Temporal variation in the phytoplankton community of Acapulco Bay, Mexico

Agustín A. Rojas-Herrera,
Juan Violante-González,
Sergio García-Ibáñez,
Víctor M. G. Sevilla-Torres,
Jaime S. Gil-Guerrero,
Pedro Flores-Rodríguez

Unidad Académica de Ecología Marina,
Universidad Autónoma de Guerrero,
Acapulco, México

Abstract

Species composition and abundance of the phytoplankton community in Acapulco Bay, Mexico, were studied from May to December 2009. Samples were collected at 5 stations (4 coastal and one oceanic) at 3 depths (1, 5 and 10 m). Eighty-seven species were identified: 54 dinoflagellates, 32 diatoms and one silicoflagellate. The community was structured mainly by adiphoric species, that is species adapted to both neritic and oceanic environments. Species abundance and composition varied significantly during the sampling period due to increased nutrient concentrations in the rainy season. Dinoflagellate species were more abundant during the dry season, and diatom species dominated numerically during the rainy season.

Introduction

Phytoplankton is one of the most complex communities in marine coastal environments. This community's structure is dictated by two important groups of organisms: i) non-motile, fast-growing diatoms; and ii) motile flagellates and dinoflagellates which can migrate vertically in the water column in response to light. All phytoplankton species are subject to water currents and have developed strategies for rapid nutrient absorption and fast reactions to fluctuations in hydrographic conditions.¹ Thus, phytoplankton distribution and species composition are affected by several processes, including high water temperature, and variations in thermal stability and nutrient circulation.

Changes can occur in the taxonomic composition of phytoplankton communities, the total cell abundance and species richness during annual seasonal cycles. These changes reflect the capacity of communities to respond to seasonal variations in light, nutrient and circula-

tion patterns.² Under specific environmental conditions (e.g. high nutrient concentrations) these factors can cause some species to proliferate massively, causing harmful algal blooms (HAB) which can negatively affect marine communities. Of the more than 5,000 known marine phytoplankton species, approximately 40 species worldwide have been linked with the production of toxins.³⁻⁵

Santa Lucia Bay, also known as Acapulco Bay, is located on the tropical Pacific coast of southern Mexico, in Guerrero State. The bay has a semi-circular (6.3 km diameter), amphitheater-like shape created by low hills (<500 m) surrounding the south-facing bay. It is considered to be very climatologically protected (Agustín, unpublished data, 2011).

Research on marine phytoplankton communities abounds,⁶⁻⁹ but to date there have been no studies assessing the phytoplankton species composition in Acapulco Bay, Mexico. The aim of the present study was to document current species composition and abundance in the phytoplankton community of Acapulco Bay, and quantify any temporal variation in these variables.

Materials and Methods

Phytoplankton samples were collected in Acapulco Bay between May and December 2009 at 5 stations: i) Club de Yates (16°50'N, 99°54'W); ii) Islote del Morro (16°51'N, 99°53'W); iii) Naval Base (16°51'N, 99°51'W); iv) Casa de Diaz Ordaz (16°50'N, 99°51'W); and v) Centro de la Bahía (16°49'N, 99°53'W). Van Dorn bottles were used to take samples of marine water (approximately 3 L in each sample) at 3 depths (1 m, 5 m, and 10 m) at each station. Water temperature, pH and salinity were measured *in situ* with a YSI probe.

Nutrient (nitrates, ammonium and phosphates) concentrations were determined in each sample following a standard colorimetric method (Hanna equip). Phytoplankton samples were fixed in concentrated Lugol's solution and cell quantification was made using the Utermöhl chamber sedimentation concentration method.¹⁰ Phytoplankton species were identified according to a specialized bibliography.¹¹⁻¹⁶ Phytoplankton species distribution was established based on a review of published records for Mexico and other countries, and each species was classified as: (ES) estuarine, (NE) neritic, (AD) adiphoric or (OC) oceanic.

The Olmstead-Tukey association test¹⁷ was applied to classify the phytoplankton species based on parameters of occurrence frequency and mean abundance: (D) dominant (abundant and frequent); (C) common (low abundance but frequent); (O) occasional (abundant

Correspondence: Juan Violante-González, Unidad Académica de Ecología Marina, Universidad Autónoma de Guerrero, Gran Vía Tropical No. 20, Fracc. Las Playas. C.P. 39390, Acapulco, Guerrero, México.

