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SHORT COMMUNICATION

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Diversity and distribution of foraminifera and tintinnids (bio-indicators) from Pulicat Lake, India

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Abstract

The foraminifera and tintinnids are essential indicators of the health status of marine and estuarine ecosystems, both past and present, and can be used for monitoring purposes in the future. Tintinnids are known to group among ciliates possessing hard loricate to be considered by hydrogeologists as one of the bio-indicator species, exhibiting a strong positive correlation with phytoplankton. Pulicat Lake is a marginal marine environment present near the south coast of India. Intertidal sediment samples were collected from September 2013 to August 2014 and were subjected to isolate the foraminiferans and tintinnids by adopting standard methods. In all, twenty-one genera and 24 species of foraminifera have been identified from the stream, where *Quinquelina seminulum* was found to be abundant. Contrary to this, a minimum number of species was present in the freshwater inflow zone, mainly *Amomalinula glabrata*, *Haplophragmoides kirki*, *Natlandia secasensi* and *Valvulineria candeiana*. Tintinnopsis are recorded in the sampling sites, belonging to 5 families and 6 genera, and 12 species have been identified, and among these *Favella campanula species* was found to be abundant in the study area. From our results, the recorded species in terms of numerical abundance of foraminiferans appeared predominant over the tintinnids. The dominant role of foraminiferans may be a significant contribution to the carbon cycle of marine/estuarine ecosystems proved elsewhere in turn responsible for the substantial uptake of phytodetritus deposition. Based on these findings, our preliminary study may be useful to explore the carbon sequestration process in the Pulicat Lake ecosystem.

KEYWORDS
ciliate protozoans, foraminifera, Pulicat Lake, southeast coast of India, tintinnids diversity

1 | INTRODUCTION

The ciliate protozoa have numerous advantages as a favorable bio-indicators to estimate the environmental stress and anthropogenic impact in aquatic ecosystems. Through their short life cycle and slight pellicles, they may respond more quickly and adapt to environmental changes than any metazoan (Feng et al., 2015). Many ciliated microbiotas can tolerate extremes of environmental conditions. Thus, ciliated protozoa have been used as favorable bioindicators of water quality in many aquatic environments. Encrusting foraminifera was also important in providing the geologic record of reefs (Varrone & d'Atri, 2007) similar to benthic foraminifera (Murray, 2006). Foraminifera is an important biological community and can be valuable indicators of the overall health of a marine water body as they are sensitive to changing environmental variables (Buzas-stephens et al., 2003). It has been estimated that the total number of foraminiferans species might be approximately 4000 living species (Anand & Venkataraman, 2012). Several researchers have extensively documented the responses of foraminifera to different natural and anthropogenic environmental stresses (Alve, 1995; Pati & Patra, 2012). Khare et al. (2007) documented the published literature about foraminiferal studies from the west and east coast of India. Tintinnids are ciliate chromists, which possess a shell (lorica) and constitute a ubiquitous component of microzooplankton (Dolan, 2010). Among microzooplankton, tintinnids are the most thoroughly investigated component, due to their role as grazers, in regenerating nutrients, and as food for higher trophic levels. The majority of tintinnid species are marine (Dolan et al., 2012) and cosmopolitan in the world's oceans, but some have a more restricted distribution, occurring in shallow, brackish-water environments like estuaries (Pierce & Turner, 1993). A few species are known from freshwater plankton, but no tintinnids are benthic (Dolan et al., 2012). The forms that fossilize constitute one of the most extensive and continuous fossil records for zooplanktonic organisms, dating back to the Ordovician (Dolan et al., 2012). Holocene paleoenvironmental studies of estuarine sediments only rarely include tintinnids, with foraminifera, testate amoebae, and diatoms being preferred micro-proxies (Scott et al., 2005). Pulicat Lake (2nd largest brackish water lake in India) boundary limits range between 13°26′ and 13°43′ N latitude and 80°03′ and 80°81′ E longitude with a dried part of the lagoon covering up to 14.0° N with around 84% of the Lake in Andhra Pradesh and 16% in Tamil Nadu. Pulicat Lake is united parallel to the coastline with its western and eastern parts covered with sand ridges. Despite its ecological, economic, social, and cultural significance of Pulicat Lake is under serious pressure due to anthropogenic activities. The main threat is siltation and sandbar developing at the mouth of the lake, which endangers the complete ecological balance of the biota. Therefore, the present study delineates the diversity and distribution of foraminifera and tintinnids in the Pulicat Lake.

