

Seasonal variations in species composition, abundance, biomass and estimated production rates of tintinnids at tropical estuarine and mangrove waters, Parangipettai, southeast coast of India

N. Godhantaraman*

Center of Advanced Study in Marine Biology, Annamalai University, Parangipettai, Tamil Nadu 608 502, India

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Abstract

Seasonal variations in species composition, abundance, biomass and production rates of tintinnids (Protozoa: Ciliata) were investigated in the tropical estuarine and mangrove systems of Parangipettai, South India, monthly from January to December 1994. There were remarkable seasonal variations in environmental parameters, chlorophyll *a* concentrations and abundance, biomass and production rates of tintinnids: highest in postmonsoon/summer and lowest in monsoon. The total abundance and biomass of tintinnids were in the range of 2–420 indiv. l^{-1} and 0.02–3.01 $\mu g C l^{-1}$, respectively, with the peak appearing in the estuarine waters. A total of 47 species of tintinnids belonging to 14 genera was identified. Of which, *Tintinnopsis* was the most abundant genus in terms of number of species (20), followed by *Codonellopsis* (4), *Stenosemella* (4), *Favella* (3), *Eutintinnus* (3), and the remaining genus, number of species are one or two. Most of the tintinnid species occurred on distinct seasonal pattern and closely associated to species-specific environmental conditions. Due to large thermal gradients (range: 22.5–33.8 °C), the overall mean biomass was highest (mean: 1.64 $\mu g C l^{-1}$) during summer than the remaining seasons. Estimated production rates of tintinnids ranged from 0.02 to 2.5 $\mu g C l^{-1} day^{-1}$, with peak in summer. The trophodynamic role of tintinnids was assessed by estimating their grazing impact as expressed by daily removal of phytoplankton biomass. The grazing impact also demonstrated a seasonal pattern and ranged from 0.03% to 1.24% removal day^{-1} . The higher grazing impact estimated during summer could be related to high concentrations of food supply. Due to significant positive relationship between the total biomass of tintinnids and chlorophyll *a* concentrations, food supply is not a problem for tintinnids harboring in this estuarine and mangrove systems. Hence, predation loss by meso- and macrozooplankton might be the possible reasons for the estimated low biomass of tintinnids in the present study. Therefore, the results demonstrate that tintinnids play an important role to transfer the production of pico- and nanoplankton to meso- and macrometazoan predators. Thus, the seasonal environmental factors exert major influence on the species composition, abundance, biomass and production rates of tintinnids. © 2002 Elsevier Science B.V. All rights reserved.

Keywords: Abundance; Biomass; Production rate; Tintinnids; Seasonal variations; Estuarine and mangrove waters

* Present address: Coastal Ecosystem Research Group, Institute for Marine Resources and Environment, National Institute of Advanced Industrial Science and Technology (AIST), 2-2-2 Hiro-Suehiro, Kure, Hiroshima 737-0197, Japan.

E-mail addresses: godhantaraman-microzoo@aist.go.jp, vighnesh8@yahoo.com (N. Godhantaraman).

1. Introduction

Tintinnids are the dominant ciliates and thoroughly investigated taxa among the marine microzooplank-

ton community owing to their prominent structure of lorica, which enables easy identification (Kofoed and Campbell, 1929, 1939). Due to their ubiquitous in distribution, small size, and rapid metabolic and growth rates (Heinbokel, 1978; Verity, 1985; Fenchel, 1987), they are undoubtedly considered to play an important role in transferring the production of pico- and nanoplankton to meso- and macrocarnivores (Capriulo and Ninivaggi, 1983; Stoecker and Govoni, 1984; Porter et al., 1985; Gifford, 1991). Furthermore, they often represent an important link between the microbial fraction and the larger grazers (Laval-Peuto et al., 1986; Pierce and Turner, 1994). On the other hand, few studies have also been demonstrated that tintinnids may be an important food source for small, first feeding larvae of many fish (Frank and Leggett, 1986; Stoecker and Govoni, 1984). Hence, detailed studies on the species composition, abundance, biomass and production rates of tintinnids have been investigated in many marine coastal waters (Hargraves, 1981; Capriulo and Carpenter, 1983; Sanders, 1987; Kršinić, 1987; Verity, 1987; Abboud-Abi Saab, 1989; Kamiyama and Tsujino, 1996). The authors, Taniguchi and Kawakami (1983, 1985), Verity (1985, 1986), Kamiyama and Aizawa (1987) and Kamiyama (1997) have estimated the growth and feeding capabilities of tintinnids in laboratory and natural environments. However, the trophodynamic role of these shell-building tintinnid protozoans is still insufficient in tropical coastal marine waters, particularly in Indian estuarine and coastal waters.

The Vellar estuary is one of the important tropical estuaries at southeast coast of India with a complexity of environmental conditions. Like other estuaries in tropical regions, this estuary is also characterized by a predominant monsoon regime, due to the active northeast monsoon, which brings heavy rainfall (ca. 1000 mm) for 3-month period from October to December. For the remaining period of the year (January–September), the climatic conditions were warmer temperature and this 9-month period is included into three different seasons, namely post-monsoon: January–March; summer: April–June; and premonsoon: July–September. Because of the shallow condition of the estuary (average depth 2.5 m), the water temperature and salinity are influenced by the degree of mixing of the neritic and fluvial elements and tidal inflow due to ebb and flow. Their

mixing proportion may also be changed seasonally, thus providing unique hydrographic and environmental conditions. Hence, it is of interest to investigate the tintinnids community structure in the varied ecological conditions of the tropics, because the generation time of tintinnid species are much shorter than large animals so that their occurrence and distribution are influenced more by varying environmental factors. Despite the considerable accumulation of data on seasonal distribution and abundance of various plankton groups on tropics, there are not many studies on the taxonomic composition, abundance and biomass of tintinnids in the coastal waters along the east coast of India (Krishnamurthy and Santhanam, 1975, 1978; Damodara Naidu et al., 1976; Krishnamurthy and Damodara Naidu, 1977; Krishnamurthy et al., 1978, 1979; Damodara Naidu, 1977; Srinivasan et al., 1988). In order to gain more knowledge on the role of tintinnids in the aquatic planktonic food web, the species composition, abundance, biomass and production rates of tintinnids in relation to seasonal variations of environmental conditions were investigated. For first time, the trophodynamic role of tintinnids in the tropical Vellar estuary and adjacent mangrove waters was assessed under natural conditions.

2. Description of the study area

The Vellar estuary is situated at Parangipettai, South India (11°29' N, 79°46' E), southeast coast of India (Fig. 1). The river Vellar originates from the Servarayan hills in Salem district, Tamil Nadu. After meandering for a length approximately 480 km, it forms an estuarine system at Parangipettai, where it enters into the Bay of Bengal. The estuary is subjected to tides with maximum amplitude of ca. 1 m., is influenced by the considerable flow of mixed water originating from the Pichavaram mangroves, and is connected with the Coleroon estuary in south, through a network of creeks, canals and gullies.

