AACL BIOFLUX
Aquaculture, Aquarium, Conservation & Legislation
International Journal of the Bioflux Society

Diversity and abundance of phytoplankton in Casiguran waters, Aurora Province, Central Luzon, Northern Philippines

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Abstract. Phytoplankton composition, diversity, abundance and their relation with the physico-chemical parameters of the waters during high and low tides in the thirteen sampling stations in Casiguran Sound and Bay, Aurora Province, Philippines were compared. A total of 115 species belonging to four major groups (Bacilariopphyceae, Dinophyceae, Dictyochophyceae, and Cyanophyceae) were identified, with the Bacilariopphyceae or commonly known as diatoms being the chief component of the phytoplankton. Using several diversity indices, results showed no differences in the phytoplankton species between Casiguran sound and bay during the two tidal cycles. Likewise, the results of NPMANOVA revealed no significant differences ($p>0.05$) in phytoplankton relative abundance between and within sampling stations between and during high and low tides. The results may imply that the level of phytoplankton diversity and abundance did not fluctuate with changes in the tide levels and that phytoplankton species were thus uniformly distributed in the waters of Casiguran. It is suggested that the alteration of high and low tides accompanied by intense horizontal and vertical mixing which are apparent during spring tide may have influence the uniform distribution of phytoplankton. Since results of the study reflect the importance of physical as well as chemical factors of the water on the phytoplankton community structure, the present records are essentially vital in order to assess further the relationship between environmental conditions of the water and the organisms and to evaluate future development towards conservation and management in the said areas.

Key Words: Phytoplankton diversity and abundance, high and low tide, Casiguran waters, Philippines.

Introduction. Phytoplanktons, an assemblage of heterogenous microscopic algal forms, are situated at the lowest level of production and correspond with the most important part of the primary production of the oceans (Kudela & Peterson 2009). They influence the concentration of dissolved oxygen and light penetration in our marine environment. Aside from their vital role in the aquatic food webs, phytoplankton community also acts as indicators of water quality (Abuzer & Okan 2007) by providing information concerning the ecosystem condition or health. Among the phytoplankton groups, the bacillariophyceaen members can specifically be used as suitable bio-indicators for water quality assessments as they have short generation time and many species have a specific sensitivity to ecological characteristics (Stevenson & Pan 1999; Goma et al 2005; Salomoni et al 2006).

Phytoplankton species composition, biomass, distribution and abundance are often affected by environmental temperature (Harris 1986), light, nutrient availability (Kennish 2001; Paula et al 1998), and the physical and hydrographic properties of the area or environment such as tidal stirring (Cebrian & Valiela 1999), tide and water movements (Balch 1981; Demers et al 1986). In particular, tides are basically responsible for the mid-term spring-neap cycles and short-term low-high water cycles in many coastal systems. In fact, changes in the tides resulted to variations in biotic and abiotic characteristics of estuarine and marine ecosystems. Several studies on tidal influenced and control of phytoplankton communities showed the importance of tidal currents in the transport of new species from surrounding areas into the estuary (Sodre et al 2011) leading to their high diversity. Hsiao (1992) reported that the tides had a double beneficial effect that is they not only flush in water masses from nearby areas during flooding or high tide but also generates an upward mixing particularly when ebbing or low tide. Therefore, understanding the role they play and the factors that influence their growth form a critical step in learning how to manage our marine environment for sustainable healthy ecosystems.

Despite the vital role these phytoplankton communities occupy in the aquatic food chains and their function as bio-indicators for water quality assessment, their composition, diversity and abundance in the waters of Casiguran, Aurora Province are still poorly known. To address this issue, this study was carried out during high and low tides in order to investigate (1) the composition, diversity and abundance of phytoplankton, (2) to get a general view of the physico-chemical condition of the water and then (3) correlate the physico-chemical parameters of the water to the phytoplankton diversity and abundance. It is hoped that the data generated from this study will represent as baseline information needed for monitoring future effects caused by both natural and anthropogenic activities in the bay.

