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Research Article

Seasonal variation of the phytoplankton community in tuna farms in Bahía de La Paz, southern Gulf of California, Mexico

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ABSTRACT. The phytoplankton community of tuna farms in Bahía de La Paz, southern Baja California, Mexico was studied. Samples were taken from tuna farms near San Juan de la Costa, Rancheros del Mar and from a station in El Mogote, away from the influence of these farms. Water samples were collected monthly (June 2006-May 2007) with a van Dorn bottle at different depths in San Juan de la Costa (0, 25 and 50 m), Rancheros del Mar (0, 15 and 30 m) and El Mogote (0 m) to measure temperature, dissolved oxygen, inorganic nutrients, and chlorophyll-*a* and to determine phytoplankton composition and abundance. The index of simple dominance, Shannon-Weaver diversity, and Pielou evenness were estimated. The water column was stratified from June to September (~27.5°C) and mixed from October to May (~18.5°C). Nutrient concentrations at the three sampling sites did not increase significantly. Nanophytoplankton dominated, followed by microplanktonic diatoms, and the highest diatom abundance occurred during the warm period. The phytoplankton community was more diverse in San Juan de la Costa than in Rancheros del Mar. In the latter, a superficial bloom of the cyanobacterium *Trichodesmium erythraeum* (1630×10^3 cel L^{-1}) occurred in September, and in San Juan de la Costa the diatom *Pseudo-nitzschia fraudulenta* reached the highest abundance (183.8×10^3 cel L^{-1}) in July.

Keywords: algal blooms, nutrients, phytoplankton, tuna farms, Bahía de La Paz.

INTRODUCTION

Phytoplankton is a fundamental natural resource in the functioning of the seas, coastal lagoons, and bodies of fresh water. It is responsible for 90% of the organic matter production of these aquatic environments (Margalef, 1981). Studies on the phytoplankton communities of la Bahía de La Paz have shown that diatoms and dinoflagellates are the most abundant groups in this ecosystem (Gilmartin & Revelante, 1978; Signoret & Santoyo, 1980; García-Pámanes, 1981; Bustillos-Guzmán, 1985; Verdugo-Díaz, 2004; Villalejo-Fuerte *et al*., 2005; Verdugo-Díaz & Gárate-Lizárraga, 2018). Recently, Villegas-Aguilera (2009) found that nanoflagellates were the dominant group in the Bahía de La Paz. Furthermore, blooms of harmful microalgae species (HAB) have been observed to cause mortality in various fish species in captivity and in natural conditions due to the obstruction of the gills (Gárate-Lizárraga *et al*., 2004, 2007). In other cases, HAB have been innocuous (Gárate-Lizárraga *et al*., 2001, 2006, 2009a, 2009b; Sierra-Beltrán *et al*., 2005; López-Cortés *et al*., 2006). In fish fattening farms the composition, dominance, and biomass of the phytoplankton community can be modified by the waste produced in these farms, as has happened on the Philippine Bolinao coasts where environmental changes were observed for a 10 year period (1995-2005). The most significant effect was recorded in 2002 in a milkfish farm (*Chanos chanos*). The excess organic matter not consumed by these fishes as well as their excreta caused a decrease in the dissolved oxygen concentration below 2.0 mg L^{-1}, and the nutrient imbalance promoted the blooming of opportunistic harmful algal species such as *Prorocentrum cordatum* and caused changes in the succession of phytoplankton species (Diego-McGlone *et al*., 2008). Thus it is essential to analyze the phytoplankton community in tuna fattening farms for the possible influence of these farms, the waste they provide and the HAB species that

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can proliferate and cause mortality of aquatic organisms. Tuna in captivity would also be affected. However, phytoplankton studies have not been conducted in bay tuna farms. Our objective was to determine if there are any changes in the structure of the phytoplankton associations suggesting promotion of HAB due to the possible influence of tuna farms in relation to temporal changes in physical and chemical variables in two sampling stations located within the tuna farms and at a station outside the influence of the farms in Bahía de La Paz, Baja California Sur (BCS).

MATERIALS AND METHODS

Bahía de La Paz is located approximately 180 km from the mouth of the Gulf of California, between 24º6’-24º48’N and 110º12’-110º48’W, on the southeastern coast of the Baja California Peninsula. Monthly samples were taken from June 2006 to May 2007 at three sampling stations (Fig. 1). San Juan de la Costa station (E1) was located inside the tuna enclosure. The Rancheros del Mar sampling station was located 500 m from the tuna enclosure, adjacent to Isla Gaviota (E2). The E3 station (El Mogote) was far from the influence of the farms. At station E1 the samples were collected from the surface at 25 and 50 m depth; at E2 samples were from the surface and at 15 and 30 m depth. At station E3, given the bathymetry, it was not possible to take stratified samples; this prevented comparisons with stations E1 and E2 for physical, chemical and biological parameters. At each station three liters of water were collected with a Van Dorn bottle. To determine cell abundance, they were placed in 250 mL bottles and fixed with acetate-Lugol. The temperature was measured with a bucket thermometer. The samples for the determination of nutrient concentrations were quantified following the methodology of Strickland & Parsons (1972) using a continuous ions flow autoanalyzer (Lachat Instruments mod. 8000). Total nitrogen was considered as the sum of nitrite (NO_2), nitrate (NO_3) and ammonium (NH_4), and phosphorus was orthophosphates (PO_4). Samples for dissolved oxygen were placed in DOB bottles and fixed with 1 mL of manganous sulfate and 1 mL of potassium iodide. Dissolved oxygen was quantified by the Winkler method (Strickland & Parsons, 1972). For the determination of chlorophyll-*a* and accessory pigments, 1.5 liters of seawater were filtered using Whatman GF/F glass fiber filters that were frozen at -20°C and subsequently analyzed by high performance liquid chromatography resolution (HPLC), (Bustillos-Guzmán *et al*., 1995; Vidussi *et al*., 1996). Data were obtained from [http://www.cibnor.mx/meteo/ecibmet.html] to describe wind (direction and speed) seasonal variability.

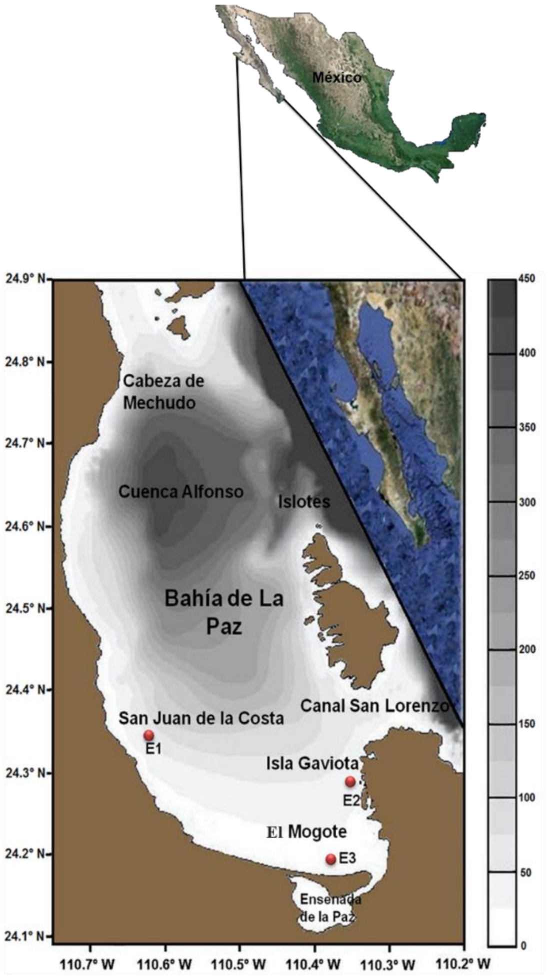

Figure 1. Location of three sampling stations in the Bahía de La Paz: E1 (San Juan de La Costa) and E2 (Rancheros del Mar) within tuna farms and E3 located in El Mogote.