The Pichavaram mangrove forest is one of the fertile region of the Vellar–Coleroon estuarine complex, covering an area of ca. 1100 ha and consisting of 51 islets ranging in size from 10 m² to 2 km². About 50% of the total is covered by forest, 40% by waterways, and the remaining 10% by sand and mudflats. The channels

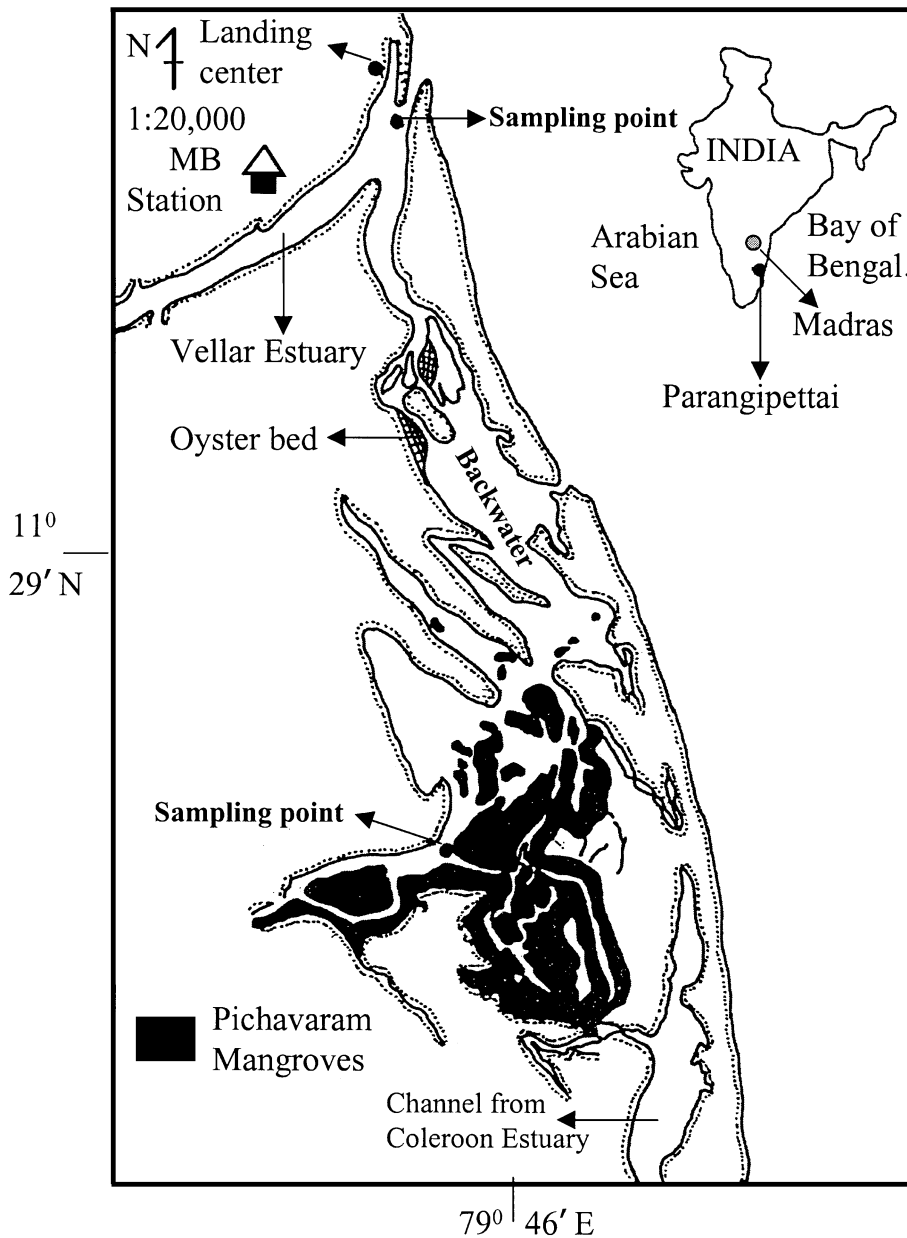


Fig. 1. Map of study area with the locations of sampling points.

in the mangroves are lined by a luxuriant vegetation of salt marsh plants, trees, shrubs and thickets totaling about 30 species, of which ca. 20 are woody. The dominant trees belong to *Rhizophora* and *Avicennia* and the salt marsh plants are *Salicornia branchiata*, *Suaeda maritima* and *Sesuvium portulacastrum*.

3. Materials and methods

Surface water samples were collected at the Vellar estuary and the Pichavaram mangroves at Parangipettai (Fig. 1), monthly from January to December 1994. Environmental parameter such as water temperature

was measured by a Celsius thermometer (with 0.5 °C accuracy) and salinity was estimated according to the procedure of Strickland and Parsons (1972). For estimation of chlorophyll *a*, 500 ml of surface water samples were collected and filtered onto glassfiber (Whatman GF/F filters). The extracts were prepared in 90% acetone. Later, chlorophyll concentration was measured spectrophotometrically by using Milton-Roy Spectronic 1001, according to the procedure of Strickland and Parsons (1972).

For tintinnids, 500 or 1000 ml of surface water samples was collected by plastic bottles and immediately preserved with glutaraldehyde at a final concentration of 1%. Samples were kept refrigerated in dark until microscopic examination. Particles were concentrated to a volume of 25 ml by settling, from which a 10-ml sample was transferred to Sedgwick–Rafter chamber for counting, according to the method of Utermöhl (1958), under an inverted microscope. Tintinnids were identified using lorica morphology described by Kofoed and Campbell (1929, 1939) and Marshall (1969). Cell dimensions, i.e. length and oral diameter of the lorica, were measured for each tintinnid species (minimum 10 individual species) to the nearest 1 µm. Lorica volume (LV, µm³) was converted to body carbon weight using the regression equation: $C_t = 444.5 + 0.053 \text{ LV}$ (Verity and Langdon, 1984). Lorica occupancy was assumed to be 100%.

Production rate (P , µg C l⁻¹ day⁻¹) was estimated from biomass (B , µg C l⁻¹) and empirically determined specific growth rate (g , day⁻¹): $P = B \times g$. Multiple regression: $\ln g = 1.52 \ln T - 0.27 \ln \text{CV} - 1.44$, where T is the temperature (°C) and CV is the cell volume (µm³), proposed by Müller and Geller (1993) for ciliates was used. In this case, the cell volume of tintinnids was calculated back from their body carbon weight using the conversion factor of 0.14 pg C µm⁻³.

