Temporal changes in the community structure of phytoplankton in Panguil Bay, Philippine mangrove estuary

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Abstract. Phytoplankton is an excellent indicator of marine ecosystem change. This study was conducted to investigate the influence of environmental parameters on the temporal assemblage structure of net phytoplankton in Panguil Bay, Philippines, using biodiversity indices and multivariate techniques. A total of 49 species were identified during the 12 months sampling period. Net phytoplankton was documented in decreasing order of abundance: diatoms > dinoflagellates > cyanobacteria. The centric diatom *Coscinodiscus wailesii* dominated in almost all of the sampling months but outnumbered by the chain-forming *Thalassiothrix frauenfeldi, Melosira nummuloides* and *Thalassionema nitzschioides* during the southwest monsoon months (February, August and October). Two discrete clusters formed (species of higher and lower abundance, diversity, evenness and richness). Environmental parameters such as salinity, dissolved oxygen and phosphate exhibited highly significant contribution to the temporal assemblages and composition of phytoplankton in Panguil Bay. The study of phytoplankton community response to these variables is crucial for interpreting hydrological variations in coastal areas.
Key Words: diatoms, environmental parameters, marine ecosystem, monthly sampling, net phytoplankton.

Introduction. Marine ecosystems are rapidly changing in response to human activities, climate change and natural processes (Hoegh-Guldberg & Bruno 2010). These initiators of change have become the subject of progressively intense focus from both management perspectives and research (Cloern et al 2007). Phytoplankton is a key indicator of marine ecosystem change aside from their crucial role in the marine food chain (Yin 2002; McCarthy 2005; Hays et al 2005). Temporal changes in the community structure of phytoplankton are vital to aquatic system metabolism (Calijuri et al 2002). These changes in community structure of phytoplankton (i.e. assembly or succession) have long attracted the attention of aquatic ecologists (Dickey 2001).

According to Falkowski & Piekarek-Jankowska (2006), changes in mixed layer dynamics may change both the timing and magnitude of the phytoplankton blooms as well as community composition (Winder & Sommer 2012). Significant changes in community composition due to climatic alterations are being observed in the ocean (Karl et al 2002). The disappearance of functional groups or individual species as forecasted in some worldwide change settings may have a dramatic influence on the community and ecosystem dynamics (Berlow 1999). Two important factors were recognized as controlling community structure of phytoplankton. The first is related to physical processes such as mixing of water masses, light, temperature, turbulence, and salinity (Jones et al 2001) and the second is associated with nutrients (Roalke et al 2003).

Mangrove estuaries are said to be productive and crucial nursery grounds for fishery resources (Saifullah et al 2016). In the southern part of the Philippines, Panguil Bay in Northwestern Mindanao is a mangrove estuarine ecosystem and is one of the richest body of water in the Philippine Archipelago (Lacuna et al 2012). It has been considered a natural spawning and breeding ground for many commercially important fin fish and invertebrate species (Jimenez et al 1996). Nevertheless, studies on the biology and ecology of phytoplankton communities in this mangrove estuary are very scarce considering that phytoplankton are among the primary producers in shallow coastal areas and factors that affect them will most likely affect the overall productivity of a given site.

This study aimed to investigate the temporal changes in the community structure of phytoplankton in Panguil Bay, Philippines in relation to selected environmental parameters. The study of phytoplankton community response to these variables is considered useful for interpreting hydrological variations in coastal areas. The findings of this study could also provide an ecological baseline data that serve as the basis for establishing management plans for the site.

Material and Method

Study area and sampling period. Panguil Bay is a 219 km^2 water body that forms a partial natural boundary separating the Zamboanga Peninsula from the rest of the island in Mindanao, Philippines. Three provinces (Misamis Occidental, Zamboanga del Sur, and Lanao del Norte) share this water body as a common border (Figure 1).