Material and Method. The Casiguran waters, namely Casiguran Sound and Bay, in Aurora Province is nearly enclosed by the Sierra Madre mountain range and the 12,000 hectare San Ildefonso Peninsula where it provides protection from the typhoons that seasonally ravage most of the province. The Sound and Bay stretches to around a kilometer-wide where it connects itself to the sea. Due to its natural protective spot, the bay area of Casiguran was selected as the country's future first economic zone (or Ecozone and later on as APECO) in the Pacific Coast. The Ecozone or APECO is a custom designed seaport and airport driven economic center which seeks to promote tourism and rake in investments in aquamarine, agro-industrial, commercial trading, banking, outsourcing and financial industries. It aims to boost social, economic and industrial developments in Aurora and nearby provinces by generating jobs for the people, improving the quality of their living conditions, advocating an eco-friendly approach to industrialization and enhancing the potential of the community in productivity (http://www.edangara.com/apeco/). A total of thirteen sampling stations were positioned in the waters of Casiguran (Figure 1) using a GPS (GPS map 76S, Garmin). Stations 1-7 were strategically established in Casiguran Sound while, stations 8-13 at Casiguran Bay. The areas have typical semidiurnal tides with high and low waters in a lunar day of 24 hours. All hydrographic data and phytoplankton samples were collected in each of these stations at high and low tides during spring tide in July 23-25, 2012. Hydrographic data, namely surface water temperature, pH, salinity, and dissolved oxygen, were measured *in situ* using the Oxical DO meter while salinity was estimated with the aid of a handheld refractometer (Atago, Japan). For total suspended solids, the gravitational filtration method was adopted. For nutrient analysis, surface water samples were collected in a pre-acid washed polyethylene bottles and stored in an ice box for transport to the laboratory. The water samples were analyzed for inorganic nitrates and phosphates using an auto analyzer. Surface phytoplankton samples were collected in each of the 13 stations using an 8 L bucket. Eighty liters of surface water were collected and were then filtered through a 50 µm mesh plankton net. The filtered sample was immediately transferred into a properly labeled polyethylene bottle and preserved in a 20 % neutralized formaldehyde solution. Two ml of the 20 % neutralized solution were added for every 100 ml phytoplankton samples collected (Sukhanova 1978). Triplicate samples were collected in each sampling station. Representative of each identified phytoplankton was individually transferred into a vial half-filled with 20 % neutralized formaldehyde solution for photodocumentation and measurement. For phytoplankton counting, the volume of the whole phytoplankton sample representing each station collected was measured and recorded. Since the sample collected was not rich with phytoplankton, the whole sample was further filtered through a 30 µm mesh net sieve and the concentrate (10 ml) was then washed into a small beaker. The whole 10 ml concentrate was used for quantitative analysis.

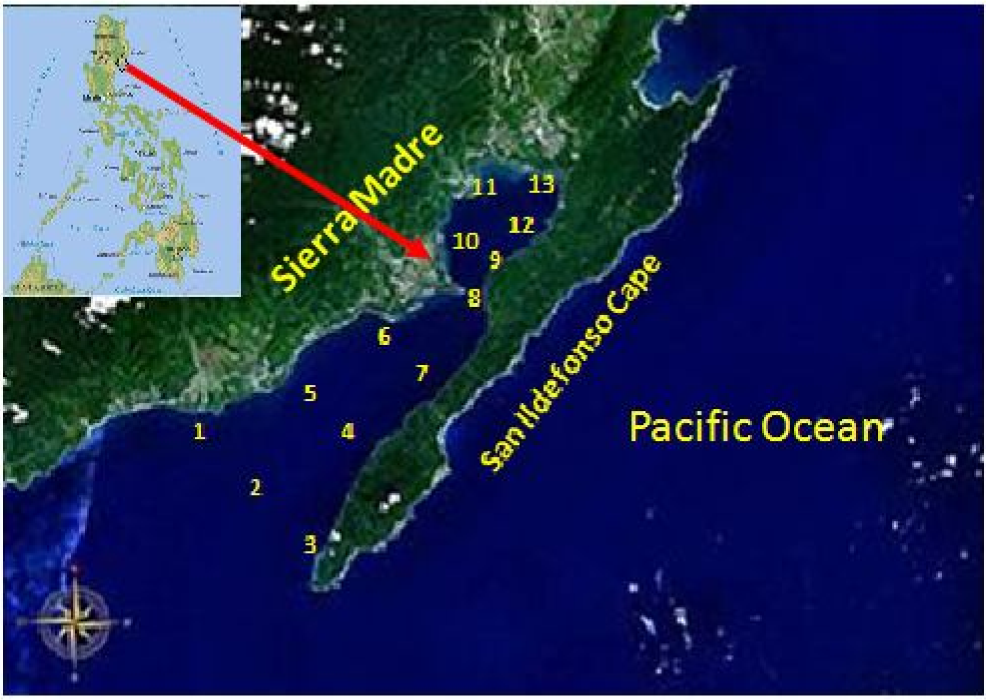

Figure 1. Geographical location of the thirteen sampling stations where phytoplankton samples were collected. Inset is Casiguran enclosed in a diamond.

For numerical counting of the phytoplankton samples, a Sedgewick-Rafter counting chamber cell was used and the strip counting method was adopted. The total number of phytoplankton cells per liter of water was then computed. Relative abundance of phytoplankton species was based on cell density derived from the numerical counting of the phytoplankton sample. The phytoplankton individuals were identified to the nearest taxa possible using the standard works of Cupp (1943), Yamaji (1962), Marshall (1986), Thomas (1997), Garcia & Odebretch (2008) and Al-Kandari et al (2009).

