> | + | | LC | R |
| 49. <i>Silene aprica</i> | + | | X | Charadriidae | | | | |
| 50. <i>Stellaria apetala</i> | + | | M | 52. <i>Vanellus cinereus</i> | + | | LC | S |
| 51. <i>Myosoton aquaticum</i> | + | + | M | 53. <i>Vanellus vanellus</i> | + | | LC | P |
| 52. <i>Arenaria serpyllifolia</i> | + | + | M | 54. <i>Charadrius dubius</i> | + | | LC | S |
| 53. <i>Cerastium glomeratum</i> | + | | M | 55. <i>Charadrius alexandrinus</i> | + | | LC | S |
| Phytolaccaceae | | | | 56. <i>Pluvialis fulva</i> | + | | LC | P |
| 54. <i>Phytolacca americana</i> | + | | M | 57. <i>Charadrius veredus</i> | + | | LC | P |
| Malvaceae | | | | Scolopacidae | | | | |
| 55. <i>Abutilon theophrasti</i> | + | + | M | 58. <i>Calidris ferruginea</i> | + | | LC | P |
| 56. <i>Corchorus aestuans</i> | + | | M | 59. <i>Calidris temminckii</i> | + | | LC | P |
| 57. <i>Hibiscus trionum</i> | + | | X | 60. <i>Gallinago gallinago</i> | + | | LC | P |
| 58. <i>Sida acuta</i> | + | | X | 61. <i>Gallinago stenura</i> | + | | LC | P |
| Violaceae | | | | 62. <i>Numenius arquata</i> | + | | NT | P |
| 59. <i>Viola philippica</i> | + | + | X | 63. <i>Tringa erythropus</i> | + | | LC | P |
| 60. <i>Viola prionantha</i> | + | | X | 64. <i>Tringa nebularia</i> | + | | LC | P |
| Umbelliferae | | | | 65. <i>Tringa stagnatilis</i> | + | | LC | P |
| 61. <i>Ligusticum jeholense</i> | + | | M | 66. <i>Tringa ochropus</i> | + | | LC | P |
| 62. <i>Daucus carota</i> | + | | M | 67. <i>Actitis hypoleucos</i> | + | | LC | S |
| 63. <i>Torilis scabra</i> | + | | M | 68. <i>Scolopax rusticola</i> | + | | LC | P |
| 64. <i>Cnidium monnieri</i> | + | | M | Glareolidae | | | | |
| 65. <i>Oenanthe javanica</i> | + | | H | 69. <i>Glareola maldivarum</i> | + | | LC | S |
| Cruciferae | | | | Laridae | | | | |
| 66. <i>Lepidium virginicum</i> | + | | X | 70. <i>Chroicocephalus ridibundus</i> | + | | LC | W |
| 67. <i>Rorippa dubia</i> | + | | H | 71. <i>Chlidonias hybrida</i> | + | | LC | S |
| 68. <i>Rorippa islandica</i> | + | | H | 72. <i>Sterna hirundo</i> | + | | LC | S |
| 69. <i>Rorippa indica</i> | + | | H | Jacaniidae | | | | |
| 70. <i>Rorippa cantoniensis</i> | + | | H | 73. <i>Hydrophasianus chirurgus</i> | + | | LC | S |
| 71. <i>Capsella bursa-pastoris</i> | + | + | M | Columbidae | | | | |
| 72. <i>Erysimum cheiranthoides</i> | + | + | X | 74. <i>Streptopelia orientalis</i> | + | + | LC | R |
| 73. <i>Descurainia sophia</i> | + | + | M | 75. <i>Spilopelia chinensis</i> | + | + | LC | R |
| 74. <i>Draba nemorosa</i> | + | | H | 76. <i>Streptopelia tranquebarica</i> | + | | LC | S |
| 75. <i>Cardamine hirsuta</i> | + | | M | Cuculidae | | | | |
| 76. <i>Cardamine flexuosa</i> | + | | M | 77. <i>Cuculus canorus</i> | + | | LC | S |
| 77. <i>Nasturtium officinale</i> | + | | M | Alcedinidae | | | | |
| Primulaceae | | | | 78. <i>Ceryle rudis</i> | + | | LC | S |
| 78. <i>Lysimachia candida</i> | + | | H | 79. <i>Alcedo atthis</i> | + | | LC | R |
