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Effects of land use changes on winter-active Collembola in Sanjiang Plain of China

Bing Zhang[a,b], Liang Chang[b,**], Zhen Ni[a,b], Mac A. Callaham Jr.[c], Xin Sun[b], Donghui Wu[a,b,*]

[a] College of Earth Sciences, Jilin University, Changchun 130061, China
[b] Northeast Institute of Geography and Agroecology, Chinese Academy of Sciences, Changchun 130102, China
[c] USDA, Forest Service, Southern Research Station, Center for Forest Disturbance Science, Athens, GA 30602, USA

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ABSTRACT

Sanjiang Plain is the largest concentrated area of freshwater wetlands in China, however nearly 80% of these freshwater wetlands were drained or reclaimed in the past 50 years. It is important to know whether wetlands reclamation would affect soil invertebrates, especially the winter-active invertebrates. During November 2011 to April 2012, we used pitfall traps and in-field direct observation methods to study the activity of collembolans in wetland, and a reclaimed forest plantation and soybean field. In total, 3465 collembolans were captured and identified to 8 species from 6 families. *Desoria* sp. 1, *Desoria* sp. 2 and *Desoria* sp. 3 were the three dominant species. Collembolan abundance and assemblages were significantly affected by the land use changes. The results showed that (1) Collembola captured by pitfall traps showed a highest abundance in wetland, with ∼50% decreased abundance in soybean field, and ∼75% decreased in the forest plantation. (2) Collembola activity changed during the winter season, their activity significantly increased from early winter to late winter; with a peak in March in all three land use types. (3) Collembola assemblages were affected by land use changes with a significant decrease of frequency of *Desoria* sp. 3 and a significant increase of frequency of *Desoria* sp. 2 in soybean field and forest plantation. (4) Collembolan densities on the snow surface usually peaked between 1400 h and 1500 h, and decreased quickly when the temperature dropped below freezing. Mean abundance reached 119 individuals m^{-2} on the snow surface in wetland, 152 individuals m^{-2} in soybean field, and 64 individuals m^{-2} in forest plantation. All collembolans moved up and down through the snow profile depending on temperature, no collembolans were found on the snow surface in the evening. Our study indicated that the reclamation of wetland resulted in a significant decrease of abundance and a different assemblage of winter active Collembola in Northeast China, but land use changes did not change their pattern of activity: Collembolans were rarely active in early and middle winter and mostly active in late winter. Their daily densities on the snow surface fluctuated according to both air temperatures and land use types.

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1. Introduction

Land use change is one of the primary factors determining patterns of biodiversity of soil organisms, such as Collembola, at local and regional levels (Lavelle et al., 1997; Bengtsson, 2002). Moreover, landscape configuration (e.g., heterogeneity, fragmentation) and the type of land use (e.g., pasture, farm forest) also regulate Collembola community composition (Filser et al., 1996; Lauga-Reyrel and Deconchat, 1999; Alvarez et al., 2000; Dombos, 2001). For instance, Collembola communities react to change in management practices (Dekkers et al., 1994; Filser et al., 1995; Loranger et al., 1999; Frampton, 2000; Alvarez et al., 2001). Collembolan communities have also been shown to vary in abundance and species composition according to changes in vegetation and soil conditions (Hågvar, 1982; Ponge, 1993; Chagnon et al., 2000). A decrease of species richness and total abundance was observed toward more intensively managed land from natural forests to agricultural fields (Ponge et al., 2003, 2006; Sousa et al., 2000, 2004, 2006).

* Corresponding author at: College of Earth Sciences, Jilin University, Changchun 130061 China. Tel.: +86 0431 8554 2264; fax: +86 0431 8554 2298.
** Corresponding author. Tel.: +86 0431 8554 2264; fax: +86 0431 8554 2298.
E-mail addresses: zhangbing061989@126.com (B. Zhang), springtail@neigae.ac.cn (L. Chang), nizhen09@gmail.com (Z. Ni), mac.callaham@gmail.com (M.A. Callaham Jr.), sunxin@neigae.ac.cn (X. Sun), wudonghui@neigae.ac.cn (D. Wu).

