

## Chapter 2

# Methodology

**Abstract** The Indian Sundarbans wetland, the largest delta situated at the mouth of the Ganges River Estuary (GRE), is situated in the low-lying, meso–macrotidal, humid and tropical belt, which harbors the world’s largest mangrove forest together with associated flora and fauna. The total estuarine phase of the wetland is very irregular and criss-crossed by several tributary rivers, creeks, and waterways. Five study sites of different hydrodynamic conditions were chosen covering the eastern and western flank of Sundarbans coastal region. These sites belong to a lower deltaic plain experiencing intense semidiurnal tides and wave action with a meso–macrotidal setting (3–6 m amplitude). Detailed of the selection of study sites, sampling strategy, and numerical analyses of the water quality and plankton are discussed.

**Keywords** Community structure • Water quality • Lorica • Tintinnids morphology

### 2.1 Study Sites

India has a large coastline and vast stretches of coastal wetlands, estuaries, bays, backwater lagoons, and mangrove swamps, which extend over large part of the coasts. The term “tide-dominated wetland” has been used by Selvan (2003) for the Indian Sundarbans, as the study area involves the tide-dominated estuarine stretch of the Hugli (Ganges) and Matla rivers, the intertidal creeks and canals and the marshy mangrove swamps of Sundarbans. The wetland (7,658 km<sup>2</sup>) is characterized by a large wealth of water resources, faunal and floral biodiversity, commercially exploitable species of shell and fin fishes (Bhattacharya and Sarkar 2003), and recreational potential and luxuriant wildlife including a tiger reserve (Naskar and Guha Bakshi 1987; Stanley and Hait 2000). Shared between two neighboring countries, Bangladesh and India, the larger part (62 %) is situated in the southwest corner of Bangladesh. At present, the total land area is 4,143 km<sup>2</sup> (including exposed sandbars of 42 km<sup>2</sup>), and the remaining water area of 1,874 km<sup>2</sup> encompasses rivers, small streams, and canals. As it is the transition zone of freshwater and saltwater, it offers a specialized habitat for both plant and animals. A significant

part of this wetland has been undergoing denudation due to deforestation, agriculture, and reclamation of lands.

The Indian Sundarbans (21° 32' N–22° 40' E and 88° 85' N–89° 00' E), the largest delta in the estuarine phase of the River Ganges, is famous for its luxuriant mangrove vegetation, acclaimed as UNESCO World Heritage Site for its capacity of sustaining rich and diverse fauna and floral communities. Situated in the low-lying, meso–macrotidal, humid and tropical belt, the area is interspersed with a large number of islands (~101 in number) and tidal channel systems through which semidiurnal tides of meso–macrotidal amplitude interplay with moderate to strong wave effects. Due to combination of interaction of geography, topography, and climate, the delta has a variety of habitats and ecosystems, inhabited by globally threatened species, critically endangered and endangered species.

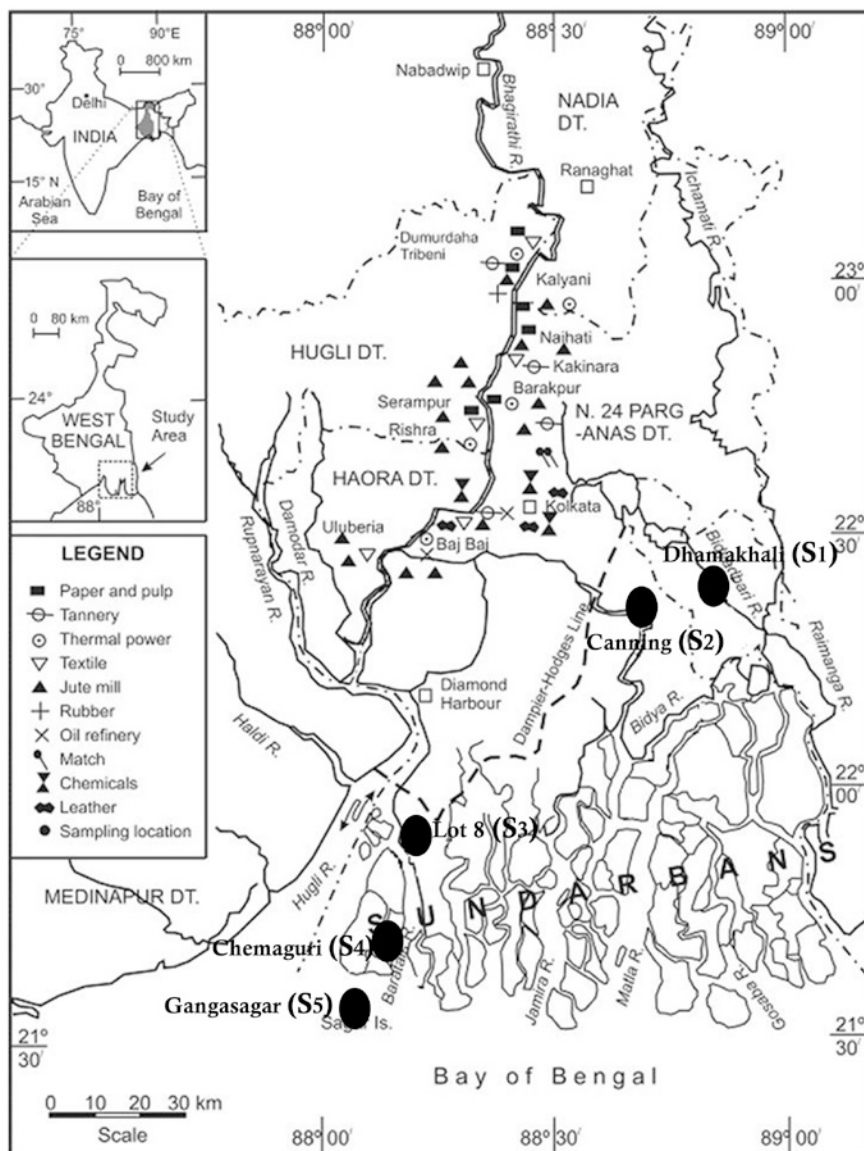
The total estuarine phase of the Indian Sundarbans is very irregular and crisscrossed by several tributary rivers (such as Matla, Gosaba, Muriganga, Saptamukhi), creeks, and waterways. The area is characterized by shallow waters which are constantly mixed by wind and tidal currents. The velocity of the current varies considerably with the state of the tides and the season in this estuarine system. Both the flood and ebb currents go up to 6 knots during high spring tides. This highly turbid estuary allows a scarce light penetration due to a great amount of organic and inorganic suspended materials. Like other estuaries, this is also characterized by a predominant monsoon regime and the total 12-month period in a year was classified into three different seasons, namely premonsoon (March–June) dry season with occasionally higher temperature, monsoon (July–October) accompanied by heavy rainfall (annual average precipitation is ~1,800 mm) and postmonsoon (November–February) characterized by lower temperatures and lower precipitations. Seven sampling sites [Dhamakhali (S<sub>1</sub>), Canning (S<sub>2</sub>), Basanti (S<sub>3</sub>), Lot 8 (S<sub>4</sub>), Phuldubi (S<sub>5</sub>), Chemaguri (S<sub>6</sub>), and Gangasagar (S<sub>7</sub>)] have been selected covering both eastern and western flank of Sundarbans (as shown in Fig. 2.1). They are of diverse environmental stresses and of different hydrodynamic conditions in the context of depth, tidal amplitude, and wave action gradually being less toward the upstream direction (Table 2.1).

## 2.2 Sampling Strategy and Analytical Protocol

### 2.2.1 Collection and Preservation of Tintinnid

**Collection of tintinnids** For tintinnids, 1,000 ml of surface water samples were collected by precleaned plastic bottles from each site and immediately preserved with Lugol's solution (2 % final concentration, volume/volume) and stored refrigerated in darkness except during transport and settling (Dolan 2002).

**Settlement of the sample** In the laboratory, the water samples were placed in measuring cylinders of 1,000 ml with 2 special outlets at the level of 500 and



**Fig. 2.1** Map of Indian Sundarbans showing the location of five study sites (S<sub>1</sub>–S<sub>5</sub>). The location of multifarious industries is shown in the upstream of Hugli River along with the primary rivers and tributaries

250 ml, respectively, which were blocked by clumps. After 24 h, when almost all the planktons were settled at the bottom of the cylinder, the clumps were being opened and the water from the upper portion of the measuring tube was allowed to flow out without disturbing the last 250 ml sample. After that, the sample was

**Table 2.1** Justification for the selection of the study sites in Sundarbans coastal regions

Characteristic features of the study sites	Dhamakhali (River Vidyadhori) S <sub>1</sub>	Canning (River Matla) S <sub>2</sub>	Lot 8 (River Muriganga) S <sub>3</sub>	Chemaguri (narrow creek) S <sub>4</sub>	Gangasagar (mouth of the estuary) S <sub>5</sub>
Geomorphic coordinates	22° 20' 26" N 88° 53' 18" E	22° 12' 13" N 88° 40' 01" E	21° 52' 34" N 88° 09' 06" E	21° 40' 45" N 88° 09' 03" E	21° 36' 10" N 88° 01' 43" E
Tidal environment	Semidiurnal micro (<2 m)	Semidiurnal meso (2–4 m)	Semidiurnal macro (>4 m)	Semidiurnal macro (>4 m)	Semidiurnal macro (>4)
Wave action	Low	Low	Moderately low	Moderately low	High
Distance from sea (km)	100.53	94.71	29.73	5	0
Depth (m)	~2.0–3.0	~2.0–3.5	~2.0	~3.0–4.6	~8.0–9.8
Anthropogenic stress	Boating, use of antifouling paints, domestic sewage	Agriculture fishing, boating	Boating, agricultural runoff, domestic sewage	Boating, fishing, antifouling paints, ice factory discharge	Fisheries, boating, antifouling paints

transferred to a beaker and again kept for 24 h. Lastly, the sample was concentrated to a volume of 25 ml by siphoning out the rest of the volume from the beaker (Godhantaraman 2002).

**Qualitative analysis** From the concentrated volume (25 ml) of the sample, it was taken on a glass slide with a dropper for identification and observed under a phase-contrast microscope at a magnification of  $40\times$ . As there are no other criteria for identification, tintinnids were identified using lorica morphology (Lorica shape, size as well as the agglomeration type) described by Kofoid and Campbell (1929, 1939) and Marshall (1969).

**Quantitative analysis** For quantitative analysis, the sample was taken as a drop of known volume on a glass slide with the help of a micropipette. Three to five aliquots of each sample were counted, and the mean value was considered.

**Calculation of lorica volume, biomass, and production rate of tintinnids** Biomass was calculated as the total biovolume of the tintinnid community for each sampling date. Both lorica length and oral diameter were measured, and volumes were calculated by assigning standard geometric configurations. Lorica volume (LV,  $\mu\text{m}^3$ ) was converted to body carbon weight using the regression equation:  $444.5 + 0.053 \text{ LV}$  (Verity and Langdon 1984). Production rate (P,  $\mu\text{g C l}^{-1} \text{ day}^{-1}$ ) was estimated from biomass (B,  $\mu\text{g C l}^{-1}$ ) and empirically determined specific growth rate (g,  $\text{day}^{-1}$ ):  $P = B \times G$ . Multiple regression,  $1.52 \ln T - 0.27 \ln \text{CV} - 1.44$ , where  $T$  is the temperature ( $^{\circ}\text{C}$ ) and CV is the cell volume ( $\mu\text{m}^3$ ) proposed by Müller and Geller (1993) for ciliates, was used.

### 2.2.2 Collection and Analysis of Water Samples

**Collection of water samples** Simultaneously with plankton samples, surface water samples were also collected for the analyses of temperature, pH, salinity, turbidity, dissolved oxygen (D.O.), biological oxygen demand (B.O.D.), nutrients (nitrate, phosphate and silicate), and chlorophyll pigments. Water samples were taken in precleaned plastic bottles and were immediately preserved in  $4^{\circ}\text{C}$  and taken to the laboratory for further analyses. For chlorophyll pigment analyses, one liter of surface water sample was wrapped by black paper and was taken to the laboratory for further analyses. For dissolve oxygen, water samples were taken in B.O.D. bottles (125 ml) and the D.O. was fixed immediately using Winkler's reagents.

**Temperature** For measurement of water temperature, 1 L of seawater on board was taken and a centigrade thermometer of  $\pm 0^{\circ}\text{C}$  accuracy was dipped into the water immediately after their collections and the water temperature was recorded after 5 min, when the mercury level stood constant. Temperature values are expressed in  $^{\circ}\text{C}$ .