| 79. <i>Androsace umbellata</i> | + | | M | Upupidae | | | | |
| Crassulaceae | | | | 80. <i>Upupa epops</i> | + | + | LC | S |
| 80. <i>Sedum aizoon</i> | + | | X | Picidae | | | | |
| Rosaceae | | | | 81. <i>Dendrocopos canicapillus</i> | + | + | LC | R |
| 81. <i>Duchesnea indica</i> | + | + | M | 82. <i>Dendrocopos major</i> | + | | LC | R |
| 82. <i>Potentilla supina</i> | + | | M | 83. <i>Picus canus</i> | + | | LC | R |
| Leguminosae | | | | Laniidae | | | | |
| 83. <i>Glycine soja</i> | + | | H | 84. <i>Lanius schach</i> | + | + | LC | R |
| 84. <i>Gueldenstaedtia multiflora</i> | + | | X | 85. <i>Lanius sphenocercus</i> | + | | LC | W |
| 85. <i>Gueldenstaedtia maritima</i> | + | | X | 86. <i>Lanius cristatus</i> | + | | LC | P |
| 86. <i>Kummerowia stipulacea</i> | + | + | X | Dicruridae | | | | |
| 87. <i>Lespedeza juncea</i> | + | | X | 87. <i>Dicrurus macrocercus</i> | + | | LC | S |
| 88. <i>Melilotus officinalis</i> | + | | M | Corvidae | | | | |
| 89. <i>Vicia tetrasperma</i> | + | | X | 88. <i>Pica pica</i> | + | + | LC | R |
| 90. <i>Vicia hirsuta</i> | + | | X | 89. <i>Cyanopica cyanus</i> | + | | LC | R |
| 91. <i>Vicia bungei</i> | + | | X | 90. <i>Corvus corone</i> | | + | LC | P |
| 92. <i>Vicia sativa</i> | + | | X | Paridae | | | | |
| 93. <i>Vicia kioshanica</i> | + | | X | 91. <i>Parus major</i> | + | + | - | R |
| 94. <i>Vicia angustifolia</i> | + | + | X | 92. <i>Parus minor</i> | + | + | LC | R |
| 95. <i>Vigna minima</i> | + | | X | Remizidae | | | | |

| | | | | | | | | |
|--|---|---|---|---------------------------------------|---|---|----|---|
| 96. <i>Medicago lupulina</i> | + | | X | 93. <i>Remiz consobrinus</i> | + | | LC | R |
| Haloragidaceae | | | | Alaudidae | | | | |
| 97. <i>Myriophyllum spicatum</i> | + | | A | 94. <i>Alauda arvensis</i> | + | + | LC | P |
| 98. <i>Myriophyllum verticillatum</i> | + | | A | 95. <i>Alauda gulgula</i> | + | + | LC | R |
| Lythraceae | | | | Pycnonotidae | | | | |
| 99. <i>Ammannia multiflora</i> | + | | H | 96. <i>Pycnonotus sinensis</i> | + | + | LC | R |
| Trapaceae | | | | Hirundinidae | | | | |
| 100. <i>Trapa bicornis</i> | + | | A | 97. <i>Hirundo rustica</i> | + | + | LC | S |
| 101. <i>Trapa bispinosa</i> | + | | A | 98. <i>Cecropis daurica</i> | + | + | LC | S |
| Onagraceae | | | | Aegithalidae | | | | |
| 102. <i>Gaura parviflora</i> | + | | M | 99. <i>Aegithalos glaucogularis</i> | + | | LC | R |
| 103. <i>Ludwigia prostrata</i> | + | | H | Phylloscopidae | | | | |
| Euphorbiaceae | | | | 100. <i>Phylloscopus fuscatus</i> | + | | LC | P |
| 104. <i>Acalypha australis</i> | + | + | M | 101. <i>Phylloscopus proregulus</i> | + | | LC | P |
| 105. <i>Euphorbia esula</i> | + | + | X | 102. <i>Phylloscopus inornatus</i> | + | | LC | P |
| 106. <i>Euphorbia helioscopia</i> | + | + | M | 103. <i>Phylloscopus coronatus</i> | + | | LC | S |