2 | MATERIALS AND METHODS

The Pulicat Lake has been classified into five ecological zones based on the freshwater region (Westside) and marine water region (East side) shown in Figure 1a. The present study is based on samples collected from five stations in these four zones of the lake (Figure 1b and Table 1). Sampling was carried out twice a month from the period of September 2014 to August 2015 (12 months). The tintinnids samples were collected in the forenoon period from the Pulicat Lake using plankton net pore size of 20 μm by towing horizontally at a depth of 45 cm for about 5 min. Samples were immediately transported to the laboratory within an hour in an insulated polyethylene container, fixed with 4% formalin solution for further identification. The identification of tintinnids was done using standards by Meunier (1919) and Kofoid and Campbell (1929). Sediment samples were also collected from 5 stations using Van Veen grab. Samples were preserved in rose Bengal-stained and 70% ethanol on the spot. The species were identified according to the standard method of Loeblich and Tappan (1987). Field data, like temperature, were measured using a thermometer. Dissolved oxygen (DO) was estimated by the modified Winkler's method (Strickland and Parson, 1972), while pH was analyzed using the standard methods of Adoni (1985) and APHA (1995). Water salinity was recorded using a Hand Refractometer (ATAGO-Japan).

3 | RESULTS AND DISCUSSION

A total of 21 genera and 24 species of foraminifera have been identified from the lake, where *Quinquelina seminulum* was found to be abundant. Tintinnopsis contributed to the sampling sites, belonging to 5 families, 6 genera, and 12 species have been identified, among them *Favella campanula* was found to be abundant. Linked to a previous study (Lei et al., 2009), the tintinnid species composition and abundance were studied in the solar salterns of the Yellow Sea, and the abundance in a salinity ranges from 30 to 70 ppt. In the present study, salinity ranges from 26.3 to 41 ppt were recorded. Similar results were reported in the salinity (16–18 ppt), and dissolved oxygen (7.96–13.10 mg L^{-1}) was recorded at the sampling stations in Turkish coastal waters (Durmuş et al., 2011). In the present study, the water pH values varied from 8.2 to 9.0, the water temperature attained peak was recorded during the summer season (SUM 2015) (33°C), and at least value recorded in the post monsoon (POM 2014) (24.6°C) season. The dissolved oxygen level (DO) fluctuated between L1 (1.02 mg/L POM 2014 and 4.22 mg/L MON 2013), and water salinity was ranged from L1 [30 ppt monsoon (MON) 2014 to 41 ppt SUM 2014, 2015]. Higher range of salinity was recorded during summer season in the present study, and the lake might be hypersalinic due to the high rate of evaporation. Dhib et al. (2013) also recorded the water salinity varied from 26.6 in December to 51.2 in July and peaked in summer owing to the combined effect of high temperature, inducing water evaporation and the low inflow of freshwater to the lagoon.

Similar research was done, like the current study, at hypersaline Lagoon Bardawil (Egypt); 15 species of Ciliophora (Tintinnina) and two species of foraminifera were recorded during the period of 2009 and 2010 and associated with water quality parameters, such as temperature, salinity, dissolved oxygen and pH (El-Shabrawy & Gohar, 2008). Pecqueur et al. (2011) recorded the gradient of salinity ranged between 20 and 36 in a Mediterranean coastal lagoon. Our findings of salinity values are comparable with earlier results reported by Riandey et al. (2005) in the North Lagoon of Tunis, Annabi-Trabelsi et al. (2006) in the Bizerte Lagoon, Sakka Hlaili et al. (2008) in the Bougrara Lagoon.

