Composition and spatio-temporal variation of soil arthropods in the wetland of the Daxia River on the Qinghai-Tibet Plateau

Chen Delai (cdlbuck@163.com)
Gansu Agricultural University
Changzhong Liu
Gansu Agricultural University
Zhengxue Ma
Gansu Agricultural University
Jingjing Su
Gansu Agricultural University

Article

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Abstract

The Daxia River Basin on the eastern edge of the Chinese Qinghai-Tibetan Plateau is one of the typical distribution regions of alpine wetlands and a global biodiversity hotspot. The aim of this study is to analyze the composition and spatio-temporal distribution of the soil arthropods, and to use them as an indicator for the soil environment in the wetland. The soil arthropods of 32 taxa and 7706 individuals were collected from the soil samples at two soil layers (0–10 and 10–20 cm depth) in each habitat of six habitats along the Daxia River in cold season and warm season between 2016 and 2017. The habitat of Tumenguan had a greater arthropod abundance than all other habitats in both cold season and warm season. A significant seasonal variation was observed in the composition, abundance and diversity of the soil arthropod community in each habitat. In cold season the dominant groups were Chironomidae larvae, Sejidae and Trombidiidae. In warm season the dominant groups were Chironomidae larva, *Onychiurus*, *Pygmephorus* and *Tullbergia*. The soil arthopod communities exhibited significant differences among the habitats at the 0–10 and 10–20 cm depth. The multivariate tests with the linear model redundancy analysis (RDA) revealed the significant impact of soil physical and chemical factors on the seasonal change of soil arthropod community. The results demonstrate that soil arthropods in the study area respond more actively to temporal changes than to habitat changes.

Introduction

Soils is one of the last great frontiers for biodiversity research and home to an extraordinary range of soil biota[1]. In most ecosystems, soil is extremely rich in invertebrates, which comprise a high proportion of the total biodiversity[2]. It was reported that soil invertebrates represent as much as 23% of the total diversity of living organisms that has been described to date[3]. Soil arthopods are a critical part of soil invertebrates, serve as a nutrition mediator between the primary producers and secondary consumers, making them an important food. They also promote the decomposition of soil organic matter, accelerate the circulation of nutrient elements, regulate energy flow, and monitor and indicate the soil environment[4-8].

Soil arthopods are an important component in wetland ecosystems, and a key point in the food chain[9, 10] . Their community composition varies with spatial and temporal variability[11, 12] . The spatial distribution of soil arthropod communities can be affected by abiotic and biotic factors both above- and belowground, including climate[13, 14], plant community[11, 12] and soil properties[15]. However, it is not clear which of these factors is most important in determining the spatial distribution of soil arthropods. Moreover, seasonal changes in their habitats can directly or indirectly influence the soil invertebrate community.

The Qinghai-Tibet Plateau is an ecological security barrier of southwestern China, and plays a driving and increasing effect on the ecosystems of China and the Eastern Hemisphere depending on the degree of ecological sensitivity in global change[16]. The wetlands of the Qinghai-Tibet Plateau is an unique wetland type in China[17]. According to the definition of wetland in Convention on Wetlands (Ramsar, Iran, 1971), the Qinghai-Tibet plateau wetland can be divided in to four types: grass wetland, wood wetland, river wetland and lake wetland. The wetland in the cold regions of China covers the northern part of cold-temperate and mid-temperate zone. The plateau wetlands perform many ecological functions, such as supplying water and regulating climate[16]. Previous studies have mainly focused on the climate[18, 19], vegetation[20-22], soil microorganism[23-26], soil nematodes[27] and macroinvertebrate[28] of alpine wetland on the Qinghai-Tibet Plateau. Research regarding soil arthropods of the wetlands on the Qinghai-Tibetan Plateau has rarely been reported[16].

The objectives of this study are to examine for the first time the characteristics of the ecological distribution, to describe the composition and spatio-temporal dynamics of the soil arthropod communities in the wetland of the Daxia River on the Qinghai-Tibet Plateau. We hypothesize that (1) the composition of the soil arthropod community in this biodiversity hotspot would show a unique zonal pattern due to the complex geographical environment; (2) the structure and diversity of the soil arthropod community would vary with the habitats environment due to the important role of plant communities and soil properties in different habitats; and (3) the soil arthropod community would show stronger temporal variation than spatial variation because the soil arthropods are more sensitive to seasonal changes.

Results

Soil physical and chemical properties. Figure 1, Supplementary Table S1 and Supplementary Table S2 show that the soil properties in different habitats and different seasons. The difference in the soil temperatures (ST) at various habitats was significant in the warm season ($P< 0.05$). The seasonal difference in the average temperatures of the superficial layer (0~10 cm) was significant and not significant in those of the deep layer (10–20 cm) ($P< 0.05$) (Fig.1 a, b). The difference in soil pHs between soil layers at various habitats and between seasons were not significant (Fig. 1 e, f). The difference in soil water content (WC), total nitrogen (TN), total phosphorus (TP) and soil organic carbon (SOC) between habitats in cold season and warm season was significant (Fig. 1 c, d, g-l, Supplementary Table S1, Supplementary Table S2).

