Zoological Studies **49**(6): 713-723 (2010)

Zoological Studies

Community Characteristics of Soil Ciliates at Baiyun Mountain, Guangzhou, China

Jing Li[1], Ming-Guang Li[1], Jian Yang[2], Ying Ai[3], and Run-Lin Xu[1,*]

[1]*School of Life Sciences, Sun Yat-sen University, Guangzhou 510275, China*
[2]*South China Institute of Environmental Science, Guangzhou 510655, China*
[3]*Institute of Hydrobiology, Chinese Academy of Sciences, Wuhan 430071, China*

(Accepted May 27, 2010)

Jing Li, Ming-Guang Li, Jian Yang, Ying Ai, and Run-Lin Xu (2010) Community characteristics of soil ciliates at Baiyun Mountain, Guangzhou, China. *Zoological Studies* **49**(6): 713-723. We investigated the relationships between the soil ciliate community and environmental factors at 7 different habitats at Baiyun Mountain, Guangzhou, southern China. The abundance, dominance, biodiversity, colpodid/polyhymenophoran (C/P) ratio, and community similarity of soil ciliates were investigated using qualitative and quantitative analyses. We found a total of 114 species of ciliates belonging to 9 classes, 18 orders, and 47 genera. The 1st dominant group (i.e., the group richest in species) was the Spirotrichea, followed by the Colpodea, with dominance values of 38.6% and 21.93%, respectively. The highest abundance of ciliates was found in winter at site 5 (with representative vegetation of *Tetradium ruticarpum* Hartley), reaching 3.87×10^4 individuals (ind.)/g, and the lowest in spring at site 2 (with representative vegetation of Schima superba Gardn. et Champ.) at 9.2×10^2 ind./g. Margalef's richness index ranged 2.07-5.46. Statistical analyses demonstrated that ciliate abundances were positively correlated with soil moisture, organic matter, ammonia-nitrogen, total nitrogen, and total phosphorus, but negatively correlated with total potassium. Soil pH, nitrate-nitrogen, and sulfate showed insignificant effects. Analyses of C/P ratios and diversity indices implied that habitat conditions of sites 2 and 7 were relatively unfavorable for soil protozoa. http://zoolstud.sinica.edu.tw/Journals/49.6/713.pdf

Key words: Biodiversity, Colpodid/Polyhymenophoran ratio, Community structure, Habitat, Soil ciliates.

Many critical processes of major biogeochemical cycles in the biosphere occur in soils and are facilitated by soil organisms, especially small and microscopic protozoa even if they are largely ignored and mostly insignificant in terms of individual biomass (Coûteaux and Darbyshire 1998, Fontaneto 2007). On account of their species richness and large biomass, soil protozoa play important roles in carbon and nitrogen cycles and energy transmission by regulating both the decomposition rate and specific metabolic pathways in almost all types of soil, including those under human influence (Bamforth 1973, Foissner 1987, Díaz et al. 2006). Accordingly, studies on the community structure and dynamics of soil protozoa can provide powerful means for assessing and monitoring changes in natural and human-influenced environments (Foissner 1999a). However, because of their small size and difficulties in identification, ciliated protozoa are less understood in soil environments compared to other organisms (Bedano et al. 2005, Fontaneto et al. 2007, Lee et al. 2009).

Most ciliated protozoa in the soil are naked, fast-growing, and predominantly bacterivores (Bamforth 1973). They have specific adaptations to various terrestrial habitats (e.g., soil and tree bark), and the diversity of ciliates is higher in terrestrial than aquatic habitats (Foissner 1999a). On the other hand, these unicellular soil ciliates

*To whom correspondence and reprint requests should be addressed. Tel: 86-20-84113185. E-mail:xurunlin_1960@yahoo.com

are extremely sensitive to external factors and are accordingly considered to be informative bioindicators of environmental conditions (Foissner et al. 2005). It was proposed that external factors, such as vegetation, weathering, podzolization, soil processes, and other environmental changes can influence the character of the ciliate fauna (Foissner 1987).

Although many studies on terrestrial protozoa have been carried out (Cui et al. 1989, Foissner 1997a b 1999b, Foissner et al. 2005, Li et al. 2010), there is still little knowledge about relationships between soil ciliate communities and physicochemical properties. Moreover, there are few publications about soil ciliate communities in China, especially from the south subtropical hilly area. The objective of the present study was to investigate relationships between ciliate communities and some abiotic environmental factors by analyzing the abundance, dominance, biodiversity, colpodid/polyhymenophoran (C/P) ratio, and community similarity of soil ciliates at 7 different habitats in the Baiyun Mountain (Mt.) area, southern China.