The distribution of foraminifera clearly shows a decreasing trend toward the upper reaches of the Pulicat Lake. The following species are distributed in the lagoon of Pulicat, 24 species were recorded (Table 2 and Figure 2), where *Quinquelina seminulum* was found to be abundant. Contrary to this, a smaller number of species were

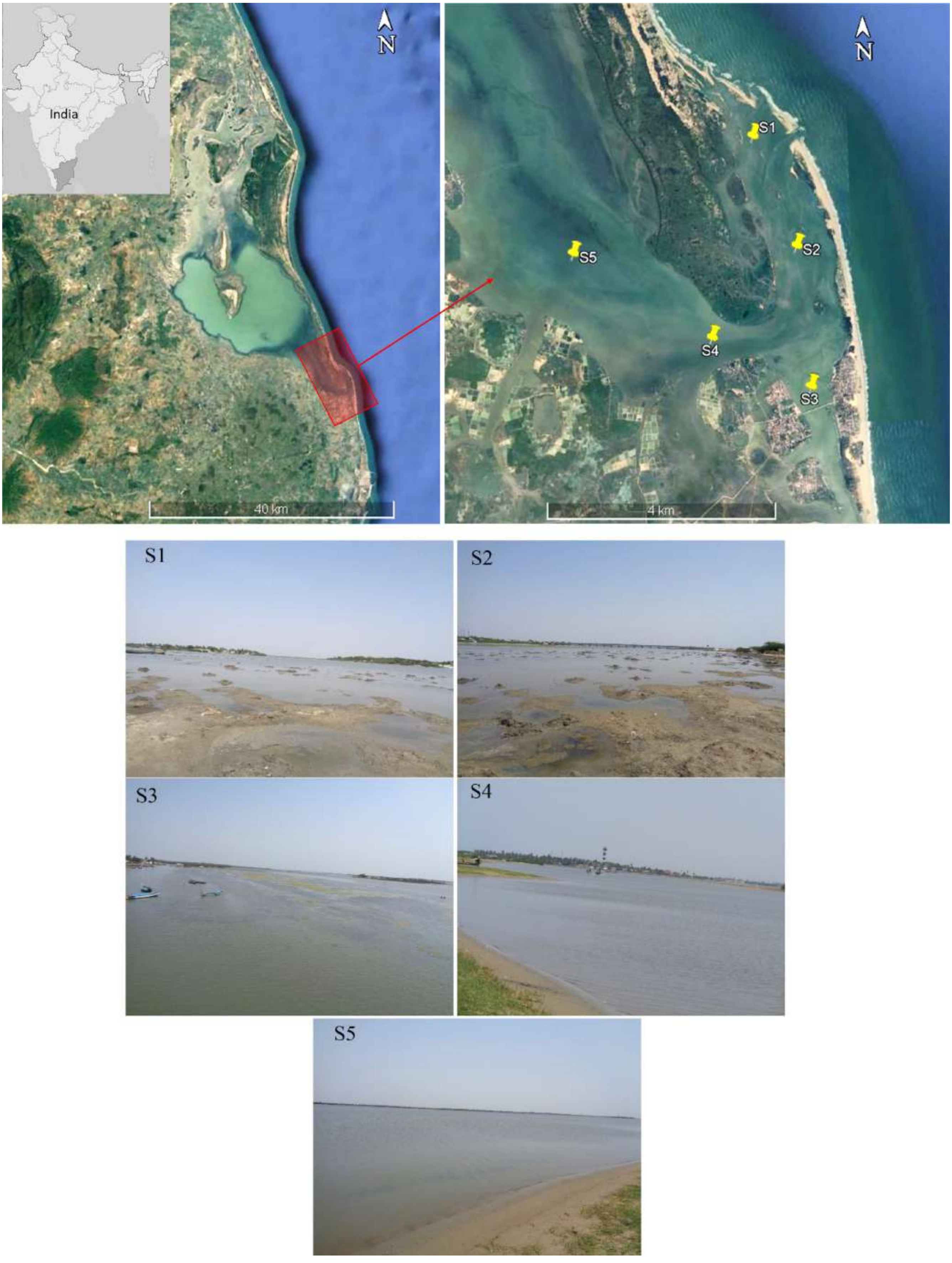


FIGURE 1 Study area with sampling stations of Pulicat lagoon, Southeast coast of India.

TABLE 1 Geological information for the collection sites around Pulicat lagoon.

Station code	Name of the stations	Geo-coordinates	
		Latitude (°N)	Longitude (°E)
S1	Barmouth	13°28′13″	80°18′60″
S2	Kunankuppam	13°25′29″	80°19′27″
S3	Light-house kuppam	13°25′07″	80°19′03″
S4	Sattankuppam	13°25′00″	80°19′07″
S5	Jameelabad	13°25′39″	80°18′26″

TABLE 2 List of Foraminiferans recorded from Pulicat Lagoon.

S.No	Name of the organism	S1	S2	S3	S4	S5
