Diversity and Distribution of Ciliated Protozoans on the Mangrove Leaf Litters in a Tropical Mangrove Ecosystem

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Abstract

Litter production and its decomposition is a major nutrient source for mangrove ecosystems. The bacterivores nature of ciliates in mangrove leaf litters, increase the mineralization and making nutrients more available to the next trophic level. This study was conducted to access the species composition, diversity and abundance of ciliates in mangrove leaf litters. Monthly samples were collected for one year (June 2014 – May 2015) from ten selected stations. Eight physicochemical variables such as temperature, dissolved oxygen, pH, conductivity, chloride, sulfate, nitrate, and phosphate were also monitored during the study. Taxonomic studies recorded 115 species of ciliates belonging to 16 subclasses, among them Peritricha represent the subclass having the maximum species number and abundance followed by Suctoria. *Vorticella companula* records the maximum abundance and dominance index followed by *Euplotes minuta*. Analyzing the seasonal distribution of ciliates, a maximum number of species were recorded during post-monsoon and minimum during monsoon. The study establishes the distributional difference, diversity and abundance of peritrich ciliates on mangrove leaf litters according to seasonal fluctuations. Multivariate statistical analysis of different environmental parameters regarding species diversity and abundance of mangrove ciliates, it was found that the environmental parameters have an impact on the distribution and diversity of ciliates in mangrove leaf litters. The study signifies the importance of leaf litters and environmental variables in the dynamics of ciliates composition and abundance.

Introduction

Leaf litterers deposited on the mangrove soil mainly consisted of ungrazed material largely processed through detritus-based food chain, and accounts for considerable near shore secondary productivity [1]. Heavy ligno cellulose disposition is an adaptation possessed by mangrove leaves to survive in any harsh environmental fluctuations; these depositions make the leaf hard and slowdown the degradation process [2, 3]. Degradation of fallen mangrove vegetation starts immediately after its colonization by fungi and bacteria [4, 5]. The fungal saprophytic enzymes deteriorate the lignocellulose compounds of mangrove leaves [6]. The degraded mangrove vegetative materials support the colonization of heterogeneous microbial communities [1, 7]. Microscopic examination of vegetative matter reveals the presence of complex community composed of fungi, bacteria, protozoa, and microalgae [1]. The essential nutrients released by these organisms are absorbed by mangroves for their growth [8, 9, 10]. Therefore, nutrient cycling by litter fall does not only promote nutrient recycling in mangroves but also strengthen the bonds between different trophic levels in mangrove chain [10].

Ciliates associated with mangrove leaf litters are one of the important detritivores organism showed a characteristic role in nutrient cycling. They are the main bacterial consumers showed some special characteristics such as modified oral cilia, short generation times, and rapid multiplication [11]. Ekelund and Ronn [12] experimentally showed that the organic matter released by plants could stimulate bacterial and ciliate activity in the root zone leading to mineralization of organic soil nitrogen and assimilation by plants. The activity of ciliates may be important in mangrove plant nutrition; on other hand, the growth of

plants may significantly affect ciliate community. Kathiresan and Bingham [13] have extensively studied the role of benthic communities on the growth of mangrove ecosystem in Pichavaram mangrove ecosystem India. Dorothy *et al.*, [14] confirmed the role of protozoan ciliates in the decomposition of mangrove leaf litters. However, there have been no previous studies, which examined the diversity of mangrove ciliates on the sedimented leaf litters of southern coast of India. Thus, the objectives of this study were to investigate the species composition, diversity and density of ciliates on the sedimentary leaf litters with respect to the seasonal hydrological parameters.

Materials And Methods

Study area

The study area was located in Ayiramthengu mangrove situated (lat. $9^{\circ} 6'$ to $9^{\circ} 8'$ N long. $76^{\circ} 28'$ to $76^{\circ} 29'$ E) in Kollam district of Kerala, a part of Kayamkulam estuary, which is the narrow stretch of tropical backwater on the southwest coast of India (Fig. 1). The area covers about 20 acres, and most of the inner regions of mangrove forest patches were left untouched by humans. Two streams and a canal enter into the lake during the rainy season, which links the rivers Pamba and Achankoil. Ten sampling sites were considered for the study and each site was fixed at an interval of 50 m.

