UNIVERSIDADE FEDERAL DE PERNAMBUCO
Departamento de Oceanografia

TROPICAL OCEANOGRAPHY
Revista online

ISSN: 1679-3013
D.O.I.: 10.5914/to.2014.0106

CELL BIOVOLUME AND BIOMASS IN CARBON OF MICROPHYTOPLANKTON SPECIES OF OCEANIC REGIONS, EQUATORIAL ATLANTIC

Andressa RIBEIRO DE QUEIROZ[1]
Maria Luise KOENING[1]
Felipe Lima GASPAR[1]

Recebido em: 13/05/2013
Aceito em: 16/09/2014

ABSTRACT

The interactions between physical-chemical features in the ocean directly reflect on the behavior of the phytoplankton community, so studying them, is fundamental to the knowledge of the islands in oceanic regions. This study aimed to obtain the values of organic carbon in biomass through cell biovolume of microphytoplankton species collected from the São Pedro and São Paulo Archipelago in order to contribute and update the models mentioned in the literature. Samples were collected in March 2008, at four transects perpendicular to the Archipelago. Among the 110 identified species, 33 species were selected for the measurement of cell biovolume. Three geometric shapes not previously combined were prepared for the genus *Ceratium* whose morphological complexity was not observed in previous protocols, and it was verified the lack in the literature of more precise measurements of the cell dimensions of certain organisms. The highest values of cell biovolume and biomass carbon were obtained for *Pyrocystis noctiluca* Murray ex Haeckel. It is expected that the implementation of the proposed recommendations on the models will encourage research in this area and increase the accuracy in determining the morphological measurements.

Key words: marine phytoplankton, morphological measurements, ocean island.

RESUMO

As interações entre os recursos físico-químicos no oceano refletem diretamente no comportamento da comunidade fitoplactô-nica, assim, estudá-las torna-se fundamental para o conhecimento das ilhas em regiões oceânicas. O presente trabalho teve como objetivo, obter os valores de biomassa em carbono orgânico através do biovolume celular das espécies do microfitoplâncton do Arquipélago São Pedro e São Paulo no intuito de contribuir e atualizar os modelos citados na literatura. Foram realizadas coletas em março/2008, em quatro transectos perpendiculares ao Arquipélago. Dentre as 110 espécies identificadas na composição microfitoplanctônica, 33 espécies foram selecionadas para a medida do biovolume celular. Foram elaboradas três formas geométricas combinadas inéditas para o gênero *Ceratium* cuja complexidade morfo-lógica não foi observada em protocolos anteriores e verificada a carência, na literatura, de medidas mais precisas das dimensões celulares de determinados organismos. Os maiores valores de biovolume celular e biomassa em carbono foram de *Pyrocystis noctiluca* Murray ex Haeckel. Espera-se que a aplicação das recomendações propostas, no presente trabalho, sobre os modelos venha encorajar estudos nesta área e aumentar a precisão na determinação das medidas morfológicas.

Palavras chave: fitoplâncton marinho, medições morfológicas, ilha oceânica.

INTRODUCTION

Complex interactions between environmental resources and the spatial and temporal variations of climatological, geological, hydrodynamics, chemical and hydrological factors directly reflect on the behavior of marine phytoplankton, thus determining changes in primary production and consequently in the energy transfer in the form of carbon for other trophic levels, including organisms of economic importance (LASTERNAS et al., 2008) .

[1] Departamento de Oceanografia, Universidade Federal de Pernambuco - UFPE, Av. Arquitetura, s/n, Cidade Universitária, CEP 50610-901, Recife-PE, Brasil. aribeiroq@yahoo.com.br; koening@ufpe.br; felipe.gaspar@ufpe.br.

Studies conducted in the vicinity of the Saint Peter and Saint Paul Archipelago are scarce due to the difficulties of access in remote waters off the coast, especially in oceanic islands, hampering research involving these complex physicochemical interactions with the phytoplankton in the tropical and equatorial Atlantic (BRÖCKEL; MEYERHÖFER, 1999; KOENING; OLIVEIRA, 2009; QUEIROZ, 2011; TIBURCIO et al., 2011), and thus, it becomes crucial the knowledge and the development of research in the area (SKIELKA et al., 2006).

There are several methods reported in the literature that estimate the algal biomass. These methods are considered automatic or semi-automatic and bring with them methodological advantages and disadvantages, constantly debated (HILLEBRAND et al., 1999; SUN; LIU, 2003; VADRUCCI et al., 2007).

The study of biomass in carbon by determining the biovolume is connected to several publications related to the dynamics of the phytoplankton community (SOURNIA, 1981; HILLEBRAND et al., 1999). Evidence from studies of variability and distribution of biomass and productivity of phytoplankton by size classes have shown the important implications of cell size in the biogeochemical cycle of carbon and the structure of the pelagic food web (MALONE, 1980; LARA-LARA; GUZMÁN, 2005).

The cell biovolume can be defined as a descriptive analysis that uses measurements of cell size and shapes, being able to reliably estimate the values of biomass in carbon. It is of fundamental interest to obtain a more accurate picture of the carbon contents contained in the cells, defining the trophic status of the environment (SUN; LIU, 2003; OLENINA et al., 2006; VADRUCCI et al., 2007).

Thus, the environmental understanding and modeling of the aquatic ecosystem are not possible without the knowledge of the species composition, the values of productivity and biomass in carbon of phytoplankton (OLENINA et al., 2006).

For this reason, adopting the methodology of cell biovolume becomes more reliable by counting the cells, eliminating the detrital particles (VERITY et al., 1992; MONTAGNES et al., 1994). It is considered a relevant quantitative analysis, using appropriate geometric models associated with cell shape, considering the wide range of size classes of phytoplankton, which varies greatly between different genres, and even between different individuals (HILLEBRAND; SOMMER, 1996; ROTT et al., 2007).

The present study aimed to obtain the values of biomass in organic carbon through the cell biovolume of some species of microphytoplankton of the São Pedro and São Paulo Archipelago, in order to update the models proposed by Hillebrand et al., (1999); Sun and Liu (2003); Olenina et al., (2006) and Vadrucci et al., (2007).