Component of soil arthropod communities. Table 2 and Supplementary Table S3 shows that the number and abundance of individual soil arthropods and groups at both larval and adult stages. We collected 7706 individuals belonging to 32 taxa, and classified them into 3 classes, 9 orders, 30 families. In the cold season, the dominant groups were Chironomidae larvae, Sejidae and Trombidiidae, accounting for 36.30% of the total individuals. The common groups included *Arrhopalites*, Ceratopgonidae, Doilchopodidae, *Entomobrya*, *Isotoma*, *Isotomiella*, *Oribatella*, Phlaeothripidae, *Proisotoma*, *Sminthurus*, Tabanidae and Uropodidae, accounting for 61.19% of the total individuals. The other 4 taxa were in the rare groups, accounting for 2.51% of the total individuals. In the warm season, the dominant groups were Chironomidae larva, *Onychiurus*, *Pygmephorus* and *Tullbergia*, accounting for 43.57% of the total individuals. The common groups included Aphididae, Cecidomyidae,*Cryptopygus*, Doilchopodidae, *Entomobrya*, *Galumna*, *Isotoma*, Limoniidae, *Oribatella*, *Proisotoma*, Staphylinidae, Tabanidae, Trichoceratidae and Trombidiidae, accounting for 46.04% of the total individuals. The other 4 groups were rare groups, accounting for 10.39% of the total individuals. In whole year, the dominant group was Chironomidae larva, accounting for 14.61% of the total individuals. The common groups included Aphididae, Ceratopgonidae, *Cryptopygus*, Doilchopodidae, *Entomobrya*, *Isotoma*, *Isotomiella*, Limoniidae, *Onychiurus*, *Oribatella*, Phlaeothripidae, *Proisotoma*, *Pygmephorus*, *Sejidae*, Tabanidae, Trichoceratidae, Trombidiidae, *Tullbergia* and Uropodidae, accounting for 81.07% of the total individuals. The other 10 groups were rare groups, accounting for 4.32% of the total individuals (Table 2). Some were only found in the cold season (*Arrhopalites*, Ceratopgonidae larva, Chrysomeilidae, Elateridae, Formicinae, *Isotomiella*, Phlaeothripidae larva, Sejidae, *Sminthurus*, Uropodidae), and some were only found in the warm season (Aphididae, Cecidomyidae, Cicadellidae, Coreidae, Ephydridae, *Galumna*, Limoniidae, *Onychiurus*, *Pygmephorus*, Tenthredinidae, Trichoceratidae, *Tullbergia*).

Arthropod	Cold season			Warm season			Whole year		
	Individuals	%	A	Individuals	%	A	Individuals	%	A
Aphididae				31.00±9.83	1.06	++	31.00±9.83	0.40	+
Arrhopalites	240.53±10.50	5.04	++				240.53±10.50	3.12	++
Cecidomyidae				65.28±0.83	2.22	++	65.28±0.83	0.85	+
Ceratopgonidae larva	223.11±3.72	4.68	++				223.11±3.72	2.90	++
Chironomidae larva	480.99±0.24	12.18	+++	644.63±3.42	18.56	+++	1125.62±0.15	14.61	+++
Chrysomeilidae	20.64±9.27	0.43	+				20.64±9.27	0.27	+
Cicadellidae				6.96±0.84	0.24	+	6.96±0.84	0.08	+
Coreidae				6.39±1.55	0.22	+	6.39±1.55	0.08	+
Cryptopygus	122.34±0.92	2.56	++	43.94±4.61	1.50	++	166.28±6.18	2.16	++
Doilchopodidae larva	396.90±4.15	8.32	++	243.27±4.55	8.29	++	640.17±2.47	8.31	++
Elateridae	41.39±0.05	0.87	+				41.39±0.05	0.54	+
Entomobrya	137.38±2.83	2.88	++	84.51±0.22	2.88	++	221.89±3.62	2.88	++
Ephydridae				22.29±0.82	0.76	+	22.29±0.82	0.29	+
Formicinae	20.55±3.91	0.43	+				20.55±3.91	0.27	+
Galumna				58.94±4.18	2.01	++	58.94±4.18	0.76	+
Isotoma	414.27±1.85	8.68	++	59.41±0.66	2.02	++	473.68±7.35	6.15	++
Isotomiella	343.37±8.44	7.20	++				343.37±8.44	4.46	++
Limoniidae				43.27±4.18	1.47	++	43.27±4.18	0.56	+
Onychiurus				417.69±3.88	14.23	+++	417.69±3.88	5.42	++
Oribatella	123.29±3.16	2.58	++	56.74±2.65	1.93	++	180.03±3.55	2.34	++
Phlaeothripidae larva	90.29±3.52	1.89	++				90.29±3.52	1.18	++
Proisotoma	454.57±1.91	9.53	++	99.17±3.28	3.38	++	553.74±6.58	7.19	++
Pygmephorus				535.25±6.11	18.24	+++	535.25±6.11	6.95	++
Sejidae	651.52±9.42	13.65	+++				651.52±9.42	8.45	++
Sminthurus	141.37±6.19	2.96	++				141.37±6.19	1.83	++
Staphylinidae	37.51±0.08	0.79	+	47.23±5.66	1.61	++	84.74±0.57	1.10	+
Tabanidae larva	53.38±5.62	1.12	++	65.83±0.69	2.24	++	119.21±6.55	1.55	++
Tenthredinidae				16.17±4.72	0.55	+	16.17±0.33	0.21	+
Trichoceratidae				99.17±3.41	3.38	++	99.17±3.41	1.29	++
Trombidiidae	499.37±5.53	10.47	+++	71.25±0.38	2.43	++	570.62±2.53	7.40	++
Tullbergia				316.54±8.19	10.79	+++	316.54±8.19	4.11	++

Uropodidae	178.81±0.18	3.75	++				178.81±0.18	2.32	++

Table 2. Composition of soil arthropod in Gannan section of Daxia River wetland. Note: A: abundance, +++: dominant groups (percentage of individual number>10 %), ++: common groups (1 %<percentage of individual number<10 %), +: rare groups (0.1 %<percentage of individual number<1 %).

Spatio and temporal variations of community composition

Distribution of soil arthropods between seasons. Figure 2, Supplementary Table S4, Supplementary Table S5 show that the soil arthropod communities showed significant differences among the habitats ($P < 0.05$) and between the seasons. In the cold season, Tumenguan of the habitat 6 had a greater abundance than the other habitats ($P < 0.05$), accounting for 41.39% of the total individuals. Sejidae and Trombidiidae were dominant groups in Tumenguan. Sangke of the habitat 1 had less arthropods than Tumenguan and more than other habitats, accounting for 21.55% of the total individuals. Chironomidae larva was the dominant group. In the warm season, Tumenguan also had a greater abundance than the other habitats ($P <$ 0.05), accounting for 37.92% of the total individuals. *Tullbergia* was the dominant group. Sangke was nearly essentially equal Tumenguan, accounting for 37.83 % of the total individuals. Chironomidae larva and *Onychiurus* were dominant groups. Quao of the habitat 5 had less arthropods than Sangke and more than other habitats, accounting for 12.32% of the total individuals. *Pygmephorus* was the dominant group. In whole year, Chironomidae larva was the only dominate group. Tumenguan and Sangke had a greater abundance than the other habitats, accounting for 30.00% and 29.49% of the total individuals.

