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Research article

Phytoplankton composition and abundance as indicators of aquaculture effluents impact in coastal environments of mid Gulf of California

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ABSTRACT

Composition and abundance of phytoplankton in two areas of Gulf of California, one near (ND) and one far (FD) from shrimp farms discharge, were studied in 3 seasons: late fall (farms finishing operations); spring (farms not operating); and summer (farms operating). In ND, 61 diatoms, 33 dinoflagellates, 4 cyanobacteria, and 2 silicoflagellates were identified; in FD, 72 diatoms, 38 dinoflagellates, 5 cyanobacteria, and 4 silicoflagellates were found. Thirty-three species were recorded only in ND (20 diatoms, 11 dinoflagellates, 1 silicoflagellate), whereas 39 species appeared exclusively in the FD (28 diatoms, 9 dinoflagellates, 1 cyanobacteria, 1 silicoflagellate). Thirty-seven species were common for both areas (23 diatoms, 10 dinoflagellates, 3 cyanobacteria and 1 silicoflagellate). In ND, 9 species potentially toxic (3 diatoms, 5 dinoflagellates, 1 cyanobacteria) were identified. From FD, 3 species potentially toxic (2 diatoms and 1 cyanobacteria) were found. Total abundance of phytoplankton was more than double in ND than in FD. The species richness and diversity, were greater in FD. Higher phytoplankton abundance was observed when farms were operating or finishing operations. The composition and abundance of phytoplankton is a good indicator of shrimp effluents impact, diminishing the species richness and diversity, but augmenting the abundance.

1. Introduction

The phytoplankton is one of the most important communities in aquatic ecosystem, constituting the first step of diverse trophic chain, and being one of the main primary producers in the marine, coastal, and continental water bodies. It provides food for primary consumers from zooplankton, benthos and nekton communities (Harris 1986; Hernández-Becerril 1993). Accordingly to Metting (1996) microalgae are primarily responsible for the 40–50% of total global photosynthetic primary production. Another important function of phytoplankton in natural or aquaculture ecosystems is the production of oxygen. It has been demonstrated that a great proportion of oxygen in the atmosphere and the water column come from phytoplankton photosynthesis (Balkanski et al. 1999).

The composition and abundance of phytoplankton vary widely in the diverse aquatic ecosystems, exhibiting sometimes a pronounced seasonal succession, influenced by diverse factors such as temperature and salinity (Muylaert et al. 2000), as well as changes in the concentration and proportion of nutrients, resulting from movements of water masses, upwellings, and continental drains. Páez-Osuna et al. (2013) found a pattern of variation of macroalgal and phytoplankton biomass mainly related to different nutrient loads in subtropical coastal lagoons of the SE Gulf of California. According to Peng et al. (2012), the seasonal variability in phytoplankton can be explained by water temperature, nutrient, and hydrodynamic conditions (includes mixing during spring and stratification during summer).

Some anthropogenic activities can also modify the structure and abundance of the phytoplankton community, including discharge of effluents from agricultural, domestic, and aquacultural activities. Alonso-Rodriguez and Paez-Osuna (2001) documented the impact of anthropogenic discharges on the trophic level change and the structure of phytoplankton communities in coastal ecosystems of Sinaloa, Mexico. Particularly, aquaculture have increased its importance in many countries of the world as an activity capable to impact the water bodies in

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which their effluents are discharged (Martinez-Cordova et al., 2009; Martinez-Porchas and Martinez-Cordova, 2012). The explosive blooms of phytoplankton, sometimes known as red tides, may be harmful for many aquatic organisms, especially mollusks, and also for the human who consume them (Ochoa et al. 2003).