STUDY AREA

The São Pedro and São Paulo Archipelago (ASPSP) is located in the tropical Atlantic Ocean between the coordinates 0° 55′ 02″ N and 29° 20′ 42″ W. It is formed by a set of 15 rocky islets, from an outcrop of sub-oceanic mantle (CAMPOS et al., 2005).

Is distant about 330 nautical miles from the Fernando de Noronha archipelago, which belongs to the State of Pernambuco, and 510 nautical miles from Calcanhar Capel in the State of Rio Grande do Norte. Its base is located at 4,000 m depth, being the only Brazilian oceanic archipelago located in the Northern Hemisphere, since it is located about 100 km (62.14 nautical miles) north of the equator line (CAMPOS et al., 2009). The extent of the emerged area is around 17,000 m² and the distance between endpoints, which lie between the Sacadura Cabral and Graça Aranha rocks, is of 420 m.

Pelagic systems in the Northeast and Eastern Brazil should be considered as a single system, mainly controlled by the impact of oligotrophic waters of the South Equatorial Current (SEC) and derived currents. Due to the impact of the South Equatorial Current, the Northeast is considered a region of low primary productivity, which according to Platt et al., (1983), are plausible for tropical oceanic waters (EKAU; KNOPPERS, 1999).

Tropical regions of the oceans, although oligotrophic by containing a minimum of vertical flux of nutrients and low biological productivity, are considered areas with very high diversity (LONGHURST; PAULY, 1987). This oligotrophic character is explained by the existence of a permanent thermocline in the region, which does not allow deep waters, rich in nutrient, to mix with surface waters. In these areas, the possible mixtures occurring in the water column are promoted by local mechanisms such as winds and interactions between ocean currents and/or submarine relief (TRAVASSOS et al., 1999).

From the scientific point of view, its geographical position, between the North and South Hemispheres, and the American and African continents, gives the archipelago a single condition for conducting research in various branches of science. It is an area of biological importance because it exerts relevant role in the life cycle of various species that have the archipelago as an important stage of their migration routes, either as reproduction or feeding zone (PORTO, 2006).

MATERIALS AND METHODS

Samples were taken in March 2008 (rainy season), in four transects perpendicular to the São Pedro and São Paulo Archipelago, under the north (N), south (S), east (E) and west (W) orientations, each one having four stations, distant from one another approximately 926 m, corresponding to 0.5 nautical miles (Fig. 1).

Samples were collected with a plankton net of 45 µm mesh size and the material was stored in plastic pots of 200 mL.

The samples were fixed in formaldehyde (4% volume), buffered with sodium tetraborate and later deposited in the Laboratory of Phytoplankton of the Oceanography Department of UFPE. Then, they were homogenized and five sub-samples of 0.5 mL were taken for analysis of the composition, relative density, with the identification and counting of taxa made using the microscope Motic (BA- 300 model) with 10x and 20x objectives, coupled with the photographic camera CANON A620.

For calculating cell biovolume, 33 species that had frequency of occurrence higher than 30% were selected, and approximately 20 measurements were made for each species from the capture of images (HILLEBRAND et al., 1999).

The frequency of occurrence of taxa was expressed in terms of percentage, according to Mateucci and Colma (1982), using the following formula: F = Px100/p, where: F = frequency of occurrence; P = number of samples containing the species; p = total number of samples collected. Depending on the value of F, i.e., the degree of frequency of occurrence, the species were classified into the following categories: Sporadic <10%; Common >10 to ≤50% and Very frequent >50%.

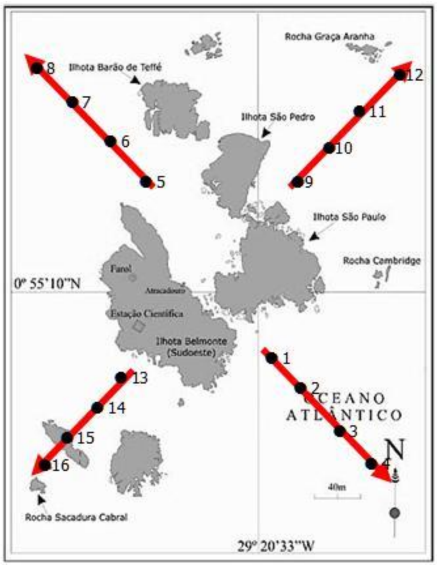


Figura 1 – Arquipélago de São Pedro e São Paulo, situando as quatro ilhotas maiores, a estação científica (ECASPSP) e o farol, tendo como base a carta náutica n° 11 da DHN. As setas representam os transectos e os pontos em preto os locais onde foram realizadas as coletas. Fonte: Modificado de MELO et al. (2010).

Some methodological aspects were considered before the morphological measurements were made. The cells were measured at high magnification (x100, x200, x400) of the optical microscope, avoiding distortions in cell shape and halos of light, in an attempt to reduce super or sub-estimations of cell volume (OLENINA et al., 2006). Subsamples were used to photograph the organisms in various views (lateral, apical, dorsal, ventral), including images of the third dimension. Most frequent species are seen with greater occurrence from different points of view, so that each dimension is photographed and measured. In cases where species were seen with a fixed position in the sample, tweezers was used (SUN and LIU, 2003) to lightly touch the coverslip, allowing movement of the cell. That made it possible to capture images of other views of the organisms. Measurements were made with the pictures, using a manual ruler and the data in cm were converted into μm.

The cells were measured in the vegetative phase avoiding changes in cell shape and the counting unit was the cell, independent of colonial or chain forms, with the exception of filamentous species in which the trichomes were measured (ROUND et al., 1992, VADRUCCI et al., 2007).