For phytoplankton quantification preserved samples were thoroughly mixed, and aliquots of 25 mL were placed in an Utermöhl sedimentation chamber. Nanophytoplankton (2-20 µm) and microphytoplankton (20-200 µm) cells were counted and identified using an inverted Olympus CK2 microscope (Dussart, 1965; Malone, 1980). The identification of the microphytoplankton species was performed by consulting taxonomic guides or specialized keys: Cupp & Allen (1938), Osorio-Tafall (1942), Prescott (1970), Taylor (1976), Balech (1988), Licea-Durán *et al*. (1995), Moreno *et al*. (1996), Hasle & Syvertsen (1997), Steidinger & Tangen (1997), Hernández-Becerril & Bravo-Sierra (2001), and Siqueiros-Beltrones (2002).

Tests of normality were carried out for the environmental variables using the Kolmogorov-Smirnov technique and homogeneity of variances (homoscedasticity) with the Bartlett technique (Sokal & Rohlf, 1981). The possible differences between sea-

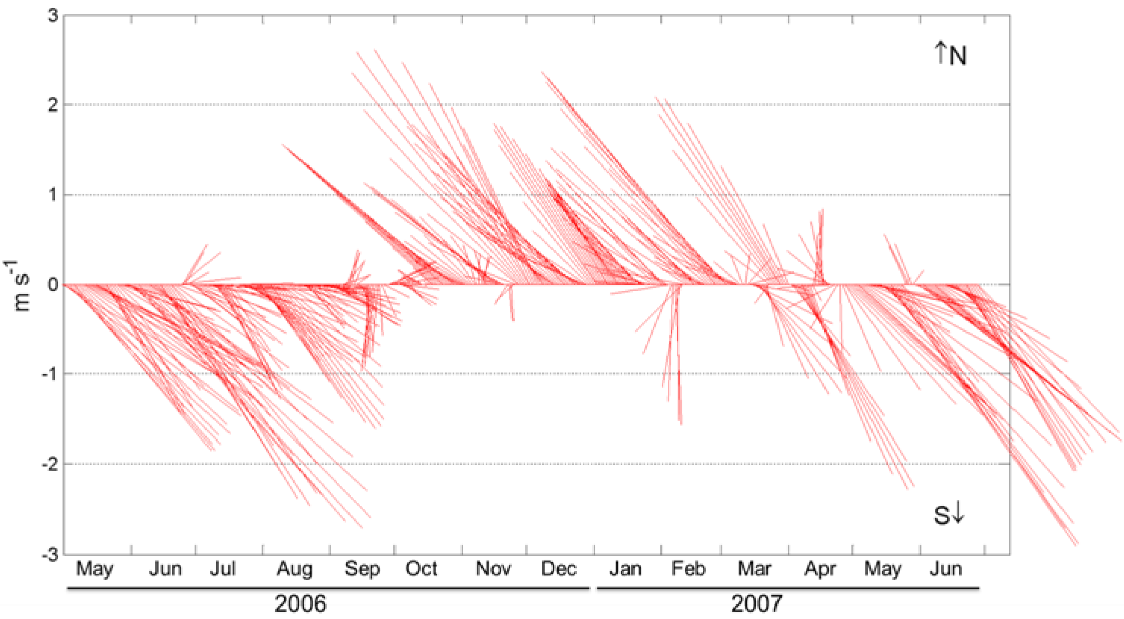

Figure 2. Direction and daily average speed of winds (m s^{-1}) from June 2006 to May 2007.

sons, in the strata (depth levels), warm months (June-November 2006), and cold months (December 2006-May 2007), were defined by a variance analysis with non-parametric Mann-Whitney tests.

Based on the composition and abundance of the phytoplankton species, the community was characterized by the following descriptors: the Shannon-Weaver index (H') and Pielou's evenness index (J') were used (Magurran, 1989) to assess diversity, as well as the simple dominance index (De La Cruz-Agüero, 1994). The codominant species index was used to distinguish between abundant and rare species in the taxocenosis (Kikvidze & Osawa, 2002).

RESULTS

During the study period, it was observed that the winds presented a definite pattern with an alternation between southeast and northwest directions; the southeasterly winds were predominant during June through October, reaching speeds of 1.8 to 2.8 m s^{-1}. From November to April 2007 a greater persistence of the northwesterly winds was observed, with an average speed of 2.5 m s^{-1}. In May 2007, the direction of the winds changed towards the southeast, with an average speed of 2.2 m s^{-1} (Fig. 2).

Physical and chemical variables

Temperature

Low temperatures (16.0 to 20.0°C) were recorded at San Juan de la Costa at 50 m depth (Fig. 3a) and at 30 m at Rancheros del Mar (Fig. 3b), while highest values (24.0 to 30°C) were at the surface at the three stations (Figs. 3a-3c). The temperature showed no significant differences (Mann-Whitney, $P > 0.05$) between the sampled depth levels or between sampling stations. From surface temperature values that did not show differences between sampling stations, two seasons were defined: the warm season from June to November, with a temperature average of 27°C, and the cold season from December to May with an average of 19.7°C.

Dissolved oxygen

The temporal variation of surface oxygen concentration at the three sampling stations fluctuated similarly during both the warm and cold months (Figs. 4a-4c). However, at Rancheros del Mar a high concentration (9.2 mg L^{-1}) was detected in October (Fig. 4b). For San Juan de la Costa, lower values were recorded than at Rancheros del Mar (1.5 to 9.1 mg L^{-1}), with values between 1.8 mg L^{-1} at 50 m depth in April and May, indicating hypoxia (<2 mg L^{-1} O_2) (Drabroswski *et al.*, 2004).

Dissolved inorganic nitrogen (DIN) components

Nitrate was the major contributor to DIN throughout the annual cycle at San Juan de la Costa at 25 m and 50 m, contributing 60 and 79% to the DIN. This component contributed up to 65% at 30 m at Rancheros del Mar. However, at El Mogote nitrate was not the main nutrient, contributing only 29% to the DIN (Table 1). The other important DIN component was ammonium.

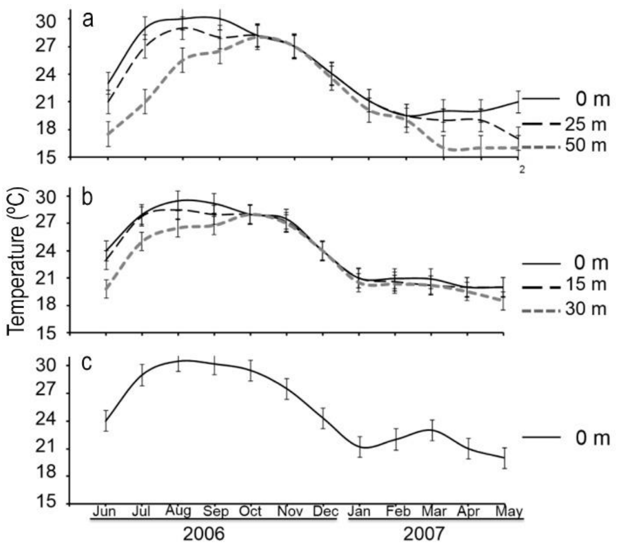

Figure 3. Average daily temperature (°C). a) San Juan de la Costa, b) Rancheros del Mar, and c) El Mogote from June 2006 to May 2007. The value of December at San Juan de la Costa was calculated by averaging the values in November and January.