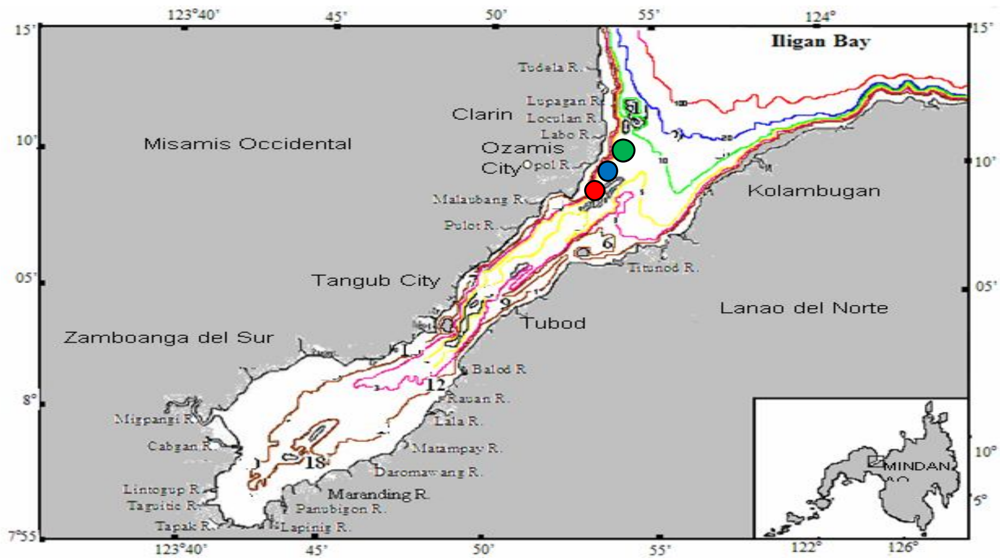

Figure 1. Bathymetric map of Panguil Bay with the location of the sampling stations. Inset: map of Mindanao, Philippines with Panguil Bay enclosed in a square. Legend: ● station 1; ● station 2; ● station 3.

The water current system and circulation pattern in the Bay were mainly influenced by tidal forcing and, to some extent, by strong seasonal monsoon winds (Gorospe & Prado 1992; Canini et al 2013). Twenty nine (29) rivers and 46 minor tributaries transport nutrients and sediments into the bay. The freshwater contribution from tributaries was estimated to reduce the flushing time of bay water in 9 days (Gorospe & Prado 1992).

This study was carried out for twelve months, beginning at November 2008 and last to October 2009. Three sampling stations near the seaport of Ozamis City were established. It is situated 8^{0}08'13 North Latitude and 123^{0}50'06 East Longitude. This area receives the anthropogenic waste and drainage via minor tributaries. However, the local residents use the coast for bathing. In addition, this site is also used as a transport route for commercial inter-island shipping and local ferry boats plying Mukas, Kolambogan, Lanao del Norte and Ozamiz City (Hopkins & McCoy 1976).

Collection, preservation and enumeration of phytoplankton samples. Phytoplankton samples were collected using a conical plankton net (General Oceanics) with a mesh size of 20 μm and a 1-liter capacity cod end. A sinker was attached (2 kg) to the bridle at 1.5-meter below net mouth (Figure 2). The net was lowered until the sinker attaches to the bottom. The net was retrieved at a constant speed (ca. 0.5 m/s). Then the net was rinsed from outside with surface water, allowing the water samples inside the net to collect into the cod-end. Triplicate vertical tows were made and samples from each tow that collect in the cod end were placed in labeled bottles and preserved in 5% buffered formaldehyde solution then stored in a cool and dark environment allowing the collected phytoplankton to settle on the bottom of the sample bottle (Utermohl 1958).

To determine the physicochemical environmental conditions standard methods following the work of Canini et al (2013) were used. These parameters include water temperature (^{0}C), pH, dissolved oxygen, chlorophyll *a*, inorganic phosphate and nitrate, amount of total suspended solids and tidal height values.

Data analysis. Comparison of the diversity and abundance of phytoplankton between sampling months was analyzed using biodiversity indices, Bray-Curtis similarity dendrograms, and non-metric multidimensional scaling available in the software Primer version 5 (Clarke & Warwick 2001). The relationship between environmental factors and the phytoplankton community structure was determined by obtaining the value of the gradient length which was derived from Detrended Correspondence Analysis (DCA) (available in the software Canoco version 4.5 (Ter Braak & Smilauer 2002)) if the length of gradient is <4, the Redundancy Analysis (RDA) was used. Monte Carlo simulation was used to test for the statistical significance of output multivariate axes, and stepwise multiple regression (Forward Selection) was used to relate environmental parameters with phytoplankton counts and biomass.

Results

Monthly environmental parameters. Table 1 presents the environmental parameters of the 12 sampling months.