To standardize the measures, the following abbreviations were taken into consideration: TL - Total length; CL - Cell length; H1 - Ellipsoid height; H2 - Monoraphidioid height; h1 - Cylinder height; h2 - Cone 1 height; h3 - Cone 2 and truncated cone 1 height; h4 - Cone 3 and truncated cone 2 height; L1- Ellipsoid width; L2 - Smaller diameter of monoraphidioid; D - Larger diameter of monoraphidioid; d1- Cylinder diameter; d3- Ellipsoid diameter; d4 - Truncated cone 1 and cone 1 diameter; d5 - Largest diameter of truncated cone and cone 2; d6 - Smaller diameter of truncated cone 2 and cone 3; d7 - Smaller diameter of truncated cone 2; d8- Cone diameter. The following calculations were also performed: Min- minimum; Max- maximum; C.V.- Coefficient of Variation; D.P.- Standard Deviation, X - Mean; med- Median (Annex 2).

For confirmation, the measurements of the cells were compared with the works of Hasle and Syvertsen (1997), Steidinger and Tangen (1997), Therriault et al., (1999), Tenenbaum (2004) and Tenenbaum et al., (2006) Komárek and Anagnostidis (2005) and Avancini et al., (2006). The geometric shapes used in this study were based on protocols of Hillebrand et al., (1999), Sun and Liu (2003), Olenina et al., (2006) and Vadrucci et al., (2007).

For the calculation of cell biovolume, the mean value of a suite of cells was used, not the individual value as proposed by Hillebrand et al., (1999).

For the extrapolation of the organic carbon, the following conversion factors were applied: Dinoflagellates: $pgC= 0.216*BV^{0.939}$ (MENDEN-DEUER; LESSARD, 2000). Bacillariophyta: $pgC= 0.288*BV^{0.811}$ (MENDEN-DEUER; LESSARD, 2000). Cyanobacteria: $pgC= 0.436*BV^{0.863}$ (VERITY et al., 1992).

RESULTS

The microphytoplankton specific composition of the São Pedro and São Paulo Archipelago was constituted of 110 taxa represented by four taxonomic divisions, distributed among 85 dinoflagellates (Division Dinoflagellata), 18 diatoms (Division Bacillariophyta), six cyanobacteria (Division Cyanobacteria) and one silicoflagellate (Division Heterokontophyta).

Only the species of the genus *Trichodesmium* were dominant. From the identified taxa, 21% were considered very frequent, 48% frequent and 31% sporadic. The number of taxa per sample, i.e., species richness, ranged from 31 to 48 (40±12 taxa).

Of the total taxa recorded, 12 species were new records for the region: *Trichodesmium tenue* Wille, *Katagnymene spiralis* Lemmermann, *Katagnymene pelagica* Lemmermann and *Richellia intracellularis* Schmidt, *Phalacroma mitra* Schütt, *Gonyaulax birostris* Stein, *Ceratium belone* Cleve, *C. declinatum* var. *angusticornum* (Karsten) Jørgensen, *C. karstenii* Pavillard, *C. pentagonum* var. *longisetum* Jørgensen, *Spiraulax kofoidii* Graham and *Protoperidinium oceanicum* Vanhøffen.

To identify the geometric shapes that best combine the cellular forms of this study, a comparison of the forms created by other authors was performed and the chosen ones were adopted in this study (Tab. 1).

Table 1 - List of the 33 most representative taxa of microphytoplankton of São Pedro and São Paulo Archipelago with associated forms based on the literature and in the proposed study.

Authors	**1**	**2**	**3**	**4**	**5**
Cyanobacteria					
Katagnymene pelagica	C	C	C	C	C
Trichodesmium erythraeum	C	C		C	C
Trichodesmium thiebautii	C	C		C	C
Dinoflagellata					
Ceratocorys horrida	ES/2	ES/2			E
Gonyaulax polygramma	2 CO	2 CO	CO + ES/2	CO + ES/2	CO + ES/2
Goniodoma polyedricum	ES	ES		ES	ES
Histioneis milneri	E	E			E
Ceratium belone	E + 2 CO + C	E + 2 CO + C		E + 2 CO + C	3 CO
Ceratium candelabrum var. *candelabrum*	E + 2 CO + C	E + 2 CO + C		E + 2 CO + C	E + 2 CO + C
Ceratium cotortum	E + 2 CO + C	E + 2 CO + C		E + 2 CO + C	E + 2 CO + C
Ceratium declinatum var. *declinatum*	E + 2 CO + C	E + 2 CO + C		E + 2 CO + C	E + 2 CO + C
Ceratium digitatum	E + 2 CO + C	E + 2 CO + C		E + 2 CO + C	E + COT+ MO +CO
Ceratium fusus	E + 2 CO + C	E + 2 CO + C		2 CO	2 CO
Ceratium gibberum	E + 2 CO + C	E + 2 CO + C		E + 2 CO + C	E + 2 CO + C
Ceratium lineatum	E + 2 CO + C	E + 2 CO + C		E + 2 CO + C	C + CO + COT
Ceratium macroceros	E + 2 CO + C	E + 2 CO + C		E + 2 CO + C	E + 2 CO + C
Ceratium massiliense	E + 2 CO + C	E + 2 CO + C		E + 2 CO + C	E + 2 CO + C
Ceratium pentagonum var. *longisetum*	E + 2 CO + C	E + 2 CO + C		E + 2 CO + C	C + CO + COT
Ceratium pentagonum var. *tenerum*	E + 2 CO + C	E + 2 CO + C		E + 2 CO + C	C + CO + COT
Ceratium teres	E + 2 CO + C	E + 2 CO + C		E + 2 CO + C	C + CO + COT
Ceratium tripos	E + 2 CO + C	E + 2 CO + C		E + 2 CO + C	E + 2 CO + C
Ceratium trichoceros	E + 2 CO + C	E + 2 CO + C		E + 2 CO + C	E + 2 CO + C
Ceratium vultur	E + 2 CO + C	E + 2 CO + C		E + 2 CO + C	E + 2 CO + C
Ornithocercus magnificus	ES/2	ES/2			ES
Ornithocercus quadratus	ES/2	ES/2			ES
Phalacroma doryphorum	E	E		E	E
Protoperidinium depressum	2 CO	2 CO	EA -20%	2 CO	3 CO
Protoperidinium ovum	2 CO	2 CO		2 CO	CO + ES/2
Pyrocystis fusiformis	E	E	MO		MO
Pyrocystis noctiluca	E	E	MO		ES
Spiraulax kofoidii	2 CO	2 CO			2 CO
Bacillariophyta					
Hemiaulus membranaceus	PBE	PBE		C	C
Hemiaulus sinensis	PBE	PBE		C	C

Caption: 1- Hillebrand et al., (1999); 2- Sun and Liu, (2003); 3- Olenina et al., (2006); 4- Vadrucci et al., (2007); 5-Queiroz, (2011). ES- sphere; ES/2- half sphere; E- ellipsoid; C- cylinder; CO- cones; COT- truncated cone; MO- monoraphidioid.