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Most of the studies discussed above had a focus on changes in Collembola communities during the growing season. However, some species are active in winter, and the responses of winter-active Collembola, which is a sub-set of the surface-dwelling species in an area, to land use changes have not previously been studied. They usually represent a group of species with patchy distribution that may be difficult to study quantitatively during summer, even though they can be among the most abundant species in a particular area (Leinaas, 1981a). In winter time, however, they are more dispersed, and easier to be studied on the snow surface. Invertebrates active in winter are affected by the snow cover. Ecologically, the snow layer creates three different microhabitats: subnivean (below snow), intranivean (within snow), and supranivean (the snow surface), each with its characteristic arthropod fauna (general summary by Aitchison, 2001). Collembola active in subnivean environments have been documented by using pitfall traps (Näsmark, 1964; Aitchinson, 1974, 1979; Schmidt and Lockwood, 1992; Hägvar and Hägvar, 2011), some of them may migrate up into the snow or to the snow surface to escape water logging or predation (Brummer-Korvenkontio and Brummer-Korvenkontio, 1980; Leinaas, 1981a, 1983). Supranivean activity of Collembola was studied by many authors (Fitch, 1850; Latzel, 1907a,b; MacNamara, 1919, 1924; Stürbing, 1958; Durbin, 1975; Leinaas, 1981a,b,c, 1983; Zettel, 1984, 1985; Janetschek, 1990; Hägvar, 1995, 2000). *Hypogastrura socialis* was the most abundant species on snow in forests in Norway. Leinaas (1981a) repeatedly measured a density on snow of approximately 4000 individuals m^{-2} during February and March, and Hägvar (1995) found that they were roughly 2000–10,000 m^{-2} on the snow surface during the middle of April 1995, and showed a directional mass migration on the snow surface. Several species of Collembola have been documented to perform directional migration on the snow, orienting by the sun or toward tall objects (Leinaas and Fjellberg, 1985; Hägvar, 2000). The migration ability on the snow surface in winter makes it possible for them to move over great distances, partly to establish new colonies and partly to exchange genes between colonies (cf. Leinaas, 1981c; Zettel, 1985). Land use changes may change their habitat preferences in harsh winter conditions.

Sanjiang Plain, located in the east of Heilongjiang province, northeastern China, is the largest concentrated area of freshwater wetlands in China. Due to large-scale agricultural development, nearly 80% of the freshwater wetlands in Sanjiang Plain have been extensively converted to agricultural fields in the past 50 years, and thus has been significantly degraded (Liu and Ma, 2002). While many efforts have been made to analyze climate changes, landscape changes, and effects of wetland reclamation on local environment in Sanjiang Plain (Zhang et al., 2001; Yan et al., 2001; Wang et al., 2006), there is still a lack of information on the local biodiversity of soil invertebrates and the effects of land use change on them (Wu et al., 2008; Bao et al., 2010; Sun and Wu, 2012). The snow cover in Sangjiang Plain may create various living habitats for winter-active collembolans, which deserve further studies.

Previous studies have shown that collembolan communities were affected by land use change during the plant growing season (Ponge et al., 2003, 2006; Sousa et al., 2004, 2006; Chang et al., 2013). However, no studies focused on whether and to what extent the winter activity of Collembola is affected by land use change. Pitfall traps and direct in-field observations methods were used to study the effects of land use on the abundance and community structure of collembolans in winter during the period of snow cover. Expected effects are indicated in the following three hypotheses: (1) Abundance and species dominance of winter active Collembola are affected by the different land use of the area. (2) Land use has no effect on Collembola activity in the subnivean space, within the snow pack and on the snow surface. (3) The Collembola activity in winter is affected by temperature and time. To our knowledge, this is the first report of winter-active Collembola in China, and the first study on the responses of winter-active collembolans to land use changes.

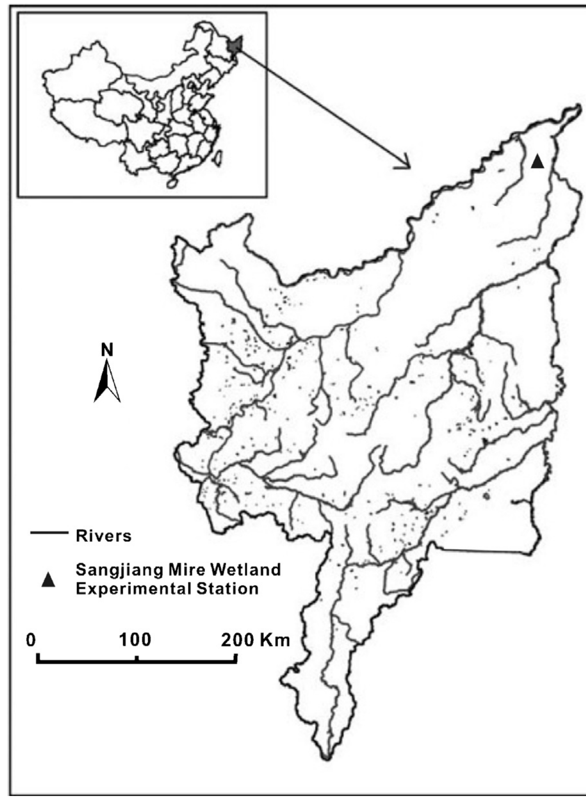

Fig. 1. Location of the Sanjiang Plain and the Sanjiang Mire Wetland Experimental Station.

2. Materials and methods

2.1. The study area

The study was carried out from November 2011 to April 2012, at the 35 years old long-term observation station-Sanjiang Mire Wetland Experimental Station (47°13′ N, 133°13′ E), Chinese Academy of Sciences, located in the center of the Sanjiang Plain. The site is situated in Heilongjiang Province of northeastern China; it is a low alluvial plain, which was formed by the Heilong, the Songhua and the Wusuli rivers. This region experiences a temperate humid to sub-humid continental monsoon climate. The position of the study site is shown in Fig. 1.

