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Research Article

Community Structure and Biodiversity of Soil Ciliates at Dongzhaigang Mangrove Forest in Hainan Island, China

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The distribution of soil ciliates in three different habitats within a typical mangrove forest in Dongzhaigang, Hainan, China was investigated. The abundance, biodiversity, and community similarity of ciliates in fresh and air-dried soil with different, physical/chemical properties were analyzed. Three Classes, 11 Orders, 34 Genera, and 70 species of ciliates were found with the first dominant group being Hypotrichida. Ciliate biodiversities followed Site B < Site A < Site C in both fresh and dried samples. Ciliate abundance was positively correlated with soil moisture, salinity, organic matter (OM), total nitrogen (TN), total phosphorus (TP), and sulfate (SO_4^{2-}), but negatively with pH and total potassium (TK). Site A and Site B and Site B and Site C showed the highest similarity in fresh and dried samples, respectively. The ubiquitous characteristics of ciliate distribution suggested their important role in food webs and nutrient cycling. The presence of Colpodida was linked with mangrove plants.

1. Introduction

Mangrove ecosystems are typical wetland systems in coastal deposits of mud and silt throughout the tropics and subtropical latitudes. They play an important role in maintaining and improving biological environments, purifying air, and resisting wastewater pollution and natural disasters in bays or estuary areas. They are treated as “maritime forests” for their special ecological, economical, and tourist values [1]. The importance of mangroves has attracted increasing attention in recent years, especially after the recent huge tsunami in Indian Ocean [2]. More and more research has been conducted on mangrove ecosystems.

Although all major groups of mangrove plants and animals have been studied to some extent [3–7], little information is available on single-celled soil protozoan organisms except a few described species of foraminifera, amoeboid, and ciliated protists [8–11]. Investigations on soil ciliates in mangrove forest habitats are rare.

Being an important group in nutrient cycling, energy flow, and food webs [12, 13], soil ciliates have participated in the decomposition of benthic residual deposit and the formation and development of mangrove soil and accelerated the mineralization processes of carbon, nitrogen, and other mineral nutrient elements [14]. As the main bacterial consumers, soil ciliates also have special characteristics such as high respiration, short generation times, and rapid multiplication. In the rhizosphere of living plants, protozoa play an important role in the mineralization of mineral nutrient elements. The pot experiments of Ekelund and Rønn [14] showed that organic matter released by plants could stimulate bacterial and ciliate activity in the root zone leading to mineralization of organic soil nitrogen and assimulation by plants. The prominent effect brought by soil ciliates may be important in mangrove plant nutrition; on other hand, the growth of plants may also significantly affect the soil quality and ciliate community. The plant roots and soil ciliate community are interdependent.

Moreover, they are good bioindicators of soil environments [15–17]. It is important to study the community structure of soil ciliates and their significance in soil environments, to have a better understanding of the function of

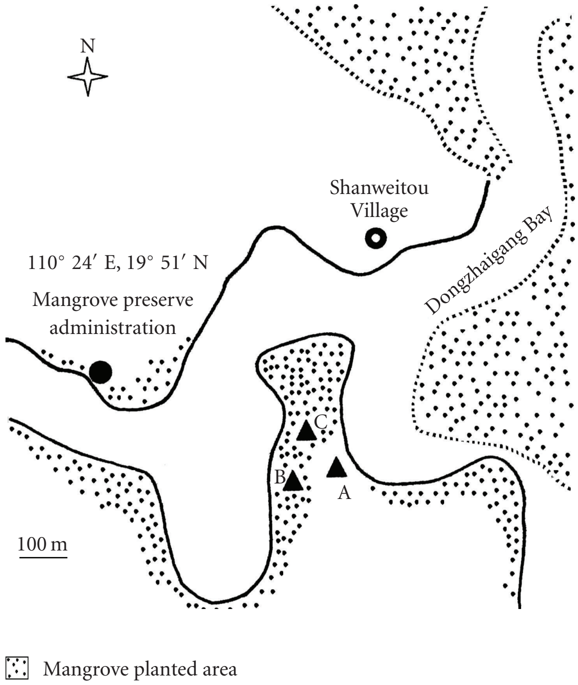

Figure 1: Map of sampling sites (A, B, and C) [10].

the mangrove ecosystem and so help in protecting mangrove resources. The present study aims to investigate the species abundance, biodiversity and community similarity index of soil ciliates in a typical mangrove forest in Dongzhaigang, Hainan Island in China. The study also attempts to compare the difference in ciliates community among three different habitats, bare land, and planted and natural mangroves, within forest and relates the ciliate abundance to soil properties.