In the last three decades the aquaculture in Mexico has grown very fast, particularly in the northwest of the country, reaching productions over 230,000 MT in 2009 (Conley and Fossbakk, 2009). This has increased the volume of effluent discharged in adjacent water bodies such as estuaries, bays, coastal lagoons, and directly in the coastal marine zone. It seems evident this situation must have an effect on the response of phytoplankton since aquaculture effluents are mostly loaded by particulate and dissolved organic matter and inorganic nutrients, which may be used by the microalgae from the receiving ecosystems. Another important effect is the great amounts of suspended solids that increment the turbidity, reducing the penetration of light in the water column and affecting the photosynthesis of the primary producers. Despite of that, no specific studies in this region have been done about the effects of aquaculture discharges on the phytoplankton community, at least in the last 10 years when the activity has grown more significantly. Based on this, the present study was focused on evaluating the composition and abundance of phytoplankton in two coastal areas of mid Gulf of California, one near and one far from aquaculture effluents discharges, as indicators of the impact of those discharges. Special emphasis was put in the presence and abundance of potentially toxic species.

2. Materials and methods

2.1. Study area

Two coastal zones of the mid Gulf of California in the state of Sonora, Mexico, were selected for the study (Figure 1). Area 1 (ND) is located just in front of the effluent discharge from 7 shrimp aquaculture farms, which annually produce around 2000 MT. Area 2 (FD) is located approximately 42 km north, and it is a zone non-impacted for any type of anthropogenic input. In each one of the two areas, three sampling were done through one year: the first (S1) in November–December, when farms just were finishing their operations; the second (S2) in April, when farms were out of operation and the third (S3) in August when the farms were operating. In each area, three transects perpendicular to the coast were established at distances of 50, 150 and 300 m from the coastline. In each transect, three points equidistant 300 m one from the other, were sampled.

2.2. Qualitative analysis

For the identification of the species present in both areas, the samples were obtained by horizontal surface trawling for 10 min, using a plankton sampler with a conic net (mesh 30-μm). The phytoplankton concentrates were put in plastic bottles (500 mL) and preserved with formalin 4% for the subsequent analysis. The species identification was done placing a drop of the preserved samples in a glass slide to observe the organisms with a compound microscope Carl Zeiss, using the objectives 10x, 40x and 100x, depending on the size of the organisms to be identified. The keys of Balech (1988), Cupp (1943), Taylor (1987), Sournia (1984), Hernández-Becerril (1987, 1988, 1991, 1995), Licea et al. (1995), and Moreno-Ruiz et al. (1996), were consulted for the species identification.

2.3. Quantitative analysis

To know the number of cells/mL of each species in every one of the sampling points, 500 mL of water was taken at 40 cm depth using a Van Dorn bottle. The samples were preserved with Lugol-Acetate, adding 1 mL for each 100 ml of sample (Throndsen, 1978). The quantification of specific cells was made from preserved samples, using sedimentation chambers, tubular chambers (2, 10 or 50 mL), or Neubauer chamber, depending on the cell concentration. For very low densities the tubular chamber of 50 mL was used following the method Utermöhl modified by Edler and Elbrächter (2010), by allowing a sample to settle in a sedimentation cylinder and giving adequate time, it is assumed that all organisms present in the sample are in the sedimentation chamber. The counting and identification were done in a Carl Zeiss inverted microscope, after 4 h of sedimentation for chambers of 4 cm height.

The species abundance was calculated as:

$$Abundance\left(Cells/_{L}\right) = \left((Z \times F)/_{V}\right) \times 1000$$

where: Z is the number of individuals of a particular species, F is the counted area over the total area of the chamber and V is the volume of the sample. Both the quantitative analysis and the identification followed the UNESCO protocols proposed by Karlson et al. (2010).

2.4. Diversity indexes

Two different indexes were used to calculate the diversity of the phytoplankton community in the two areas and the three samplings.The diversity index of Shannon was calculated as:

$$H = \sum_{i=1}^{a}\left\{ -\frac{n_i}{N}\log\left(\frac{n_i}{N}\right)\right\}$$

where

a is the number of species
n_i is the number of individual of species i
N is the total number of individualsThe diversity index of Margaleff was calculated as:

$$d = \frac{S-1}{LnN}$$

Where

S is the number of species
N is the total number of individuals in the sample.

The use of the above indices is because they have been consistently used for phytoplankton communities, including for the Gulf of California.