Table 1
Average values of physico-chemical parameters for the one year period, monthly sampling

Month	*Depth (m)*	*Temp. (^{o}C)*	*Salinity (ppt)*	*pH*	*NO_3 (mgN L^{-1})*	*PO_4 (mgP L^{-1})*	*DO (mgL^{-1})*	*Chl a*	*TSS (g L^{-1})*	*Tide (m)*
November	11	30.67	29.67	6.33	0.60	0.20	6.81	0.82	0.073	0.23
December	10	29.33	21.33	6.97	0.40	0.12	9.83	1.30	0.088	0.41
January	9	30.00	29.00	7.04	0.40	0.12	7.37	1.34	0.072	0.61
February	9	29.67	30.00	9.04	0.80	2.90	6.55	1.48	0.065	0.52
March	9	29.33	31.00	6.97	0.80	2.90	6.76	1.23	0.052	0.51
April	9	30.67	29.67	6.33	0.80	2.90	5.38	1.20	0.053	0.34
May	9	31.00	31.67	7.02	0.70	0.05	6.73	1.25	0.001	1.67
June	9.5	29.33	27.00	6.63	0.50	0.05	6.88	1.26	0.012	0.52
July	9.5	29.00	28.67	6.23	0.50	0.05	7.35	2.35	0.029	0.35
August	11	29.00	30.33	6.20	0.60	0.25	6.85	3.33	0.002	1.14
September	10	28.33	28.67	7.23	0.50	0.07	7.23	2.98	0.003	0.78
October	10	27.67	28.00	6.23	0.50	0.07	8.13	3.04	0.002	1.24

November and August recorded the maximum depth ranging from 10 to 11 m while summer months registered a ranged of 9-9.5 m. Salinity values were highest during May (31.67 ppt) due to evaporation but lower in December (21.33) due to frequent rains. May was the hottest month with a maximum temperature of 31^{o}C and July and August were the coolest months with the mean temperature of 29^{o}C. For the pH, the maximum value of 7.23 was observed on September while the minimum of 6.23 recorded on July and October. Total suspended solids lowest value was during the month of May (0.0012 g L^{-1}) while the maximum was in the rainy month of December (0.088 g L^{-1}). Dissolved oxygen concentration ranges from 6.73 to 9.83 mg L^{-1}. The highest value was during the wet month of December. Most of the wet months observed lower concentration of dissolved nitrate than the summer months which recorded the maximum value of 0.80 mg L^{-1} (February, March, April). Summer months of February, March and April observed a relatively higher concentration of phosphate than the rest of the months. The southwest monsoon of August recorded the maximum chlorophyll value of 3.33 μg/L while the minimum of 0.82 μg/L was on the northeast monsoon of November.

Monthly changes in the community structure of phytoplankton. Monthly fluctuations in phytoplankton composition and abundance were observed in this study. A total of 49 species were identified during the 12 months sampling period (Table 2).

Table 2

Abundance of phytoplankton species for the one year period, monthly sampling

Species	Code	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct
A. Diatom													
Bacillaria paradoxa	*Bpar*		●										
Bacteriastrum delicatulum	*Bdel*								●	●	●	●	●
Bacteriastrum elongatum	*Belo*				●			●	●	●	●	●	●
Bacteriastrum hyalinum	*Bhya*		●					●	●	●	●	●	●
Biddulphia sinensis	*Bsin*							●		●	●		
Biddulphia obtuse	*Bobt*										●	●	
Caloneis crassa	*Ccra*							●					
Chaetoceros affinis	*Caff*												
Chaetoceros curvisetus	*Ccur*				●				●			●	
Chaetoceros decipiens	*Cdec*		●	●				●	●	●	●	●	●
Climacodium frauenfeldianum	*Cfra*							●					
Cocconeis placentula	*Cpla*									●			
Corethron hystrix	*Chys*				●							●	●
Coscinodiscus wailesii	*Cwai*	●	●	●	●	●	●	●	●	●	●	●	●
Ditylum brightwellii	*Dbri*		●	●	●	●	●	●	●	●	●	●	●
Eucampia zodiacus	*Ezod*					●	●	●	●	●	●	●	
Grammatophora oceanica	*Goce*									●			
Gyrosigma sp.	*Gysp*			●		●	●	●		●			●
Hemicaulus sinensis	*Hsin*											●	
Leptocylindricus danicus	*Ldan*			●	●	●	●	●		●		●	
Melosira nummuloides	*Mnum*	●	●	●	●	●			●	●	●	●	●
Nitschia seriata	*Nser*				●					●	●	●	●
Nitzschia longissima	*Nlon*									●		●	●
Pleurosigma angulatum	*Pang*	●	●					●		●	●	●	●
Pleurosigma elongatum	*Pelo*									●		●	
Pleurosigma sp.	*Plsp*									●		●	●
Rhizosolenia bergonii	*Rber*		●							●	●	●	
Rhizosolenia hebetata f. Semispina	*Rheb*				●			●			●	●	●
Rhizosolenia imbricate	*Rimb*							●		●	●		
Rhizosolenia setigera	*Rset*							●	●	●		●	●
Skeletonema costatum	*Scos*	●	●	●		●				●	●	●	●
Stephanopyxis palmeriana	*Spal*							●			●		
Thalassionema nitzschioides	*Tnit*				●			●	●	●	●	●	●
Thalassiosira pacifica	*Tpac*												●
Thalassiothrix frauenfeldi	*Tfra*	●			●			●		●	●	●	●
B. Dinoflagellates													
Ceratium dens	*Cden*							●					
Ceratium furca	*Cfur*		●	●	●	●	●			●		●	●
Ceratium fusus	*Cfus*				●			●		●		●	●
Ceratium macroceros	*Cmac*									●			●
Ceratium trichoceros	*Ctri*				●			●	●		●		●
Ceratium tripos	*Ctrp*					●	●	●		●		●	
Dinophysis caudata	*Dcau*				●					●	●	●	
Gonyaulax verior	*Gver*	●	●		●					●		●	●
Peridinium depressum	*Pdep*				●		●	●	●	●			●
Peridinium pellucidum	*Ppel*				●							●	
Peridinium pentagonum	*Ppen*											●	
Triceratium revale	*Trev*							●					
C. Cyanobacteria													
Oscillatoria kawamurae	*Okaw*		●					●		●	●	●	
Trichodesmium theibauti	*The*							●					

