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Phytoplankton community structure in one sector of Guanabara Bay (RJ, Brazil) during 2011 and 2012

Katia Regina Vieira de Rezende, Melissa Medeiros Ferreira Hatherly, Cristiane Marques Monteiro Pimenta, Janaina Eduardo, Simone de Castro Vianna, Norberto Mangiavacchi*

GESAR, Unidade de Desenvolvimento Tecnológico, Universidade do Estado do Rio de Janeiro
(Rua Fonseca Teles, 121, São Cristóvão, Rio de Janeiro, Brazil)

*Corresponding author: katiarvr@gmail.com

Abstract

This study analyzed the temporal variability of phytoplankton assemblages in the surface waters of Guanabara Bay (RJ, Brazil), at six stations in front of Icaraí Inlet from April/2011 to April/2012. Our results highlight the great contribution of diatoms, dinoflagellates and cyanobacteria, represented by 111 taxa typical of estuarine and coastal areas. The coexistence of benthic and planktonic species suggests considerable hydrodinamism in these waters. All variables were homogeneous ($p > 0.05$) between the stations, but differed between sampling periods. On average, phytoplankton abundance (10^7 cells.L^{-1}) was higher than that of other estuaries and its temporal behavior was closely correlated ($p < 0.01$) with diatoms and cyanobacteria. The richness distribution pattern (7 to 27 taxa) was closely correlated ($p < 0.01$) with dinoflagellates and diatoms. Ninety per cent of all samples presented a low diversity index (< 2.0 bits.cell^{-1}), which indicated the unstable balance of the system, typical of environments subjected to eutrophication. The population structure analysis revealed that 10% of all taxa were resident, 12% visitors and 78% accidental, suggesting the influence of continental and oceanic water influxes. Between the "typical" taxa, the most common were the cyanobacteria of the order Oscillatoriales, the diatoms *Ceratoneis closterium* (=*Cylindrotheca closterium*) and *Leptocylindrus minimus* and the dinoflagellate *Prorocentrum triestinum*.

Descriptors: Tropical estuary, Temporal variation, Species Diversity, Microphytoplankton.

Resumo

Este trabalho analisou a variabilidade sazonal da comunidade microfitoplanctônica em águas superficiais da Baía da Guanabara (RJ, Brasil) em 6 estações em frente à Enseada de Icaraí, de abril de 2011 a abril de 2012. Os resultados destacaram a alta representatividade de diatomáceas, dinoflagelados e cianobactérias, representados por 111 táxons típicos de ambientes estuarinos/costeiros. A coexistência de espécies bentônicas e planctônicas indicou o alto hidrodinamismo local. Houve homogeneidade ($p >$ 0,05) entre as estações de coleta para todas as variáveis, mas diferenças entre campanhas. A densidade média (10^7 cel.L^{-1}) foi superior à de outros sistemas estuarinos e seu comportamento temporal esteve altamente correlacionado ($p <$ 0,01) com diatomáceas e cianobactérias. Por sua vez o padrão de distribuição da riqueza (7 a 27 táxons) apresentou alta correlação positiva ($p <$ 0,01) com dinoflagelados e diatomáceas. Baixos índices de diversidade (< 2,0 bits.cel^{-1}) em 90% das amostras reafirmaram o equilíbrio instável do sistema, típico de ambientes sujeitos à eutrofização. A análise da estrutura das populações estabeleceu que 10% dos táxons são residentes, 12% visitantes e 78% acidentais, reafirmando a influência do aporte continental e/ou águas oceânicas. Entre os táxons "típicos", destacaram-se cianobactérias da Ordem Oscillatoriales, diatomáceas *Ceratoneis closterium* (=*Cylindrotheca closterium*) e *Leptocylindrus minimus* e o dinoflagelado *Prorocentrum triestinum*.

Descritores: Estuário tropical, Variação temporal, Diversidade específica, Microfitoplâncton.

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INTRODUCTION

The evaluation of the condition of an ecosystem requires the assessment of its primary productivity and trophic dynamics in view of the structure and ecological functions of its communities. Phytoplankton represents the basis of the main food webs in aquatic ecosystems, and its taxonomic composition and abundance respond to environmental disturbances (i.e. physical processes such as advective currents and turbulence, and chemical composition - nutrients), and to the interaction between species (i.e. competition for resources: light and nutrients) (MARGALEF, 1963; 1978). Consequently, the assessment of an aquatic ecosystem dynamics is relevant not only for the system's production, but also for the possibility of using organisms as an efficient proxy for determining natural and anthropogenic disturbances (LOBO; CALLEGARO; BENDER, 2002).

SIEBURTH, SMETACEK and LENZ (1978) proposed the classification of planktonic cells in three groups according to their size, named pico (0.2-2 µm), nano (2-20 µm) and microplankton (20-200 µm). Because of their small size, these organisms present a short generation time (hours-days), and their rapid response to environmental conditions makes them good indicators of important environmental processes such as eutrophication (HARRIS, 1986; SOMMER, 1989; REYNOLDS; PADISÁK; SOMMER, 1993).

Coastal and estuarine areas present high productivity due to nutrient rich terrestrial inputs and anthropogenic effects on distinct temporal and spatial scales. The great hydrodynamism caused by these impacts increases the ability of these regions to sustain high primary production and metabolic rates of phytoplanktonic cells (CLOERN; FOSTER; KLECKNER, 2014), due to alterations in phytoplankton community structure that are reflected in the marine food web (JI et al., 2007; CLOERN; JASSBY, 2010; LLEBOT et al., 2011).