**pH** The pH of the water samples was recorded with the help of a Deluxe Digital pH Meter (Model No. 101 E) considering three replicate samples of each station studied.

**Salinity** Salinity was measured on board using a refractometer. Immediately after collection of the water sample, the instrument was rinsed with distilled water for 2 or 3 times and it was standardized at zero. Then, sample water was added to it drop by drop and the reading was taken. This process was repeated for 5 times, and the mean reading was taken and expressed in parts per thousand (ppt).

**Turbidity** Turbidity was measured using a turbidity meter (Model no: SYS 304 E).

**Dissolved oxygen** The D.O. content was estimated adopting Winkler's titrimetric method. The water samples drawn carefully into 125 ml B.O.D. avoiding the interference of air bubbles were treated with 1 ml each of the Winkler's I and Winkler's II solution. The bottles were restoppered and well shaken. This was done in the field immediately after the collections are over and was transported to the laboratory for further analysis. The brownish white precipitates of manganous hydroxide were dissolved by adding 1 ml of concentrated  $\text{H}_2\text{SO}_4$ , which liberated iodine equivalent to the original D.O. The brown color solution was qualitatively transferred to a 250 ml conical flask and was titrated against standard sodium thiosulfate solution of 0.01 N (W/V). 2 % starch solution (W/V) was used as the indicator. Change of blue color, developed due to the reaction between iodine and starch, to colorless was taken as the end point. From the amount of thiosulfate consumed in the titration, the D.O. content in each sample was calculated employing the formula below. The values of oxygen are presented as  $\text{mg l}^{-1}$ .

### Calculations

$$\text{Dissolved oxygen in mg l}^{-1} = \frac{\text{CD} \times N \times E \times 1,000}{4 \times (V-2)}$$

CD Burette reading for thiosulfate titration

N Normality of thiosulfate (0.01 N)

E Equivalent weight of oxygen (32,000)

V Volume of the B.O.D. bottle (125 ml)

**Biological oxygen demand** B.O.D. is the measure of the degradable organic material present in a water sample and can be defined as the amount of oxygen required by the microscopic organisms in stabilizing the biologically degradable organic matter under aerobic condition. The principle of this measuring is the difference of oxygen concentration between the sample and after incubating it after 5 days at 20 °C. Water sample was taken in a precleaned plastic container (>1 l), and it was made oxygen saturated by compressed air bubbling using an aerator for 30 min. After the saturation, 1 l of that water was taken and 1 ml each of the reagents, phosphate buffer, magnesium sulfate solution, calcium chloride solution, and ferric chloride solution were added to it and mixed thoroughly. Two B.O.D. bottles were taken for the analysis, and both the bottles were filled

with water and stoppered. D.O. was immediately determined using Winkler's titrimetric method, and the second bottle was incubated at 20 °C for five days. After completion of five days, D.O. of the second bottle was determined using the same procedure. B.O.D. was calculated using the following formula, and B.O.D. was expressed by  $\text{mg l}^{-1}$ .

**Calculations**  $\text{B.O.D. (mg l}^{-1}\text{)} = \text{D.O. content of the first bottle (mg l}^{-1}\text{)} - \text{D.O. content of the second bottle after five days (mg l}^{-1}\text{)}$ .

**Estimation of Nitrate–Nitrite** All nitrates present in the sample water were converted to nitrite by reduction. A glass column packed with copper-coated cadmium chips was used for reduction. Method was based on the formation of azo dye. 100 ml of water sample was mixed with ammonium chloride solution (2 ml of 25 %) and passed through the amalgamated cadmium redactor column with a speed of 2 drops s<sup>-1</sup>. The effluent (50 ml) collected from the column was then treated with 1 ml solution of sulfanilamide; the resultant diazonium ion was coupled with 1 ml of N-(1-Naphthyl)ethylenediamine dihydrochloride to give an intensely pink dye. The absorbance of the resulting pink solution was measured spectrophotometrically at 543 nm against a reagent blank. Efficiency of the redactor column (>90 %) was tested periodically with standards and was subjected to identical treatment in each batch. The concentration of total nitrate and nitrite was computed from calibration curve.

**Dissolved inorganic Phosphate–Phosphorus** Phosphate–phosphorus of sample water was determined using acidified molybdate solution and ascorbic acid. 35 ml of sample water was treated with 1 ml mixed reagent (mixture of 0.073 M ammonium molybdate and 9.1 N H<sub>2</sub>SO<sub>4</sub> and a small portion of potassium antimonyl tartrate) followed by the addition of 1 ml 0.4 M ascorbic acid solution. Dissolved inorganic phosphate present in seawater was converted to the formation of phosphomolybdate complex with acidified molybdate reagent, which on reduction with ascorbic acid formed a highly colored molybdenum blue compound. The absorbance of the resultant molybdenum blue was measured spectrophotometrically at 882 nm against reagent blank. Samples and standards were subjected to identical treatment in each batch. Turbidity blank was used whenever it was necessary. The concentration of PO<sub>4</sub><sup>-3</sup>-P was then computed from calibration curve.

**Dissolved Silicate–Silicon** Silicate–silicon was determined using acidified molybdate solution and ascorbic acid solution. Oxalic acid was added to avoid interference of phosphate in samples. 25 ml of sample and a set of standards were mixed with 1 ml of mixed reagent (mixture of equal volume of 0.16 M ammonium heptamolybdate solution and 7.3 N H<sub>2</sub>SO<sub>4</sub> acid solution) followed by the addition of 1 ml oxalic acid solution (0.7 M) and 1 ml 0.1 M ascorbic acid solution. Determination of dissolved silicate was based on the formation of a yellow silicomolybdic complex when



an acidified sample was treated with ammonium molybdate solution. This on reduction with ascorbic acid yields intensely colored molybdenum blue complex. The blue silicomolybdic complex is formed within 30 min and stable for hours. The absorbance of the blue complex was measured photometrically at 810 nm against reagent blank, and the concentration of  $\text{SiO}_4^{4-}$ -Si was computed from calibration curve.

**Estimation of Chlorophyll Pigment Concentration** To estimate the chlorophyll pigment (a, b and c) concentration in the surface water of the sampling sites, 1 l of the surface water was collected in acid-washed dark plastic bottles, kept in ice and taken to the laboratory. In laboratory, the collected water sample was filtered through a Millipore filter paper ( $0.45 \mu$ ) using a suction pump. After the filtration, the filter paper was extracted in acid-cleaned centrifuge tube by 10 ml 90 % acetone and kept in dark and frozen for 24 h. Next day, the content in the centrifuge tube was homogenized in acid-cleaned glass homogenizer and again transferred into the centrifuge tube. Then, it was centrifuged at 20,000 rpm for 20 min. The clear solution was decanted from the tube, and the absorbance was measured at 630, 645 and 665 nm. The concentration of the chlorophyll pigments was expressed in  $\text{mg l}^{-1}$ , and it was formulated using the following formula (Strickland and Parsons 1972).

### Calculations

$$\text{Chlorophyll } a \text{ (mg pigment/m}^3\text{)} = 11.6 E_{665} - 1.31 E_{645} - 0.14 E_{630}$$

$$\text{Chlorophyll } b \text{ (mg pigment/m}^3\text{)} = 20.7 E_{645} - 4.34 E_{665} - 4.42 E_{630}$$

$$\text{Chlorophyll } c \text{ (mg pigment/m}^3\text{)} = 55 E_{630} - 4.64 E_{665} - 16.3 E_{645}$$

where E stands for the extinction values at wavelengths indicated by the subscripts, measured in 10 cm cells after correcting for a blank.

### 2.2.3 Statistical Analyses

Species diversity ( $H'$ ), evenness ( $J'$ ), and richness ( $d$ ) of samples were calculated

as follows: the equation:  $H' = -\sum_{i=1}^s Pi(\ln Pi)$ ,  $J' = H/\ln(S)$ , and  $d = (s - 1)/\ln(N)$ ,

where  $P_i$  = proportion of the total count arising from the  $i$ th species;  $S$  = total no of species; and  $N$  = total no of individuals (Xu et al. 2008). Correlations were calculated using Pearson's correlation coefficient (Sokal and Rohlf 1981) to analyze the relationships among all the variables for each station. Hierarchical cluster analysis, one way ANOVA, and multiple stepwise regression analysis were performed to establish the relationships between the biotic and abiotic factors and variation between months and stations using the statistical software MINITAB.

Data were transformed using the log  $10 (n + 1)$  function to allow the less abundant species to exert same influence on the calculation of similarities (Clarke and Warwick 1994).



## 2.3 General Morphology of a Tintinnid ciliate

(Illustrated in Fig. 2.2)

**Oral end** Cavity lying at the upper end of the alimentary canal.

**Aboral end** The end of an animal's body opposite to its mouth.

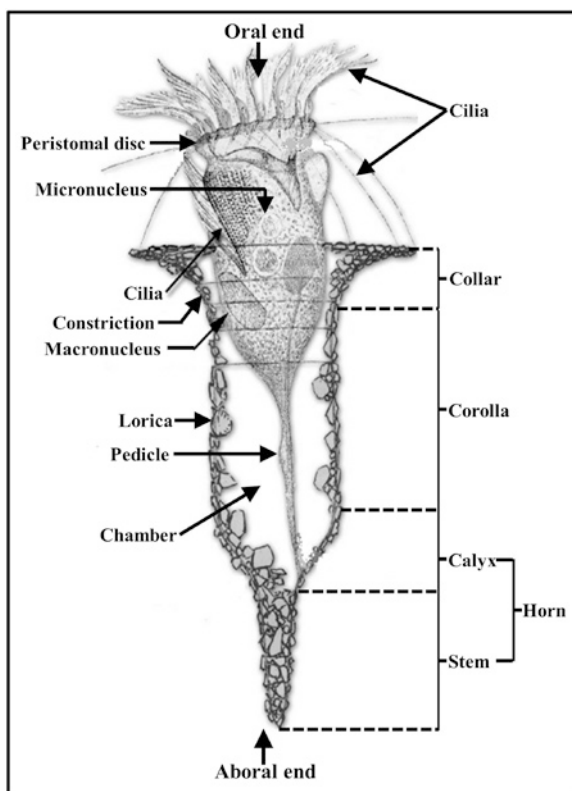
**Micronucleus** The micronucleus is the smaller nucleus in ciliate protozoans which gives rise to the macronuclei and micronuclei of the individuals of the next cycle of fission.

**Macronucleus** Often evident, polyploid in nature, undergo direct division without mitosis.

**Oral cilia** Comprised of oral membranelles arranged in closed circle around the funnel-shaped oral cavity. Tintinnids use their ring of cilia around the open end both for feeding and for swimming. The cilia create currents that bring food items into the lorica and to the cell for ingestion. When the cilia are more active, they propel the tintinnids through the water.

**Lorica** A lorica is a shell-like protective outer covering, *often* reinforced with sand grains and osmiophilic particles collected from the surrounding water. This

**Fig. 2.2** Sectional view showing the basic morphological features of a tintinnid ciliate



is made up of protein and usually tubular or conical in shape, with a loose case that is closed at one end. Lorica oral diameter (LOD) is a conservative taxonomic character, hence used as an important tool for taxonomic diversity. Based on lorica types, tintinnids are traditionally grouped into (i) agglutinated—composed of particles and (ii) hyaline—generally transparent loricae.

**Pedicle/Peduncle** A stalk-like contractile portion by which the tintinnid cell is attached at the bottom end of the lorica. During feeding, the cell extends out of the lorica and the tintinnid is propelled mouth-end forward.