Among the species studied, for the division Cyanobacteria, the pattern suggested by the literature was followed, i.e., the cylindrical pattern for measurement of the trichomes.

Among the Dinoflagellata, the geometric pattern of the species *Ceratocorys horrida* Stein was modified, opting for ellipsoid. For the species *Gonyaulax polygramma* Stein, the geometry associated form has also been modified considering the cone + half sphere form.

To calculate the biovolume, four simple shapes (cylinder, sphere, ellipsoid and monoraphidioid) were applied, as well as three combined forms already applied in previous studies (cone + half sphere, 2 cones, and ellipsoid + 2 cones + cylinder).

Three geometric shapes were designed to measure the complex morphology of the genus *Ceratium* that did not fit the pattern proposed in the literature (*Ceratium belone* Cleve, *C. digitatum* Schütt, *C. lineatum* Ehrenberg, *C. pentagonum* var. *longisetum* Jørgensen, *C. pentagonum* var. *tenerum* Jørgensen and *C. teres* Kofoid). This was the main contribution of this protocol for further studies, called 3 cones; ellipsoid + 2 cones + cylinder; and ellipsoid + truncated cone + monorafidióide + cylinder cone + cone + truncated cone, respectively (annex 1).

The genus *Ornithocercus* was considered as a sphere, and not as a half sphere, although that does not cause morphometric changes in structure since in both cases, only the cell diameter was used.

The species *Protoperidinium depressum* (Bailey) Balech was considered as a combination form of three cones and not two cones, also fitting on the formula suggested in this study. On the other hand, *Protoperidinium ovum* was considered the combined form between cone + half sphere, and not 2 cones.

Although geometric shapes adapted to the genera are used, there are species that escape the rule as: *Pyrocystis fusiformis* (Wyville-Thomson) Blackman and *Pyrocystis noctiluca* Murray ex Haeckel that have distinctive cell shapes, opting for associate them with geometric shapes: monoraphidioid and sphere, respectively.

Regarding the division Bacillariophyta, the genus *Hemiaulus* showed differences among the authors, but this protocol followed Vadrucci et al., (2007).

From the values of cell biovolume, calculations of carbon biomass were applied for the selected species (Table 2).

Table 2 - Values of biovolume and biomass from the association of cell shapes to the geometric shapes of the 33 most representative taxa in the São Pedro and São Paulo Archipelago.

Species	**Biovolume (μm^3)**	**Biomass (pgC. μm^{-3})**
Cyanobacteria		
Katagnymene pelagica	284.603	22.207
Trichodesmium erythraeum	5.950	789
Trichodesmium thiebautii	10.254	1.262
Dinoflagellata		
Ceratocorys horrida	472.994	46.041
Gonyaulax polygramma	3.505	460
Goniodoma polyedricum	121.626	12.862
Histioneis milneri	2.485	333
Ceratium belone	130.849	13.775
Ceratium candelabrum var. *candelabrum*	61.938	6.825
Ceratium cotortum	53.157	5.912
Ceratium declinatum var. *declinatum*	28.081	3.247
Ceratium digitatum	257.983	26.058
Ceratium fusus	34.294	3.918
Ceratium gibberum	61.703	6.801
Ceratium lineatum	72.492	7.912

Ceratium macroceros	14.490	1.745
Ceratium massiliense	20.604	2.428
Ceratium pentagonum var. *longisetum*	518.579	50.251
Ceratium pentagonum var. *tenerum*	125.259	13.222
Ceratium teres	71.301	7.789
Ceratium tripos	135.669	14.251
Ceratium trichoceros	20.604	2.428
Ceratium vultur	274.135	27.587
Ornithocercus magnificus	208.137	21.300
Ornithocercus quadratus	69.393	7.594
Phalacroma doryphorum	133.811	14.068
Protoperidinium depressum	238.304	24.187
Protoperidinium ovum	27.162	3.147
Pyrocystis fusiformis	484.139	47.059
Pyrocystis noctiluca	21.269.151	1.641.388
Spiraulax kofoidii	265.103	26.733
Bacillariophyta		
Hemiaulus membranaceus	92.813	3.077
Hemiaulus sinensis	23.918	1.025

In the division Cyanobacteria, the species that showed higher cell biovolume and biomass in carbon (284,603 μm^3 and 22,207 pgC. μm^3, respectively) was *Katagnymene pelagica*.

Regarding the Division Dinoflagellata, *Histioneis milneri* showed the lowest cell biovolume and biomass in carbon (2.485 μm^{3}and 333 pgC. μm^3, respectively). On the other hand, the highest values were found in *Pyrocystis noctiluca* (21,269,151 μm^3 and 1,641,388 pgC. μm^3, respectively) and among species of the genus *Ceratium*, *Ceratium pentagonum* var. *longisetum* stood out with the highest values of cell biovolume and biomass in carbon (518,579 μm^3 and 50,251 pgC. μm^3, respectively).

For the division Bacillariophyta, *Hemiaulus membranaceus* showed the highest value of cell biovolume and biomass in carbon (92,813 μm^3 and 3077 pgC. μm^3, respectively).

