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Periphytic ciliate colonization of an artificial substrate in Korean coastal waters

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Summary

In order to reveal the taxonomic composition and the species distribution of periphytic ciliates in Korean coastal waters, a three-month survey was carried out using glass slides as artificial substrates at two depths (1 and 2 m) in the coastal area of Incheon, Korea, from August to November 2007. A total of 40 ciliates with twelve dominant species, about half of which belonged to the orders Hypotrichida and Cyrtophorida, were identified by *in vivo* observation and silver impregnation method. The sessile ciliates were represented by the species of the orders Peritrichida and Suctorida, and the motile forms belonged primarily to the orders Hypotrichida, Cyrtophorida and Pleurostomatida. The peritrich *Zoothamnium* spp. and the heterotrich *Folliculinopsis producta* were the most dominant species in the samples from the both depths, but appeared more predominating at the lower depth. Multivariate analysis showed that the species distribution was considerably different between the two sampling depths mainly due to 12 dominant species, which had different abundance and occurrence. Our results suggest that for detecting the temporal and spatial dynamics of ciliate communities it is necessary to position the colonizing depths in marine ecosystems.

Key words: periphytic ciliate, marine biofilm, microbial ecology, artificial substrate

Introduction

Ciliates form an important assemblage of the microbial communities and usually dominate in both the number of species and abundance in the microbial food loop (Beers et al., 1980; James and Hall, 1995; Corliss, 2002). Many ciliates can live in the environments unfavorable to most other eukaryotic organisms and some can even tolerate the conditions extreme to the macrofauna (Fenchel, 1969; Patterson et al., 1989). Moreover, with their shot life cycle and delicate external membranes, ciliates may response to external changes more quickly than most metazoans and can thus be indicators of the quality

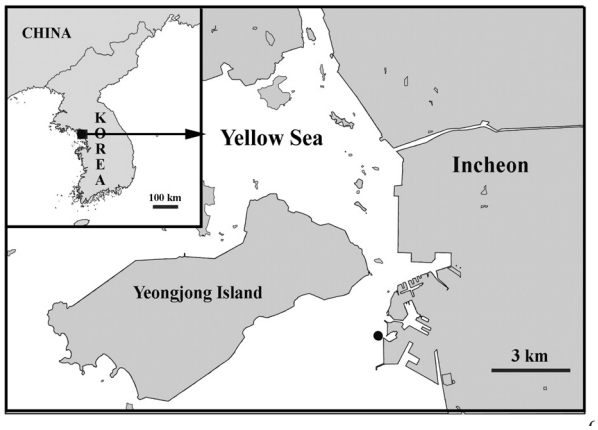

Fig. 1. A map of the sampling station in coastal waters near Incheon Harbour, Korea.

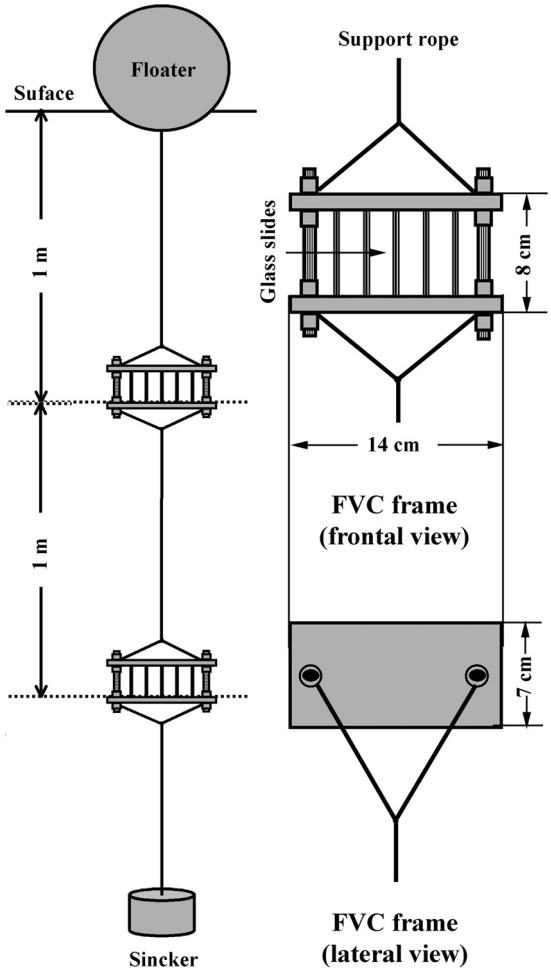

Fig. 2. Anchoring system for glass slides.

of soil, fresh and sea waters, etc. (Cairns et al., 1972; Foissner et al., 1992; Coppellotti, 1998).

Periphytic ciliates colonize the submerged natural and artificial substrates. The abundance and richness of ciliates in *Aufwuchs* (or periphyton) is usually high (Fenchel, 1987; Foissner et al., 1992; Song et al, 1999). With their easy sampling, the increasing availability of taxonomic references and the standardization of temporal and spatial comparisons, ciliates have been widely used to evaluate and monitor responses to contamination in ecological and ecotoxicological investigations (Coppelotti and Matarazzo, 2000; Gong et al., 2005). To use periphytic ciliates as bioindicators and to track the effects of pollution and recovery of the biotic components, it is necessary to know the specific community structure and the spatial and temporal species distribution. Such studies , however, have rarely been carried out in the marine environment. The vertical variation of ciliate colonization is especially poorly investigated, although it is important to confirm the optimal colonizing position in a ciliate community study (Persoone, 1968; Agamaliev, 1974; Coppelotti and Matarazzo, 2000; Gong et al., 2005)

A three-month baseline survey of periphytic ciliates colonizing glass slides was carried out in a coastal area of Incheon, Korea. The aim of the study was to document the taxonomic composition and the temporal and spatial species distribution of the ciliates .