MATERIALS AND METHODS

This study was performed within the framework of a larger project. Accordingly, characteristics of the sampling sites are described in detail in previous publications (Li et al. 2010), and for a description of Baiyun Mt., see Li et al. (2010).

Study sites and soil sampling

In total, 7 habitats, 4 on the southern slope and 3 on the northern slope of Baiyun Mt., were selected according to the elevation and main vegetation characteristics of the sites (Fig. 1). Site characteristics, such as the predominant vegetation, elevation, and annual climate, are listed in table 1. Samples were collected quarterly using the parallel leaping method (Foissner 1987 1997a) in Sept. 2005 to June 2006. Briefly, 10 replicated surface soil samples (0-5 cm soil depth), including litter, surface soil, and fine plant roots, were randomly collected from an area of up to 100 m^2 at each site, and immediately mixed together (Li et al. 2010).

Fig. 1. Location and distribution contour map of soil sampling sites (1-7) (units: m elevation).

Table 1. The characteristics of the investigated sites

Site	Location (Longitude, Latitude)	Dominant vegetation	Elevation (m)	Annual climate	
				Temp (°C)	Humidity (%)
1	113°17'08"E, 23°11'46"N	*Acacia mangium*	88	25	75
2	113°17'22"E, 23°11'36"N	*Schima superba*	163	25.4	86
3	113°17'36"E, 23°11'23"N	*Acronychia pedunculata*	269	28.2	57.2
4	113°17'45"E, 23°11'10"N	*Schefflera heptaphylla*	343	26.8	71.6
5	113°17'34"E, 23°10'34"N	*Tetradium ruticarpum*	269	26	78.5
6	113°17'32"E, 23°10'32"N	*Pinus massoniana*	166	23.1	79
7	113°17'29"E, 23°09'48"N	*Lagerstroemia speciosa*	82	22	53

Sample analysis

After air-drying for 1 mo, all samples were processed using the non-flooded Petri dish method (Foissner 1987 1992). Briefly, this simple method involves placing 10-50 g of terrestrial material in a Petri dish (10-15 cm in diameter) and saturating but not flooding it with distilled water (Foissner 1997a). In order to find more species, a larger amount (150 g) of soil was used in the present study. Ciliate species were identified on days 2, 6, 13, 21, and 30, mainly on live specimens with bright-field and differential interference contrast microscopy (YS2-H and E800 microscopes, Nikon, Japan) complemented with a protargol staining technique (Foissner 1991). Identifications were based on descriptions by Kahl (1935), Foissner (1987 1993), Berger (1999), Shen et al. (1990), Foissner et al. (2002), Lynn and Small (2002), and Lynn (2008). Quantitative analysis of soil ciliates was based on the most-probable number (MPN) method after air-drying the soil sample for at least 1 mo and observing the presence or absence of ciliates on days 4, 7, and 11 (Stout 1962, Chen et al. 2009). The physicochemical parameters of soil samples were measured in samples collected in summer 2006 as the environmental background. These parameters were determined according to standard procedures; the soil texture classification system was based on the USA classification (Lu 1999).

Statistical analysis

The dominance was the ratio of the species number of the dominant group and the total species number (Ma et al. 2008). The constancy of species was the percentage of habitats in which a species was present. The C/P ratio was the ratio of r-selected colpodid and k-selected polyhymenophoran ciliates (Foissner et al. 2005). Margalef's richness index (Shen et al. 1990, Ma et al. 2008) was used to evaluate the diversity of the ciliate communities, and differences in Margalef's richness index between different samples were compared with the least significant difference (LSD) test. The Jaccard formula (McCormick et al. 1992) was used to calculate the similarity between communities from different samples. A hierarchical cluster analysis, using a Euclidean distance function and Jaccard similarly, was performed to determine the similarity of physicochemical characters and ciliate communities at the 7 sampling sites. Relationships between ciliate abundances and soil physicochemical parameters were revealed by bivariate correlations and multiple stepwise regressions. Statistical analyses were performed using SPSS 11.5 software (SPSS, Chicago, IL, USA).

RESULTS

Physicochemical parameters

Most of the physicochemical factors at the 7 habitats at Baiyun Mt., such as soil moisture, organic matter, total nitrogen, and ammonia-nitrogen greatly differed among the different sampling sites (Table 2). The mechanical composition of the soil and the size distribution of soil granules at the 7 investigated sites are listed in table 3. According to the USA classification, the soil texture at sites 1, 4, 5, and 6 was sandy clay loam, and that at sites 2, 3, and 7 was sandy loam. The hierarchical cluster dendrogram revealed that soil physicochemical properties at sites 2 and 7, and at sites 1 and 6 were more similar,

Table 2. Main physicochemical factors of the 7 sites investigated within Baiyun Mountain