3. Results

3.1. Species richness and toxic species

The list of the total species found in the area near (ND) and far (FD) to the farm discharge during the 3 samplings (S1, S2, and S3) is presented in Table 1. In ND, 61 species of diatoms, 33 species of dinoflagellates, 4 species of cyanobacteria, and 2 species of silicoflagellates, were identified; while in the FD, 72 species of diatoms, 38 species of dinoflagellates, 5 species of cyanobacteria and 4 species of silicoflagellates, were found. From the total identified species, 32 were found only in ND (20 diatoms, 11 dinoflagellates and 1 silicoflagellate), while 39 species were only found in FD (28 diatoms, 9 dinoflagellates, 1 cyanobacteria, and 1 silicoflagellate). A total of 37 species were common for both areas (23 diatoms, 10 dinoflagellates, 3 cyanobacteria and 1 silicoflagellate). From

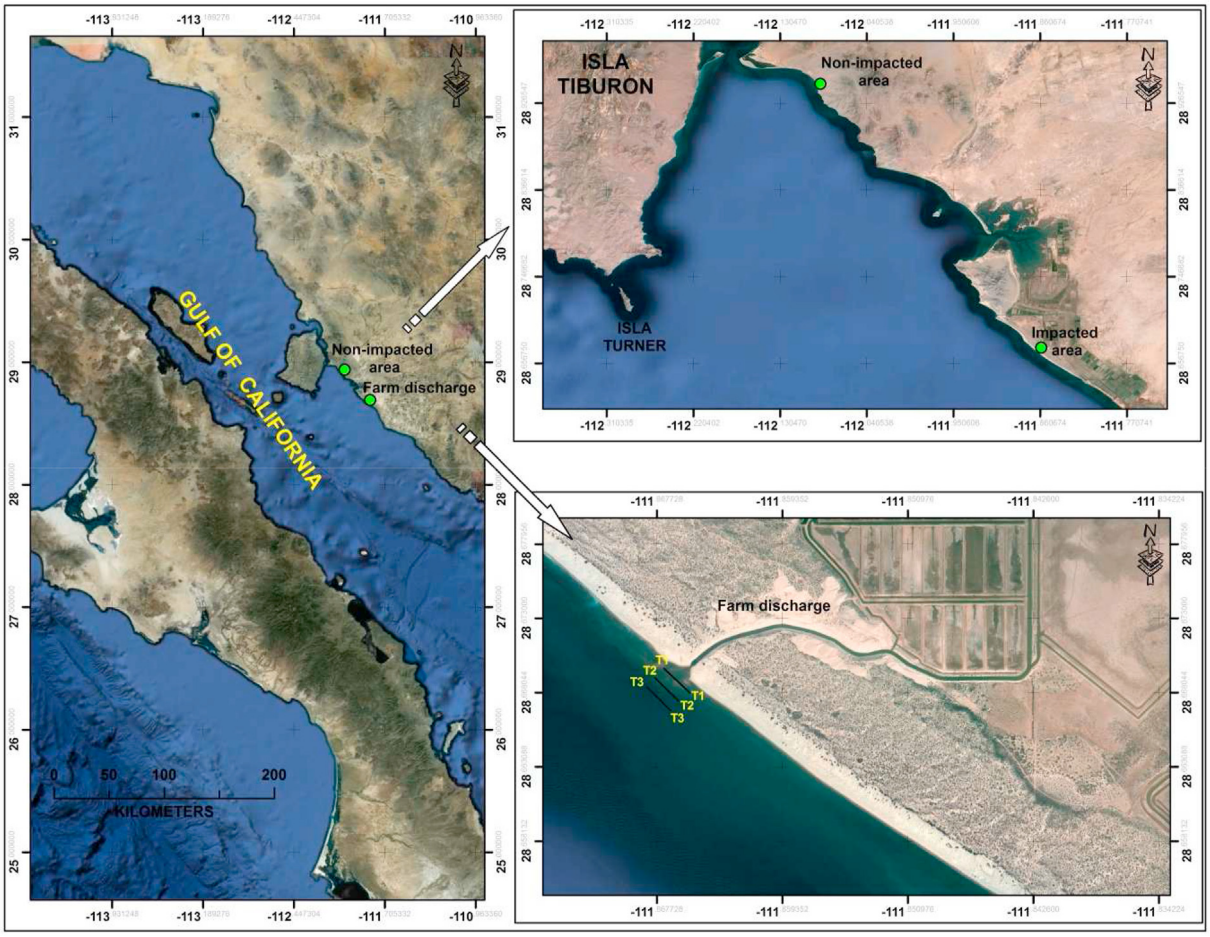

Figure 1. Study area location.

the species identified in ND, 9 have been reported as potentially toxic for human; 3 of them are diatoms, 5 are dinoflagellates, and 1 cyanobacteria. From FD, 3 species have been reports as potentially toxic, 2 of them diatoms and 1 cyanobacteria (Table 2).

