Seasonal changes of phytoplankton in the Paquera-Tambor Marine Area for Responsible Fishing, Gulf of Nicoya, Costa Rica

Cambios estacionales del fitoplancton en el área marina de pesca responsable de Paquera-Tambor, Golfo de Nicoya, Costa Rica

Andrea García-Rojas[1*] *& Hannia Vega Bolaños*[1]

ABSTRACT

The implementation of Marine Areas for Responsible Fishing (MARF) is a tool for fisheries management; therefore, baseline studies play an important role in understanding the ecological dynamics from the bases of the food web in the MARF. The aim of this study was to identify the abundance of the phytoplankton communities associated with the MARF to determine the seasonal changes between abiotic variables and phytoplankton in the Paquera-Tambor MARF, Gulf of Nicoya, Costa Rica. Monthly sampling (September 2013 to August 2014) was performed for physical-chemical factors and phytoplankton. The data showed a temporal variation of both environmental factors and the phytoplankton community. The most representative microalgae were diatoms and dinoflagellates with a richness of 51 and 32 species, respectively, where the presence of some algal bloom forming species such as *Cochlodinium catenatum* was highlighted, with a concentration of 5.85×10^4 cells L^{-1}. Regarding diatoms and parameters such as Secchi disk depth ($r = -0.558$) and the percentage of oxygen saturation ($r = -0.490$), a negative correlation was found due to climate variability in the area. Zooplanktonic tintinnids were identified and showed a positive correlation with diatoms ($r = 0.433$). A fundamental ecosystem dynamic was evident for the trophic development of the Tambor-Paquera-MARF, which underpins the importance of the fishing zone and reflects the relevance of continued biotic and abiotic monitoring for the area.

Keywords: Microalgae, seasonal changes, Marine Areas for Responsible Fishing, Gulf of Nicoya, Costa Rica.

RESUMEN

La implementación de Áreas Marinas de Pesca Responsable (AMPR) es una herramienta para el ordenamiento pesquero, por ello, los estudios de línea base juegan un rol importante para comprender la dinámica ecológica desde las bases de la red trófica en las AMPR. El objetivo de este trabajo fue caracterizar la abundancia de los grupos taxonómicos del fitoplancton en el AMPR-Paquera-Tambor, para la determinación de cambios estacionales entre variables abióticas y el fitoplancton. Se realizó un muestreo mensual (de septiembre-2013 a agosto-2014) para la toma de muestras de factores fisicoquímicos, así como de microalgas planctónicas. Los datos evidenciaron una variación temporal tanto de los factores ambientales como del fitoplancton. Las microalgas más representativas fueron las diatomeas y los dinoflagelados con una riqueza de 51

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[1] Juan Bertoglia Richards Marine Biology Station, School of Biological Sciences, Universidad Nacional, Costa Rica. andrea.garcia.rojas@una.cr*; hannia.vega.bolaños@una.cr

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y 32 especies, respectivamente, donde se resalta la presencia de algunas especies productoras de florecimientos algales como *Cochlodinium catenatum* con una concentración de 5.85x10^4cél L^{-1}. Con respecto a las diatomeas y los parámetros, como la profundidad del disco Secchi (r = -0.558) y el porcentaje de saturación de oxígeno (r = -0.490), se reflejó una correlación negativa debido a la variabilidad climática de la zona. Se identificaron organismos del grupo zooplanctónico de los tintínidos, los cuales presentaron una correlación positiva con las diatomeas (r = 0.433). Se evidenció una dinámica ecosistémica fundamental para el desarrollo trófico del AMPR-Paquera-Tambor, que fundamenta la importancia pesquera de la zona y refleja la relevancia de continuar con un monitoreo biótico y abiótico para la zona.

Palabras claves: Microalgas, cambios estacionales, áreas marinas de pesca responsable, Golfo de Nicoya, Costa Rica.

INTRODUCTION

In Costa Rica, overfishing and the lack of planning in the use of coastal resources has promoted the implementation of Marine Areas for Responsible Fishing (MARF), which are marine areas demarcated and managed by coastal communities together with the relevant authorities in order to regulate fishing activities with a better use of resources in the long term (MAG, 2009). MARFs provide some advantages for fisheries management. For instance, they reduce conflict in the use of fishing gear harmful to marine biodiversity that affect the abundance of organisms. Fishing efforts are reduced in recruitment areas, which leads to conservation of sites and resources. There is a better collection of fisheries data which helps improve policies that directly affect the sector. Mainly, products are guaranteed to come from a sustainably exploited area that combines the human development of the social groups involved (OCEANA, 2013; Hoff *et al.* 2015).