Legend: ● = 1-1000; ● = 1001-5,000; ● = 5,001-10,000; ● = 10,001-15,000; ● = 15,000-20,000; ● = 20,001-25,000; ● = 25,001- 35,000; ● = 35,001 and above.

Among these, the cosmopolitan *Coscinodiscus wailesii* was observed to be the most abundant in nine sampling months but varied with their average density values (December: 6,334 cells/m^3; January: 8,343 cells/m^3; March: 7,715 cells/m^3; April: 8,109 cells/m^3; May: 21,973 cells/m^3; June: 16,100 cells/m^3; July: 15,173 cells/m^3; September: 31,551 cells/m^3; and November: 6,334 cells/m^3) (Figure 2). However, for the month of February, the chain-forming diatom *Thalassionema nitzschioides* became dominant with an average density of 36,736 cells/m^3. In February, the second and third most dominant species were *Thalassiothrix frauenfeldi* (35,142 cells/m^3) and *C. wailesii* (25,987 cells/m^3). Both the months of August and October registered *T. frauenfeldi* and *Melosira nummuloides* as the top two dominant species. In general, the month with the highest species abundance was August with a total density of 248,211 cells/m^3 and the least abundant was during the dry months of March and April (Figure 2-A).

Diversity indices revealed that February and July was the most diverse month with a Shannon index value of 2.38 which corresponds to a more even distribution of 0.77 (Figure 2). The low species diversity was observed in the month of November when the low species richness was recorded. The high species richness was noted on the month of July with a value of 3.22 when the highest number of species was determined Figure 2-B.