Diversity indices were computed using Shannon-Weaner Index, Margalef Index and Menhinick index. Cluster analysis was used to deternine the major groupings of phtyoplantkon present between the thirteen sites between high and low tides. Canonical Correspondence Analysis (CCA) was employed to determine the physico-chemical parameters that influenced the relative abundance of phytoplankton during high and low tides. Non-Parametric Multivariate Analyses of Variance (NPMANOVA) was used to determine the differences in phytoplankton relative abundance between sites, within sites and between two tidal cycles. All statistical analyses were done using the software PAST version 2.17 (http://folk.uio.no/ohammer/past/) (Hammer et al 2001).

Results and Discussion. A total of 115 phytoplankton species belonging to four major groups (Bacillariophyceae: 72 species, Dinophyceae: 41 species, Dictyochophyceae: 1 species, and Cyanophyceae: 1 species) were identified in the waters of Casiguran, Aurora Province (Table 1), with more species occurring during high tide (112) when compared to low tide (108). Majority of these identified species during the two tidal cycles were noted in Casiguran Sound (stations 1-7), with 103 and 99 species for high and low tides, respectively. Among the four groups categorized, the diatoms (Bacillariophyceae) were the chief components of the phytoplankton recorded in the Casiguran waters during the two tide cycles with centric diatoms (46 species) dominating when compared to the pennate diatoms (26 species). Moreover, the largest number of species observed were from *Chaetoceros* (10 species), *Pleurosigma* (7 species), *Coscinodiscus* and *Hemialus* (4 species), *Bacteriastrum* and *Nitzchia* (3 species). Although, majority of these diatoms are pelagic, there are some species that are benthic (as indicated by an asterisk in Table 1) in its mode of existence. In the marine environments, especially in nutrient-rich nearshore and well-mixed waters, small-sized diatoms are the dominant groups in phytoplankton communities (Pingree et al 1978; Levasseur et al 1984; Valiela 1984), whereas dinoflagellates are more abundant at fronts between well-mixed waters and more stable offshore waters (Holligan 1978).

Table 1

Composition and species richness of phytoplankton species in Casiguran Sound and Bay during high and low tides

Phytoplankton species	*High tide*		*Low tide*	
	CS	*CB*	*CS*	*CB*
Bacillariophyceae (Diatoms)				
Centric Diatoms				
Asterolampra marylandica	+	+	+	+
Asteromphalus hookeri	+	+	+	-
Bacteriastrum delicatulum	+	+	+	+
Bacteriastrum elongatum	+	+	+	+
Bacteriastrum hyalinum	+	+	+	+
Odontella auritia	+	-	+	+
Odontella mobiliensis	+	-	-	+
Chaetoceros affinis	+	+	+	+
Chaetoceros coarctatus	+	+	+	+
Chaetoceros compressus	+	+	+	+
Chaetoceros curvisetus	+	+	+	+
Chaetoceros decipiens	+	+	+	+
Chaetoceros didymus	+	+	+	+
Chaetoceros diversus	+	+	+	+
Chaetoceros laeve	-	-	+	+
Chaetoceros lorenzianus	+	+	+	-
Chaetoceros peruvianus	+	+	+	+
Climacodium frauenfeldianum	+	-	-	-
Climacosphenia moniligera	+	-	-	-
Coscinodiscus granii	+	+	+	+
*Coscinodiscus oculus-iridis**	+	+	+	+
*Coscinodiscus radiatus**	+	+	+	+
Coscinodiscus wailiesii	+	+	+	+
Dactyliosolen antarticus	+	-	-	-
Ethmodiscus gazellae	-	-	+	-
Guinardia striata	+	-	+	-
Hemiaulus hauckii	+	+	+	+
Hemiaulus indicus	+	+	+	+
Hemiaulus membranaceus	+	-	+	+
Hemiaulus sinensis	+	+	+	+
Podosira stelligera	+	+	+	+
Lauderia annulata	+	-	+	-
Leptocylindrus danicus	-	+	+	-