Material and Methods

Study site and time

The study station was located in the coastal waters near Incheon Harbour, Korea (Fig. 1). This was a polluted inshore area, with a maximum depth of about 8 m, a high turbidity and a mud-sandy bottom. Investigations were carried out in August-November 2007.

Sampling

Eighteen samples (referred to as 13-Aug I, 13-Aug II, 23-Aug I, 23-Aug II, etc.) were collected from August to November 2008. Ten glass slides (2.5 × 7.5 cm) were clipped to a polyvinyl chloride (PVC) frame (14 × 8 × 7 cm), and two frames were submerged at two depths (1 and 2 m) beneath the water surface (Fig. 2). The slides were exposed as back-to-back pairs, so that they could be split and observed directly without cleaning. They were placed vertically in the frames and were collected every 10 days.

According to Wilbert (1969), there are no significant differences between ciliate communities colonizing slides within the same frame. Thus, for every sampling date 7 replicate slides were randomly selected and evaluated. The slides were transferred into Petri dishes containing water from the sampling site and transported to the laboratory in a cooling box within 12 h after sampling.

Identification and counting

Species were first examined at a 45-fold magnification under a stereomicroscope (Olympus SZH10 research stereo) to observe the behavior and movement of the cells. They were then transferred with a micropipette onto a clean glass slide and placed under a microscope (Leica DM2500) at 100- to 125-fold magnification to reveal details of the cell size and other morphological characters (Foissner et al., 1999). Over 30 cells of each morphotype were picked out with the micropipette and identified to the species level using protargol method (Wilbert, 1975). Species were identified following keys and guides such as Kahl (1931) and Song et al. (2003). The taxonomic scheme used was according to Corliss (1979). The designation of species as sessile, vagile or planktonic was made judging by their mobility and the ecological niches they occupied. This approach has been used in previous studies including those by Foissner et al. (1992, 1999), Coppellotti and Matarazzo (2000) and Gong et al. (2005).

The counting and measurement of ciliates *in vivo* was carried out under an inverted microscope as soon as possible after sampling (generally within 2 to 4 h) in order to prevent significant changes in species number and composition. At a 90-fold magnification, 20 fields of view per slide were randomly chosen for counting. The ciliate abundances were calculated from all 7 replicate slides to confirm the average cell density (cell cm^{-2}).

Data analysis of samples

Species diversity (H'), evenness (J) and species richness (d) of samples were calculated as follows:

$$H' = - \sum_{i=1}^{s} Pi(\ln Pi)$$

$$J = H' / \ln S$$

$$d = (S - 1) / \ln N$$

where H' = observed diversity index; Pi = proportion of the total count arising from the i^{th} species; S = total number of species; and N = total number of individuals.

The community structures of samples were analyzed using the PRIMER (Plymouth Routines in Multivariate Ecological Research) package (Clarke and Warwick, 1994). The multivariate analysis of cluster and multidimensional scaling (MDS) ordination were used to summarize species distribution, using the Bray-Curtis similarity from the log-transformed data of species abundance (Clarke and Warwick, 1994). Differences between communities at different depths were tested by the PRIMER program ANOSIM. The contribution of each species to the average Bray-Curtis dissimilarity between groups of samples, as well as to the similarity within a group was examined by the analysis program SIMPER.

For statistical analyses the community parameter data were log-transformed. The calculations were carried out with SPSS (ver. 11.5) software. Paired *t*-test was used to test for differences of ecological parameters between ciliate communities from different depths at the 0.05 level.

Results

Taxonomic composition

The ciliate taxa identified are listed in Table 1. A total of 40 ciliate species from 9 orders and 28 genera were found. Hypotichida and Cyrtoporida were the two orders with most species, accounting for 47% and 17%, respectively, of the species recorded; each of the other seven orders had a comparatively low number of species (Table 1, Fig. 3). The sessile taxa were represented by four spe-

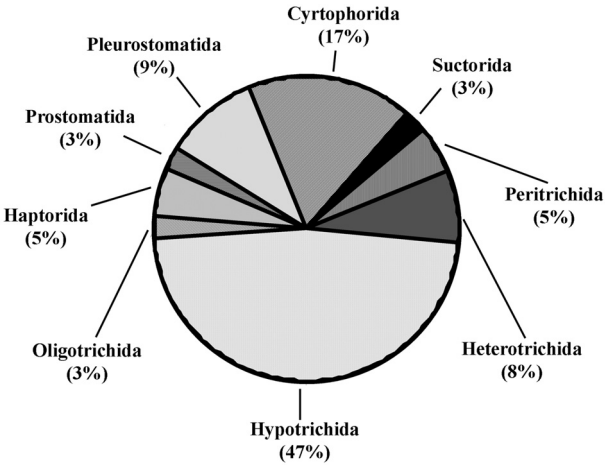

Fig. 3. Taxonomic composition of periphytic ciliate communities: the percentage of the total number of species recorded through out the period of sampling is shown for each order.

Table 1. List of the species of ciliates recorded in 18 samples from the two depths (1 m and 2 m), including biohabit, degree of average abundance and occurrence.