Hydrology

The water samples were collected in a properly labeled clear airtight container. The temperature was measured using portable mercury thermometer (-20° - 110° C). The pH of the sample was analyzed using a pH meter (MK 6) and Conductivity meter (EQ 660A) was used to analyse the presence of electrolytes in the sample. Winkler method was used to determine the amount of dissolved oxygen in the sample. Mohr's method was used to analyze the presence of chloride and Phenol disulphonic acid method was used to analyze the presence of nitrate concentration in mangrove water. Stannous chloride method was used to analyze the presence of phosphate and Turbidimetric method was used to analyze the presence of sulphate concentration in mangrove water. All the above-mentioned analysis was carried out according to the standard method prescribed in APHA [15].

Collection, identification and enumeration of epibenthic ciliates

For the collection of epibenthic organisms from mangrove leaf litter, the methods described by Maybruck [16] was adopted. Mangrove leaf litters were covered with a heterogeneous mixture of trapped material (Fig. 1). Samples were collected by taking one cm^2 patch of the moist film of trapped material to a sterile 15 ml sampling bottle. Continuous one-year sampling (June 2014 to May 2015) was carried out to analyze the composition and distribution of epibenthic organisms in mangrove leaf litter. Biometrical characteristics of the epibenthic organisms collected from the mangrove leaf litter were carefully examined under live condition. For detailed analysis, samples were gone through silver carbonate

technique proposed by Fernandez Galiano [17]. The data collected were analyzed using PAST 4.03 [18], statistical software packages for Social Sciences (SPSS) software version 16.0 [19] and Biodiversity pro [20].

Results

Environmental factors

The overview of hydrological parameters analysed during the study period is given in Table 1. Temperature and dissolved oxygen records its minimum values in post monsoon, temperature exhibit its maximum values in pre monsoon, and dissolved oxygen records its maximum values in monsoon. pH, conductivity and salinity exhibit its minimum values in monsoon and maximum values in pre monsoon. Nitrate, phosphate and sulphate exhibit its minimum values in pre-monsoon and maximum values in monsoon. The average annual precipitations relative to the baseline time periods of 2014 June–2015 May are presented in Table 1. The data reveals that the maximum average rainfall (374.97 mm) was recorded in monsoon and the minimum (100.47 mm) recorded in post monsoon.

Species composition, dominance index and density

An aggregate of 115 species spread over 16 subclasses were identified during the one-year study period. Among them Peritricha represent the subclass having the maximum species number (64) followed by Suctoria (11). Heterotrichea, Hypotrichia, Nassophorea and Stichotrichia are the subclasses having only one species record during the entire study period. *Vorticella campanula* records the maximum abundance (1480 no./cm²) and dominance index (0.0460) followed by *Euplotes minuta* (1349 no./cm² & 0.04198). *Epiphyllum soliforme*, *Acanthocystis aculeate*, *Cothurnia recurvate*, *Pyxicola annulata*, *Vorticella campanulate*, *Cohnilembus sp.1*, *Tintinnopsis sacculus*, *Acineta calkinsi* and *Ephelota plana* are the rarest distributional records from Ayiramthengu mangroves. *Cothurnia* represent the genus with maximum number of species (18) followed by *Zoothamnium* (11) (Table 2).

Out of 32,132 individuals counted during the during the one year survey, maximum numbers of ciliates were recorded during post monsoon (14431) trailed by monsoon (10403) and pre monsoon (7298). Peritricha represent the subclass having the maximum number of individuals (19778) followed by suctoria (4026) and spirotrichea (3143) (Table 3). Percentage distribution pattern also highlight that 62% of the total ciliate composition in Ayiramthengu margrave ecosystem is occupied with peritricha followed by suctoria (13%) and spirotrichea (10%) (Fig.2). Among the recorded peritrichs, 45 % of them are distributed in post-monsoon 32% on monsoon and 23% on pre-monsoon (Fig. 2). Investigating the species dispersion pattern 93 species were recorded during monsoon, 111 during post-monsoon and 105 during pre-monsoon.