Soil parameter	Site						
	1	2	3	4	5	6	7
pH	4.13	3.78	4.70	4.67	4.58	5.87	4.82
Soil moisture (g/kg)	141.6	87.5	174.6	247.2	330.6	131.1	99.4
Organic matter (g/kg)	38.8	24.3	48.7	61.7	70.7	53.4	30.9
Total nitrogen (g/kg)	4.21	1.48	3.19	5.50	6.35	2.77	1.61
Total phosphorus (g/kg)	0.53	0.62	0.59	0.61	0.78	0.56	0.61
Total potassium (g/kg)	14.0	15.6	14.3	13.4	12.8	13.2	13.7
Ammonia-nitrogen (mg/kg)	31.5	10.5	16.7	54.4	60.6	26.3	10.2
Nitrate-nitrogen (mg/kg)	4.13	3.29	5.10	7.48	7.81	2.70	5.35
Sulfate (g/kg)	3.98	4.15	3.59	4.16	4.01	4.06	3.91

respectively, and those of sites 4 and 5 differed from the others (Fig. 2).

Community structure of soil ciliates

In total, 114 species of ciliates, belonging to 9 classes, 18 orders, and 47 genera, were identified in the soil samples (Table 4). Among these 114 species, 59 species were found at ≥ 1/2 of the investigated sites, and the most prevalent species occurring at all 7 sites were *Blepharisma hyalinum*, *Cinetochilum margaritaceum*, *Colpoda cucullus*, *Col. inflate*, *Col. irregularis*, *Cyclidium elogatum*, *Cyc. musicola*, *and Opercularia curvicaule* (100% constancy). The 1st dominant group was the Spirotrichea (4 orders, 44 species) with a dominance of 38.60%, followed by the Colpodea (2 orders, 25 species) with a dominance of 21.93%; then were the Litostomatea, Oligophymenophorea, Nassophorea, Armophorea, and Phyllopharyngea, with dominances of 12.28%, 10.53%, 7.89%, 3.51%, and 3.51%, respectively. Rare groups were the Heterotrichea and Prostomatea, each with only 1 order and 1 species found. The total species number (TSN) at each site varied with soil habitats; site 4 had the highest total species number (73 species), and site 2 had the lowest (40 species) (Fig. 3). The C/P ratio showed that more colpodid than polyhymenophoran species were found at sites 2 and 7 (C/P > 1) (Fig. 3).

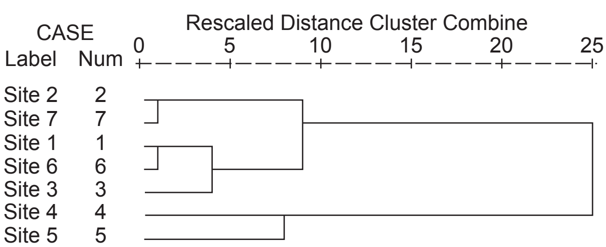


Fig. 2. Dendrogram showing the cluster analysis of soil physicochemical properties at 7 sites investigated at Baiyun Mountain.

Seasonal dynamics of ciliate abundance and diversity

Seasonal changes in ciliate abundance and diversity are shown in figure 4. The highest abundance was at site 5 in winter, reaching 3.87×10^4 individuals (ind.)/g; this site also had the highest mean annual abundance. In contrast, site 2 in spring had the lowest ciliate abundance, at only 9.2×10^2 ind./g, and it also had the lowest mean annual abundance (Fig. 4A). Margalef's biodiversity index ranged 2.07-5.46. Sites 3, 4, and 5 had higher biodiversities, whereas lower biodiversities were found at sites 2 and 7 (Fig. 4B).

Cluster analysis of the soil ciliate community

Jaccard coefficients (J) among the 7 sites ranged 0.289-0.542, indicating a moderately dissimilar community similarity (0.25 < J < 0.50) to moderately similar (0.50 < J < 0.75). The hierarchical cluster dendrogram of the community composition of soil ciliates demonstrated that communities at sites 1, 4, and 5 had closer relationships, whereas those at sites 2, 6, and 7 differed from the other sites (Fig. 5).

Table 3. The percentage size distribution of soil granules (mm) of the 7 sites investigated within Baiyun Mountain

Size distribution of granules (mm)	Site						
	1	2	3	4	5	6	7
> 2	3.6	6.9	18	13	0.43	6.8	3.2
2-1.0	2.5	7.4	5.7	3.9	2.9	2.2	5.2
1.0-0.5	9.4	10.5	12.6	7.9	16	12	24
0.5-0.25	13	10	16	15	20	20	15
0.25-0.05	25	25	25	26	17	26	15
0.05-0.02	5.1	14	16	8.3	4.1	0	4.1
0.02-0.002	22	14	7.4	15	17	19	20
< 0.002	23	20	17	24	23	21	18
Soil texture[a]	SCL	SL	SL	SCL	SCL	SCL	SL

[a]SCL, sandy clay loam; SL, sandy loam.