Species	Biohabit	1 m		2 m	
		Abund.	Occurr. (%)	Abund.	Occurr. (%)
ORDER: Haptorida					
Lacrymaria marinum Kahl, 1933	V	+	22	+	33
Tracheloraphis sp.	V	+	22	+	44
ORDER: Prostomatida					
Holophrya oblonga Maupas, 1883	V	+	50	+	13
ORDER: Pleurostomatida					
Amphileptus litonotiformis Song, 1991	V	+	63	+	75
Amphileptus gui Lin, Song et Warren, 2005.	V	+	25	+	25
Litonotus paracygnus Song, 1994	V	+	50	+	75
Loxophyllum rostratum Coln, 1866	V	+	13	+	13
ORDER: Cyrtophorida					
Aegyriana oliva Deroux, 1976	V	+	25	+	25
Chlamydodon triquetrus Müller, 1786	V	+	50	+	25
Dysteria brasiliensis Cunha et al., 1925	V	+	25	+	25
Dysteria monostyla Kahl, 1931	V	-	-	+	11
Dysteria pusilla Claparède et Lachmann, 1859	V	+	67	+	78
Hartmannula angustipilosa Deroux et Dragesco, 1968	V	+	22	+	33
Lynchella dirempta Deroux, 1970	V	+	25	+	25
ORDER: Suctorida					
Corynophrya lyngbyi Ehrenberg, 1833	Se	-	-	+	33
ORDER: Peritrichida					
Zoothamnium duplicatum Kahl, 1933	Se	++++	100	++++	100
Zoothamnium plumula Kahl, 1933	Se	++	22	++	22
ODER: Heterotrichida					
Folliculinopsis producta Fraure-Fremiet, 1936	Se	+	78	++	56
Gruberia aculeata Ozaki et Yagiu, 1941	P	+	33	+	11
Gruberia lanceolata Kahl, 1930	P	+	11	+	22
ORDEE: Hypotrichida					
Aspidisca leptaspsis Fresenium, 1865	V	+	78	+	78
Aspidisca steini Buddenbrock, 1920	V	+	78	+	67
Diophrys appendiculata Ehrenberg, 1838	P	+	44	+	22
Discocephalus rotatorius Ehrenberg, 1831	V	+	67	+	44
Euplotes minuta Yocum, 1930	V	+	56	+	56
Euplotes vannus Мьller, 1786	V	+	11	-	-
Gastrostyla pulchra Kahl, 1932	V	+	78	+	33
Holosticha bradburyae Gong et al., 2001	V	+	44	+	56
Holosticha diademata Hahl, 1932	V	+	78	+	67
Holosticha heterofoissneri Hu, Song et Warren, 2002	V	+	33	+	44
Ponturostyla enigmatica Jankowski, 1989	V	+	33	+	33
Pseudokeronopsis flava Wirnsberger et al., 1937	V	+	22	+	44
Pseudokeronopsis rubra Ehrenberg, 1838	V	+	11	-	-
Oxytricha saltans Kahl, 1932	P	+	33	+	22
Stichotricha marina Stein, 1867	V	+	11	+	22
Trachelostyla pediculiformis Borror, 1972	V	+	11	+	11
Uronychia binucleata Young, 1922	P	+	11	+	22
Uronychia multicirrus Song, 1997	P	+	11	-	-
Uronychia setigera Calkins, 1902	P	+	33	+	11
ORDER: Oligotrichida					
Strobidinium sulcatum Claparède et Lachmann, 1858	P	+	33	+	11

Notes: Se = sessile; V = vagile; P = planktonic; + = 0-10 cells cm^{-2}; ++ = 10-100 cells cm^{-2}; +++ = 100-400 cells cm^{-2}; ++++ = over 400 cells cm^{-2}

cies: the peritrichs *Zoothaminium duplicatum* and *Z. plumula*, the suctorian *Corynophyra lyngbyi*, and the heterotrich *Folliculinopsis producta*. All the other ciliates belonged to the vagile and the planktonic component and were mainly represented by the members of the seven orders other than Peritrichida and Suctorida (Table 1).

The taxonomic composition of ciliate communities colonizing the glass substrates at two depths showed similar patterns. A total of 38 ciliate species from 8 orders and 27 genera were found in the 1m samples, and 37 species from 9 orders and 28 genera were found in the 2 m samples (Table 1). Although the two orders Hypotrichida and Cyrtophorida had the largest number of species, they accounted for different proportions (49% versus 43%; 16% versus 19%) in the 1 m and 2 m samples, respectively (Fig. 4). The other orders were represented by the same proportion except for the order Suctorida, which was not found in the 1 m samples (Fig. 4).