2. Materials and Methods

2.1. Descriptions of Study Area and Soil Sampling. Dongzhaigang (110°30′–110°37′E, 19°51′-20°01′N), is a shoal-water bay formed by continental sink during the Great Qiongzhou Earthquake of 1605. The total everglade area is 5400 m^2, with 2065 m^2 of mangrove forest, and 3335 m^2 of mudflat and shoal water area. Dongzhaigang has a typical subtropical monsoon marine climate. annual average air temperature ranges from 23.3°C to 23.8°C; Annual average rainfall reaches 1676.4 mm, and average sunlight is 2200 h [18].

Soil samples were collected from three different habitats in Dongzhaigang National Mangrove Nature Reserve in April and September 2006 (Figure 1). Site A was bare land without any vegetation; Site B was a *Sonneratia apetala* mangrove forest artificially planted (at a distance between two trees of 2.5 m apart) by the Reserve three years ago and reached 2 m tall; Site C was a natural mangrove habitat dominated by *Bruguiera gymnorrhiza* with a few individuals of *Ceriops tagal*. The three sites were located within a triangle of about 100 m from each other. The sampling area of each sample site was about 10 m^2, and ten replicated surface soil samples (0–5 cm) with fine plant roots were collected using the "parallel leaping method" [15, 19]. Because only surface soil samples (0–5 cm) were needed, instead of a soil corer, here a shovel had been used to collect soil samples. The ten replicated surface soil samples were mixed round equably and combined to a composite sample in the field, then immediately collected about 3 kg of this composite sample, and immediately placed inside a sterilized plastic bag, sealed and transferred back to the laboratory [19]. Fresh samples were analyzed immediately; the remaining portions were air-dried for at least one month and then analyzed.

2.2. Analysis of Physical/Chemical Parameters of Soil Samples. The following soil properties of each soil samples were determined according to standard procedures [20]. Each pooled sample was hand cleaned of plant fragments and pebbles, weighed, dried at 60°C for 72 h, and reweighed to determine the moisture content. The pH and salinity values were obtained using a 1 : 5 soil/water solution by electrical conductivity (automatic, temperature-compensated conductivity meter). Analyses of organic matter were conducted using the acid-dichromate oxidation method, total nitrogen (TN) using the semi-micro kjeldahl method, total phosphate (TP) using the ammonium molybdate spectrophotometry method, total potassium (TK) using the flame photometer method, and SO_4^{2-} using barium sulfate turbidity. Soil mechanical composition of each dried sample was analyzed by a hydrometer method.

2.3. Qualitative Investigations of Soil Ciliates. All samples, both fresh and air-dried, were qualitatively analyzed following the "nonflooded Petri dish method" described by Foissner [15]. About 100–150 g soil sample was placed in a Petri dish (15–20 cm in diameter), saturated but not flooded with distilled water. About 2 mL of the run-off from each culture was collected on days 2, 4, 7, 14, 21, and 28 for the determination of ciliate species [15, 19]. The live specimens were observed under a high-power oil-immersion objective with bright field, phase contrast, or differential interference contrast microscopy (magnifications of ×40–1000; Nikon, YS2-H and E800) and complemented with silver line staining [21]. The identification, nomenclature and terminology of ciliate species were done according to the following: Berger [22], Carey [23], Foissner [21], Kahl [24], Lee et al. [25], Shen and Gong [26] Shen et al. [27], and Song [28].