3.2. Abundance of groups and diversity

The total abundance of phytoplankton cells, considering all samplings and groups, was more than double in ND when compared to FD, as shown in Table 3. In general terms, for both areas, but particularly for ND, greater abundances were recorded in the third sampling when the farms were fully operating.

In ND, the diatoms were the dominant group, with their greatest abundance in the third sampling when the farms were fully operating, and the lowest in the second sampling with the farms out of operation. The dinoflagellates were the second dominant group, with their highest abundance in the third sampling and the lowest during the first and second. Cyanobacteria observed a very similar trend with the greater abundance during the third sampling and the lowest in the second. Silicoflagellates also followed the same trend although their abundances were much lower than the other groups.

For FD, diatoms were once again the dominant group with higher abundances in the third and first sampling as compared to the second. Dinoflagellates showed their greatest abundance in the first sampling and the lowest in the second. Silicoflagellates were slightly more abundant in the third sampling as compared to the first and second. Cyanobacteria observed their greater abundance in the first sampling and the lowest in the second.

The diversity of the phytoplankton community in both areas during the three samplings, as indicated by the Shannon and Margaleff indexes is shown in Table 4. No significant differences were observed in any case, but in the three samplings slightly higher values were recorded in FD when compared to ND.

4. Discussion

A noticeable difference in abundance and composition of phytoplankton were found among the ND and FD areas, with abundances more than double in the first area as compared to the second. The total phytoplankton cells L-1 in the ND considering the three samplings, were much greater than was reported in previous studies for the Gulf of California (Verdugo-Diaz et al., 2012). Hernández-Becerril et al. (2007) found densities between 7×10^2 and 1.4×10^6 cells L^{-1} in the western coast of the Gulf. Garate-Lizarraga and Siqueiros-Beltrones studied the phytoplankton abundance in a coastal lagoon of the Gulf of California and found densities from 0.5 to 1.5 10^6 cells $L^{-1}$from November to May, and much lower (5–250 10^3 cells L-1) from late spring to late fall. The differences were mostly related to diverse events that modify the environmental conditions and availability of nutrients such as "El Niño" event and upwellings. The high phytoplankton densities found in the present study are more common for areas with great organic matter and nutrient loads. Piehler et al. (2004) found that the load of nutrients produced by human activities increased significantly the concentration of chlorophyll in an estuary where the effluents were discharged.

The species richness, however, was greater in the area far to the discharge of effluents (FD). Species richness and diversity of microalgae

Table 1. Species of phytoplankton identified in the area near (ND) and far (FD) of farm discharge in the first (S1), second (S2), and third (S3) samplings.