E.mail: viojuang@yahoo.com.mx

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but low frequency); and (R) rare (low abundance and low frequency). A one-way ANOVA was applied to identify significant differences in monthly parameters (temperature, pH and salinity) and nutrient concentrations. When significant deviations from normality were identified, parameters and concentration data were log-transformed ($\log x+1$) to meet normality and homoscedasticity requirements. Any differences in phytoplankton abundance at the 3 tested depths were identified with a one-way ANOVA. A χ^2 test was applied to identify significant differences in mean phytoplankton group abundance between months.

Community parameters included total number of species, total number of cells, the Shannon-Wiener (H) diversity index, species evenness (J) and the Berger-Parker Index (BPI) as a measure of numerical dominance.^{18,19} The qualitative Jaccard similarity index was used to evaluate similarity or difference in species composition between months. Student's *t*-test was applied to identify differences between community parameters, and correlations calculated using the Spearman's range coefficient (r_s) were applied to identify the parameters that determined observed species distribution and composition patterns.

Results

Mean temperature at the sampling stations during the study period varied significantly from 25.8 ± 0.56 to $30.89 \pm 0.44^\circ\text{C}$ (ANOVA, $F=92.18$, $P<0.05$), (Figure 1). Salinity varied from 32.31 ± 0.07 to 38 ± 0.01 psu (ANOVA, $F=164.89$, $P<0.05$), while pH ranged from 7.82 ± 0.21 to 8.43 ± 0.23 (ANOVA, $F=34.21$, $P<0.05$). Nutrient concentrations for the 3 tested nutrients varied significantly ($P<0.05$) during the study period: nitrate (NO_3^-) and phosphate (PO_4^{3-}) concentrations increased from June to November, with highest levels in November; ammonium concentration (NH_4^+) was highest in December (Figure 2).

Phytoplankton community taxonomic composition included a total of 87 species: 54 dinoflagellates (Dinophyta), 32 diatoms (Bacillariophyta) and one silicoflagellate (Heterokontophyta). Although the number of microalgal diatom species was relatively low, this group's total cell abundance represented more than 70% of the total cells collected during the sampling period. Phytoplankton species group differentiation showed that dinoflagellates dominated numerically from May to June, while diatoms increased constantly in abundance beginning in July and peaked between September and December (Figure 3). Monthly mean diatom species abundance was positively correlated with nitrate ($r_s=0.857$, $P<0.05$) and phosphate ($r_s=0.786$, $P<0.05$) concentrations; dinoflagellate abundance exhibited no correlation.

Six species numerically dominated the community: 2 dinoflagellate species (*Neoceratium belechii* and *Scrippsiella trochoidea*) and 4 diatoms (*Chaetoceros tetrastichon*, *Leptocylindrus danicus*, *Pseudosolenia calcaravis*, and *Pseudonitzschia* sp.) (Table 1). These six species accounted for 66% of the total estimated cell counts in the samples. The dinoflagellates *Dinophysis caudate*, *Neoceratium furca* and *Protoperidinium divergens* were identified in all samples though none were numerically dominate. Based on phytoplankton species distribution, over 70% of the dinoflagellate and diatom species were classified as adiaiphoric (*i.e.* they occur in neritic and oceanic areas) (Figure 4). The frequency-abundance graphic method indicated that 60% of the diatom species were dominant (*i.e.* abundant and frequent) while only 27% of dinoflagellate species were classified as dominant (Figure 5).

No differences in phytoplankton abundance (cell/L) were observed at the 3 sampled depths (1, 5 and 10 m) (ANOVA $F=0.283$, $P>0.05$), therefore all abundance data were pooled for subsequent analyses. Monthly mean abundance varied (χ^2 test, $P<0.05$) between sam-

pling stations, with stations 1 (Club de Yates) and 4 (Casa de Diaz Ordaz) each having the highest mean values for three months, although not in the same months (Figure 6). Mean abundance was highest at station 1 from September to November, but highest at station 4 in May, June and September (Figure 6).