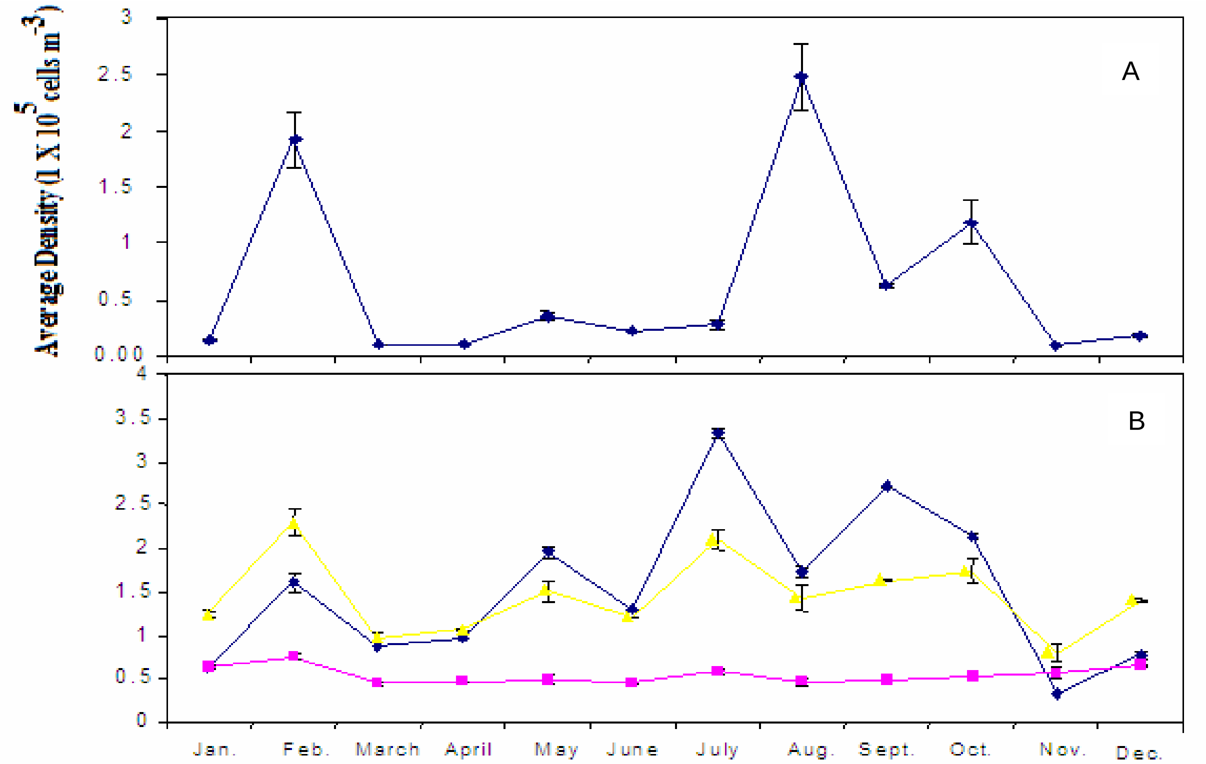

Figure 2. Average density of phytoplankton () and diversity indices of the monthly sampling for one year at station four (B). (Yellow triangle- Shannon Diversity), (blue diamond-Margalef species richness Index), (Purple Square- Pielou's evenness index).

Results of the multidimensional scaling and similarity dendrogram showed clustering of the Northeast monsoon months (November, December, January, March and April) with assemblages showing 50% similarity (Figure 3). These months registered low density value, low species richness, evenness and diversity. The other cluster comprised the rest of the sampling months with higher density value, richness, evenness and diversity. Detrended Correspondence Analysis and Redundancy Analysis triplot is shown in (Figure 4). RDA explained 99.8% species-environment correlations in axis one. Monte Carlo simulation revealed statistical significance ($p<0.01$) for all canonical axes. Salinity, dissolved oxygen and phosphate were highly significant environmental factors ($P<0.05$). Concentration of phosphate level favored the growth and abundance of *Caloneis crassa, Triceratium revale, Ceratium dens* and *Trichodesmium theibauti* in the summer month of

May with the association of slightly warmer temperature, lower tide level and lower pH level. Conversely, slightly higher salinity value observed on February was highly significant for the increase abundance of diatoms (*Chaetoceros curvisetus, C. wailesii, Corethron hystrix, Chaetoceros decipiens, Chaetoceros affinis, Bacteriastrum elongatum, Rhizosolenia hebetata f. semispina*, *Skeletonema costatum*, *Ditylum brightwellii, Thalassionema nitzschioides*) and dinoflagellates (*Gonyaulax verior, Ceratium furca, Ceratium fusus, Peridinium pellucidum, Dinophysis caudata, Ceratium trichoceros,* and *Peridinium depressum*). However, the appearance of *Hemiaulus sinensis* and *Peridinium pentagonum* only in the month of September was related to the slightly higher concentration of dissolved oxygen level.