4. Results

4.1. Environmental parameters

The seasonal variations in temperature, salinity and chlorophyll *a* concentration are shown in Fig. 2, for estuarine and mangrove waters. The surface temperature showed slight stratification between estuarine

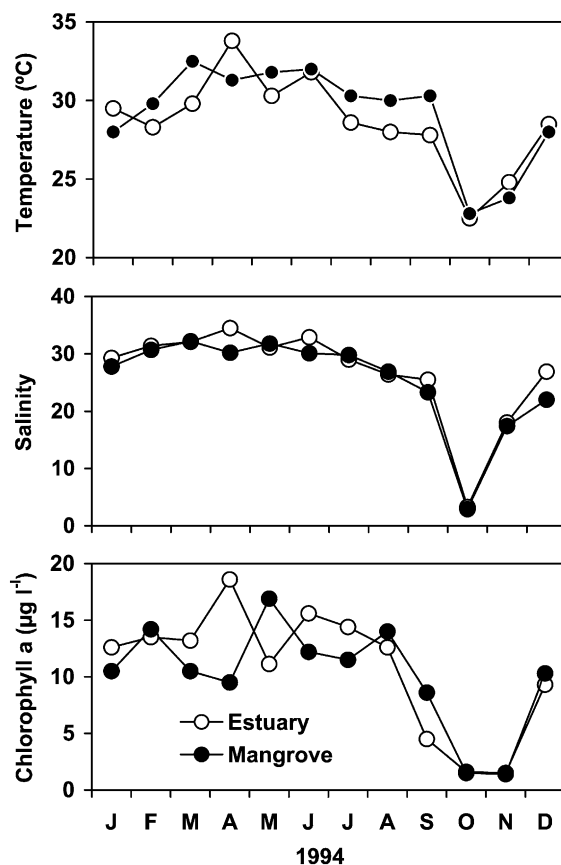


Fig. 2. Seasonal variations of temperature, salinity and chlorophyll *a* in estuarine and mangrove system.

and mangrove systems; however, the seasonal thermal fluctuations were largest, varied from 22.5 to 33.8 °C during monsoon and summer seasons, respectively. The maximum and minimum salinity in the estuary and mangroves were in the ranges of 3.3–34.5 and 2.9–32.2, respectively (Fig. 2). The minimum salinity was presumably due to the influence of heavy rainfall and the resultant river run-off, as a regular annual event in this area during monsoon. The slight variations of salinity between the estuarine and mangroves was owing to the proximity of the former to the Bay of Bengal. The chlorophyll *a* concentrations varied from 1.5 to 18.6 and 1.4 to 16.9 µg l⁻¹ in estuarine and mangrove waters, respectively (Fig. 2). Average chlorophyll *a* concentration during summer was 3.2-fold (estuary) and 2.9-fold (mangrove) higher than during the monsoon season.

4.2. Seasonal variations in species composition, abundance, biomass and production rate of tintinnids

4.2.1. Estuary

There were remarkable seasonal variations in abundance of tintinnids: highest ($420 \text{ indiv. l}^{-1}$) during summer and lowest (2 indiv. l^{-1}) during monsoon (Fig. 3). The seasonal abundance was highest (mean: $270 \text{ indiv. l}^{-1}$) during the summer, followed, by postmonsoon ($115 \text{ indiv. l}^{-1}$), premonsoon ($105 \text{ indiv. l}^{-1}$) and monsoon (27 indiv. l^{-1}). Over the entire study period, genus *Tintinnopsis* was numerically dominant (ca. 67%). The other important genera were *Stenosemella* and *Favella* (Fig. 3).

Total of 47 species of tintinnids belonging to 14 genera was identified, of which 42 species were occurred in the estuary (Table 1). They are *Tintinnidium*, *Tintinnopsis*, *Leprotintinnus*, *Codonellopsis*, *Stenosemella*, *Dictyocysta*, *Favella*, *Eutintinnus*, *Amphorellopsis*, *Coxiella*, *Dadayiella*, *Helicostomella*, *Metacylis* and *Rhabdonella*. Among them, genus *Tintinnopsis* was the most abundant in terms of number of species (18), followed by *Codonellopsis* (3), *Favella* (3) and *Eutintinnus* (3), and the remaining genera were represented by one or two. Most of tintinnid species occurred on distinct seasonal pattern. Species as *Tintinnopsis minuta*, *T. beroidea*, *T. mortensenii*, *T. uruguayensis*, *Codonellopsis ostenfeldii* and *Favella philippinensis* were found commonly and abundantly over the entire period of study. Typical species in the post-premonsoon period included *Tintinnidium incertum*, *Tintinnopsis butschlii*, *T. gracilis*, *T. glans*, *T. nucula*, *T. radix*, *T. tubulosa*, *Favella enhrenbergii*, *Stenosemella ventricosa*, *Codonellopsis orthoceros*, *C. schabi*, *Dictyosysta seshaiyai* and *Favella brevis*. Species as *T. cylindrica*, *Eutintinnus tenuis* and *Leprotintinnus simplex* were found only during monsoon and *T. lohmanni*, *T. kofoidi*, *T. bermudensis*, *T. tenuis*, *S. nivalis*, *C. annulata*, *H. longa*, *R. spiralis* and *D. ganymedes* were found particularly in summer. Species of the genus *Coxiella*, *Metacylis*, *Rhabdonella* and *Dadayiella* were found only in the estuary.

The biomass of tintinnids ranged from 0.04 to $3.01 \mu\text{g C l}^{-1}$ (Fig. 3). Seasonal averages were 1.41, 1.64, 0.93 and $0.09 \mu\text{g C l}^{-1}$ during postmonsoon, summer, premonsoon and monsoon, respectively. In general, most of the species were smaller in size fraction

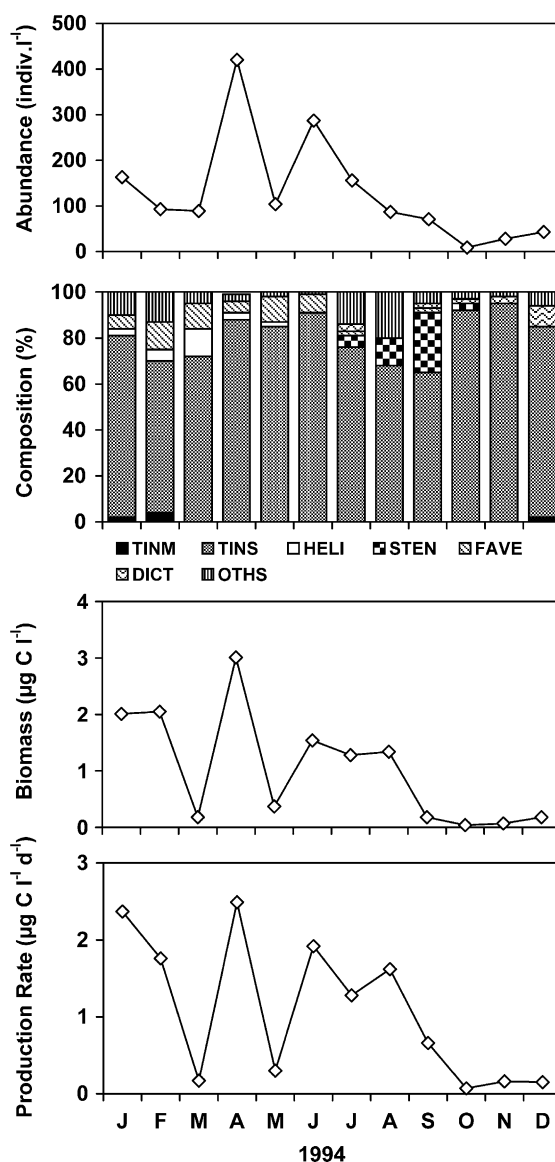


Fig. 3. Seasonal variations in abundance, species composition, biomass and estimated production rates of tintinnids in estuarine system (TINM—*Tintinnidium*; TINS—*Tintinnopsis*; HELI—*Helicostomella*; STEN—*Stenosemella*; FAVE—*Favella*; DICT—*Dictyocysta*; OTHS—Others).