Phytoplankton species	*High tide*		*Low tide*	
	CS	*CB*	*CS*	*CB*
Bacillariophyceae (Diatoms)				
Centric Diatoms				
Paralia sulcata	+	-	+	+
*Paralia sulcata**	+	-	+	-
Pseudosolenia calcar-avis	+	+	+	+
Proboscia alata	+	+	+	+
Rhizosolenia bergonii	+	+	+	+
Rhizosolenia castracanei	+	+	+	+
Guinardia cylindrus	+	+	+	-
Rhizosolenia setigera	+	+	+	+
Rhizosolenia styliformis	+	+	+	+
Stephanopyxis palmeriana	+	-	+	-
*Thalassiosira eccentric**	+	-	+	-
Shionodiscus oestrupii *	+	+	+	+
Pennate Diatoms				
Amphora hyalina	+	+	+	+
*Amphora proteus**	+	+	+	+
*Bacillaria paxillifera**	+	-	-	+
*Bacillaria socialis**	+	-	+	-
Caloneis westii	+	+	+	+
*Diploneis litoralis**	+	+	-	+
*Diploneis weissflogii**	+	+	+	+
Fragilaria striatula	+	-	-	-
*Grammatophora marina**	-	+	+	+
Mastogloia cf Arabica	-	+	+	+
Mastogloia minuta	+	+	+	+
*Navicula cancellata**	+	+	-	+
Nitzschia acuminata	-	+	-	+
*Nitzschia longissima**	+	+	+	+
Pseudo-nitzschia seriata	+	+	+	+
Plagiodiscus nervatus	-	-	+	-
*Plagiotropis lepidoptera**	+	+	+	+
*Pleuorosigma elongatum**	+	+	+	+
*Pleurosigma normanni**	+	+	+	+
*Pleurosigma angulatum**	+	+	+	+
*Pleurosigma strigosum**	+	+	+	+
Pleurosigma formosum	+	+	-	+
*Pleurosigma intermedium**	-	+	+	+
Carinasigma rectum	+	-	-	+
Pseudo-nitzschia multiseries	-	+	-	-
Thalassionema frauenfeldi	-	+	-	+
*Thalassionema nitzschioides**	+	+	+	+

Phytoplankton species	High tide		Low tide	
	CS	CB	CS	CB
Dinophyceae (Dinoflagellates)				
Neoceratium breve	+	+	+	+
Neoeratium candelabrum	+	+	+	+
Neoceratium furca	+	+	+	+
Neoceratium fusus	+	+	+	+
Neoceratium macroceros	+	+	+	+
Ceratium massiliense	+	+	+	+
Neoceratium teres	+	+	+	+
Neoceratium trichoceros	+	+	+	+
Neoceratium tripos	+	+	+	+
Ceratocorys horrida	+	+	+	+
Phalacroma doryphorum	+	-	+	-
Dinophysis caudata	+	+	+	+
Dinophysis miles	+	+	+	+
Phalacroma mitra	+	+	+	+
Dinophysis punctata	+	+	-	-
Phalacroma rapa	+	-	+	-
Phalacroma rotundatum	+	+	+	+
Dinophysis schuettii	+	+	-	-
Diplopsalis lenticula	+	-	+	+
Heterocapsa triquetra	+	+	+	+
Ornithocercus steinii	+	+	+	+
Ornithocercus thumii	+	+	+	+
Oxytoxum scolopax	+	+	+	+
Protoperidinium abei	+	+	+	+
Protoperidinium cerasus	+	+	+	+
Protoperidinium conicum	-	+	+	+
Protoperidinium divergens	+	+	+	+
Protoperidinium inflatum	+	+	+	+
Protoperidinium majus	+	+	+	+
Protoperidinium oceanicum	+	+	+	+
Protoperidinium pentagonum	+	+	+	+
Protoperidinium rectum	+	+	+	+
Podolampas bipes	+	+	+	+
Podolampas spinifera	+	+	+	+
Prorocentrum micans	+	+	+	+
Protoperidinium solidicorne	+	+	+	+
Pyrocystis lunula	-	+	+	-
Pyrocystis obtusa	+	-	-	-
Pyrodinium bahamense	+	+	+	+
Pyrophacus horologicum	+	+	+	+

Phytoplankton species	*High tide*		*Low tide*	
	CS	*CB*	*CS*	*CB*
Dinophyceae (Dinoflagellates)				
Pyrophacus steinii	+	+	+	+
Dictyochophyceae				
Dictyocha fibula	+	+	+	+
Cyanophyceae (Blue-green)				
Trichodesmium sp.	+	+	+	+
Total number of species	103	92	99	92
Grand Total number of species	112 (HT)		108 (LT)	

Legend: + present; - absent; *benthic diatoms; HT - High tide; LT - Low tide; CS - Casiguran Sound (stations 1-7); CB - Casiguran Bay (stations 8-13).

The level of the diversity of phytoplankton in Casiguran waters between high and low tides is shown in Table 2. It can be seen from the results that difference in the number of taxa was minimal, having only a difference of four taxa between the two tidal cycles which favors that in high tide.