Given the advantages provided by this fishery regulation, there are a number of provisions that must be met to designate an area as a MARF, including baseline studies, which represent a fundamental tool to learn about the biodiversity and environmental state of the ecosystem to be managed. As a result, the analysis of the phytoplankton community is important, since this group of organisms represents the plant material of marine plankton, and they are the primary producers of the aquatic ecosystems, which bears ecological importance since this is the basis of the marine food chain (Valiela, 1995; Rochelle-Newall *et al.* 2011). This group is made up of a wide variety of taxa, including the Cyanophyta, Prochlorophyta, Chlorophyta, Euglenophyta, Dinophyta, Haptophyta, Cryptophyta, and Chromophyta (Bacillariophyceae, Chrysophyceae, Raphidophyte, and Prymnesiophyceae), with diatoms and dinoflagellates being the most diverse groups (Dawes, 1991; Valiela, 1995; Jeffrey *et al.* 1997; Knox, 2000; Mann, 2000; MacIntery *et al.* 2000; Nybakken, 2001; Throndsen *et al.* 2007; Hoppenrath *et al.* 2009; Simon *et al.* 2009; Widdicombe *et al.* 2010).

Phytoplankton, due to their short life cycles, respond quickly to environmental changes, and their qualitative and quantitative composition allows an estimation of water quality. The development of these organisms is controlled by biological, physical and chemical processes (Hu *et al.* 2011); therefore, the information that they may give as bioindicators should be interpreted with other physical and chemical data. In addition, the rapid response of the phytoplankton community to changes induced by human activity (introduction of nutrients, organic matter, or pollutants) currently makes them a key element in the evaluation of the quality of seawater (Domingues *et al.* 2008; Spatharis & Tsirtsis, 2010).

Similarly, interspecific relationships in communities affect the stability of food webs, which have been evaluated in order to analyze their effects on ecosystems and their relationship with trophic chains (Li *et al.* 2009); for instance, the relationship between phytoplankton and cod production has been studied, which shows that primary productivity determines the load capacity of systems (Steingrund & Gaard, 2005; Hansen *et al.* 2005) and, therefore, the production of commercial species.

The aim of this study was to characterize the abundance of the taxa of the phytoplankton in the Paquera-Tambor Marine Area for Responsible Fishing to determine seasonal changes of microalgae, influenced by abiotic variables.

MATERIALS AND METHODS

Study area

This study was conducted on the outer part of the Gulf of Nicoya (GN), Costa Rica, specifically in the Paquera-Tambor Marine Area for Responsible Fishing (Paquera-Tambor-MARF). This area is characterized for having the greatest depths within the GN (25 to 100 m) and a strong influence by oceanic water masses (Brenes & León, 1995).

Four sampling stations were located in the Paquera-Tambor MARF, taking into account bathymetric, geographic and biological characteristics of the area. Stations 1 and 2 were located in the outermost zone in the Paquera-Tambor MARF, the first station in front of the Tambor Beach area, with depths close to 45 m, and the second station between Tortuga Island and the Negritos Islands, since the latter constitute a natural barrier dividing the MARF. Sampling station 3 was located in front the sanitary landfill (*El Relleno*) in Paquera, since it is an important area for the reproduction and growth of the spotted snapper *Lutjanus guttatus* (Steindachner, 1869), a fish species important for the area (Araya *et al.* 2007). Station 4 was located between San Lucas Island and Naranjo Beach, in the shallowest and innermost part of the sampling area (Fig. 1).

Collecting data and water samples:

Monthly water and environmental data samples were taken from September 2013 to August 2014 for phytoplankton analysis. Temperature, salinity, total dissolved solids concen-

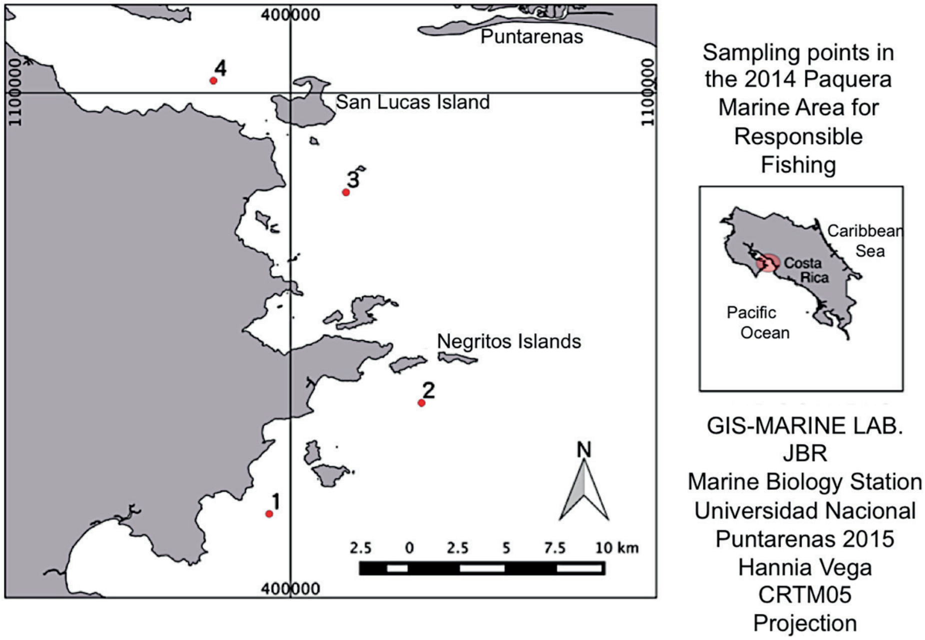

Fig. 1. Study area and sampling points in the Paquera-Tambor MARF
Fig. 1. Localización del área de estudio y los puntos de muestreo en el AMPR-Paquera-Tambor

tration, and percentage of dissolved oxygen saturation were measured with a YSI 556 MPS multiparameter in-situ at each of the sampling stations, as well as the Secchi disk depth.