Diversity indices

The maximum Shannon diversity was observed in Monsoon (0.637) and minimum recorded during pre-monsoon (0.588). Similar to Shannon diversity index, maximum Simpson diversity value (0.432) with minimum diversity observed in Monsoon and minimum value with maximum diversity was observed in Monsoon (0.398). Analysing the species richness using Margaleff index maximum species richness observed in Pre-monsoon (4.142) and the lowest recorded in Post-monsoon (3.847). Maximum Shannon Evenness was observed in monsoon (0.529) and minimum recorded during Pre-monsoon (0.488) (Table-4).

Analysing the sub class wise diversity index, Suctoria (1.017), Stichotrichia (1.016) and Peritricha (1.015) records the maximum Shannon diversity values and Heterotrichea (0.843) and Cyrtophoria (0.853) showed the minimum diversity. Maximum Simpson diversity value (0.176) with minimum diversity observed in the case of Cyrtophoria and minimum value with maximum diversity was observed in the case of Stichotrichia (0.091). Similar to Shannon diversity index, Shannon evenness also shows the similar trend, were also the maximum evenness was observed in the case of Suctoria (0.8446) followed by Stichotrichia (0.8438) and Peritricha (0.8429). Minimum evenness was observed in the case of Heterotrichea (0.7001). The sub class Heterotrichea showed the maximum species richness value (5.537) and the minimum observed in the case of peritricha(2.344) (Table-4).

Relationship between ciliates and environmental factors

Analysis of variance (ANOVA) showed the relationship between different subclasses of ciliates with environmental factors. Distributional variance of ciliates in different months was performed considering $p < 0.05$ as significant. Analyzing the monthly data of soil ciliates by one way ANOVA p-value is $2.7E-106$ and this is lesser than the significance level 0.05, and showed that most of the month have different means (Table-5).

Multivariate statistical analysis

Cluster analysis revealed five distinct groupings, which appeared to reflect differences in the monthly distribution of ciliates in Ayiramthengu mangroves ecosystem (Fig.3). Cluster 1 consisted of the month of June, July and August in monsoon season, with high diversity and evenness of organisms. Cluster 2 consisted of the months of September and October, represented by late monsoon period and early post-monsoon with unique climatic and physicochemical characteristics, with a similar population density. Cluster 3 consisted of the months of November, December and January with maximum population density, a rapid influx in population density and species number was observed in cluster 3. Cluster 4 consisted of the months of February and march a similar population density values are observed in this cluster also. Cluster 5 consisted of the months of April and May with minimum population density, this cluster also experience maximum richness and lowest diversity.

Canonical correspondence analysis (CCA)

CCA revealed sixteen distinct ciliate subclass groupings, which appeared to reflect differences in environmental characters within the Ayiramthengu mangroves (Fig.3). Abundance of each subclass was depending upon the influence of physicochemical parameters of water. The lowest level of phosphate, nitrate, salinity and conductivity favors the influx of Spirotrichea, Nassophorea, Haptoria and Peritricha in mangrove leaf litter. Holotrichia reach its maximum abundance in higher sulphate concentration and Stichotrichia reach its maximum number in moderate temperature range. Similarly, phyllopharyngea reach its maximum abundance in mid low pH and peniculia reach its maximum number in moderate salinity condition. Oligotrichia reach its maximum number in mid low conductivity.

***k*-dominance**

A k-dominance plot curve was drawn based on the community structure of ciliates in Ayiramthengu mangrove ecosystem. In the present investigation the data collected during the one year survey was fed into to the dominance plot (Fig.3). The highest dominance was seen at the month of May, where the ciliate assemblage had the highest diversity.

Discussion

The present investigation describes the species composition, distribution, diversity and abundance of epibenthic ciliates from the sedimentary leaf litters of Ayiramthengu mangroves in relation to the abiotic factor prevailing in the ecosystem. Several studies have been conducted on the physicochemical analysis of mangrove water from various parts of India` and only a few studies have been reported on the taxonomy and community structure of ciliates from Indian mangroves [14, 21, 22, 23, 24, 25, 26, 27]. Monthly variations in the distribution of epibenthic ciliates in mangrove leaf litters were well documented by analyzing the level of significance through one-way ANOVA and CCA. The analysis of the data revealed that the epibenthic ciliates attach to the mangrove soil exhibit monthly variations according to the changes in hydrological conditions. Chen *et al.* [28] had made a similar study in the tropical mangrove ecosystem and recorded that the changes in hydrological parameters determine the distribution of mangrove species in each habitat.