Guanabara Bay is one of the largest embayments of the Brazilian coast. It is shallow (5-50 m depth) but presents a north-south axis of 30 km, a perimeter of 131 km, an area of 384 km^2, and 1.87 x 10^9 m^3 of water volume (KJERFVE et al., 1997; KJERFVE, SEELIGER; LACERDA, 2001). The climate of this region is warm and wet all year around (average humidity of 78% and temperature of 23.7º C), with a rainy season during spring-summer (September to March) and a drier period during autumn-winter (April to August), a seasonality that influences the hydrobiology of the bay. Hydrological characteristics respond to temporal (daily and seasonal) variations of tides and cold fronts (precipitation and winds), which influence the terrestrial freshwater inflow that impacts certain areas of the bay strongly: high precipitation in summer causes an increase of the terrestrial freshwater input, the opposite occurring in winter. The freshwater input is derived from river catchment basins, which receive domestic and industrial effluents (MAYR; TENENBAUM; VILLAC, 1989), and the input of coastal seawater increases during high tide (VALENTIN et al., 1999). Tides present a semi-diurnal regime (AMADOR, 1997) with average amplitude of 0.7 m, ranging from 1.1 m during spring to 0.3 m in neap tide periods (JICA, 1994; VALENTIN et al., 1999; KJERFVE, SEELIGER; LACERDA, 2001). Guanabara Bay is surrounded by large urbanized areas such as the cities of Rio de Janeiro and Niterói (SCHWAMBORN et al., 2004), and by the second largest industrial park in the country, with around 6000 factories 1% of which account for 80% of the industrial pollution poured into the bay (CIDS, 2000). Because of these conditions, Guanabara Bay is considered a polluted eutrophic system (JICA, 1994), despite the processes of autodepuration that occur through interchanges with the ocean, which save the biota from irreversible damage (VALENTIN et al., 1999).

The sampling area is located in front of Icaraí Inlet (22º55´S-43º08´W) in Niterói city, RJ (Figure 1). The waves that enter the inlet, coming from south and southwest, lead to great hydrodynamism in this area, especially during storm surges (SILVA; RESENDE; SANTOS, 1999; SANTOS; SILVA; SALVADOR, 2004).

Phytoplankton from Guanabara Bay has been studied since the early XX century, but most of the studies are scattered in academic thesis and dissertations. The first studies that include analyses of population dynamics as a function of environmental variables were published during the 80's, and generated a broad characterization of the system's hydrobiology (MAYR; TENENBAUM; VILLAC, 1989). Recently, VILLAC and TENENBAUM (2010) have gathered information contained in 57 publications with data obtained between 1913 and 2004 in a state of art manuscript on the phytoplankton biodiversity of Guanabara Bay. The analysis of this information allowed them to conclude that, despite the fact that some of the studies published contain lists of microphytoplankton species, most of them adopt an ecological approach and highlight only the most abundant species. According to this historical study, the inventory of phytoplankton

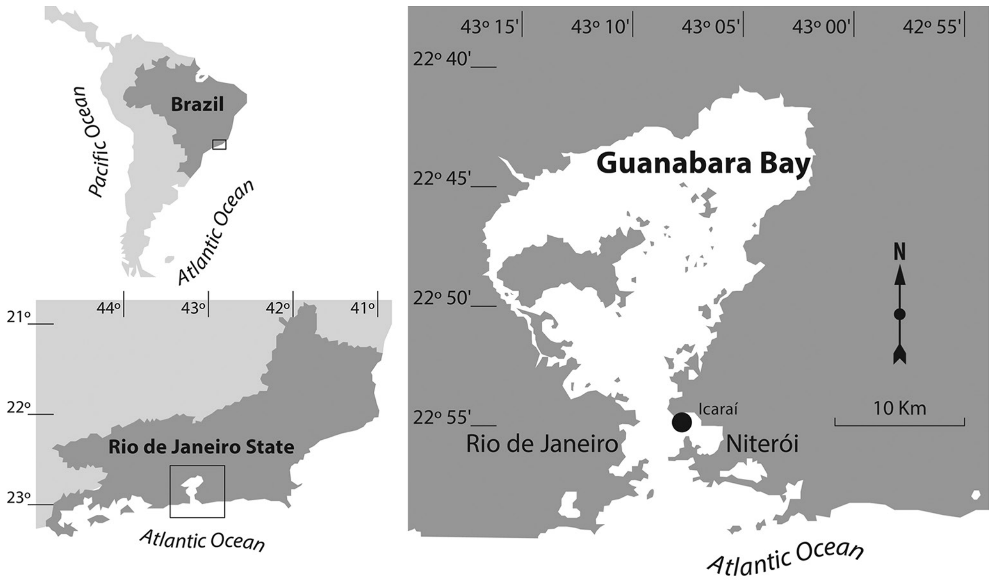

Figure 1. Map of Guanabara Bay showing location of the sampling area (Niterói, Rio de Janeiro).

species from Guanabara Bay totaled 308 taxa, with the dominance of diatoms (62%) and dinoflagellates (32%), and other groups such as cyanobacteria, euglenophyceans, chlorophyceans, prasinophyceans, silicoflagellates and ebriidae were also represented. Other studies revealed that, in Guanabara Bay, phytoplankton assemblages present spatial heterogeneity, and their abundance is comparable to that of intensely polluted estuaries.

Changes in phytoplankton communities due to the effects of natural events or pollutants can be determined by the investigation of the species' composition, cell numbers and diversity indices. Thus, the goal of this work is to describe the abundance and community structure of microphytoplankton in surface waters of one sector of Guanabara Bay, during the period between April 2011 and April 2012. These results broaden the information available on the temporal change of the phytoplankton of this system under the influence of the variation of coastal water quality and anthropogenic activities and may be valuable for future environmental monitoring and assessment programs.

MATERIAL AND METHODS

Sampling and Analysis

Surface water samples were taken using a Van Dorn bottle and then stored in 500 to 1000 ml glass vials and fixed with a Lugol solution (THRONDSEN, 1978). Sampling was carried out fortnightly (36 samples) from April to June 2011, and monthly during the remaining period (60 samples) at six stations in front of Icaraí inlet (Figure 1). Microphytoplankton abundance and species composition were evaluated in accordance with HASLE (1978). Aliquotes of 2 to 10 ml were analyzed by the UTERMOHL (1958) method, using inverted microscopes (Coleman NIB-100 and Nikon TS100F) with phase contrast and 200x magnification. The phytoplankton counts were based on a minimum of 150 settled units (single cells, chain-forming and filamentous organisms). In addition, the number of cells in each settled unit (SHAW, 1964; TENENBAUM et al., 2001; GUENTHER et al., 2012) was also registered and the results were expressed as cells per liter (cells.L^{-1}).