In order to determine phytoplankton abundance, water samples were collected with a 6L Niskin bottle at a 2m depth. Water samples were stored in 500 ml plastic bottles (previously washed with water from the site), and a 5 ml Lugol solution was added to preserve the microalgae.

Identification and counts of phytoplankton:

Phytoplankton organisms were studied using 1 ml Sedgewick Rafter counting chambers and a Nikon's Eclipse E600 light microscope, for which a 1 ml aliquot of the sample was placed directly on the cell count (the sample was not concentrated). Phytoplankton were counted and identified observing the entire bottom of the counting chamber with 10x and 20x objectives, depending on the dimensions of the organisms. Organisms were identified up to the lowest possible taxonomic level and counts were done making groups of cells according to the main phytoplankton groups identified.

The studies by Cupp (1937), Sournia (1986), Ricard (1987), Chrétiennot-Dinet (1990), Round *et al.* (1990), Tomas (1997), Horner (2002), and Ojeda (2006) were used for the identification of microalgae.

Data analysis:

In order to determine the normality of data obtained, a Levene's test was used, and, in cases where data did not follow a normal curve, data was transformed using the log(x+1) function.

In order to determine significant temporal differences between biological and abiotic parameters, a

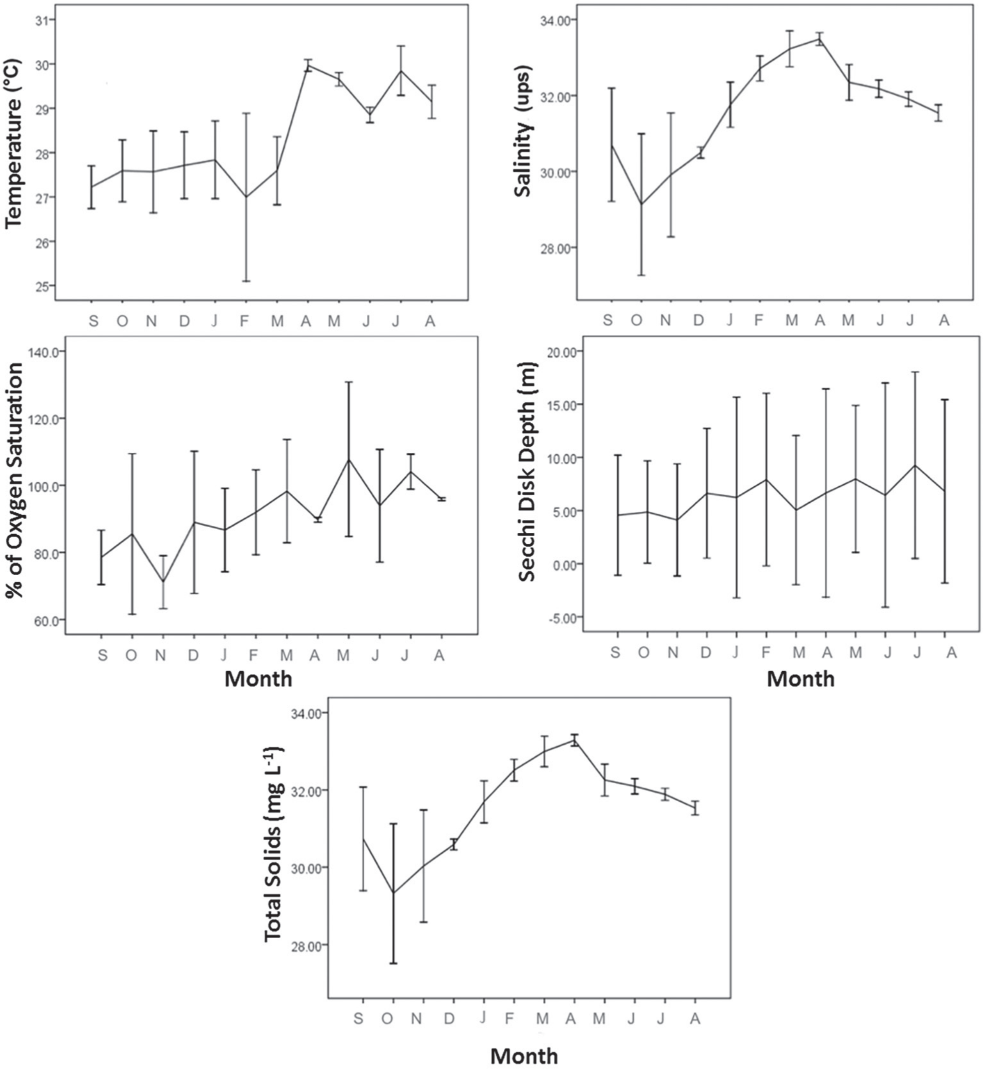

Fig. 2. Temporal variation of the 2013-2014 physical and chemical variables in the Paquera-Tambor MARF (lines correspond to average values per month with their respective standard error)