Species richness varied significantly (t -

test=6.42, $P<0.05$) from 17 species (May) to 49 species (July), while monthly total abundance ranged from 76,266 cell/L (July) to 709,000 cell/L (December), exhibiting significant increases in later months (t -test=3.32, $P<0.05$) (Table 1). Shannon-Wiener diversity index values ranged from 1.40 to 3.92 and evenness from 0.27 to 0.70; both parameters

Figure 1. Monthly temperature and salinity values in Acapulco Bay, Mexico, between May-December.

Figure 2. Monthly nutrient concentrations (mg/L) in Acapulco Bay, Mexico.

Figure 3. Temporal variation of dinoflagellate and diatom groups in Acapulco Bay, Mexico.

varied significantly between months (t -test=7.85; 10.54, $P<0.05$, respectively). Diversity index values were significantly higher in July (3.92) and October (3.23) and correlated positively with their respective evenness values ($r_s=0.97$, $P<0.05$). Similarity in species composition was low ($<10\%$) during most months, but increased to 50% in November and December (Figure 7).

Discussion

Water temperature was almost constant from June to December, varying only 3°C most months (Figure 1), whereas salinity decreased significantly during the same period (Figure 1). Temperature fluctuations are not as extreme in tropical marine areas as those seen in temperate or cold latitudes, suggesting that this environmental parameter is not very informative in terms of species composition in tropical phytoplankton communities.⁹ The fluctuations in salinity values that were observed can be attributed to freshwater flowing into the bay during the rainy season (June to November). Salinity is known to have a notable effect on the structuring of phytoplankton communities, particularly in estuarine and coastal environments.^{8,9,20,21}

The constant increase in nitrate and phosphate concentrations between June and November can also be attributed to rainfall runoff during this season.⁷ Sewage, as well as huge quantities of garbage and other solid materials from the Acapulco urban area discharge directly into the bay, contributing to higher nutrient concentrations and consequent population growth in several phytoplankton species.^{7,9}

The dinoflagellates (54 species) dominated the phytoplankton community in Acapulco Bay (Table 2), although total abundance of the group was significantly lower than that of the diatoms. This contrasts with patterns reported in other studies of phytoplankton composition carried out at tropical latitudes in which diatoms dominate in terms of species number.^{7-9,22} Phytoplankton are considered to be good indicators of water conditions in neritic and oceanic masses.^{23,24} Dinoflagellates are better adapted to the oceanic environment, while diatoms are more adapted to coastal environments.^{8,23} Therefore, our results suggest that environmental conditions in Acapulco Bay change during the year in response to variations in several environmental parameters. Changes in the bay's water masses are probably reflected in the traits presented by the phytoplankton species inhabiting it; for example, more than 70% of the dinoflagellate and diatom species recorded in

the present study are adapted to neritic or oceanic environments, that is they are classified as adiaporphic species.⁸ (Figure 4).

Phytoplankton abundance (cell/L) did not vary significantly at the 3 depths studied, probably because diatoms dominated numerically at all depths. This numeric dominance occurs because diatoms adapt to living in the entire

water column. Their large ornamentations, long cellular projections, and tendency to form chains of cells allow them to remain in superficial layers, possibly assisted by water turbulence.⁸ Variation in monthly mean abundance between sampling stations can be attributed to the presence of sewage discharge at sampling stations such as the Club de Yates (station 1)

Figure 4. Frequency distribution of phytoplankton species from Acapulco Bay, Mexico, based on origin: ES, estuarine; NE, neritic; AD, adiaporphic; OC, oceanic.

Figure 5. Phytoplankton species classification based on the frequency-abundance graphic method (Olmstead-Tukey association test). D, dominant; C, common; O, occasional; R, rare.

Figure 6. Temporal variation in mean abundance (cell/L) per sampling station: 1) Club de Yates; 2) Islote del Morro; 3) Base Naval; 4) Casa de Díaz Ordaz; 5) Centro de la Bahía.

and Casa de Diaz Ordaz (station 4), as a result of increased nutrient concentration in these areas.