Table 4. List of soil ciliate taxa found at the Baiyun Mountain with the percentage distribution of species numbers in the orders and the constancy of species (based on the taxonomic information system of Lynn, 2008)

Class	Order	Species	Constancy of species (%)
Armophorea	Armophorida (3.51%)	*Metopus hasei* Sondheim, 1929	28.6
		Metopus minor Kahl, 1927	42.9
		Metopus rectus Foissner, 1980	42.9
		Metopus sp.	14.3
Colpodea	Colpodida (15.79%)	*Bresslaua vorax* Kahl, 1931	85.7
		Colpoda aspera Kahl, 1926	42.9
		Colpoda augustini Foissner, 1987	42.9
		Colpoda colpidiopsis Kahl, 1931	14.3
		Colpoda cucullus Müller, 1773	100
		Colpoda edaphoni Foissner, 1980	71.4
		Colpoda elliotti Bradbury and Outka, 1967	14.3
		Colpoda fastigata Kahl, 1931	57.1
		Colpoda flavicans Stokes, 1885	28.6
		Colpoda inflata Kahl, 1931	100
		Colpoda irregularis Kahl, 1931	100
		Colpoda lucida Greeff, 1888	71.4
		Colpoda magna Lynn, 1978	85.7
		Colpoda maupasi Enriques, 1908	57.1
		Colpoda minima Foissner, 1993	85.7
		Colpoda simulans Kahl, 1931	85.7
		Colpoda steinii Maupas, 1883	85.7
		Pseudoplatyophrya nana Foissner, 1980	57.1
	Cyrtolophosidida (6.14%)	*Cyrtolophosis elongata* Kahl, 1931	100
		Cyrtolophosis major Kahl, 1926	42.9
		Cyrtolophosis mucicola Stokes, 1885	71.4
		Pseudocyrtolophosis sp.	57.1
		Platyophrya macrostoma Foissner, 1980	42.9
		Platyophrya spumacola Kahl, 1927	28.6
		Woodruffia rostrata Kahl, 1931	71.4
Heterotrichea	Heterotrichida (0.88%)	*Blepharisma hyalinum* Perty, 1849	100
Litostomatea	Haptorida (10.53%)	*Diplites* sp.	14.3
		Fuscheria sp.	57.1
		Sikorops namibiensis Foissner, Agatha and Berger, 2002	42.9
		Pseudoholophrya terricola Berger, Foissner and Adam, 1984	42.9
		Arcuospathidium muscorum Foissner, 1984	71.4
		Spathidium longicaudatum Buitkamp, 1977	28.6
		Spathidium musicola Kahl, 1930	14.3
		Spathidium procerum Kahl, 1930	71.4
		Spathidium spathula Moody, 1912	85.7
		Dileptus alpinus Kahl, 1932	57.1
		Dileptus terrenus Foissner, 1981	14.3
		Dileptus sp.	14.3
	Pleurostomatida (1.75%)	*Litonotus fasciola* Wrzesniowski, 1870	71.4
		Litonotus lamella Ehrenberg, 1833	57.1
Nassophorea	Colpodidiida (1.75%)	*Colpodidium caudatum* Wilbert, 1982	57.1
		Colpodidium horribile Foissner, Agatha and Berger, 2002	42.9
	Microthoracida (6.14%)	*Leptopharynx eurystoma* Foissner, 1988	14.3
		Leptopharynx sphagnetorum Levander, 1900	57.1
		Drepanomonas obtusa Penard, 1922	71.4
		Drepanomonas revoluta Penard, 1922	71.4
		Drepanomonas sphagni Kahl, 1931	42.9
		Microthorax simulans Kahl, 1931	28.6
		Stammeridium kahli Wenzel, 1969	71.4
Oligohymenophorea	Peniculida (2.63%)	*Frontonia angusta* Kahl, 1931	85.7
		Frontonia depressa Kahl, 1931	57.1
		Frontonia sp.	14.3

Table 4. (continued)