Fig. 2. Comportamiento temporal de las variables físicas y químicas determinadas en el AMPR-Paquera-Tambor en el 2013-2014 (las líneas corresponden a valores promedio por mes con su respectivo error estándar)

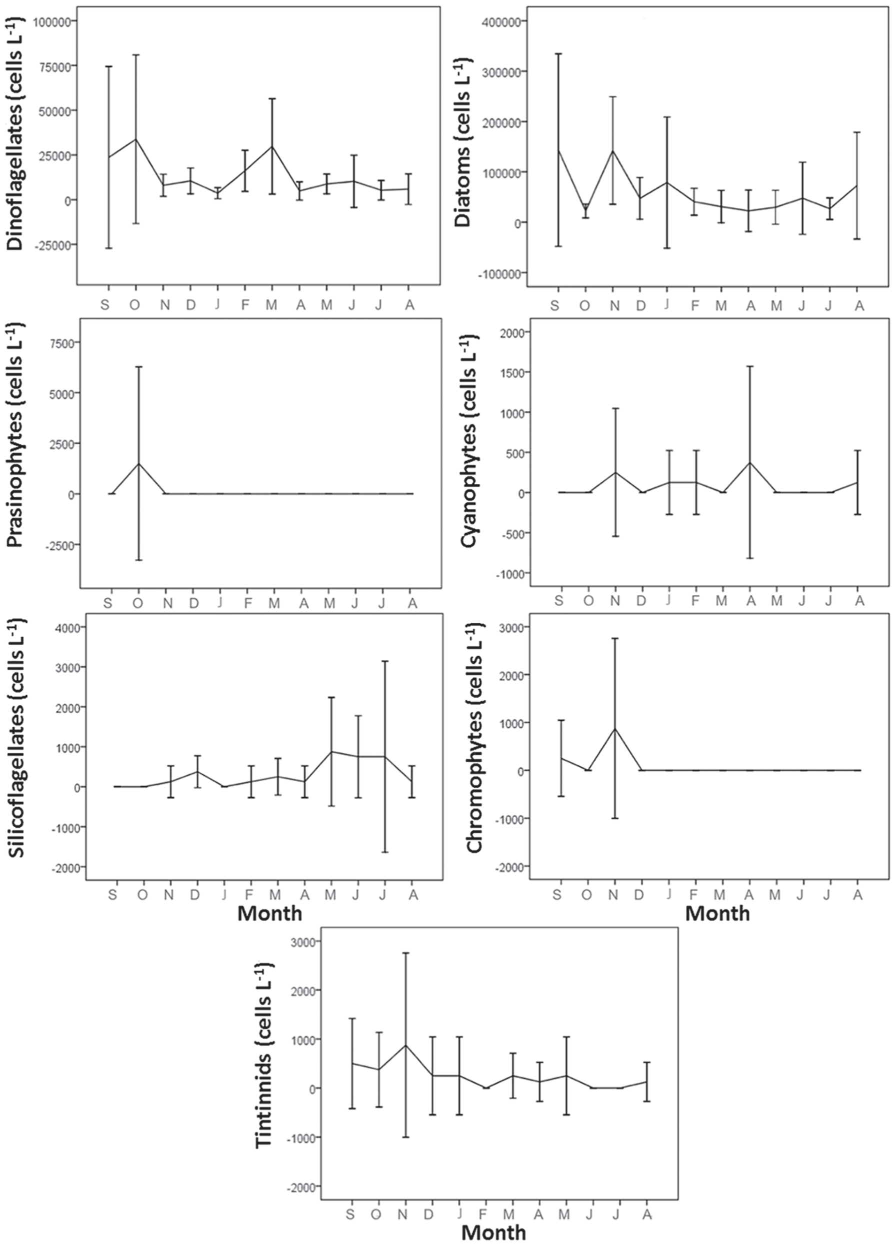

Fig. 3. Temporal variation of the abundance of phytoplankton groups in the Paquera-Tambor MARF in 2013-2014 (lines correspond to average values per month with their respective standard error)

Fig. 3. Comportamiento temporal de la concentración de los grupos fitoplanctónicos determinados en el AMPR-Paquera-Tambor en el 2013-2014 (las líneas corresponden a valores promedio por mes con su respectivo error estándar)

one-way ANOVA test was used, and the significance of each variable was confirmed with a multiple comparison Student-Newman-Keuls (S-N-K) post-hoc test. The relationship of the different phytoplankton groups identified with respect to the physical and chemical factors was determined using the Pearson correlation. The ANOVA, correlation, and normality analyses were conducted using the SPSS 17.0 statistical program (SPSS, 2008).