Different species dominated numerically in each month, indicating wide variability in species composition over time. The dinoflagellate *N. belechii* dominated at the end of the dry season and beginning of the rainy season (May to June), while different diatom species dominated during the rainy season (Table 1). Changes in phytoplankton community structure have been associated with small changes in water temperature^{9,22} or with the different strategies used by phytoplankton groups to absorb available nutrients in the water column.⁶ The higher abundance of some dinoflagellate species in June and August may, therefore, be associated with warmer temperatures during these months since high temperatures favor growth in some dinoflagellate populations (Figure 1). In contrast, diatoms respond more rapidly to increases in available nutrient

Figure 7. Similarity percentages for monthly phytoplankton samples in Acapulco Bay, Mexico.

Table 1. Characteristics of the phytoplankton community in Acapulco Bay, Mexico. Dino, dinoflagellates; Diat, diatoms; BPI, Berger-Parker index; H, Shannon-Wiener diversity index; J, evenness.

Month	N. of species	Dino. N. cell	Diat. N. cell	Total cell	Dominant specie	BPI	H'	J'
May	17	142173.3	2133.3	144306.6	<i>Neoceratium belechii</i>	0.76	1.45	0.36
June	28	66400.1	28400.2	94800.3	<i>Neoceratium belechii</i>	0.38	2.99	0.62
July	49	31466.9	44800	76266.9	<i>Chaetoceros tetraschiton</i>	0.25	3.92	0.70
Aug.	16	195399.9	63266.6	258666.5	<i>Scrippsiella trochoidea</i>	0.57	2.11	0.53
Sep.	14	4266.7	92533.3	96800	<i>Pseudosolenia calcar-avis</i>	0.22	1.99	0.52
Oct.	42	58600.1	189733.4	248333.5	<i>Pseudonitzschia</i> sp.	0.27	3.23	0.60
Nov.	37	31400.3	461399.9	492800.2	<i>Leptocylindrus danicus</i>	0.42	2.84	0.55
Dec.	35	24000.1	685000	709000.1	<i>Leptocylindrus danicus</i>	0.81	1.40	0.27

Table 2. Composition and abundance (cell/L) of the phytoplankton community in Acapulco Bay, Mexico.

Specie	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
Dinophyta								
<i>Akasiwo sanguinea</i> ^{2 (D)}				1933.3		1933.3	1000	200
<i>Alexandrium catenella</i> ^{2 (R)}						133.3		66.7
<i>Balechina coerulea</i> ^{3 (R)}				666.7				
<i>Dinophysis caudata</i> ^{3 (D)}	1333.3	1933.3	5333.3	17133.3	266.7	3066.7	733.3	933.3
<i>Dinophysis doryphora</i> ^{3 (C)}						733.3		466.7
<i>Dinophysis odiosa</i> ^{3 (R)}			133.3					
<i>Dinophysis rudgei</i> ^{3 (R)}						266.7		
<i>Gonyaulax spinifera</i> ^{3 (D)}		1000	200			8400	600	2466.7
<i>Gymnodinium catenatum</i> ^{2 (D)}	3800	1266.7	133.3	3133.3		12466.7	17266.7	1933.3
<i>Lingulodinium polyedrum</i> ^{2 (O)}				2600				
<i>Neoceratium azoricum</i> ^{3 (R)}		266.7	266.7					
<i>Neoceratium belechii</i> ^{3 (D)}	109640	35666.7	133.3		600	800	466.7	66.7
<i>Neoceratium belechii f. longum</i> ^{3 (D)}	10400	466.7	466.7					
<i>Neoceratium biceps</i> ^{3 (R)}		133.3	200					
<i>Neoceratium breve</i> ^{4 (R)}		1066.7						
<i>Neoceratium breve var. parallelum</i> ^{4 (R)}		600			200	333.3	266.7	
<i>Neoceratium candelabrum</i> ^{3 (R)}		933.3						
<i>Neoceratium candelabrum var. depressum</i> ^{3 (R)}	200		133.3				400	

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Table 2. Continued from previous page.