Fig. 2 c, d, Supplementary Table S4, Supplementary Table S5 show that distribution differences exist in the groups among the habitats and seasons. In the cold season, Quao had a greater abundance than the other habitats ($P < 0.05$), accounting for 59.38% of the total groups. The arthropods in Sangke and Tumenguan accounted for 56.25% and 46.88% of the total groups, respectively. In the warm season, Sangke had a greater abundance than the other habitats ($P<0.05$), accounting for 65.63% of the total groups. The arthropods in Quao and Tumenguan accounted for 62.50% and 56.25% of the total groups, respectively.

Distribution of soil arthropod between soil layers. Figure 2 shows that the warm season had a higher abundance than the cold season in the 0–10 cm soil layer ($P < 0.05$), accounting for 87.55% of the total individuals. The cold season had a higher abundance than the warm season in the 10–20 cm soil layer ($P < 0.05$) (Fig. 2), accounting for 82.44% of the total individuals. In cold season the number of individuals in the 0~10 cm soil layer was less than in 10–20 cm soil layer, accounting for 12.45% of the total individuals. In the 0–10 cm soil layer Chironomidae larva and Sejidae were the dominant groups. Nine groups were common, i.e., *Arrhopalites*, Ceratopgonidae larva, Chironomidae, *Cryptopygus*, *Entomobrya*, *Isotomiella*, *Onychiurus*, Phlaeothripidae larva, *Sminthurus*. In the 10–20 cm soil layer Doilchopodidae larva, *Isotoma*, *Proisotoma* were the dominant groups. Eleven groups were common, i.e., *Arrhopalites*, *Entomobrya*, *Oribatella*, Phlaeothripidae larva, *Pygmephorus*, Sejidae, *Sminthurus*, Tabanidae larva, Trombidiidae, *Tullbergia*, Uropodidae. In general, in the cold season the dominant groups increased as the soil layer deepened.

However, in the warm season the number of individuals in the 0–10 cm soil layer was more than 10–20 cm soil layer, accounting for 94.83% of the total individuals. Chironomidae larva, Doilchopodidae larva, *Pygmephorus*, Trombidiidae were the dominant groups in the 0–10 cm soil layer. Fifteen groups were common, i.e., *Arrhopalites*, Cecidomyidae larva, Ceratopgonidae larva, *Cryptopygus*, *Entomobrya*, Ephydridae, *Isotoma*, *Oribatella*, *Proisotoma*, Phlaeothripidae larva, Sejidae, Staphylinidae larva, Tenthredinidae, Trichoceratidae larva, *Tullbergia.* In the 10–20 cm soil layer Limoniidae larva, Tabanidae larva, Trichoceratidae larva were the dominant groups. Nine groups were common, i.e., Chironomidae, *Cryptopygus*, *Isotomiella*, *Isotoma*, *Onychiurus*, *Proisotoma*, *Sminthurus*, Trichoceratidae larva, *Tullbergia.*

Spatio-temporal variations of the community abundance and diversity. Figure 2 shows that the community abundance and diversity varied among the habitats and sampling seasons. Figure 3 shows that the Shannon index, Pielou index and Simple

index were sensitive to the sampling seasons ($P < 0.01$). The multiple-comparison tests showed that the abundance (Table 2) responded significantly to habitats variation in cold season and warm season. The richness (Table 2) , Shannon index, Pielou index and Simple index varied significantly among habitats in cold season and warm season (Fig. 3). The temporal variations in the community abundance and richness were sensitive to the sampling period in all six habitats.

The relationship between soil arthropod community and environmental factors. Table 3 shows that the impacts of each soil physical and chemical factors are estimated by RDA. The importance of ST, WC, pH, TN, TP and SOC all exceed 0.21 and all pass the test of $P < 0.005$. Altitude (Al) is significant but less important (Table 3), so this variable is removed. Figure 4 shows that the RDA analysis results of ST, WC, pH, TN, TP and SOC variables were retained. Table 4 shows the correlation coefficient between the first two axes of RDA ranking and soil physical and chemical factors, indicating that the ranking axis reflects most of the information about the relationship between soil physical and chemical factors and soil arthropod community.

	ST	WC	pH	TN	TP	SOC	Al
Importance factor	0.36	0.31	0.33	0.27	0.28	0.21	0.07
Significance level	0.003	0.002	0.004	0.003	0.003	0.003	0.003

Table 3. Importance and significance level of each variable. Note: ST: Soil temperature; WC: Water content; TN: Total nitrogen; TP: Total phosphorus; SOC: Soil organic carbon; Al: Altitude.

RDA sequencing described the correlation between the number of individuals and groups of arthropods in different soil layers and the main physicochemical factors of soil in cold season and warm season (Fig. 4). Figure 4 (a) explains the change of arthropod community in 0–10 cm soil layer in the cold season. It can be seen from the figure that the three factors (WC, TP and ST), have the greatest impact on the structural characteristics of soil arthropod community (Table 4). In general, WC, TP, ST and pH were positively correlated with the number of arthropod groups, while TN and SOC were positively correlated with the number of arthropod individuals. Figure 4 (b) explains the changes of arthropod community in the 10–20 cm soil layer in the cold season. TP, TN and pH have the greatest impact on the structural characteristics of the arthropod community(Table 4). In general, TP, WC, SOC and ST were positively correlated with the number of arthropod groups, while TN and pH were positively correlated with the number of arthropod individuals. Figure 4 (c) explains the change of arthropod community in 0–10 cm soil layer in warm season. ST, WC and TP have the greatest impact on the structural characteristics of soil arthropod community (Table 4). In general, ST, TN, SOC and pH were positively correlated with the number of arthropod groups, while WC and TP were positively correlated with the number of arthropod individuals. Figure 4 (d) explains the changes of arthropod community in the 10–20 cm soil layer in warm season. TN, SOC and pH have the greatest impact on the structural characteristics of soil arthropod community (Table 4). In general, TN, SOC and TP were positively correlated with the number of arthropod groups, while pH, ST and WC were positively correlated with the number of arthropod individuals. Thus, the RDA sequence diagram can directly reflect the impact of soil physical and chemical factors on the seasonal change of soil arthropod community and the degree of impact.