## 2.4 Salient Features of Tintinnids Encountered in Sundarbans Coastal Regions

(A brief account of the identified tintinnids has been given in Table 2.2 along with typical morphological features)

**Table 2.2** A synoptic account of the tintinnid species encountered at five sampling sites of Indian Sundarbans during 2010–2012

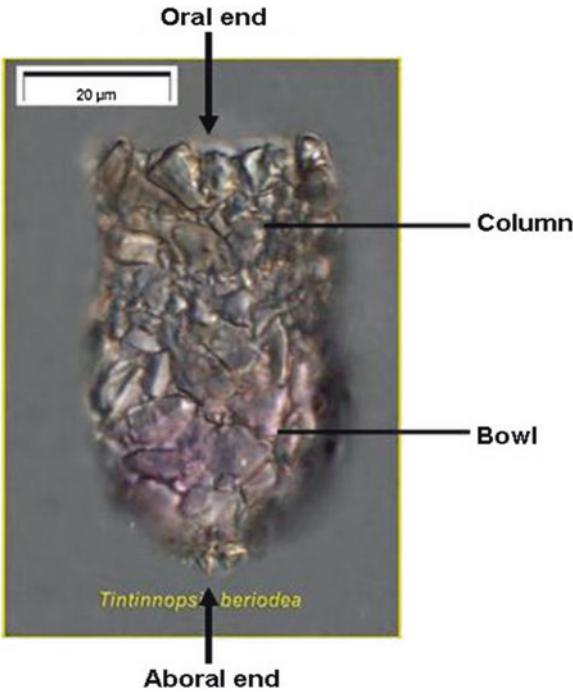
Family	Species	Status	Oral diameter (μm)	Length (μm)
	<i>Agglomerated</i>			
Codonellidae	<i>Tintinnopsis beroidea</i>	Core	12.29–38.13	31.58–118.67
	<i>T. minuta</i>	Core	6.25–11.84	18.29–21.54
	<i>T. lohmani</i>	Core	22.54–24.65	35.77–39.12
	<i>T. cylindrica</i>	Seasonal	65.03–71.44	288.58–311.11
	<i>T. lobiancoi</i>	Seasonal	10.50–11.00	20.26–25.63
	<i>T. tocantinensis</i>	Seasonal	50.65–52.77	165.37–190.64
	<i>T. uruguayensis</i>	Seasonal	20.35–21.30	42.13–44.55
	<i>T. tubulosa</i>	Seasonal	10.64–13.61	30.5–35.98
	<i>T. nucula</i>	Occasional	22.81	45.88
	<i>T. parva</i>	Occasional	7.25	21.89
	<i>T. butschlii</i>	Occasional	6.88–8.52	13.98–22.61
	<i>T. mortensenii</i>	Occasional	45.81	53.69
	<i>T. kofoidi</i>	Occasional	34–36.87	83.57–86.21
	<i>T. directa</i>	Seasonal	27.54–30.21	51.92–54.13
	<i>T. brasiliensis</i>	Occasional	23.77	39.56
	<i>T. amoyensis</i>	Occasional	39.58–41.67	55.87–58.36
	<i>T. radix</i>	Seasonal	61.98–63.77	245.39–311.86
	<i>T. orientalis</i>	Occasional	37.87	65.33
	<i>T. karajacensis</i>	Seasonal	32.67–35.88	54.18–58.44
	<i>T. gracilis</i>	Seasonal	39.7	9.34
	<i>T. parvula</i>	Occasional	41.69	18.3
	<i>T. urnula</i>	Occasional	22.9	5.3
	<i>T. rotundata</i>	Occasional	33.3	14.1
	<i>T. acuminata</i>	Occasional	41.1	22.65

(continued)

**Table 2.2** (continued)

Family	Species	Status	Oral diameter (μm)	Length (μm)
	<i>Agglomerated</i>			
Tintinnidiidae	<i>Leprotintinnus simplex</i>	Seasonal	18.72–46.87	57.59–184.79
	<i>L. nordqvisti</i>	Seasonal	24.66–30.41	54.89–59.21
	<i>Tintinnidium primitivum</i>	Seasonal	8.09–12.67	25.82–37.39
	<i>T. mucicola</i>	Seasonal	9.82–11.50	30.58–37.48
Codonellopsidae	<i>Codonellopsis schabi</i>	Occasional	34.88–38.24	67.41–70.32
	<i>Stenosemella ventricosa</i>	Seasonal	23.75	24.14
Dictyocystidae	<i>Wangiella dicollaria</i>	Occasional	27.75	14.43
	<i>Non-agglomerated</i>			
Xystonellidae	<i>Favella ehrenbergii</i>	Occasional	92.45–95.72	292.76–322.5
Tintinnidae	<i>Amphorellopsis acuta</i>	Seasonal	31.68–37.94	90.98–93.16
	<i>Eutintinnus</i> sp.	Seasonal	13.63	34.25
Metacylididae	<i>Metacylis mediterranea</i>	Occasional	28.3	37.25
	<i>Metacylis</i> sp.	Occasional	38.41–41.60	68.11–70.75
	<i>Helicostomella</i> sp.	Occasional	41.55	16.4

2.4.1 *Tintinnopsis beroidea* (Stein, 1867)



**Phylum:** Ciliophora

**Subphylum:** Intramacronucleata

**Class:** Spirotrichea

**Subclass:** Choreotrichia

**Order:** Tintinnida

**Family:** Codonellidae

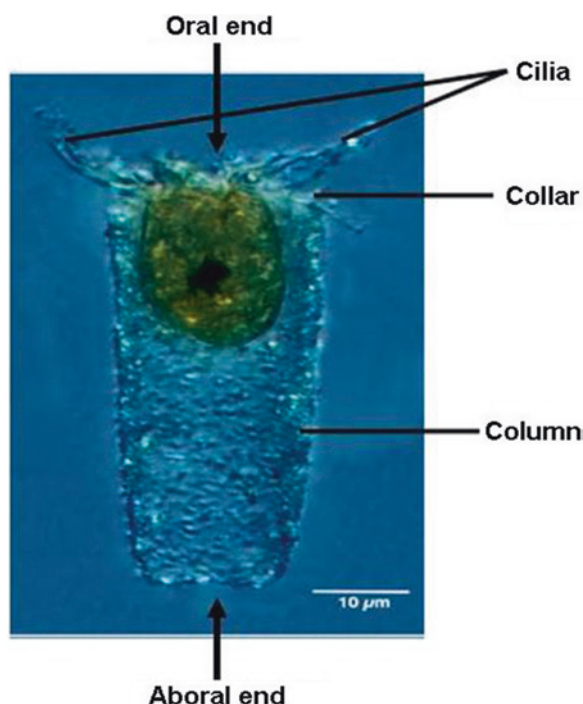
**Morphological characteristics** Lorica bullet-shaped, usually cylindrical in the anterior portion, aborally conical ( $75^{\circ}$ – $85^{\circ}$ ), oral rim ragged; aboral end acute or bluntly pointed; wall rather coarse, 0.03–0.04 oral diameters in thickness, without spiral structure.

**Measurements** The length varied throughout the year, depending on the season. The smallest loricae were observed in winter ranging from 13 to 17  $\mu\text{m}$  when the water temperature was  $\sim 21^{\circ}\text{C}$ . In contrast, during autumn and summer, the length of the lorica ranged between 75 and 118  $\mu\text{m}$  with temperatures  $\sim 31^{\circ}\text{C}$ . Oral diameters were variable, ranging between 12.29 and 30.13  $\mu\text{m}$ .

**Distribution** This species is cosmopolitan in nature, recorded mostly from Gulf of Mexico (Federal and Camp 2010), Newport (Town) (De Pauw 1975), Plymouth (Hayward and Ryland 1990). *Tintinnopsis beroidea* was registered in relatively low abundance in the northwestern waters of the Arabian Gulf. The species is considered the most common and dominant species in different coastal region of India.

**Comments** Despite the fact that this species appeared within a wide range of salinities (between 18 and 35 p.s.u.), it was often more abundant at salinities  $>25$  p.s.u. (Urrutxurtu 2004). This species is known to produce cysts that sink and deposit in the sediments until suitable environmental conditions trigger the return to a viable form. Since the light conditions have been found to play a critical role in the process, it is reasonable that the summer insolation will have induced a progressive excystment phase of *T. beroidea* on the shallow seabed (Sitran et al. 2009).

### 2.4.2 *Tintinnopsis minuta* (Wailes, 1925)



**Phylum:** Ciliophora

**Subphylum:** Intramacronucleata

**Class:** Spirotrichea

**Subclass:** Choreotrichia

**Order:** Tintinnida

**Family:** Codonellidae

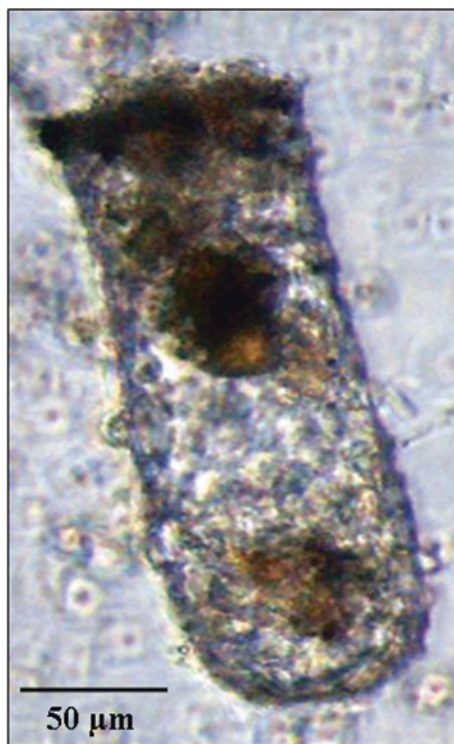
**Morphological characteristics** Lorica was not divided into collar and bowl. It is minute, conical shaped with a blunt end. Agglomeration was coarse and even.

**Measurements** Smallest tintinnids present in coastal regions of Sundarbans with a length ranging from 18.29 to 21.54 μm and an oral diameter ranging from 6.25 to 11.84 μm.

**Distribution** Recorded from Wimereux (Muller 2004), Gulf of Mexico (Federal and Camp 2010), Central Long Island Sound (Capriulo and Carpenter 1983) and Southeast coast of India (Godhantaraman 2002).

**Comments** This species was present almost throughout the year reaching in highest densities in May 2010 in Dhamakhali of Indian Sundarbans and April 2010 in Canning (250 ind l<sup>-1</sup>). Particularly in summer months, it accounted for 50–60 % of total tintinnid abundance (Godhantaraman 2001). The highest density was found when the water temperature was between 28 and 30 °C. It is generally a high temperature and wide salinity species (Godhantaraman 2001) and thus was observed in a broad range of salinity (6.3–26.6 p.s.u.).

### 2.4.3 *Tintinnopsis lohmani* (Laackmann, 1906)



**Phylum:** Ciliophora

**Subphylum:** Intramacronucleata

**Class:** Spirotrichea

**Subclass:** Choreotrichia

**Order:** Tintinnida

**Family:** Codonellidae

**Morphological characteristics** Lorica vase-like with a cylindrical collar; collar usually short, 0.16–0.40 μm of the total length; bowl expanding; aboral region rounded or convex conical; wall coarsely agglomerated, a few spiral turns appearing in the collar.

**Measurements** Length 35.77–75.2 μm; oral diameter 12.9–24.65 μm.

**Distribution** Abundant in the cool season in the waters surrounding Bubiyan Island, Kuwait (Yamani et al. 2011), rather it is more common in Indian coastal waters (Zipcodezoo.com).

**Comments** It is a seasonal species which was observed from early premonsoon and monsoon period (June–September), reaching in a highest concentration of 166 ind l<sup>-1</sup> in August 2012 at Gangasagar of Indian Sundarbans. Maximum abundance coincided with temperature ~28 °C and salinity within ~26 p.s.u.

#### 2.4.4 *Tintinnopsis cylindrica* (Daday, 1887)



**Phylum:** Ciliophora

**Subphylum:** Intramacronucleata

**Class:** Spirotrichea

**Subclass:** Choreotrichia

**Order:** Tintinnida

**Family:** Codonellidae

**Morphological characteristics** Lorica cylindrical, oral margin usually smooth without any flare. Aboral portion tapering ending with a stout aboral horn. The wall was very coarsely agglomerated.

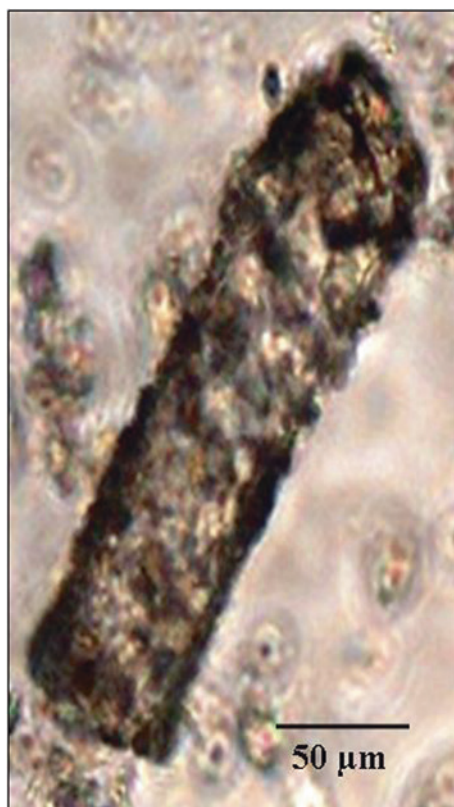
**Measurements** Lorica length varied from 288.58 to 311.11  $\mu\text{m}$ . Oral diameter remained relatively invariable, ranging from 65 to 70  $\mu\text{m}$ . The pedicel was hollow and normally appeared broken. Its length ranged between 15 and 40 mm, but normally it was  $\sim 25 \mu\text{m}$  long.



