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NYCHTHEMERAL VARIATIONS OF TINTINNINA (CILIATA: OLIGOTRICHIDA) NEAR THE ROCAS ATOLL (SOUTH ATLANTIC) AND RELATIONSHIPS WITH OTHER MICROZOOPLANKTONIC COMPONENTS

Variação nictemeral dos Tintinnina (Ciliata: Oligotrichida) na região do Atol das Rocas (Atlântico Sul) e relações com outros componentes do microzooplâncton

Eliane Maria de Souza Nogueira[1], Roberto Sassi[2]

ABSTRACT

A major consideration in the study of microzooplankton is the scarcity of data from oceanic waters of the South Atlantic. We examined tintinnines and other surface water microzooplanktonic organisms at a fixed oceanic station near the Atol das Rocas Island (northeastern Brazil) at different times of the day, from 14 to 16 March, 1999. Tintinnines dominated and were represented by 42 species. The greatest diversities and abundances of microzooplankton were found in diurnal samples, although large fluctuations were regularly observed. The greatest diversity and abundance of was observed during the daytime at 06:00 and 14:00, and during the night at 19:00 and at 21:30. The most frequent and abundant species were Rhabdonellopsis apophysata *(Cleve) Kofoid & Campbell, 1929,* Rhabdonella amor *(Cleve 1900) Brandt, 1907 , R. elegans Jörgensen, 1924,* Undella claparedei *(Entz, Sr., 1885) Daday, 1887,* Epiplocylis undella *(Ostenfeld & Schmidt 1901) Jörgensen, 1924 , and* Eutintinnus apertus *Kofoid & Campbell, 1929. Copepods and crustacean larvae were very abundant during the day, especially at 07:00 and 14:00. The Foraminifera were abundant only at 06:00, 09:00, 10:00, and 14:00. Other microzooplanktonic groups were observed occasionally. Vertical migration, patchy distributions, and the 'island effect' are the principal hypotheses suggested to explain the patterns observed.*

Key words*: microzooplankton, Tintinnina, nicthemeral variations.*

RESUMO

Informações disponíveis sobre o microplâncton em águas oceânicas do Atlântico Sul são ainda muito escassas. Os tintinídeos e outros organismos microzooplanctônicos foram obtidos nas águas da superfície oceânica em uma estação fixa nas imediações do Atol das Rocas (nordeste do Brasil) em diferentes períodos do dia, de 14 a 16 de março de 1999. Os tintinídeos dominaram e foram representados por 42 espécies. A maior diversidade e abundância de microzooplâncton foram encontradas em amostras diurnas, embora grandes flutuações fossem observadas regularmente. A maior diversidade e abundância foram observadas durante o dia às 06:00 e 14:00, e durante à noite, às 19:00 e 21:30. As espécies mais freqüentes e abundantes foram Rhabdonellopsis apophysata *(Cleve) Kofoid & Campbell, 1929,* Rhabdonella amor *(Cleve 1900) Brandt, 1907 , R. elegans Jörgensen, 1924,* Undella claparedei *(Entz, Sr., 1885) Daday, 1887,* Epiplocylis undella *(Ostenfeld & Schmidt 1901) Jörgensen, 1924 , e* s *Kofoid & Campbell, 1929. Copépodes e larvas de Crustáceos foram muito abundante durante o dia, especialmente às 07:00 e 14:00. Os foraminíferos foram abundantes apenas às 06:00, 09:00, 10:00 e 14:00. Outros grupos do microzooplâncton foram observados ocasionalmente. Migração vertical, distribuição desigual, e os efeitos insulares são as principais hipóteses sugeridas para explicar os padrões observados.*