1	*Freixialina planispiralis*	+	+	+	−	−
2	*Hyalinca balthica*	+	+	+	−	−
3	*Operculina gaimardi*	+	+	+	−	−
4	*Paraplecto gyramasanae*	+	+	+	−	−
5	*Polystomellina discorbinoides*	+	+	+	−	−
6	*Woodella nammalensis*	+	+	+	−	−
7	*Peneroplis bradyi Cushman*	+	+	+	−	−
8	*Ammonia beccarii*	+	+	+	−	−
9	*Ephidium escavatum*	+	+	+	−	−
10	*Ammonia dentate*	+	+	+	−	−
11	*Pseudobradyina pulchra*	+	+	+	−	−
12	*Islandiella australis*	+	+	+	−	−
13	*Epistomaria rimosa*	+	+	+	−	−
14	*Affinetrina planciana*	+	+	+	−	−
15	*Jadammina cyclostoma*	+	+	+	−	−
16	*Globigerina bulloides*	+	+	+	−	−
17	*Quinqueloculina seminulum*	+	+	+	−	−
18	*Sigmoilinita asperula*	+	+	+	−	−
19	*Lepidodeuterammina ochracea*	+	+	+	−	−
20	*Leptotricites hatchetensis*	+	+	+	−	−
21	*Amomalinula glabrata*	−	−	−	+	+
22	*Haplophragmoides kirki*	−	−	−	+	+
23	*Natlandia secasensis*	−	−	−	+	+
24	*Valvulintioneria candeiana*	−	−	−	+	+

Note: (+) present, (−) absent.