DIATOMS	ND S1	ND S2	ND S3	FD S1	FD S2	FD S3
Actinoptychus campanulifer	X	X	X	X	X	X
Actinoptychus parvus	X					
Actinoptychus senarius	X	X	X	X	X	X
Actinoptychus splendes					X	X
Actinoptychus vulgaris			X	X	X	X
Amphiphora sp.				X	X	X
Amphora angusta	X	X				
Amphora laevis	X	X				X
Amphora marina	X	X	X	X	X	X
Amphora proboscidea	X					
Amphora sp				X	X	X
Asterinella japonica	X	X	X	X	X	
Auliscus caelatus	X	X		X	X	X
Bacteriastrum delicatulum	X		X	X	X	X
Bacteristrum comosum				X		X
Bacteriastrum elegans	X	X	X	X	X	X
Bacteriastrum elongatum				X	X	X
Bacteriastrum hyalinum	X					
Biddulphia alternans	X			X	X	
Biddulphia aurita var. Aurita	X					
Biddulphia biddulphiana	X					
Biddulphia mobiliensis	X	X	X	X	X	X
Biddulphia pulchella	X					
Biddulphia tridens	X		X			X
Cerataulus californicus						X
Chaetoceros affinis	X	X		X	X	X
Chaetoceros curvicetus	X		X			X
Chaetoceros decipiens				X	X	X
Chaetoceros didymus	X			X	X	X
Chaetoceros diversus	X					
Chaetoceros gracilis	X	X	X	X	X	X
Chaetoceros lonceriatus	X	X	X	X	X	
Chaetoceros pendulus				X	X	X
Chaetoceros peruvianus	X	X	X			
Chaetoceros radicans	X	X				
Chaetoceros simplex						X
Chaetoceros seiracanthus	X	X				
Chaetoceros teres				X	X	X
Climacodium frauenfeldianum	X	X	X			
Climacosphenia elongata	X	X				
Coconeis sp.				X	X	X
Coconeis dirupta	X			X	X	X
Coscinodiscus asteromphalus			X			
Coscinodiscus centralis				X	X	X
Coscinodiscus gigas					X	
Coscinodiscus radians				X	X	X
Cylindrotheca closterium	X	X	X	X	X	X
Diploneis bombus						X
Diploneis vacillans	X					
Dytilum brighwellii	X					
Entomoneis alata	X			X		
Eucampia cornuta				X	X	X
Eucampia zoodiacus	X	X	X			
Eunotogramma laeve			X			
Eupodiscus radiatus	X		X	X	X	X
Fallacia focipata					X	X
Gramatophora marina				X	X	X
Guinardia delicatula	X		X			

(*continued on next page*)

Table 1 (*continued*)

DIATOMS	ND S1	ND S2	ND S3	FD S1	FD S2	FD S3
Guinardia flaccida	X	X	X	X	X	
Gyrosigma macrum	X	X	X	X		
Gyrosigma sp.				X	X	X
Gyrosigma sp.2				X	X	X
Hemiaulus membranaceus	X					
Hemidiscus cuneiformis	X		X			
Leptocilindrus danicus	X	X	X			
Licmophora abbreviata	X					
Lioloma elongatum	X					
Lyrella clavata var. Indica	X		X			
Lyrella lyra	X	X	X			X
Navicula sp.	X	X	X			
Navicula sp.2						X
Pseudonitzschia pungens	X	X				
Paralia sulcata	X	X	X	X	X	X
Pleurosygma marinum				X	X	X
Proboscia alata		X		X	X	
Poboscia alata				X	X	
Pseudosolenia calacar-avis				X		
Pseudonitzschia longa	X					
Pseudonitzschia longissima	X	X	X			
Pseudosolenia calcar-avis	X		X			
Rhabdonema adriaticum	X	X	X	X	X	X
Rhizosolenia delicatula						X
Rhizosolenia acuminata			X			
Rhizosolenia hebatata	X	X	X			
Rhizosolenia longissima	X	X				
Rhozosolenia robusta				X	X	X
Rhizosolenia setigera	X	X	X	X	X	X
Skeletonema costatum	X	X	X	X	X	
Stephanophixis turris			X			
Striatella unipunctata	X			X	X	X
Surirela fastuosa				X	X	X
Synedra fungens	X	X	X			
Synedra sp.				X	X	X
Thalassionema nitzschioides	X	X	X			
Thalassionema palmeriana				X	X	X
Thalassiosira sp.	X	X	X	X	X	X
Thalassiothrix longissima	X	X	X	X	X	X
Triceratium favus	X	X	X			
DINOFLAGELLATES						
Amphidinium sp.				X	X	X
Alexandrium catenella	X					
Amphisolenia bidentata	X	X	X	X	X	X
Amphisolenia bifurcata				X		
Ceratium azoricum	X					
Ceratium carriense			X			
Ceratium bigelowi					X	
Ceratium dens				X	X	X
Ceratium extensum			X			
Ceratium falcatum		X	X			
Ceratium furca var furca	X	X	X	X	X	X
Ceratium fusus var fusus	X	X	X	X	X	X
Ceratium fusus var hircus	X		X			
Ceratium gravidium					X	
Ceratium longipes	X					
Ceratium macroceros	X					
Ceratium macroceros gallicum	X			X	X	X
Ceratium macroceros macroceros				X		X