The mean annual temperature ranges from 1.4 to 4.3 °C, with average maximum of 21–22 °C in July and average minimum −21 to 18 °C in January. Daily maximum and minimum temperatures during the winter period are shown in Fig. 2 .The elevation of the study area is 55.4–57.9 m above sea level, and the mean annual precipitation is 565–600 mm. More than 60% of the annual precipitation falls between July and September. The freezing period is up to 7–8 months (from November to May), and the site is under continuous snow cover for a period of up to 6 months (from November to April). All three land use types are on lessive soil.

The study was performed in three adjacent areas of different land use: a wetland site (length × width = 100 m × 150 m), a reclaimed soybean field (length × width = 200 m × 200 m) and a reclaimed forest plantation (length × width = 100 m × 100 m), which separated the wetland and soybean field. The wetland was

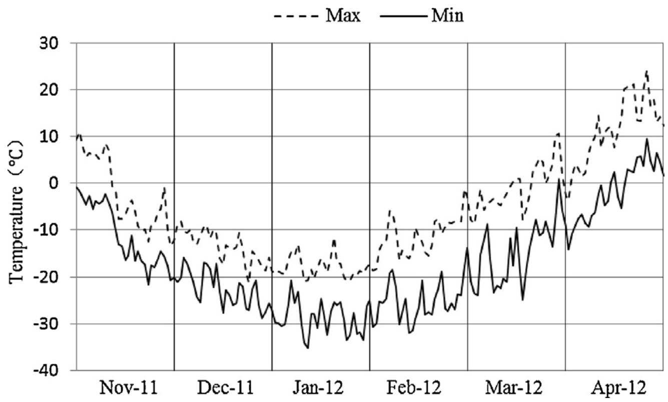

Fig. 2. Maximum and minimum air temperatures during the winter period of 2011–2012.

dominated by *Calamagrostis angustifolia*. The plantation was typical of forestry practices in the region and was dominated by *Populus davidiana*, the sparse vegetation between trees containings *Calamogrostis angustifolia*, *Carex* spp., *Phragmites communis*, *Artemisia stolonifera*. The soybean field had been reclaimed from wetland for a continuous planting of seasonal soybean for nearly 30 years. During winter the soybean field was partly covered by soybean straw and roots from the previous year's crop that had remained in the soil. The thickness of the snow cover in this area was 20–40 cm between November 25th, 2011 and January 5th, 2012; 40–60 cm between January 6th and March 6th, 2012; 0–20 cm between March 7th and March 28th, 2012; and the ground was bare after March 28th, 2012. In the peak activity days, the supranivean temperatures in these three land use types were almost the same, while the subnivean temperatures in soybean field and forest plantation were significantly higher than that in wetland (Fig. 3A and B), and the thicknesses of snow cover in three land use types were generally equal, but the snow melted faster in soybean field than in forest plantation and wetland. Though the snow near the pitfall traps was gone in March 24th, the large-scale thaw was seen after March 28th in all study sites. Soil in soybean field thawed one month earlier than that in the wetland and forest plantation and theoretically abbreviated the winter for soil living animals in soybean field.

2.2. Sampling

2.2.1. Pitfall traps on the ground

The trap design to sample Collembola was similar to Hägvar and Hägvar (2011), but without snow cover on the upper lid. The traps (diameter 7 cm; depth 9 cm) were dug into the soil to a little under their upper rim, and the trap was modified to collect collembolans that passed through the space under the upper lid (Fig. 4). A water-proof piece of plywood (length × width = 30 cm × 30 cm) (the lower lid) placed 1–3 cm over the trap had a central hole that was 10 cm in diameter. A 15 cm high support (a bracket) was placed on the plywood to allow space for animals to move into the trap area. Another water-proof roof of plywood (length × width = 30 cm × 30 cm) (the upper lid) placed on the support to prevent the snow falling into the trap, and a stone was placed on the roof to prevent the plywood from being blown away by wind. A saturated salt water solution with a few drops of detergent served as an anti-freeze preservative, and the collembolans were afterwards preserved in 95% ethanol. Sampling procedure: the upper lid and the brandreth were moved away firstly and the inner cup with the trap contents was replaced by a new one through the hole. Then the upper lid and the brandreth were replaced. The snow around the trap was not disturbed.

On November 25th, 2011, before snowfall, 5 pitfall traps (average 8 m apart) were randomly placed in areas where snow depth