Table 2

Diversity profiles of Casiguran sound and bay during high and low tides

Diversity Index	*Tide*	
	High	*Low*
Taxa (S)	112	108
Individuals	46139	44482
Dominance (D)	0.07974	0.07924
Simpson (1-D)	0.9203	0.9208
Shannon (H)	3.06	3.06
Evenness (e^H/S)	0.1905	0.1976
Brillouin	3.053	3.054
Menhinick	0.5214	0.5121
Margalef	10.34	9.997
Equitability (J)	0.6485	0.6537
Fisher_alpha	13.8	13.31
Berger-Parker	0.1622	0.1491
Chao-1	112.8	118

Results further revealed no difference in the diversity of phytoplankton species between the two tidal cycles as reflected in the Shannon-Weaver (H), where both have high species diversity values of 3.06. According to Margalef (1978) diversity of phytoplankton was usually between 1 and 2.5 in coastal waters, 3.5 to 4.5 in the oceanic areas and 5 in open tropical oceanic environments where phytoplanktons have low productivity but large number of species. In the case of Casiguran waters, the values recorded are in between those reported for coastal and oceanic areas. It is noteworthy that Casiguran is facing the Eastern Pacific Ocean with only San Ildefonso Cape separating between them (Figure 1). Our result further showed that the level of phytoplankton diversity were the same and therefore did not fluctuate with changes in the tide levels. This would mean that phytoplankton species were thus uniformly distributed by the alteration of high and low tides accompanied by intense horizontal and vertical mixing which are apparent during spring tide. It is suggested that the uniformity in the distribution as well as the high species diversity of phytoplankton might be brought about by the horizontal displacement and mixing of water masses from the pacific ocean into the Casiguran waters, namely Casiguran Sound and Bay, and by resuspension of bottom sediments caused by strong tidal mixing which occur during spring tide. Hsiao (1992) reported that the tides had a double beneficial effect. That is (1) they not only flush in water masses from nearby areas during flooding or high tide but (2) also generates an upward mixing particularly when ebbing or low tide. It has been reported by many authors that intense tidal stirring commonly occurred during spring tide where the turbulent tidal currents carry new and more phytoplankton species and resuspend benthic diatoms through horizontal transport and vertical mixing, respectively (Blauw et al 2012; Sodre et al 2011; Popovich & Marcovecchio 2008; Popovich et al 2008; Roncarti et al 2008; Hagy III et al 2005; Brunet & Lizon 2003; McQuoid & Nordberg 2003; Li & Smayda 2001; Muylaert & Sabbe 1999; De Jonge & Van Beusekom 1995; Cloern et al 1989). Conversely, during neap tide when there is only weak mixing and condition is calm, the phytoplankton sinks or settles on the bottom sediment and is often responsible for most of the phytoplanktons' low diversity and abundance. Hence, the high species diversity at high and low tides during spring tide observed in our study reflects the importance of the inflow of tidal currents both for the resuspension of benthic diatoms and for the transportation of new species from surrounding areas into Casiguran waters. Demers et al (1987) further observed that the alternating tidal cycles (high and low tides) that resulted to subsequent mixing of the waters are due to other mixing processes such as wind and convection. In addition, the intense tidal mixing during spring tide might not only resuspend the benthic diatoms in the sediments of Casiguran waters, but may have also replenish nutrients into the water column making the conditions more favorable to the growth and synthesis of centric diatoms (that have a predominantly planktonic and photoautotrophic mode of existence) (Demers et al 1987; Hsiao et al 1977; Turpin & Harrison 1979) and probably resulted to their dominance.

Relative abundance among the phytoplankton groups during high and low tides in the thirteen sampling stations (Casiguran Sound: stations 1 - 7 and Casiguran Bay: stations 8 - 13) showed the diatom group to be the most abundant (> 80 %) while the Dinophyceae, Dictyochophyceae and Cyanophyceae were low (< 23 %) (Figure 2).