RESULTS

Determining the temporal variation between the sampling months for the physical-chemical variables and the phytoplankton groups showed significant differences (*P* <0.05) for parameters such as temperature (*P* <0.001), salinity (*P* <0.001), total solids (*P* <0.001) and percentage of oxygen saturation (*P* <0.001), as well as for dinoflagellates (*P* <0.048) and diatoms (*P* <0.016) (Table 1). Since sampling began in the rainy season, temperature tended to increase throughout the study period, with a minimum value of 27°C in October and a maximum value of 30°C in April. For variables such as salinity, total solids concentration and percent of dissolved oxygen saturation, the period with the highest values was mainly the dry season, with values equal to 33.57PSU, 33.36 mg L^{-1} and 126.7%, respectively. The Secchi disk depth ranged between 0.7m and 14.6m, with a strong variability during the sampling period (Figs. 2 and 3).

Regarding the micro-algae community, diatoms and dinoflagellates were the most representative groups throughout the sampling period, followed by the silicoflagellates, with values of $1.3x10^4$ ± $2.3x10^3$ cells L^{-1}, $5.9x10^4$ ± $9.1x10^3$ cells L^{-1} and $2.9x10^2$ ± 84 cells L^{-1}, respectively. It is worth highlighting that dinoflagellates showed algal blooms associated with the harmful species, *Cochlodinium catenatum*, which exhibited a concentration of $5.85x10^4$ ± $3x10^4$ cells L^{-1} during October 2013. Other phytoplankton groups such as the prasinophytes (125 ± 125 cells L^{-1}), cyanophytes (84 ± 40 cells $L^{-1)}$ and chromophytes (94 ± 60 cells L^{-1}) had a sporadic presence and relatively low concentrations in comparison with the dominant groups. In addition, the

Table 1. Results of one-way ANOVA assessing temporal variations for the physical and chemical variables and taxonomic phytoplankton groups in the Paquera-Tambor MARF (*: significant differences with p-value <0.05)
Cuadro 1. Resultados de ANOVA de un factor evaluando las diferencias temporales para las variables físicas y químicas y los grupos fitoplanctónicos en el AMPR-Paquera-Tambor (*: diferencias significativas con p-valor <0.05)

	P
Temperature	0.001*
Salinity	0.001*
Total solids	0.001*
% of O_2 Saturation	0.001*
Secchi Disk	0.949
Diatoms	0.016*
Dinoflagellates	0.048*
Prasinophytes	0.465
Cyanophytes	0.705
Silicoflagellates	0.261
Chromophytes	0.070
Tintinnids	0.443

zooplanktonic group tintinnids was present throughout the study period, although in low concentrations (ranging between $1x10^3$ and $2.5x10^3$ cells L^{-1}) (Fig. 3).

The same trend seen in the abundance was observed in species richness, with diatoms and dinoflagellates showing 51 and 32 species, respectively. For the remaining phytoplankton groups identified, abundance of species ranged between one and four specimens, while eight species were observed for tintinnids (Table 2).

Within the dinoflagellates, the presence of the following algal bloom forming organisms was highlighted: dinoflagellates *Cochlodinium catenatum* (Okamura, 1916), *Pyrodinium bahamense* var. *compressum* (Böhm, Steidinger, Tester & Taylor, 1980), *Alexandrium monilatum* (Balech, 1995), and diatoms *Pseudo-nitzschia* spp. However, during the study period, only the dinoflagellates *A. monilatum* and *C. catenatum* generated an algal bloom with water discoloration and production of mucous substances.

The most dominant phytoplankton species were the diatoms *Cyclothella* spp., *Guinardia striata* (Hasle, 1996), *Leptocylindrus danicus* (Cleve, 1889), *Navicula* spp., *Nitzschia* spp., and *Thalassiosira* spp., with frequency percentages in the samples greater than 50%. Within the same frequency

Table 2. Phytoplanktonic richness in the Paquera-Tambor MARF for the sampling period
Cuadro 2. Riqueza fitoplanctónica en el AMPR-Paquera-Tambor durante el periodo de muestreo