In order to avoid missing the richness per sample, organisms that could not be identified to the species level were classified into broader taxonomic groups (class, order and family) and identified by their morphotypes according to cells shape and dimension. We would point out that the identification of most taxa requires complex training and the utilization of more advanced microscopy techniques with a higher resolution (SOURNIA, 1978; TOMAS, 1997). The classification systems used for taxonomic denomination were those of ROUND, CRAWFORD and MANN (1990) for Diatoms, FENSOME et al. (1993) for dinoflagellates, KOMÁREK and ANAGNOSTIDIS (1989; 2005) for cyanobacteria and THRONDSEN (1997) for Chlorophythes.

Data Analysis

The Kruskal-Wallis non-parametric test was used to test the temporal and spatial variability ($p < 0.05$) in phytoplankton abundance, richness and the Shannon-Wiener Diversity index. The Mann-Whitney non-parametric test was applied to compare co-temporal independent samples during the biweekly sampling period. To establish correlation between variables the Simple Linear Correlation (Pearson's r) test, that determines the extent to which values of the two variables are "proportional" to each other, was used. The analysis of microphytoplankton community structure was performed using three ecological indexes: a) the Constancy index: the taxon was considered "resident" when it was recorded in more than 50% of the samples, "visitor" when it was recorded in 25-50% of the samples and "accidental" when recorded in less than 25% of the samples (DAJOZ, 1983); b) the Shannon-Wiener Species Diversity index and c) Pielou´s Evenness index (LEGENDRE; LEGENDRE, 1998). The analysis of Similarity Percentages (SIMPER) identified the taxa responsible for the similarity of samples in each sampling period (CLARKE; WARWICK, 1994). Some analyses (Kruskal-Wallis, Mann-Whitney and Simple Linear Correlation) were carried out using STATISTICA (Version 7), other routines (Shannon-Wiener Diversity, Pielou´s Evenness and Simper analysis) were performed using PRIMER (Version 5).

RESULTS

Specific composition, Richness and Abundance

A total of 110 taxa were identified, belonging to 4 Divisions (Figure 2; Table 1): Diatoms (55 taxa; 25 species), Dinoflagellates (51 taxa; 25 species), Cyanobacteria (2 taxa) and Chlorophythes (2 taxa).

Richness, Abundance, Diversity Index and Evenness results are presented as the mean values of each sampling period, as the non-parametric tests revealed no differences ($p < 0.05$) between sampling stations. Table 2 presents information on these variables in each sampling period.

The richness distribution pattern (9 to 23 taxa) was highly correlated ($p < 0.01$) with dinoflagellates (r = 0.77) and diatoms (r = 0.50) which, together, represented 56 to 100% of the total number of taxa, while other groups' contributions were low (< 3 taxa per sample). Richness values lower than the total average (17 ± 3 taxa) were registered in May, October and December 2011, and from January to April 2012. During the biweekly sampling period, only May presented a distinct ($p < 0.05$) phytoplankton assemblage, with a low richness of dinoflagellates in the second sampling of the month (Figure 3).

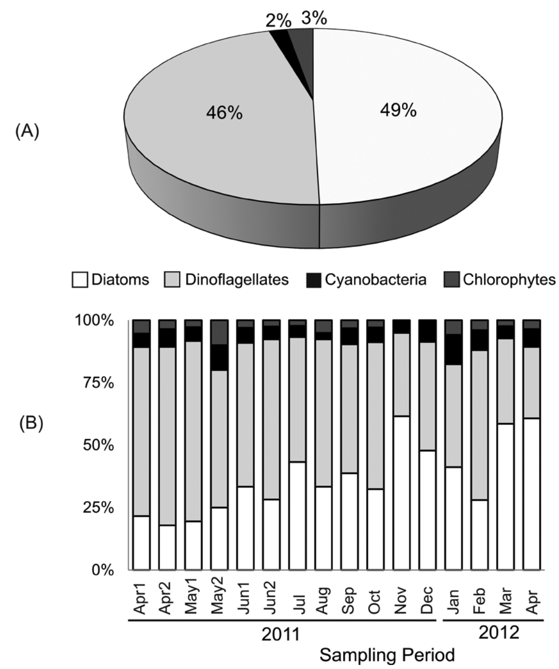

Figure 2. Percentage Contribution of Diatoms, Dinoflagellates, Cyanobacteria and Chlorophytes considering the entire study period (A) and separated by sampling cruise (B).

Variations in abundance (7.7×10^5 to 7.0×10^7 cells.L^{-1}) were correlated ($p < 0.01$) with high cell density of diatoms (R = 0.76) and cyanobacteria (R = 0.67). Values lower than the total mean ($2.0 \times 10^7 \pm 2.2 \times 10^7$ cells.L^{-1}) were registered in most of the sampling periods (Figure 4). During the biweekly sampling period, differences ($p < 0.05$) were observed due to Diatom (April), Dinoflagellate (April and June), Cyanobacteria (May and June) and Euglenophycean (June) variability. Diatom abundances varied from 1.6×10^5 to 1.0×10^8 cells.L^{-1} ($1.3 \times 10^7 \pm 1.9 \times 10^7$ cells.L^{-1}), and this group was dominant in all sampling periods (mean contribution of 66%), except in April2 and October 2011 and February 2012. Cyanobacteria were represented by the Orders Oscillatoriales and Nostocales, showing abundances between 5.7×10^3 and 4.2×10^7 cells.L^{-1} ($6.3 \times 10^6 \pm 1.2 \times 10^7$ cell.L^{-1}). Amongst the cyanobacteria, the Order Oscillatoriales was the most numerous throughout the sampling periods, with an average contribution of 79%. The mean abundances of Dinoflagellates and Chlorophythes were of the order of 10^5 cells.L^{-1} and 10^4 cell.L^{-1}, respectively, with an average contribution lower than 7%.