At the surface it was the predominant nitrogen form at the three sampling stations. The third component of the DIN was nitrite, which was detected in lower concentrations than nitrate and ammonium. There were no significant differences (Mann-Whitney, $P > 0.05$) between the warm and cold seasons or between seasons.

Reactive phosphorus

Reactive phosphorus concentrations throughout the annual cycle were similar at the three sampling stations (Figs. 5a-5c). However, two peaks occurred at the surface at San Juan de la Costa in April (4.7 µM) and at Rancheros del Mar in July (3.6 µM). There were no significant differences (Mann-Whitney, $P > 0.05$) between the warm and cold seasons or between seasons.

Silicate Ion

Silicate variation was high at 50 m depth at San Juan de la Costa and at 30 m depth at Rancheros del Mar. In San Juan de la Costa three peaks occurred, one in June 2006 (31 µM) at 50 m depth, one in April (39 µM) and one in May (42 µM) in 2007 (Fig. 6a). At Rancheros del Mar the maximum value (35 µM) was recorded (Fig. 6b) in July at 30 m. In contrast, lower values of silicates were recorded at the surface of the three sampling stations (Figs. 6b-6c). The Mann-Whitney test indicated significant differences ($P < 0.05$) between the depth levels at San Juan de la Costa and Rancheros del Mar.

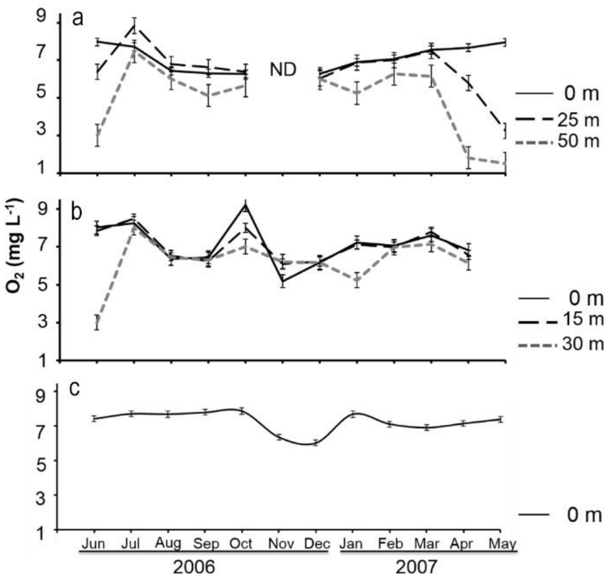

Figure 4. Seasonal variation of dissolved oxygen concentrations (mg L^{-1}). a) San Juan de la Costa, b) Rancheros del Mar, and c) El Mogote from June 2006 to May 2007. ND: no data.

Table 1. Total percentage of nitrogen forms (nitrites (NO_2), nitrates (NO_3) and ammonium (NH_4)) at San Juan de la Costa, Rancheros del Mar and El Mogote from June 2006 to May 2007.

Level	San Juan de la Costa			Rancheros del Mar			El Mogote
	0 m	25 m	50 m	0 m	15 m	30 m	0 m
NO_2 (%)	7.4	6.9	4.1	11.1	9.4	5.7	5.9
NO_3 (%)	28.6	60.4	79.6	29.7	30.4	64.5	29.4
NH_4 (%)	64.0	32.7	16.3	59.2	60.2	29.8	64.7

N:P ratio

The N:P ratio throughout the annual cycle did not exceed 16:1 except in May for the three seasons. At San Juan de la Costa the maximum value (45.6) occurred. Similarly, two increments occurred at 25 and 50 m depth (18) in this month (Fig. 7a). Similarly, at Rancheros del Mar the highest values (24 to 29) in the three levels (Fig. 7b) and at El Mogote (20) were recorded in May (Fig. 7c). The Mann-Whitney test did not show significant differences ($P > 0.05$) between the warm and cold seasons or between the three seasons and levels.

Si:N ratio

In general, the lowest proportion of the Redfield ratio (Si:N 16:16) throughout the annual cycle occurred at in San Juan de la Costa and El Mogote, compared to Rancheros del Mar. At San Juan de la Costa at 25 m depth the maximum value of 24 occurred in April, and in July (14) and March (16) values were close to the

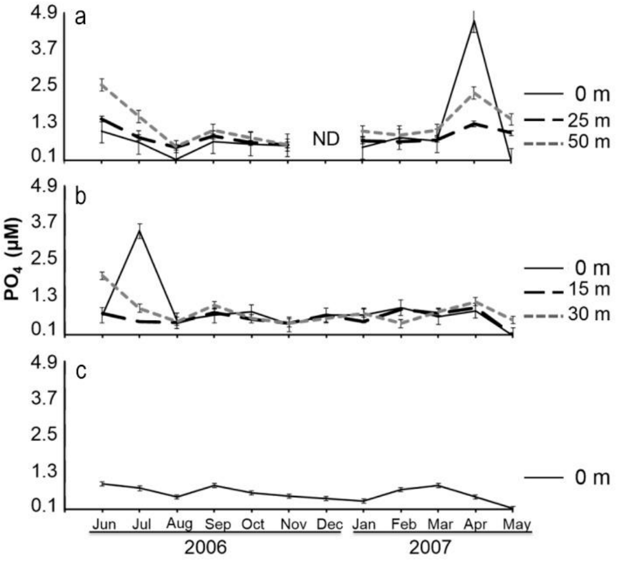

Figure 5. Seasonal variation of reactive phosphorus concentrations µM (PO_4) at: a) San Juan de la Costa, b) Rancheros del Mar and c) El Mogote during June 2006 to May 2007. ND: no data.

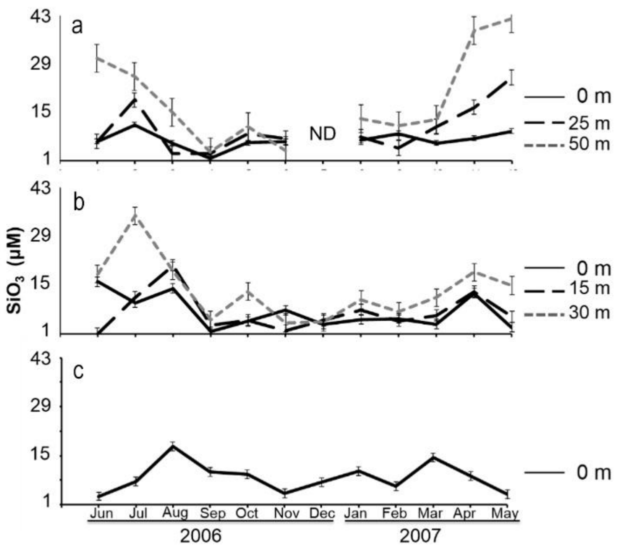

Figure 6. Seasonal variation of silicate concentrations µM (SiO_3). a) San Juan de la Costa, b) Rancheros del Mar and c) El Mogote from June 2006 to May 2007. ND: no data.

ideal ratio (Redfield, 1958) (Fig. 8a). At Rancheros del Mar in June (surface), July (30 m), August, March (30 m) and April at all three levels an excess of silicates (19 to 40) occurred (Fig. 8b). On the other hand, at El Mogote the value of 13 in January was close to the ideal proportion (Fig. 8c). Significant differences (Mann-Whitney, $P < 0.05$) occurred between San Juan de la Costa and Rancheros del Mar. However, there were no differences in the warm and cold seasons between the three surface stations and between depth levels.