Specie	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
<i>Neoceratium carriense</i> ^{3 (R)}					600			
<i>Neoceratium deflexum</i> ^{3 (O)}	266.7	1866.7				66.7		
<i>Neoceratium furca</i> ^{2 (D)}	10200	5600	5066.7	7133.3	2333.3	16600	2666.7	5266.7
<i>Neoceratium fusus</i> ^{2 (D)}		3266.7	66.7			1600	1866.7	2933.3
<i>Neoceratium lunula</i> ^{3 (R)}	200							
<i>Neoceratium macroceros</i> ^{3 (C)}			466.7			200	733.3	
<i>Neoceratium praelongum</i> ^{3 (R)}			66.7					
<i>Neoceratium ranipes</i> ^{4 (R)}	66.7							
<i>Neoceratium teres</i> ^{3 (R)}							66.7	
<i>Neoceratium tripos</i> ^{3 (D)}	2266.7		133.3					
<i>Nocticula scintillans</i> ^{3 (R)}			666.7				133.3	
<i>Ornithocercus heterophorus</i> ^{4 (C)}			66.7				1000	
<i>Ornithocercus magnificus</i> ^{4 (R)}			133.3					
<i>Ornithocercus quadratus</i> ^{3 (R)}			600					
<i>Ornithocercus</i> sp. (R)						600		
<i>Ornithocercus steinii</i> ^{4 (R)}			200					66.7
<i>Ornithocercus thumii</i> ^{3 (R)}			66.7					
<i>Oxytoxum parvum</i> ^{3 (R)}			200					
<i>Podolampas bipes</i> ^{3 (R)}	133.3		133.3					
<i>Prorocentrum compressum</i> ^{3 (R)}							66.7	
<i>Prorocentrum gracile</i> ^{2 (D)}		733.3	1266.7			1800	66.7	133.3
<i>Prorocentrum micans</i> ^{3 (D)}						4000	1066.7	2200
<i>Protoperidinium claudicans</i> ^{3 (C)}		133.3	400			400		266.7
<i>Protoperidinium conicoides</i> ^{3 (D)}			66.7			666.7	866.7	2200
<i>Protoperidinium conicum</i> ^{3 (R)}			266.7					66.7
<i>Protoperidinium depressum</i> ^{3 (D)}	133.3	11000	266.7	1200				
<i>Protoperidinium divergens</i> ^{3 (D)}	3400	133.3	466.7	14600	866.7	2066.7	1600	2733.3
<i>Protoperidinium latispinum</i> ^{3 (R)}		66.7	66.7					
<i>Protoperidinium pellucidum</i> ^{3 (O)}			12466.7					
<i>Protoperidinium pentagonum</i> ^{3 (R)}		66.7						
<i>Protoperidinium pyriforme</i> ^{3 (D)}						1533.3	466.7	66.7
<i>Protoperidinium robustum</i> ^{3 (O)}				400				1933.3
<i>Protoperidinium</i> sp. (C)			800	266.7			66.7	
<i>Protoperidinium steinii</i> ^{3 (R)}	133.3	200						
<i>Pyrodinium bahamense</i> var. <i>compressum</i> ^{3 (R)}						200		
<i>Scrippsiella trochoidea</i> ^{3 (O)}				146333.3				
Subtotal	142173.3	66400.1	31466.9	195399.9	4266.7	58600.1	31400.3	24000.1
Bacillariophyta								
<i>Chaetoceros affinis</i> ^{3 (D)}					1000			
<i>Chaetoceros constrictus</i> ^{3 (O)}			7666.7					
<i>Chaetoceros curvisetus</i> ^{3 (D)}			333.3		2333.3	266.7	9600	
<i>Chaetoceros decipiens</i> ^{3 (D)}			533.3		4400	933.3	5000	
<i>Chaetoceros</i> sp. (O)		4466.7	4400					
<i>Chaetoceros tetrastichon</i> ^{3 (D)}		19800	18866.7					
<i>Coscinodiscus concinnus</i> ^{2 (R)}					533.3			
<i>Coscinodiscus</i> sp. (D)	533.3	66.7	733.3		133.3	10333.3	5600	2733.3
<i>Cylindrotheeca closterium</i> ^{4 (R)}						66.7		
<i>Ditylum brightwellii</i> ^{3 (D)}			2733.3			3400	4733.3	2333.3
<i>Eucampia zoodiacus</i> ^{3 (D)}						66.7		1933.3
<i>Guinardia flaccida</i> ^{3 (D)}						2666.7	10600	66.7
<i>Guinardia striata</i> ^{3 (D)}				1133.3		200	1066.7	19466.7
<i>Gyrosigma peisonis</i> ^{3 (O)}			1866.7					
<i>Leptocylindrus danicus</i> ^{3 (D)}				52600		7466.7	204533.3	576066.7
<i>Melosira granulata</i> ^{1 (D)}						83800	121200	
<i>Navicula</i> sp. (O)			133.3				866.7	1200
<i>Nitzschia closterium</i> ^{3 (R)}								66.7
<i>Nitzschia sigma</i> ^{1 (R)}			66.7					
<i>Nitzschia</i> sp. (D)	1466.7	200	1333.3	1333.3		2733.3	15666.7	10800
<i>Pleurosigma decorum</i> ^{3 (D)}			66.7			1266.7	4066.7	2266.7
<i>Pleurosigma distinguendum</i> ^{3 (D)}		266.7		2800		200	600	10533.3
<i>Pseudonitzschia delicatissima</i> ^{3 (O)}			1400					2066.7
<i>Pseudonitzschia</i> sp. (D)		3066.7	400		55200	66266.7	41133.3	35333.3
<i>Pseudosolenia calcar-avis</i> ^{2 (D)}			600		21466.7	133.3	4533.3	10000
<i>Rhizosolenia hebetata</i> ^{3 (D)}				5400		2533.3	7733.3	
<i>Rhizosolenia imbricata</i> ^{3 (D)}						2666.7	21933.3	8933.3