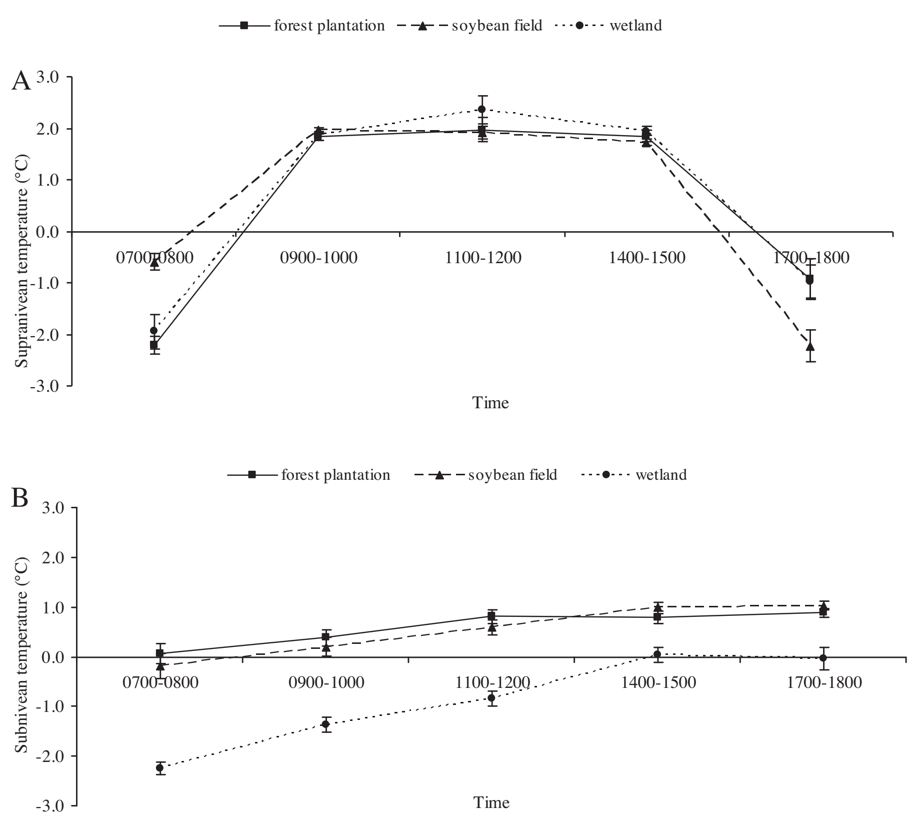

Fig. 3. (A) The supranivean temperatures (mean ± SE) in three land use types (wetland, soybean field and forest plantation). (B) The subnivean temperatures (mean ± SE) in three land use types (wetland, soybean field and forest plantation). WL = wetland, SF = soybean field, FP = forest plantation.

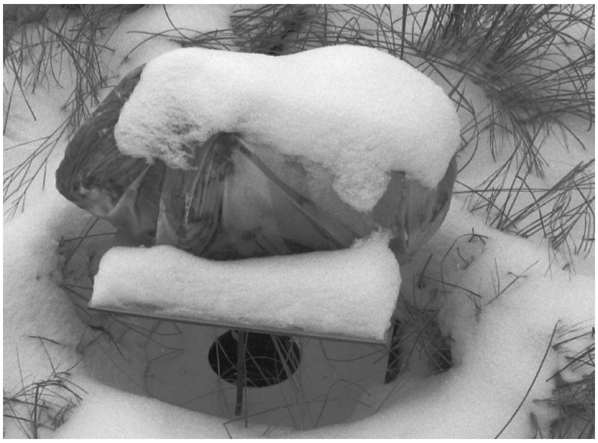

Fig. 4. The trap (diameter 7 cm; depth 9 cm) with saturated salt water solution and a few drops of detergent was dug into the soil to a little under their upper rim. A water-proof piece of plywood (length × width = 30 cm × 30 cm) (the under lid) placed 1–3 cm over the trap had a central hole that was 10 cm in diameter. A 15 cm high support (a brandreth) was placed on the plywood. Another water-proof roof of plywood (length × width = 30 cm × 30 cm) (the upper lid) pressed by a stone placed on the support to prevent the snow falling into the trap.

was adequate to accommodate the trap design in each of the three field types. Traps were emptied and replaced on January 6th, March 6th, March 28th, and April 7th, 2012. The traps were run continuously through the winter, including a short period after snow-melt (between March 28th and April 7th).

2.2.2. Field observations on the snow surface

Direct field observations of collembolan activity were carried out in wetland, forest plantation, and soybean field. Five plots (12 m apart on average) were randomly set up at each observation area in an S-shaped distribution. We recorded the number of collembolans active on 0.5 m^2 snow surface hourly at 0700–0800 h, 0900–1000 h, 1100–1200 h, 1400–1500 h, and 1700–1800 h in March 22nd, 24th, 26th, and 28th, and we also recorded the real-time temperatures on the snow surface and under the snow cover with an electronica thermometer.

2.2.3. Traps within the snow profile

In addition, 10 traps on the snow surface were made at each land use type at 0700 h at March 22nd, 24th, 26th, and 28th. The traps were made by pushing a board (length × width = 10 cm × 30 cm) 10–40 cm deep into snow (depending on the snow cover) and agitated to trap collembolans jumping on the snow surface. We recorded the number of collembolans in these traps at 0700–0800 h, 0900–1000 h, 1100–1200 h, 1400–1500 h, and 1700–1800 h.

2.3. Species identification

The collembolans were identified following Yin (1998) and Potapov (2001). The identifications of three *Desoria* species were to morpho-species and was mainly based on their color, the positioning of macrosetae of abdominal segments V & VI (*Desoria* sp. 1: dark violet, long macrosetae, Abd. V & VI fused; *Desoria* sp. 2: dark blackish, short macrosetae, Abd. V & VI separated; *Desoria* sp. 3: yellowish to green, short macrosetae, Abd. V & VI separated). Descriptions of the new species are in preparation.