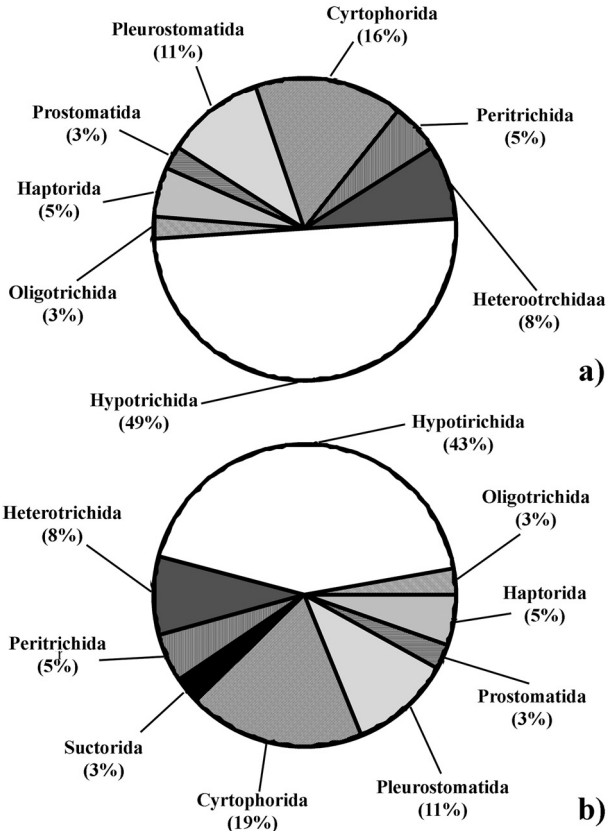

Fig. 4. Comparison of taxonomic composition of periphytic ciliate communities between 1 and 2 m depth.

Abundances, core species and diversities

Fig. 5 shows the temporal variation of the species number, richness, evenness and diversity as well as the abundance of ciliate communities colonizing the glass slides at both depths from August to November 2007. The abundances were ranged around the mean values 954 and 1122 cells cm^{-2}, with the peaks in October; maximum values 1869 and 2883 cells cm^{-2} at 1 m and 2 m depths, respectively (Table 2; Fig. 5a). However, the abundances were not significantly different in samples from the two depths (paired *t*-test, $t = -0.355$, $P = 0.732$). The sessile ciliates were the most dominant assemblage, accounting for 99.02% of the total abundance, while the vagile and the planktonic forms had comparatively low percentages (Fig. 6b).

The number of ciliate species in the samples varied in time, ranging around a mean value of 15 during the study period (Fig. 5b). The highest

Table 2. Comparison of ciliate community characterization between the 1 m and 2 m samples.

Parameters	Method	Mean value	*t* value	*P*
Species number	1 m	15	-0.355	0.732
	2 m	15		
Abundance (cells cm^{-2})	1 m	954	-1.092	0.307
	2 m	1122		
Species richness	1 m	2.21	0.047	0.964
	2 m	2.17		
Species evenness	1 m	0.12	-1.034	0.331
	2 m	0.13		
Species diversity	1 m	0.32	-1.057	0.321
	2 m	0.36		

Notes: Mean values of variables and results of paired sample *t*-test; significant difference at the 0.05 level.

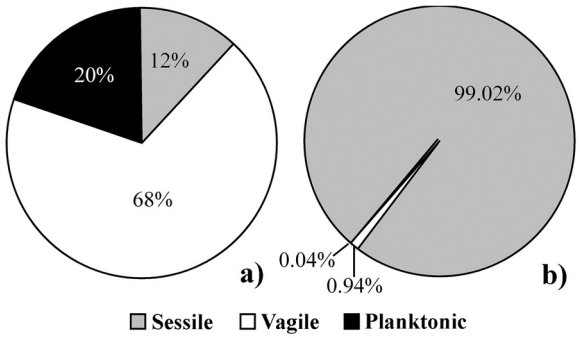

Fig. 5. Proportions of cumulative species numbers and abundances of vagile, sessile and planktonic ciliates from August to November 2007. (a) species number; (b) abundance.

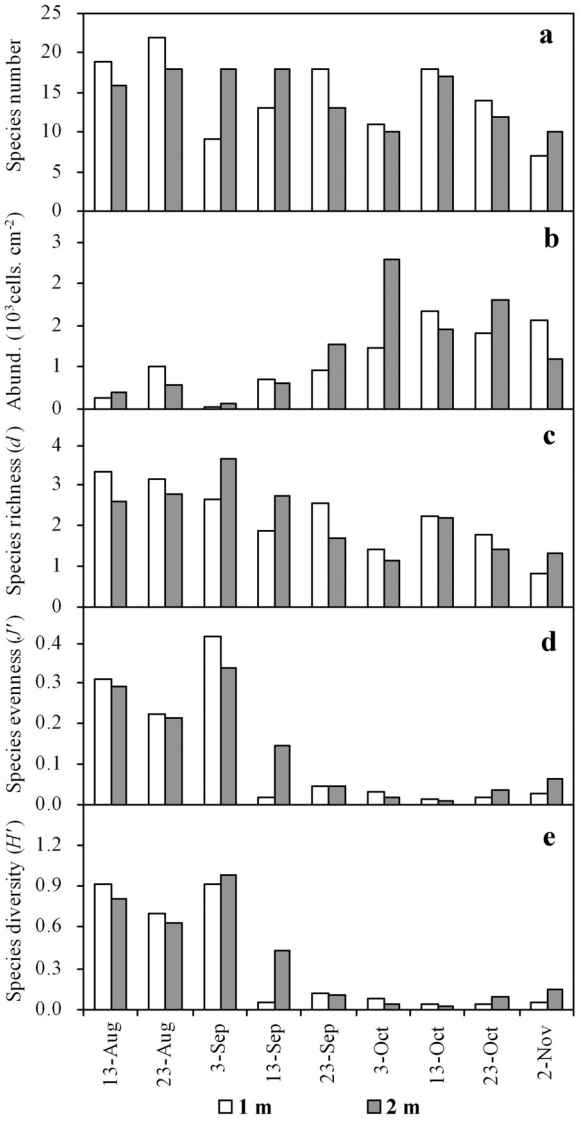

Fig. 6. Temporal dynamics of species number, abundance, richness, evenness and diversity of 1 m and 2 m samples during August to November 2007.

number was observed in August, while the lowest one, in November. The vagile ciliates were the primary contributors to the variation in the species number, accounting for 68% of the cumulative total species number from the slides at both depths; the other two components had a comparatively lower number of species (Fig. 6a). Otherwise, although no significant difference was found in the species number (paired *t*-test, $t = -0.355$, $P = 0.732$), the 1 m samples had a lower temporal variation than the 2 m samples (Fig. 5b).