(*continued on next page*)

Table 1 (*continued*)

DIATOMS	ND S1	ND S2	ND S3	FD S1	FD S2	FD S3
Ceratium trichoceros	X					
Ceratium tripos var atlanticum	X					
Dinophysis rotundata	X					
Goniodoma acuminatum			X			
Gonyaulax poliedra			X			
Gonyaulax polygramma	X		X			
Gonyaulax sp.	X	X	X		X	
Gymnodinium catenatum			X			X
Gymnodinium sp.				X	X	X
Gyrodinium spirale			X			
Oxyphysis oxytoides				X	X	X
Oxytoxum sceptrum		*X*	X			
Peridinium oblogum	X			X		X
Peridinium claudicans	X	X	X			
Peridinium conicum	X	X	X			
Peridinium depresum	X	X				
Peridinium nipponicum	X					
Peridinium pellucidum				X	X	X
Peridinium sp.				X	X	X
Peridinium tuba	X	X		X	X	X
Phalacroma argus	X					
Podolampas palmipies	X	X				
Prorocentrum gracile	X	X	X			
Prorocentrum lima	X	X	X			
Prorocentrum magnum	X					
Prorocentrum micans	X	X	X	X	X	X
Prorocentrum minimus	X					
Prorocentrum rostratum	X	X	X	X	X	X
Protoperidinium bipes	X					
Protoperidinium claudicans				X	X	X
Protoperidinium quarrnerense					X	
Protoperidinium pellucidum	X	X	X			
Pyrocystis sp.				X	X	X
Pyrophacus horologium steinii	X	X	X			
Phyrophacus steinii					X	X
CYANOBACTERIA						
Anabaena sphaerica	X	X	X	X	X	X
Choorococcus turgidus	X			X		
Gomphosphaeria sp.				X	X	X
Oscillatoria thiebautti	X	X	X	X	X	X
Spirulina máxima sp.	X					
	X	X	X			
SILICOFLAGELLATES						
Dyctiocha fibula	X	X	X	X		
Dyctiocha octonaria	X	X	X	X	X	X

have been considered as indexes of environmental health (Metting 1996), and because of their rapid response to the environmental changes, they are useful tools as indicators of water quality (Nasser & Sureshkumar 2013). This suggests that in the present study, the area near to the farm discharge could be considered as less healthy environment when compared to the area far from that discharge. Both, the Shannon and the Margaleff diversity indexes were slightly higher in the FA during the three sampling. Accordingly, to the Margaleff index, the lowest diversity was recorded in the NA area when the farms were fully operating, while the greatest was observed in FA when farms were finishing operations. Garate-Lizarraga and Siqueiros-Beltrones (1998) reported for a coastal lagoon of Baja California Sur, Mexico, diversity indexes from 2 to 4 after a "Niño" event, with the higher values between November and January. This implies that the variations of abundance, species richness, and diversity observed in our study, could be attributable to the natural variations in the region, but the differences among the areas near and far to the discharge may be at least partially driven by the effluents, since the two areas are sited in the same region with no apparent geographical and environmental differences, and the samples were taken on the same dates. Sin and Jeong (2015) found a significant decrease (up over 60 %) of phytoplankton diversity after an event of fresh water discharge in a temperate estuary. Spatharis et al. (2007) compared the phytoplankton diversity in a semi closed coastal area through one year and found that the diversity was significantly lower when the highest nutrient loads from agriculture were discharged to the coast. However, it is important to take into account that the role of the factors that control the diversity-productivity relationships is still not clear yet, since when nutrients are limited in conditions of low productivity, the strongest competitors are favored over the least competitive species (Spatharis et al. 2011).

Table 2. Potentially toxic species of phytoplankton identified in the area near (ND) and far (FD) to the farm discharge during the three samplings.