2.4. Statistical analysis

SPSS 13.0 for Windows and CANOCO Version 4.5 were used for data analyses. The number of Collembola individuals was

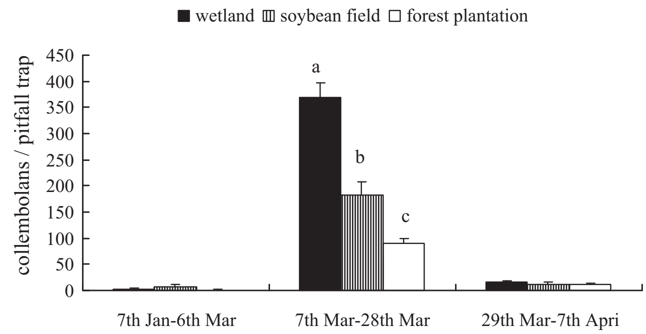

Fig. 5. The abundance of collembolans (mean ± SE) captured by pitfall traps in three land use types (wetland, soybean field and forest plantation) throughout the winter of 2011–2012. Different lowercase letters indicate significant differences (LSD test, $p < 0.05$).

$\log_{10}(n+1)$ transformed to obtain a normal distribution. One-way ANOVA was performed using SPSS to analyze the effects of land use types on the frequencies of three *Desoria* species captured by pitfall traps on the ground and the effects of time on abundance of Collembola active on the snow surface and captured by traps within the snow profile. Repeated measurement ANOVA was performed using SPSS to analyze the effects of land use on the abundance of Collembola captured by pitfall traps on the ground and profile, and the Collembola densities on the snow surface. The sampling dates were included as replication levels; the different land use types were used as “between subject” factor. The daily variations of densities of Collembola active on the snow surface were analyzed by using a repeated measurement ANOVA. The four sampling dates were included as replication levels; the different land use types and sampling times were used as “between subject” factor. The daily supranivean and subnivean temperatures were also analyzed by using a repeated measurement ANOVA. The five sampling times were included as replication levels; the different land use types were used as “between subject” factor.

3. Results

3.1. Species assemblages in pitfall traps on the ground

In total, 3465 individuals of Collembola were captured by pitfall traps and identified to 8 species from 6 families (Table 1). Specifically, 1937 individuals were captured by pitfall traps in wetland. The abundance of Collembola significantly decreased in soybean field (1023 individuals) and plantation (505 individuals) when compared to wetland (repeated measurement ANOVA: $F_{2,10} = 49.225$, $p < 0.001$, interaction time × ecosystem $F = 57.413$, $p < 0.001$, Table 1 and Fig. 5). Seven species of Collembola were captured in wetland, and 7 species in forest plantation, 6 species in soybean field. The dominant species in all three land use types were *Desoria* sp. 1, *Desoria* sp. 2, and *Desoria* sp. 3. The frequencies of the three species differed during the peak activity period as follows: *Desoria* sp. 3 was most dominant in wetland (one way ANOVA: $F_{2,12} = 285.3$, $p < 0.001$, Fig. 6), while *Desoria* sp. 2 was most dominant in soybean field and the forest plantation (one way ANOVA: $F_{2,12} = 134.1$, $p < 0.001$, Fig. 6). Only a few individuals of *Tomocerus* sp. 1, *Heteroisotoma* sp. 1, *Isotoma* sp. 1, *Entomobrya* sp. 1, and *Isotomurus* sp. 1 were captured in the study area (Table 1).

3.2. Collembola densities on the snow surface and abundance in traps within the snow profile

The land use type had a significant effect on the densities of Collembola on the snow surface. There was significantly lower

Table 1
The total number of collembolans captured by pitfall traps from November 2011 to April 2012 in three land use types in Sanjiang plain, Northeastern China. Numbers per 5 pitfall traps. WT = wetland; SF = soybean field; FP = forest plantation.

Time Snow thickness (cm)	November 25th–January 5th 20–40			January 6th–March 6th 40–60			March 7th–March 28th 0–40			March 29th–April 7th 0		
	WT	SF	FP	WT	SF	FP	WT	SF	FP	WT	SF	FP
Entomobryidae												
Entomobrya sp. 1	0	0	0	0	0	0	0	0	2	7	3	0
Isotomidae												
Desoria sp. 1	0	0	0	4	3	1	314	156	77	5	6	7
Desoria sp. 2	2	0	0	6	26	1	409	754	311	31	19	20
Desoria sp. 3	0	0	0	2	0	3	1120	24	34	29	20	21
Heteroisotoma sp. 1	0	0	0	0	0	0	0	2	21	0	0	3
Isotoma sp. 1	0	0	0	0	0	0	0	8	0	3	2	1
Isotomurus sp. 1	0	0	0	0	0	0	0		1	1	0	2
Tomoceridae												
Tomocerus sp. 1	0	0	0	0	0	0	3	0	0	1	0	0
Total			2			46			3233			180

activity in forest plantation than in wetland and soybean field (repeated measurement ANOVA: $F_{2,12} = 12.087$, $p = 0.001$, interaction time × ecosystem, $F = 8.804$, $p = 0.001$, Fig. 7A). In the peak activity day, an average density of 119 animals m^{-2} was observed in wetland, 152 animals m^{-2} in soybean field, and 64 animals m^{-2} in forest plantation. The land use types also had a significant effect on the abundance of Collembola in the traps within the snow profile. The highest abundance in traps within the snow profile was found in the wetland and the lowest in the forest plantation (repeated measurement ANOVA: $F_{2,27} = 54.527$, $p < 0.001$, interaction time × ecosystem, $F = 27.457$, $p < 0.001$, Fig. 7B).