(lorica length $< 65 \mu\text{m}$) and the contribution of these size categories to biomass was large ($> 50\%$).

The maximum and minimum daily production of 2.5 and $0.07 \mu\text{g C l}^{-1} \text{ day}^{-1}$ was estimated during summer and monsoon seasons, respectively (Fig. 3).

Table 1

Species list of tintinnids and occurrence of peak month with abundance (+: <50, ++: 50–250, +++: >250 indiv. l^{-1}) at estuarine and mangrove waters

Species name	Peak month with abundance	
	Estuary	Mangrove
<i>Tintinnidium incertum</i>	July (+)	Sept. (+)
<i>T. primitivum</i>	Feb. (+)	May (+)
<i>Leptotintinnus nordqvisti</i>	Sept. (+)	–
<i>L. simplex</i>	Nov. (+)	Oct. (+)
<i>Tintinnopsis amphora</i>	–	Nov. (+)
<i>T. directa</i>	–	Dec. (+)
<i>T. minuta</i>	Apr. (++)	Mar. (+++)
<i>T. kofoidi</i>	May (++)	Sept. (+)
<i>T. lohmanni</i>	Apr. (++)	May (++)
<i>T. karajacensis</i>	Mar. (+)	Jan. (+)
<i>T. cylindrica</i>	Oct. (+)	–
<i>T. beroidea</i>	Apr. (+++)	June (++)
<i>T. butschlii</i>	July (+)	–
<i>T. glans</i>	Jan. (+)	Feb. (++)
<i>T. gracilis</i>	Aug. (+)	Mar. (+)
<i>T. bermudensis</i>	June (++)	–
<i>T. radix</i>	Aug. (++)	Mar. (++)
<i>T. tubulosa</i>	Sept. (+)	Jan. (+)
<i>T. mortensenii</i>	July (++)	Mar. (++)
<i>T. tenuis</i>	Apr. (++)	–
<i>T. tocaninensis</i>	Feb. (++)	–
<i>T. nucula</i>	Feb. (+)	July (++)
<i>T. uruguayensis</i>	Sept. (++)	–
<i>T. nana</i>	May (++)	Mar. (++)
<i>Stenosemella ventricosa</i>	Jan. (++)	–
<i>S. stenei</i>	–	Dec. (+)
<i>S. parvicollis</i>	–	Apr. (++)
<i>S. nivalis</i>	June (+++)	–
<i>Codonellopsis ostenfeldi</i>	Mar. (++)	–
<i>C. orthoceros</i>	Mar. (+)	–
<i>C. schabi</i>	Aug. (+)	Feb. (+)
<i>C. tessellata</i>	–	Oct. (+)
<i>Dictyocysta seshaiyai</i>	July (++)	Mar. (++)
<i>Coxiella ampla</i>	Apr. (+)	–
<i>C. annulata</i>	May (+)	–
<i>Metacylis corbula</i>	Mar. (+)	–
<i>Helicostomella longa</i>	June (++)	Sept. (+)
<i>H. fusiformis</i>	Mar. (++)	–
<i>Favella brevis</i>	July (++)	–
<i>F. philippinensis</i>	Aug. (++)	May (++)
<i>F. ehrenbergii</i>	Feb. (++)	June (++)
<i>Rhabdonella spiralis</i>	June (+)	–
<i>Amphorellopsis acuta</i>	Apr. (+++)	Mar. (++)
<i>Dadayiella ganymedes</i>	June (++)	–
<i>Eutintinnus lusus-undae</i>	Dec. (+)	Apr. (+)
<i>E. tenuis</i>	Oct. (+)	Oct. (+)
<i>E. rectus</i>	Dec. (+)	Oct. (+)

Average production was $1.1 \mu\text{g C l}^{-1} \text{ day}^{-1}$, and total annual production was $0.40 \text{ mg C l}^{-1} \text{ year}^{-1}$. The seasonal average was highest in summer (mean: $1.57 \mu\text{g C l}^{-1} \text{ day}^{-1}$), followed by postmonsoon ($1.43 \mu\text{g C l}^{-1} \text{ day}^{-1}$), premonsoon ($1.19 \mu\text{g C l}^{-1} \text{ day}^{-1}$) and monsoon ($0.13 \mu\text{g C l}^{-1} \text{ day}^{-1}$). The contribution of species from genus *Tintinnopsis* and *Favella* to total production was higher (ca. 52%). The overall mean estimated production rate over the entire study period was 2.4-fold high in the estuary than in mangroves.

4.2.2. Mangroves

The monthly abundance of tintinnids varied from 3 to 290 indiv. l^{-1} , and the maximum abundance was relatively lower than the estuary (Fig. 4). Seasonally, they were most abundant during postmonsoon (mean: 170 indiv. l^{-1}), followed by summer (167 indiv. l^{-1}), premonsoon (62 indiv. l^{-1}) and monsoon (15 indiv. l^{-1}). Species from genus *Tintinnopsis* was overwhelmingly dominant, as observed at estuary.

The number of tintinnid species decreased to 29 belonging to 10 genera (Table 1), namely *Tintinnopsis*, *Tintinnidium*, *Leptotintinnus*, *Codonellopsis*, *Stenosemella*, *Dictyocysta*, *Favella*, *Eutintinnus*, *Amphorellopsis* and *Helicostomella*. Among them, genus *Tintinnopsis* was the most important in terms of number of species (14), followed by *Eutintinnus* (3), *Codonellopsis* (2), *Stenosemella* (2), *Favella* (2) and others (6). *T. minuta*, *T. beroidea*, *T. mortensenii*, *T. nana* and *H. longa* were found commonly and accounted largely to total abundance. Species as *T. glans*, *T. kofoidi*, *T. nucula*, *T. radix*, *T. tubulosa*, *F. ehrenbergii*, *C. schabi* and *D. seshaiyai* belonged to post-premonsoon type and *T. directa*, *T. amphora*, *C. tessellata*, *E. tenuis* and *E. rectus* to the monsoon type. Typical summer type species in the mangroves were *T. lohmanni*, *Stenosemella parvicollis*, *Eutintinnus lusus-undae* and *F. philippinensis*. In general, the number species decreased from dry months (January–September) to monsoon months (October–December).