factors	Cold season						Warm season					
	0-10 cm			10-20 cm			0-10 cm			10-20 cm		
	R	1st axis	2nd axis	R	1st axis	2nd axis	R	1st axis	2nd axis	R	1st axis	2nd axis
ST	0.493	0.258	0.339	0.308	0.062	0.009	0.483	-0.382	0.191	0.300	0.348	-0.191
WC	0.551	0.537	0.001	0.466	0.104	0.231	0.304	0.317	0.267	0.285	0.136	-0.083
pH	0.036	0.175	0.280	0.263	-0.226	-0.194	0.316	-0.114	0.142	0.321	0.419	-0.351
TN	0.157	-0.268	0.315	0.271	-0.319	0.204	0.412	-0.286	-0.319	0.527	-0.508	0.262
TP	0.100	0.308	-0.100	0.519	0.436	-0.183	0.298	0.290	-0.325	0.381	-0.094	0.262
SOC	0.082	-0.296	-0.201	0.310	0.113	-0.098	0.390	-0.238	-0.261	0.499	-2.105	-0.026

Table 4. Correlation coefficients of first two RDA axes and physical and chemical factors of soil. Note:ST: Soil temperature; WC: Water content; TN: Total nitrogen; TP: Total phosphorus; SOC: Soil organic carbon; R: resolution.

Discussion

Community composition. The community composition observed in this study differs from that of communities in the wetlands of the Lhasa River of the Qinghai-Tibet Plateau, where Oribatida and Isotomidae were the dominant groups[16]. Our results also differ from those of the communities in the Hengduan Mountains of the Qinghai-Tibet Plateau, where Poduromorpha, Oribatida and Entomobryomorpha were the dominant groups[1], and from the wetland ecosystems in Lhalu Wetlands of the Qinghai-Tibet Plateau, where the dominant group were Enchytraeidae[8]. The taxa of soil arthropod (thirty-two) in the wetland of the Daxia River was more than that (thirty) in typical wetlands of the Lhasa River, Tibet, China. These differences suggest that the soil arthropod community in the wetland of the Daxia River shows a unique zonal characteristics and higher taxonomic richness, indicating that this region is also a hotspot for the soil arthropods. Therefore, our first hypothesis was confirmed.

The community composition and density of soil arthropods depend to a great extent on the sampling and extraction procedures used[34]. In particular, variable extraction efficiencies depend on extraction procedure, on animal taxa involved, and to a certain extent on the vegetation/soil types[35]. Our results rely on six samples at 83.5 km river bank, which were extracted in conventional funnels by drying out the samples after 3 days of storage at variable ambient temperatures during transportation. Our results also depict only a “snapshot” of the soil arthropod community structure in a particular year. Differences between different parts of the year and between years may be substantial.

Spatial variability. In this study, soil arthropods were identified as macroarthropods and microarthropods. The habitats did not significantly affect the community structure and diversity of soil microarthropods, which differed from those of soil macroinvertebrates[36]. Many studies demonstrated that spatial variations in soil invertebrate communities are affected by plant community[11, 12], soil properties[15] and elevation[37]. Wenninger and Inouye (2008)[38] showed that plant community was closely related to soil microarthopods. However, the community composition of Mesostigmata and Prostigmata did not entirely depend on the plants on the ground due to its omnivorous feeding and worldwide distribution[39]. Wu et al. (2014)[1] also found no significant correlations between the diversity of soil-microarthropod community and plant community. Other studies have also reported that Oribatid and Prostigmatid mites did not respond significantly to habitat differences[40].

In our result population of soil arthropod tend to be significantly correlated with soil temperature but no significant change was found with the habitat elevation. Soil arthopods live in the soil, thus soil properties ought to affect soil arthopod

diversity and distribution characteristics. For example, various factors in the soil restricted the mobile ability of soil microarthopods[41]. Previous studies demonstrated that there was a close relationship between soil quality and soil fauna[42].

Furthermore, the microenvironment including soil temperature will cause the change of soil water content and then affect the characteristics of soil arthropod community. In our study, the water contents of the 0–10 cm and 10–20 cm layers in the habitats were significant difference in different seasons. In cold season, the water content was positively correlated with the number of soil arthropod groups. In warm season, it was positively correlated with the number of soil arthropod individuals. Soil microarthropods are sensitive to enrichment of soil carbon and nutrients[43]. In our study, SOC, TN and TP of soil affected the individuals and groups of soil arthropod (Fig. 3) as previous studies on soil total K and TN[16], soil SOC and TN and soil pH[44]. In present study, we found that pH affected the individuals and groups of soil arthropod though there was no significant difference in soil pH between various habitats (Fig. 1).

Therefore, these results suggest that the plant community, soil properties and elevation were the limiting factors only for the spatial distributions of special taxon. However, we could not draw the conclusion like Wu et al. (2014)[1] which of plant community, soil properties or elevation is most important in determining the spatial distribution of soil arthropods and our second hypothesis was unconfirmed.

Temporal variability. Seasonality is a distinct feature in most terrestrial ecosystems. Seasonal variations in soil invertebrate communities have been reported in many ecosystems[45]. In the present study, the abundance and taxonomic richness of the soil arthropods in all habitats were significantly higher during warm season than during cold season. Climatic conditions are generally considered to be critical determining factors in soil invertebrate communities[46]. Soil arthropods were influenced by temperature[8], precipitation[47], light[48] and solar ultraviolet radiation[12]. Shen et al.[35] found that the most important climatic factor was soil moisture content.

In the study area, monthly mean temperatures were higher warm season than cold season in different soil layers. Soil water content appeared seasonal variation. In the warm season, though precipitation increases gradually, temperature rises so quickly that evaporation of soil moisture increases and soil water contents decreases. In the cold season, with an accumulation of warm season rainfall, the surface runoff of Daxia River increases and water level rises to make the soil of sampling points along the river suffer more seepage and soaking, thus the soil water content rises again. Moreover, soil arthropod reproduction may attribute to the seasonal dynamics of the community[1]. In the wetland of Daxia River ultraviolet radiation in warm season is strong, which may also influence the seasonal change of the component of the soil arthropods community. This makes it difficult to draw any conclusion on seasonal patterns of reproduction and about the ecological significance of seasonal variations [49].