3.3. Collembola activity in winter

Over the course of the sampling period, snow cover was thickest between January 6th and March 6th, 2012, and the ground was bare after March 28th, 2012; totally 93% of the individuals were captured from March 7th to March 28th (Table 1). The collembolans in all three land use types exhibited the same peak in activity from March 7th to March 28th (Fig. 5): in wetland (one way ANOVA: $F_{2,11} = 343.8$, $p < 0.001$), in soybean field (one way ANOVA: $F_{2,12} = 55.71$, $p < 0.001$), and in forest plantation (one way ANOVA: $F_{2,12} = 70.97$, $p < 0.001$). During the winter, only several individuals were found on the snow surface before March 21st, however large numbers of collembolans were observed active on the snow surface after March 22nd in all three land use types. Their densities on the snow surface significantly decreased from March 22nd to March 28th in all three land use types (Fig. 7A): in wetland (one way ANOVA: $F_{3,16} = 28.8$, $p < 0.001$), in soybean field (one way ANOVA: $F_{3,16} = 75.8$, $p < 0.001$), and in forest plantation (one way ANOVA: $F_{3,16} = 192.5$, $p < 0.001$).

From March 22nd to 28th, the diurnal variation in supranivean temperatures in these three land use types were almost the same (repeated measurement ANOVA: $F_{2,42} = 0.341$, $p = 0.713$, interaction time × ecosystem $F = 8.294$, $p < 0.001$, Fig. 3A) while the subnivean temperatures in soybean field and forest plantation were significantly higher than that in wetland (repeated measurement ANOVA: $F_{2,42} = 47.635$, $p < 0.001$, interaction time × ecosystem $F = 7.732$, $p < 0.001$, Fig. 3B). Collembolans began to be active on the snow surface at ca.0700 h when the temperature was close to zero, and densities increased as the supranivean temperature rose above freezing. Highest densities were observed at 1400–1500 h, followed by 1100–1200 h, and the lowest densities

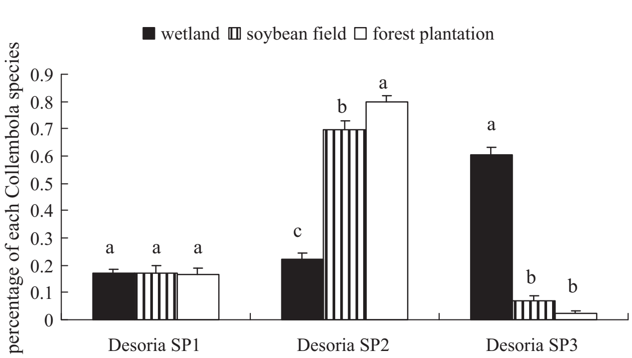

Fig. 6. Relative frequency (%) of different species (mean ± SE) captured in three land use types (wetland, soybean field and forest plantation) throughout the winter of 2011–2012. Different lowercase letters indicate significant differences (LSD test, $p < 0.05$).

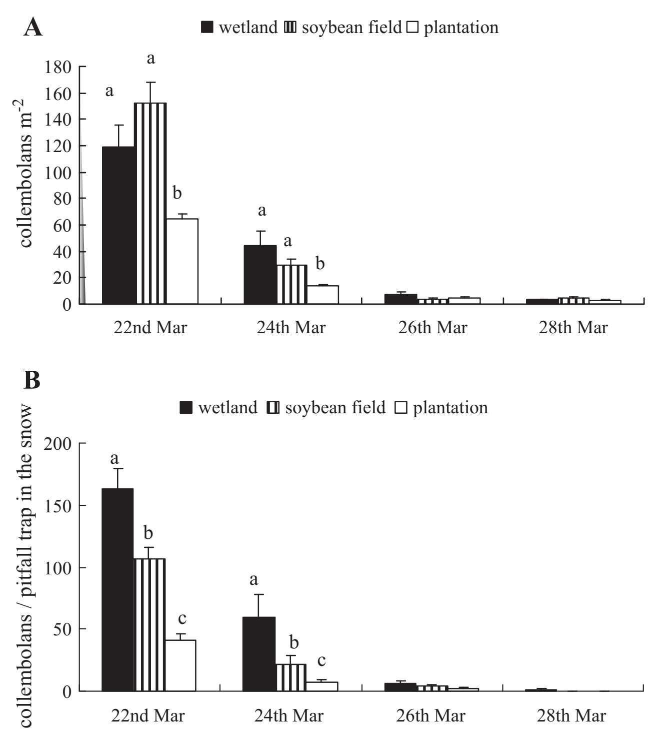

Fig. 7. (A) The densities of collembolans (mean ± SE) active on the snow surface in three land use types (wetland, soybean field and forest plantation) in late winter of 2011–2012. The original data were observed on 0.05 m^2 snow surface, and translated to densities on 1 m^2 snow surface. (B) The abundance of collembolans captured in traps within the snow profile in three land use types (wetland, soybean field and forest plantation) in late winter of 2011–2012. Different lowercase letters indicate significant differences (LSD test, $p < 0.05$).