	Sampling period											
	2013				**2014**							
	S	**O**	**N**	**D**	**J**	**F**	**M**	**A**	**M**	**J**	**J**	**A**
DINOFLAGELLATES												
Alexandrium catenella	-	-	x	-	x	-	-	-	x	-	-	-
Alexandrium monilatum	-	x	-	x	-	x	x	x	x	-	-	-
Ceratium candelabrum	-	-	-	-	-	-	-	-	-	-	x	-
Ceratium furca	x	x	x	-	x	-	x	-	x	x	x	-
Ceratium fusus	x	x	-	-	-	-	x	-	-	x	-	x
Ceratium horridum	-	-	-	-	-	x	-	-	-	-	-	-
Ceratium macroceros	-	-	-	-	x	-	-	-	-	-	x	-
Cochlodinium catenatum	x	x	x	x	-	x	x	x	x	x	x	-
Corythodinium tesselatum	-	-	-	-	-	-	x	-	-	-	-	-
Dinophysis caudata	-	-	-	-	x	-	x	-	x	-	-	-
Gonyualax cf. polygramma	-	-	-	x	x	-	-	-	-	-	-	-
Gymnodinium catenatum	-	-	x	x	-	x	-	-	-	-	-	-
Gyrodinium cf. spirale	x	x	x	x	-	x	x	-	x	x	-	x
Noctiluca scintillans	x	-	-	-	-	-	-	-	-	-	-	-
Oxyphyxis cf.	-	-	-	-	x	x	-	-	-	-	-	-
Phalacroma rotundatum	-	-	-	-	-	-	-	x	-	-	-	-
Prorocentrum gracile	x	x	-	-	x	x	-	x	x	-	x	x
Prorocentrum cf. mexicanum	-	-	-	-	x	-	-	x	-	-	-	-
Prorocentrum micans	-	x	-	x	-	x	-	x	x	x	x	x
Prorocentrum rostratum	-	-	x	x	-	-	x	-	-	-	-	-
Prorocentrum cf. scutellum	-	-	-	x	-	-	-	-	-	-	-	-
Protoperidinium conicum	-	x	x	-	x	x	-	-	x	x	-	-
Protoperidinium pellucidum	x	x	x	x	-	x	x	-	x	x	-	-
Protoperidinium pentagonum	x	-	-	-	-	x	-	-	x	-	-	-
Protoperidinium steinii	x	-	x	-	x	-	-	-	-	-	-	-
Protoperidium claudicans	-	x	-	-	-	-	-	-	-	-	-	-
Pyrocistys cf. lunata	x	-	x	-	-	-	-	-	-	-	-	-
Pyrodinium bahamense var. compressum	x	-	x	x	-	-	-	-	x	-	x	-
Pyrophacus cf. steinii	-	-	-	x	x	x	-	-	-	-	-	-
Scripsiella trochoidea	x	x	x	x	-	x	x	x	x	x	x	x
Torodinium cf.	-	-	x	-	-	-	-	-	-	-	-	-
Warnowia cf.	-	-	-	-	-	x	-	-	-	-	-	-

DIATOMS												
Amphiprora cf.	-	-	-	-	x	-	-	-	-	x	-	-
Bacteriastrum delicatum	x	-	x	-	x	-	-	-	x	-	-	-
Bacteriastrum hyalinum	-	-	x	x	-	-	-	-	x	x	-	x
Cerataulina bergonii	-	-	-	-	-	x	x	-	-	-	-	-
Chaetoceros aequatorialis	x	-	-	-	-	-	-	-	-	-	-	-
Chaetoceros affinis	-	x	-	-	-	-	-	-	-	-	-	-
Chaetoceros cf. atlanticus	-	-	x	-	-	-	-	-	x	-	-	-
Chaetoceros coarctatus	-	-	x	-	-	-	-	-	-	-	-	-
Chaetoceros cf. debilis	-	-	x	-	x	-	-	-	-	-	-	-
Chaetoceros decipiens	x	x	x	x	-	-	-	-	-	-	-	-
Chaetoceros lorenzianus	-	x	x	-	x	-	-	-	-	-	-	-
Chetoceros cf. laevis	-	-	-	x	-	-	-	-	-	-	-	-
Cocconeis cf.	-	-	-	-	-	-	-	-	-	-	-	-
Corethron criophylum	x	-	x	-	x	-	-	-	-	-	-	x
Coscinodiscus sp	x	-	-	-	x	x	x	x	x	x	x	x
Cyclotella	x	x	x	x	x	x	-	-	x	x	x	x
Cylindrotheca closterium	-	-	x	-	-	-	x	-	-	x	-	-
Diploneis bombus	-	-	-	-	x	-	-	x	-	-	x	-
Ditylum brightwelli	x	-	-	x	-	-	x	-	x	x	x	x
Eucampia cornuta	-	-	x	-	-	-	-	-	-	-	-	-
Fragilaria cf.	-	-	-	-	-	-	-	-	-	-	-	x
Guinardia cylindrus	x	-	x	-	-	-	-	-	-	-	-	-
Guinardia delicatula	x	-	-	x	-	-	-	-	-	-	-	-
Guinardia flaccida	-	-	-	x	x	-	-	-	-	-	-	-
Guinardia striata	x	x	x	x	-	-	x	x	x	-	x	x
Gyrosigma cf.	-	-	-	-	-	-	-	x	-	-	x	x
Haslea cf.	-	x	x	-	x	-	-	-	-	-	-	-
Hemiaulus hauckii	x	-	x	x	-	-	-	-	x	-	-	x
Hemiaulus sinensis	x	x	x	x	x	x	-	-	-	-	-	-
Leptocylindrus danicus	x	x	x	x	x	x	x	x	x	x	x	x
Lithodesmium undulatum	x	-	x	x	-	x	x	-	x	x	x	x
Navicula cf. granii	x	-	-	-	x	-	-	-	-	-	-	-
Navicula sp	x	x	x	x	x	x	x	-	x	x	x	x
Nitzschia cf.	-	x	-	x	-	x	x	-	x	x	x	x
Odontella aurita	x	-	-	x	-	-	x	-	-	-	-	x
Odontella mobiliensis	-	-	-	-	x	-	-	x	x	-	-	x
Odontella sinensis	x	-	x	x	x	-	x	x	x	-	x	x
Paralia sulcata	x	x	x	x	x	x	x	x	-	x	x	x
Pleurosigma cf.	-	-	-	-	x	x	x	-	x	x	x	-
Prosbocia alata	x	-	x	-	-	x	x	-	-	-	-	-
Pseudo-nitzschia cf.	x	x	x	x	-	-	-	-	-	-	-	-
Rhizosolenia cf.	-	-	x	-	x	-	-	-	-	-	-	-
Rhizosolenia cf. setigera	-	-	-	x	x	-	x	-	-	x	-	x
Rhizosolenia striata	-	-	-	-	x	-	x	x	-	-	-	-
Skeletonema costatum	x	x	x	x	x	-	-	-	-	-	-	x
Stephanopyxis turris	-	-	x	x	x	x	x	-	x	x	-	x
Striatella unipucntata	-	-	x	x	-	-	-	-	-	-	-	x
Surirella fastuosa	-	-	-	-	-	x	x	-	-	x	-	-
Thalassionema nitzschiodes	x	x	x	x	x	-	x	-	-	x	x	x
Thalassiosira sp	x	x	x	x	-	x	x	x	x	x	x	x
Triceratium	-	-	-	-	-	-	-	-	x	-	-	-
PRASINOPHYTES												
Pyramimonas cf.	-	x	-	-	-	-	-	-	-	-	-	-
CYANOPHYTES												
Merismopedia cf. (colonies)	-	-	x	-	-	-	-	x	-	-	-	-
Oscillatoria cf.	-	-	-	-	x	x	-	x	-	-	-	x
Spurulina cf.	-	-	x	-	-	-	-	-	-	-	-	-
SILICOFLAGELLATES												
Dictyoca fibula	-	-	x	x	-	x	x	x	x	x	x	x
CHROMOPHYTES												
Hermesium adriaticum cf.	x	-	x	-	-	-	-	-	-	-	-	-
TINTINNIDS												
Codonellopsis gaussi cf. coxliella	-	-	x	-	-	-	-	-	-	-	-	-
Eutintinnus fracknoi	x	-	-	-	-	-	-	-	-	-	-	-
Salpingella cf.	-	x	-	-	-	-	-	x	-	-	-	-
Tintinnopsis fimbriata	x	-	x	-	x	-	-	-	-	-	-	-
Tintinnopsis lobiancoi	x	-	-	-	-	-	-	-	-	-	-	-
Tintinnopsis parva	-	x	x	x	-	-	x	-	x	-	-	x
Tintinnopsis radix	-	-	x	-	-	-	-	-	-	-	-	-
Undella claparedei	-	-	x	-	-	-	-	-	-	-	-	-