Species	ND	FD
DIATOMS		
Pseudonitzchia delicatisima	X	
Pseudonitzschia longissima	X	
Pseudonitzschia pungens	X	
DINOFLAGELLATES		
Alexandrium catenella	X	
Dinophysis acuminata	X	
Gymnodinium catenatum	X	
Prorocentrum lima	X	X
Prorocentrum micans	X	X
CYANOBACTERIA		
Oscillatoria thiebautii	X	X

reported that although effluents from fish farms did not significantly increase phytoplankton density, it drastically enhanced dinoflagellate abundance and domination. Primavera (2006) documented that the composition of phytoplankton communities may be altered by nutrients added to the water column from aquaculture farm wastes, as occurred in this study in the ND area (Barraza-Guardado et al. 2013, 2014). Nishimura (1982) has shown that farmed yellowtail feces may stimulate growth of the red tide-forming dinoflagellate *Gymnodinium*. Hwang & Lu. (2001) reported that another dinoflagellate, *Alexandrium minutum* appeared only in samples from aquaculture ponds and coastal areas but was not present at other sites. In the present study, dinoflagellates were more abundant during the second sampling in the area near to the farm discharge, and were always more abundant in ND than in FD, demonstrating that effluents from shrimp farms enhance the proliferation of this group. The phytoplankton abundance and composition may also vary by seasonal changes as reported by many authors (Muylaert et al. 2000;

Table 3. Mean abundance of the phytoplankton groups (Cells L^{-1} x 10^6) in the area near (ND) and far (FD) of the farm discharge during the first (S1), second (S2), and third (S3) samplings.

Group	ND/S1	FD/S1	ND/S2	FD/S2	ND/S3	FD/S3
All groups	10 ± 3.50	5.2 ± 2.30	7.1 ± 0.69	4.1 ± 4.30	17 ± 14.0	8.0 ± 1.80
Diatoms	4.5 ± 0.24	2.5 ± 2.10	3.3 ± 0.80	2.5 ± 0.24	8.0 ± 1.8	4.8 ± 0.62
Dinoflagellates	1.0 ± 0.94	1.1 ± 0.24	1.0 ± 0.90	0.4 ± 0.24	0.74 ± 0.48	1.1 ± 0.18
Cyanobacteria	0.5 ± 0.08	0.15 ± 0.27	0.15 ± 0.90	0.04 ± 0.18	0.19 ± 0.32	0.16 ± 0.63
Silicoflagellates	2.7 ± 0.36	0.15 ± 0.24	3.2 ± 0.18	0.07 ± 0.24	0.53 ± 0.41	0.15 ± 0.32

Table 4. Diversity of phytoplankton community in the area near (ND) and far (FA) of farms discharge during the three samplings (S1, S2, and S3) as indicated by the Shannon and Margaleff indexes.

	ND			FD		
	S1	S2	S3	S1	S2	S3
Shannon	3.6357	3.4325	4.0129	3.8963	3.5930	4.0718
Margaleff	9.5022	8.7893	9.7341	9.5146	9.3763	9.8090

The abundance and composition of phytoplankton is mainly a response to the nutrients availability as has been documented by some other authors such as Martínez-López et al. (2007).

The aquaculture effluents impact the receiving ecosystems provoking changes in some of the main water quality parameters such as: chemical oxygen demand (COD), pH, total organic carbon (TOC), nutrients load, and chlorophyll-*a* concentration (Jones et al. 2001; Biao et al. 2004; Barraza-Guardado et al. 2013). The high concentration of chlorophyll-*a*, indicates a high abundance of phytoplankton, enhanced mainly by the sufficient availability of inorganic nutrients (Paez-Osuna 2001). Trott and Alongi (2000) found an increase in chlorophyll-*a*, and phytoplankton biomass in a tropical mangrove estuary affected by pond aquaculture effluents. Costanzo et al. (2004) documented that nutrient loading from a shrimp farm, resulted in greater nutrient dispersal, increasing the extent of phytoplankton blooms downstream from the site of effluent discharge. Similarly, Herbeck and Unger (2013) reported the effect of aquaculture pond effluents on the water quality of back-reef waters, including changes in phytoplankton.