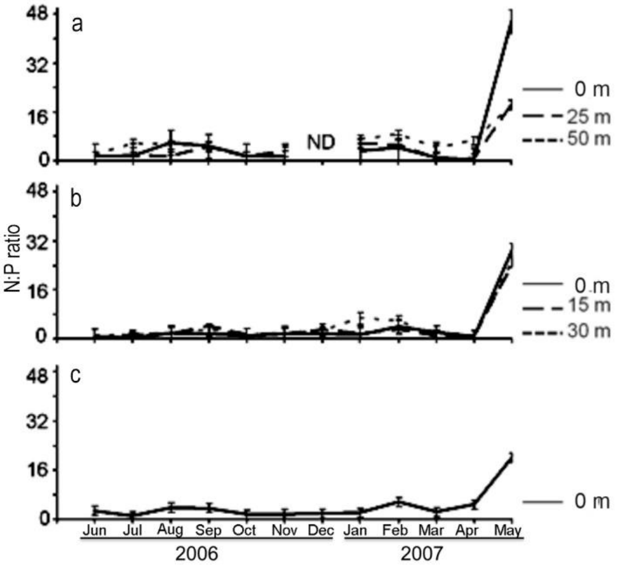

Figure 7. Seasonal variation of N:P ratio. a) San Juan de la Costa, b) Rancheros del Mar and c) El Mogote from June 2006 to May 2007. ND: no data.

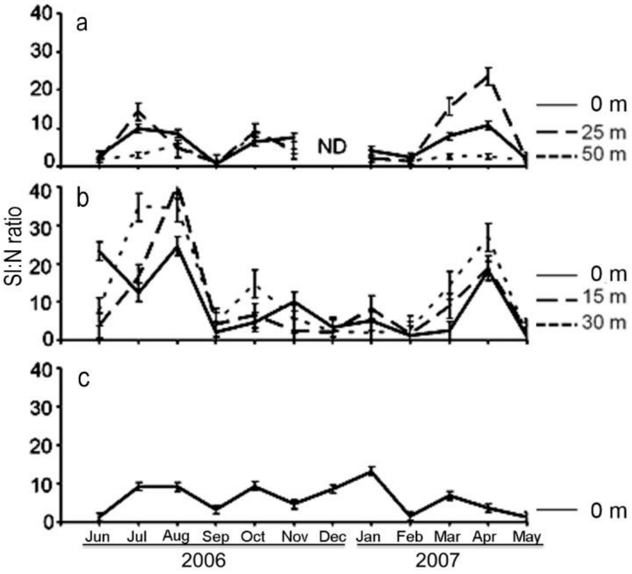

Figure 8. Seasonal variation of Si:N ratio. a) San Juan de la Costa, b) Rancheros del Mar and c) El Mogote from June 2006 to May 2007. ND: no data.

Biological variables

Photosynthetic pigments

The chlorophyll-*a* concentration did not vary in the different strata at San Juan de la Costa, although a peak of 4.7 mg m^{-3} was present at 25 m in June (Fig. 9a). At Rancheros del Mar this pigment fluctuated in the different strata (Fig. 9b). At El Mogote, three peaks were recorded (from 1.1 to 1.4 mg m^{-3}) in June, October, and March (Fig. 9c). Significant differences (Mann-Whitney, $P < 0.05$) occurred between the three stations.

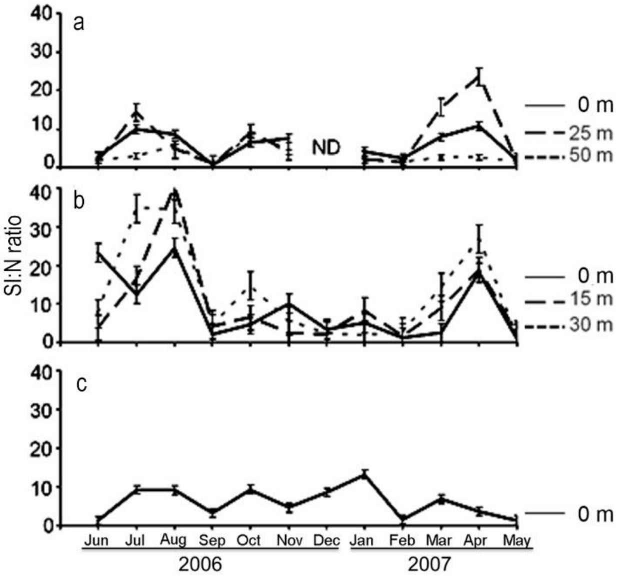

Figure 9. Seasonal variation of Chlorophyll-*a* (mg m^{-3}). a) San Juan de la Costa, b) Rancheros del Mar and c) El Mogote from June 2006 to May 2007. ND: no data.

Cell densities

Percentages of nanophytoplankton of the total abundance were between 4 and 99% at the three stations (Fig. 10a). However, at San Juan de la Costa in June at 25 m depth the microphytoplankton contributed 82% (Fig. 10a2). A maximum abundance of phytoplankton (206×10^3 cells L^{-1}) was reached due to the blooming of the diatom *Pseudo-nitzschia fraudulenta.* Similarly, at Rancheros del Mar at the three levels in September, cyanobacteria contributed between 51 and 99%. High abundances (41 to 1647×10^3 cells L^{-1}) were due to the blooming of *Trichodesmium erythraeum* (Figs.10b-10b2). There were significant differences (Mann-Whitney, $P < 0.05$) between the three sampling stations.

Microphytoplankton

Planktonic diatoms were the main microphytoplankton at San Juan de la Costa, co-dominating with cyanobacteria and, to a lesser degree, with dinoflagellates and tychoplanktonic diatoms (Figs. 11a-11a2). At Rancheros del Mar this phytoplankton fraction was mainly represented by tychoplankton diatoms, followed by planktonic diatoms, cyanobacteria, dinoflagellates, silicoflagellates and ebriids (Figs. 11b-11b2). At El Mogote the community structure differed, being mainly represented by dinoflagellates (Fig. 11c).

Species richness

The microphytoplankton community species consisted of 435 taxa, of which 243 were diatoms (55%), 179 dinoflagellates (43%), 6 silicoflagellates (1.8%), 4 cyanobacteria (0.9%), 1 ebriid (0.2%), 1 raphidophyte (0.2%) and the photosynthetic ciliate *Mesodinium rubrum* (0.2%). At San Juan de la Costa, this fraction constituted 264 taxa, of which 175 were identified at species level. At Rancheros del Mar, 299 taxa were identified, 193 at the species level, while at El Mogote 231 taxa were recorded, with 155 identified at the species level (Figs. 12-13).