The seasonal effect on soil arthropods varies among different ecosystems[50]. In the present study, the temporal dynamics of the community composition and diversity and of the abundance of each taxonomic group differed among the six habitats. The habitats of the wetland of Daxia River responses to seasonal changes in litter production and nutrient cycling differed among vegetation and seasons. These differences in the seasonal dynamics of the vegetation community may lead to variations in microclimate, resource availability and soil properties among different habitats, and thus directly or indirectly affect the soil arthropod community. The soil arthropod community showed a stronger temporal variation in the wetland of Daxia River among habitats (Fig. 2, Fig. 3). Previous study showed that different groups of soil invertebrates varied in their responses to climatic changes[51]. For example, increasing temperatures may significantly decrease the number of Prostigmata mites, but increase the diversity of fungivorous mites[51]. In the present study, the arthropod community generally responded more strongly to the sampling periods than to the habitats, suggesting the soil arthropod community would show stronger temporal variation than spatial variation because the soil arthropods are more sensitive to seasonal changes (our third hypothesis).

Conclusions

The composition of the soil arthropod community in the Daxia river wetland exhibits a unique zonal pattern compared to other China localities. The soil arthropods vary significantly across the sampling periods in each habitat. In both cold and warm seasons, the habitat of Tumenguan had a greater abundance than all the other habitats. The warm season had a higher abundance than the cold season in the 0–10 cm soil layer, accounting for 87.55% of the total number of individuals. The cold season had a higher abundance than the warm season in the 10–20 cm soil layer, accounting for 82.44% of the total number of individuals. Significant seasonal variation was observed in the composition, abundance and diversity of the soil arthropod in each habitat. In cold season the dominant groups were Chironomidae larvae, Sejidae and Trombidiidae. In warm season the dominant groups were Chironomidae larva, *Onychiurus, Pygmephorus* and *Tullbergia*. The soil arthopod communities was significantly correlated with SOC, TN and TP. The results demonstrate that soil arthropods in the study area respond more actively to temporal changes than to habitat changes.

Materials And Methods

Site description. The experiment was carried out at the wetlands of the Daxia River (35°06'25" – 35°24'95" N, 102°25'56" – 102°56'51" E) on the eastern edge of the Qinghai-Tibet plateau, China. The Daxia river is a primary tributary of the Yellow river. The Xiahe river from Dabuleheke mountain and the Luohe river from Lalida mountain converge at Wangatan and form the Daxia river, which flows through Xiahe County, Linxia County, Linxia City and Dongxiang County into Liujiaxia Reservoir at Kangjia Bay. It has a full length of 203 km and a drainage area of 7152 km^2. The Gannan section of the Daxia river has a length of 83.5 km and flows through Sangke grassland, passing the county town Labrang Monastery, a sacred site of Tibetan Buddhism, to Tumenguan out of Xiahe county.

Sampling Design. To analyze the characteristics of ecological distribution of soil microarthropod communities in the wetlands of the Daxia river, the wetlands were divided into six habitats based on their vegetation community features and environment (Table 1). The habitat 1 (N35°06'25", E102°25'56") is set in the Sangke grassland at the headwaters of the Daxia river, where the riparian vegetation covers well and human activities are mainly grazing. The habitat 2 (N35°12'93", E102°40'50") is in the Damai area of Xiahe county with sparse riparian vegetation. The habitat 3 (N35°13'41", E102°49'38") is at Luo river (a tributary of Daxia river) in the downstream of the living area of Hezuo city. The habitat 4 (N35°14'50", E102°49'30") is in Wangertang at the confluence of Daxia river and Luo river with sparse riparian vegetation. The habitat 5 (N35°21'90", E102°53'01") is in Quao, with sparse riparian vegetation and little human activities. The habitat 6 (N35°24'95", E102°56'51") is at the inlet of Tumenguan reservoir with sparse vegetation along the river bank.

Habitat code	Location	Elevation	Main vegetation
1#	N35°06'25" E102°25'56''	2,780 m	*Kobresia capillifolia*、*Kobresia humilis*、*Ligularia dentata* spp.、*Artemisia sieversiana*、*Anemone silvestris*、*Elsholtzia ciliata*、*Plantago asiatica*、*Elymus nutans*、*Thalictrum* sp.、*Potentilla bifurca*、*Potentilla anserina*、*Heteropappus hispidus*
2#	N35°12'93" E102°40'50''	2,758 m	*Kobresia capillifolia*、*Artemisia sieversiana*、*Elsholtzia ciliata*、*Plantago asiatica*、*Potentilla bifurca*、*Potentilla anserina*、*Heteropappus hispidus*
3#	N35°13'41" E102°49'38''	2,510 m	*Kobresia humilis*、*Ligularia dentata* spp.、*Elsholtzia ciliata*、*Potentilla anserine*
4#	N35°14'50" E102°49'30''	2,413 m	*Kobresia humilis*、*Ligularia dentata* spp.、*Elsholtzia ciliata*、*Elymus nutans*、*Potentilla bifurca*、*Melissitus ruthenicus*
5#	N35°21'90" E102°53'01''	2,269 m	*Kobresia capillifolia*、*Artemisia sieversiana*、*Elsholtzia ciliata*、*Plantago asiatica*、*Potentilla bifurca*、*Potentilla anserina*、*Heteropappus hispidus*
6#	N35°24'95" E102°56'51''	2,143 m	*Kobresia capillifolia*、*Anemone silvestris*、*Elsholtzia ciliata*、*Plantago asiatica*、*Potentilla bifurca*、*Elymus nutans*

Table 1. Location and vegetation characteristics of sampling point. Note: 1# is the habitat in the Sangke grassland. 2# is the habitat in the Damai. 3# is the habitat in the Luo river. 4# is the habitat in the Wangertang. 5# is the habitat in the Quao. 6# is the habitat in the Tumenguan.

The plots (5 m × 50 m) were established using permanent signs in each of the six habitats. Within each plot, five subplots were selected at 10 m horizontal intervals. Soil arthropods were identified as macro-arthropods (body width≥2 mm) and meso- and micro-arthropods (body width<2 mm)[29]. The samples (50 cm × 50 cm) for macro-arthropods and the samples (10 cm×10 cm) for meso- and micro-arthropods were collected in each subplot from the soil layers of 0–10 cm and 10–20 cm during the warm seasons (June、July、August 2016) and the cold seasons (May 2016, September, October 2017). Therefore, a total of 360 soil samples (6 habitats × 5 subplots ×2 sample types ×2 soil lays × 3 biological repetition) were collected.