There were 12 species with at least 40% occurrence and the mean abundance higher than 0.2 cells cm^{-2} at some point during the period of sampling. They were: *Zoothamnium duplicatum*, *Fulliculinopsis producta*, *Aspidisca steini*, *Gastrostyla pulchra*, *Aspidisca leptaspsis*, *Amphileptus litonotiformis*, *Holosticha bradburyae*, *Litonotus paracygnus*, *Dysteria pusilla*, *Holosticha diademata*, *Euplotes minuta* and *Diophrys appendiculata*. The first four species had abundances exceeding 6 cells cm^{-2} at some point, while the last eight species appeared in comparatively low numbers during the study period (Fig. 7). It was also shown that the 12 dominant species exhibited various differences in abundance and/or occurrence between the two depths. For example, the sessile heterotrich *Foliculinopsis producta* showed a significantly higher abundance in the 2 m samples than in the 1 m samples (paired *t*-test, $t = -2.329$, $P = 0.048$), while the hypotrich *Gastrostyla pulchra* occurred more often at 1 m depth (78%) than at 2 m depth (Table 1, Fig. 7).

All the three diversity indices of ciliate communities showed temporal variation, with a peak in August and September at both depths during the period of sampling (Fig. 6c, d, e). Except for richness (*t*-test; $P = 0.946$), the indices had comparably higher values in the 1 m samples than in the 2 m samples (*t*-test; $P < 0.35$) (Table 2).

Species distribution and multivariate analysis

A dendrogram of the species distribution in the samples from both depths were plotted using the group-average clustering from the Bray-Curtis similarities on log-transformed abundances (Fig. 8). The cluster analysis resulted in the 40 ciliates of the total 18 samples falling into six groups (I-VI) at a 40% similarity level: group II was the most common assemblage comprising 9 dominant ciliates with high abundance and/or occurrence; groups I, III and IV represented the common assemblages with low abundance and/or occurrence, including at least one dominant species; groups V and VI occurred usually at a low frequency (Table1; Fig. 6).

Table 3. Contribution to the average Bray-Curtis dissimilarity (43.18%) of the top 18 ciliates between the 1 m and 2 m samples.

Species	Average dissimilarity	Contributions (%)	Cumulation (%)
Zoothamnium duplicatum	20.68	47.89	47.89
Zoothamnium plumula	5.34	12.37	60.26
Folliculinopsis producta	2.90	6.72	66.98
Aspidisca steini	1.86	4.30	71.27
Gastrostyla pulchra	1.20	2.77	74.04
Holosticha diademata	0.99	2.29	76.33
Aspidisca leptaspsis	0.84	1.95	78.28
Amphileptus litonotiformis	0.71	1.65	79.93
Holosticha bradburyae	0.57	1.32	81.25
Dysteria pusilla	0.48	1.12	82.36
Euplotes minuta	0.48	1.10	83.47
Holosticha heterofoissneri	0.46	1.06	84.53
Litonotus paracygnus	0.44	1.01	85.54
Discocephalus rotatorius	0.43	1.00	86.54
Lynchella dirempta	0.43	0.98	87.53
Aegyriana oliva	0.42	0.98	88.51
Diophrys appendiculata	0.39	0.90	89.41
Chlamydodon triquetrus	0.39	0.89	90.30

Notes: Significant difference at the 0.05 level.

Analysis of similarities (ANOSIM) revealed that the species distribution was considerably different at the 43.18% dissimilarity level between the two ciliate communities. SIMPER analysis revealed the average Bray-Curtis dissimilarity involving 18 ciliate taxa at 90 % level of cumulative contribution percentage between the 1 m and 2m samples (Table 3). The sessile ciliates *Zoothamnium duplicatum*, *Z. plumula* and *Folliculinopsis producta* were the primary contributors to the dissimilarity of the two groups, almost certainly due to the higher abundance in the 2m samples of CS than in the 1 m samples although they predominated in both groups (Table 1 and 3). The vagile ciliates, for example *Aspidisca steini* and *Gastrostyla pulchra*, presented a higher contribution to the 1 m samples due to the high frequency of occurrence.

It should be noted that the 12 dominant species accounted for 73.02% of total dissimilarity (Table 3). Clustering analysis on the Bray-Curtis similarities indicated that the distribution of the 7 dominant species (*Folliculinopsis producta*, *Holosticha diademata*, *Aspidisca leptaspsis*, *Holosticha bradburyae*, *Amphileptus litonotiformis*, *Euplotes minuta* and *Diophrys appendiculata*) represented less than 50% of the similarities between the samples at both depths (Fig. 9).

Comparison of ciliate communities between the two depths

A dendrogram and an MDS ordination of the 18 samples from both depths were plotted using group-average clustering from Bray-Curtis similarities on log-transformed abundances (Fig. 10). The cluster analysis resulted in the 16 samples falling into five groups (I, IIa, IIb, IIIa and IIIb) at a 70% similarity level: group I comprised four samples in August; groups IIa and IIb, almost all of the 2 m and 1 m samples, respectively, in September; group IIIa, the 1 m samples in October; group IIIb almost all of both samples in October and November. Thus, the ciliate communities exhibited a clear temporal dynamics at both depths, while their similarities between the two depths were lower in September and October than in August and November .