Table 1. List of taxa found in Guanabara Bay from April 2011 to April 2012 indicating percentage of occurrence (%) in all samples (n = 96), classification by Constancy Index (R = resident; V = visitor and A = accidental) and occurrence by month (n = 13). The following classification systems were adopted: Round, Crawford and Mann (1990) for Diatoms (Bacillariophyta); Fensome et al. (1993) for dinoflagellates (Dinoflagellata); Komárek and Anagnostidis (1989; 2005) for cyanobacteria (Cyanophyta) and Throndsen (1997) for Chlorophythes (Chlorophyta). The morphotypes are not included in this table.

TAXONOMY CATEGORY	Total Occurrence (%) n = 96	Constancy Index	Occurrence by month (n = 13)												
			2011									2012			
			Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr
Division Bacillariophyta															
Class Coscinodiscophyceae															
Order Thalassiosirales															
Family Thalassiosiraceae															
Thalassiosira sp.	18	A	*			*	*		*	*	*			*	*
Family Skeletonemataceae															
Skeletonema cf. *costatum* (Greville) Cleve	25	A	*		*	*			*	*				*	*
Skeletonema sp.	6	A						*	*						
Order Paraliales															
Family Paraliaceae															
Paralia sulcata (Ehrenberg) Cleve	1	A								*					
Order Coscinodiscales															
Family Coscinodiscaceae															
Coscinodiscus sp.	1	A													*
Order Triceratiales															
Family Triceratiaceae															
Odontella aurita (Lyngbye) C. Agardh	1	A								*					
Order Hemiaulales															
Family Hemiaulaceae															
Cerataulina pelagica (Cleve) Hendey	3	A								*					
Eucampia cornuta (Cleve) Grunow	1	A								*					
Eucampia sp.	1	A								*					
Hemiaulus membranaceus Cleve	1	A								*					
Order Rhizosoleniales															
Family Rhizosoleniaceae															
Dactyliosolen fragilissimus (Bergon) Hasle	1	A													*
Dactyliosolen phuketensis (B. G. Sundström) G. R. Hasle	2	A									*				
Guinardia flaccida (Castracane) H. Peragallo	1	A		*											
Guinardia striata (Stolterfoth) Hasle	2	A				*								*	
Guinardia sp.	15	A			*	*		*							
Proboscia alata (Brightwell) Sundström	2	A			*										*
Rhizosolenia setigera Brightwell	42	V	*			*	*	*	*	*	*			*	*
Rhizosolenia setigera f. *pungens* (Cleve-Euler) Brunel	2	A									*				
Order Chaetocerotales															
Family Chaetocerotaceae															

Continued Table 1.

Chaetoceros compressus Lauder	3	A								*	*				
Chaetoceros curvisetum Cleve	2	A								*					
Chaetoceros danicus Cleve	6	A						*		*					*
Chaetoceros radians F. Schütt	2	A						*	*						
Chaetoceros socialis H. S. Lauder	1	A													*
Chaetoceros cf. *socialis* H. S. Lauder	4	A								*					
Chaetoceros spp.	15	A		*	*			*		*	*			*	
Order Leptocylindrales															
Family Leptocylindraceae															
Leptocylindrus danicus Cleve	31	V	*		*	*	*		*	*	*	*	*	*	*
Leptocylindrus minimus Gran	76	R	*	*	*	*	*	*	*	*	*	*	*	*	*
Class Flagilariophyceae															
Order Fragilariales															
Family Fragilariaceae															
Asterionellopsis glacialis (Castracane) Round	5	A					*		*	*				*	
Order Licmophorales															
Familia Licmophoraceae															
Licmophora sp.	1	A				*									
Order Thalassionematales															
Familia Thalassionemataceae															
Thalassionema nitzschioides (Grunow) Mereschkowsky	5	A				*								*	*
Class Bacillariophyceae															
Order Naviculales															
Family Phaeodactylaceae															
Phaeodactylum tricornutum Bohlin	11	A								*			*	*	*
Family Diploneidaceae															
Diploneis sp.	6	A				*	*	*	*						
Family Naviculaceae															
Complex Tropidoneis	3	A								*					
Family Pleurosigmataceae															
Complex *Pleurosigma/Gyrosigma*	4	A		*										*	*
Order Thalassiophysales															
Family Catenulaceae															
Amphora sp.	1	A					*								
Order Bacillariales															
Family Bacillariaceae															
Complex C. *closterium/Nitzschia longissima*	7	A				*	*								
Ceratoneis closterium Ehrenberg (=*Cylindrotheca closterium*)	97	R	*	*	*	*	*	*	*	*	*	*	*	*	*
Pseudo-nitzschia "complex *delicatissima*"	14	A	*		*		*	*				*		*	
Pseudo-nitzschia "complex *seriata*"	4	A								*		*		*	
Division DINOFLAGELLATA															
Class Dinophyceae															
Order Gymnodiniales															
Family Gymnodiniaceae															
Akashiwo sanguinea (K. Hirasaka) G. Hansen & Ø. Moestrup	6	A	*												

Continued Table 1.