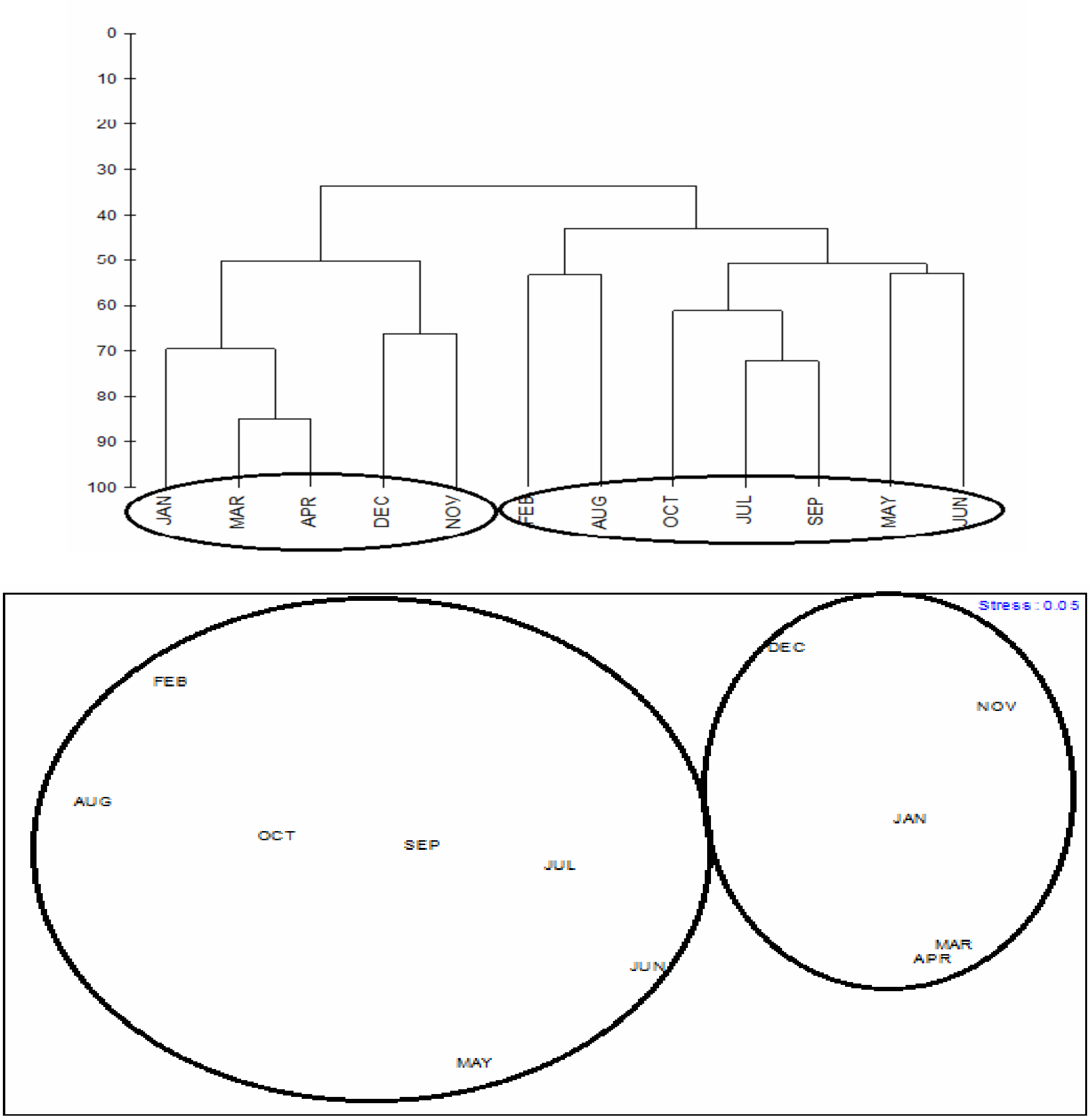

Figure 3. Bray-Curtis similarity dendrogram (A) and multidimensional scaling (B) during the monthly sampling for one year.