Soil analysis and fauna identification. The soil samples (0–10 cm and 10–20 cm soil layers) were collected at each subplot. The soil samples were then used for determination of soil temperature, water content, pH, total N, P and organic carbon. The soil temperature meter (ADCON ST, USA) was used to measure and record the soil temperatures at a depth level of 0 cm, 10 cm and 20 cm. The soil temperatures at the surface and at the depth of 10 cm, and at the depths of 10 cm and 20 cm were averaged as the temperature of 0–10 cm and the temperature of 10–20 cm, respectively. The soil water content was measured by oven drying method (105°C、24h) (BGX198, China). The soil pH was measured by the pH meter (STARTER 3C, China). Total soil nitrogen (N) and phosphorus (P) were measured by elemental analyzer (UNICUBE Elementar, Germany). The soil organic carbon was measured by the soil organic carbon meter (LH-SOC350, China).

The soil macro-arthropods were separated manually at the subplot, the soil samples of soil meso- and micro-arthropods were labelled, bagged with sealed packages and took to labs. In the laboratory, the soil arthropods were extracted from each of the soil samples using a Tullgren funnel extractor, then preserved in 75% alcohol. They were then counted under a stereoscopic microscope, and identified to the levels of order or family[29]. The extracted arthropod samples are stored in the Longdong Normal University, Qingyang, China.

Biodiversity of soil arthropods. The soil arthropods are classified into three groups based on their abundance in the community: those with an abundance of 10% are classified as the dominant groups, those with an abundance of 1% –10% are classified as the common groups, and those with an abundance of 0.1% –1.0% are classified as the rare group.

The biodiversity of soil arthropod community was estimated using the total abundance of soil arthropods, total group number of soil fauna[8,30], the Shannon-Wiener index (H') $H' = -\Sigma(P_i \ln P_{i});$[31], Simpson index (C) $C=\Sigma P_{i;}$[32] and Evenness index (E) $E = H'/\ln S$[33]; where S is the number of groups, and Pi is the ratio of individuals to the total collected individuals in group i for each habitat.

Statistical analysis. All statistical analyses were preformed using the software Microsoft excel 2016. The abundance of soil arthropods and soil physical and chemical factors of the samples can be regarded as variables. To examine the correlation between the soil arthropod groups and the soil physical and chemical properties, the multivariate tests RDA (Redundancy Analysis) were done with R version 3. 6. 1 for Windows. The variation range of soil arthropod community structure is relatively small, so a linear model analysis method, namely redundancy analysis (RDA), is selected to analyze the relationship between soil arthropod community and the main physical and chemical properties of soil.

Data Availability

The datasets analyzed during during the current study are available from the corresponding author on reasonable request.

Declarations

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Author Contributions

DLC designed the experiment and performed field investigations, data analysis and manuscript writing. CZL and ZXM identified soil arthropods. JJS identified vegetation. All authors discussed the results and commented on the manuscript.

Competing Interests: The authors declare that they have no competing interests.

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Figures

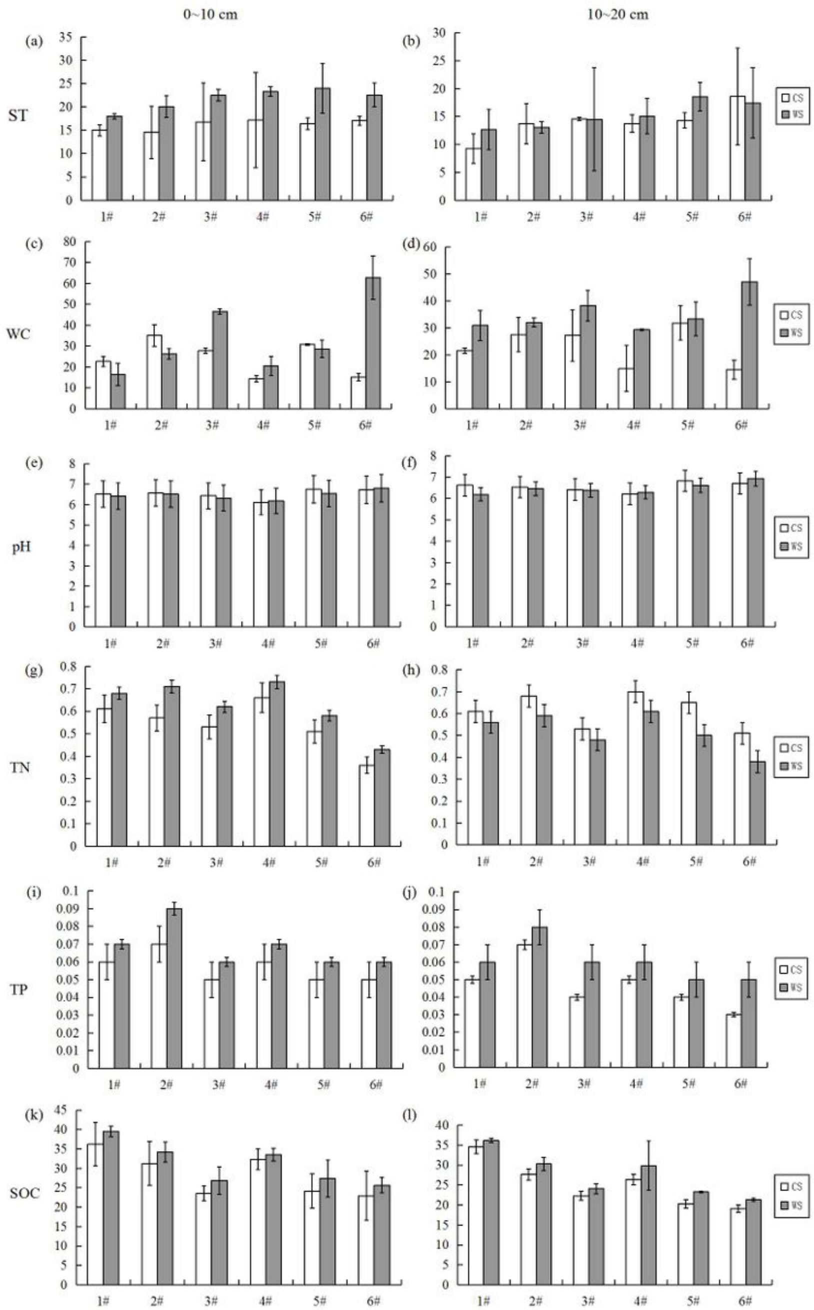

Figure 1

Physical and chemical factors of soil in the study area (mean ± S.E. P< 0.05). Habitat codes 1–6 correspond to the Wetlands listed in Table 1. Capital letters behind the legends indicate cold season (CS) and warm season (WS).