Biomass varied from 0.02 to $2.18 \mu\text{g C l}^{-1}$ (Fig. 4). Seasonally, it was highest (mean: $0.98 \mu\text{g C l}^{-1}$) during postmonsoon, followed by summer ($0.65 \mu\text{g C l}^{-1}$), premonsoon ($0.11 \mu\text{g C l}^{-1}$) and monsoon ($0.07 \mu\text{g C l}^{-1}$). Species belonging to the genus *Tintinnopsis* and *Favella* (>65 μm in size categories) largely contributed to the total biomass.

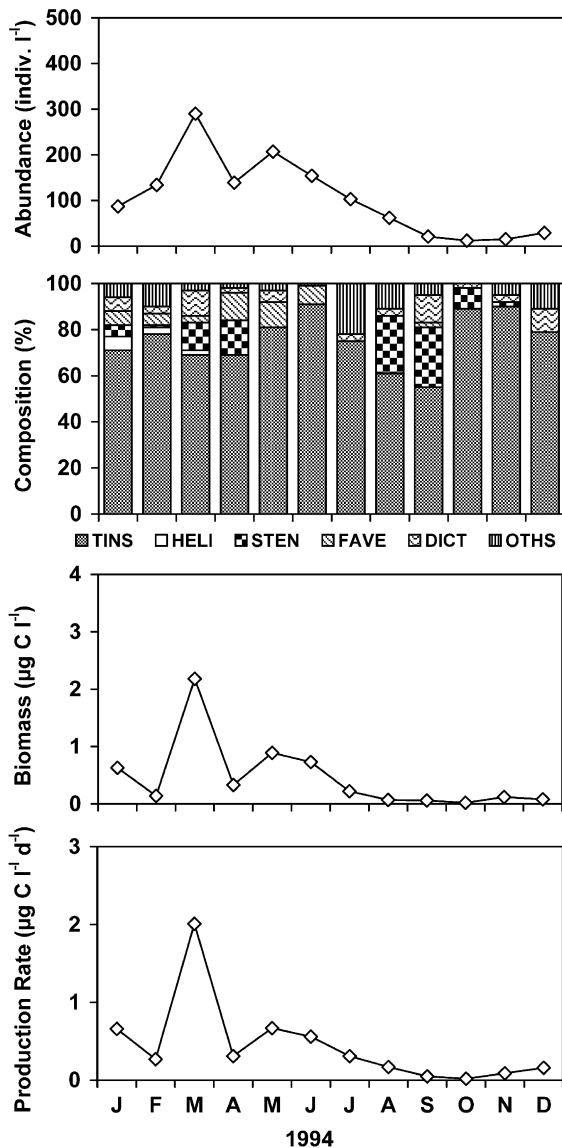


Fig. 4. Seasonal variations in abundance, species composition, biomass and estimated production rates of tintinnids in mangrove system (TINS—*Tintinnopsis*; HELI—*Helicostomella*; STEN—*Stenosomella*; FAVE—*Favella*; DICT—*Dictyocysta*; OTHS—Others).

The production rate was relatively high ($2.01 \mu\text{g C l}^{-1} \text{ day}^{-1}$) during postmonsoon and low ($0.02 \mu\text{g C l}^{-1} \text{ day}^{-1}$) during monsoon (Fig. 4). The average production was $0.44 \mu\text{g C l}^{-1} \text{ day}^{-1}$, and total annual production was $0.16 \text{ mg C l}^{-1} \text{ year}^{-1}$. Seasonal averages were 0.98, 0.51, 0.18 and $0.09 \mu\text{g C l}^{-1}$

day^{-1} during postmonsoon, summer, premonsoon and monsoon seasons, respectively. Species belonging to the genus *Tintinnopsis* contributed on an average about 65% of the total production.

5. Discussion

In general and in particular in tropical waters, the distribution and abundance of tintinnids varied remarkably due to the seasonal environmental fluctuations, and these variations are well pronounced in the sheltered systems like estuarine and mangrove waters. In the Vellar estuarine and mangrove waters, total abundance of tintinnids was highest in summer and postmonsoon than the other seasons, as commonly observed in many marine coastal and estuarine waters (Capriulo and Carpenter, 1983; Verity and Langdon, 1984; Verity, 1987; Sanders, 1987; Paranjape, 1987; Abboud-Abi Saab, 1989; Edwards and Burkill, 1995; Kamiyama and Tsujino, 1996). Similar seasonal variations have also been reported in the Parangipettai coastal waters by Krishnamurthy and Santhanam (1975), Damodara Naidu (1977), Godhantaraman (1994). The higher proliferation of tintinnids in summer months might be attributed to higher temperature and chlorophyll *a* concentrations, which both are often considered as the most important factors to increase the growth rate (Revelante and Gilmartin, 1983; Verity, 1985; Sanders, 1987; Abboud-Abi Saab, 1989; Kamiyama, 1994; Godhantaraman, 2001).

The abundance of tintinnids was lowest during monsoon months, when the water column was markedly stratified to a large extent because of heavy rainfall, overcast sky and cool conditions. As a result of these, water temperature, salinity and chlorophyll *a* concentration decreased largely with increased turbidity. The low temperature and chlorophyll concentrations drastically affect the life cycles of many tintinnids. Hence, the influence of these factors severely affects the abundance and growth rate of tintinnids (Kamiyama and Aizawa, 1987; Godhantaraman, 1994; 2001). Moreover, many tintinnids disappeared during flood and species composition also changed, since they are mostly euryhaline and stenohaline. When the conditions are favorable, normal plankton composition reappeared. This kind of cyclic change in the species composition of tintinnids was a character-

istic feature of the Vellar estuarine and mangrove systems.

Total of 47 species of tintinnids was identified in this estuarine and mangrove waters, of these 20 species belonged to the genus *Tintinnopsis*. They are often common and contributed significantly to the total abundance of tintinnids, as reported in many coastal and oceanic waters (Verity, 1987; Graziano, 1989; Laybourn-Parry et al., 1992; Edwards and Burkill, 1995), indicating that they are adapted to different thermal and salinity gradients. Species as *T. minuta*, *T. beroidea*, *T. mortensenii*, *C. ostenfeldii* and *F. philippinensis* were noticed over the entire study period, implying their euryhaline and eurythermal nature. Most tintinnid species occurred on a remarkable seasonal basis. Species from the genus *Tintinnopsis*, *Favella*, *Stenosemella* and *Codonellopsis* was noticed at high numbers during all seasons except monsoon season in both estuarine and mangrove waters, indicating their thermophilic nature. A few tintinnid species (*E. tenus*, *T. cylindrica*, *L. simplex*, *T. directa*, *T. amphora* and *C. tessellata*) were particularly abundant during monsoon season, indicating that these species are adapted to low temperature conditions. Thus, the seasonal occurrence of tintinnid species may be closely associated with the species-specific environmental conditions that required to encystment or excystment (Paranjape, 1987; Kamiyama and Aizawa, 1992). The occurrence of species from the genus *Coxiella*, *Dadayiella*, *Metacylis* and *Rhabdonella* in estuary was conspicuous. The higher number and variety of tintinnid species in the estuary might be influenced by the migration of species belonging to the adjacent sea, i.e. Bay of Bengal, and these migration activities are limited in the mangroves due to the distance from the sea. Kršinić (1987) observed that the number of tintinnid species increased consistently towards the outer region of the Bay of Mali Ston, where the salinity was high.