DISCUSSION

The cell biovolume was thoroughly detailed with morphological measurements of cell dimensions, at the level of species, from the association of cell shape to simple or complex geometric shapes. A comparison between cellular forms used by authors who have supported this study served to initially standardize which and how many measures should be applied for each studied species.

Analyzing the formulas, differences among the authors were observed in the formulas of geometric shapes: Monoraphidioid, cone + half sphere, and ellipsoid + 2 cones + cylinder (Table 1) and this lack of standardization enabled to view different results, making it difficult to select the most appropriate form to be used. Besides, there are no explanations in their studies on why the adoption of different formulas for the same geometric shapes. For this reason, as a form of a specific author was adopted, the respective geometrical formula was also used.

The deficiency in the literature of more accurate measurements of cell dimensions of certain organisms was observed, i.e., some data include total diameter and lengths. The width of *Protoperidinium depressum* or length of the hipothec of *Ceratium digitatum* are necessary measurements in the study of biovolume and only the protocol of Olenina et al., (2006) deals with subtle detailing such measures.

The exposed morphometric values (minimum and maximum values of the dimensions, the mean, the standard deviation, the coefficient of variance and the median) were prepared in order that the morphological data of each organism were reported to contribute to further studies related to possible changes in cell morphology, i.e., in search of deepening the knowledge of the species studied.

For the selected species in this study that did not have combined geometric shapes, unpublished models were developed, with particular attention to species *Ceratium digitatum*, *C. belone*, *C. lineatum*, *C. pentagonum* var. *longisetum*, *C. pentagonum* var. *longisetum*, *C. teres* and *Protoperidinium depressum* (Annex 2).

Regarding the obtained values of biovolume, the only comparable work was published by Olenina et al., (2006) in the Baltic Sea, where there were some differences (Table 3). The studied species were in adverse conditions of a semi-enclosed environment with large discharge of nutrients from countries around the Baltic Sea, which may have directly influenced their cell morphology. The variability and instability in the size of organisms depend on the environmental influence, e.g., light and nutrient availability, but also on the way and the life cycle of different phytoplankton groups.

Yet according to the authors cited above, the species were divided into size classes, therefore for each class there is a biovolume, being shown in Table 3.

Table 3 - Comparative data regarding cell biovolume between Olenina et al. (2006) and the present study.

Species	**Olenina et al., (2006)**	**Queiroz (2011)***
Gonyaulax polygramma	10.598	3.506
Ceratium fusus	12.000-27.000	34.294
Ceratium lineatum	9.000-28.000	72.492
Ceratium macroceros	41.258-60.000	14.490
Ceratium tripos	23.200-210.000	135.669
Protoperidinium depressum	148.731-546.766	238.304

*In the present study, the average of the cell measurements for each studied species was used.

Among the species that were used to compare the cell biovolumes found by Olenina et al., (2006) and this study, *Gonyaulax polygramma* obtained a value lower than that found by Olenina et al., (2006), but the diameter (±58) and total length values (±77) are in accordance with the patterns of Licea et al., (1995) and Hallegraeff (1991).

The geometric forms adopted by Olenina et al., (2006) for the species of genus *Ceratium* were not exposed in their work, so the data for comparison of geometric shapes and formulas of biovolume are considered insufficient, even if the measures of the dimensions are in the patterns of Licea et al., (1995) and Steidinger and Tangen (1997).

The geometric form that was developed in this study diverged from the form adopted by Olenina et al., (2006) for *Protoperidinium depressum* which directly influences the result, even though the morphological patterns found and compared with Steidinger and Tangen (1997) are consistent.

It would be expected a greater contribution in terms of biomass for species *Katagnymene pelagica* and *Trichodesmium thiebautii* and *T. erytrhaeum* since they are dominant organisms in the study area and usually form blooms. Therefore, a directly proportional relationship with the relative density was expected. However, as trichomes were measured, it has become immeasurable the contribution of all filaments in terms of biomass for the environment, even that in several times, many colonies or possible blooms in the sampled stations were observed.

For the Division Dinoflagellata, the species *Pyrocystis noctiluca* showed the highest values in relation to biomass and biovolume, specially due to the diameter that has an average of 344 µm. Regarding the genus *Ceratium*, the species *Ceratium pentagonum* var. *longisetum* also presented the highest values of biomass and biovolume when compared to other species of the genus, in particular because of the longer epithec, which has an average height of 328 µm.

Regarding the Division Bacillariophyta, the species *Hemiaulus membranaceus* had a biovolume and biomass higher than *Hemiaulus sinensis*, mainly due to cellular diameter, averaged 51 µm.

CONCLUSION

Trichodesmium tenue Wille, *Katagnymene spiralis* Lemmermann, *Katagnymene pelagica* Lemmermann, *Richellia intracellularis* Schmidt, *Phalacroma mitra* Schütt, *Gonyaulax birostris* Stein, *Ceratium belone* Cleve, *C. declinatum* var. *angusticornum* (Karsten) Jørgensen, *C. karstenii* Pavillard, *C. pentagonum* var. *longisetum* Jørgensen, *Spiraulax kofoidii* Graham, *Protoperidinium oceanicum* Vanhøffen, constitute new records for the oceanic region of the Northeast of Brazil.

Three new morphometric combinations were developed and serve as a suggestion for improvement and standardization of geometric shapes.

Biovolume studies are new to the region. Therefore, this study will serve as contribution and basis of improvement for future studies in Brazilian oceanic regions.

ACKNOWLEDGMENT

To CNPq for granting the scholarship, fundamental to the development of this work. To Prof. Silvio Macedo, project coordinator (Process # 680082/2004-2).

REFERENCES

AVANCINI, M.; CICERO, A. M.; GIROLAMO, I.; INNAMORATI, M; MAGALETTI, E.; ZUNINI, T. S. **Guida al riconoscimento del plâncton dei mari italiani. Volume I Fitoplancton Programma di monitoraggio per il controllo dell'ambiente marino costiero**. Ministero dell'Ambiente della Tutela del Territorio e del Mare – DPN ICRAM - Instituto Centrale per la Ricerca Scientifica e Tecnologica Applicata al Mare. 2006. 263 p.