| 107. <i>Euphorbia humifusa</i> | + | | X | Acrocephalidae | | | | |
| 108. <i>Euphorbia maculata</i> | + | + | X | 104. <i>Acrocephalus orientalis</i> | + | | - | S |
| 109. <i>Phyllanthus ussuriensis</i> | + | | X | 105. <i>Acrocephalus arundinaceus</i> | + | | LC | S |
| Oxalidaceae | | | | Cisticolidae | | | | |
| 110. <i>Oxalis bowiei</i> | + | | M | 106. <i>Cisticola juncidis</i> | + | + | LC | P |
| 111. <i>Oxalis corniculata</i> | + | | X | Sylviidae | | | | |
| Geraniaceae | | | | 107. <i>Paradoxornis heudei</i> | + | | NT | R |
| 112. <i>Erodium stephanianum</i> | + | | X | 108. <i>Sinosuthora webbiana</i> | + | + | LC | R |
| 113. <i>Geranium carolinianum</i> | + | + | X | Sturnidae | | | | |
| Vitaceae | | | | 109. <i>Spodiopsar cineraceus</i> | + | | LC | R |
| 114. <i>Cayratia japonica</i> | + | + | M | 110. <i>Spodiopsar sericeus</i> | + | | LC | P |
| Asclepiadaceae | | | | Turdidae | | | | |
| 115. <i>Metaplexis japonica</i> | + | + | X | 111. <i>Turdus eunomus</i> | + | | - | P |
| 116. <i>Euphorbia esula</i> | + | + | X | 112. <i>Turdus merula</i> | + | + | LC | R |
| 117. <i>Cynanchum thesioides</i> | + | | X | Muscicapidae | | | | |
| 118. <i>Cynanchum chinense</i> | + | | X | 113. <i>Tarsiger cyanurus</i> | + | | LC | P |
| Solanaceae | | | | 114. <i>Phoenicurus auroreus</i> | + | + | LC | R |
| 119. <i>Solanum nigrum</i> | + | | M | 115. <i>Saxicola maurus</i> | + | + | - | P |
| 120. <i>Nicandra physalodes</i> | + | | M | 116. <i>Ficedula parva</i> | + | | LC | P |
| 121. <i>Datura stramonium</i> | + | | X | 117. <i>Copsychus saularis</i> | + | + | LC | R |
| 122. <i>Physalis minima</i> | + | | M | 118. <i>Rhyacornis fuliginosa</i> | + | | LC | P |
| Convolvulaceae | | | | Passeridae | | | | |
| 123. <i>Pharbitis purpurea</i> | + | + | M | 119. <i>Passer montanus</i> | + | + | LC | R |
| 124. <i>Calystegia hederacea</i> | + | | X | Motacillidae | | | | |
| 125. <i>Calystegia sepium</i> | + | + | X | 120. <i>Motacilla tschutschensis</i> | + | | LC | P |
| 126. <i>Calystegia pellita</i> | + | | X | 121. <i>Motacilla alba</i> | + | + | LC | S |
| 127. <i>Convolvulus arvensis</i> | + | + | X | 122. <i>Motacilla tschutschensis</i> | + | | LC | P |
| 128. <i>Pharbitis hederacea</i> | + | + | M | 123. <i>Dendronanthus indicus</i> | + | | LC | S |
| 129. <i>Pharbitis nil</i> | + | + | M | 124. <i>Anthus spinoletta</i> | + | | LC | P |
| 130. <i>Cuscuta chinensis</i> | + | | X | 125. <i>Anthus hodgsoni</i> | + | + | LC | P |
| Gentianaceae | | | | 126. <i>Anthus cervinus</i> | + | | LC | W |
| 131. <i>Nymphoides peltata</i> | + | | A | Fringillidae | | | | |
| Boraginaceae | | | | 127. <i>Carduelis sinica</i> | + | + | LC | R |
| 132. <i>Lithospermum arvense</i> | + | | X | 128. <i>Fringilla montifringilla</i> | + | | LC | W |
| 133. <i>Lithospermum erythrorhizon</i> | + | | X | 129. <i>Eophona migratoria</i> | + | | LC | P |
| 134. <i>Trigonotis peduncularis</i> | + | + | X | 130. <i>Fringilla montifringilla</i> | + | | LC | W |