The maximum abundance of tintinnids was recorded 420 indiv. l^{-1} . The value estimated now is higher than the maximum abundance of tintinnids estimated 100 indiv. l^{-1} in Larzarev Sea (Froneman et al., 1996); 219 indiv. l^{-1} in Funka Bay, Japan (Dohi, 1982); 288 indiv. l^{-1} in Bay of Mali Ston (Kršinić, 1987); and also lower than the maximum values were estimated 1000 indiv. l^{-1} in Solent estuary, England (Burkill, 1982); >1000 indiv. l^{-1} in Chesapeake Bay,

USA (Coats and Heisler, 1989); 5700 indiv. l^{-1} in the Seto Inland Sea of Japan (Kamiyama and Tsujino, 1996); 7000 indiv. l^{-1} in Damariscotta River estuary, USA (Sanders, 1987); 11300 indiv. l^{-1} in Bahia Blanca estuary, Argentina (Barria de Cao, 1992); 270 000 indiv. l^{-1} in Narragansett Bay (Verity, 1987). However, in Parangipettai coastal waters, Krishnamurthy and Santhanam (1975) and Damodara Naidu (1977) estimated maximum abundance of 375 and 413 indiv l^{-1} , respectively, in the estuarine and mangrove waters. These values are slightly lower than or in the same level as the maximum value (420 indiv. l^{-1}) in the present study. However, the abundance of tintinnids is not strictly comparable, because some of the values are water column average abundance of tintinnids.

The total biomass of tintinnids also demonstrated a strong seasonal pattern with the highest (3.01) in summer and lowest (0.02) in monsoon (Fig. 3). The elevated higher biomass in summer could be attributed to water temperature and chlorophyll *a* concentration, which were also recorded higher in summer (Fig. 2). Hence, the seasonal changes in biomass of tintinnids in the estuarine and mangrove waters could be related to the interactive effects of temperature and food availability. Hence, significantly ($p < 0.05$) positive relationship was obtained between the total biomass of tintinnids and chlorophyll *a* concentrations for all water samples (Fig. 5). Although these estimated biomasses of tintinnids are not strictly comparable, the values

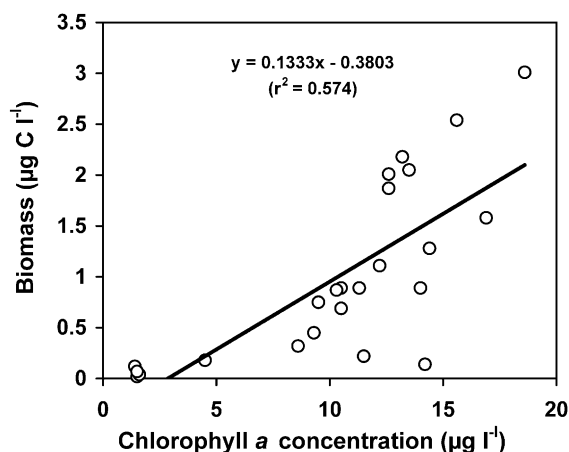


Fig. 5. Relationship between biomass of tintinnids and chlorophyll *a* concentration over the study period.

consistently lower within typical ranges of similar coastal and estuarine waters (Beers and Stewart, 1970; Burkill, 1982). As indicated above, the availability of food is sufficient for the growth of tintinnids. Hence, predation loss by meso- and macrozooplankton might be responsible for the lower biomass of tintinnids in this estuarine and mangrove systems, because these systems are supporting high mesozooplankton populations (Krishnamurthy et al., 1974; Santhanam et al., 1975; Godhantaraman, 1994). Furthermore, the contribution of small size categories of tintinnids (lorica length $<65\ \mu\text{m}$) to the total biomass was higher (ca. $>50\%$). Hence, the collective study of tintinnids size categories and numerical abundance (data of previous studies by Damodara Naidu, 1977; Godhantaraman and Krishnamurthy, 1997), presumably indicated that tintinnids harbored in the estuarine and mangrove waters may be suitable food sources for the first feeding fish larvae of many fishes (Stoecker and Govoni, 1984; Edwards and Burkill, 1995), as supporting from the study of Prince Jeyaseelan and Krishnamurthy (1980) that the Vellar estuarine and mangrove systems harboring about 200 species of shell and fin fishes.

5.1. Trophodynamic roles

The average production rate of tintinnids was higher during summer than the remaining seasons might be due to the combined effects of higher biomass and

temperature. However, in winter, the growth rates of tintinnids were depressed by the low temperature. The estimated annual production of 0.40 and $0.16\ \text{mg C l}^{-1}\ \text{year}^{-1}$ in the estuarine and mangrove waters are comparable to or lower than the values reported by Verity (1987) and Burkill (1982) in the Narragansett Bay and Solent estuary, respectively.

In order to understand the trophodynamic role of tintinnids, with reference to phytoplankton grazing, the rate of daily removal of phytoplankton biomass was estimated. To estimate this, the phytoplankton carbon biomass was estimated from chlorophyll *a* concentration using a carbon/chlorophyll ratio of 40 (Parsons et al., 1984). The amount of phytoplankton food required to meet the production rate was estimated assuming that the gross growth efficiency is 0.4 for ciliated protozoans (Fenchel, 1987). The potential percentage of the initial phytoplankton biomass removed by grazing of tintinnids remarkably varied seasonally. It was estimated highest (1.24%) in summer and lowest (0.03%) in winter (Fig. 6), and these results indicated that the seasonal environmental conditions not only affect the distribution and growth rate of tintinnids, but also changing their grazing activities. The grazing activities was higher in summer when the chlorophyll *a* concentrations was estimated higher (3.2-fold) than in monsoon, because they required high concentrations of food to sustain population growth rate. The low grazing activities during monsoon might be due to the less food availability and high predation of mesozoo-

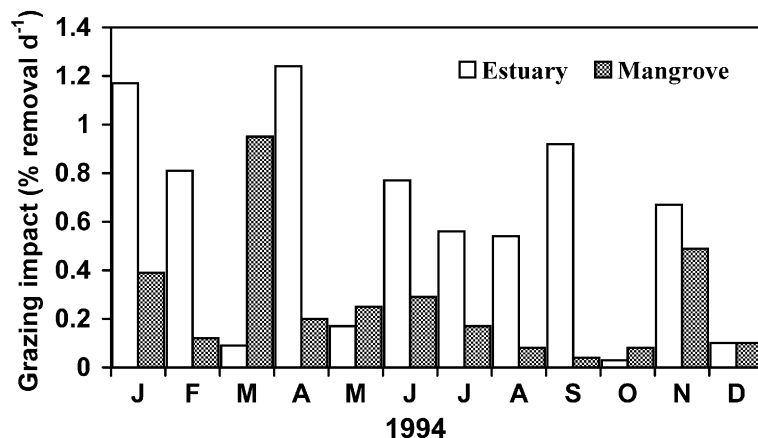


Fig. 6. Seasonal variations in grazing impact of tintinnids as expressed by percent (%) removal of phytoplankton biomass per day in estuary (open columns) and mangroves (filled columns).

plankton. Hence, the food abundance appears to have important effects on populations abundance, survival and growth of tintinnids (Stoecker et al., 1984; Verity and Villareal, 1986). Thus, tintinnid-based food web is changing remarkably due to the characterized seasonal environmental conditions of the Vellar estuarine and mangrove systems.