Mangrove soils are typically saline, anoxic, acidic, and frequently waterlogged. These soil properties directly affect the distribution of mangrove ciliates [29]. In the present study conductivity and dissolved oxygen exhibited high negative correlations with ciliates. The conductivity and the dissolved oxygen frequently affect ciliates distribution [30, 31, 32] and it affects ciliate species composition, as well as ciliate species diversity and density in the soil[33]. Very few studies have been reported to investigate the ciliate community structure and physicochemical properties [34, 35, 29, 36, 37, 38] and the information is still lacking from India.

Peritrichs are the dominant ciliate subclass recorded from the study area. They are become adapted to a wide range of habitats. Sedentary forms are abundant in marine, brackish and fresh water habitats attaching to a wide variety of substrata, plant, animals and inanimate [39]. Most of the peritrichs recorded from the study habits are attached to algal communities, mostly on spirogyra. Interspecific factors such

as growth pattern and cyst formation may also be highly significant in the case of peritrichs. Pseudo colony formation and solitary life in peritrichs may provide survival value by enhancing feeding efficiency, surface dominance, conjugation and predator avoidance [40]. Along with physicochemical characteristics of mangrove water, food availability in the form of bacterial density is frequently cited as an important factor that determines the peritrichs abundance [41, 42].

Suctorians are the second dominant epibionts observed from the study habitat, similar to peritrichs most of the suctorians are attached to a living or nonliving substratum. Suctorians are very common both in marine and freshwater environments [43]. They attach to their hosts directly or by using stalks, and they feed mainly on other ciliates [44]. While analyzing the species wise abundance *Vorticella companula* shows the maximum abundance and dominance index. During un-favourable conditions, they develop a posterior ring of cilia to become a teiotroch. It separates away from the stalk and swims away to some favourable place where it develops stalk and starts leading normal life. The teiotroch helps in its dispersal. *Vorticella companula* is generally a gregarious solitary species and typically form pseudocolonies because of telotrochs settling on the same substrate and very close to the mature organisms⁵³. *Euplotes minuta* is the second most dominant species found to be dominant in Ayiramthengu mangrove ecosystem. It is a highly diversified and cosmopolitan genus, with a large number of species that have been observed and investigated in all kinds of biotopes [45]. Zoothamnium can be found in freshwater, brackish and marine waters between 0–8 meters deep and typically form a symbiotic relationship with a wide variety of animals, although some may be free living and attaching to aquatic plants and inanimate substrates [46].

Analyzing the species composition of ciliates with respect to three seasons post monsoon represent the season having the maximum species number followed by pre-monsoon. Thus, the dominant occurrence of above-mentioned ciliates in each season may be closely associated with the species-specific environmental conditions that required to encystment or excystment [47]. Moreover, the specialty in biological and other characteristic features of these ciliates support their dominance in the dynamic mangrove habitat. The present study reports the occurrence of 31 species of ciliates which were evenly distributed throughout the study period. It is purely because of their ability to switch to a different diet throughout the three seasons [48]. During the study period, maximum Evenness, Shannon and Simpson diversity values were observed in monsoon and minimum recorded in pre-monsoon, this is due to the impact of highest species richness in pre-monsoon. Similar studies were reported from the Vellar mangrove waters, where the total species richness of ciliates was highest in Pre- monsoon and lowest during monsoon, as commonly observed in many marine coastal and estuarine waters [49, 50, 51, 52, 53, 54]. Similar seasonal variations have also been reported in the Parangipettai coastal waters [55, 56, 47]. Cluster analysis and k-dominance index also revealed the similar diversity, abundance and distribution pattern of ciliates during the one-year study period. Studies on ANOVA records a station-wise heterogeneity during the one-year study period. Analysing the species wise diversity and evenness Suctoria, Stichotrichia and Peritricha record the maximum diversity values and Heterotrichea and Cyrtophoria showed the minimum diversity. Suctorians can be found in all types of water bodies on a