BRÖCKEL, K. V; MEYERHÖFER, M. Impact of the Rocks of São Paulo and São Pedro upon the quantity and quality of suspended particulate organic matter. **Archive of Fishery** and Marine Research, v. 47, n. 2/3, p. 223-238, 1999.

CAMPOS, T. F. C.; NETO, J. V.; SRIVASTAVA, N. K.; PETTA, R. A.; HARTMANN, L. A.; MORAES, J. F. S.; MENDES, L.; SILVEIRA, S. R. M. **Arquipélago de São Pedro e São Paulo**: Soerguimento tectônico de rochas infracrustais no Oceano Atlântico. In: WINGE, M. et al (Edit.). Sítios Geológicos e Paleontológicos do Brasil. Brasília: CPRM, v. 2. 2005. 515 p.

CAMPOS, T. F. C.; PETTA, R. A.; THEYE, T; SICHEL, S. E.; SIMÕES, L. S. A.; SRIVASTAVA, N. K. S; NETO, J. V.; ANDRADE, F. G. G. **Posição ímpar do Arquipélago São Pedro e São Paulo na diversidade ecológica da Terra**. In: VIANA, D. L. (Org.). O arquipélago São Pedro e São Paulo: 10 anos de Estação científica. Brasília, DF: SECIRM. 2009. p. 54-63.

EKAU, W.; KNOPPERS, B. An introduction to the pelagic system of the north-east and east Brazilian shelf. **Archive Fisheries Marine Research**, v. 2-3, n. 47, p. 113-132, 1999.

HALLEGRAEFF, G. M. **Aquaculturists guide to harmful australian microalgae**. Fishing Industry Training Board of Tasmania/CSIRO Division of Fisheries, Hobart. 1991. 111 p.

HASLE, G. R.; SYVERTSEN, E. E. **Marine diatoms**. In: TOMAS, C.R. (ed.). Identifying marine phytoplankton. Academic Press a division of Harcourt Brace and Company. San Diego, USA: Chapter 2, 1997. p. 5-385.

HILLEBRAND, H.; DÜRSELEN, C. D.; KIRSCHTEL, D.; POLLINGHER, D.; ZOHARY, T. Biovolume calculation for pelagic and benthic microalgae. **Journal of Phycology**, v. 2, n. 35, p. 403-424. 1999.

HILLEBRAND, H.; SOMMER, U. Nitrogenous nutrition of the potential toxic diatom Pseudonitzschia pungens f. multiseries Hasle. **Journal Plankton Research**, v. 18, p. 295-301. 1996.

KOENING, L. M; OLIVEIRA, M. S. **Estrutura da comunidade fitoplanctônica. In. O arquipélago de São Pedro e São Paulo**: 10 anos de Estação científica/ Orgs. Danielle de Lima Viana [et al.] Brasília, DF: SECIRM, 2009. p. 116- 127.

KOMÁREK, J.; ANAGNOSTIDIS, K. **Cyanoprokaryota 2. teil: Oscillatoriales. Süsswasserflora von Mitteleuropa**. Alemanha: Elsevier spektrum ak. verlag. v. 19, 2005. 752 p.

LASTERNAS, S.; TUNIN-LEY, A.; IBÃNEZ, F.; ANDERSEN, V.; PIZAY, M.-D.; LEMÉE. R. Dynamics of microphytoplankton abundance and diversity in NW Mediterranean Sea during late summer condition (DYNAPROC 2 cruise; September–October, 2004). **Biogeosciences Discussions**, v. 5, p. 5163–5202, 2008.

LARA-LARA, J. R.; GUZMÁN, C. B. Distribución de clorofila y producción primaria por classes de tamaño en la costa del pacifico mexicano. **Ciencias Marinas**, v. 31, n. 001a, p. 11-21, 2005.

LICEA, L.; MORENO, J. L.; SANTOYO, H.; FIGUEROA, G. **Dinoflagelados del Golfo de California**. Universidad Autonoma de Baja California Sur. 1995. 166 p.

LONGHURST, A. R.; PAULY E. D. **Ecology of Tropical Oceans**. San Diego: Academic Press. 1987. 407 p.

MATEUCCI, S. D.; COLMA, A. La **Metodologia para el Estudo de la Vegetacion**. [S.l.]. Collecion de Monografias Cientificas. Ser. Biología. 1982. 168 p.

MALONE, T. C. Size-fractionated primary productivity of marine phytoplankton. In: P.G. FALKOWSKI (ed.) Primary Productivity in the sea. Book haven **Simposia in Biology**. v. 31, p. 301-309. 1980.

MELO, M. A. F.; KOENING, M. L.; MACEDO, S. J.; GASPAR, F. L. Nova ocorrência de Podolampas bipes var. reticulata em Áreas Oceânicas do Brasil. In**: Iii Congresso Brasileiro de Oceanografia** – CBO'2010, Rio Grande (RS), 2010.

MENDEN-DEUER, S.; LESSARD, E. J. Carbon to volume relationships for dinoflagellates, diatoms and other protist plankton. **Limnology and Oceanography**, v. 33, n. 45, p. 569-579. 2000.

MONTAGNES, D. J. S.; BERGES, J. A.; HARRISON, P. J.; TAYLOR, F. J. Estimating carbon, nitrogen, protein, and chlorophyll a from volume in marine phytoplankton. **Limnology and Oceanography**, v. 39, p. 1044-1060. 1994.

OLENINA, I.; HAJDU, S.; EDLER, L.; ANDERSSON, A.; WASMUND, N.; BUSCH, S.; GÖBEL, J.; GROMISZ, S.; HUSEBY, S.; HUTTUNEN, M.; JAANUS, A.; KOKKONEN, P.; LEDAINE, I.; NIEMKIEWICZ, E. **Biovolumes and size-classes of phytoplankton in the Baltic Sea**. HELCOM Baltic Sea Environment Proc. No. 106, 2006. 144 p.