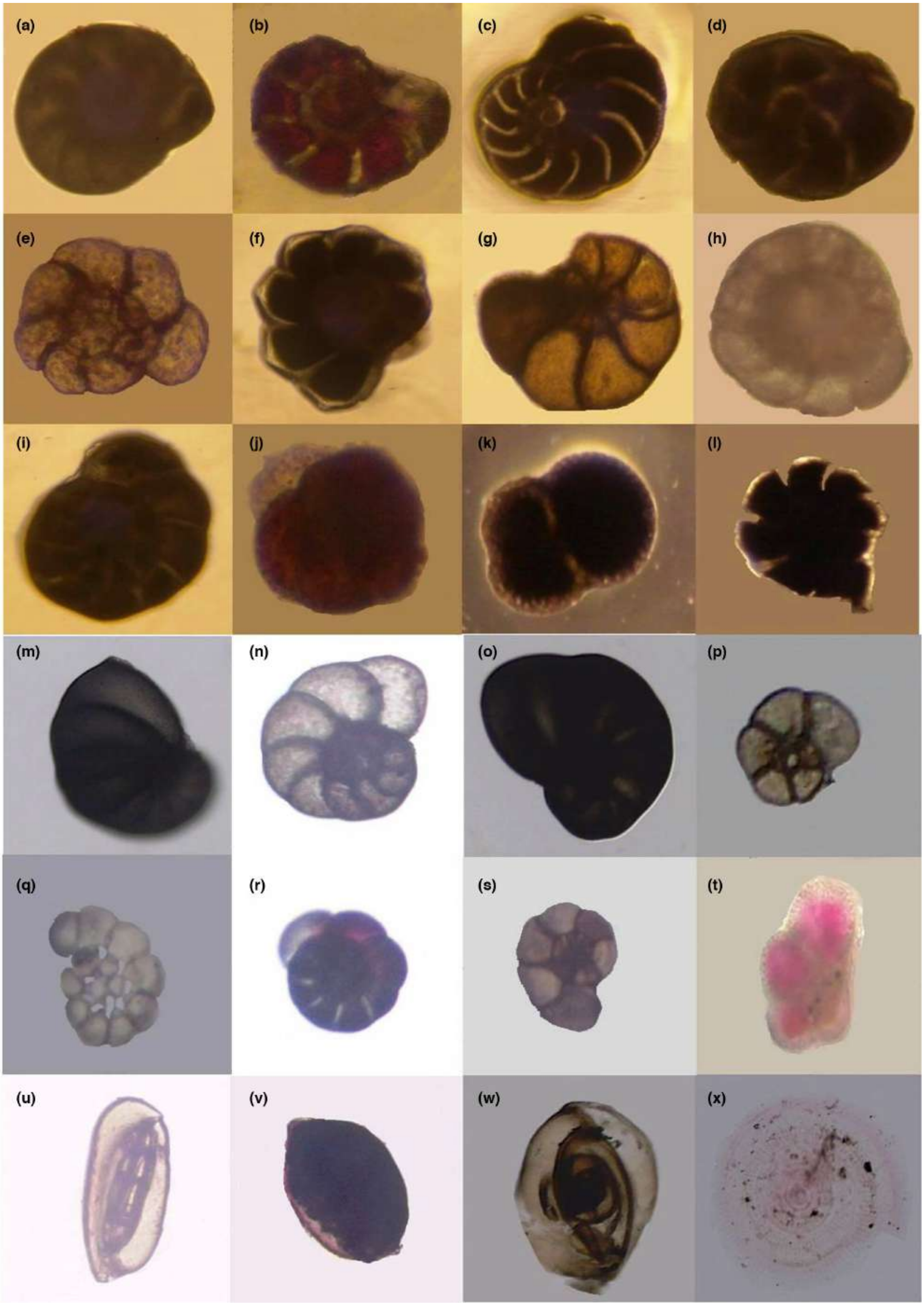
present in the freshwater inflow zone, mainly *Amomalinula glabrata*, *Haplophragmoides kirki*, *Natlandia secasensi*, and *Valvulineria candeiana* (Table 2). Suresh Gandh et al. (2013) reported that the Foraminifera distribution was collected by scuba diving in the areas around the Adyar River, Chennai, Tamil Nadu. It includes 46 species of benthic foraminifera that were found to belong to 22 genera. In addition, Subhadra Devi and Patil (2012) studied the distribution of foraminifera species from east (57) and west (74) coasts of India. Symphonia and Senthil Nathan (2014) reported 95 species (47 genera and 6 orders) of benthic foraminifera in the offshore region of Cuddalore, southeast coast of India. Within these species, *Amphistegina*, *Quinqueloculina*, *Operculina*, and *Elphidium* are more dominant.