wide diversity of hosts and substrates. Larger ciliate subclasses such as Heterotrichea and Cyrtophoria were found occasionally in the sampling area because the species of this subclass are more adapted to freshwater habitat [57]. The majority of these ciliates are commensals of various water invertebrates or vertebrates [58]. Taxonomic studies highlighting the distributional records of above mentioned groups were reported earlier from the study habitat [26, 27, 28, 29, 30]. When analyzing the CCA, abundance of each subclass was depending upon the influence of physicochemical parameters of water. The changes in variables influence the distribution of some species of ciliates. Ciliates depend on the suspended material, and which favour's the occurrence of bacterivorous, algivorous and omnivorous ciliates in the study habitat [59].

Conclusion

The present study highlighted the role of physicochemical parameters in structuring the ciliate community in the Ayiramthengu mangrove ecosystem. Ciliates, generally considered among the most evolved and complex protozoa, can perceive and react to a wide variety of environmental stimuli. The study also revealed that the ecological variations recorded from the mangrove habitat were much significant to make a change in the ciliate distribution. Meanwhile in an aspect of ciliate as ecological indicators, evenly distributed community structure reflects the existence of a healthy food web in the present ecosystem. Literature survey revealed the fact that little work has been done on the diversity and distribution of ciliates on mangrove leaf litters and this work may provide detailed information for researchers in the field of mangrove ciliates.

Declarations

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Tables

Table 1 Overview of Hydrological parameters

S.I.No	Hydrological parameter	Minimum	Maximum
1	Temperature	26.5 ⁰ C	32.7 ⁰ C
2	pH	6.2	8.2
3	Conductivity	0.2 s/m	37.4 s/m
4	Dissolved oxygen	0.8 mg/l	7.6 mg/l
5	Salinity	10 ppm	25.2 ppm
6	Nitrate	0.09 mg/l	7.74 mg/l
7	Phosphate	2.26 mg/l	2.87 mg/l
8	Sulphate	7.94 mg/l	295.18 mg/l
Rain fall			
	Monsoon	Post Monsoon	Premonsoon
Average Rainy days	17	7	6
Average rain fall (mm)	374.97	100.47	183.4

Table 2 Abundance and dominance index of ciliates counted during the study period

Sl. No.			
	CILIATES	Abundance	Dominance index
	Cyrtophoria (3)		
1	<i>Chilodonella cucullulus</i>	59	0.001836176
2	<i>Chlamydodon sp1</i>	106	0.003298892
3	<i>Dysteria proraefrons</i>	196	0.006099838
	Haptoria (5)	0	0
4	<i>Acineria incurvata</i>	80	0.00248973
5	<i>Epiphyllum shenzhenense</i>	127	0.003952446
6	<i>Epiphyllum soliforme</i>	49	0.00152496
7	<i>Litonotus paracygnus</i>	88	0.002738703
8	<i>Litonotus petzi</i>	50	0.001556081
	Heliozoa (3)	0	0
9	<i>Acanthocystis aculeata</i>	3	9.33649E-05
10	<i>Actinophrys eichhorni</i>	97	0.003018797
11	<i>Actinophrys sol</i>	108	0.003361135
	Heterotrichea (1)	0	0
12	<i>Blepharisma lateritium</i>	73	0.002271879
	Holotrichia (3)	0	0
13	<i>Coleps hirtus</i>	689	0.021442798
14	<i>Holophyra oblonga</i>	92	0.002863189
15	<i>Prorodon Sp1</i>	246	0.007655919
	Hymenostomatia (2)	0	0
16	<i>Uronea acutum</i>	247	0.007687041
17	<i>Uronea caudata</i>	160	0.00497946
	Hypotrichia (1)	0	0
18	<i>Diophrys hystrix</i>	141	0.004388149
	Nassophorea (1)	0	0
19	<i>Nassula Ornata</i>	347	0.010799203