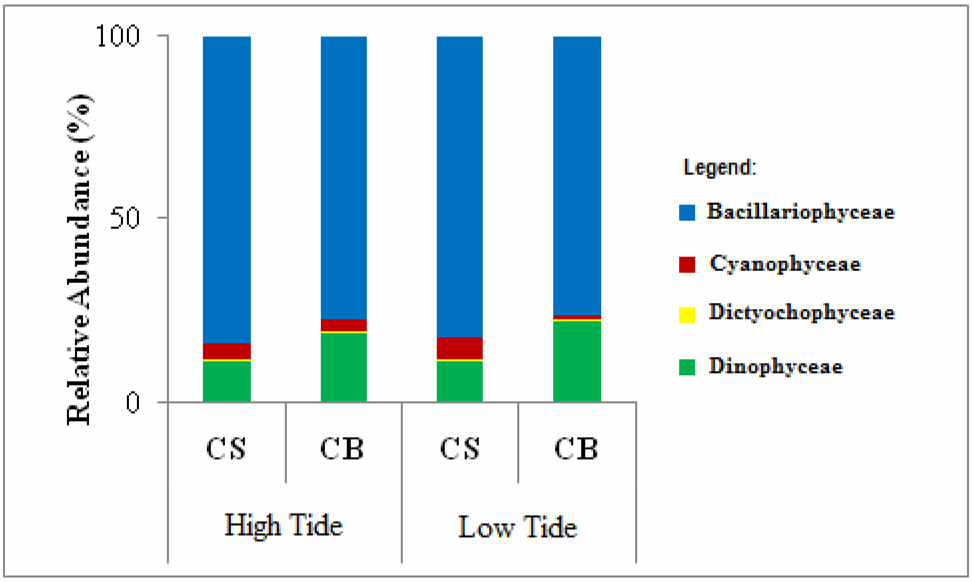

Figure 2. Relative Abundance (%) of phytoplankton groups during high and low tides in Casiguran sound and bay, Aurora Province, Philippines.

Among these diatoms (Figure 3), the following were the top 4 diatom species in the waters of Casiguran Sound during the two tidal cycles: *Chaetoceros decipiens* (11.14 %), *C. affinis* (18.43 %), *Bacteriastrum hyalinum* (15.35 %) and *B. elongatum* (9.99 %) dominated during high tide, while the appearance of *C. didymus* (10.90 %), *C. affinis* (17.06 %), *B. hyalinum* (17.21 %) and *Thalassionema nitzschioides* (12.08 %) were prevalent during low tide. In the waters of Casiguran Bay, high tide was observed to be dominated by the appearance of *C. affinis* (22.28 %), *B. delicatulum* (6.86 %), *B. hyalinum* (20.48 %) and *T. nitzschioides* (22.98 %) (Figure 3), while low tide was dominated by *C. didymus* (26.23 %), *C. affinis* (20.95 %), *B. hyalinum* (20.49 %), and *T. nitzschioides* (20.66 %). It seems that the chain-forming pelagic diatoms, such as *Chaetoceros* spp. (Figures 4a-c) and *Bacteriastrum* spp. (Figures 4d-f) which are attached with each other by mucilage threads and silicon setae, and the benthic diatom *T. nitzschioides* (Figures 4g) are affected by the turbulence and tidal mixing that are prevalent at high and low tides during spring tide. It has been observed that the effects of turbulence processes (resuspension and advection) on particle concentrations are related to the particle size and shape and the aggregation and disaggregation properties of the phytoplankton (Van De Kreeke et al 1997; Velegrakis et al 1997; Kiorboe et al 2001; Ellis et al 2004).

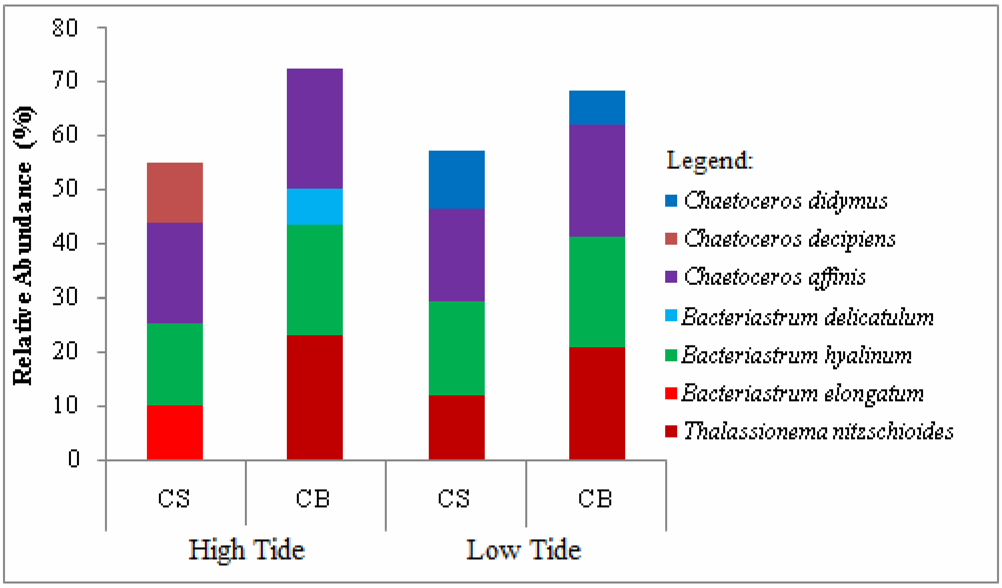

Figure 3. Relative abundance of the top 4 diatom genera during high and low tides in Casiguran sound and bay, Aurora Province, Philippines.