**Distribution** Recorded from Lake Nakaumi, China (Uye and Godhantaraman 2003), Cochin backwaters, south India (Jyothibabu et al. 2006) and Vellar estuary, south India (Godhanraman 2001).

**Comments** Generally observed in peak summer and early autumn, at temperatures between 21.7 and 32.8 °C. The highest abundance,  $\sim 75$  ind  $l^{-1}$ , was registered at Chemaguri (S<sub>4</sub>) of Indian Sundarbans, when salinity values were  $>21$  p.s.u.

#### 2.4.5 *Tintinnopsis lobiancoi* (Daday, 1887)



**Phylum:** Ciliophora

**Subphylum:** Intramacronucleata

**Class:** Spirotrichea

**Subclass:** Choreotrichia

**Order:** Tintinnida

**Family:** Codonellidae

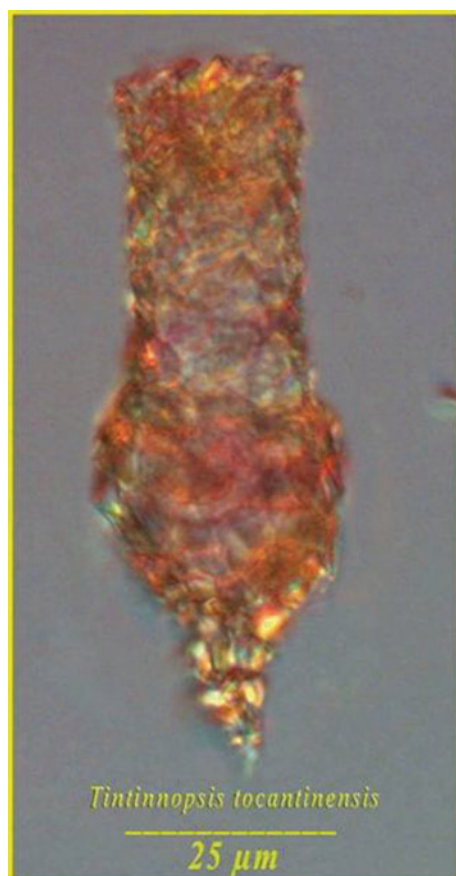
**Morphological characteristics** Lorica elongate, tubular, usually straight, oral rim ragged; aboral end rounded or shaped somewhat irregularly; wall agglomerated roughly, but comparatively thin without a spiral structure.

**Measurements** Length of the lorica ranged from 20.26 to 25.63  $\mu\text{m}$  and the oral diameter ranged from 10.50 to 11.0  $\mu\text{m}$

**Distribution** Predominant species in Asia recorded from Lake Nakaumi, Japan (Uye and Godhantaraman 2003), Northern China (Jiang et al. 2012) and Southeast coast of India (Godhantaraman 2002).

**Comments** It is a seasonal species which was observed from late monsoon to early postmonsoon period (August–October), reaching in a highest concentration of 100 ind  $\text{l}^{-1}$  in October 2010 at Lot 8 ( $S_3$ ) of Indian Sundarbans. The highest numerical density coincided with temperature between 31 and 33  $^{\circ}\text{C}$  and salinity within 15 p.s.u.

#### 2.4.6 *Tintinnopsis tocaninensis* (Kofoid and Campbell, 1929)



**Phylum:** Ciliophora

**Subphylum:** Intramacronucleata

**Class:** Spirotrichea

**Subclass:** Choreotrichia

**Order:** Tintinnida

**Family:** Codonellidae

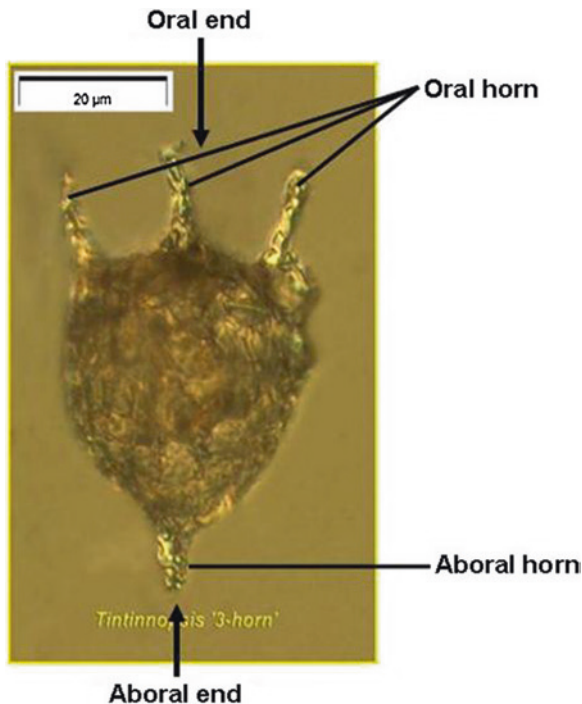
**Morphological characteristics** Lorica elongated, cylindrical anteriorly, expanding posteriorly, tapering distally into a stout aboral horn; dilated part not spiraled, aboral horn conical, obliquely or irregularly open at the tip.

**Measurements** Total length 165.37–190.64  $\mu\text{m}$ . Oral diameter 50.65–52.77  $\mu\text{m}$ .

**Distribution** Common in the northwestern waters of the Arabian Gulf (Yamani et al. 2011), Gulf of Mexico (Felder and Camp 2010), coastal waters of China (Jiang et al. 2012) and India (Naha Biswas et al. 2013).

**Comments** Seasonal species, generally found from late monsoon to early post-monsoon period. Maximum abundance (50 ind  $l^{-1}$ ) was found in Canning of Indian Sundarbans during August 2010 coincided with the water temperature of 30.7 °C and salinity 19.98 p.s.u.

#### 2.4.7 *Tintinnopsis uruguayensis* (Nie and Cheng, 1947)



**Phylum:** Ciliophora

**Subphylum:** Intramacronucleata

**Class:** Spirotrichea

**Subclass:** Choreotrichia

**Order:** Tintinnida

**Family:** Codonellidae

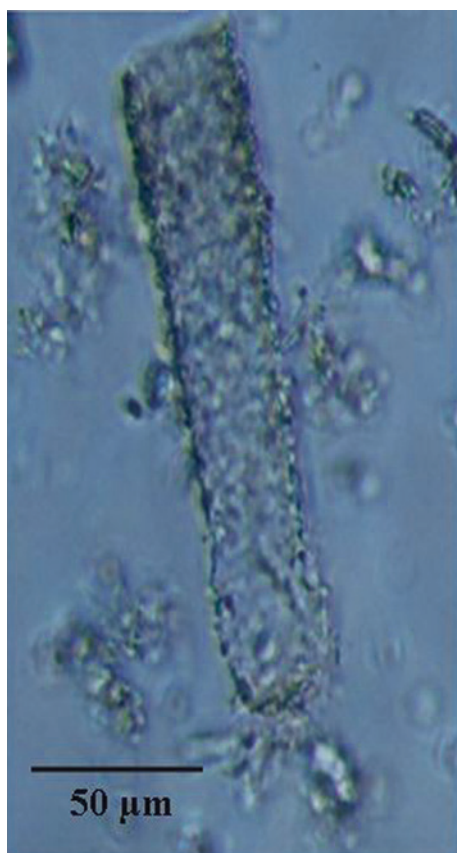
**Morphological characteristics** Lorica is divided into two parts—A very short column and a spherical bowl. Short aboral horn was present at the end of the lorica. Mouth flaring with two to three “horn”-like structures for which it was also denoted as *Tintinnopsis* 3 horn.

**Measurement** The length of the lorica did not vary much, ranging between 42.13 and 44.55  $\mu\text{m}$ . The oral diameter ranged from 20.35 to 21.30  $\mu\text{m}$ . The aboral horn was much short ranging between 3 and 4  $\mu\text{m}$ . Approximate ratio between length and oral diameter was  $\sim 1.0:2.0$ .

**Distribution** Recorded from Central Long Island Sound (Capriulo and Carpenter 1983), Cochin backwater, India (Jyothibabu et al. 2006) and Vellar estuary, India (Godhantaraman 2001).

**Comments** It is a postmonsoon species, found only during October–November of each year. The species seems to prefer the temperature between 28 and 30  $^{\circ}\text{C}$  and salinity below 15 p.s.u. The shape and size of this species varied slightly between different seasons.

#### 2.4.8 *Tintinnopsis tubulosa* (Levander, 1900)



**Phylum:** Ciliophora

**Subphylum:** Intramacronucleata

**Class:** Spirotrichea

**Subclass:** Choreotrichia

**Order:** Tintinnida

**Family:** Codonellidae

**Morphological characteristics** Lorica is differentiated into two regions: a cylindrical collar and a bowl, its length 2.1–3.5 oral diameters; collar 0.25–0.50 of the total length long; bowl somewhat inflated, broadest in the posterior 0.33–0.40 of the lorica, its greatest transdiameter 1.05–1.25 oral diameters; aboral region usually conical ( $75^{\circ}$ – $90^{\circ}$ ) to an acute distal end or rarely rounded with a blunt end; wall rather thin, but irregular in appearance, no spiral structure.

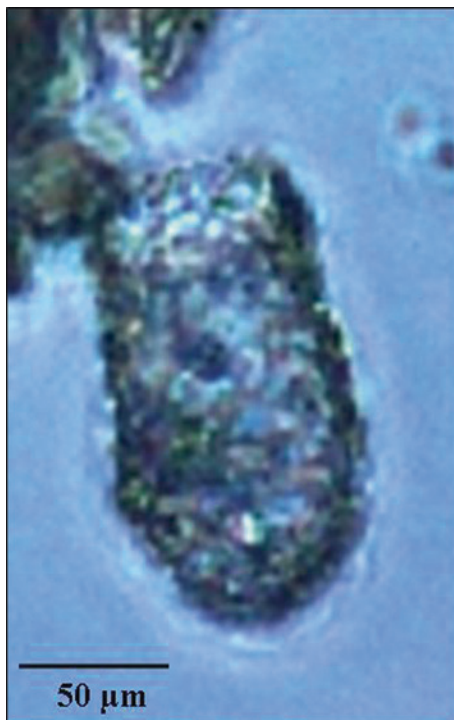
Lorica is differentiated into two regions—a long collar and a short bowl at the end. Oral flare absent. Bowl and column uniformly agglomerated.

**Measurement** The length of the lorica varied from 30.5 to 35.98  $\mu\text{m}$  and the oral diameter ranged from 10.64 to 13.61  $\mu\text{m}$ .

**Distribution** Recorded from Gulf of Mexico (Federal and Camp 2010), Japan, Portugal and Spain (Zipcodezoo.com). This species is highly common in Indian coastal waters found from Southeast coast of India (Godhantaraman 2002), Cochin backwaters (Jyothibabu et al. 2008), Bahuda estuary, East coast of India (Mishra and Panigrahy 1999), Porto novo region, India (Krishnamurthy and Santhanam 1975).

**Comments** The species was recorded mostly during postmonsoon followed by premonsoon. The maximum abundance (100 ind  $\text{l}^{-1}$ ) was noticed during February 2010 at Dhamakhali ( $S_{12}$ ) of Indian Sundarbans when the temperature was  $25^{\circ}\text{C}$  and the salinity was 14.51 p.s.u.

### 2.4.9 *Tintinnopsis nucula* (Fol, 1884)



**Phylum:** Ciliophora

**Subphylum:** Intramacronucleata

**Class:** Spirotrichea

**Subclass:** Choreotrichia

**Order:** Tintinnida

**Family:** Codonellidae

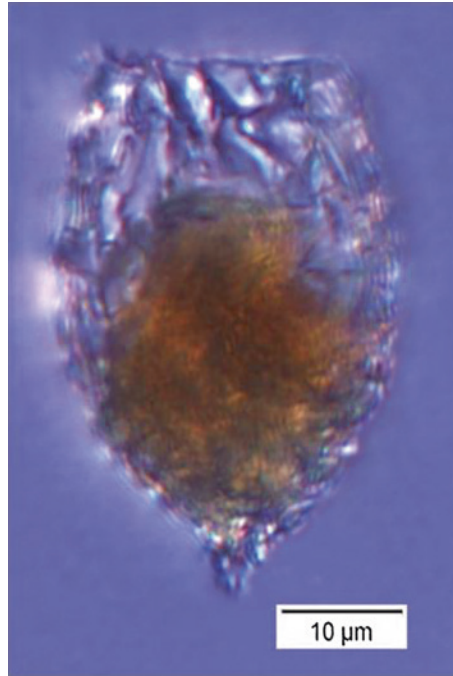
**Morphological characteristics** Lorica oval shaped with rounded aboral end. Agglomeration of the lorica was even and coarse. Mouth without oral flare.