Amphidinium spp.	27	V	*	*	*	*	*	*	*		*				
Gymnodinium spp.	6	A		*											
Gyrodinium cf. *spirale* (Bergh) Kofoid & Swezy	2	A			*										
Gyrodinium spp.	2	A			*										
Order Gonyaulacales															
Family Goniodomaceae															
Alexandrium spp.	1	A	*												
Order Peridiniales															
Family Peridiniaceae															
Scrippsiella cf. *spinifera* G. Honsell & M. Cabrini	2	A	*												
Scrippsiella cf. *trochoidea* (Stein) Balech ex Loeblich III	31	V	*	*	*	*									
Scrippsiella sp.	28	V	*		*	*	*	*	*	*	*			*	
Family Congruentidiaceae															
Protoperidinium cf. *bipes* (Paulsen) Balech	5	A			*	*	*	*							
Protoperidinium cf. *steinii* (Jorgensen) Balech	1	A				*									
Protoperidinium spp.	43	V	*	*	*	*	*	*	*					*	*
Order uncertain															
Family Oxytoxaceae															
Oxytoxum crassum Schiller	5	A	*		*				*						
Oxytoxum cf. *gladiolus* Stein	2	A					*		*						
Oxytoxum gracile Schiller	7	A		*		*	*	*			*				
Oxytoxum laticeps Schiller	3	A				*			*				*		
Oxytoxum scolopax Stein	2	A	*	*											
Oxytoxum cf. *turbo* Kofoid	1	A					*								
Oxytoxum sp.	1	A		*											
Order Dinophysiales															
Family Dinophysiaceae															
Dinophysis acuminata Claparède & Lachmann	9	A	*	*	*	*	*	*		*					
Dinophysis fortii Pavillard	3	A	*												
Dinophysis sp.	2	A	*							*					
Family Oxyphysaceae															
Oxyphysis oxytoxoides Kofoid	38	V	*	*	*	*	*	*	*		*		*		
Order Prorocentrales															
Family Prorocentraceae															
Prorocentrum balticum (Lohmann) Loeblich	4	A	*		*									*	
Prorocentrum compressum (J. W. Bailey) Abé ex Dodge	2	A		*	*										
Prorocentrum dentatum Stein	1	A								*					
Prorocentrum gracile Schütt	5	A	*												
Prorocentrum micans Ehrenberg	47	V	*	*	*	*	*	*	*	*		*	*	*	*
Prorocentrum minimum (Pavillard) J. Schiller	40	V	*	*	*	*	*	*	*	*		*	*	*	
Prorocentrum scutellum Schröder	2	A	*												
Prorocentrum triestinum J. Schiller	79	R	*	*	*	*	*	*	*	*	*	*	*	*	*
Prorocentrum sp.	7	A					*		*		*			*	

Continued Table 1.

Class Noctiluciphyceae															
Order Noctilucales															
Family Noctilucaceae															
Pronoctiluca pelagica Fabre-Domérgue	3	A	*										*		
Pronoctiluca spinifera (Lohmann) Schiller	2	A					*		*						
Division Chlorophyta	5	A		*			*								
Class Euglenophyceae	73	R	*	*	*	*	*	*	*			*	*	*	*
Eutreptiella sp.	1	A	*												
Division Cyanophyta															
Class Cyanophyceae															
Order Nostocales	67	R	*	*	*	*		*	*	*	*	*	*	*	*
Order Oscillatoriales	91	R	*	*	*	*	*	*	*	*	*	*	*	*	*

Table 2. Microphytoplankton (Total and by groups) Richness, Abundance and Ecological Indexes (Species Diversity and Evenness) from April 2011 to April 2012.

Date	Richness					Abundance					Index	
	Total	Diatoms	Dinoflagellates	Cyanobacteria	Chlorophythes	Total	Diatoms	Dinoflagellates	Cyanobacteria	Chlorophythes	Species Diversity	Evenness
Apr1	18	4	12	1	1	35580718	10284643	24712437	410283	173355	0.44	0.15
Apr2	17	2	12	1	1	69754673	45297123	19789149	4639174	29226	0.44	0.15
May1	18	3	13	2	1	4107270	2244201	1392402	430008	40659	0.33	0.14
May2	12	2	6	2	2	6631668	4894936	360093	905809	470830	0.10	0.07
Jun1	19	6	10	2	1	18664938	17702565	189872	486232	286269	1.14	0.42
Jun2	20	5	13	1	1	10407854	9241535	93210	1051068	53111	0.94	0.34
Jul	23	10	11	2	1	56865758	56645156	118060	66902	35640	0.99	0.33
Aug	19	5	12	1	1	28571795	27728657	125740	439361	278036	0.11	0.04
Sep	18	5	9	2	1	13277285	12723868	286800	203216	63401	0.10	0.04
Oct	16	5	8	2	1	10212120	2486926	7372138	246037	107019	1.08	0.37
Nov	18	10	6	1	-	768861	718381	5652	46713	-	1.57	0.48
Dec	13	7	4	2	-	12459305	10876155	1569261	13889	-	0.16	0.07
Jan	9	3	4	2	1	2728105	1885932	531635	306591	3946	1.03	0.51
Feb	16	5	9	2	1	53614363	10990133	42197291	405632	21308	0.81	0.33
Mar	17	9	6	2	1	2168300	851195	1197935	109175	9996	1.07	0.40
Apr	15	7	5	2	1	1454119	345550	1008292	84125	16152	1.49	0.60

Community Structure

According to the Constancy analysis in the study area (Table 1), 78% of the taxa were categorized as ACCIDENTAL (49 diatoms; 36 dinoflagellates; 2 chlorophythes), 10% as RESIDENT (3 diatoms; 5 dinoflagellates, 2 cyanobacteria, 1 chlorophythe), and 12% as VISITORS (3 diatoms; 10 dinoflagellates).

The Shannon-Wiener diversity index varied between 0.10 and 1.57 bits.cell^{-1} (Table 2), with most values (56%) higher than the mean (0.74 ± 0.50 bits.cell^{-1}; Figure 5). The lowest values were registered in April, May, August, September and December 2011, related to high abundances of certain taxa of Diatoms and Dinoflagellates. Pielou's evenness varied from 0.04 to 0.60 (0.28 ± 0.18), following the same pattern as the diversity index (Figure 5).

A total of 42 taxa (19 diatoms, 19 dinoflagellates, 2 cyanobacteria and 2 chlorophythes) was defined by SIMPER analysis as the most representative ("typical") in the study area (Table 3), for their contribution of up to 90% of the similarity between the samples of each sampling period. The taxonomic classes with the greatest contributions to the similarity between samples were the dinoflagellates (13-60%) and diatoms (13-55%) (Figure 6). Individual contribution to sample similarity by a singular taxon varied between 2 and 19% in each sampling period. We highlight unidentified cyanobacteria

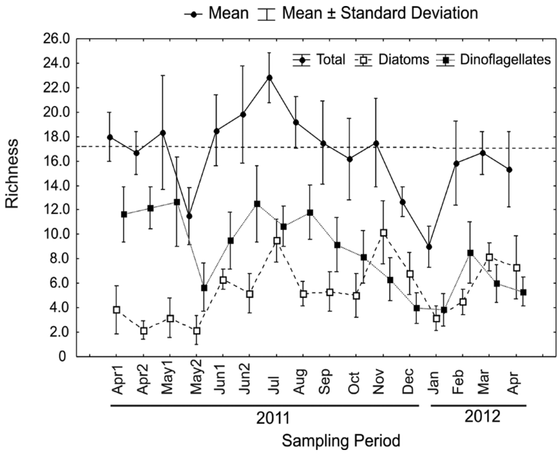

Figure 3. Total Microphytoplankton, Diatoms and Dinoflagellates Richness from April 2011 to April 2012. Dotted line indicates general mean of Total Richness.