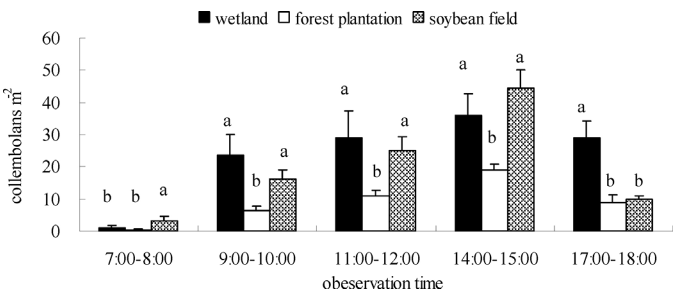

Fig. 8. Diurnal variation in densities of Collembola (mean ± SE) active on the snow surface in three land use types (wetland, soybean field and forest plantation) in late winter of 2011–2012. The original data were observed on 0.05 m^2 snow surface, and translated to densities on 1 m^2 snow surface. Approximately no collembolan was observed on snow before 7 o'clock and after 19 o'clock. Different lowercase letters indicate significant differences (LSD test, $p < 0.05$).

were observed at 0700–0800 h (repeated measurement ANOVA: $F_{4,60} = 37.03$, $p < 0.001$, see Fig. 8). All collembolans ceased surface activity and migrated into the snow when temperatures dropped in the evening, and they were not found on the snow surface until the next morning.

4. Discussion

4.1. Land use affects abundance and species dominance of winter-active Collembola

We suggest that the first hypothesis is operating in our ecosystems. Land use change from wetland to soybean field or forest plantation influenced species assemblages of winter-active Collembola both under snow cover and on the snow surface. The total number of collembolans captured by pitfall traps on the ground was significantly higher in wetlands compared to soybean field and forest plantation. Wetland is the initial land cover type in the study area, and as we have shown, wetland habitats showed a relatively higher richness of Collembola species in summer (Chang et al., 2013). We observed a phenomenon that each collembolan could migrate in a certain direction by performing continuous jumping behavior. However unlike the mass migration in a particular direction of *Isotoma hiemalis* (Hägvar, 2000), the collembolans in Sanjiang Plain were often observed migrating in quite different directions, which was also been reported before (Hägvar, 2000). Snow-melting and soil-thawing result in increasing water logging in wetlands in the late winter, with extensive ponding in the early spring. Collembola may therefore randomly migrate (but each individual migrates in a certain direction) to higher ground during the thaw in order to avoid the advent of water logged conditions.

During winter Collembola are capable of feeding at temperatures near 0 °C (Whittaker, 1981; Leinaas, 1981a; Aitchinson, 1983; Hägvar, 2010). Leinaas (1981a) found that the winter-active Collembola hardly eat during most of the winter, and general feeding on the snow surface (or below) was only observed in early spring, shortly before they left the snow. Thus the general winter activity is probably not due to foraging preferences. Leinaas (1980) showed that three *Desoria species* coexist in coniferous forests, but with different micro-habitat occupancy and thus different distribution on the snow. So their distribution may be caused by food resources in different land use types. Analyses of the gut contents of these collembolans would help to understand the reasons for the different frequencies of species in the three land use types.

This suggests that winter-active Collembola pass most of the winter in wetland. Reclaiming wetlands will result in lower numbers of Collembola if wetland is replaced by soybean or forest plantation. It may be caused by the changes of the living habitats (e.g., water logging, food resources, temperature, and predators). The large scale reclamation of wetland may also cause an unstable regional snowfall and a faster overall snowmelt, which will affect the life-cycles of winter-active Collembola. As we know, snow cover affects fauna when 15–25 cm of snow cover persists for at least 2–8 weeks per year (Aitchison, 2001). They may even not be able to survive the low temperature in night or unpredicted drop in temperature without snow cover. Collembolans active in winter undoubtedly decrease their abundance as the land use changes from natural wetlands to artificial lands, and may even worse extinct as the change of living habitats according to the large reclamations of wetlands.

4.2. Collembolan activity patterns on the snow surface, in the subnivean space and within the snow pack are not affected by land use

The second hypothesis was confirmed by the data of collembolans captured by pitfall traps on the ground (Table 1 and Fig. 5) and traps within the snow profile (Fig. 7B) and Collembola densities on the snow surface (Figs. 7A and 8) in three land use types. Collembolan activity fluctuated during the winter season, and increased from early winter to late winter with a peak in March. This pattern, which is in line with previous research (Wallwork, 1970; Willard, 1973), was essentially synchronous in the three land use types. From March 22nd to March 28th, densities of Collembola on the snow surface and the abundance of Collembola captured by traps within the snow profile showed the same decrease in the three land use types (Fig. 7B). The same decreases of densities on the snow surface in soybean field and forest plantation from March 22nd to March 28th imply that although highly efficient migration ability, winter-active collembolans Collembola do not benefit from the land use changes, and will inevitably decrease naturally.