	Oligotrichia (2)	0	0
20	<i>Strobidinopsis elongata</i>	76	0.002365243
21	<i>Strobidinopsis paracalkinsi</i>	341	0.010612474
	Peniculia (2)	0	0
22	<i>Frontonia subtropica</i>	354	0.011017055
23	<i>Frontonia tchibisovae</i>	149	0.004637122
24	<i>Paramecium brusaria</i>	489	0.015218474
25	<i>Paramecium polycaryum</i>	80	0.00248973
	Peritricha (64)	0	0
26	<i>Cothurnia acuta</i>	79	0.002458608
27	<i>Cothurnia angusta</i>	141	0.004388149
28	<i>Cothurnia annulata</i>	266	0.008278352
29	<i>Cothurnia anomala</i>	212	0.006597784
30	<i>Cothurnia asymmetrica</i>	582	0.018112785
31	<i>Cothurnia carinogammari</i>	412	0.012822109
32	<i>Cothurnia coarctata</i>	354	0.011017055
33	<i>Cothurnia elegans</i>	168	0.005228433
34	<i>Cothurnia kahli</i>	261	0.008122744
35	<i>Cothurnia kiwi</i>	267	0.008309473
36	<i>Cothurnia limnoriae</i>	183	0.005695257
37	<i>Cothurnia recurva</i>	355	0.011048176
38	<i>Cothurnia recurvata</i>	31	0.00096477
39	<i>Cothurnia Sp 1</i>	121	0.003765716
40	<i>Cothurnia Sp 2</i>	87	0.002707581
41	<i>Cothurnia trophonicola</i>	171	0.005321798
42	<i>Cothurnia vaga</i>	350	0.010892568
43	<i>Cothurnia variabilis</i>	182	0.005664135
44	<i>Epistylis coronata</i>	329	0.010239014
45	<i>Epistylis hentscheli</i>	95	0.002956554

46	<i>Epistylis nayagarae</i>	365	0.011359393
47	<i>Epistylis plicatilis</i>	267	0.008309473
48	<i>Epistylis procumbens</i>	245	0.007624798
49	<i>Paravorticella sp</i>	457	0.014222582
50	<i>Platycola mollis</i>	104	0.003236649
51	<i>Platycola truncata</i>	91	0.002832068
52	<i>Pseudovorticella banatica</i>	364	0.011328271
53	<i>Pseudovorticella clampi</i>	444	0.013818001
54	<i>Pseudovorticella stilleri</i>	553	0.017210258
55	<i>Pyxicola annulata</i>	44	0.001369351
56	<i>Pyxicola constricta</i>	139	0.004325906
57	<i>Pyxicola eforiana</i>	86	0.00267646
58	<i>Pyxicola ligae</i>	52	0.001618324
59	<i>Pyxicola limbata</i>	115	0.003578987
60	<i>Thuricola folliculata</i>	107	0.003330014
61	<i>Thuricola gracilis</i>	193	0.006006473
62	<i>Thuricola incisa</i>	83	0.002583095
63	<i>Thuricola valvata</i>	84	0.002614216
64	<i>Vaginicola ceratophylli</i>	63	0.001960662
65	<i>Vaginicola compressa</i>	84	0.002614216
66	<i>Vaginicola elongata</i>	112	0.003485622
67	<i>Vaginicola gigantea</i>	76	0.002365243
68	<i>Vaginicola inclinata</i>	51	0.001587203
69	<i>Vaginicola ingentia</i>	64	0.001991784
70	<i>Vaginicola vestita</i>	120	0.003734595
71	<i>Vorticella alba</i>	1181	0.036754637
72	<i>Vorticella annulata</i>	564	0.017552596
73	<i>Vorticella bidulphae</i>	733	0.02281215
74	<i>Vorticella campanulate</i>	48	0.001493838