2.4. Quantitative Investigations of Soil Ciliates. The quantitative analysis of soil ciliates was based on the modified "most probable number" (MPN) method employed by Darbyshire et al. [29]. According to our preliminary experiment, dilution factors of 10^2–10^4 were adopted for both fresh and air-dried soil samples.

2.5. Data Processing and Statistical Analyses. The Margalef formula [30] was used to calculate ciliate community diversity index:

$$d = \frac{(S-1)}{\ln N}, \qquad (1)$$

Table 1: Main physical/chemical factors at the three habitats of the mangrove forest [10].

Environmental factors	Bare land	Man-made mangrove	Natural mangrove
pH	6.51	6.16	4.77
Water percentage (%)	24.2	35.6	45.4
Salinity	19.243	25.695	24.288
OM ($g\,Kg^{-1}$)	31.267	42.087	150.276
TN ($g\,Kg^{-1}$)	1.345	0.831	3.962
TP ($g\,Kg^{-1}$)	0.511	0.568	0.626
TK ($g\,Kg^{-1}$)	13.094	11.953	11.652
SO_4^{2-} ($g\,Kg^{-1}$)	2.001	2.895	5.503

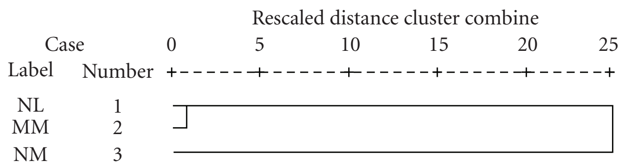

Figure 2: The dendrogram showing the cluster analysis of soil physical/chemical properties at 3 sites.

where d is the diversity index; S is species number; N is total number of individuals of all species.

The dominance was the ratio of dominant group number and total species number [31]. The Jaccard formula [32] was used to calculate community similarity analysis of the ciliates that were from different soil samples:

$$J = \frac{c}{(a + b - c)}, \quad (2)$$

where J is similarity index; a and b are total number of species in sites 1 and 2, respectively; c is the number of species common in both sites 1 and 2.

The stepwise regression analysis was conducted to reveal the integrated effect of multifactors on soil ciliate abundance and the correlation degree between these factors and ciliate abundance [33]. The hierarchical cluster was conducted to analyze the similarity of physicochemical characters of 3 sampling sites. All statistical analyses were performed using SPSS 13.0 software.

3. Results

3.1. Physical/Chemical Parameters of Soil Samples in the Mangrove Forest. The main physical and chemical parameters at the three habitats of the mangrove forest measured with samples collected in April 2006 as environmental background are listed in Table 1. Some physical/chemical factors, such as water percentage, OM, TN, and SO_4^{2-}, are much different at different sampling sites. Others like pH, salinity, TP and TK are slightly different. The hierarchical cluster dendrogram revealed that soil physical/chemical properties at bare land and Man-made mangrove are more similar; otherwise the Natural mangrove is disparate from other sites (Figure 2).

Table 2: Ciliate species found in all soil samples from the mangrove forest of Dongzhaigang, Hainan, China.

Ciliate species	Site A		Site B		Site C	
	FS	DS	FS	DS	FS	DS
Aspidisca steini	+		+		+	
Colpoda cucullus			+	+	+	+
Colpoda inflata			+	+	+	+
Colpoda patella				+	+	+
Colpoda penardi			+		+	+
Colpoda reniformis			+	+	+	+
Colpoda steinii			+	+	+	+
Cyclidium elongatum					+	+
Cyclidium simulans					+	+
Cyrtolophosis bursaria					+	
Cyrtolophosis major	+				+	
Diphrys appendiculata	+		+		+	
Euplotes affinis	+		+		+	
Euplotes bisulcatus	+					
Euplotes elegans	+		+		+	
Gonostomum affine		+	+	+	+	+
Gonostomum sp.		+		+		
Halteria grandinella	+	+		+	+	+
Holosticha adami			+		+	
Lacrymaria pupula	+				+	
Metopus es	+	+			+	+
Metopus hasei		+			+	+
Oxytricha fallax		+		+	+	+
Oxytricha marina				+		+
Paruroleptus caudatus		+			+	+
Plagiocampa atra	+		+		+	
Plagiocampa longis	+		+		+	
Strombidium elegans	+	+	+	+		+
Strombidium fourneleti	+					+
Strombidium stylifer	+	+	+		+	+
Strombidium sulcatum	+			+		+
Tachysoma pellionella	+	+		+		
Trachelostyla caudata					+	+
Uroleptus caudatus		+		+	+	
Uroleptus dispar		+		+	+	+
Urotricha agilis	+				+	
Vorticella aequilata			+	+	+	+
Vorticella cupifera				+	+	+