In a similar report to the present findings, Sundara Raja Reddy et al. (2012) reported that 50 benthic foraminiferal species including *Ammonia* sp, recorded in Araniyar, and *Elphidium* sp. *Ammonia dentate* and *Quinqueloculina* sp., reported at Pulicat, Southeast India. In the present study, the foraminifera—*Quinquelina* genera—was more dominant in the sampling stations.

The diversity of the tintinnids from the Pulicat Lake belongs to 6 genera and 12 species (Figure 3 and Table 3). In the marine water region, there were only 9 species of tintinnids at stations 3, 4, and 5 (*Leprotintinnus elongates*, *Tintinnopsis schotti*, *Tintinnopsis lobiancoi*, *Petalotricha ampulla*, *Eutintinus elongatus*, *Eutintinnopsis apertus*, *Tintinnopsis tocantinensis*, *Codonellopsis ostenfeldi*, and *Eutintinnopsis franknoi*). In the freshwater region, *Favella adriatica*, *Tintinnopsis karajacensis*, and *Favella campanula* (Figure 3 and Table 3) were observed during the study period. To the best of our knowledge, no previous studies reported about tintinnids diversity in the Pulicat Lake. However, previously only one species of tintinnid, namely, *Favella philippinensis*, has been reported by Elayaraja and Ramanibai (2006), which is not in our present reported species in the Pulicat Lake. Recent studies have confirmed that tintinnids are sensitive to ecological variables, and some species of coastal ciliates (protozoa) can be used as bioindicators for assessing the environmental contaminants (Jiang et al., 2013; Sivasankar et al., 2018).

The distribution of tintinnids in Pulicat Lake reported that the occurrence of 12 species was persistent over the entire study period. Tintinnids populations are indicating their tolerance to seasonal ecological fluctuations. This reflects the degree of stability of the zooplankton community in Pulicat Lake. These observations were