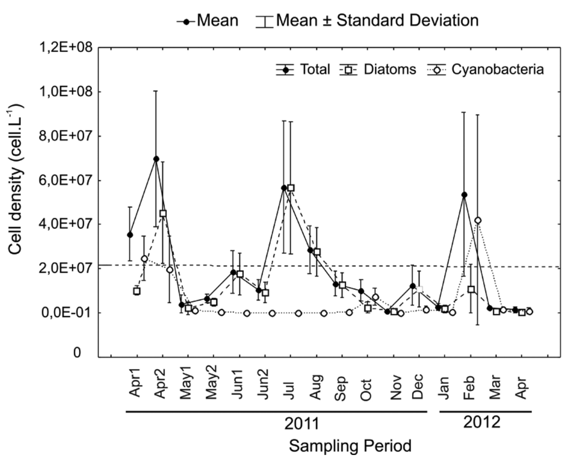

Figure 4. Total Microphytoplankton, Diatoms and Dinoflagellates Abundance (cell.L^{-1}) from April 2011 to April 2012. Dotted line indicates general mean of Total Density.

of the Order Oscillatoriales and Order Nostocales, diatoms *Ceratoneis closterium* (=*Cylindrotheca closterium*) and *Leptocylindrus minimum* and dinoflagellate *Prorocentrum triestinum* for their broad occurrence (> 80%) with high mean abundance (10^4-10^7 cells.L^{-1}) in many periods. Table 3 shows the high abundance of certain morphotypes with several shapes and dimensions between 20 and 150 µm (1 centric diatom, 4 pennate diatoms and 8 dinoflagellates) and brings out the need for taxonomic studies so that species that make a major contribution to community structure may be correctly identified.

When compared with the Constancy index, SIMPER analysis was more effective in determining which taxa made a greater contribution to sample similarity in each

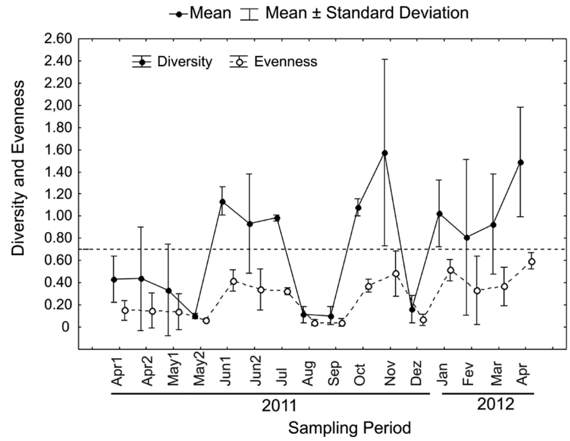

Figure 5. Shannon-Wiener Species Diversity index (bits.cell^{-1}) and Pielou's Evenness index from April 2011 to April 2012. Dotted line indicates general mean of Diversity index.

period. The Constancy index just takes into account the occurrence of each taxon, while SIMPER considers abundance as well as occurrence. This could be observed for the diatom *Skeletonema costatum* classified as ACCIDENTAL by the Constancy index with occurrence in only 25% of the samples. However, this taxon was highlighted by SIMPER for its high mean densities (2.8×10^6 - 2.2×10^7 cells.L^{-1}) that favored a contribution of up to 12% for the similarity of the samples for the periods of June1, June2 and July.

DISCUSSION

The microphytoplankton community of Guanabara Bay was characterized by typical estuarine and coastal species, influenced by a large number of multifactorial abiotic and biotic processes (LLEBOT et al., 2011; CLOERN; FOSTER; KLECKNER, 2014). Among all the factors that may affect the taxonomic composition and temporal variation of phytoplankton in Guanabara Bay are found: tidal cycle, seasonality of water masses of adjacent continental shelf, cold fronts and continental drainage (rainfall, inflow of domestic sewage, etc.)

The elevated number of taxa classified as ACCIDENTAL confirmed the high local hydrodynamism as being a consequence of the environmental factors mentioned above. The processes which caused such turbulence were probably responsible for the presence of benthic species (diatoms *Paralia sulcata*, *Licmophora* sp., *Diploneis* sp., *Amphora* sp.) along with planktonic ones (diatoms *Leptocylindrus danicus, L. minimus*,

Table 3. Simper analysis results showing average abundance (cell.L^{-1}) of each taxon from April 2011 to April 2012. Values underlined represent taxa with contribution ≥ 10%. Taxa were ordered by the sum (Σ) of average abundance considering the entire sampling period. The Morphotypes are included.

		2011	**2012**														
	Σ	**Apr1**	**Apr2**	**May1**	**May2**	**Jun1**	**Jun2**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**
DIATOMS																	
Ceratoneis closterium	1.5×10^8	268795	45288034	2204603	4875816	4900030	6361924	34217077	27582734	12664516	375628		10722583	1450707	107327	15027	34250
Skeletonema cf. *costatum*	3.7×10^7					12054996	2771530	22341109									
Leptocylindrus minimus	2.5×10^7	9827038		24869		488356	13543		97592		1992860	53319	124846	423125	10596338	690848	238276
Rhizosolenia setigera	4.2×10^5										10755	377664	8050			12286	9575
Phaeodactylum tricornutum	2.7×10^5														269895		
Guinardia sp.	1.7×10^5					135964	31867										
Chaetoceros cf. *socialis*	8.2×10^4											82115					
Leptocylindrus danicus	4.3×10^4							13255				14908				14872	
Chaetoceros spp.	3.0×10^4											29791					
Complex C. *closterium/ Nitzschia longissima*	2.2×10^4							22222									
Pseudo-nitzschia "delicatissima complex"	2.2×10^4									22107							
Thalassiosira sp.	1.7×10^4											13311	3630				
Skeletonema sp.	1.1×10^4									11087							
Complex Tropidoneis	1.2×10^3											1222					
MORPHOTYPES																	
Centric diatom (20-50 µm)	1.1×10^5			7062				20207	24962			61032	947				13048
Pennate diatom (linear; 50-100 µm)	5.9×10^4															58953	
Pennate diatom (lanceolate; 20-50 µm)	2.3×10^4									6174						16701	
Pennate diatom (linear; 100-150 µm)	1.6×10^4															16464	
Pennate diatom (retangular; 20-50 µm)	4.7×10^4							4658									
DINOFLAGELLATES																	
Akashiwo sanguinea	4.2×10^6		4200474														
Prorocentrum triestinum	8.2×10^5	51624	36760		30273	116844	254136	7780	119102	45344	93210	23541		23938	8681		10838
Prorocentrum micans	1.8×10^5	126192	6904				27087				18854						