| 135. <i>Bothriospermum tenellum</i> | + | | X | Emberizidae | | | | |
| 136. <i>Bothriospermum secundum</i> | + | | X | 131. <i>Emberiza cioides</i> | + | | LC | R |
| 137. <i>Thyrocarpus glochidiatus</i> | + | | X | 132. <i>Emberiza pusilla</i> | + | + | LC | W |
| 138. <i>Lappula myosotis</i> | + | | X | 133. <i>Emberiza chrysophrys</i> | + | + | LC | P |
| Portulacaceae | | | | 134. <i>Emberiza elegans</i> | + | | LC | P |
| 139. <i>Portulaca oleracea</i> | + | | M | 135. <i>Emberiza rustica</i> | + | | LC | W |
| 140. <i>Portulaca grandiflora</i> | + | | M | 136. <i>Emberiza fucata</i> | + | | LC | P |
| Labiatae | | | | 137. <i>Emberiza spodocephala</i> | + | + | LC | P |
| 141. <i>Lagopsis supina</i> | + | + | X | 138. <i>Emberiza pallasi</i> | + | | LC | S |

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|--|---|---|---|------------------------------------|-----------|-----------|----|---|
| 142. <i>Leonurus artemisia</i> | + | + | X | 139. <i>Emberiza yessoensis</i> | + | | NT | P |
| 143. <i>Mentha haplocalyx</i> | + | + | M | Species list of beetles | | | | |
| 144. <i>Scutellaria barbata</i> | + | | H | Species | MS | IS | | |
| 145. <i>Glechoma longituba</i> | + | | H | Coccinellidae | | | | |
| 146. <i>Lamium amplexicaule</i> | + | | M | 1. <i>Propylaea japonica</i> | + | | | |
| 147. <i>Salvia plebeia</i> | + | + | M | 2. <i>Oenopia conglobata</i> | | | + | |
| Plantaginaceae | | | | 3. <i>propylaea</i> sp. | | | + | |
| 148. <i>Plantago asiatica</i> | + | + | M | 4. <i>illeis</i> sp. | | | + | |
| 149. <i>Plantago depressa</i> | + | | M | 5. <i>Calvia</i> sp. | | | + | |
| 150. <i>Veronica persica</i> | | + | X | 6. <i>Anisosticta kobensis</i> | + | | | |
| Scrophulariaceae | | | | Scarabaeidae | | | | |
| 151. <i>Mazus japonicus</i> | + | | M | 7. <i>Gymnopleurus</i> sp. | | | | |
| 152. <i>Lindernia procumbens</i> | + | | H | 8. <i>Copris ochus</i> | | | | |
| 153. <i>Rehmannia glutinosa</i> | + | | X | 9. <i>Brahmina faldermanni</i> | + | | | |
| 154. <i>Veronica anagallis-aquatica</i> | + | | H | Cryptophagidae | | | | |
| 155. <i>Veronica peregrina</i> | + | | M | 10. <i>Atomaria lewisi</i> | + | | | |
| 156. <i>Veronica didyma</i> | + | + | M | 11. <i>Haptoncus</i> sp. | + | | | |
| Acanthaceae | | | | 12. <i>Cryptophagidae</i> sp. | + | | | |
| 157. <i>Rostellularia procumbens</i> | + | | M | Carabidae | | | | |
| Lentibulariaceae | | | | 13. <i>Cicindela raleea</i> | + | | | |
| 158. <i>Utricularia vulgaris</i> | + | | M | 14. <i>Carabus brandti</i> | + | | | |
| Cucurbitaceae | | | | 15. <i>Pheropsophus jessoensis</i> | + | | | |
| 159. <i>Actinostemma tenerum</i> | + | | M | 16. <i>Chlaenius micans</i> | + | | | |
| 160. <i>Cucumis bisexualis</i> | + | | X | 17. <i>Chlaenius</i> sp. | + | | | |
| Compositae | | | | 18. <i>Chlaenius spoliatus</i> | + | | | |