Diatoms with small sizes have large surface area and therefore they do not weigh very much and improving their bouyancy. The presence of setae and other bodily projections in diatoms further slow their sinking process by adding more surface area without increasing density. Our results revealed that these dominant diatoms are much smaller in size and have long setae making them more bouyant and float on the surface waters. Reports have also shown that diatom that aggregates is often much higher than for single cells, ranging from 50-150 m d^{-1} (Smetacek 1985; Alldredge & Gotschalk 1989; Burd & Jackson 2009). According to Bienfang et al (1982), single diatoms such as *Chaetoceros* sink at 0.5 m d^{-1}. Diatoms have passive movements, since they have a particulate nature and hence behave as passive particles, so that their concentration and distribution may depend on water displacement (Blauw et al 2012; Guinder et al 2009).

To compare the phytoplankton relative abundance between the thirteen sampling stations during and between high and low tides, NPMANOVA (Non-Parametric Multivariate Analysis of Variance) showed no significant differences (p>0.05). This would imply that phytoplankton relative abundance were the same among the thirteen stations and did not differ with changes in the tide levels as reflected in figures 5a-b.

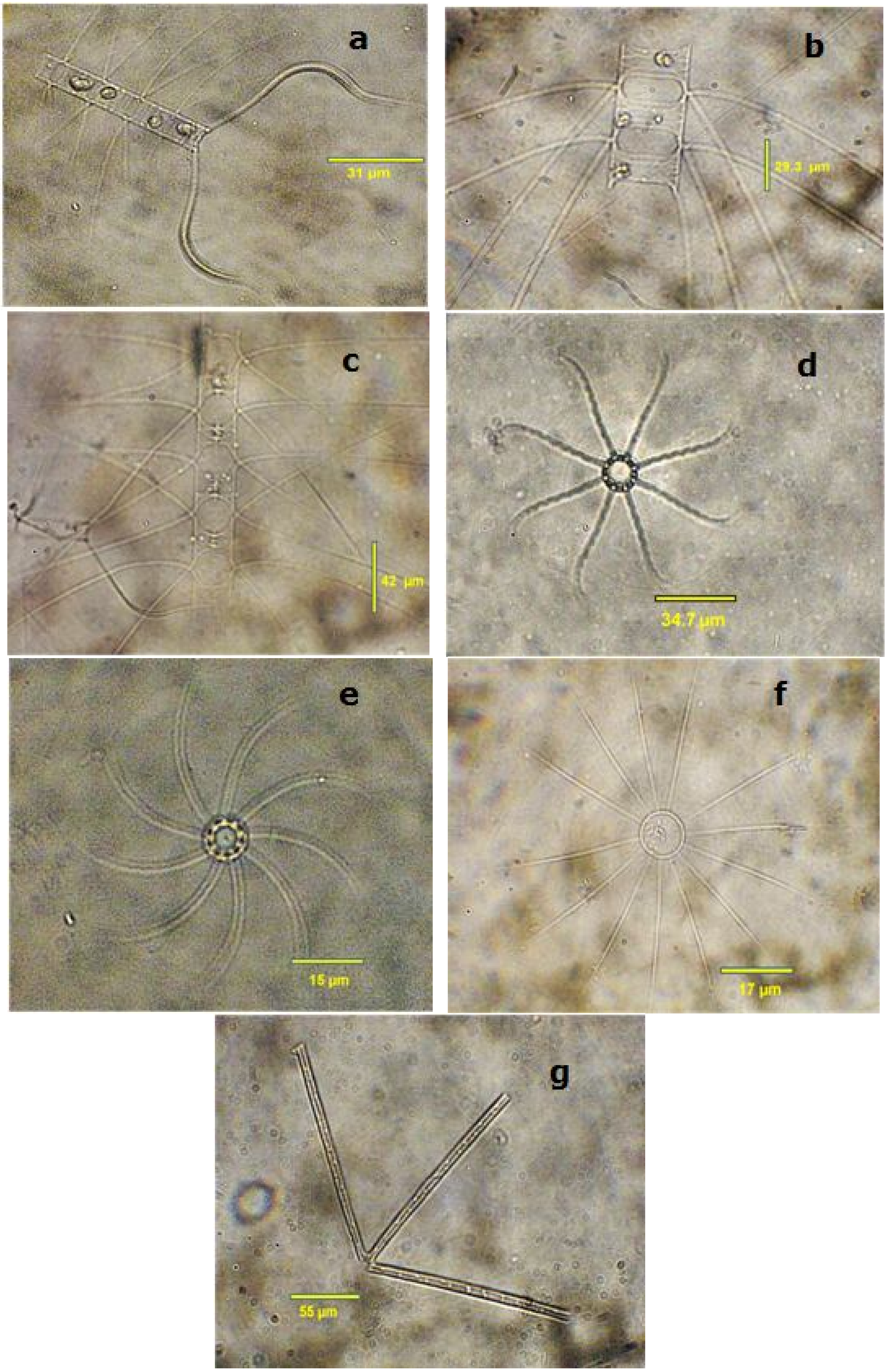

Figure 4. Images of (a) *Chaetoceros affinis*, (b) *C. decipiens*, (c) *C. didymus*, (d) *Bacteriastrum elongatum*, (e) *B. hyalinum*, (f) *B. delicatulum*, (g) *Thalassionema nitzchioides*.