**Measurement** Lorica length was found to be  $\sim 45.8 \mu\text{m}$ , and oral diameter was around  $23 \mu\text{m}$ .

**Distribution** Recorded from Wimereux, Belgium (Muller 2004), Southeast coast of India (Godhantaraman 2002).

**Comments** Occasional species found only 2–3 times throughout the study period. Maximum abundance ( $50 \text{ ind l}^{-1}$ ) was recorded during November 2010 at Canning ( $S_3$ ) of Indian Sundarbans when the temperature and salinity were  $26.75^\circ\text{C}$  and  $14.9 \text{ p.s.u.}$ , respectively.

#### 2.4.10 *Tintinnopsis parva* (Merkle, 1909)



**Phylum:** Ciliophora

**Subphylum:** Intramacronucleata

**Class:** Spirotrichea

**Subclass:** Choreotrichia

**Order:** Tintinnida

**Family:** Codonellidae

**Morphological characteristics** Lorica small, widest in middle, narrowing slightly to mouth, more sharply to pointed aboral end.

**Measurements** It is a comparatively smaller species with the length of 21.89 μm, and the oral diameter was 7.25 μm.

**Distribution** Recorded from Wimereux (Muller 2004), northwestern waters of the Arabian Gulf (Yamani et al. 2011) and Southeast coast of India (Godhantaraman 2002).

**Comment** Found in comparatively cool season during November–January 2011 mainly in Canning of Indian Sundarbans. Highest abundance reached up to 50 ind l<sup>-1</sup> when the water temperature was ~19.01 °C and the salinity was 15.3 p.s.u.



### 2.4.11 *Tintinnopsis butschlii* (Daday, 1887)



**Phylum:** Ciliophora

**Subphylum:** Intramacronucleata

**Class:** Spirotrichea

**Subclass:** Choreotrichia

**Order:** Tintinnida

**Family:** Codonellidae

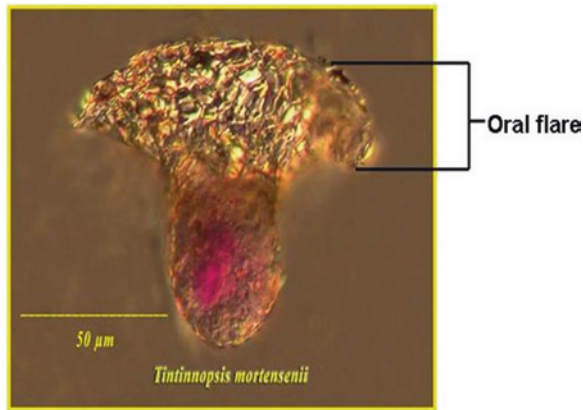
**Morphological characteristics** Lorica cylindrical in shape with a medium-sized oral flare. Aboral end sharply pointed without any horn. Agglomeration was coarse and even.

**Measurement** Lorica length ranged from 13.98 to 22.61 μm, whereas the LOD did not vary much, ranging from 6.88 to 8.5 μm.

**Distribution** Recorded from Indian coastal waters.

**Comments** Occasional species found to prefer the premonsoon season with temperature ~30–32 °C and salinity >20 p.s.u. Maximum abundance (100 ind l<sup>-1</sup>) was recorded at Lot 8 of Indian Sundarbans during March 2010.

#### 2.4.12 *Tintinnopsis mortensenii* (Schmidt, 1901)



**Phylum:** Ciliophora

**SubphylumL:** Intramacronucleata

**Class:** Spirotrichea

**Subclass:** Choreotrichia

**Order:** Tintinnida

**Family:** Codonellidae

**Morphological characteristics** Lorica bell-shaped with slightly concave collar, very wide, horizontal oral funnel, and rounded aboral end.

**Measurements** Length 45.81 µm; oral diameter 53.69 µm;

**Distribution** Commonly recorded from the Gulf of Mexico (Felder and Camp 2010), northwestern waters of the Arabian Gulf (Yamani et al. 2011), Southeast coast of India (Godhantaraman 2002), Cochin backwater (Jyothibabu et al. 2006; Mishra and Panigrahy 2006).

**Comments** Absolutely occasional in Sundarbans coastal region, found only twice throughout the study period. The maximum abundance reached to 75 ind l<sup>-1</sup> in March 2010 at Lot 8 of Indian Sundarbans which coincided with ~32.85 °C water temperature and ~21.3 p.s.u salinity.

### 2.4.13 *Tintinnopsis kofoidi* (Hada, 1932)



**Phylum:** Ciliophora

**Subphylum:** Intramacronucleata

**Class:** Spirotrichea

**Subclass:** Choreotrichia

**Order:** Tintinnida

**Family:** Codonellidae

**Morphological characteristics** Lorica bullet-shaped, usually cylindrical in the anterior 0.6–0.7 of the total length, aboral end opened. Oral rim ragged; wall rather coarse, without spiral structure. A small horn present at the end of the lorica.

**Measurement** Length of the lorica varied from 83.57 to 86.21 μm and the oral diameter ranged from 34 to 36.87 μm.

**Distribution** Recorded from Florida (Casper 1972), Gulf of Mexico (Felder and Camp 2010), South Atlantic (Balech 1951), Pichavaram mangrove, India (Godhantaraman 1994).

**Comments** This species was found to exist from late postmonsoon (February) to early premonsoon (around mid-April) period. But it was an occasional species in this specific mangrove wetland, and the maximum abundance ( $75 \text{ ind l}^{-1}$ ) was recorded during March 2010 at Lot 8 of Indian Sundarbans when the temperature was  $\sim 32.85^\circ\text{C}$  and the salinity was 21.3 p.s.u.

#### 2.4.14 *Tintinnopsis directa* (Hada, 1932)



**Phylum:** Ciliophora

**Subphylum:** Intramacronucleata

**Class:** Spirotrichea

**Subclass:** Choreotrichia

**Order:** Tintinnida

**Family:** Codonellidae

**Morphological characteristics** The species is characterized by the presence of a moderately erect lorica which is campanulate anteriorly and subspherical posteriorly. The lorica is about 1.7 oral diameters in length. Agglomeration is light on the

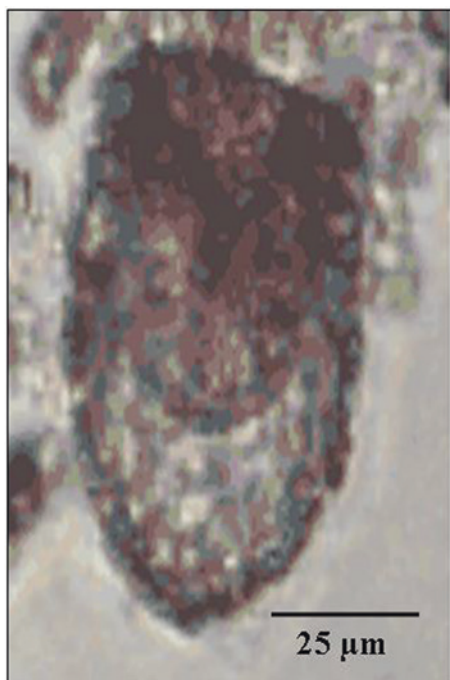
cylindrical part of the lorica and fairly pronounced on the bowl. Oral rim irregular, flaring suboral region somewhat tapering, conical, laid up with about 6 spiral turns, narrowest at the basal portion of the subcylindrical part, wall rather coarse in the posterior part at the thickest portion of the aboral region, aboral end hemispherical; suboral region somewhat tapering, conical ( $5^{\circ}$ – $10^{\circ}$ ), laid up with about 6 spiral turns, narrowest at the basal portion of the subcylindrical part, its smallest transdiameter 0.68–0.82 of the oral diameter posterior region subspherical, with a rounded aboral end, 0.80–0.95 oral diameters in transdiameter; wall rather coarse in the posterior part, about 0.035 diameters in thickness at the thickest portion of the aboral region.

**Measurements** Total length and the oral diameter varied from 27.54 to 30.21  $\mu\text{m}$  and from 51.92 to 54.13  $\mu\text{m}$ , respectively.

**Distribution** Found to be common in Gulf of Mexico (Federal and Camp 2010), in the northwestern waters of the Arabian Gulf, in the central region of the Gulf, mainly along the Iranian coast (Al Yamani et al. 2011), Southeast coast of India (Godhantaraman 2002), Cochin backwaters (Jyothibabu et al. 2008) and Bahuda estuary (Mishra and Panigrahy 1999).

**Comments** It is a premonsoon species recorded maximum during March 2010 when the temperature was  $32.85^{\circ}\text{C}$  and the salinity was 21.3 p.s.u.

#### 2.4.15 *Tintinnopsis brasiliensis* (Kofoid and Campbell, 1929)



**Phylum:** Ciliophora  
**Subphylum:** Intramacronucleata  
**Class:** Spirotrichea  
**Subclass:** Choreotrichia  
**Order:** Tintinnida  
**Family:** Codonellidae

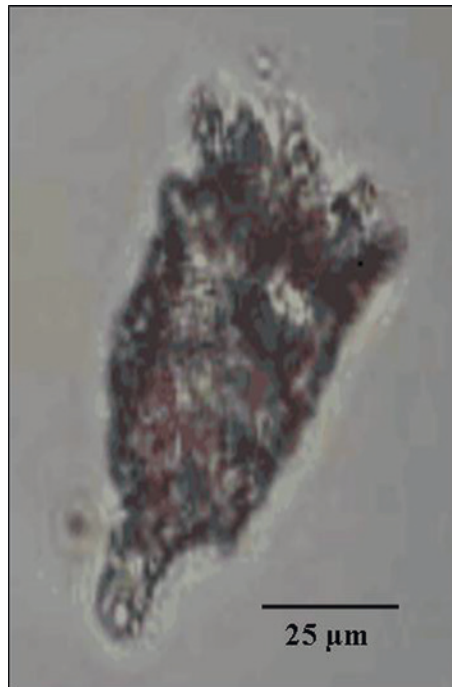
**Morphological characteristics** Body generally conical in shape, truncate at the anterior end, the buccal area is wide. *Tintinnopsis directa* (Hada, 1932) posterior portion narrowed and always forming a short stalk, with which the cell adheres to the inside of the lorica. Buccal cavity prominent and deep. Cilia of membranelles. Shape rather constant, subconical with posterior portion blunt to slightly tapering, without collar margin of lorica opening with some particles forming an uneven edge. Wall thin and opaque, with coarse surface due to outer covering, which is composed of many large, irregularly shaped mineral-like particles.

**Measurements** Length 23.77  $\mu\text{m}$  and oral diameter 39.56  $\mu\text{m}$ .

**Distribution** Recorded from Taiping Cape of Qingdao, China (ShengfangTsai et al. 2006).

**Comments** *T. brasiliensis* was registered during premonsoon (April 2010) at Lot 8 of Indian Sundarbans, when the temperature and salinity were 31 °C and 20.1 p.s.u, respectively.

#### 2.4.16 *Tintinnopsis amoyensis* (Nie, 1934)



**Phylum:** Ciliophora

**Subphylum:** Intramacronucleata

**Class:** Spirotrichea

**Subclass:** Choreotrichia

**Order:** Tintinnida

**Family:** Codonellidae

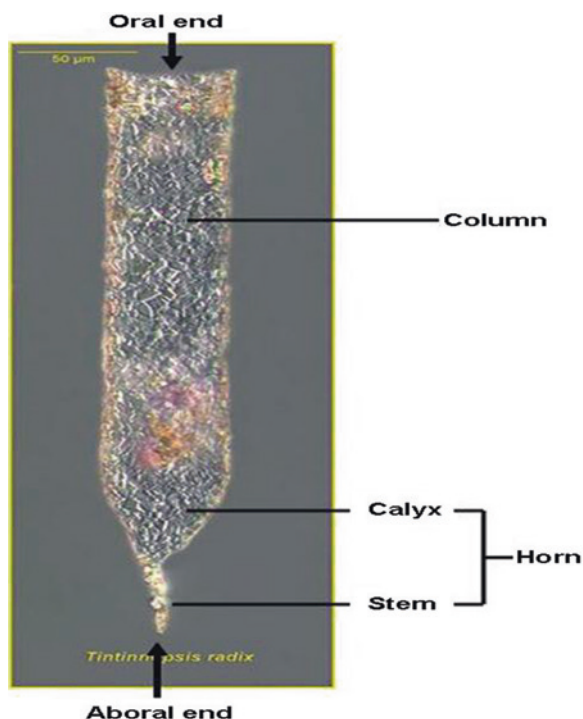
**Morphological characteristics** Lorica thistle-funnel shaped, oral rim very roughened; collar flaring, inverted conical; bowl subcylindrical anteriorly, convex conical at aboral region; aboral horn stout, short, obliquely or irregularly opened at the tip; wall thick and coarsely agglomerated.