Species diversity

At San Juan de la Costa the highest diversity (H' = 4.7) and evenness values (J = 0.75) were recorded at 50 m in June, with a richness of 82 species, with 11 co-dominant species and two peaks in June and September. In June, but at 25 m depth, the lowest value of H' = 0.9 was estimated, with J = 0.15 and a richness of 49 species. The diatom *Pseudo-nitzschia fraudulenta* was the dominant species (Figs. 14-16a). At Rancheros del Mar in June, November, December, and February the diversity values at the three depth levels varied from H' = 4.0 to H' 4.3 with an evenness of J = 0.68 to 0.79 and a richness of 31 to 62 species and from 6 to 10 co-dominant species. In September we observed the lowest diversity value, H' = 0.1, with an evenness of J = 0.15 and a richness of 40 species. *T. erythraeum* was the dominant species (Figs. 14-16b). At El Mogote, the greatest diversity (surface) was H' = 4.7 to 4.9, with an evenness of J = 0.74 and 0.81. The richness was 53 to 99 species in June and July 2006, respectively, with 12 to 19 co-dominant species. In March the lowest diversity value was recorded and was H' = 2.8, with an evenness of J = 0.48 and species richness of 58 taxa with three co-dominant species (Figs. 14-16c). Significant differences (Mann-Whitney, $P < 0.05$) occurred among, and no differences occurred between the warm and cold seasons.

Dominant species

Based on the simple dominance index, five dominant species were present throughout the annual cycle. *Pseudo-nitzschia* spp. reached the maximum abundance (184×10^3 cells L^{-1}) at San Juan de la Costa in June at 25 m depth (Figs. 17a and 17a1). At Rancheros del Mar *Thalassionema nitzschioides* was the second most abundant species. This species was recorded throughout the cycle, although in August its maximum abundance (12×10^3 cells L^{-1}) was recorded at the surface level. The diatom *Fragilariopsis doliolus* was abundant at Rancheros del Mar (Figs. 18b and 18b1), particularly in April where its maximum abundance (10×10^3 cells L^{-1}) occurred at 15 m. The fourth dominant species was the dinoflagellate *Prorocentrum rhathymum*, although it was not very abundant; at El Mogote its highest abundance (5×10^3 cells L^{-1}) was recorded (Fig. 19).

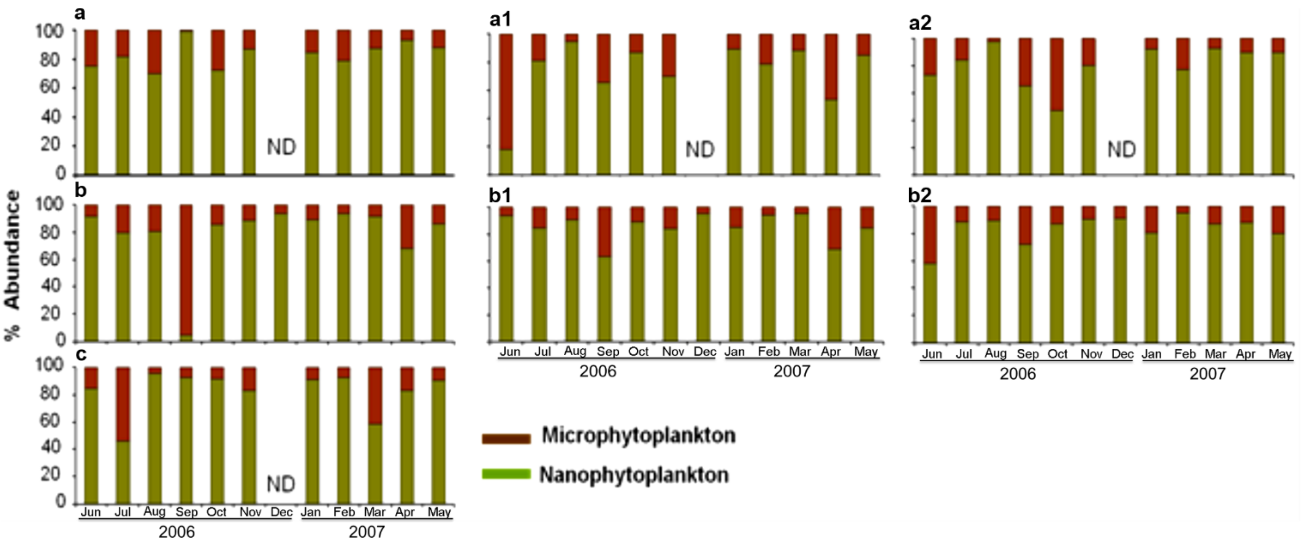

Figure 10. Seasonal variation of abundance of nanophytoplankton and microphytoplankton at: San Juan de la Costa: a) surface, a1) 25 m, a2) 50 m; Rancheros del Mar: a) surface, a1) 15 m, a2) 30 m, and c) El Mogote from June 2006 to May 2007. ND: no data.

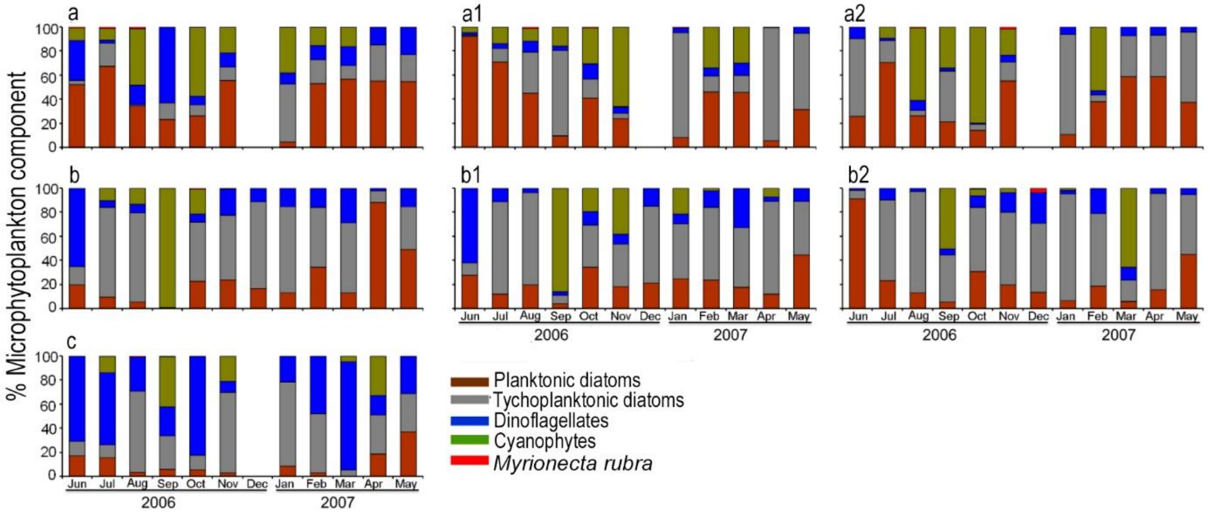

Figure 11. Contribution of percentage of microphytoplankton component at: San Juan de la Costa: a) surface, a1) 25 m, a2) 50 m, Rancheros del Mar a) surface, a1) 15 m, a2) 30 m, and c), El Mogote from June 2006 to May 2007. ND: no data.

The fifth abundant species was the diatom *Thalassionema frauenfeldii* at San Juan de la Costa (Figs. 17a and 17a1); its maximum abundance (15 to $17 \times 10x^3$ cells L^{-1}) was found in September, both on the surface and 50 m depth.