Palavras-chaves: *microzooplâncton, Tintinnina, variação nictemeral.*

[1] Universidade do Estado da Bahia. Campus VIII. Paulo Afonso, Bahia, Brazil. CEP: 48600-000. E-mail: emsnogueira@gmail.com.br
[2] Universidade Federal da Paraíba (UFPB). CCEN/DSE/NEPREMAR. Cidade Universitária, João Pessoa, CEP: 58049-900, PB, Brazil. E-mail: sassi_rs@yahoo.com.br

INTRODUCTION

Information about microplankton in oceanic waters off the Brazilian coast is still scarce, and only the forms with rigid skeleton or lorica have been emphasized in the available literature, such as the foraminifers (Boltovskoy, 1964, 1968) and the tintinnines (Balech, 1971; Pompeu, 1998; Fernandes, 1998, 1999; and Galvão, 2000). The main emphasis on the first group has been on their taxonomy, while studies of the tintinnines have examined not only their taxonomy but also their ecological and/or biogeographical aspects, especially their abundance and distribution. However, short-term variations of microzooplanktonic populations in Brazilian oceanic waters have not been investigated.

The few studies on oceanic plankton and on the continental shelf in northeastern Brazil, (*e.g.* Paranaguá, 1966 a, b; Gusmão,1986; Menezes, 1986; Sant'anna 1988; and Nascimento-Vieira *et al.* 1990) were undertaken during oceanographic surveys by the Brazilian Navy, especially the expeditions by the R.V " Almirante Saldanha": the North-Northeast I (Oceanographic) Survey carried out in 1967, and II in 1968; GEOMAR I in 1968, II in 1970, and III in 1971; and Northeast III in 1986. However, microzooplanktonic components were normally only secondarily considered during these expeditions. These organisms were more recently studied by Galvão (2000) and Nogueira & Sassi (2001) based on collections made by researchers of the R.V.s "Victor Hensen"(Brazilian German Victor Hensen Programme JOPS – II), "Antares" (Live Resources Program of the Exclusive Economic Zone or REVIZEE/Brazil, in Portuguese), and "Seward Johnson" (Branch-Harbor Oceanographic Institute, USA).

The present work examined various aspects of the nychthemeral variation of microzooplankton collected near the Rocas Atoll, northeastern Brazil, with emphasis on the taxonomy of tintinnines.

MATERIAL AND METHODS

The Rocas Atoll is unique in Brazil as well as in the southern Atlantic Ocean; it is located 148 km to the west of Fernando de Noronha Archipelago at 03°52 S; 33°49 W and is characterized as an elliptic, almost circular calcareous algal reef covering approximately 5.5 km^2 and with an opening connecting its central lagoon to the open sea; the longest axis (E-W) measures 3.7 km and the shortest axis (N-S) 2.5 km (Rodrigues, 1940; Kikuchi, 1994; Maida & Ferreira, 1997). To the northwest and southwest of the atoll are two coarse-sand islands of fractionated coral-calcareous algae that are permanently above sea level - the Ilha do Farol (Lighthouse Island) with an area of 34,637 m^2, and the Ilha do Cemitério (Cemetery Island) with an area of 31,513 m^2 (Rodrigues, 1940). An equatorial hot climate prevails in the study area, with a cool trade wind from the southwest. The average air temperature varies between 28°C and 32°C during the year (Pinto, 1993) and the surface water temperature is approximately 27.7°C. The rainy season is between March and July, with peaks in April (250 mm) and May; with October being the driest month (6 mm). The relative humidity is high throughout the year, almost always above 80%. The study area is within the 'Atol das Rocas and Fernando de Noronha Biological Reserve', a marine protected area created by Federal Law in 1979, presently managed by the Brazilian Institute for the Environment and Natural Resources (IBAMA).

The material examined was obtained during a scientific expedition on board the (R.V.) "Seward Johnson" (USA), as a part of the project 'Life History of the Lemon Shark (*Negaprion brevirostris*)', which sought to study this animal's behavior near the Fernando de Noronha archipelago (Pernambuco State) and the Atol das Rocas (Rio Grande do Norte State), both off the northeastern coast of Brazil.