**Measurements** Length of the lorica varied from 55.87 to 58.36  $\mu\text{m}$  and the oral diameter ranged from 39.58 to 41.67  $\mu\text{m}$ .

**Distribution** Scarce in Indian coastal waters.

**Comments** *T. amoyensis* is a small species, and it seems to be more closely related to *T. meunieri* Kofoid and Campbell; however, the lorica of the present species is more slender in form and much smaller in size. Species was registered during March 2010 at the site Lot 8 of Indian Sundarbans.

#### 2.4.17 *Tintinnopsis radix* (Imhof, 1886)





**Phylum:** Ciliophora

**Subphylum:** Intramacronucleata

**Class:** Spirotrichea

**Subclass:** Choreotrichia

**Order:** Tintinnida

**Family:** Codonellidae

**Morphological characteristics** Lorica elongate, slender, tubular, oral rim generally entire (smooth and round) or sometimes irregular; bowl long, cylindrical; aboral region tapering gradually into an aboral horn, usually more or less curved, with an irregularly formed aboral opening typically set laterally as gouged, wall thin and fragile, with a variable spiral structure.

**Reported measurements** The range of total length varied from 245.39 to 311.86  $\mu\text{m}$ . Oral diameter ranged from 61.98 to 63.77  $\mu\text{m}$ .

**Distribution** *Tintinnopsis radix* is common and abundant at Gulf of Mexico (Federal and Camp 2010), Rijeka Bay, Croatia (Zavodnik and Kovacic 2000), all the studied locations in the Arabian Gulf, from Bubiyan Island in the north to the Strait of Hormuz in the south (Yamani et al. 2011) and all studied Indian Coastal waters from Porto Novo region east coast of India (Krishnamurthy and Santhanam 1975) to Parangipettai Southeast coast of India (Godhantaraman 2002).

**Comments** It is completely a postmonsoon species which was noticed for the first time in Gangasagar of Indian Sundarbans during November 2010 coinciding with a sudden outburst of phytoplankton population dominated by a centric diatom *Hemidiscus hardmannianus*. The highest abundance of this species was found to be 200 ind  $\text{l}^{-1}$  during February 2010 which coincided with 23.4 °C water temperature and 21.8 p.s.u salinity.

### 2.4.18 *Tintinnopsis orientalis* (Kofoid and Campbell, 1929)



**Phylum:** Ciliophora

**Subphylum:** Intramacronucleata

**Class:** Spirotrichea

**Subclass:** Choreotrichia

**Order:** Tintinnida

**Family:** Codonellidae

**Morphological characteristics** Lorica with distinct collar; collar 1/4–1/3 length of the bowl, convex outwardly; bowl acorn shaped, widest near or shortly below its middle; aboral end baggy, not flattened, with or without a faintly emergent point.

**Reported measurements** Length 65.33 μm; oral diameter 37.87 μm.

**Distribution** *Tintinnopsis orientalis* is relatively common in the northwestern waters of the Arabian Gulf during the warm season (Yamani et al. 2011) and Northern China (Jiang et al. 2011).

**Comments** Occasional species found only once during March 2010 in Lot 8 of Indian Sundarbans with an abundance of 75 ind l<sup>-1</sup>.

#### 2.4.19 *Tintinnopsis karajacensis* (Brandt, 1896)



**Phylum:** Ciliophora

**Subphylum:** Intramacronucleata

**Class:** Spirotrichea

**Subclass:** Choreotrichia

**Order:** Tintinnida

**Family:** Codonellidae

**Morphological characteristics** Lorica capsular; oral margin roughened; bowl cylindrical in the margin part, rounded in the aboral end; wall coarsely agglomerated, often with a spiral structure in the anterior region of the lorica; aboral end rounded or disfigured as the result of irregularly agglomerated particles; wall coarse, having several slight spiral turns in the anterior half.

**Reported measurements** Length 60–172 μm; oral diameter 30–64 μm; approximate ratio L/oral diameter 2.0–2.7

**Distribution** *Tintinnopsis karajacensis* was registered in relatively low abundance in the northwestern Arabian Gulf (Yamani et al. 2011), Lake Nakaumi, Japan (Uye and Godhantaraman 2003), Central Long Island Sound (Capriulo and Carpenter 1983), Vellar estuary, India (Godhantaraman 2001) and Nervion estuary, Spain (Urrutxurtu 2004).

**Comments** This is an occasional species which differs from *T. directa* in the absence of the oral flare and the posterior inflation, from *T. cochleata* in less extensive spiral organization and in roughened agglomeration, from *T. lobiancoi* in the shorter lorica, and from *Tintinnopsis rotundata* in more slender proportions and in the shape of the aboral end.

#### 2.4.20 *Tintinnopsis gracilis* (Kofoid and Campbell, 1929)



**Phylum:** Ciliophora

**Subphylum:** Intramacronucleata

**Class:** Spirotrichea

**Subclass:** Choreotrichia

**Order:** Tintinnida

**Family:** Codonellidae

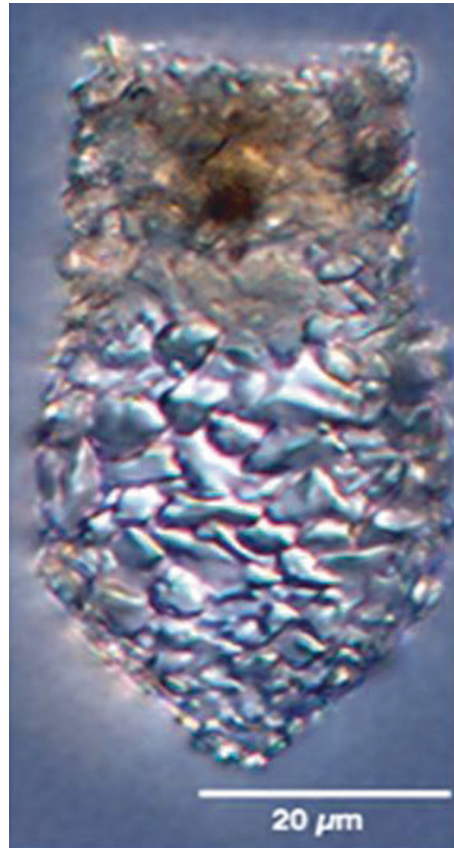
**Morphological characteristics** Lorica finger-shaped, oral margin usually comparatively smooth; bowl tubular, sometimes slightly swollen in the posterior one-third of the bowl; aboral region convex conical with a blunt distal end; wall coarsely agglomerated without a spiral structure.

**Measurements** Length 105–125  $\mu\text{m}$ ; oral diameter 28–34  $\mu\text{m}$ ; approximate ratio of length and oral diameter was found to be 3.3–4.0.

**Distribution** *Tintinnopsis gracilis* is one of the most common and abundant species in the Northwestern Arabian Gulf and in the central region of the Gulf, mainly along the Iranian coast (Al Yamani et al. 2011), Gulf of Mexico (Federal and Camp 2010), Asia (Japan) [Zipcodezoo.com] and Indian coastal waters.

**Comments** The species differs from *T. karajacensis* Brandt in the conical aboral region instead of the round.

#### 2.4.21 *Tintinnopsis parvula* (Jørgensen, 1912)



**Phylum:** Ciliophora  
**Subphylum:** Intramacronucleata  
**Class:** Spirotrichea  
**Subclass:** Choreotrichia  
**Order:** Tintinnida  
**Family:** Codonellidae

**Morphological characteristics** Lorica small, slightly expanded below a cylindrical anterior region, pointed aborally.

**Measurements** Length 51–70  $\mu\text{m}$ ; oral diameter 18.3–29  $\mu\text{m}$ .

**Distribution** Common and abundant in the northwestern waters of the Arabian Gulf and in the waters surrounding Bubiyan Island.

**Comments** Lorica more pointed aborally than *T. nucula* and more expanded than *T. beroidea*. *T. parvula* is an occasional species, found during early monsoon period with a maximum abundance of 50 ind  $\text{l}^{-1}$  at the site Gangasagar ( $S_7$ ) of Indian Sundarbans.

#### 2.4.22 *Tintinnopsis urnula* (Meunier, 1910)



**Phylum:** Ciliophora

**Subphylum:** Intramacronucleata

**Class:** Spirotrichea

**Subclass:** Choreotrichia

**Order:** Tintinnida

**Family:** Codonellidae

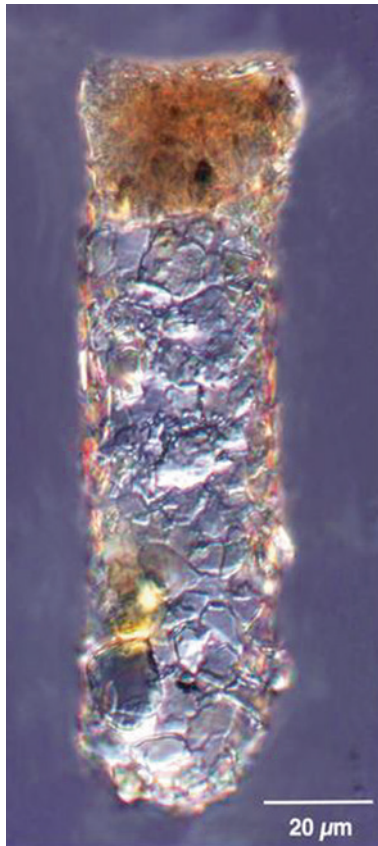
**Morphological characteristics** Lorica campanulate; oral rim ragged; bowl constricted at the suboral 1/3 of the total length, sides concave in the anterior 2/3 of the lorica; aboral end subacute; wall more or less coarse, with very slight spiral organization in the suboral part.

**Measurement** Length 58.2  $\mu\text{m}$ ; oral diameter 41.1  $\mu\text{m}$ .

**Distribution** The species is very much abundant in East China Sea.

**Comments** Differs from *T. beroidea* Stein in the presence of the suboral constriction. *Tintinnopsis urnula* is very rare in HRE water and documented only at Lot no. 8 of Indian Sundarbans with an abundance of 83 ind  $l^{-1}$  during premonsoon (June 2012) coinciding by moderate temperature (30 °C) and salinity (11.5 p.s.u).

#### 2.4.23 *Tintinnopsis rotundata* (Kofoid and Campbell, 1929)



**Phylum:** Ciliophora

**Subphylum:** Intramacronucleata

**Class:** Spirotrichea



**Subclass:** Choreotrichia

**Order:** Tintinnida

**Family:** Codonellidae

**Morphological characteristics** Lorica cylindrical with hemispherical aboral end; oral margin usually ragged; wall comparatively thin, thickly encrusted with particles, spiral structure invisible.

**Measurement** Length 62  $\mu\text{m}$ ; oral diameter 38  $\mu\text{m}$ ;

**Distribution** *Tintinnopsis rotundata* was registered in low abundance in the northwestern waters of the Arabian Gulf.

**Comments** This species differs from the typical form of *T. karajacensis* Brandt in the possession of the thin wall without spiral structure. *Tintinnopsis rotundata* was registered in low abundance (41 ind  $\text{l}^{-1}$ ) in the high-energy zone Gangesagar of Indian Sundarbans during January 2013 assessed by low temperature (19 °C) and high salinity (22 p.s.u).

#### 2.4.24 *Tintinnopsis acuminata* (Daday, 1887)



**Phylum:** Ciliophora

**Subphylum:** Intramacronucleata

**Class:** Spirotrichea

**Subclass:** Choreotrichia

**Order:** Tintinnida

**Family:** Codonellidae

**Morphological characteristics** Lorica tubular, oral rim ragged, aboral region in lower 1/4 conical, aboral end blunt. Wall without spiral structure, with sparse agglomeration. Oral region has no oral funnel.