75	<i>Vorticella companula</i>	1480	0.046060002
76	<i>Vorticella longitricha</i>	525	0.016338852
77	<i>Zoothamnium duplicatum</i>	867	0.026982447
78	<i>Zoothamnium foissneri</i>	429	0.013351176
79	<i>Zoothamnium hentscheli</i>	436	0.013569028
80	<i>Zoothamnium kentii</i>	788	0.024523839
81	<i>Zoothamnium mengi</i>	418	0.013008839
82	<i>Zoothamnium mucedo</i>	242	0.007531433
83	<i>Zoothamnium parahentscheli</i>	450	0.01400473
84	<i>Zoothamnium pararbuscula</i>	730	0.022718785
85	<i>Zoothamnium plumula</i>	699	0.021754015
86	<i>Zoothamnium procerius</i>	188	0.005850865
87	<i>Zoothamnium ramosissimum</i>	161	0.005010581
88	<i>Zoothamnium sinense</i>	658	0.020478028
89	<i>Zoothamnopsis liui</i>	172	0.005352919
	Phyllopharyngia (3)	0	0
90	<i>Aegyriana oliva</i>	152	0.004730487
91	<i>Chlamydodon mnemosine</i>	167	0.005197311
92	<i>Chlamydodon pedarius</i>	56	0.001742811
	Scuticociliatia (3)	0	0
93	<i>Cohnilembus verminus</i>	158	0.004917216
94	<i>Cohnilembus sp.1</i>	44	0.001369351
95	<i>Pleuronema wilberti</i>	55	0.001711689
	Spirotrichea (8)	0	0
96	<i>Euplotes antarcticus</i>	328	0.010207892
97	<i>Euplotes eurystomus</i>	107	0.003330014
98	<i>Euplotes minuta</i>	1349	0.04198307
99	<i>Euplotes muscicola</i>	111	0.0034545
100	<i>Stentor roeseli</i>	314	0.00977219

101	<i>Tintinnopsis rotundata</i>	647	0.02013569
102	<i>Tintinnopsis sacculus</i>	43	0.00133823
103	<i>Tintinnopsis schotti</i>	244	0.007593676
	Stichotrichia (1)	0	0
104	<i>Stichotricha secunda</i>	106	0.003298892
	Suctoria (11)	0	0
105	<i>Acineta biloba</i>	726	0.022594299
106	<i>Acineta calkinsi</i>	32	0.000995892
107	<i>Acineta compressa</i>	212	0.006597784
108	<i>Acineta papillifera</i>	96	0.002987676
109	<i>Crossacineta annulata</i>	216	0.006722271
110	<i>Ephelota gemmipara</i>	724	0.022532055
111	<i>Ephelota mammillata</i>	708	0.022034109
112	<i>Ephelota plana</i>	29	0.000902527
113	<i>Ephelota turncata</i>	438	0.013631271
114	<i>Metacineta mystacina</i>	71	0.002209635
115	<i>Podophrya macrostyla</i>	774	0.024088136
			1

Table 3 Monthly distribution of different sub classes of ciliates during the study period

Sub class	Monsoon	Post-monsoon	Premonsoon	Total
Cyrtophoria	91	246	24	361
Haptoria	115	196	83	394
Heliozoa	44	123	41	208
Heterotrichea	38	16	19	73
Holotrichia	568	230	229	1027
Hymenostomatia	182	204	21	407
Hypotrichia	66	57	18	141
Nassophorea	122	184	41	347
Oligotrichia	89	283	45	417
Peniculia	261	557	254	1072
Peritricha	6293	8847	4638	19778
Phyllopharyngia	79	126	170	375
Scuticociliatia	93	100	64	257
Spirotrichea	807	1633	703	3143
Stichotrichia	45	37	24	106
Suctoria	1510	1592	924	4026
	10403	14431	7298	32132

Due to technical limitations, table 4 is only available as a download in the Supplemental Files section.

Table 5 ANOVA table showing the monthly distributional variations of epibenthic ciliates in relation to hydrological parameters

<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Between Groups	31112248	23	1352706	82.20345	2.7E-106	1.570294
Within Groups	4344276	264	16455.59			
Total	35456524	287				

Figures

Figure 1

Map of Ayiramthengu mangrove ecosystem (a); Mangrove leaf litter with heterogeneous trapped material (b) Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

Figure 2

Percentage composition of the epibenthic ciliates on the study area (a); Percentage composition of the peritrich ciliates on the study area (b)

Figure 3

Cluster analysis dendrogram showing grouping of different months sampled during the study period (a); CCA plot similarity showing grouping of sub classes sampled during different seasons along with environmental factors (b); K dominance plot showing the abundance of ciliates in study year (c)

Supplementary Files

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