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Table 2. Continued from previous page.

Specie	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
<i>Rhizosolenia</i> sp. ^(R)	133.3	266.7						
<i>Skeletonema costatum</i> ^{3 (R)}			1666.7					
<i>Skeletonema</i> sp. ^(O)		266.7			6866.7			
<i>Striatella unipunctata</i> ^{3 (D)}			2000		600	4733.3	2533.3	133.3
<i>Thalassionema nitzschioides</i> ^{3 (R)}								1066.7
Subtotal	2133.3	28400.2	44800	63266.6	92533.3	189733.4	461399.9	685000
Heterokontophyta								
<i>Dictyocha octonaria</i> ^{4 (R)}						66.7		
Subtotal						66.7		
Total abundance	144306.6	94800.3	76266.9	258666.5	96800	248400.2	492800.2	709000.1

Distribution: 1, Estuarine; 2, Neritic; 3, Adriaphoric; 4, Oceanic. Classification: D, dominant; C, common; O, occasional; R, rare.

concentration,²⁵ resulting in faster population growth than in dinoflagellates and possibly explaining their higher counts during the rainy season.

At least 8 of the 54 identified dinoflagellate species (*Alexandrium catenella*, *Dinophysis caudata*, *Gymnodinium catenatum*, *G. sanguinum*, *Neoceratium furca*, *N. fusus*, *N. tripos* and *Pyrodinium bahamense* var. *compressum*) have been reported in HAB, or red tides, in other locations in Mexico.^{26,27} Of these, only *D. caudata* and *N. furca* were found to be abundant and frequent (dominant) during the sampling months. *Pyrodinium bahamense* var. *compressum* was also identified in the present study but it was a rare species with low abundance collected only in October (Table 2); it was, however, the cause of an HAB event in Acapulco Bay in July 2010, some months after the final sampling carried out for the present study.

The pattern of species distribution of the phytoplankton community in Acapulco Bay was similar to patterns reported for other marine or estuarine communities. Community structure was determined by a low number of dominant species (2 dinoflagellates and 4 diatoms) which contributed over 60% of total abundance, and a high number of occasional and rare species (>50%) (Figure 5). Total richness (87 species) in the study area was within the species number range reported for other locations in Mexico²⁶ and other countries with similar climatological conditions.^{7,8,22} The diversity values recorded here are similar to those reported for other locations in the tropical Pacific.⁸ The higher diversity values recorded in the months of July (3.2) and October (3.23) can be attributed to the fact that some species' dominance diminished, whereas in other months these species' abundances (and therefore their dominance) remained fairly constant (evenness ≥ 0.60 , Table 1). The low similarity values observed here (Figure 7) suggest the possibility that species composition differed between months in response to variability in environmental conditions over time.

Overall, the results indicate that phytoplankton species composition and abundance in Acapulco Bay varied spatially and temporally due to variations in environmental conditions. These environmental variations were caused by changes in nutrient concentrations which were a result of differences in rainfall between the local dry and rainy seasons. Higher nutrient concentrations promoted population growth in dinoflagellate or diatom species at different time points during the year.

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