FS: fresh soil samples; DS: dried soil samples; +: detected in this sample

3.2. Community Structure of Soil Ciliates in Mangrove Forest. Three Classes, 11 Orders, 34 Genera, and 70 species of ciliates were found in all soil samples (Table 2). The first dominant group was Hypotrichida (24 species) with dominance of 0.34, followed by Colpodida (14 species) with dominance of 0.2. These two Orders together contributed more than half of the total species identified in the present study. The Sessilinia (Peritrichia) were represented by eight species.

Table 3: Comparison of the ciliate abundance and biodiversity indices in the mangrove forest from Dongzhaigang, Hainan, China.

Sites	Average abundance (ind. g^{-1})		Biodiversity indices	
	FS	DS	FS	DS
Site A	4,630	114	2.25	2.32
Site B	7,080	1,800	2.03	2.13
Site C	13,770	2,920	5.88	2.76

FS: fresh soil samples; DS: dried soil samples.

Table 4: Comparison of ciliate community similarity indices between the habitats/sites from Dongzhaigang mangrove forest, Hainan, China.

Sites	Similarity indices	
	FS	DS
Site A & Site B	0.26	0.38
Site A & Site C	0.18	0.35
Site B & Site C	0.25	0.54

FS: fresh soil samples; DS: dried soil samples.

3.3. Ciliate Abundance and Biodiversity. Table 3 shows that the abundance of soil ciliates in three habitats declined in the order Site A < Site B < Site C. The abundance of ciliates was the highest in the fresh sample from Site C, reaching 13,770 ind. g^{-1}, while the lowest one was found in the dried sample from Site A, with only 114 ind. g^{-1}. Results also indicated that the Margalef's biodiversity index of all samples ranged from 2 to 3 except the fresh sample from Site C. The biodiversity index of ciliates in both fresh and dried samples also varied among three habitats, followed the order of Site B < Site A < Site C. The difference was more obvious in fresh samples (the discrepancy was 3.12) than that in dried samples.

3.4. Ciliate Community Similarity Indices. The ciliate community similarity indices ranged from 0.18 to 0.26 (fresh samples) and from 0.38 to 0.54 (dried sample) (Table 4). It was larger in dried samples than that in fresh ones. The order of similarity index in fresh samples followed Site A & Site C < Site B & Site C < Site A & Site B, while the order was slightly different in dried samples (Site A & Site C < Site A & Site B < Site B & Site C).

3.5. Relationship between Ciliate Abundance and Physical/Chemical Properties in Soil

3.5.1. Correlation in Fresh Samples. According to multiple stepwise regression analysis, the ciliate abundance was negatively correlated with pH, but the relationships with soil moisture and salinity were positive (Table 5). Among these three factors, the most significant factor was pH, followed by soil moisture, and the last was salinity. The ciliate abundance was also positively correlated with OM, TN, TP, and SO_4^{2-} ($P < .01$), but negatively correlated with TK ($P < .05$). The effect of TN on the ciliate abundance was the largest, followed by TP, OM, and SO_4^{2-}, and TK showed the least effect.