Continued Table 3.

Amphidinium spp.	1.4×10^{5}					99583	25759		12879								
Scrippsiella cf. *trochoidea*	1.2×10^{5}	11472	69601	5659		21244	15137										
Protoperidinium spp.	1.2×10^{5}			9040		48597	18323	1398	29344	11884							
Prorocentrum minimum	8.5×10^{4}	15774					15402	13283	19120	21776							
Gymnodinium sp.	7.5×10^{4}				74887												
Scrippsiella sp.	7.1×10^{4}								62937	4448		3495					
Oxyphysis oxytoxoides	5.2×10^{4}	15137		7252			5046	2158							22097		
Prorocentrum gracile	1.9×10^{4}	19279															
MORPHOTYPES																	
Order Gymnodiniales (oblong; 50-100 μm)	9.5×10^{5}		17898	220521	697083	15668											
Order Gymnodiniales (oblong; 20-50 μm)	9.2×10^{5}	33460	52111	59541		47800	452506	9613	26024	23767	12348	7003			125478	44700	23412
Order Gymnodiniales (rounded; 20-50μm)	5.4×10^{5}	44135	130952	2002				2927	12083			1955	3946	266081	35513	30636	
Armoured cell (rounded; 20-50 μm)	5.3×10^{5}	25971	65873	14080	41427	64530	113923	8003	45941	47269	45012		1578	4998		29679	18309
Order Gymnodiniales (biconic; 20-50 μm)	1.5×10^{5}			3260			23369	1732							102592		18256
Armoured cell (oblong; 20-50 μm)	1.2×10^{5}	21510	29852	11468				4520	51119			3657					
Order Gymnodiniales (ovoid; 20-50 μm)	9.0×10^{4}														72603	9079	8733
Order Gymnodiniales (biconic; 50-100 μm)	1.3×10^{4}			12957													
CIANOBACTERIA																	
Order Oscillatoriales	1.0×10^{8}	24710047	19786421	1383809	150570	165441	35850	107037	125740	141010	7271626	903	1536905	500332	42182297	1479714	921115
Order Nostocales	7.1×10^{5}			8593	209523	24431		11023		145790	100513		32356	31304	14994	43369	87177
CHLOROPHYTHES																	
Unidentified Euglenoficeans	1.5×10^{6}	171761	29226	40659	402316	286269	53111	35640	242983	63401	107019				21308		
Unidentified Cloroficeans	6.9×10^{4}				68513												

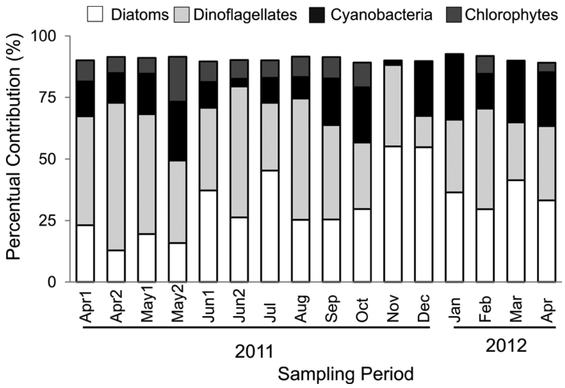

Figure 6. Percentual Contribution of phytoplankton groups determined by similarity percentage analysis (SIMPER).

Thalassionema nitzschioides, *Coscinodiscus* spp., *Pseudo-nitzschia* spp., *Skeletonema* cf. *costatum*; Dinoflagellates *Alexandrium* sp.; *Protoperidinium* spp.) (RICARD, 1987; HASLE; SYVERTSEN, 1997). It is important to state that benthic microalgae are important primary producers in shallow aquatic ecosystems and that their production exceeds that of planktonic microalgae in certain periods (BERGESCH; ODEBRECHT; ABREU, 1995; BRANDINI; FERNANDES, 1996). The relevance of a taxon in the study area was determined by its high contribution to sample similarity in each season. Thus SIMPER analysis confirmed the representativity of “RESIDENT” taxa as well as the occasional contribution of others during the study period.

The organisms identified in the present study had already been observed in Guanabara Bay due to their wide distribution in the system (VILLAC; TENENBAUM, 2010). The low frequency and abundance of *Skeletonema costatum* called the authors’ attention since this diatom has been consistently reported as opportunist in eutrophic environments. This pattern change may be associated with the location of the sampling stations close to the bay’s entrance, a less polluted site due to the contribution of more saline, cleaner and clearer coastal water (SANTOS et al., 2007). Similar results were found by GUENTHER et al. (2012) in a short temporal scale investigation also in the entrance of Guanabara Bay during summer 2004, in which *S. costatum* was not considered an abundant taxon. Likewise, SANTOS et al. (2007) registered higher densities of this species in the inner portion when compared with the entrance of the bay. These outcomes suggest that the hydrodynamic conditions found in different areas of Guanabara Bay may exercise great influence on the representation of *S. costatum*. Another important aspect to be considered is that this diatom was the subject of a taxonomic review revealing that the genus biodiversity at any given place is most likely underestimated and may include more than one species (SARNO et al., 2007; KOISTRA et al., 2008). For instance, the morphology of *Skeletonema* species was examined in coastal waters of southern Brazil and the authors came to the conclusion that this genus is highly diverse in that geographical area, with the occurrence of four confirmed species: *S. costatum, S. pseudocostatum, S. potamos* and *S. tropicum* (BERGESCH; GARCIA; ODEBRECHT, 2009).