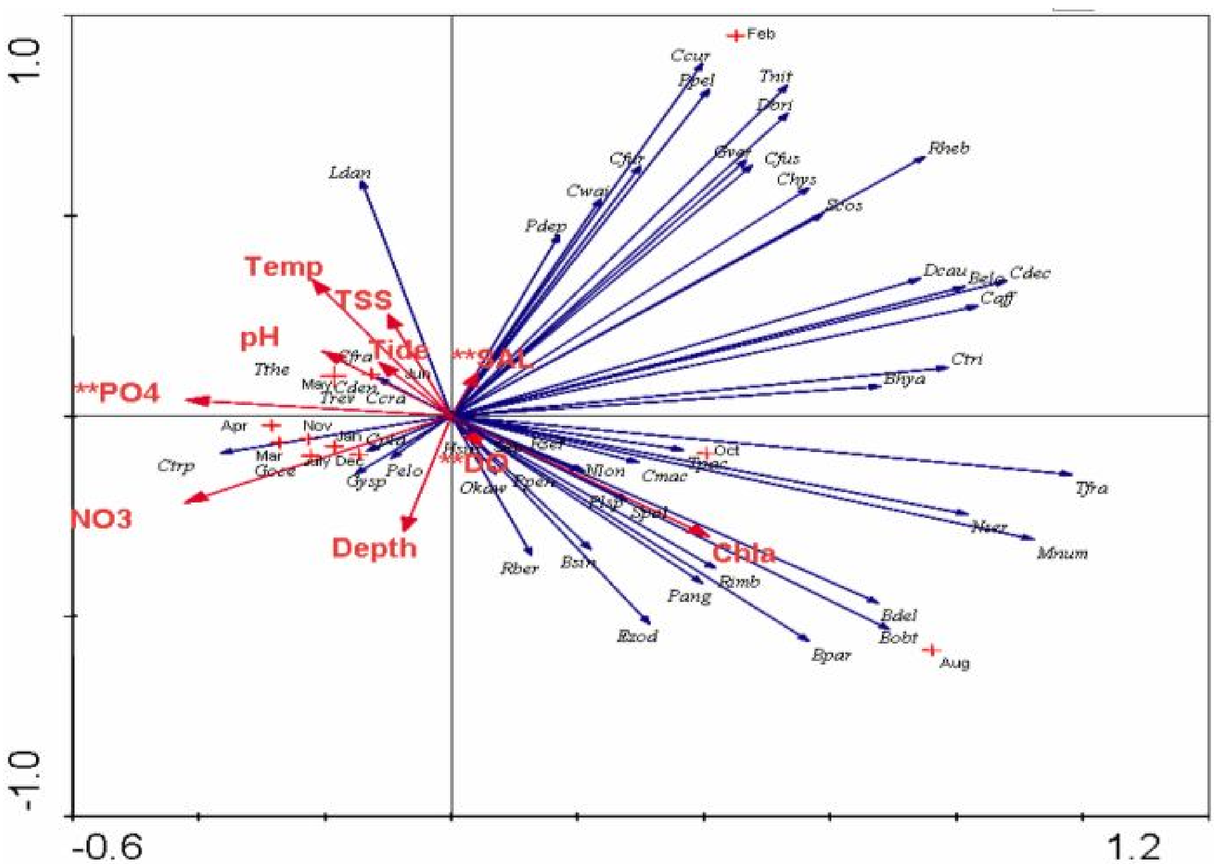

Figure 4. Canoco Redundancy Analysis (RDA) triplots of the relationship of environmental factors (red text with red arrows), abundance of different phytoplankton species (black text with blue arrows) during the monthly sampling (numbers with red cross) November 2008-October 2009. Legend: ** - highly significant; * - significant; Sal- salinity; Chl- Chlorophyll; Temp-temperature; TSS-total suspended solids. For species codes refer to Table 2 of this study.

Discussion

Monthly changes in the community structure of phytoplankton. Phytoplankton community structure in Panguil Bay, Philippines, showed temporal variations. In this study, net phytoplankton was recorded in decreasing order of abundance: diatoms > dinoflagellates > cyanobacteria. Diatom cells appeared as chain-forming, centric, zigzag colonies, elongated and solitary or united in a chain by spines. Some species were common in estuarine, marine, typical of tropical coastal waters, neritic and euryhaline brackish water (Boyer 1927; Hasle et al 1996; Amato et al 2007).

The centric diatom *C. wailesii* was the dominant species except for the months of February, August and October when the chain-forming *T. frauenfeldi, M. nummuloides* and *T. nitzschioides* became dominant. These species were cosmopolitan in coastal waters, estuarine and euryhaline (Boyer 1927; Rick & Durselen 1995; Çinar et al 2014). This characteristic might help them to place at a competitive advantage over other species during these wet months. The findings could indicate that Panguil Bay environment is subjected to temporal variability, with the recurrent restructuring of phytoplankton species composition and relative abundance, as an effect of interaction between chemical, physical, and biological variables. The water current system and circulation pattern in Panguil Bay were mainly influenced by tidal forcing and, to some extent, by strong seasonal monsoon winds (Gorospe & Prado 1992; Canini et al 2013). The reasons of these sequences have been explicated by both the equilibrium approach (which permits the coexistence of species limited by different resources), and the non-equilibrium approach (which takes the frequency of environmental variability, permitting species that share the similar resources to coexist) (Stachowicz et al 2002; Carpenter & Brock 2006).