| 161. <i>Artemisia carvifolia</i> | + | | X | 19. <i>Chlaenius naeviger</i> | + | | | |
| 162. <i>Artemisia annua</i> | + | | X | 20. <i>Carabus granulatus</i> | + | | | |
| 163. <i>Artemisia selengensis</i> | + | | X | 21. <i>Harpalus pallidipennis</i> | + | | | |
| 164. <i>Artemisia argyi</i> | + | | X | 22. <i>Harpalus</i> sp. | + | | | |
| 165. <i>Artemisia lavandulaefolia</i> | + | | X | 23. <i>Tachys</i> sp1. | + | | | |
| 166. <i>Artemisia capillaris</i> | + | | X | 24. <i>Tachys</i> sp2. | + | | | |
| 167. <i>Artemisia rubripes</i> | + | | X | 25. <i>Dolichus</i> sp. | + | | | |
| 168. <i>Erigeron annuus</i> | + | + | X | 26. <i>Dischissus</i> sp. | + | | | |
| 169. <i>Aster subulatus</i> | + | + | M | 27. <i>Calosoma chinense</i> | + | | | |
| 170. <i>Bidens frondosa</i> | + | + | M | 28. <i>Scarites</i> sp. | + | | | |
| 171. <i>Bidens bipinnata</i> | + | + | X | <i>Carabus smaragdinus</i> | + | | | |
| 172. <i>Bidens biternata</i> | + | + | M | 29. <i>Calosoma lugens</i> | + | | | |
| 173. <i>Bidens pilosa</i> | + | | H | Curculionidae | | | | |
| 174. <i>Carpesium abrotanoides</i> | + | | X | 30. <i>Sympiezomias</i> sp. | + | | | |
| 175. <i>Cirsium setosum</i> | + | + | M | 31. <i>Phytoscaphus gossypii</i> | | | | |
| 176. <i>Conyza canadensis</i> | + | + | X | 32. <i>Orchestes</i> sp. | + | | | |
| 177. <i>Conyza bonariensis</i> | + | + | X | Chrysomelidae | | | | |
| 178. <i>Dendranthema lavandulifolium</i> | + | | X | 33. <i>Medythia nigrobilineata</i> | + | | | |
| 179. <i>Eclipta prostrata</i> | + | + | H | 34. <i>Psylliodes</i> sp. | + | | | |
| 180. <i>Hemistepta lyrata</i> | + | + | M | 35. <i>Chrysochus chinensis</i> | + | | | |
| 181. <i>Inula japonica</i> | + | + | M | Dryopidae | | | | |
| 182. <i>Inula britannica</i> | + | | M | 36. <i>Praehelichus sericatus</i> | + | | | |
| 183. <i>Kalimeris integrifolia</i> | + | | M | Elateridae | | | | |
| 184. <i>Siegesbeckia orientalis</i> | + | | M | 37. <i>Pleonomus</i> sp. | + | | | |
| 185. <i>Tripolium vulgare</i> | + | | M | Anthicidae | | | | |
| 186. <i>Xanthium sibiricum</i> | + | + | M | 38. <i>Stricticollis tobias</i> | + | | | |
| 187. <i>Xanthium mongolicum</i> | + | | M | Nitidulidae | | | | |
| 188. <i>Centipeda minima</i> | + | | M | 39. <i>Urophorus</i> sp. | + | | | |
| 189. <i>Gnaphalium affine</i> | + | | M | Lucanidae | | | | |
| 190. <i>Carduus crispus</i> | + | | M | 40. <i>Dorcus</i> sp. | + | | | |
| 191. <i>Olgaea tangutica</i> | + | | X | Scolytidae | | | | |
| Cichorioideae | | | | 41. <i>Ips</i> sp. | | | | |
| 192. <i>Ixeridium chinense</i> | + | + | X | Histeridae | | | | |
| 193. <i>Ixeridium sonchifolium</i> | + | | X | 42. <i>Atholus depistor</i> | + | | | |
| 194. <i>Ixeris polycephala</i> | + | | X | 43. <i>Atholus pirithous</i> | + | | | |
| 195. <i>Mulgedium tataricum</i> | + | | M | Mycetophagidae | | | | |

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|---------------------------------------|---|---|---|-----------------------------------|-----------|-----------|