Class	Order	Species	Constancy of species (%)
	Philasterida (0.88%)	*Cinetochilum margaritaceum* Perty, 1852	100
	Pleuronematida (4.39%)	*Cyclidium elogatum* Schewiakoff, 1896	100
		Cyclidium musicola Kahl, 1931	100
		Cyclidium oblongum Kahl, 1931	85.7
		Cyclidium simulans Kahl, 1928	28.6
		Cyclidium sp.	14.3
	Sessilida (2.63%)	*Opercularia arboricolum* Foissner, 1981	71.4
		Opercularia curvicaule Foissner, 1998	100
		Vorticella astyliformis Foissner, 1981	85.7
Phyllopharyngea	Chlamydodontida (3.51%)	*Chilodonella labiata* Stokes, 1891	57.1
		Chilodonella turgidula Penard, 1922	14.3
		Chilodonella uncinata Strand, 1928	28.6
		Pseudochilodonopsis mutabilis Foissner, 1981	42.9
Prostomatea	Prorodontida (0.88%)	*Holophrya atra* Svec, 1897	28.6
Spirotrichea	Euplotida (2.63%)	*Euplotes affinis* Kahl, 1932	57.1
		Euplotes musicola Kahl, 1932	71.4
		Euplotes sp.	14.3
	Sporadotrichida (21.93%)	*Halteria grandinella* Dujardin, 1841	57.1
		Histriculus muscorum Kahl, 1932	14.3
		Histriculus similis Corliss, 1960	57.1
		Oxytricha affinis Stein, 1859	42.9
		Oxytricha alfredi Berger, 1999	28.6
		Oxytricha fallax Stein, 1859	57.1
		Oxytricha islandica Berger and Foissner, 1989	14.3
		Oxytricha lanceolata Shibuya, 1930	42.9
		Oxytricha longa Hemberger, 1982	14.3
		Oxytricha minor Kahl, 1932	14.3
		Oxytricha setigera Stokes, 1891	42.9
		Oxytricha siseris Vuxanovici, 1963	57.1
		Oxytricha sp.	14.3
		Stylonychia muscorum Kahl, 1932	42.9
		Urosoma acuminata Kahl, 1932	14.3
		Urosoma caudata Berger, 1999	57.1
		Urosoma cienkowskii Kowalewski, 1882	57.1
		Gonostomum affine Sterki, 1878	14.3
		Gonostomum algicola Gellert, 1942	57.1
		Gonostomum franzi Foissner, 1982	14.3
		Gonostomum strenuum Sterki, 1878	57.1
		Gonostomum sp.	14.3
		Hemisincirra gellerti Foissner, 1984	57.1
		Hemisincirra gracilis Foissner, 1984	42.9
		Hemisincirra kahli Hemberger, 1985	28.6
	Stichotrichida (3.51%)	*Amphisiella acuta* Foissner,1982	28.6
		Psilotricha viridis Kahl, 1932	57.1
		Stichotricha secunda Perty, 1849	71.4
		Strongylidium muscorum Kahl, 1932	42.9
	Urostylida (10.53%)	*Pseudourostyla franzi* Foissner, 1987	57.1
		Australothrix simplex Liu et al., 1992	57.1
		Holosticha muscorum Foissner, 1982	57.1
		Holosticha oculata Mereschkowsky, 1879	42.9
		Holosticha sigmoidea Foissner, 1982	57.1
		Paruroleptus muscorum Foissner, 1982	28.6
		Paruroleptus sp.	14.3
		Uroleptus mobilis Engelmann, 1861	57.1
		Uroleptus piscis Ehrenberg, 1831	42.9
		Uroleptus rattulus Stein, 1859	57.1
		Uroleptus sphagni Stokes, 1886	14.3
		Uroleptus sp.	14.3
9 classes	18 orders	114 species	

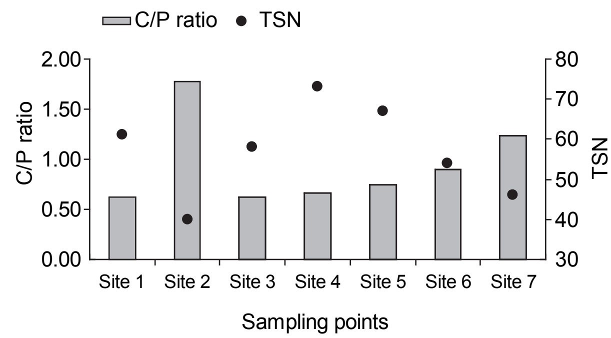
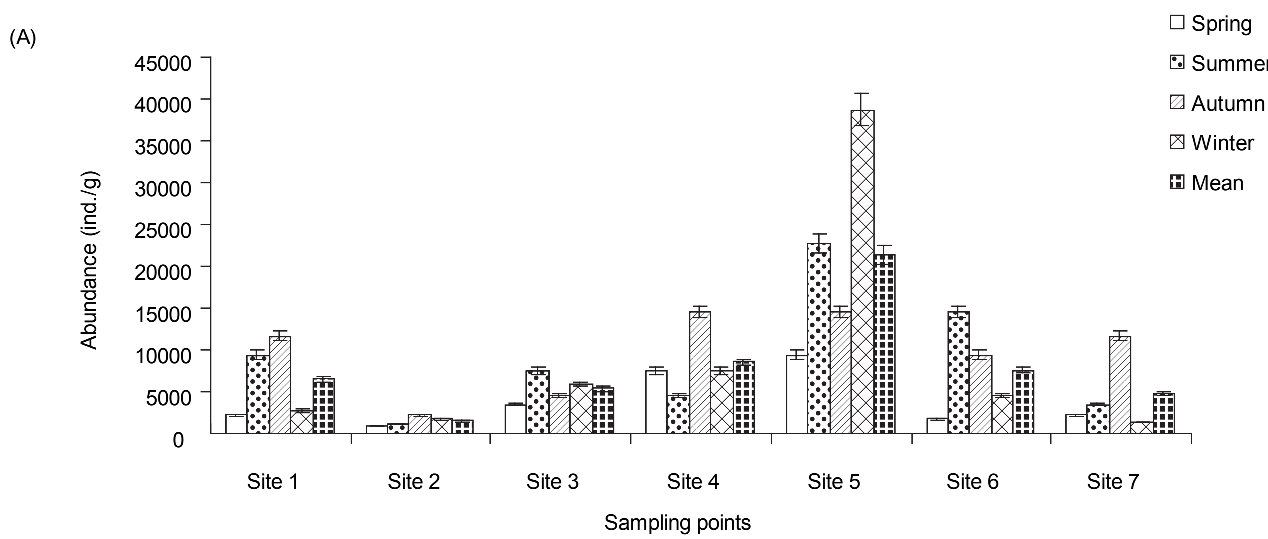