FIGURE 2 Foraminiferal diversity in Pulicat lagoon. (a) *Freixialina planispiralis*, (b) *Hyalinca balthica*, (c) *Operculina gaimardi*, (d) *Paraplectogyra masanae*, (e) *Polystomellina discorbinoides*, (f) *Woodella nammalensis*, (g) *Peneroplis bradyi Cushman*, (h) *Ammonia beccarii*, (i) *Ephidium escavatum*, (j) *Ammonia dentate*, (k) *Pseudobradyina pulchra*, (l) *Islandiella australis*, (m) *Epistomaria rimosa*, (n) *Lepidodeuterammina ochracea*, (o) *Jadammina cyclostoma*, (p) *Amomalinula glabrata*, (q) *Haplophragmoides kirki*, (r) *Natlandia secasensis*, (s) *Valvulineria Candeiana*, (t) *Globigerina bulloides*, (u) *Quinqueloculina seminulum*, (v) *Sigmoilinita asperula*, (w) *Affinetrina planciana*, and (x) *Leptotricites hatchetensis*.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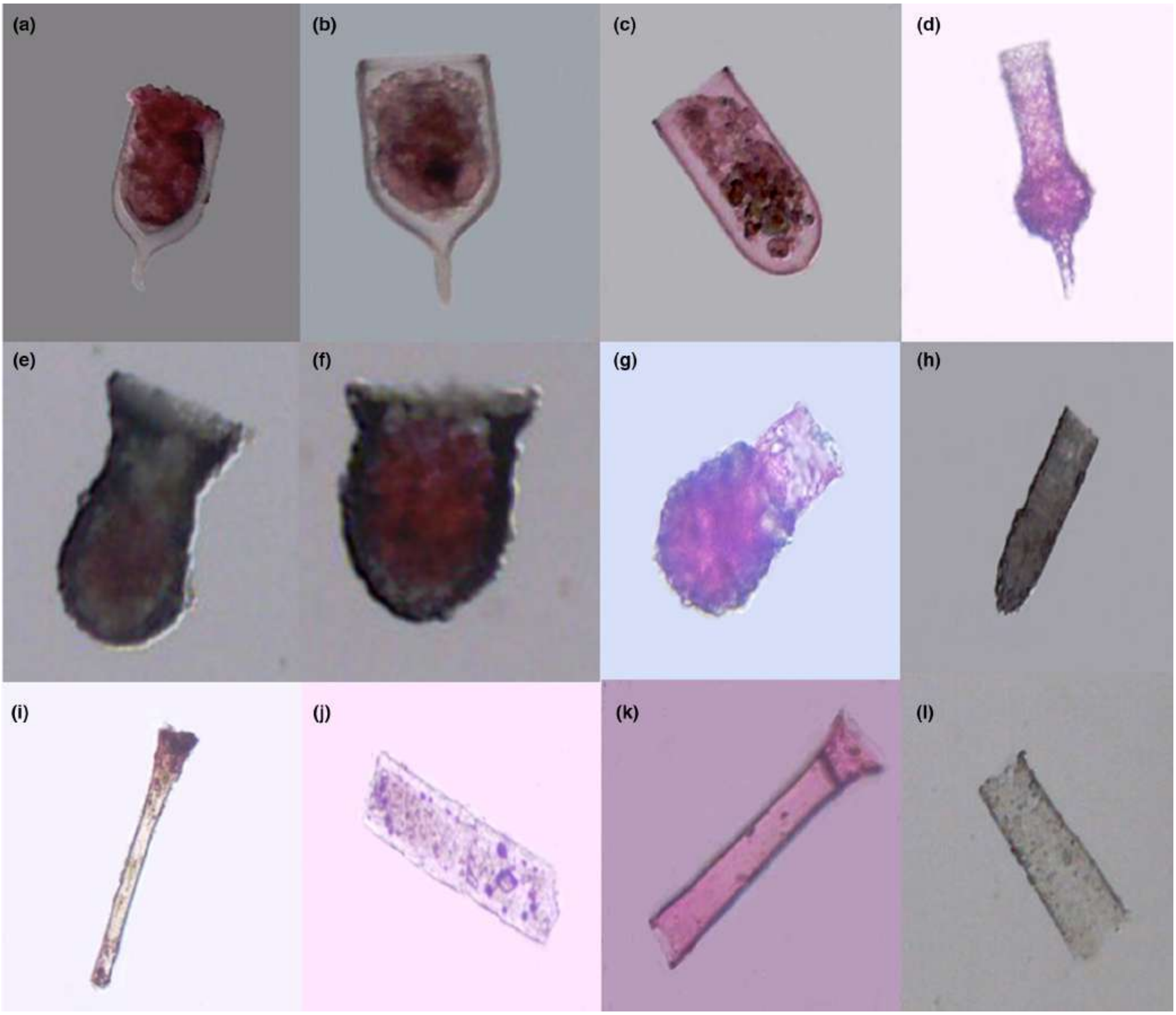


FIGURE 3 Tintinnids diversity in Pulicat lagoon. (a) *Favella campanula*, (b) *Favella adriatica*, (c) *Tintinnopsis karajacensis*, (d) *Tintinnopsis tocantinensis*, (e) *Tintinnopsis schotti*, (f) *Petalotricha ampulla*, (g) *Codonellopsis ostenfeldi*, (h) *Tintinnopsis lobiancoi*, (i) *Eutintinus elongatus*, (j) *Eutintinnopsis apertus*, (k) *Eutintinnopsis franknoi*, and (l) *Leprotintinnus elongates*.

supported by Dorgham et al. (2009) who found that the sheltered environment gives aquatic organisms the opportunity to persist for a longer period in the preferred zone. Similar research was carried out by Mukherjee et al. (2015) at Chilika lagoon, and there are 27 species of tintinnids belonging to eight genera and five families of which 26 are new records from the lagoon. Figure 3 and Table 3 represent the 12 Tintinnids species that have been recorded in the Pulicat Lake for the first time. The low diversity of tintinnids was recorded in the study area compared to the freshwater region highly influenced by anthropogenic disturbance, such as dredging, industrial and domestic effluents and aquaculture practices. The tintinnids of Pulicat Lake were less diversified than Damietta Harbor of Egypt coast (Dorgham et al., 2009).