| 196. <i>Pterocypsela laciniata</i> | + | + | M | 44. <i>Mycetophagus</i> sp. | | + |
| 197. <i>Pterocypsela formosana</i> | + | | M | Staphylinidae | | |
| 198. <i>Sonchus oleraceus</i> | + | + | M | 45. <i>Paederus fuscipes</i> | + | + |
| 199. <i>Sonchus asper</i> | + | | X | 46. <i>Paederinae</i> sp1. | + | + |
| 200. <i>Taraxacum mongolicum</i> | + | + | X | 47. <i>Paederinae</i> sp2. | + | |
| 201. <i>Youngia japonica</i> | + | + | M | 48. <i>Stenus</i> sp. | + | |
| 202. <i>Lactuca seriola</i> | + | | M | 49. <i>Steninae</i> sp. | + | + |
| Butomaceae | | | | 50. <i>Aleochara curtula</i> | + | + |
| 203. <i>Butomus umbellatus</i> | + | | A | 51. <i>Phacophallus japonicus</i> | + | + |
| Hydrocharitaceae | | | | 52. <i>Anotylus latiusculus</i> | + | + |
| 204. <i>Hydrocharis dubia</i> | + | | A | 53. <i>Staphylininae</i> sp1. | + | |
| 205. <i>Hydrilla verticillata</i> | + | | A | 54. <i>Staphylininae</i> sp2. | + | + |
| Potamogetonaceae | | | | 55. <i>Scaphidinae</i> sp. | + | + |
| 206. <i>Potamogeton crispus</i> | + | | A | 56. <i>Aleochara bilineata</i> | + | |
| 207. <i>Potamogeton lucens</i> | + | | A | 57. <i>Aleocharinae</i> sp. | + | + |
| 208. <i>Potamogeton malaianus</i> | + | | A | Species list of spiders | | |
| 209. <i>Potamogeton pectinatus</i> | + | | A | Species | MS | IS |
| Najadaceae | | | | Lycosidae | | |
| 210. <i>Najas marina</i> | + | | A | 1. <i>Pardosa astrigera</i> | + | + |
| Araceae | | | | 2. <i>Pardosa</i> sp. | + | + |
| 211. <i>Acoris calamus</i> | + | | H | 3. <i>Trochosa ruricola</i> | + | + |
| Lemnaceae | | | | Linyphiidae | | |
| 212. <i>Spirodela polyrrhiza</i> | + | | A | 4. <i>Erigone prominens</i> | + | + |
| 213. <i>Lemna minor</i> | + | | A | 5. <i>Ummeliata feminea</i> | + | + |
| Commelinaceae | | | | 6. Linyphiidae sp. | + | |
| 214. <i>Commelina communis</i> | + | | M | Araneidae | | |
| 215. <i>Commelina bengalensis</i> | + | + | M | 7. <i>Araneus</i> sp. | + | + |
| Juncaceae | | | | 8. <i>Larinioides cornuta</i> | + | + |
| 216. <i>Juncus taonanensis</i> | + | | H | Gnaphosidae | | |
| Cyperaceae | | | | 9. <i>Gnaphosa kansuensis</i> | + | + |
| 217. <i>Carex raddei</i> | + | | H | 10. <i>Drassodes</i> sp. | + | + |
| 218. <i>Carex neurocarpa</i> | + | | H | 11. Gnaphosidae sp. | + | |
| 219. <i>Cyperus rotundus</i> | + | + | H | Clubionidae | | |
| 220. <i>Cyperus glomeratus</i> | + | | A | 12. <i>Clubiona</i> sp. | + | + |
| 221. <i>Cyperus exaltatus</i> | + | | H | Philodromidae | | |
| 222. <i>Cyperus microiria</i> | + | + | H | 13. <i>Thanatus</i> sp. | + | |
| 223. <i>Cyperus amuricus</i> | + | | H | Thomisidae | | |
| 224. <i>Cyperus fuscus</i> | + | | H | 14. <i>Xysticus</i> sp. | + | + |
| 225. <i>Cyperus nipponicus</i> | + | | H | 15. <i>Xysticus eohippiatus</i> | + | + |
| 226. <i>Cyperus difformis</i> | + | | H | Salticidae | | |