range, the dinoflagellates *Gyrodinium spirale* (Kofoid and Swezy, 1921), *Scripsiella trochoidea* (Loeblich III, 1976) and *Cochlodinium catenatum* were observed.

When determining the correlation between environmental variables and phytoplankton, negative relationships were observed between diatoms and some variables such as depth (r = -0.448), percentage of dissolved oxygen saturation (r = -0.490) and Secchi disk depth (r = -0.558), as well as between dinoflagellates and water temperature (r = -0.429). In addition, diatoms were also positively correlated with the abundance of the tintinnids (r = 0.443) (Table 3).

DISCUSSION

This study showed a temporal variability in most of the data obtained, both physically and chemically as well as biologically. From the abiotic perspective, results reflected a clear trend related to the climatic variability that characterizes Costa Rica: on one hand, a dry season marked by increased temperatures and the influence of the wind mixing the waters, which generates greater turbulence in the water column and resuspension of sediments, and, on the other hand, a rainy season characterized by a high input of fresh water and sediment into the sea (Lizano & Vargas, 1994; Brenes *et al.* 2001). According to Voorhis *et al*. (1983) and Brenes (2001), the influence of the discharge of rivers such as the Tempisque, Barranca, and Grande de Tárcoles is a determining factor in the Gulf of Nicoya, since it increases the variability of physical and chemical factors of the water, due to the constant input of fresh water in the estuary, which fluctuates depending on the weather period.

The variation in the percentage of oxygen saturation also reflected constant changes experienced by the estuary of the Gulf of Nicoya throughout an annual cycle. The values obtained from the percentages of oxygen saturation during the rainy

Table 3. Significant values of Pearson correlation between physical and chemical variables and phytoplankton in the Paquera-Tambor MARF (*: significant correlation with *P* <0.05)
Cuadro 3. Valores significativos de la correlación de Pearson entre las variables físicas y químicas y los organismos fitoplanctónicos del AMPR-Paquera-Tambor (*: Correlación significativa a *P*-valor <0.05)

Correlation	r-Pearson Value
Dinoflagellates / Temperature	-0.429*
Diatoms / Depth	-0.448*
Diatoms / % of Dissolved Oxygen Saturation	-0.490*
Diatoms / Secchi Disk Depth	-0.558*
Tintinnids / Diatoms	0.433*

season agree with those obtained by Kress *et al.* (2001) and Epifanio *et al.* (1983), who determined that the Gulf of Nicoya is an unsaturated estuary when there is an increase in rainfall in the area, caused by the consumption of oxygen by the organic matter that enters through the runoff.