3.5.2. Correlation in Dried Samples. Similar to that in fresh samples, negative correlation between ciliate abundance and pH but positive with moisture and salinity was found in dried samples (Table 6). However, the most influencing factor on ciliate abundance in dried samples was soil moisture, not pH, slightly different from that in fresh samples. The relationships between ciliate abundance and soil chemical properties, namely, OM, TN, TP SO_4^{2-}, and TK, were all positive except TK, the same trend as that in fresh samples. Among these five factors on ciliate abundance, TP was most significant, followed by TN, SO_4^{2-}, and OM, and the effect of TK was the least.

4. Discussion

4.1. Analysis of Ciliate Communities in Different Habitats. The dominant groups in soils from Sites B and C were Hypotrichida and Colpodida which were similar with those in other terrestrial soil samples in China [35]. The ciliate species of Colpodida were found in most soil samples from all over the world [17, 19, 21, 34, 37–39]. With their flat body, Hypotrichida ciliates could not only swim in water, but also creep adjacent to soil granules or litters [35]. In addition, Hypotrichida and Colpodida ciliates had special adaptive strategies in their life cycles; for example, they were easy to encyst when the soil moisture decreased but they could excyst to recover their normal morphology if the soil was rewetted again [21, 39]. Such biological characteristics allow these two groups of ciliates to adapt to intertidal mangrove soil where the habitat is alternately submerged and exposed conditions. It also helps to explain why Hypotrichida and Colpodida, which are common in terrestrial soils, are also dominant in mangrove soil habitats. However, the dominant group in Site A was the Oligotrichida and not Colpodida, suggesting that the habitat of Site A was different from terrestrial soils. Oligotrichida ciliates, especially *Halteria* spp., were generally considered as planktonic ciliate species. Site A, the bare land in the most seaward location, had lower terrain and the soil was more frequently covered by tidal seawater than the other sites. It is also possible that some planktonic ciliate species were brought to Site A by incoming tides. Oligotrichida ciliates were the uppermost consumers of algae and bacteria in aquatic environments and played a very important role in aquatic food webs because of their expansive feeding, rapid growing, swift moving, and strong activity [40].

When compared with other studies on the ciliate community in literatures, the percentages of Colpodids and Spirotrichs in Dongzhaigang mangrove soils were higher than those in Africa soil, Antarctic soil, and freshwater assemblage but were similar to those in Australia soil and world soil list (Table 7), indicating that the mangrove soil ciliates contained a representative subset of the world soil ciliate fauna [34]. According to Foissner [15], ciliate distribution in soil was correlated with morphological and ecological peculiarities of respective ciliate groups. Similar

Table 5: Correlation of ciliate abundance (ind. g^{-1})) with soil physical/chemical properties in fresh samples.

	Factors	Correlation	Formulas of stepwise regression	R^2	P value
Physical factors	pH (pH)	−[a] 1[b]	$Ab = 43122.15 - 5927.667\ p$	0.934	.002
	Soil moisture (SM)	+2	$Ab = -7286.268 + 442.911\ SM$	0.922	.002
	Salinity (S)	+3	/[c]	/	>.05
Chemical factors	OM (OM)	+3	$Ab = 3162.637 + 71.091\ OM$	0.946	.001
	TN (TN)	+1	$Ab = -11879.4 + 2170.297\ TN + 26775.13\ TP$	0.979	.002
	TP (TP)	+2			.012
	SO_4^{2-} (SO)	+4	$Ab = 1634.473 + 2300.289\ SO$	0.918	.003
	TK (TK)	−5	$Ab = 73563.27 - 5390.347\ TK$	0.701	.038

[a]+ means positive correlation; − means negative correlation.
[b]Correlation degree (1 means the largest effect on ciliates abundance, followed 2, 3, in sequence).
/[c], no data.

Table 6: Correlation of ciliate abundance with soil physical/chemical properties in dried samples.