Fig. 3. Colpodida/polyhymenophoran (C/P) ratios of soil ciliate species, and total species number (TSN) at each sampling point.

Relationships between ciliate abundances and physicochemical properties

When single factors were considered, soil moisture, organic matter, ammonia-nitrogen, total nitrogen, and total phosphorus significantly affected ciliate abundances (Table 5). However, when all of these parameters were included, the impact of total potassium also became significant. According to a multiple stepwise regression analysis, ciliate abundances were positively correlated with soil moisture, organic matter, total nitrogen, ammonia-nitrogen, and total phosphorus, whereas a negative correlation was found with total



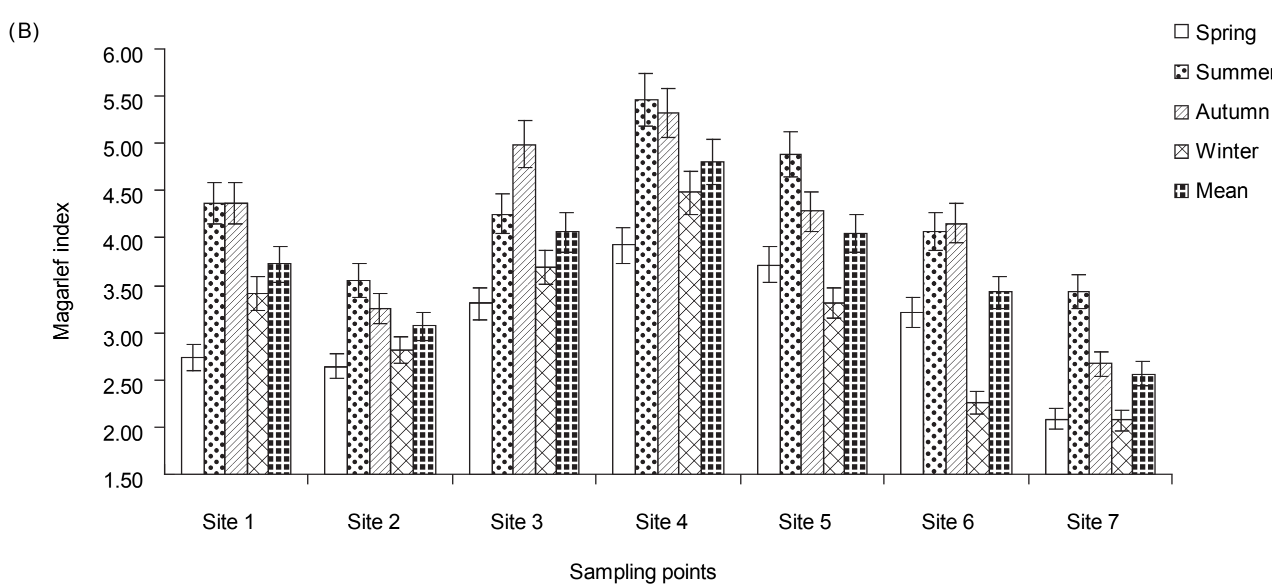


Fig. 4. Seasonal dynamics of ciliate abundances (individuals (ind.)/g) (A) and Margalef's index (B).

potassium (Table 6). Among these factors, the most significant one was soil moisture, followed by organic matter, ammonia-nitrogen, total nitrogen, and total phosphorus, while the effect of potassium was the least. Soil pH, nitrate-nitrogen, and sulfate showed no significant effect.