Discussion

Sampling strategy

Artificial substrates provide a means of controlling community colonization , and are thus commonly used to reduce the spatial heterogeneity, which is usually associated with various natural substrates, such as stones and macrophytes (Coppelotti

and Matarazzo, 2000). Although many artificial substrates (such as polyurethane foam units (PFU), styrofoam spheres, plastic Petri dishes, glass and acrylic slides and glass coverslips, rods and tubes) have been widely used in colonization experiments on protozoan communities, glass slides seem be the most convenient in the case of ciliates, since most species can be observed, enumerated and even identified *in vivo* by placing the whole slide under an inverted microscope or a stereomicroscope (Coppellotti and Matarazzo, 2000; Gong et al., 2005).

Periphyton colonization of a glass slide is a dynamic process, during which the number of species generally increases and then equilibrates,

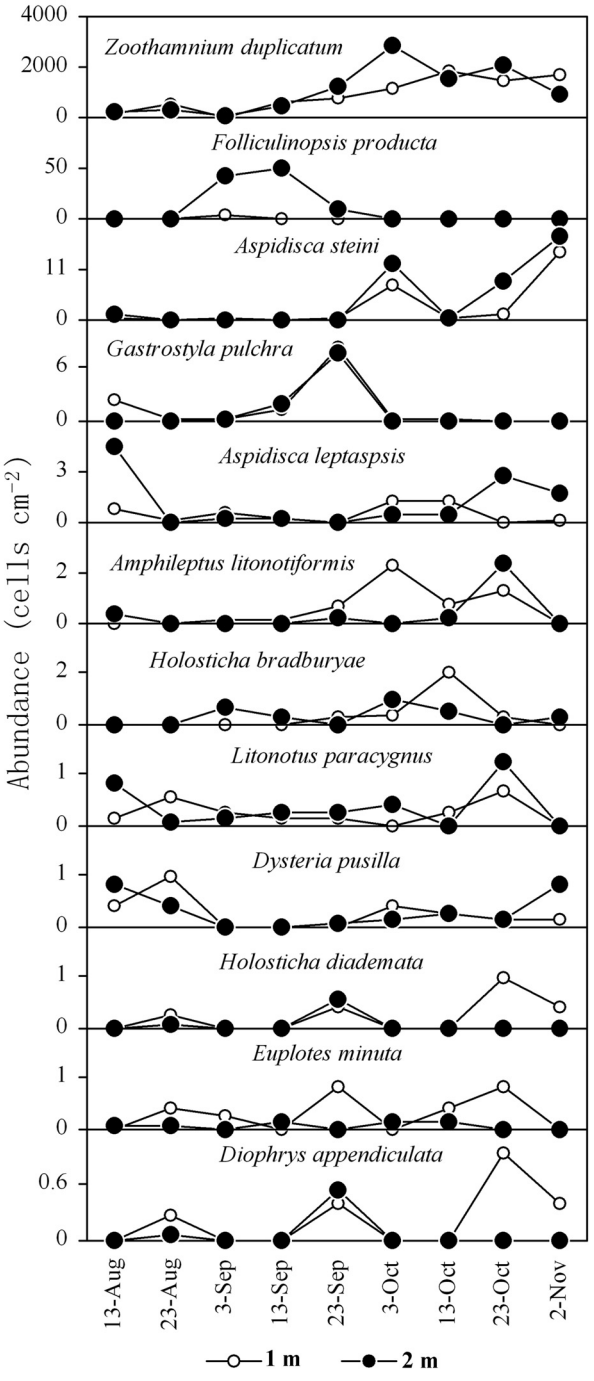

Fig. 7. Temporal dynamics of the twelve dominant species within the 1 m and 2 m samples.