| 227. <i>Cyperus michelianus</i> | + | | H | 16. <i>Asianellus</i> sp. | + | |
| 228. <i>Fimbristylis bisumbellata</i> | + | | H | 17. <i>Evarcha</i> sp. | + | |
| 229. <i>Juncellus serotinus</i> | + | | H | | | |
| 230. <i>Pycreus sanguinolentus</i> | + | | H | | | |
| 231. <i>Pycreus globosus</i> | + | | H | | | |
| 232. <i>Scirpus planiculmis</i> | + | | A | | | |
| 233. <i>Scirpus triqueter</i> | + | | A | | | |
| 234. <i>Scirpus ehrenbergii</i> | + | | A | | | |
| 235. <i>Scirpus validus</i> | + | | H | | | |
| Gramineae | | | | | | |
| 236. <i>Arthraxon hispidus</i> | + | | X | | | |
| 237. <i>Beckmannia syzigachne</i> | + | | H | | | |
| 238. <i>Bromus inermis</i> | + | | X | | | |
| 239. <i>Bromus japonicus</i> | + | + | M | | | |
| 240. <i>Bothriochloa ischaemum</i> | + | | X | | | |
| 241. <i>Chloris virgata</i> | + | | X | | | |
| 242. <i>Cleistogenes chinensis</i> | + | | X | | | |
| 243. <i>Cynodon dactylon</i> | + | + | M | | | |
| 244. <i>Digitaria sanguinalis</i> | + | + | X | | | |
| 245. <i>Digitaria ischaemum</i> | + | | X | | | |
| 246. <i>Diplachne fusca</i> | + | | H | | | |

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|--------------------------------------|---|---|---|--|--|
| 247. <i>Echinochloa crusgalli</i> | + | + | H | | |
| 248. <i>Echinochloa caudata</i> | + | | H | | |
| 249. <i>Eleusine indica</i> | + | + | X | | |
| 250. <i>Eragrostis cilianensis</i> | + | | X | | |
| 251. <i>Eragrostis Pilosa</i> | + | | X | | |
| 252. <i>Eragrostis autumnalis</i> | + | | X | | |
| 253. <i>Eriochloa villosa</i> | + | | X | | |
| 254. <i>Hemarthria altissima</i> | + | + | M | | |
| 255. <i>Imperata cylindrica</i> | + | + | X | | |
| 256. <i>Leersia japonica</i> | + | | H | | |
| 257. <i>Leptochloa panicea</i> | + | | X | | |
| 258. <i>Leptochloa chinensis</i> | + | | X | | |
| 259. <i>Paspalum paspaloides</i> | + | | H | | |
| 260. <i>Phragmites australis</i> | + | + | H | | |
| 261. <i>Polygogon fugax</i> | + | | H | | |
| 262. <i>Poa sphondylodes</i> | + | | X | | |
| 263. <i>Setaria faberii</i> | + | + | X | | |
| 264. <i>Setaria viridis</i> | + | + | X | | |
| 265. <i>Themeda japonica</i> | + | | X | | |
| 266. <i>Triarrhena sacchariflora</i> | + | + | X | | |
| 267. <i>Avena fatua</i> | + | + | X | | |
| 268. <i>Alopecurus aequalis</i> | + | + | M | | |
| 269. <i>Aegilops tauschii</i> | + | + | M | | |
| 270. <i>Roegneria japonensis</i> | + | + | M | | |
| Typhaceae | | | | | |
| 271. <i>Typha angustifolia</i> | + | | A | | |
| Dioscoreaceae | | | | | |
| 272. <i>Dioscorea opposita</i> | + | | M | | |

Abbreviations: WE, Water ecotypes (H, hygrophytic plant; A, aquatic plant; X, xerophytic plant; M, mesophytic plant); IUCN, IUCN Red List of Birds (EN, endangered; VU, vulnerable; NT, near threatened; LC, least concern; -, no assessment); Migration (R, resident bird; P, passing migrant birds; S, summer migratory bird; W, winter migratory bird)