**Measurement** Length 63.75  $\mu\text{m}$ ; oral diameter 22.65  $\mu\text{m}$ .

**Distribution** *Tintinnopsis acuminata* was registered in relatively low abundance in the northwestern Arabian Gulf.

**Comments:** *Tintinnopsis acuminata* was registered only in Gangasagar of Indian Sundarbans with a maximum abundance of 12 ind  $\text{l}^{-1}$  during monsoon period (October 2012) coincided by temperature  $<30^\circ\text{C}$  and salinity  $<20$  p.s.u.

#### 2.4.25 *Leprotintinnus simplex* (Schmidt, 1901)



**Phylum:** Ciliophora

**Subphylum:** Intramacronucleata

**Class:** Spirotrichea

**Subclass:** Choreotrichia

**Order:** Tintinnida

**Family:** Tintinnidiidae

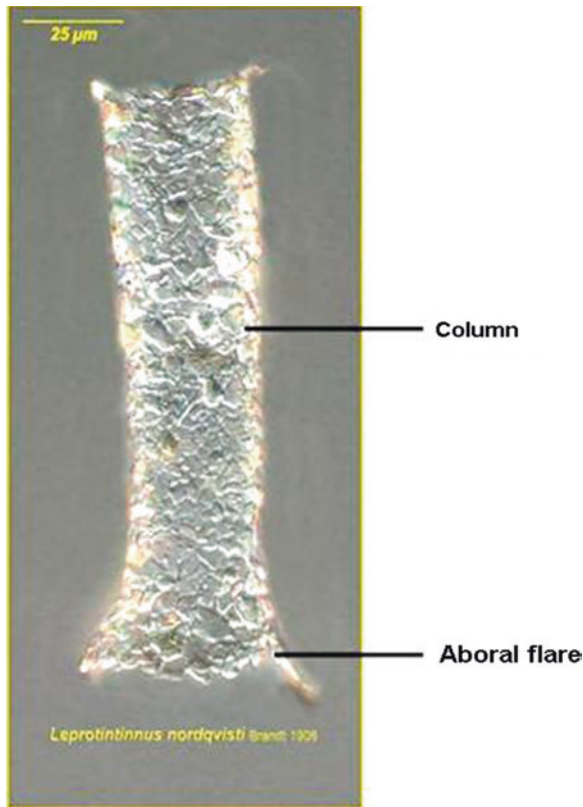
**Morphological characteristics** Lorica soft and fragile, cylindrical, never with flaring oral or aboral ends sometimes slightly narrowing toward the aboral end. Wall often shows a weak spiral structure, more pronounced at aboral half of lorica, and it usually depends both on the shape of the wall and of the distribution of particles. Agglomeration is relatively poor and even at the oral part of lorica and denser at the aboral part.

**Measurement** Total body length ranges from 57.59 to 184.79  $\mu\text{m}$ , and the oral diameter ranges from 18.72 to 46.87  $\mu\text{m}$ . Lorica is very fragile, especially in the aboral part, such that the minimum size of this tintinnid is not identifiable. Usually, there are many fragments of loricas in the samples (loricas could be broken during sampling or transportation), which makes it difficult to determine the real size of tintinnids.

**Distribution** Recorded mostly from India, especially from Parangipettai, Southeast coast of India (Godhantaraman 2002) and Cochin backwaters, Southwest coast of India (Jyothibabu et al. 2008). It was also found to be abundant in northern waters of Kuwait of Boubiyan Island but only in winter and early spring. In spring, this tintinnid produces one or two cysts and survives the warm period as a resting stage (Al Yamani et al. 2011).

**Comments** Unlike all other species, *L. simplex* showed its highest abundance during monsoon and early postmonsoon and differs from *L. nordquisti* in its absence of the aboral funnel and longer lorica. Its maximum abundance reached up to 450 ind  $\text{l}^{-1}$  in November 09 in Dhamakhali ( $S_2$ ) of Indian Sundarbans with 26.7 °C temperature and 5.4 p.s.u salinity.

#### 2.4.26 *Leprotintinnus norqvisti* (Kofoid and Campbell, 1929)



**Phylum:** Ciliophora

**Subphylum:** Intramacronucleata

**Class:** Spirotrichea

**Subclass:** Choreotrichia

**Order:** Tintinnida

**Family:** Tintinnidiidae

**Morphological characteristics** Lorica consisting of a tubular shaft and an inverted funnel-shaped aboral flare, oral rim irregular, usually slightly flaring; shaft more or less tapering, expanding near the posterior region to form a distinct aboral conical flare; aboral margin very ragged; wall showing a faint spiral structure, made of rather scarce particles aggregated more thickly on the surface of the aboral flare than on that of the shaft.

**Measurements:** Length ranged from 54.89 to 59.21  $\mu\text{m}$  and the LOD ranged from 24.66 to 30.41  $\mu\text{m}$ .

**Distribution** Common in Kuwait waters and around Bubiyan Island. This species occurred along the Iranian coast with southeastern direction (Yamani et al. 2011) and from Southeast coast of India (Parangipettai) (Godhantaraman 2002).

**Comments** Distribution and abundance of this species are very much related to the abundance of phytoplankton of that particular site. Generally, it is a stenothermal and stenohaline species (Godhantaraman and Uye 2003). Maximum abundance ( $100 \text{ ind l}^{-1}$ ) was recorded from Gangasagar ( $S_5$ ) of Indian Sundarbans during February 2010.

#### 2.4.27 *Tintinnidium primitivum* (Busch, 1923)



**Phylum:** Ciliophora

**Subphylum:** Intramacronucleata

**Class:** Spirotrichea

**Subclass:** Choreotrichia

**Order:** Tintinnida

**Family:** Tintinnidiidae

**Morphological characteristics** Lorica rod shaped with an open aboral end. Soft and sparse agglomerated particles were included inside lorica.

**Measurement** The length of the lorica varied widely ranging from 25.82 to 37.39  $\mu\text{m}$  and the oral diameter ranged from 8.09 to 12.67  $\mu\text{m}$ . Highest lorica length (57.61  $\mu\text{m}$ ) was found in premonsoon (March 2010) followed by postmonsoon (Av:  $36.72 \pm 10.3 \mu\text{m}$ ) and monsoon (Av:  $25.2 \pm 9.73 \mu\text{m}$ ).

**Distribution** Recorded from Gulf of Mexico (Federal and Camp 2010) and Pichavaram mangrove, India (Godhantaraman 1994).

**Comments** This species was mostly frequent during postmonsoon season, but the maximum abundance 250 ind  $l^{-1}$  was recorded during May 2010 at the site Canninig (S<sub>3</sub>) of Indian Sundarbans when the temperature was 30.5 °C and the salinity was 25.8 p.s.u.

#### 2.4.28 *Tintinnidium mucicola* (Claparède and Lachmann, 1858) Daday, 1887



**Phylum:** Ciliophora

**Subphylum:** Intramacronucleata

**Class:** Spirotrichea

**Subclass:** Choreotrichia

**Order:** Tintinnida

**Family:** Tintinnidiidae

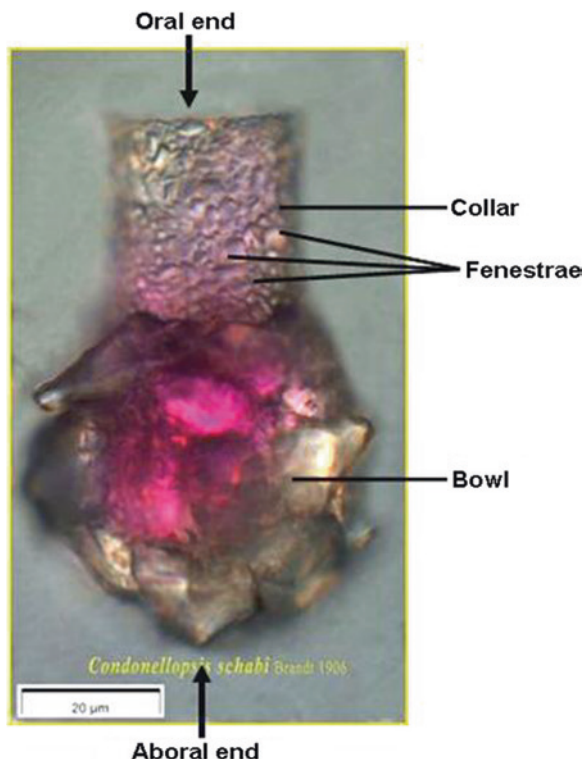
**Morphological characteristics** Lorica was not divided into collar and bowl. It is large, conical shaped with a blunt end. Agglomeration is sparse. No aboral horn present.

**Measurement** Body length varied from 30.58 to 37.48 μm and the LOD ranged from 9.82 to 11.50 μm. Ratio between length and oral diameter was ~1.0:3.25.

**Distribution** Found from Gulf of Mexico (Federal and Camp 2010) and Ekraianian exclusive economic zone (Alexandrov and Korshenko 2007).

**Comments** It was a typical postmonsoon species recorded maximum abundance (100 ind  $l^{-1}$ ) during December 2010 at the site Dhamakhli of Indian Sundarbans. It prefers temperature range  $<25^{\circ}C$  and salinity between 13 and 15 p.s.u.

#### 2.4.29 *Codonellopsis schabi* (Brandt, 1906) Kofoid and Campbell, 1929



**Phylum:** Ciliophora

**Subphylum:** Intramacronucleata

**Class:** Spirotrichea

**Subclass:** Choreotrichia

**Order:** Tintinnida

**Family:** Codonellopsidae

**Morphological characteristics** Lorica divided into a collar and a medium-sized bowl; collar with a somewhat flaring rim, slightly bulging near its middle, usually lower than the bowl, its height 0.22–0.34 of the total length, composed of 4–11 spiral turns with a few elliptical fenestrae; bowl generally ovate, aboral region convex conical; aboral end usually round or rarely bluntly pointed; wall of the bowl thick, coarsely agglomerated.

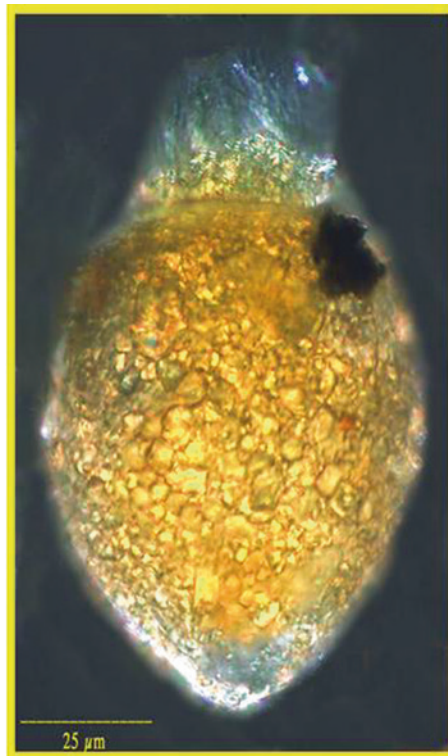


**Measurements** Length and oral diameter varied from 65 to 95  $\mu\text{m}$  and 29 to 32  $\mu\text{m}$ , respectively. Length of the collar was 14–32  $\mu\text{m}$ ; greatest diameter of the bowl 43–65  $\mu\text{m}$ . Approximate ratio between length and oral diameter was 2.2–3.2.

**Distribution** *Codonellopsis schabi* is common in the northwestern and central regions of the Arabian Gulf and in the Strait of Hormuz, with high abundance in the central region of the Gulf (Al Yamani et al. 2011), Gulf of Mexico (Federal and Camp 2010), and India (Godhantaraman 2002).

**Comments** Occasional species in Sundarbans mangrove wetland found only once during March 2010 associated with a monospecific bloom of *T. beroidea*.

#### 2.4.30 *Stenosemella ventricosa* (Claparède and Laachmann, 1858) Jörgensen, 1924



**Phylum:** Ciliophora

**Subphylum:** Intramacronucleata

**Class:** Spirotrichea

**Subclass:** Choreotrichia

**Order:** Tintinnida

**Family:** Codonellopsidae

**Morphological characteristics** Lorica was divided into two parts—Collar and bowl both are short in length. Gutter absent between bowl and collar.

**Measurement** Lorica length found to be  $\sim 24.14 \mu\text{m}$ , while the LOD is also of almost similar size ( $23.7 \mu\text{m}$ ).

**Distribution** Recorded from Gulf of Mexico (Federal and Camp 2010), Rijeca Bay (Zavodnik and Covacic 2000), Russian part of the black sea, Ukrainian exclusive economic zone Bulgaria (Alexandrov and Korshenko 2007) and Southeast coast of India (Godhantaraman 2002).