	Factors	Correlation	Formulas of stepwise regression	R^2	P value
Physical factors	pH (pH)	−[a]2[b]	$Num = 2825.583 + 94.947\ W - 779.06\ p + 19.107\ S$	0.966	.002
	Soil moisture (SM)	+1			.006
	Salinity (S)	+3			.048
Chemical factors	TP (TP)	+1	$Num = -12599.7 + 25592.82\ TP$	0.959	.001
	TN (TN)	+2	$Num = -467.485 + 1063.69\ TN$	0.937	.002
	SO_4^{2-} (SO)	+3	$Num = -279.373 + 770\ SO$	0.893	.004
	OM (OM)	+4	$Num = 265.429 + 23.383\ OM$	0.888	.005
	TK (TK)	−5	$Num = 24242.76 - 1841.423\ TK$	0.710	.035

[a]+ means positive correlation; − means negative correlation.
[b]correlation degree (1 means the biggest effect on ciliates abundance, followed 2, 3, in sequence).

Table 7: Comparison (%) of the taxonomic composition of the faunas investigated with the world list of soil ciliates and a representative freshwater ciliates assemblage.

Ciliate groups	Soil (%)*					Freshwater assemblage
	Dongzhaigang	Africa	Australia	Antarctica	World list	
Spirotrichs	45.7	39.3	40.5	25.8	40.0	30.3
Colpodids	20.0	16.4	18.2	27.4	23.0	3.0

*All data except data from Dongzhaigang, Hainan, China were from Foissner [34].

Table 8: Relationship comparison of soil ciliate abundance on physical/chemical factors between mangrove soil habitats and terrestrial soil habitats.

	Factors	Habitat in mangrove forest		Habitat in terrestrial soil of China*
		FS	DS	
Physical factors	pH	−[a]1[b]	−2	+3[c]
	Soil moisture	+2	+1	+1
	Salinity	+3	+3	/[d]
Chemical factors	OM	+3	+4	+1
	TN	+1	+2	+2
	TP	+2	+1	+3
	SO_4^{2-}	+4	+3	/
	TK	−5	−5	−4

*Data from Ning and Shen [35, 36].
[a]+; positive correlation; −; negative correlation.
[b]Correlation degree (1 means the largest effect on ciliates abundance, followed 2, 3, in sequence).
[c]Number 2 is temperature.
[d]/, no data.

relationship was also demonstrated in ciliate distribution in mangrove forest soil in this study.

Some common ciliate species widely distributed all over the world such as *Gonostomum affine* and *Colpoda* spp. were also found at large abundance in soil samples collected in the present study (except Site A). In Namibia, West Africa, *Gonostomum affine* was found in 45 out of 73 samples while *Colpoda steinii* was present in 66 samples except the salt land samples with Cyanobacteria [39]. The frequencies of *Colpoda cucullus* and *Colpoda inflata* were also high in Antarctica [37]. As pointed out by Finlay et al. [41, 42], ciliate species that were locally rare or abundant were similarly rare or abundant on a global scale. For example, *Gonostomum affine* and *Colpoda* spp. could be considered as cosmopolitan ciliate species in all soil samples with different locations and environments, due to their morphological and distribution characteristics. In the present study, these ciliates were also dominant in mangrove forest soils, suggesting that Finlay's conclusion could be applied to this kind of soil habitat.

4.2. Differences of Soil Ciliate Composition among Three Mangrove Habitats. The architecture of the habitable soil pore network, which was determined by soil texture and structure, and the soil moisture were the most important factors determining the composition of soil ciliates. Their interaction established the basic environmental condition for soil ciliates [14]. Vargas and Hattori [43] showed that the aggregate structure of soil would effectively restrict ciliate movement, and only if the soil moisture was sufficiently high, their movement from one aggregate to another would be possible. Therefore, the ciliate fauna from different aggregates in the same soil may differ greatly.