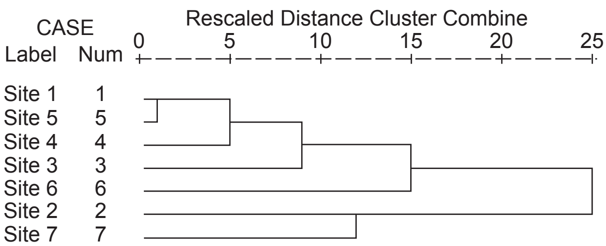


Fig. 5. Dendrogram based on the Jaccard formula showing the cluster analysis of community similarity of soil ciliates at 7 sites investigated at Baiyun Mountain.

Table 5. Bivariate correlation of ciliate abundance with soil physicochemical parameters

Soil parameter	Pearson correlation coefficient	Significance (p)
pH	0.17	0.710
Soil moisture	0.90**	0.005
Organic matter	0.84*	0.019
Total nitrogen	0.83*	0.022
Total phosphorus	0.79*	0.034
Total potassium	-0.74	0.055
Ammonia-nitrogen	0.84*	0.019
Nitrate-nitrogen	0.68	0.090
Sulfate	0.082	0.860

**Correlation was significant at the 0.01 level. *Correlation was significant at the 0.05 level.

DISCUSSION

Ciliate community composition

Although both the total species numbers and abundances differed, the dominant and rare groups in the 7 habitats were almost the same, with all dominant groups being the Spirotrichea and Colpodea. This is in accordance with results from other terrestrial regions of the world (Stout 1962, Ning and Shen 1998, Foissner 1997a 1999b, Foissner et al. 2005). In the present study, totally 114 ciliate species with 40-73 species among sites were found; these are higher species numbers compared to those of a tropical rainforest in Puerto Rico (totally 80 species with 13-42 species at the various sites) (Bamforth 2007). However, they are much lower numbers compared to those of a natural forest in Central Europe (totally 233 species with 45-120 species at various sites) (Foissner et al. 2005). Compared to the taxonomic compositions of faunas investigated on the world list of soil ciliates, greater similarity was found in dominant groups between Baiyun Mt. and Antarctica or the world list; whereas much greater similarity was found in rare groups of Baiyun Mt. with Africa and Australia since they all had Prostomatea as one of the rare groups (Foissner 1997a). According to Foissner (1987), the taxonomic composition of ciliates correlates with morphological and ecological peculiarities of the respective ciliate groups. As to species of Spirotrichea and Colpodea, their ecological characteristics allow them to easily adapt to terrestrial habitats. For example, the Colpodea, of which most species belonged to Colpodida in this study, can encyst when the soil moisture decreases and excyst in a timely manner and recover their normal morphology when the soil moisture increases (Foissner 1993, Foissner et al. 2002).

Table 6. Correlation degree and multiple stepwise regression of ciliate abundance with soil physicochemical parameters

Soil parameter	Correlation	Formula of stepwise regression	R^2	p value
Soil moisture (*SM*)	+1[a]	*Ab* = -3418 + 65.52 *SM*	0.82	0.005
Organic matter (*OM*)	+2	*Ab* = -7004 + 318.2 *OM*	0.70	0.019
Ammonia-nitrogen (*AN*)	+3	*Ab* = 135.4 + 259.4 *AN*	0.70	0.019
Total nitrogen (*TN*)	+4	*Ab* = -2151 + 2809 *TN*	0.68	0.022
Total phosphorus (*TP*)	+5	*Ab* = 29779 + 48564 *TP* - 3731 *TK*	0.83	0.026
Total potassium (*TK*)	-6	*Ab* = 29779 + 48564 *TP* - 3731 *TK*	0.83	0.038

[a]Correlation degree (1 means the largest effect of this factor on soil ciliate abundance, followed to a lesser degree by 2, 3, and so on).

With their flattened bodies, the Sporadotrichida can creep into adjacent soil granules or litter. This may explain why these species were the dominant groups (Ning and Shen 1998, Foissner et al. 2002).

Seasonal dynamics of ciliate abundance and diversity

Soil ciliate abundances at Baiyun Mt. varied 9.2×10^2-3.87×10^4 ind./g, which were higher than values of a tropical rainforest in Puerto Rico (Bamforth 2007). High abundance and diversity of soil ciliated protozoa appeared more often in summer and autumn, although there was 1 exception at site 5, and this seasonal dynamic was in accordance with investigation results in typical zones of China, although ciliate abundances at Baiyun Mt. were much higher than those of typical zones (0.63×10^2-7.48×10^3 ind./g) (Ning and Shen 1998). Soil moisture plays a big role in determining the presence and activity of protozoa; similarly, moderate temperatures (22-28°C) are favorable for most soil protozoa (Ning and Shen 1998). Enjoying an oceanic and subtropical monsoon climate, the Baiyun Mt. area has abundant rainfall, and suitable temperatures are available in summer and autumn (mean temperatures of the 7 investigated sites in summer and autumn were 26.1 and 25.4°C, respectively). This may partially explain the characteristics of seasonal dynamics of ciliate abundances and diversity in the present study.