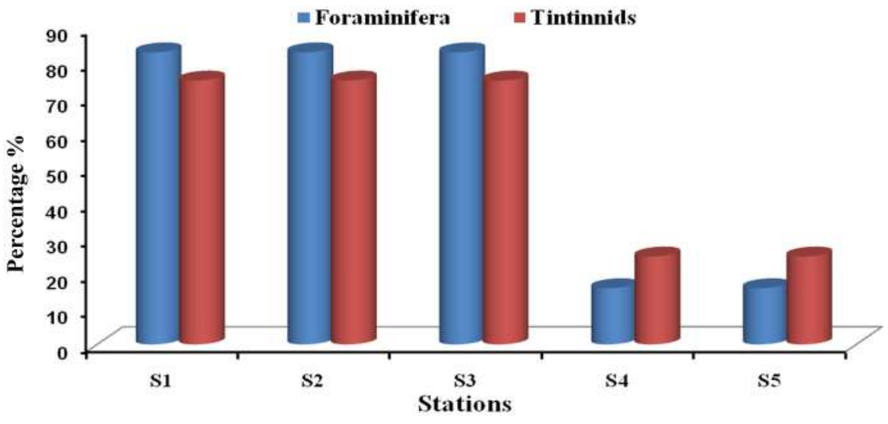
The percentage-wise compositions of tintinnids and foraminiferans in the present study are given in Figure 4. The stations 1–3 (80%) and stations 4–5 (20%) recorded foraminifera, and the

TABLE 3 Occurrence of tintinnids species in Pulicat lagoon.

S.No	Tintinnids	S1	S2	S3	S4	S5
1	*Leprotintinnus elongates*	+	+	+	–	–
2	*Tintinnopsis schotti*	+	+	+	–	–
3	*Tintinnopsis lobiancoi*	+	+	+	–	–
4	*Petalotricha ampulla*	+	+	+	–	–
5	*Eutintinus elongatus*	+	+	+	–	–
6	*Eutintinnopsis apertus*	+	+	+	–	–
7	*Tintinnopsis tocantinensis*	+	+	+	–	–
8	*Codonellopsis ostenfeldi*	+	+	+	–	–
9	*Eutintinnopsis franknoi*	+	+	+	–	–
10	*Favella campanula*	–	–	–	+	+
11	*Favella adriatica*	–	–	–	+	+
12	*Tintinnopsis karajacensis*	–	–	–	+	+

Note: (+) present, (–) absent.

FIGURE 4 Percentages of foraminifera and tintinnids diversity in Pulicat lagoon.



tintinnids were observed in the sampling stations 1–3 (80%) and 4–5 (20%). In the present study, 24 species of foraminifera and 12 species of tintinnids have been identified from water and sediment samples in the Pulicat Lake. The foraminiferal assemblage shows an increase in species diversity on the inner continental shelf. The species foraminifera *Quinqueloculina* and the tintinnids *Favella* are the dominant genera. Seawater convergence regions are more prone to the abundance of tintinnids and foraminiferans than freshwater zones of the Lake, which warrants that both tintinnids and foraminiferans act as bio-indicators for assessing the ecological status of Pulicat Lake. Further detailed study is needed to support this data and to also know the importance of the carbon sequestration process to mitigating climate change and to focus more on this lake for high bio-resource to the research communities and various stakeholders.

AUTHOR CONTRIBUTIONS

S. Govindan: Concept, writing and statistical analysis; R. Ramanibai: Formal Analysis; R. Murugan: Writing and Formal analysis.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

DATA AVAILABILITY STATEMENT

All data generated or analysed during this study are included in this published article.

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