The recurrent observation of potentially harmful species in the bay requires some attention, specially concerning diatoms of the genus *Pseudo-nitzschia* due to its ability to produce a powerful neurotoxin known as domoic acid (VILLAC; TENENBAUM, 2001; VILLAC; DOUCETTE; KACZMARSKA, 2010). Some studies have shown that *Pseudo-nitzschia* abundance is related to a major entry of nutrients into the water column (PARSON; DORTCH, 2002). Some other potentially harmful species were also found in Guanabara Bay, such as the diatoms *Cerataulina pelagica, Leptocylindrus danicus*, L. minimus and Dinoflagellates *Akashiwo sanguinea, Oxyphysis oxytoxoides, Prorocentrum micans, P. balticum, Dinophysis acuminata, Scrippsiella cf. trochoidea* (FRYXELL; VILLAC, 1999; HALLEGRAEFF; ANDERSON; CEMBELLA, 2003).

The average cell density (10^7 cel.L^{-1}), described in this study, were higher than those found in other Brazilian coastal estuaries: Sepetiba Bay-RJ (10^4-10^6 cel.L^{-1}; TENENBAUM et al. 2004), Estuary of Paraíba do Norte River-PB (10^3-10^6 cel.L^{-1}; SASSI, 1991), Paranaguá Bay-PR (10^4-10^6 cel.L^{-1}; BRANDINI, 1985; BRANDINI; THAMM, 1994), São Sebastião Channel-SP (10^5-10^6 cel.L^{-1}; GIANESELLA et al., 1999). However, studies in Guanabara Bay carried out between 1913 and 2004 showed similar values (10^5-10^9 cel.L^{-1}) (VILLAC; TENENBAUM, 2010). These differences may be related to different environmental conditions related to changes in time and space as well as to human intervention (artificial eutrophication, dredging, navigation, etc.).

Diatoms and dinoflagellates were the predominant groups and together were responsible for more than 96% of the specific composition, in accordance with the literature that indicates their predominance in Brazilian coastal regions (BRANDINI et al., 1997). The dominance of diatoms in shallow coastal regions reflects the instability of this environment, where turbulence homogenizes the water column, increases nutrient concentration in the euphotic zone and reduces cell sinking (MARGALEF, 1978; SMETACEK, 1988; LLEBOT et al., 2011). The high representativeness (40%) of chain-forming diatoms (species of *Chaetoceros*, *Leptocylindrus*, *Hemiaulus, Skeletonema*, *Pseudo-nitzschia*, *Eucampia*) has been related to estuarine and coastal environments (FERNANDES; BRANDINI, 2004; BÖTTJER; MORALES, 2005). According to REYNOLDS; PADISÁK and SOMMER (1993) this morphology provides a larger surface for light capture and represents an advantage over environments with high suspended solid concentrations. Laboratory assays also suggest that these organisms thrive in the environment as a result of a lower grazing pressure by microzooplankton (BODE et al., 2005).

The combination of different nutrition strategies (autotrophic and mixotrophic) may give dinoflagellates a competitive advantage over other organisms, even in the conditions of limited light that are very common in estuaries and river deltas (LALLI; PARSONS, 1993). Some taxa such as species of the genus *Protoperidium* and of the Order Gymnodiniales, considered heterotrophics (STEIDINGER; TANGEN, 1997), have also been frequently observed in samples. The high contribution of organisms of the Order Gymnodiniales to richness and abundance confirms VILLAC and TENENBAUM (2010) statement that Guanabara Bay dinoflagellates, although frequent and highly representative, are underestimated by virtue of the sampling and analysis procedures used in most of the studies. These dinoflagellates have extremely fragile cells that are deformed or destroyed by the commonly used fixative substances. So that a more precise identification of most taxa demands a different methodology from fixation to sample handling combined with the utilization of more advanced microscopy techniques with higher resolution.

The cyanobacteria, of the Orders Oscillatoriales and Nostocales, were also very important in phytoplankton's attaining up to 99% of abundance in some samples. These results were expected and suggest that the increase in filamentous cyanobacteria density is a response to rainy periods and high levels of eutrophication (SANTOS et al., 2007; VILLAC; TENENBAUM, 2010).

The high concentration of euglenophyceans in the study area can be associated with inland polluted waters (LIMA; TENENBAUM; VALENTIN, 2010; GUENTHER et al. 2012), whereas these organisms require organically enriched water for growth (LEE, 2008).

The presence of the diatoms *Proboscia alata, Rhizosolenia setigera, Hemiaulus membranaceus, Guinardia striata, Eucampia cornuta, Dactyliosolen phuketensis* and the dinoflagellates *Prorocentrum balticum, Pronoctiluca pelagica, Oxytoxum gracile* indicates the influence of the Tropical Water that flows along the Brazilian continental shelf mixed with Coastal Water (HASLE; SYVERSTSEN, 1997; STEIDINGER; TANGEN, 1997).

The low diversity index (< 2.0 bits.cell^{-1}), in 90% of samples, is a typical characteristic of systems in unstable equilibrium such as estuaries or polluted environments subject to local eutrophication (LLEBOT et al., 2011). Water mass enrichment processes first induce the proliferation of a reduced number of species and consequently a profound reduction in the species diversity index (MARGALEF, 1958; MARGALEF, 1980).

CONCLUSION

The composition and abundance of the phytoplankton of a certain region is certainly associated with the local hydrography. The interaction between water movements and phytoplankton organisms results from a combination of environmental factors. Thus the hydrodynamic properties of each region play an important role in the temporal variability and structure of phytoplankton populations (MARGALEF, 1978; ESTRADA; BERDALET, 1997). The information produced by this study will, therefore, add to knowledge of the Guanabara Bay system and will be useful for management purposes and also for the regulation of land use in the area surrounding the bay.

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