Twenty-two samples were collected from the surface waters at a fixed station close to the atoll (3°51'36" S and 33°49'58" W) at different times during the day and night, between March 15 and 17, 1999. At each sampling, 20 L of water was collected in plastic buckets and filtered through a 20 µm mesh nylon net using reverse filtration. The concentrated material was preserved in 4% neutral formaldehyde and each sample was decanted in the laboratory after settling for 48 hr in 50 ml counting chambers, and were subsequently examined under a Zeiss inverted microscope. All microzooplanktonic components were counted. The tintinnines were identified to the species level.

RESULTS

Tintinninas were present in the greatest numbers among the groups investigated here. During the day, large numbers of copepods and crustacean larvae were also found, mainly in the samples collected at 07:00 and 14:00. Foraminifers were also abundant at 06:00, 09:00, 10:00, and 14:00. During the night there were only limited numbers of several microzooplanktonic components, but large counts of copepods (18:00), crustacean larvae (21:30 and 01:00), and foraminifers (21:00) were found in the samples (Figure 1).

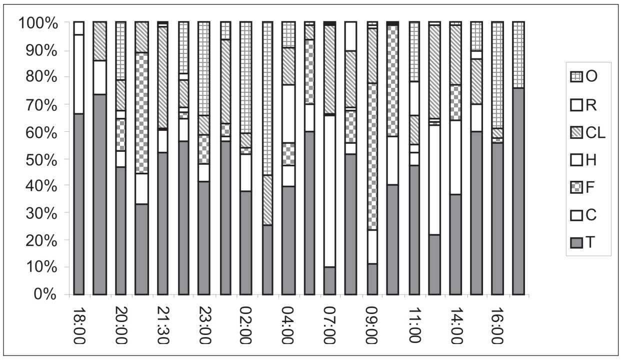

Figure 1- Nychthemeral variations in the numbers of individuals of tintinnines (T), copepods (C), crustacean larvae (CL), heliozoan (H), radiolarian (R), foraminifers (F), and other microzooplankton components (O) at the Rocas Atoll, northeastern Brazil, in March,

Tintinnines represented approximately 45.4% of the total number of microzooplankton individuals (Table I). These ciliates showed wide variations in the numbers of species and their density, with the greatest biodiversities and densities being recorded during the day. Both the largest numbers of species and greatest total densities of organisms were collected at 19:00 (23 species and 38,45 individuals X $10^3 \cdot m^{-3}$), at 21:30 (13 species and 14,95 individuals X $10^3 \cdot m^{-3}$), at 6:00 (19 species and 18,25 individuals X $10^3 \cdot m^{-3}$), and at 14:00 hours (19 species and 18,05 individuals X $10^3 \cdot m^{-3}$) (Fig. 2 and Tab. II).

Table I- Relative contributions of the different microzooplanktonic groups found throughout the nychthemeral cycle at Rocas Atoll, northeastern Brazil, in March, 1999.

Components of the microzooplankton	Individuals ($10^3.m^{-3}$)		Mean contribution (%)
	minimun	maximun	
Tintinnines	0.6	38.45	45.40
Copepods	0	30.05	12.70
Foraminifers	0	11.45	10.41
Heliozoan	0	0.90	1.94
Crustacean larvae	0	17.70	14.88
Radiolarian	0	0.75	1.71
Others	0	1.35	12.98