PORTO, M. A. C. **Arquipélago de São Pedro e São Paulo**. In: SERAFIM, C. F. S. (Org.). O mar no espaço geográfico brasileiro. Brasília: Ministério da Educação, Secretaria de Educação Básica. p. 74-80. 2006.

PLATT, D. V.; SUBBA, R.A.O; IRWIN, B. Photosynthesis of picoplankton in the oligotrophic ocean. **Nature**, v. 300, p. 702-704. 1983.

QUEIROZ, A. R. **Estrutura do microfitoplâncton no Arquipélago de São Pedro e São Paulo (Lat. 00 56' 2" N e Long. 29 20' 6" W): Estimativa da biomassa em carbono através do biovolume celular**. Recife, 2011. 91f. Dissertação (Mestrado em Oceanografia) – Departamento de Oceanografia. Universidade Federal de Pernambuco. 2011.

ROUND, F. E.; CRAWFORD, R. M.; MANN, D. G. **The Diatoms Biology and Morfology of the Genera**. Cambridge: University Press, 1992. 747 p.

ROTT, E.; SALMASO, N.; HOEHN, E. Quality control of Utermöhl-based phytoplankton counting and biovolume estimates—an easy task or a Gordian knot?. **Hydrobiologia**, v. 578, p. 141-146, 2007.

SKIELKA, U; SOARES, J; OLIVEIRA, AP. Investigação dos fluxos turbulentos na interface no arquipélago de São Pedro e São Paulo. Santa Catarina. In: **Anais do XIV Congresso Brasileiro de Meteorologia**. p. 6, 2006.

SMAYDA, T. J. **From phytoplankton to biomass**. In: SOURNIA, A. (ed.) Phytoplankton Manual. Monographs on Oceanographic Methodology 6. UNESCO, Paris, 1978. p. 273-279.

SOURNIA, A. Morphological bases of competition and succession. **Canadian Bulletin Fisheries Aquatic Science**, v. 210, p. 339-346. 1981.

SUN, J; LIU, D. Geometric models for calculating cell biovolume and surface area for phytoplankton. **Journal of Plankton Research**, v. 11, n. 25, p. 1331-1346. 2003.

STEIDINGER, K. A.; TANGEN, K. **Dinoflagellates**. In: TOMAS, C. R. Identifying Marine Phytoplankton. San Diego, Academic Press, p. 387-589, 1997.

TENENBAUM, D. R.; VILLAC, M. C.; VIANA, S. C.; MATOS, M.; HATHERLY, M.; LIMA, I. V.; MENEZES, M. Phytoplankton Atlas of Sepetiba Bay, Rio de Janeiro. IMO, LONDON. (GLOBALLAST MONOGRAPH SERIES, 16). 2004.

TENENBAUM, D. R. **Dinoflagelados e Tintinídeos da região central da Zona Econômica exclusiva brasileira: guia de identificação**. Rio de Janeiro: Museu Nacional, 2006. 288 p.

THERRIAULT, L. B.; POULIN, M.; BOSSÉ, L. **Guide d'identification du phytoplankton marin de l'estuaire et du golfe du Saint- Laurent**. Publication special canadienne des sciences halieutiques et aquatiques. 1999. 387 p.

TRAVASSOS, P.; HAZIN, F. H. V.; ZAGAGLIA, J. R.; ADVINCULA, R.; SCHOBER, J. Thermohaline structure around seamounts and islands off North-Eastern Brazil. **Archive of Fishery and Marine Research**, v. 47, n. 2/3, p. 211-222. 1999.

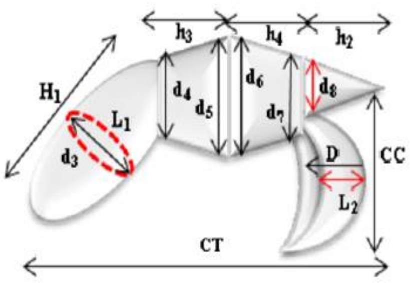
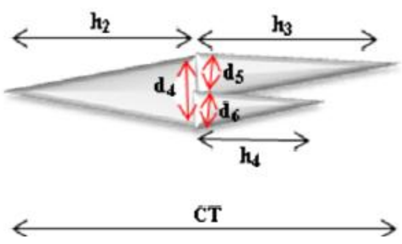
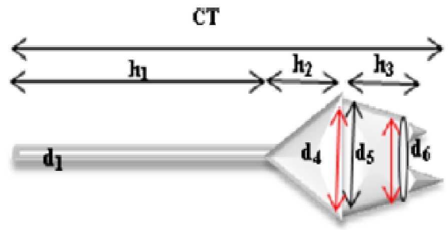
TIBURCIO, A. S. X. S.; KOENING, M. L.; MACÊDO, S. L.; MELO, P. A. M. C. A comunidade microfitoplanctônica do Arquipélago de São Pedro e São Paulo (Atlântico Norte-Equatorial): variação diurna e espacial. **Biota Neotropica**, v. 11, n. 2. p. 2-13. 2011.

VADRUCCI, M. R.; CABRINI, M.; BASSET, A. Biovolume determination of phytoplankton guilds in transitional water ecosystems of Mediterranean Eco-region. **Transitional Waters Bulletin**, v. 2, p. 83-102, 2007.

VERITY, P. G.; ROBERTSON, C. Y.; TRONZO, C. R.; ANDREWS, M. G.; NELSON, J. R.; SIERACKI, M. E. Relationships between cell volume and the carbon and nitrogen content of marine photosynthetic nanoplankton. **Limnology and Oceanography**, n. 37, p. 1434-1446, 1992.

UNIVERSIDADE FEDERAL DE PERNAMBUCO
Departamento de Oceanografia
TROPICAL OCEANOGRAPHY
Revista online

Annex 1 - Geometric shapes, drawn covering the third dimension and in cross sections, developed for the chosen species with frequencies higher than 30%, occurring in the São Pedro and São Paulo Archipelago.