To conclude, the species composition, abundance and biomass of tintinnids varied seasonally due to wide temperature fluctuations (range: 22.5–33.8 °C), salinity gradients (2.9–34.5) and chlorophyll *a* concentrations (1.4–18.6 $\mu\text{g l}^{-1}$). The estimated high chlorophyll *a* concentrations (18.6 $\mu\text{g l}^{-1}$) indicated that food supply is not causing problem for tintinnids populations, hence predation loss by meso- and macrozooplankton might be responsible for the lower biomass of tintinnids in this estuarine and mangrove systems.

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References

- Abboud-Abi Saab, M., 1989. Distribution and ecology of tintinnids in the plankton of Lebanese coastal waters (eastern Mediterranean). *J. Plankton Res.* 2, 203–222.
- Barria de Cao, M.S., 1992. Abundance and species composition of Tintinnina (Ciliophora) in Bahía Blanca Estuary, Argentina. *Estuar. Coast. Shelf Sci.* 34, 295–303.
- Beers, J.R., Stewart, G.L., 1970. The ecology of the plankton off La Jolla, California, in the period April through September 1967: VI. Numerical abundance and estimated biomass of microzooplankton. *Bull. Scripps Inst. Oceanogr.* 17, 67–86.
- Burkill, P.H., 1982. Ciliates and other microzooplankton components of a nearshore food web: standing stocks and production processes. *Ann. Inst. Oceanogr.* 58, 335–350 (Supplement).
- Capriulo, G., Carpenter, E., 1983. Abundance, species composition and feeding impact of tintinnid microzooplankton in central Long Island Sound. *Mar. Ecol. Prog. Ser.* 10, 277–288.
- Capriulo, G.M., Ninivaggi, D.V., 1983. A comparison of the feeding activities of field collected tintinnids and copepods feed identical natural particle assemblages. *Ann. Inst. Oceanogr. (Paris)* 58, 325–334.
- Coats, D.W., Heisler, J.J., 1989. Spatial and temporal occurrence of the parasitic dinoflagellate *Duboscquella cachoni* and its tintinnine host *Entintinnus pectinis* in Chesapeake Bay. *Mar. Biol.* 101, 401–409.
- Damodara Naidu, W., 1977. Studies on tintinnids (Protozoa: Ciliata) of Porto Novo region, S. India. PhD thesis, Annamalai University, Tamil Nadu, India, unpublished.
- Damodara Naidu, W., Santhanam, R., Krishnamurthy, K., Natarajan, R., 1976. The species biomass and seasonal composition of Tintinnida (Protozoa: Ciliata). In: Qasim, S.Z. (Ed.), Symposium Proceedings on Warm Water Zooplankton. Spec. Publ. UNESCO. NIO, Goa, India, pp. 520–527.
- Dohi, K., 1982. Seasonal change in tintinnid community in Funka Bay. *Bull. Plankton Soc. Jpn.* 29, 77–87.
- Edwards, E.D., Burkill, P.H., 1995. Abundance, biomass and distribution of microzooplankton in the Irish Sea. *J. Plankton Res.* 17, 771–782.
- Fenchel, T., 1987. Ecology of Protozoa—The Biology of Free Living Phagotrophic Protists Springer-Verlag, Berlin, p. 197.
- Frank, K.T., Leggett, W.C., 1986. Effects of prey abundance and size on the growth and survival of larval fish: an experimental study employing large volume enclosures. *Mar. Ecol. Prog. Ser.* 34, 11–22.
- Froneman, P.W., Perissinotto, R., McQuaid, C.D., 1996. Dynamics of microplankton communities at the ice-edge zone of the Lazarev Sea during a summer drogue study. *J. Plankton Res.* 18, 1455–1470.
- Giffort, D.J., 1991. The Protozoa—Metazoan trophic link in the pelagic ecosystems. *J. Protozool.* 38, 81–86.
- Godhantaraman, N., 1994. Species composition and abundance of tintinnids and copepods in the Pichavaram mangroves (South India). *Cienc. Mar.* 20, 371–391.
- Godhantaraman, N., 2001. Seasonal variations in taxonomic composition, abundance and food web relationship of microzooplankton in estuarine and mangrove waters, Parangipettai region, southeast coast of India. *Indian J. Mar. Sci.* 30, 151–160.
- Godhantaraman, N., Krishnamurthy, K., 1997. Experimental studies on food habits of tropical microzooplankton (prey–predator interrelationship). *Indian J. Mar. Sci.* 26, 345–349.
- Graziano, C., 1989. On the ecology of tintinnids (Ciliophora: Oligotrichida) in the North Irish Sea. *Estuar. Coast. Shelf Sci.* 29, 233–245.
- Hargraves, P.E., 1981. Seasonal variations of tintinnids (Ciliophora: Oligotrichida) in Narragansett Bay, Rhode Island, USA. *J. Plankton Res.* 3, 81–91.
- Heinbokel, J.F., 1978. Studies on the functional role of tintinnids in the Southern California Bight: 1. Grazing and growth rates in laboratory cultures. *Mar. Biol.* 47, 177–189.
- Kamiyama, T., 1994. The impact of grazing by microzooplankton in northern Hiroshima Bay, the Seto Inland Sea, Japan. *Mar. Biol.* 119, 77–88.