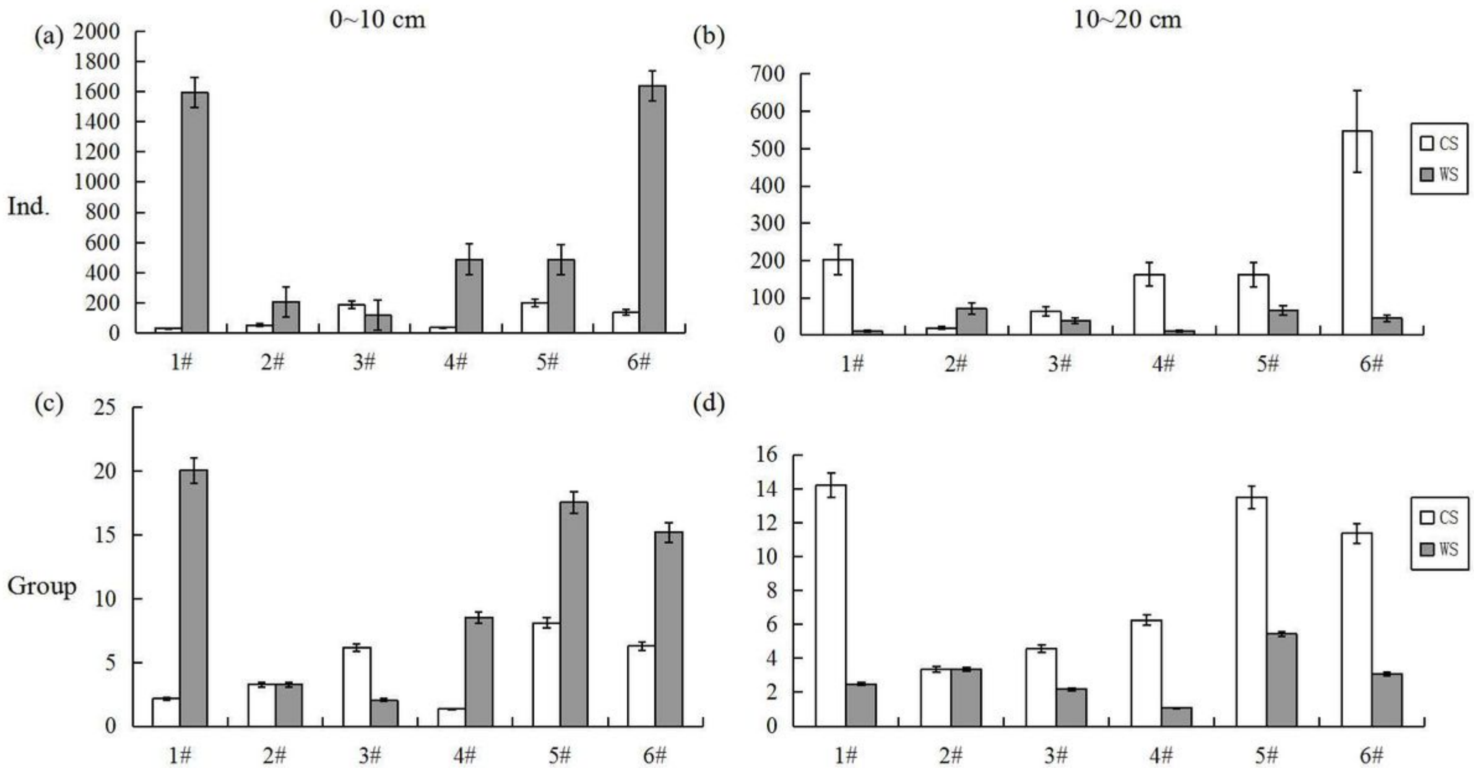

Figure 2

Distribution of individuals and groups of soil arthropods in two soil layers. Note: 1. CS:cold season; WS:warm season. 2.Ind.: individuals.