In the present study, significant differences in ciliate composition and biodiversity were found among three mangrove habitats. The differences could be explained by special characteristics of Vargas' aggregates [43]. Although the three habitats were just separated by a small distance (100 m), their physical/chemical circumstances were so different leading to different vegetation and different soil aggregates. Firstly, the soil structure and texture of topsoil in Site C (natural mangroves) was very loose so that more ciliate species could exist there especially the big individuals. On the contrary, Site A (bare land) was made up of just compact mud, and around 50% of the soil granules had diameter less than 0.002 mm. Such soil texture was fine and lacked many suitable pores for mobile ciliates and ciliate activity [44]. Secondly, the soil moisture in Site C was significantly higher than that in Site A; the values in Sites A, B, and C were 24.2%, 35.6%, and 45.4%, respectively. It was reported that soil moisture was a main restricting factor on the survival, multiplication, and distribution of soil protozoan in the Fildes Peninsula, Antarctica [45]. High soil moisture in Site C explained why ciliate species were more abundant and biodiversity was higher in this habitat than the other two sites. Thirdly, plenty of organic residues and the plant litters were found in bottom mud in Site C (natural mangroves). Litters not only supplied sufficient organic matter, humus and other nutrients to soil ciliate, but also allowed greatly ciliate mobility (especially for Hypotrichida ciliates). Lastly, the synergic effect of several factors, such as pH, salinity, and temperature, would enhance the differences among different mangrove soil aggregates/habitats.

4.3. Effect of Drying Samples on Ciliate Abundance and Composition. It has often been assumed that direct microscopic examination of soil would result in an unreliable picture of the populations of ciliates, because their numbers are relatively small and they cannot be readily separated from the soil particles [46]. On the other hand, most soil ciliates have the ability to encyst, which can protect themselves against adverse conditions [14]. Although the MPN method is commonly used for enumerating soil ciliates, this method suffers from serious shortcomings. It might underestimate total protozoan numbers if the organisms were killed during the setting up of the cultures [47], or if they were unable to grow on the food offered. It is also possible that this method cannot reactivate all cysts and the species present; for example, the real number of species in the sample was very likely considerably higher than that in MPN [34]. The soil samples from the three different habitats were determined by MPN and compared with the direct counting method. The ciliate abundance in fresh samples was much greater than that in dried samples, suggesting that some ciliates failed to encyst or to excyst after air-drying, which caused direct decreases of ciliate abundance. In the other hand, the decrease of bacteria (serving as ciliate food) in dried samples might indirectly affect the ciliate abundance. In this study, the ciliate species which were abundant in fresh samples but disappeared in dried samples were *Euplotes*, *Diphrys*, *Cyrtolophosis*, and *Plagiocampa*, indicating that these species had lower ability to encyst or excyst than the other ciliates such as *Colpoda* and *Gonostomum*. Similar findings were also reported by Foissner [19]. The present data on the composition and abundance of ciliates proved that for more detailed information of soil ciliate community, the MPN and other methods for soil ciliate analysis should be used together.

4.4. Relationship between Ciliate Abundance and Soil Physical/Chemical Factors. Although the effects of one physical/chemical-factor on ciliates have been widely studied [14, 43, 45, 48–50], reliable data on multiple effects or interactions of several physical/chemical factors are extremely rare. In this study, an integrated effect of multifactors on the soil ciliate of mangrove forest soils showed that the correlations between ciliate abundance and physical/chemical factors were similar to those in terrestrial habitats except for pH values (Table 8). Under the salty condition in mangrove forest habitats, the acidic pH favored the protozoan osmotic regulation and nutrient absorption and explained why the ciliate abundance was negatively correlated with pH.

4.5. Relationship between the Ciliate Community Similarity Indices and the Mangrove Ecological Restoration. Ning and Shen [36] explained the important significance of community similarity indices and biodiversities by reflecting the complexity and stability of communities themselves and the ecological or environmental quality. The soil ciliate similarity index between habitats was very low (appeared quite dissimilar or a little dissimilar), which not only supported the opinion that different aggregates had different protozoan biodiversities [43, 51] but also showed the significant effects of vegetation and soil physical/chemical factors on soil protozoan communities. In this study, results of ciliate community similarity index proved that ciliate community in Site B was between Sites A and C. In fact, Site B (artificially planted mangroves) was the transitional stage from Site A (bare land) to Site C (natural mangroves) in a mangrove forest. Thus, we can deduce the evolvement of different mangrove soils and the mangrove vegetation restoration through their similarity indices. The soil ciliate community could be used to assess the restoration of the mangrove ecosystem.

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