A total of 42 species of tintinnines were identified during the nychthemeral cycle, but demonstrated irregular distributions during the study period. Most species occurred only sporadically, except *Rhabdonellopsis apophysata* (Cleve) Kofoid & Campbell, 1929, which occurred in all 22 samplings; the other species and their respective numbers of sample presences were: *Rhabdonella* amor (Cleve 1900) Brandt, 1907 (21), *Rhabdonella elegans* Jörgensen, 1924 (20), *Undella claparedei* (Entz, Sr., 1885) Daday, 1887 and *Epiplocylis undella* (Ostenfeld & Schmidt 1901) Jörgensen, 1924(19), and *Eutintinnus apertus* Kofoid & Campbell, 1929 (14). The species which were encountered in nearly 50% of the scheduled samplings were: *Eutintinnus fraknoi* (Daday) Kofoid & Campbell, 1929, *Codonellopsis tuberculata tuberculata* (Daday) Jörgensen, 1924, *Poroecus apicatus* Kofoid & Campbell, 1929, and *Protorhabdonella simplex* (Cleve) Jörgensen, 1924. The species collected only during the day were: *Amphorellopsis acuta* (Schmidt, 1901), *Codonellopsis morchella* (Cleve, 1900) Jörgensen, 1924, *Codonella nationalis* Brandt, 1906, *Coxliella* sp., *Dictyocysta mitra* Haeckell, 1837, *Eutintinnus lususundae* (Entz, Sr.) Kofoid & Campbell, 1939, *E. medius* Kofoid & Campbell, 1939, *Favella ehrenbergii*, (Claparìde e Laahmann, 1858), *Metacylis mereschkowskyi* Kofoid &Campbell, 1929, *M. perspicax* (Hada, 1938), *Tintinnopsis dadayi* Kofoid, 1905 , *Undella californensis* Kofoid & Campbell, 1929, and *U. hyaline* Daday, 1887. The species collected only during the night were: *Coxliella laciniosa* (Brandt) Brandt, 1907, *Dictyocysta elegans lepida* (Ehrenberg) Balech, 1959, *Eutintinnus haslea* Taniguchi & Hada, 1981, *Salpingella subconica Kofoid & Campbell, 1929, Steenstrupiella steenstrupii* (Claparère & Laackmann, 1858) Kofoid & Campbell, 1929, and *S. gracilis* (Jörgensen) Kofoid & Campbell, 1929. (Tab. II).

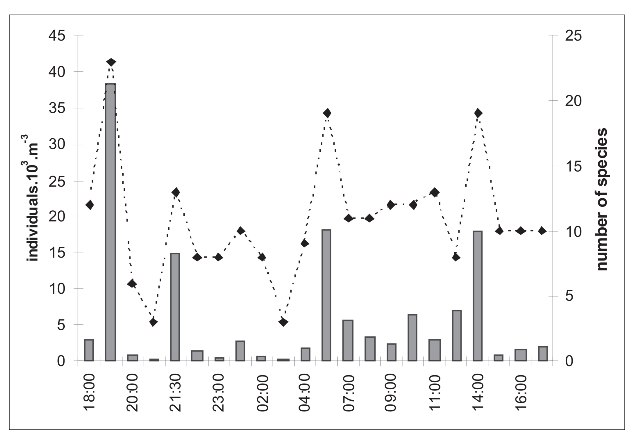

Figure 2- Nychthemeral variations in tintinnines at the Rocas Atoll, northeastern Brazil, in March, 1999.

Table II- Tintinnines found in 22 samples collected throughout the nychthemeral cycle at the Rocas Atoll, northeastern Brazil, in March 1999 (N = number of times the species was recorded; % = maximum percentage of loricate individuals found in comparison to other hours of the nychthemeral cycle; abundance levels: + = up to 2,500 ind.·m^{-3}; ++ = from 2,500 to 5,000 ind.·m^{-3}; +++ = from 5,000 to 7,500 ind.·m^{-3}).