DISCUSSION

Temperature variation throughout the annual cycle was evidenced by the presence of a warm and a cold period that showed some relation to the phytoplankton community abundance. The highest abundances occurred in the warm season and the lowest abundances in the cold season, with a homogeneous distribution in the water column. This trend has been previously reported for Bahía de La Paz (Verdugo-Díaz 2004; Villegas-Aguilera, 2009). These periods directly influence the physical and chemical conditions of the area and the structure and physiological response of the existing phytoplankton community (Cortés-Lara *et al.*, 1999). During the warm period (June to November) the bay is under the influence of the prevailing southeasterly winds, so its influence on the water column is at the surface level, which allows the stratification of the water column. The opposite occurs when the cold period is established, and the prevailing northwest

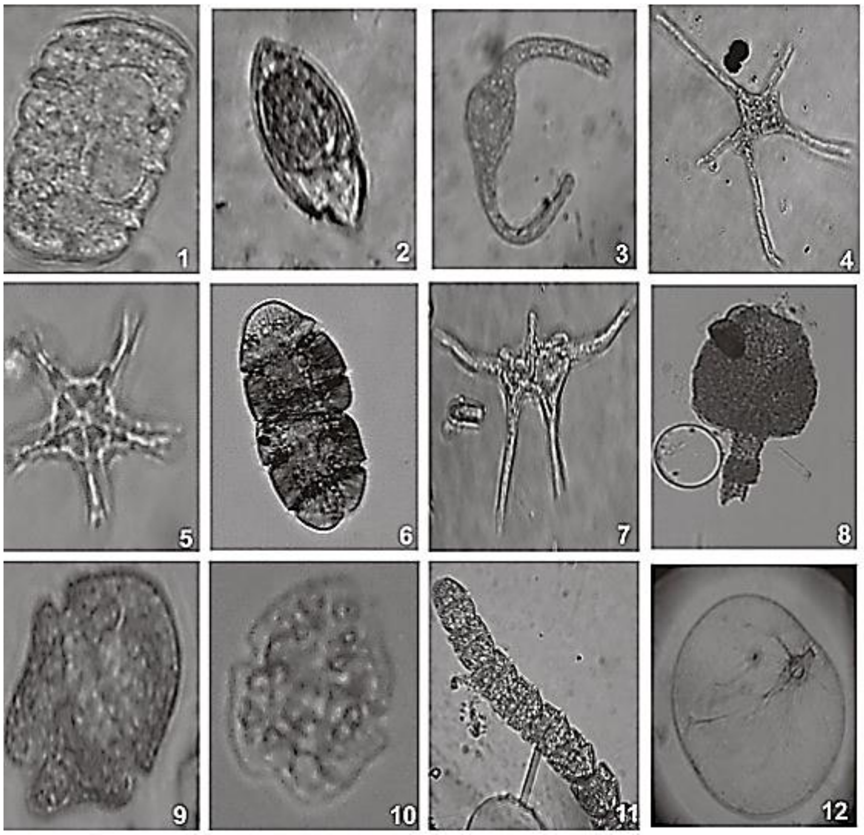

Figure 12. Dinoflagellates species found at the three sampling stations. *Polykrikos kofoidii*, 2) *Kapelodinium vestifici*, 3) *Ceratoperidinium falcatum*, 4) *Asterodinium gracile*, 5) *Actiniscus pentasterias*, 6) *Marfalefidinium polykrikoides*, 7) *Brachidinium capitatum*, 8) *Erythropsidinium agile*, 9) *Akashiwo sanguinea*, 10) *Gymnodinium* sp., 11) *Gymnodinium catenatum*, 12) *Noctiluca scintillans.*

winds are strongly mixing the water column (Salinas-González, 2000; Gárate-Lizárraga *et al*., 2009). The vertical extension of the surface mixed layer of aquatic systems influences the distribution and abundance of the phytoplankton community because these microorganisms are passively moved within the water column. During the mixed layer period, decrease in phytoplankton abundance and biomass is observed (Verdugo-Díaz, 2004).

As a consequence of the above, the phytoplankton biomass in the water column decreases, directly affecting the growth rate and other aspects of the life cycle of the primary producers, and is in some cases a limiting factor in different processes of the phytoplankton community (Smetacek & Passow, 1990). In the present study, chlorophyll-*a* concentrations were relatively low (0.1 to 4.7 mg m^{-3}), although Martínez-López *et al*. (2001) have reported concentrations of 0.1 to 10.9 mg m^{-3} in Bahía de La Paz. The nanophytoplankton domain can explain the relatively low values of chlorophyll-*a* recorded in this study; this phytoplankton fraction has a chlorophyll-*a* low concentration relative to the carbon content (Gilmartin & Revelante, 1978). When microphytoplankton was abundant, there was an increase in biomass, particularly when harmful algal blooms (HAB) of *Pseudo-nitzschia fraudulenta* and *Trichodesmium erythraeum* occurred. Therefore, chlorophyll-*a* is an indirect measure of biomass, and it is used as an indicator of the eutrophication of coastal lagoons (Kruskopf & Flynn, 2006).

Throughout the annual cycle, the phytoplankton community was numerically dominated mainly by nanophytoplankton, which agrees with observations made by Verdugo-Díaz (2004) and Villegas-Aguilera (2009). It has been suggested that the nanophytoplankton fraction, because of its size, generally has a greater capacity to acquire and assimilate nutrients when resources are limited, having a competitive advantage over larger cells when cohabiting in oligotrophic environments (Fogg & Thake, 1983). The concentrations of the nutrients in the annual cycle were nearly homogeneous, probably due to the more extended mixing period and a short stratification period.