The highest phytoplankton abundance was recorded during the southwest monsoon of August which also recorded the highest chlorophyll value and quite the opposite for the dry months of March and April. This may be attributed to the high influx of nutrient during the wet season than in dry season that favored the growth of phytoplankters (Prado & Parcia 1992). The abundance of phytoplankton in the wet months could be attributed to the rich organic load from sewage and domestic waste brought about by heavy rains (Arimoro et al 2008) which could be indicative of high nutrients supplied in the area. Fixed nitrogen (largely nitrate) is frequently the limiting primary production in the marine food chain (Smith 1982; Zehr & Ward 2002). In the wet season, when the gradients of temperature split the system vertically, spill and turbine effects act discretely on the stored volume. While spills eradicate excess volume from the surface, the turbines cause a discharge of deep waters, which are denser and richer in nutrients (Korhonen et al 2010). This reservoir does not develop persistent thermal stratification. During this rainy season the higher Brunt–Väisälä frequencies occurred.

It is revealed in this study that the community assemblage of phytoplankton in Panguil Bay formed two discrete clusters. The sampling months that recorded higher abundance, diversity, evenness and richness were distinctly and uniquely separated to those months with lower abundance, diversity, evenness and richness. The clustering might suggest the influence of physicochemical parameters which are frequently the limiting factors for the growth of phytoplankton species (Smith 1982; Zehr & Ward 2002). It is also inferred that monsoonal winds greatly influenced the community assemblage of phytoplankton in the Bay (Canini et al 2013).

Since the sampling area is situated near the seaport of Ozamiz City and relatively near the mouth portion of the Bay which is connected with the bigger Iligan Bay, it can be deduced that the constant exchange with marine waters from Iligan Bay introduces new species to Panguil Bay mainly during the strong monsoonal winds that may greatly affect phytoplankton community structure. Cloern et al (2007) highlighted that phytoplankton floristic composition and productivity are also subjected to physical forcings such as horizontal exchange between the open sea and estuaries and vertical mixing regimes since their buoyant cells on the sea surface may easily conveyed by oceanic currents, prevailing winds and tides (Le Fevre & Grall 1970; Schaumann et al 1988; Huang & Qi 1997).

Fortes & Pinosa (2007) emphasized that the physicochemical changes in the environment could have influenced the phytoplankton generic composition. Lacuna et al (2012) also stressed that the physicochemical factors of the water are significant on the phytoplankton community structure. It was documented in this study that the intermonsoon month of May, phosphate concentration is highly significant and favored the growth and abundance of *C. crassa*, *T. revale*, *C. dens* and *T. theibauti* with the association of slightly warmer temperature, lower tide level and lower pH level. Phosphates belong to a group of nutrient substances which are often the limiting factor in the process of photosynthesis. During vegetative periods, the phosphates are used up rapidly by aqueous plant organism, mainly phytoplankton, thus affecting their community assemblage (Prado & Parcia 1992). Temporal changes in phosphate concentration levels could be attributed to the circulation pattern of the bay which is mainly governed by the seasonally reversing monsoon winds. It has been reported that the distribution and succession of phytoplankton in the global ocean are influenced by seasonal variation (Twomey & John 2001).

Conversely, slightly higher salinity values observed in February was highly significant for the increase abundance of many diatoms while dissolved oxygen recorded during the month of September favored the growth of *H. sinensis* and *P. pentagonum* which only appeared during this month. This result could indicate that these parameters are crucial for the metabolic activity of these unique species.

In Panguil Bay, tidal flushing influences physical, chemical, and biological conditions in the estuary and during flood tide, coastal plankton may be carried into the estuary promoting species composition variability (Hodel & Menezes 2000). The freshwater flow and tidal activity play crucial roles in phytoplankton growth and abundance in an estuary (Cloern 1996). Lucas & Cloern (2002) stressed that the tidal range changes in water surface elevation could define whether long-term phytoplankton growth is negative or positive, causing in significantly various phytoplankton dynamics. In general, studies on phytoplankton community dynamics consider the physical unpredictability of the water column to be the primary factor controlling species composition changes.

Conclusions. This study successfully describes the temporal changes in the community structure of phytoplankton in Panguil Bay in relation to a number of environmental factors. The species community assemblage exhibited variability among sampling months. Two distinct clusters formed between species of higher and lower diversity, evenness and richness. This could be due to the influence and changes in the physical and chemical parameters of the area. Salinity, dissolved oxygen and phosphate level were highly significant environmental factors that contribute to the variability in temporal species assemblages and composition of phytoplankton. Although results obtained from this study were explanatory, it is recommended that concerned authorities (local governments units of the three provinces) have to conduct systematic and continuous long term monitoring of phytoplankton in Panguil Bay employing the baywide horizontal sampling. This may serves as important basis in determining the crucial changes or possible problems that may arise in this marine ecosystem.

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