**Comments** Appeared mostly during postmonsoon period followed by monsoon when the temperature was between 11 and 16 °C. Although recorded in salinity values  $\sim 9$  p.s.u, the abundance was maximum  $>17$  p.s.u. It had an enlargement of the oral region formed by small particles attached to the hyaline collar. Maximum abundance ( $82 \text{ ind l}^{-1}$ ) was recorded during January 2011 at Dhamakhali of Indian Sundarbans.

#### 2.4.31 *Favella ehrenbergii* (Claparède and Laachmann, 1858)



**Phylum:** Ciliophora

**Subphylum:** Intramacronucleata

**Class:** Spirotrichea

**Subclass:** Choreotrichia

**Order:** Tintinnida

**Family:** Xystonellidae

**Morphological characteristics** Lorica long and cylindrical, wall thick, bowl sometimes slightly expanded below middle, rounded below and joined by wings to a short blunt, pedicel. Spiral turns were present sometimes suborally.

**Reported measurements** Total length 145–400  $\mu\text{m}$ . Oral diameter 54–124  $\mu\text{m}$ . Approximate ratio LOD 2.4–4.2.

**Distribution** Wide species recorded from Gulf of Mexico (Federal and Camp 2010), Rijeca Bay (Zavodnik and Covacic 2000), Romanian exclusive economic zone, Russian part of the black sea, Ukrainian exclusive economic zone Bulgaria (Alexandrov and Korshenko 2007), Southeast coast of India (Godhantaraman 2002) and Cochin back waters (Jyothibabu et al. 2008), India. But it was registered in low abundance in the northwestern waters of Arabian Gulf (Yamani et al. 2011).

**Comments** This species owned the largest LOD among all, and the existence of the second tintinnid inside *F. ehrenbergii* in the figure proves that it feeds not only upon phytoplankton but on smaller tintinnid also. This could be considered as an occasional species recorded only two times during the entire study period, coinciding with algal blooms in coastal regions of Sundarbans.

### 2.4.32 *Amphorellopsis acuta* (Schmidt, 1901)



**Phylum:** Ciliophora

**Subphylum:** Intramacronucleata

**Class:** Spirotrichea

**Subclass:** Choreotrichia

**Order:** Tintinnida

**Family:** Tintinnidae

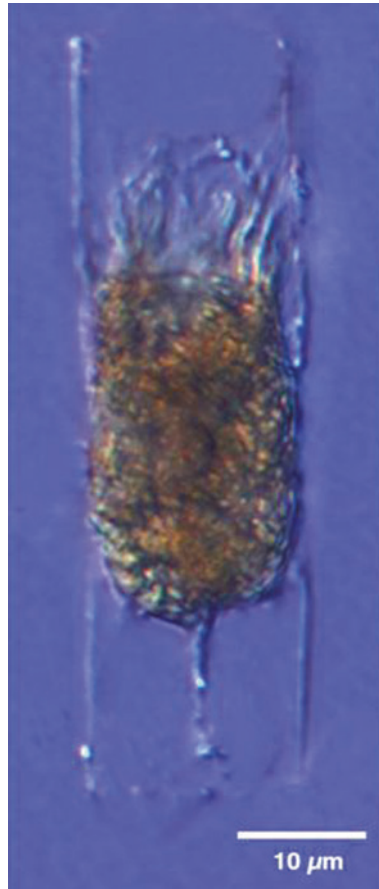
**Morphological characteristics** Lorica fusiform, oral aperture circular; collar low-funnel-shaped, bowl circular in cross section below the collar, then gradually becoming triangular, posteriorly with three ridges in the aboral end; wall hyaline, composed of separated laminae in the anterior of the lorica.

**Measurements** Length 90.98–93.16 μm; oral diameter 31.68–37.94 μm. Approximate ratio Lorica/oral diameter 2.3–3.9.

**Distribution** Common at all studied areas of the Arabian Gulf (Yamani et al. 2011), Gulf of Mexico (Felder and Camp 2010), Southeast coast of India (Godhantaraman 2002), Bahuda estuary, East coast of India (Mishra and Panigrahy 1999), Porto Novo region, India (Krishnamurthy and Santhanam 1975), East Asian waters (Lee and Kim 2000).

**Comments** This is a typical stenothermal and euryhaline species (Godhantaraman and Uye 2003). Mostly, thermophilic was found in water temperature  $>25^{\circ}\text{C}$ . It was found to tolerate a wide range of salinity (14.49–21.3 p.s.u) but showed highest density at  $>20$  p.s.u.

#### 2.4.33 *Eutintinnus* sp. (Kofoid and Campbell, 1939)



**Phylum:** Ciliophora  
**Subphylum:** Intramacronucleata  
**Class:** Spirotrichea  
**Subclass:** Choreotrichia  
**Order:** Tintinnida  
**Family:** Tintinnidae

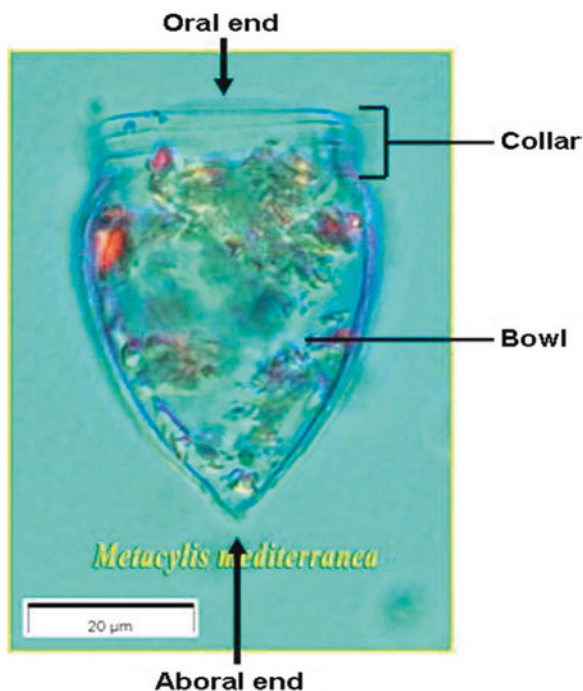
**Morphological characteristics** Lorica very small, almost cylindrical. Ciliate is bigger in comparison with lorica. Its body takes all the width of lorica and occupies about 80 % of its total length. The wall of lorica is very thin, transparent, and flimsy. In general, most of these tintinnids in the collected samples have more or less misshapen loricas.

**Measurement** Total length 53.4  $\mu\text{m}$ ; oral diameter 13.8  $\mu\text{m}$ .

**Distribution** *Eutintinnus* sp. was registered near the north coast of Bubiyan Island and in Kuwait Bay.

**Comments** *Eutintinnus* sp. was registered in estuarine site Lot no. 8 of Indian Sundarbans only with abundance of 10 ind  $l^{-1}$  during postmonsoon (November 2012), when the temperature and salinity were 25  $^{\circ}\text{C}$  and 15.04 p.s.u, respectively.

#### 2.4.34 *Metacylis mediterranea* (Mereschkowsky, 1880) Jørgensen, 1924



**Phylum:** Ciliophora

**Subphylum:** Intramacronucleata

**Class:** Spirotrichea

**Subclass:** Choreotrichia

**Order:** Tintinnida

**Family:** Metacylididae

**Morphological characteristics** Lorica small, hyaline, cup-shaped with rings or spiral bands on part or entire lorica. Aboral end is blunt and round. Collar wide, relatively short, with 4–6 spiral turns.

**Measurement** Total length of the lorica ranged from 68.11 to 70.75  $\mu\text{m}$  and the oral diameter ranged from 38.41 to 41.60  $\mu\text{m}$ . Approximate ratio between length and oral diameter was 1.0:1.7

**Distribution** Recorded mostly from Russian part of the Black Sea, Ukrainian exclusive economic zone Bulgaria (Alexandrov and Korshenko 2007), Porto Novo region, India (Mishra and Panigrahy 1999).

**Comments** Scarce species recorded only once in March 2010 at Lot 8 (S<sub>4</sub>) of Indian Sundarbans. The temperature and salinity at that specific time were 32.85 °C and 21.3 p.s.u., respectively.

#### 2.4.35 *Metacyllis* sp. (Jørgensen, 1924)



**Phylum:** Ciliophora

**Subphylum:** Intramacronucleata

**Class:** Spirotrichea

**Subclass:** Choreotrichia

**Order:** Tintinnida

**Family:** Metacyllididae



**Morphological characteristics** Lorica small, hyaline, cup-shaped, with rounded aboral end. Collar wide, relatively short, with 4–6 spiral turns.

**Measurements** Length 65.55  $\mu\text{m}$ ; oral diameter 37.25  $\mu\text{m}$ .

**Distribution** Common in Bubiyan Island waters, Kuwait.

**Comments** *Metacylis* sp. was registered only in Lot no. 8 (S<sub>4</sub>) of Indian Sundarbans in very low abundance (50 ind l<sup>-1</sup>) during premonsoon (April 2012).

#### 2.4.36 *Helicostomella* sp. (Jørgensen, 1924)



**Phylum:** Ciliophora

**Subphylum:** Intramacronucleata

**Class:** Spirotrichea

**Subclass:** Choreotrichia

**Order:** Tintinnida

**Family:** Metacyclididae

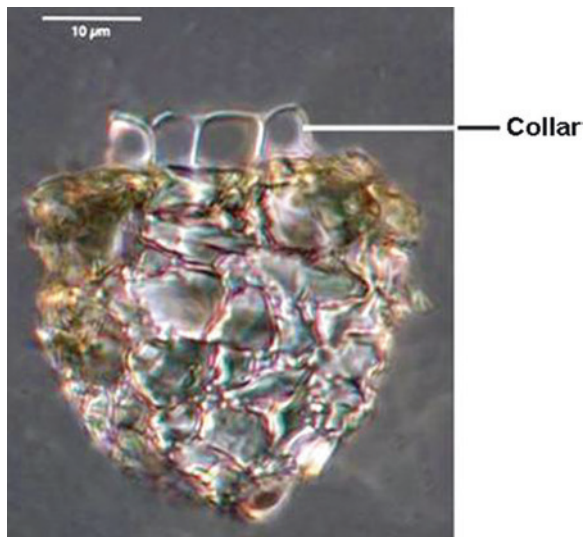
**Morphological characteristics** Lorica very short, bullet-shaped, 2.2–4.4 oral diameters in length; oral rim entire; bowl expanding slightly, widest 0.5–1.0 oral diameter below the spiral, convex conical aborally; aboral horn scarcely differentiated, conical.

**Measurement** Total length 57.95  $\mu\text{m}$ ; length of collar 16.4  $\mu\text{m}$ .

**Distribution** *Helicostomella longa* was registered in very low abundance in the northwestern waters of the Arabian Gulf.

**Comments** *Helicostomella* sp. remarkably differs from other tintinnids in having shorter, stouter lorica. *Helicostomella* sp. was registered only in Lot no. 8 of Indian Sundarbans, with an abundance of 15 ind  $l^{-1}$ . It is an occasional species, found only during December 2012, coinciding with moderate temperature (25 °C) and salinity (15–17 p.s.u.).

#### 2.4.37 *Wangiella dicollaria* (Nie, 1934)



**Phylum:** Ciliophora

**Subphylum:** Intramacronucleata

**Class:** Spirotrichea

**Subclass:** Choreotrichia

**Order:** Tintinnida

**Family:** Dictyocystidae

**Morphological characteristics** Lorica with oral margin undulating, with a single row of 4–5 tall rectangular windows; beams sometimes bowed outwards. Bowl subglobular, or rarely wider than long, set off by distinct shoulder from the bowl; aboral region sub hemispherical. Wall of bowl with large, subuniform, coarse, rounded and overlapping meshes and with smaller ones intermingled, formed by included coccoliths.

**Measurement** Length 55.6  $\mu\text{m}$ ; oral diameter 36.3  $\mu\text{m}$ .

**Distribution** Recorded from Bohai Sea, China (Zhang et al. 2002).

**Comments** The species differs from other representatives belonging to the family Dictyocystidae in the extensive coccolith inclusions and duplex nature of the wall structure. *Wangiella dicollaria* is rarely available in estuarine waters and recorded exclusively at the site Gangasagar (S<sub>5</sub>) of Indian Sundarbans with an abundance of 20 ind l<sup>-1</sup> during February 2013, coinciding with 20 °C temperature and 20 p.s.u salinity.

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Wetland

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