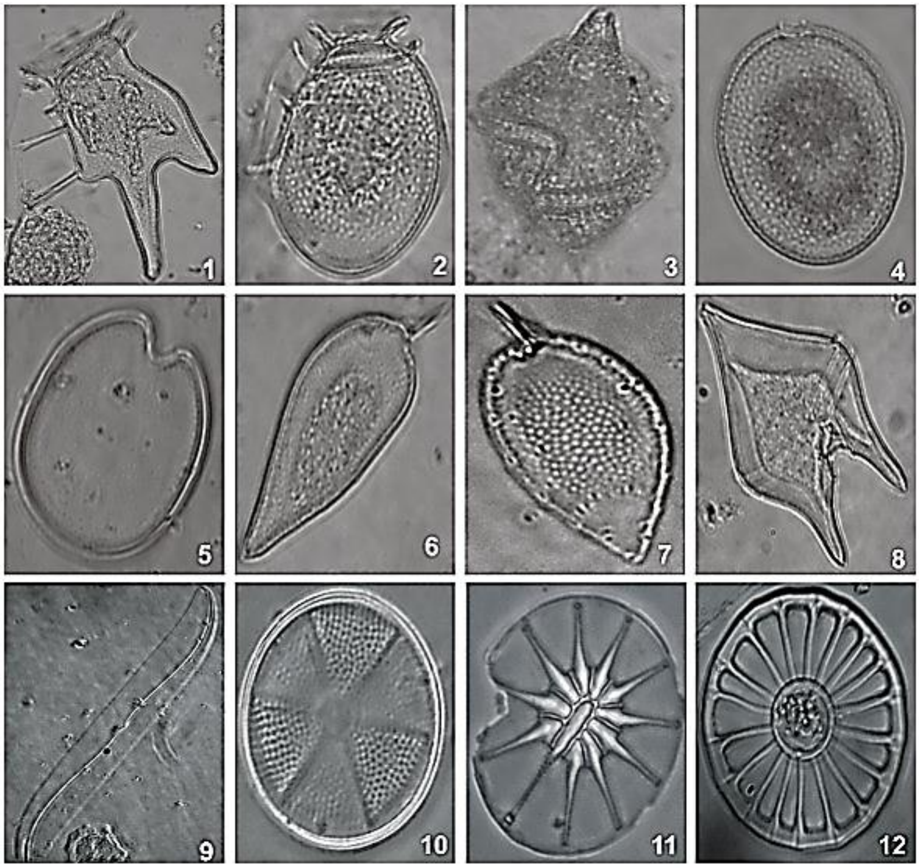

Figure 13. Dinoflagellates (1-8) and diatoms (9-12) species found at the three sampling stations.1) *Dinophysis tripos*, 2) *Dinophysis ovum*, 3) *Gonyaulax spinifera*, 4) *Prorocentrum compressum*, 5) *Prorocentrum* sp., 6) *Prorocentrum gracile*, 7) *Prorocentrum koreanum*, 8) *Protoperidinium claudicans*, 9) *Pleurosigma formosum*, 10) *Actinoptychus senarius*, 11) *Asteromphalus flabellatus*, 12) *Planktoniella sol.*

It is possible that these factors caused the nanophytoplankton to be dominant at all depths throughout the annual cycle.

On the other hand, although the microphytoplankton fraction was significantly lower in the annual cycle, it showed some important pulses of abundance at San Juan de la Costa in June at 25 m due to a bloom of *P. fraudulenta*, a temperature of 21.0°C, and concentrations of 0.5 NH_4 µM, 3.24 NO_3 µM, 0.18 NO_2 µM, 1.5 PO_4 µM and 6.7 SiO_2 µM and a stratified water column. These conditions were similar to those reported by Gárate-Lizárraga *et al.* (2007) during the proliferation of *P. fraudulenta* at several points in the bay. At Rancheros del Mar there was a bloom of *T. erythraeum* on the surface in September 2006, and it is likely that environmental conditions such as temperature (30°C) and nutrients such as NH_4 (0.04 µM), NO_3 (1.09) µM), NO_2 (0.1 µM) and PO_4 (0.8 µM) favored its proliferation. Blooms of *T. erythraeum* are common in Bahía de La Paz (Gárate-Lizárraga & Muciño-Marquez, 2012). The blooms of *T. erythraeum* usually occur when there is little agitation in the water column, which allows the massive development of this species (Carvalho *et al.*, 2008). The stratification of the water layer plays an important role in the phytoplankton community, allowing certain opportunistic species to proliferate (*P. fraudulenta* and *T. erythraeum*) as happened in the present study.

When water-column mixing conditions prevail, resuspension of sediments, nutrients, and of plankton cells towards the surface occurs (Gárate-Lizárraga & Siqueiros-Beltrones, 1998; Siqueiros-Beltrones, 2002). Our results show that under these conditions at Rancheros del Mar and San Juan de la Costa there was an important contribution of tychoplanktonic diatoms, mainly of the genera *Actinoptychus*, *Cocconeis*, and *Thalassionema*. Siqueiros-Beltrones (2002) mentioned that some species of tychoplanktonic diatoms can be indicative of marine sediment disturbance by water movements, and some species can even indicate the depth of their habitat from where they were displaced, as was the case of *Fragilariopsis doliolus*, a phytoplank-

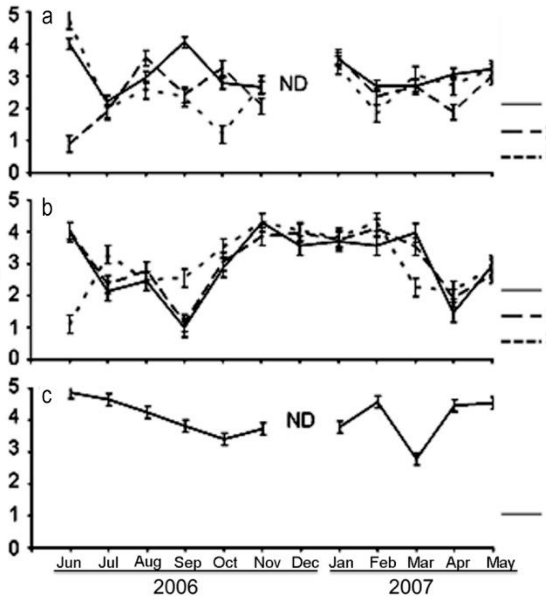

Figure 14. Diversity (H') of the microphytoplankton community. a) San Juan de la Costa, b) Rancheros del Mar, and c) El Mogote from June 2006 to May 2007. ND: no data.

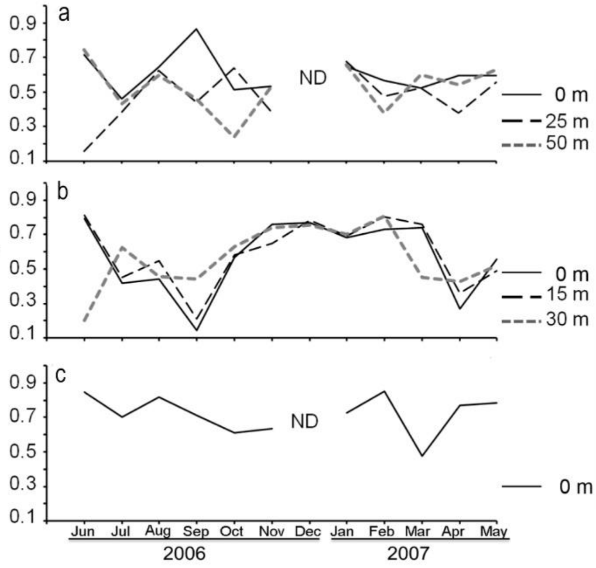

Figure 15. Evenness (J) of the microphytoplankton community at: a) San Juan de la Costa, b) Rancheros del Mar, and c) El Mogote from June 2006 to May 2007. ND: no data.

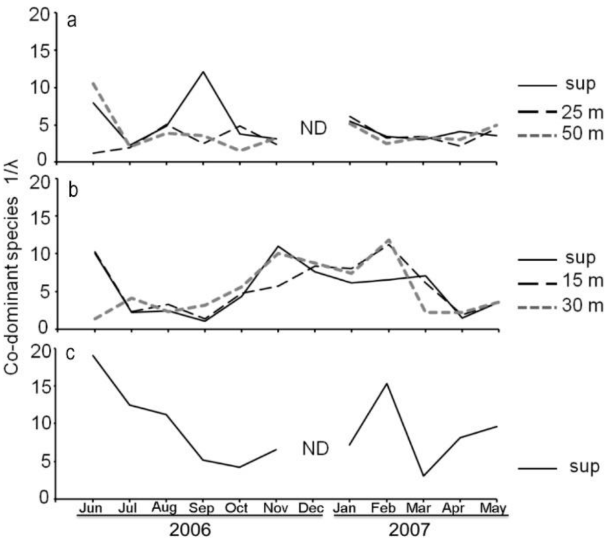

Figure 16. Co-dominant species in the microphytoplankton community. a) San Juan de la Costa, b) Rancheros del Mar, and c) El Mogote from June 2006 to May 2007. ND: no data.