Species	N			Times of highest peaks			Times of highest peaks		
	Night	Day	Total	Night	%	Abundance	Day	%	Abundance
Amphorellopsis acuta	0	1	1						
Amphorides quadrilineata	4	6	10	19:00	78.94	+	14:00	41.17	+
Ascampbelliella urceolata	6	6	12	19:00	84.00	+	14:00	54.28	+
Codonella apicata	3	2	5	19:00	93.65	+			
Codonella aspera	4	1	5	19:00	75.00				
Codonella nationalis	0	2	2						
Codonellopsis morchella	0	2	2						
Codonellopsis tuberculata	5	7	12	19:00	73.91	+	14:00	43.10	+
Coxliella laciniosa	2	0	2						
Coxliella massuti	2	2	4						
Coxliella meuniere	2	2	4						
Coxliella sp	0	2	2						
Dadayella ganymedes	2	2	4						
Dictyocysta elegans	2	0	2						
Dictyocysta mitra	0	2	2						
Epiplocylis undella	10	9	19	19:00	61.72	++	13:00	52.60	+++
Epiplocyloides reticulata	4	6	10	19:00	86.95	+	14:00	50	+
Eutintinnus apertus	7	7	14	01:00	36.84	+	08:00	32.00	+
Eutintinnus fraknoi	7	6	13	18:00	52.63	+	06:00	73.58	++
Eutintinnus haslea	2	0	2						
Eutintinnus lususundae	0	3	3						
Eutintinnus medius	0	2	2						
Eutintinnus stramentus	6	4	10	21:30	40.00	+			
Eutintinnus tubulosus	2	3	5				06:00	61.11	+
Favella erhenbergii	0	2	2						
Metacylis mereschkowskyi	0	2	2						
Metacylis perspicax	0	2	2						
Poroecus apicatus	2	9	11	21:30	100.00	+	14:00	38.09	+
Poroecus curtus	2	2	4						
Protorhabdonella curta	2	2	4	19:00	100.00	+			
Protorhabdonella simplex	3	7	10	19:00	97.77	+	14:00	42.85	+
Rhabdonella amor	10	11	21	19:00	57.07	++	14:00	38.28	++
Rhabdonella cornucopia	3	2	5						
Rhabdonella elegans	10	10	20	21:30	48.71	++	06:00	50.34	++
Rhabdonellopsis aphophysata	10	12	22		72.84	++	06:00	38.85	++
Salpingella subconica	2	0	2	19:00	100.00	+			
Steenstrupiella gracilis	5	0	5	19:00	66.66	+			
Steenstrupiella	2	0	2						
Tintinnopsis dadayi	0	5	5						
Undella californiensis	0	2	2						
Undella claparedei	9	11	19	19:00	62.31	++	14:00	54.09	+++
Undella hyalina	0	3	3				14:00	8.50	+

DISCUSSION

The tintinnina, as well as other microzooplanktonic components, had marked diurnal occurrences, with the highest numbers of individuals and species being seen during the daylight hours. This result is likely due to mechanisms of vertical migration, and their distribution in distinct patches. There are many reports in the literature describing distinct diurnal and nocturnal periods of zooplankton abundance and diversity associated with mechanisms of species migration. High concentrations of adult copepods have been reported during nocturnal samplings - but their young appear to be distributed more uniformly in the water column or to be concentrated at different depths (Raymont, 1983).

Distinct ontogenetic cycles of vertical zooplankton distribution (either nychthemeral or seasonal) have been observed in various organisms, especially in the genera *Calanus* and *Metridia*, and in many amphipods as well. These behavioral patterns seem to be related to physiological differences between the organisms (Raymont, 1983), or they could be due to the capacity (or incapacity) of many species to maintain geographic stability of their populations. Boden and Kampa (1967) suggested that vertical migration could be associated with changes in luminosity.

In oceanic waters of the Current of Brazil, specifically over the submarine seamounts Vitória-Trindade (Espírito Santo State, southeastern Brazil), zooplankton have been observed to concentrate between the isobaths of 0 - 50 m; however, in areas more distant from submarine seamounts, their highest concentrations were recorded in deeper waters - especially at the 0 - 100 m and 0 - 200 m layers (Schutze *et al,* 1990). It is noteworthy that this phenomenon was not observed by Vanucci & Almeida-Prado (1959) and Razouls *et al.* (1987), who had studied that region earlier.