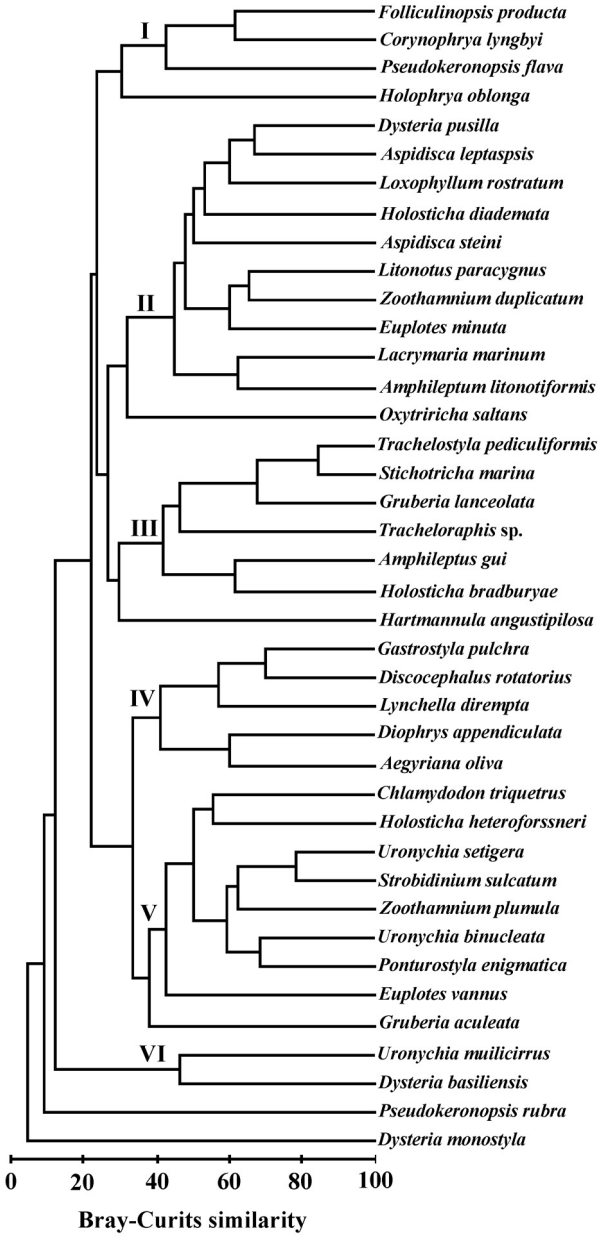

Fig. 8. Dendrogram of species distribution using group-average clustering from Bray-Curtis similarities on log-transformed abundance data of each species colonized at the both depths. I-VI - group I-VI.

following the MacArthur-Wilson equilibrium model (MacArthur and Wilson, 1967; Franco et al., 1998). Once the colonization reaches the equilibrium, the internal factors such as competition and predation pressure become more important (Cairns and Henebry, 1982; Railkin, 1995). The time required for ciliate colonization to reach equilibrium generally depends on the seasonality and trophic conditions, usually ranging from 1 to 4 weeks (Wilbert, 1969; Basmforth, 1982; Strüder-Kypke, 1999; Coppellotti and Matarazzo, 2000; Beech and Landers, 2002; Gong et al., 2005).

In the present study, although glass slides were exposed for a fixed period of 10 days, typical periphytic ciliates were found in all the samples and the ciliate colonization was highly consistent with that in scallop-farming waters of Jiaozhou Bay near Qingdao, China (Gong et al., 2005). This suggested that the exposure time in our study was sufficient for optimal ciliate colonization in the autumn season.

It must be noted that the use of solid artificial substrates for ciliate colonization allowed the recovery of sessile forms, which are generally lost in the most commonly used material, the PFU (Pratt and Kepner, 1992; Xu et al., 2002). To our best knowledge, the typical species in these ciliate communities are permanently attached forms, especially the orders Peritrichida (e.g. *Zoothamnium* spp.), Suctorida (e.g. *Corynophrya lyngbyi*) and the sessile heterotrich *Folliculinopsis produnda*. In addition, squeezing PFUs may result in the failure to recover other types of ciliates, e.g. highly thigmotactic species.

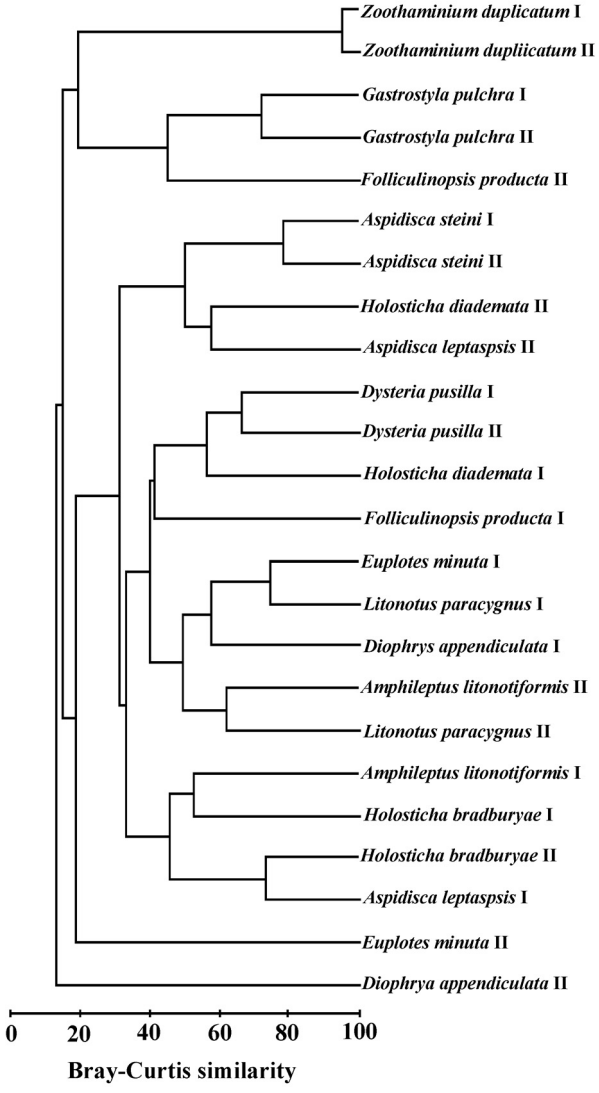

Fig. 9. Cluster analysis of the twelve dominant species using Bray-Curtis similarities log-transformed abundance data from the 1 m and 2 m samples.