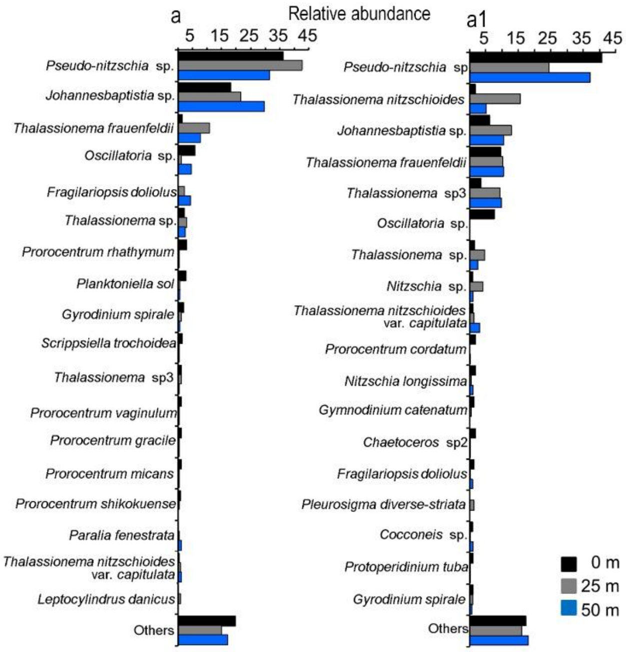

Figure 17. Relative abundance of dominant species in the a) warm season and a1) cold season at San Juan de la Costa from June 2006 to May 2007.

ton species abundant at Rancheros del Mar. This site is a shallow area that experienced a more extended mixing period than at San Juan de la Costa; this could promote the resuspension of this species. Gárate-Lizárraga & Muñetón-Gómez (2009) found that this and other species of tychoplankton origin are usually abundant in the bay when upwelling conditions occur. The presence of tychoplanktonic microalgae in the water column could promote an increase in diversity and evenness. This results in a homogeneous water column regarding species diversity, attenuating the effect of opportunistic species. It has been reported that for shallow marine areas of Bahía de La Paz, diversity is increased by the resuspension of benthic diatoms due to water mixing (Signoret & Santoyo, 1980; Gárate-Lizárraga & Siqueiros-Beltrones, 1998). Our results suggest that this process could occur during the mixing

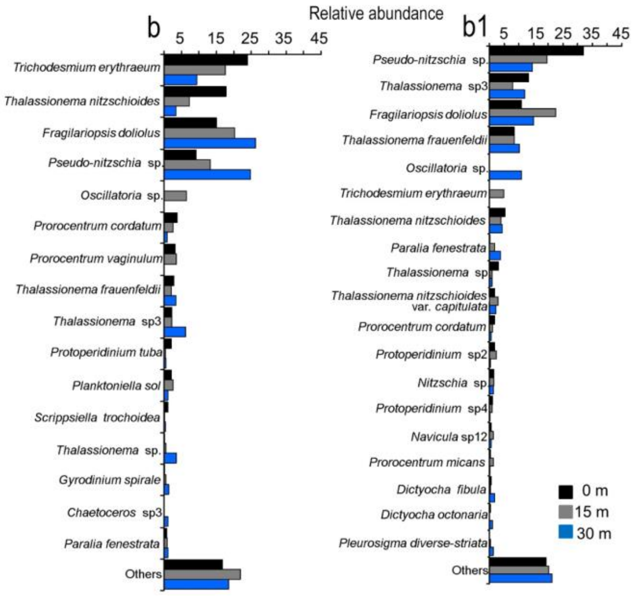

Figure 18. Relative abundance of dominant species in the b) warm season and b1) cold season at Rancheros del Mar from June 2006 to May 2007.

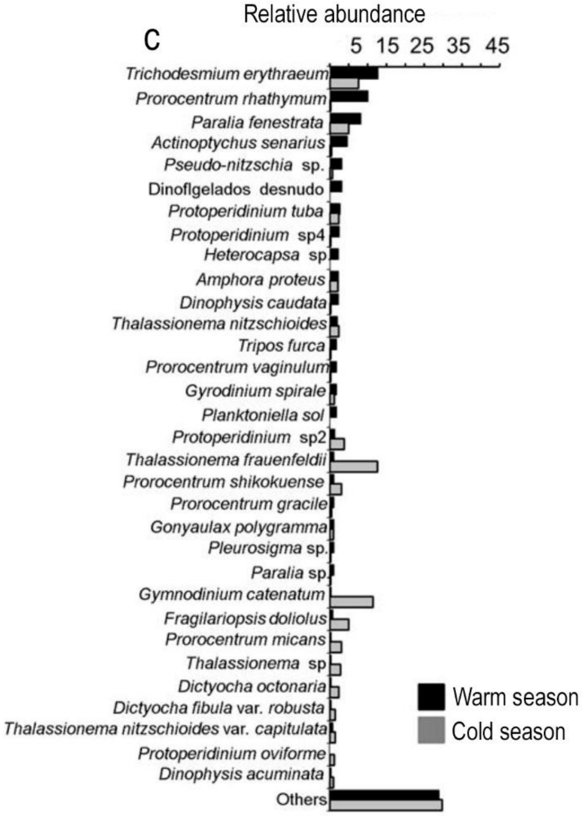

Figure 19. Relative abundance of dominant species in the warm season and cold season at: El Mogote, from June 2006 to May 2007.

(Hodgkiss & Ho, 1997). However, the Bahía de La Paz was not exempt from HAB including toxic species. period at Rancheros del Mar when there was a high diversity and equitability at the same time that tychoplanktonic diatoms prevailed in the water column.

According to Margalef (1981) and Gárate-Lizárraga *et al*. (1990), diversity is low when there is a phytoplankton bloom. Our results show that in June (at 25 m) at San Juan de la Costa and in September (surface) at Rancheros del Mar there were blooms of *P. fraudulenta* and *T. erythraeum*, respectively, conditions that could lead to the observed low diversity index and evenness. Gárate-Lizárraga & Siqueiros-Beltrones (1998) in Bahía Magdalena-Almejas, reported high dominance values due to monospecific blooms and considered them a characteristic of immature phytoplankton communities.

There were no significant increases in nutrients in the study area, only small pulses in silicates and nitrates. The observed concentrations were found within the interval reported for the bay (Avilés-Agúndez, 2004; Villegas-Aguilera, 2009). The incidence of harmful algal blooms in this study was not persistent and may be related to the ratios of N:P and low rates of Si:N, which did not favor the HAB species Among the species identified in this study that have been reported as HAB formers are *Margalefidinium polykrikoides*, *Dictyocha californica*, *Gymnodinium catenatum*, *Pseudo-nitzschia fraudulenta*, *Trichodesmium erythraeum* and others. Our results agree with the works of Gárate-Lizárraga *et al*. (2006, 2007) and López-Cortés *et al*. (2006, 2015) that have reported HAB of these species which, under certain conditions of light, temperature, stability of the water column and nutrients, could proliferate. We recommend establishing frequent monitoring in tuna farms. Microalgal blooms should be considered natural phenomena that can cause economic losses to fish farm concessionaires. A case in point occurred in Puerto Escondido, Baja California, in 2002 when a bloom of the dinoflagellate *Tripos furca* (= *Ceratium furca*) was associated with the death of fishes in less than 48 h in enclosures with more than 500 t of tuna, causing losses of US$631.924,84-789.906,05 (Orellana-Cepeda *et al*., 2002).

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