Patchy spatial distributions are commonly found among planktonic populations, and these are usually the result of mechanisms of multispecific physical aggregation. The formation of planktonic patches in the study area may initiate at sites experiencing a vertical addition of nutrients through upwelling, resulting in fertilization of the water and a consequent increase in phytoplankton biomass. Distinct water circulation patterns in the area may maintain these patches for relatively long periods of time.

According to data published by Uda & Ishino (1958), orographic-driven divergence or convergence of currents occur close to oceanic seamounts. Upwelling movements resulting from such phenomena can result in significant enrichment of the upper water layers. However, the data available from our study area is not sufficient to attribute a positive effect of resurgence on fertilizing the euphotic zone (Travassos *et al.,* 1997). The thermocline identified in the area during our study period (Cordeiro *et al,* 2000; unpublished report) remained below 100 m, and the maximum concentrations of chlorophyll-*a* were restricted to this depth. However, it is worth noting that the umbrophilic species of tintinnines collected at the surface (*e.g. Dictyocysta mitra* and *U. hyaline*, according to Balech, 1972) seem to indicate that some upwelling from deeper levels may occur in the area.

We hypothesize an alternative explanation for the nychthemeral pattern - an *island* or *oceanic seamount effect* due to a greater availability of food for zooplankton as a result of water fertilization close to the atoll, even though no 'island effect' influencing the productivity at adjacent oceanic sites have yet been confirmed (Brandini *et al,* 1997). In the present study no influence of the atoll on vertical distribution of the water mass above 200 m was observed; the pycnocline remained between 100 m and 80 m depth and the isopycnic appeared to be structurally similar both above and below those levels (Cordeiro *et al,* 2000; unpublished report).

The observed predominance of tintinnines in diurnal samples may be a brief artifact in our study area, since in other regions (*e.g.* in the Arabian Sea, as reported by Zeitzschel 1969), no differences were observed between diurnal and nocturnal samples.

Temperature seems to affect the vertical distribution of tintinnines, while water currents influence their horizontal distribution, as was observed in the Adriatic Sea by Krsinic (1982). This author reported that tintinnines are more abundant and diversified in the 100-0 m layer, and that they as well as other microzooplanktonic components markedly decrease in abundance and species diversity with increasing depth.

Some authors have reported patterns of aggregated distribution of tintinnine populations in samples collected in surface waters (Reid, 1982, Pompeu 1998). Sime-Ngando *et al.* (1992) observed a similar distribution of ciliates above the Cobb submarine seamount on the western coast of Canada, and discussed how environment heterogeneity caused by physical processes such as local vortices and local fronts favor opportunist species.

Some of the species reported here, such as *Rhabdonellopsis apophysata*, *Rhabdonella amor*, *R. elegans*, *Undella claparedei*, *Epiplocylis undella*, and *Eutintinnus fraknoi* that were encountered in 50% of the samples could be examples of aggregated species and their greater ability to efficiently utilize the available food.

Capriulo (1990) found that the abundance and generic composition of ciliates depend on the amount of available food and on predation. Copepods and crustacean larvae are known to be predators of tintinnines, but it was not possible to affirm here any relationship of that nature, because copepods and crustacean larvae occurred in expressive densities in some of the collections but their totals did not exceed the number of tintinnines.

The low values of chlorophyll-a in the mixing layer and the maximum values (never above 0.22 $\mu g.L^{-1}$) found only near the thermocline (Sampaio, 1998; Cordeiro *et al*., 2000) indicate low concentrations of phytoplankton in the study area, leading us to believe that alternative food sources may subsidize the pelagic food web around the atoll. It is likely that detrital matter near the atoll, such as 'mucus' and 'organic aggregates' produced by benthic communities (especially corals) make up the main food source of the local microzooplankton.

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