The Secchi disk depth was closely related to the behavior of the phytoplankton community, presenting the highest values when the microalgae concentration was lower, and vice versa. This is confirmed with the negative correlation between the concentration of diatoms and the Secchi disk depth. In addition, according to Medina (1995), Litchman & Klausmeier (2008) and Aktan (2011), the extinction of light in water is proportional to the abundance of phytoplankton. This condition is reflected only in the diatoms since this is the dominant group as far as concentration, unlike the other phytoplankton organisms.

The richness of the phytoplankton in the Paquera-Tambor MARF reflects an important group of organisms, mainly belonging to diatoms and dinoflagellates. This research, as well as others in other coastal areas (Eker & Kideyş, 2000; Peña & Pinilla, 2002; Varela & Prego, 2003; Álvarez-Góngora & Herrera-Silveira, 2006; Simon *et al.* 2009; Haraguchi *et al.* 2015) reported higher concentrations of diatoms with respect to the other phytoplankton groups identified, with the dinoflagellates being the next highest group in terms of the number of present species. This has already been noted for other coastal estuarine environments and is also evidenced by the fact that the most common species in this study belonged to these phytoplankton groups. Rochelle-Newall *et al.* (2011) evaluated the distribution and diversity of phytoplankton in northern Viet Nam estuarine environments and found that between 43% and 99% of the samples were diatoms. In addition, Cabrita (2014) determined the richness of the phytoplankton community as an indicator of changes related to the drainage in the Tagus estuary in Portugal, determining that groups such as the diatoms, dinoflagellates, and cryptophytes represent a total of 92-99% of the phytoplankton community.

On the other hand, several authors have determined that the dominant numbers of diatoms species is strongly related to increased concentrations of nutrients (Ishizaka *et al.* 1986; Day *et al.* 2012), which could be associated to the characteristics of the Gulf of Nicoya, where the dynamics of the estuary with constant inputs of freshwater, mangrove ecosystems near shore and the processes of mixing waters (Brenes & León, 1995) favor a constant flow of nutrients (Magnone *et al*. 2015; Sin *et al*. 2015).

The low numbers of prasinophytes, cyanophytes and chromophytes can be related to the fact that they are phytoplankton groups common in coastal ecosystems of oligotrophic nature. According to several authors, these phytoplanton groups represent some of the most important nanoplankton groups in the oligotrophic systems (Puigserver *et al*. 2002; Resende *et al*. 2007; Aktan, 2011; Huete-Ortega *et al*. 2010; Schlüter *et al*. 2011).

The presence of tintinnids in the waters of the Paquera-Tambor MARF is related to the adaptation of this group of organisms to areas where freshwater and saltwater converge (Zhang *et al*. 2015). However, few studies of tintinnids have been reported in tropical areas, as subtropical to temperate areas are considered to be the comfort zone of this group of ciliates (Quevedo *et al*. 2003; Safi *et al*. 2007; Santoferrara & Alder, 2009; Li *et al.* 2015).

The positive relationship between diatoms and tintinnids is due to a primary trophic relationship, since it was observed that the increase in the concentration of diatom cells coincides with the increase in the abundance of ciliates, suggesting a relevant grazing process in the Paquera-Tambor MARF (Stelfox-Widdicombe *et al*. 2004). This is consistent with what was observed by Widdicombe *et al*. (2010), who determined that the seasonal pattern of abundance of the ciliates in the Western English Channel was similar to the population dynamics of the diatoms and the phytoflagellates.

The presence of algal bloom forming species in the waters of the Paquera-Tambor MARF proves the wide distribution of these organisms in the Gulf of Nicoya, where the presence of dinoflagellates *Cochlodinium catenatum*, *Pyrodinium bahamense* var. *compressum*, *Alexandrium monilatum*, and diatoms *Pseudo-nitzschia* spp. has been reported from the inside to the outside area of the Gulf of Nicoya (García, 2005; Calvo *et al*. 2014). In the case of dinoflagellates, these species are common in the waters of the Gulf of Nicoya; *C. catenatum* is a recurring species in the production of red tides in the Gulf (García, 2005) as well as *P. bahamense* var. *compressum* (Víquez & Hargraves, 1995). In the case of *A. monilatum*, it was not until 2005 that the first red tide caused by this species was reported for this area (Calvo *et al*. 2005).

In general, results reflect that the Paquera-Tambor MARF is an important ecological area, since the presence of different microalgae groups and zooplankton organisms (tintinnids) are the basis of the food chain in the area (Magnone *et al*. 2015; Feng *et al*. 2015; Rakshit *et al*. 2016), and, therefore, favor the following levels of the food chain. In addition, given that this is an important area for aquaculture and fishery production, this study is of vital importance to ensure an ecosystem assessment that allows for the recognition of guidelines for a comprehensive management of the marine area for responsible fishing.

This type of monitoring should be maintained in Marine Areas for Responsible Fishing, since they are areas susceptible to harmful and toxic algal blooms, and, consequently, can affect the economy of the communities exploiting them.

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