Diverse studies have documented the proliferation of certain microalgae species or genera, and the suppression of some other in water bodies receiving aquaculture effluents discharges. This is related to the capacity of the organisms to thrive under the conditions prevalent in the discharge area such as high nutrients and organic matter load (hypernutrification and eutrophication), total suspended solids (organic and inorganic), turbidity, and sometimes low pH and oxygen levels. In the present study a considerable number of species were only found in the area near to the farm discharge, and some others only in the area far away, which suggests an important effect of the effluents on the composition of the phytoplankton community. Jiang et al. (2013) Peng et al. 2012), and confirmed in the present study, since independently of the area, the highest abundances were recorded in the third sampling corresponding to August, when temperatures are the highest in this region.

Some species of microalgae including diatoms, cyanobacteria and dinoflagellates, have been reported as potentially toxic for humans and animals. Species of the genus *Alexandrium* are known as potential producers of saxitoxin, a neurotoxin that causes the paralytic shellfish poisoning (PSP) syndrome (Bouchouicha-Smida et al., 2014). Jiang et al. (2013) documented significant effects of fish farming in a semi-closed and eutrophic bay, being the most important, a great proliferation of the toxic dinoflagellate *Prorocentrum minimum*. Some other genera such as *Dinophysis, Aureococcus,* and *Gymnodininum* have been also reported as potentially toxic for mollusks and for human consumers of them (Shumway 2007). The presence of some of these species has been associated to important mortalities of diverse animals and sometimes of humans. Nuñez-Vazquez et al. (2011) published a review of the impact of harmful algal blooms on wild and cultured animals in the Gulf of California that included: *Noctiluca scintillans, Cochlodinium polykrikoides, Gymnodinium catenatum, Prorocentrum minimum, Akashiwo sanguinea, Chattonella subsalsa Ch. marina, Chattonella* sp., *Heterocapsa* sp., *Dinophysis* sp., *Fibrocapsa japonica, Heterosigma akashiwo, Thalassiosira* sp., *Chaetoceros* spp., *Pseudo-nitzschia australis, P. fraudulenta, Pseudo-nitzschia* sp., *Trichodesmium erythraeum* and *Schizotrix calcicola*. Similarly, Bustillos-Guzman et al. (2012) documented the effect of different ratios of nitrogen and phosphorous on the growth and toxicity of *Gymnodinium catantum* in the Gulf of California. Some other studies have also documented the development and negative impact of harmful microalgae in the Gulf of California (Band and Schmidt, 2011; Garate-Lizarraga, 2012).

The development of these harmful microalgae can also be toxic for farmed organisms growing in the culture facilities. Mass mortalities in a Taiwan shrimp farm, were traced to blooms of the toxic dinoflagellate *Alexandrium tamarense* (Su et al. 1993). Keawtawee et al. (2012) found that survival of *Penaeus monodon* was inversely correlated to dinoflagellates abundance in the ponds.

5. Conclusions

The results clearly indicate a significant effect of the aquaculture effluents on the abundance and diversity of phytoplankton community, with the greater abundance of most of the groups in the area near to the discharge, while the greatest diversity was found in the area far from the discharge.

Some potentially toxic species were found; five of the genus *Prorocentrum* in the area near to the farm discharge (ND), two of them were also present in FD. Two species of the genus *Gymnodinium* (1 in ND and 1 in FD), and 1 of the genus *Dinophysis* (only in ND) were found during the study.

It is necessary to establish that the abundances of these potentially toxic species were very low anytime, and that at those levels they do not represent a serious problem for humans, mollusks or any other community; however, it is important to take into consideration that the species are present (mostly in the area near to the discharge), and that under certain conditions, for instance a greater volume of effluents or higher nutrients concentrations, it is possible the development of blooms of these species with the consequent negative impacts.

Declarations

Author contribution statement

Luis Rafael Martinez-Cordova: Conceived and designed the experiments; Analyzed and interpreted the data; Wrote the paper.

Celia G. Valenzuela-Sanchez: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Norberto M.A. Pasten-Miranda: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data.

Luis Fernando Enriquez-Ocaña: Conceived and designed the experiments; Performed the experiments; Wrote the paper.

Ramon H. Barraza-Guardado: Performed the experiments.

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Data availability statement

No data was used for the research described in the article.

Declaration of interests statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

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