Taxonomic composition

In the present study, 38 species belonging to 8 orders and 27 genera of ciliates were identified in the ciliate communities colonizing glass slides at the depth of 1 m. This result is similar to the taxonomic composition in the samples from the depth of 2 m:

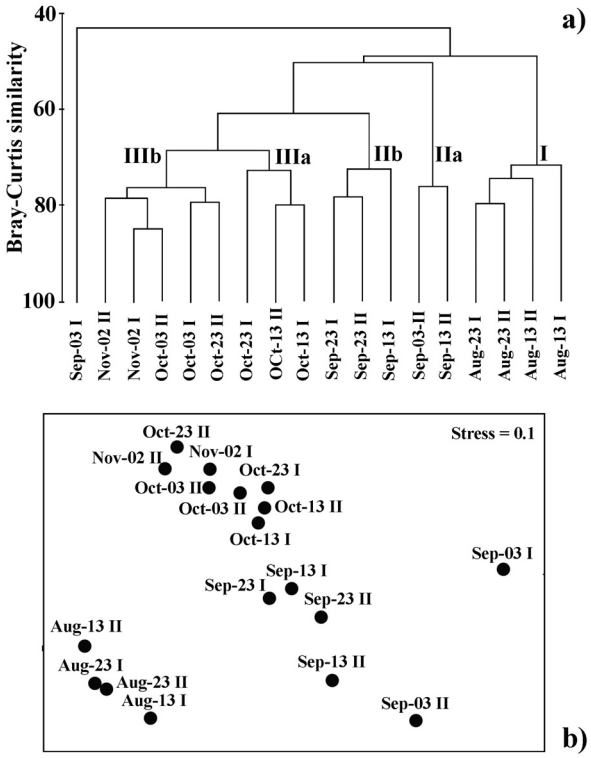

Fig. 10. Cluster analysis and MDS ordination of a total of 18 samples from the 1 m and 2 m depth, using Bray-Curtis similarity on log-transformed abundance data. (a) cluster dendrogram; (b) MDS ordination.

37 ciliates from 9 orders and 28 genera. A total of 40 ciliates were cumulatively observed from the two depths, 35 (87.5%) species being shared by the two depths during the period of sampling (Table 1).

Previous works on ciliates colonizing glass slides in marine environments revealed 130 species in the Caspian Sea (Agamaliev, 1974), 30 species in a polluted harbour near Ostend (Persoone, 1968), 47 species in the Lagoon of Venice (Coppellotti and Matarazzo, 2000) and 37 species in scallop-farming area of Jiaozhou Bay near Qingdao (Gong et al., 2005). However, the former work is based on the examination of a very large number of different natural substrates located at various depths and sites and of artificial glass substrates; ciliate fauna was quantitatively less diverse in polluted regions.

Comparing the taxonomic composition in the Incheon and the Qingdao communities, 17 species (e.g. *Zoothamnium duplicatum*, *Aspidisca leptaspsis*, *Aspidisca steini*, *Amphileptus litonotiformis*, *Holosticha bradburyae* and *Litonotus paracygnus*) and 16 (53.3%) genera were found in Qingdao samples. Comparison at the order level reveals an even higher similarity between the two faunas: 8 out of 10 ciliate orders in Qingdao were also present in the Incheon samples. Over half of the species in the Qingdao samples were from the orders Hypotrichida (36%) and Cyrtophorida (23%). These two orders accounted for similar proportions of the species composition in both our samples: 49% and 16% in 1 m samples and 43% and 19%2 m samples.

Compared with Venice samples, 13 (48%) genera were detected in Incheon study. Similarly to the ciliate faunas of Incheon, Qingdao, Ostend and the Caspian Sea, the Hypotrichida represented the largest proportion of species (33%) in the Venice samples, the Peritrichida being the second largest group (17.8%) and the Cyrtophorida accounting for only 2%. Moreover, the karyorelictids *Trachelocerca lacrymariae*, *T. multinucleata, Tracheloraphis gracilis, Remanella multnucleata* and *Geleia swedmarki* were also included in the species list although they are usually considered to be benthic species (Fenchel, 1969). The depth at which the artificial substrate was submerged might explain this finding, since most samples from the Lagoon of Venice were recovered from just 60 cm above the bottom (Coppellotti and Matarazzo, 2000).

Univariate and multivariate analysis

Species diversity, evenness and richness indices are commonly employed in community studies and are amenable to simple statistical analysis (Magurran, 1991, Ismael and Dorgham, 2003). Generally, the higher these three indices are, the better the water conditions are observed (Ismael and Dorgham, 2003). In the present study, the three indices showed no significant difference between both depths, especially the species richness. This suggested that the environmental conditions the ciliate communities were exposed to were similar at both depths.

Multivariate analyses were more sensitive than the univariate one for detecting changes in species distribution or in community structure (Martin-Cereceda et al., 2002; Gong et al., 2005). In the present study, although species composition showed similar pattern, both species distribution and community structure were considerably different between the 1 m and the 2 m samples. This may have been mainly due to the sessile ciliates overly predominating the ciliate communities at the lower depth. This finding is consistent with the ciliate faunas of the Caspian Sea and Venice (Agamaliev, 1974; Coppellotti and Matarazzo). Furthermore, analysis of MDS ordination indicated that the ciliate communities had a clear and different temporal dynamics at the two depths. It might be suggested that for detecting the temporal and spatial dynamics of ciliate communities it is necessary to position the colonizing depths in marine ecosystems.

In conclusion, the periphytic ciliate communities in Korean coastal waters had a similar pattern to Qingdao ciliate fauna. To some extent, differences in species distribution and community structure were observed between the depths of 1 m and 2 m. Our results suggest that for detecting the temporal and spatial dynamics of ciliate communities it is necessary to position the colonizing depths in marine ecosystems. However, further studies are needed on a range of marine waters and over extended time periods in order to verify this conclusion.

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