Geometric form	**ELLIPSOID + TRUNCATED CONE + MONORAPHIDIOID + CONE**	**3 CONES**	**CYLINDER + CONE + TRUNCATED CONE**
			
Types of forms	Combined	Combined	Combined
Dimensions	15	7	8
Volume	$\pi/6*H_1*d_3*L_1+\pi/12*h_3*(d_4^2+d_4*d_5+d_5^2)+\pi/12*h_4*(d_6^2+d_6*d_7+d_7^2)+(D^2/8)*(2*D-L_2+CC)*(\pi^2/6+1)$	$\pi/12*h_2*d_4^2+\pi/12*h_3*d_5^2+\pi/12*h_4*d_6^2$	$\pi/4*d_1^2*h_1+\pi/12*h_2*d_4^2+\pi/12*h_3*(d_5^2+d_5*d_6+d_6^2)$
Caption	TL- Total length CL- Cell length H_1- Ellipsoid height L_1- Ellipsoid width d_3- Ellipsoid diameter d_4- Smallest diameter of truncated cone 1 d_5- Largest diameter of cone 1 d_6- Smallest diameter of truncated cone 2 d_7- Smallest diameter of truncated cone d_8- Cone diameter D- Larger diameter of monoraphidioid L_2- Smaller diameter of monoraphidioid h_2- Cone height h_3- Truncated cone 1 height h_4- Truncated cone 2 height	TL- Total length d_4- Cone 1 diameter d_5- Cone 2 diameter d_6- Cone 3 diameter h_2- Cone 1 heigth h_3- Cone 2 height h_4- Cone 3 height	TL- Total length d_1- Cylinder diameter h_1- Cylinder height d_4- Cone 1 diameter h_2- Cone 1 heigth h_3- Truncated cone height d_5- Largest diameter of truncated cone d_6- Smallest diameter of truncated cone
Species	*Ceratium digitatum*	*Ceratium belone*	*Ceratium lineatum*
		Protoperidinium depressum	*Ceratium pentagonum* var. *longisetum*

[1] Departamento de Oceanografia, Universidade Federal de Pernambuco - UFPE, Av. Arquitetura, s/n, Cidade Universitária, CEP 50610-901, Recife-PE, Brasil. aribeiroq@yahoo.com.br; koening@ufpe.br; felipe.gaspar@ufpe.br.

			Ceratium pentagonum var. *tenerum* *Ceratium teres*

Annex 2 - Descriptive statistics of morphometric data of the species of ASPSP selected to biovolume.

Dinophyceae	**d_1**	**d_3**	**d_4**	**d_5**	**d_6**	**d_7**	**d_8**	**D**	**L_1**	**L_2**	**h_1**	**h_2**	**h_3**	**h_4**	**H_1**	**CL**	**TL**
Ceratium belone n=9																	
min-max			23-44	10-38	5-14							205-307	108-217	90-123			374-497
X			38	27	10							253	175	69			431
S.D.			9	10	3							31	34	70			40
C.V. (%)			23	38	28							12	19	101			9
med.			41	30	11							243	184	44			432
Ceratium digitatum n=9																	
min-max		35-60	46-78	43-65	38-57	42675	19-32	16-32	41586	19-32		27-60	24-41	19-43	92-149	68-136	122-224
X		42	54	51	45	13	22	38	10	20		26	98	33	99	90	153
S.D.		8	10	8	7	2	5	6	1	5		7	19	5	20	13	40
C.V. (%)		19	19	15	15	17	22	16	14	24		28	19	16	20	14	26
med.		47	62	54	47	14	26	41	9	24		31	120	32	120	87	173
Ceratium lineatum n=20																	
min-max	41397		57-65	54-62	38-42						24-38	32-38	22-27				81-127
X	3		61	59	40						29	36	25				95
S.D.	1		2	3	1						4	3	2				10
C.V. (%)	30		3	5	2						14	7	6				10
med.	3		62	60	40						30	38	24				92
Ceratium pentagonum var. *longisetum n=24*																	
min-max	41397		46-70	43-68	30-49						293-360	30-49	24-32				278-460
X	5		63	59	42						328	38	28				407
S.D.	1		5	6	5						20	4	3				47

C.V. (%)	24		8	10	12						6	11	10				11
med.	5		65	60	43						332	38	27				405
Ceratium pentagonum var. *tenerum n=31*																	
min-max	41491		57-73	54-68	35-49						30-143	35-46	22-38				138-189
X	6		64	60	42						96	41	26				167
S.D.	1		4	4	3						21	3	3				20
C.V. (%)	23		7	7	8						22	7	13				12
med.	5		62	60	43						97	41	27				175
Ceratium teres n=21																	
min-max	41367		41-51	43-49	27-33						49-108	41-51	27-35				122-184
X	3		45	45	29						76	47	29				154
S.D.	1		3	2	2						23	3	3				22
C.V. (%)	19		6	4	5						30	6	9				14
med.	3		46	46	30						69	46	27				154
Protoperidinium depressum n=32																	
min-max			60-116	60-65	57-65							62-93	35-68	35-68			
X			92	62	61							75	55	58			
S.D.			19	2	3							11	15	13			
C.V. (%)			20	3	4							15	28	23			
med.			99	62	62							72	61	63			

Caption: TL - Total length; CL - Cell length; H1 - Ellipsoid height; H2 - monoraphidioid height; h1 - Cylinder height; h2 - Cone 1 height; h3 - Cone 2 and truncated cone 1 height; h4 - Cone 3 and truncated cone 2 height; L1- Ellipsoid width; L2 - Smallest diameter of monoraphidioid; D - Largest diameter of monoraphidioid; d1- Cylinder diameter; d3- Ellipsoid diameter; d4 - Truncated cone 1 and cone 1 diameter; ; d5 - Largest diameter of truncated cone and cone 2; d6 - Smallest diameter of truncated cone 2 and cone 3; d7 - Smallest diameter of truncated cone 2; d8- Cone diameter. Min- minimum; Max- maximum; C.V.- Coefficient of Variation; S.D. - Standard Deviation, X - Mean; med- Median.