4.3. Collembolan activity in winter is affected by temperature and time

The low number of captures in early and middle winter are likely attributable to low temperatures on the snow surface (Zettel, 1984). The surface-active collembolans were found in soil samplings in late winter (data not shown), so they may be hidden in subnivean space or even in soil in early and middle winter, and migrate up to the snow layers and the snow surface when the temperature is suitable. As shown in Fig. 2, the air temperature increased markedly around March 20th; numerous collembolans were active on the snow surface during these days, and numbers of collembolans captured by pitfall traps increased as well (Table 1 and Fig. 5). Collembola showed a considerable activity in the subnivean space. Leinaas (1981a, 1983) found that all species active in the subnivean space also moved up into the snow, while Hägvar and Hägvar (2011) found that some species of winter-active Collembola kept staying in subnivean space. When the ground was partly bared from March 22nd and the snow surface was melted away, the density of Collembola on the snow surface was markedly decreased, and their migrations on the snow surface were interrupted. Importantly, the decrease in pitfall captures after the observed peaks in activity did not imply that the Collembola were dead, in fact, they began to be collected in soil samplings and on water logged surfaces. In other words, the pitfall traps underestimated the abundance of Collembola when snow cover was discontinuous.

The winter activity fluctuated during the day as supranivean and subnivean temperatures changed (Fig. 3A and B): increased density in the morning, with peak abundance at noon, and decreased abundance in the afternoon (Fig. 8). All collembolans left the snow surface to avoid cold temperatures at night, and returned the next morning. The increases of densities on the snow surface are likely caused by increasing temperature (Leinaas, 1981a) and the changing barometric pressure (Zettel, 1984). Leinaas (1981a) showed that the vertical migrations of Collembola within snow are strongly influenced by snow temperatures; they are forced down to the lowest snow layers or even back to the subnivean air space when the temperature is low. Hägvar (1995, 2000) found that during warm days in late winter, four species of Collembola were performing long directional migration behavior on the snow surface. We found that not all collembolans were going to be active on the snow surface, and probably a large part of the animals will stay within the snow pack during large part of winter; i.e., above the subnivean space, but below the snow surface. In addition, no water logging would have happened in that period in Sanjiang Plain, suggesting that migration on the snow surface was unnecessary for their survival, so the Collembola appears to migrate up into the snow either to escape waterlogging or ice formation (Leinaas, 1981a, 1983) or just to prepare for dispersal to new habitats and establishment of new colonies.

This is the first record of winter-active Collembola from China. Eight species of Collembola were captured by pitfall traps in Sanjiang wetland plain of China. It was known that Collembola is one of the few arthropod taxa capable of flourishing in the coldest terrestrial habitats of the planet (Hopkin, 1997), and they were reported active on the snow surface in many European countries. With the report from China, located in the east of the Eurasian continent, we confirm the occurrence of winter-active Collembola in the eastern part of Eurasia. Among the species of Collembola found on the snow surface in the world, there are representatives from many genera. In our study, the genus Desoria was most abundant on the snow surface. In previously published papers, Desoria species active on the snow surface have only been reported from Fennoscandia. Leinaas (1983) reported four Desoria species active on the snow: *Desoria hiemalis* (previously known as *Isotoma hiemalis*), *Desoria tolya* (previously known as *Isotoma violacea*), *Desoria blekeni* and *Desoria germanica*. But these were different from the three species found in our experiment.

Collembola active on the snow surface can survive at temperatures a little below zero, and most of them showed a long directional jumping ability on the snow surface (Hägvar, 1995, 2000). The jumping collembolans were often trapped and aggregated in depressions on snow. So their abilities to effectively migrate on the surface of snow make them good candidate species to study the responses of invertebrates to land use changes and global climate changes. Soil samplings in soybean field and forest plantation beneath the snow cover on March 20th showed a high density of winter-active collembolans (data not shown), which indicated that they are able to live in soybean field and forest plantation. Even though agricultural management practices can lead to changes in collembolan species assemblages and diversity (Dekkers et al., 1994; Frampton, 2000; Alvarez et al., 2001), we cannot demonstrate that they are not able to live in soybean field in summer since previously studies showed that they were not easy to be found in summer. More studies on their life-cycles especially in summer period should be done to understand the effects of land use changes on the species richness and abundance of winter-active Collembola.

5. Conclusion

The reclamation of wetland in Northeast China resulted in a significant decrease of abundance and a different assemblage of collembolans under snow cover in the soybean field and forest plantation. Collembola densities on the snow surface significantly decreased in forest plantation but not in soybean field, which may be caused by their different habitat preference. Collembolans were rarely active in early and middle winter and mostly active in later winter, and their daily densities on the snow surface fluctuated according to both air temperatures and land use types. Through this study, eight species of Collembola were found active in winter in Sanjiang plain, China. *Desoria* sp. 1, *Desoria* sp. 2, and *Desoria* sp. 3 were the dominant species.

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