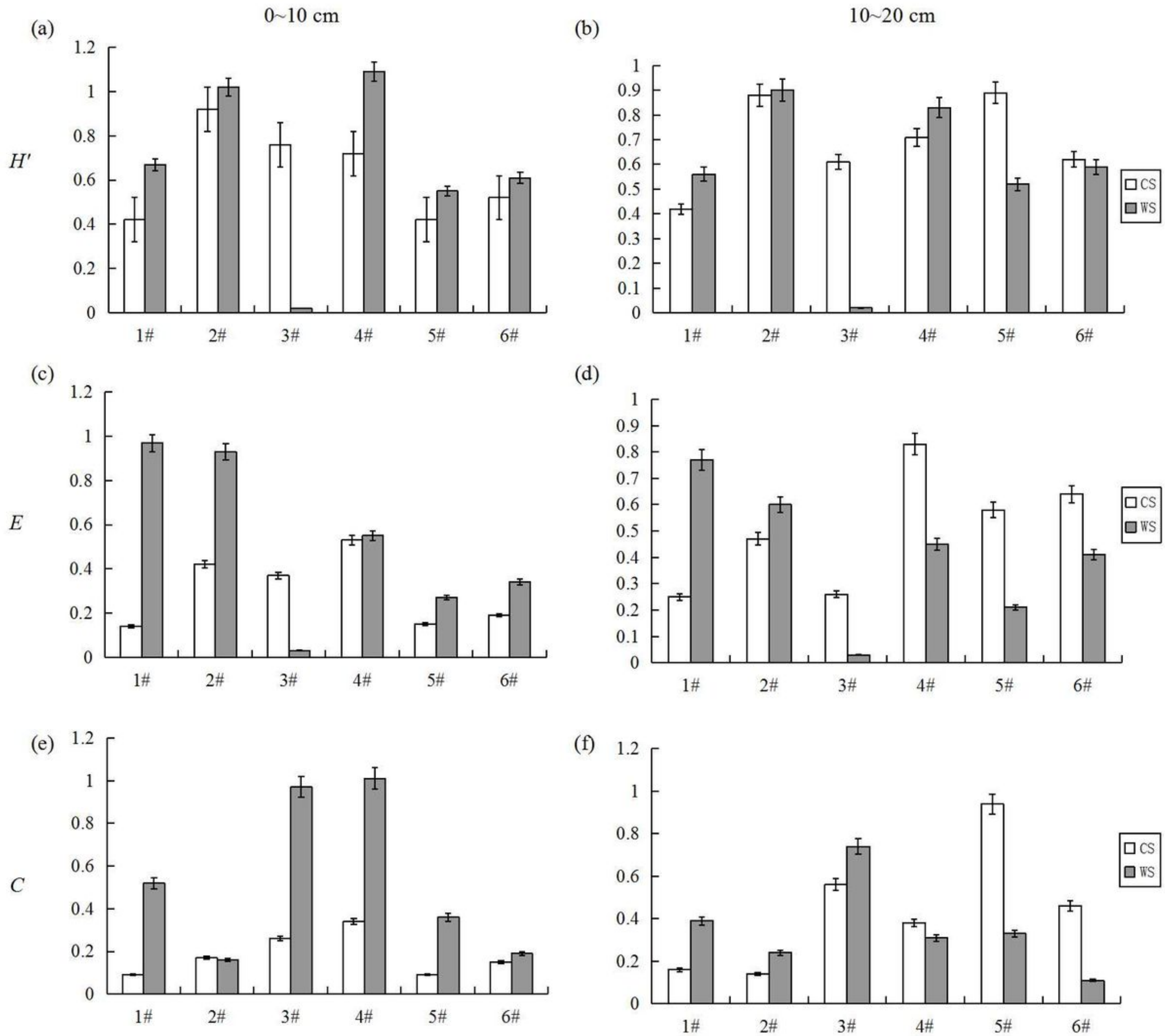

Figure 3

Diversity index of soil arthropod. Note: 1. CS:cold season; WS:warm season. 2. H': Shannon index; E: Pielou index; C: Simple index.

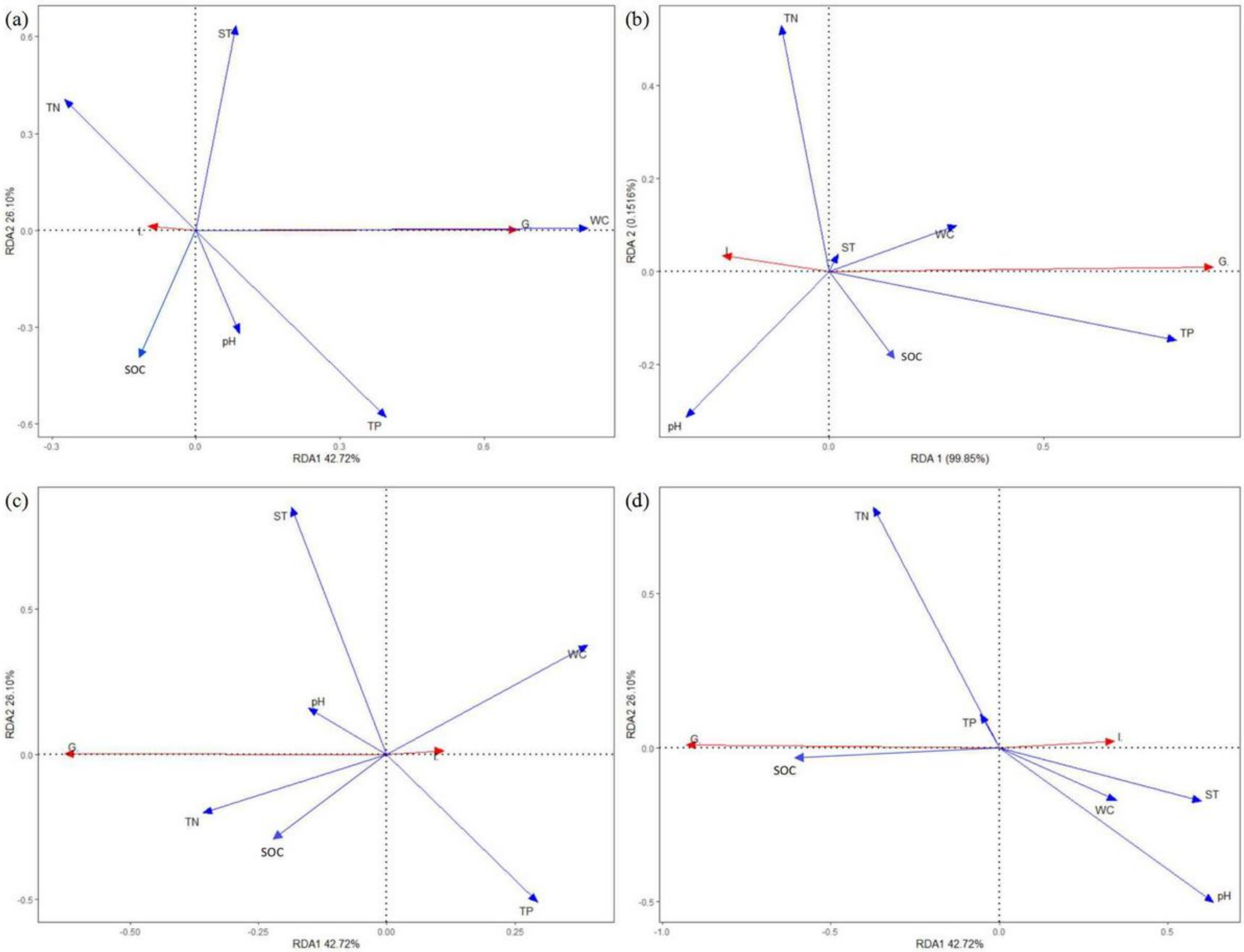

Figure 4

RDA analysis ordination diagram of community structure features-environment relationships for arthropods (The length of the solid arrow line indicates the correlation between soil physical and chemical factors and the temporal variation of soil arthropod group number and individual number. The longer the line, the greater the correlation, and vice versa. The quadrant where the solid arrow is located represents the positive and negative correlation between soil physical and chemical factors and the ordination axis.). Note: CS:cold season; WS:warm season; I:individual; G:group; ST: Soil temperature; WC: Water content; TN: Total nitrogen; TP: Total phosphorus; SOC: Soil organic carbon.

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