- Kamiyama, T., 1997. Growth and grazing responses of tintinnid ciliates feeding on the toxic dinoflagellate *Heterocapsa circularisquama*. Mar. Biol. 128, 509–515.
- Kamiyama, T., Aizawa, Y., 1987. Growth characteristics of two tintinnid ciliates, *Tintinnopsis beroidea* and *Amphorellopsis quadrilineata* in laboratory cultures. Bull. Plankton Soc. Jpn. 34, 185–191 (in Japanese with English abstract).
- Kamiyama, T., Aizawa, Y., 1992. Effects of temperature and light on tintinnid excystment from marine sediments. Nippon Suisan Gakkaishi 58, 877–884 (in Japanese with English abstract).
- Kamiyama, T., Tsujino, M., 1996. Seasonal variation in the species composition of tintinnid ciliates in Hiroshima Bay, the Seto Inland Sea of Japan. J. Plankton Res. 18, 2313–2327.
- Kofoid, C.A., Campbell, A.S., 1929. A conspectus of the marine and freshwater Ciliata belonging to the sub-order Tintinninea with descriptions of new species principally from the Agassiz Expedition to the eastern tropical Pacific, 1904–1905. Univ. Calif. Publ. Zool. 34, 1–403.
- Kofoid, C.A., Campbell, A.S., 1939. Reports on the scientific results of the expedition to the Eastern tropical Pacific. The Ciliata: The Tintinninea. Bull. Mus. Comp. Zool. Harvard 84, 1–473.
- Krishnamurthy, K., Damodara Naidu, W., 1977. Swarming of tintinnids (Protozoa:Ciliata) in Porto Novo, India. Curr. Sci. 46, 384.
- Krishnamurthy, K., Santhanam, R., 1975. Ecology of tintinnids (Protozoa:Ciliata) in Porto Novo region. Indian J. Mar. Sci. 4, 181–184.
- Krishnamurthy, K., Santhanam, R., 1978. *Dictyocysta seshaiyai* sp. Nov. (Protozoa:Ciliata). Arch. Protistenkd. 120, 138–141.
- Krishnamurthy, K., Santhanam, R., Sundararaj, V., 1974. Species distribution in aquatic environment. Indian J. Mar. Sci. 3, 135–138.
- Krishnamurthy, K., Damodara Naidu, W., Santhanam, R., 1978. Plankton biogeography of the Indian Ocean. Int. Rev. Gesamten Hydrobiol. 63, 721–726.
- Krishnamurthy, K., Damodara Naidu, W., Santhanam, R., 1979. Further studies on Tintinnids (Protozoa:Ciliata). Arch. Protistenkd. 122, 171–180.
- Kršinic, F., 1987. On the ecology of tintinnines in the Bay of Mail Ston (Eastern Adriatic). Estuar. Coast. Shelf Sci. 24, 401–418.
- Laybourn-Parry, J., Rogerson, A., Crawford, D.W., 1992. Temporal patterns of protozooplankton abundance in the Clyde and Loch Striven. Estuar. Coast. Shelf Sci. 35, 533–543.
- Laval-Peuto, M., Heinbokel, J.F., Anderson, O.R., Rassoulzadegan, F., Sherr, B.F., 1986. Role of micro- and nanozooplankton in marine food webs. Insect Sci. Appl. 7, 387–395.
- Marshall, S.M., 1969. Protozoa order Tintinnida. In: Fraser, J.H., Hansen, V.Kr. (Eds.), Fishes d' Identification du Zooplankton Cons. Per. Int. Explor. Mer Zooplankton Sheet. Charlottenlund, Denmark, pp. 112–117.
- Müller, H., Geller, W., 1993. Maximum growth rates of aquatic ciliate protozoa: the dependence on body size and temperature reconsidered. Arch. Hydrobiol. 126, 315–327.
- Paranjape, M.A., 1987. Grazing by microzooplankton in the eastern Canadian arctic in summer 1983. Mar. Ecol. Prog. Ser. 40, 239–246.
- Parsons, T.R., Takahashi, M., Hargrave, B., 1984. Biological Oceanographic Processes, 3rd ed. Pergamon, Oxford, p. 330.
- Pierce, R.W., Turner, J.T., 1994. Plankton studies in Buzzards Bay, Massachusetts, USA: IV. Tintinnids, 1987 to 1988. Mar. Ecol. Prog. Ser. 112, 235–240.
- Porter, K.G., Sherr, E.B., Sherr, B.F., Pace, M., Sanders, R.W., 1985. Protozoa in planktonic food webs. J. Protozool. 32, 409–415.
- Prince Jeyaseelan, M.J., Krishnamurthy, K., 1980. Role of mangrove forests of Pichavaram as a fish nurseries. Proc. Indian Natl. Sci. Acad. 46, 48–53.
- Revelante, N., Gilmartin, M., 1983. The microzooplankton distribution in the northern Adriatic Sea with emphasis on the importance of ciliated protozoans. Oceanol. Acta 6, 407–417.
- Sanders, R.W., 1987. Tintinnids and other microzooplankton—seasonal distribution and relationship to resources and hydrography in a Maine estuary. J. Plankton Res. 9, 65–77.
- Santhanam, R., Krishnamurthy, K., Subbaraju, R.C., 1975. Zooplankton of Porto Novo, South India. Bull. Dep. Mar. Sci. Univ. Cochin 4, 899–911.
- Srinivasan, A., Santhanam, R., Jegatheesan, G., 1988. Biomass and seasonal distribution of planktonic tintinnids of Pullavashi estuary, Southeast coast of India. Indian J. Mar. Sci. 17, 131–133.
- Stoecker, D.K., Govoni, J.J., 1984. Food selection by young larval gulf menhaden (*Brevoortia patronus*). Mar. Biol. 80, 299–306.
- Stoecker, D.K., Davis, L.H., Anderson, D.M., 1984. Fine scale spatial correlations between planktonic ciliates and dinoflagellates. J. Plankton Res. 6, 829–842.
- Strickland, J.D.H., Parsons, T.R., 1972. Practical Handbook of Sea Water Analysis. Bull. No. 167 Fish Research Board, Canada, Ottawa, 310 pp.
- Taniguchi, A., Kawakami, R., 1983. Growth rates of ciliate *Entintinnus lusundae* and *Favella tarakaensis* observed in the laboratory culture experiments. Bull. Plankton Soc. Jpn. 30, 33–40.
- Taniguchi, A., Kawakami, R., 1985. Feeding activity of a tintinnid ciliate *Favella tarakaensis* and its variability observed in laboratory cultures. Mar. Microb. Food Webs 1, 17–34.
- Utermöhl, H., 1958. Zur Vervollkommnung der quantitativen phytoplankton. Method. Mitt. Int. Verein. Theor. Angew. Limnol. 9, 1–38.
- Verity, P.G., 1985. Grazing, respiration, excretion and growth rates of tintinnids. Limnol. Oceanogr. 30, 1268–1282.
- Verity, P.G., 1986. Growth rates of natural tintinnid populations in Narragansett Bay. Mar. Ecol. Prog. Ser. 29, 117–126.
- Vetiry, P.G., 1987. Abundance, community composition, size distribution, and production rates of tintinnids in Narragansett Bay, Rhode Island. Estuar. Coast. Shelf Sci. 24, 671–690.
- Verity, P.G., Langdon, C., 1984. Relationship between lorica volume, carbon, nitrogen, and ATP content of tintinnids in Narragansett Bay. J. Plankton Res. 6, 859–868.
- Verity, P.G., Villareal, T.A., 1986. The relative food value of diatoms, dinoflagellates, flagellates and cyanobacteria for tintinnid ciliates. Arch. Protistenkd. 131, 71–84.