Relationship between ciliate abundances and soil physicochemical factors

Each soil habitat has its own distinctive pore spaces which influence the level of microbial biomass (Postma and Veen 1990). The abundance and species composition of soil organisms are closely associated with the type and physical characteristics of the soil (Pen-Mouratov et al. 2008). The architecture of the habitable soil-pore network and the soil moisture are considered the 2 most important factors regulating soil protozoa populations (Ekelund and Rønn 1994). The effects of soil moisture, texture, and structure on ciliate abundances were reported before (Vargas and Hattori 1990, Ekelund and Rønn 1994, Feng and Yu 2000), as well as other main soil environmental factors, such as pH, organic matter, total nitrogen, total phosphorus, etc. (Foissner 1987, Gupta and Germida 1988, Ning and Shen 1998, Verhoeven 2001, Forge et al. 2003). In the present study, integrated effects of many physicochemical factors on abundances of soil ciliates at Baiyun Mt. were similar to those of other terrestrial habitats where soil physicochemical factors such as soil moisture, organic matter, and nitrogen had significant correlations with soil protozoa. Different from soil moisture which directly determines the presence and activity of protozoa, the effects of organic matter, nitrogen, phosphorus, and potassium on soil protozoa are indirect, by influencing/determining the abundance of bacteria. There is little information on relationships of ciliate abundances with soil ammonia-nitrogen and nitrate-nitrogen contents, although total nitrogen was found to influence soil protozoa abundances (Ning and Shen 1998). The results of the multiple stepwise regression analysis implied that ciliates may have the capability to acclimatize to ammonia-nitrogen in soil, since another study reported that protozoa were capable of resisting ammonia-nitrogen in activated sludge (Puigagut et al. 2005).

Ciliate community similarity indices of different sampling sites

Habitats of ciliated protozoa are temporally and spatially heterogeneous, and their distributions in the field are normally patchy as reflected by the low similarity among different habitats (Taylor and Shuter 1981, Jackson and Berger 1985, Acosta-Mercado and Lynn 2002). Soil ciliate communities among the 7 habitats ranged from moderately dissimilar to moderately similar. This not only demonstrates the diversity of soil protozoa in different habitats, but reflects the pronounced effect of vegetation and environmental factors on soil protozoa communities (Vargas and Hattori 1990). This effect was reflected by the rough similarity between the cluster trees from the physicochemical characters and community structures of soil ciliates at the 7 sample sites, such as sites 2 and 7 which were the farthest away from sites 4 and 5 in both trees.

The C/P ratio, biodiversity, and habitat assessment of soil protozoa

Organisms that live in frequently disturbed habitats or in ephemeral niches within relatively stable communities are thought to have high values of r_m, the intrinsic rate of natural increase (Taylor and Shuter 1981). Colpodid species are opportunistic r-selected generalists. They have a wide tolerance to fluctuations in humidity and temperature by possessing the ability to rapidly encyst and excyst and to pass quickly between active and dormant states. In contrast, polyhymenophoran species are more sensitive to fluctuations in external conditions and are usually more abundant in stable habitats. Accordingly, the C/P ratio is often employed to distinguish disturbed and stressed ecosystems from stable systems (Foissner et al. 2005). In the present study, sites 2 and 7 had C/P ratios of > 1, indicating dominant r-selected ciliate populations and more-variable habitat conditions compared to the other sites.

The biodiversity of soil organism is considered a biological index reflecting the stability of soil ecosystems and ecological or environmental quality (Coûteaux and Darbyshire 1998, Ning and Shen 1998). At a local scale, ciliate distribution is patchy, and sizes of the auto-correlated patches varied among different habitat types (Acosta-Mercado and Lynn 2002). Ciliates are associated with and adapted to abiotic conditions; accordingly the community characteristics of soil ciliates can be a biological indicator of the environmental status of their habitat. The lower biodiversity and higher C/P ratios at sites 2 and 7 imply that these 2 sites/habitats are less suitable for soil ciliated protozoa.

Acknowledgments: This work was financially supported by the Chinese National Natural Scientific Foundation (grant no. U0633002). We are grateful to Prof. T.B. Yang and Mr. A. Shahzad for their critical reading, and helpful comments and suggestions that greatly improved the quality of the manuscript.

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