This uniformity in the distribution among phytoplankton species on the surface waters might be due to the oscillations of high and low tides during spring tide that are often accompanied by intense horizontal and vertical mixing which were likewise the case in the species diversity as discussed above.

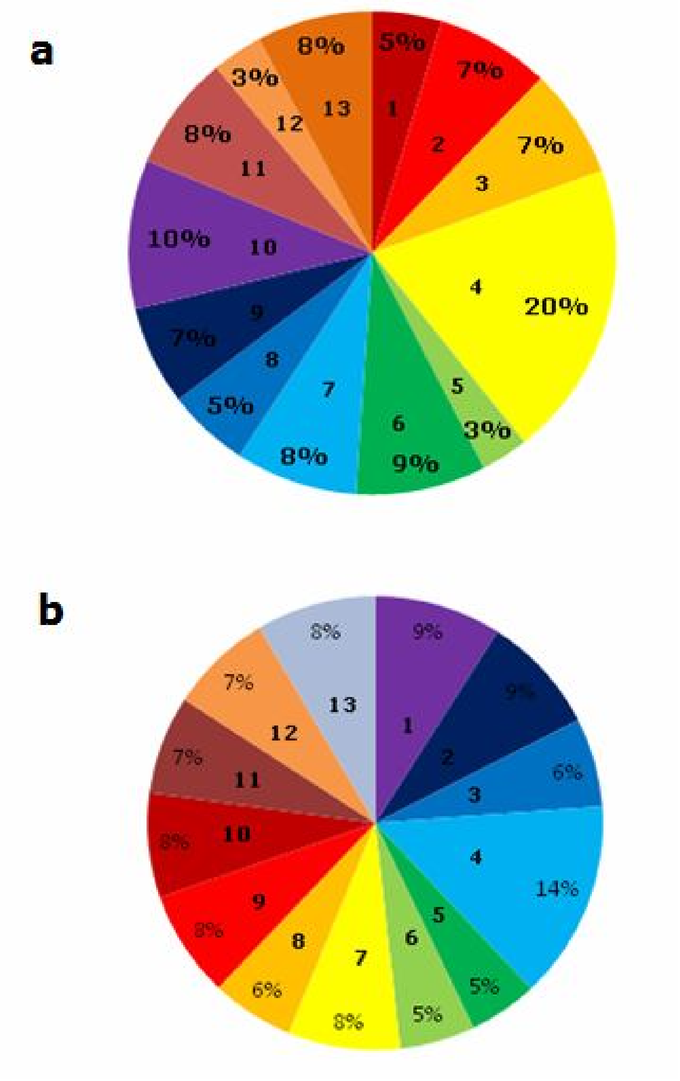

Figure 5. Total relative abundance (%) of phytoplankton in the 13 sampling stations during (a) high and (b) low tides in Casiguran waters, Aurora Province, Philippines.

The water quality parameters assessed in the thirteen sampling sites have shown variations (Figures 6a-f). For instance, the mean water temperature during high tide was highest in station 8 and lowest in station 1 with mean values of 30.23 °C and 28.03 °C, respectively (Figure 6a). During low tide, the mean water temperature was still high in station 8 and low in station 5 with mean values of 29.87 °C and 28.83 °C, respectively. Variations in the surface water temperatures among the stations were due to differences in light intensity since temperatures were measured at different times of the day. During high tide, surface water temperatures were taken around 8:30–8:45 in the morning and 12:05-12:20 at noon in stations 1 and 8, respectively. During low tide, these were measured late in the afternoon (4:28–4:42 pm in station 8 and 6:31–6:44 pm in station 5). For salinity values, high tide values were high in stations 1, 2, 3, 4, 5, 6, 7, 10 (35 ppt) but low in stations 8 and 13 (30 ppt) (Figure 6a). During low tide, salinity was highest in stations 1, 2, 3, 4, 5, 7, 8, 9 at 35 ppt and low in station 13 at 29 ppt. Low salinity values in station 13 might be attributed to inflow of freshwater from the four rivers present near the station resulting to dilution of the waters.

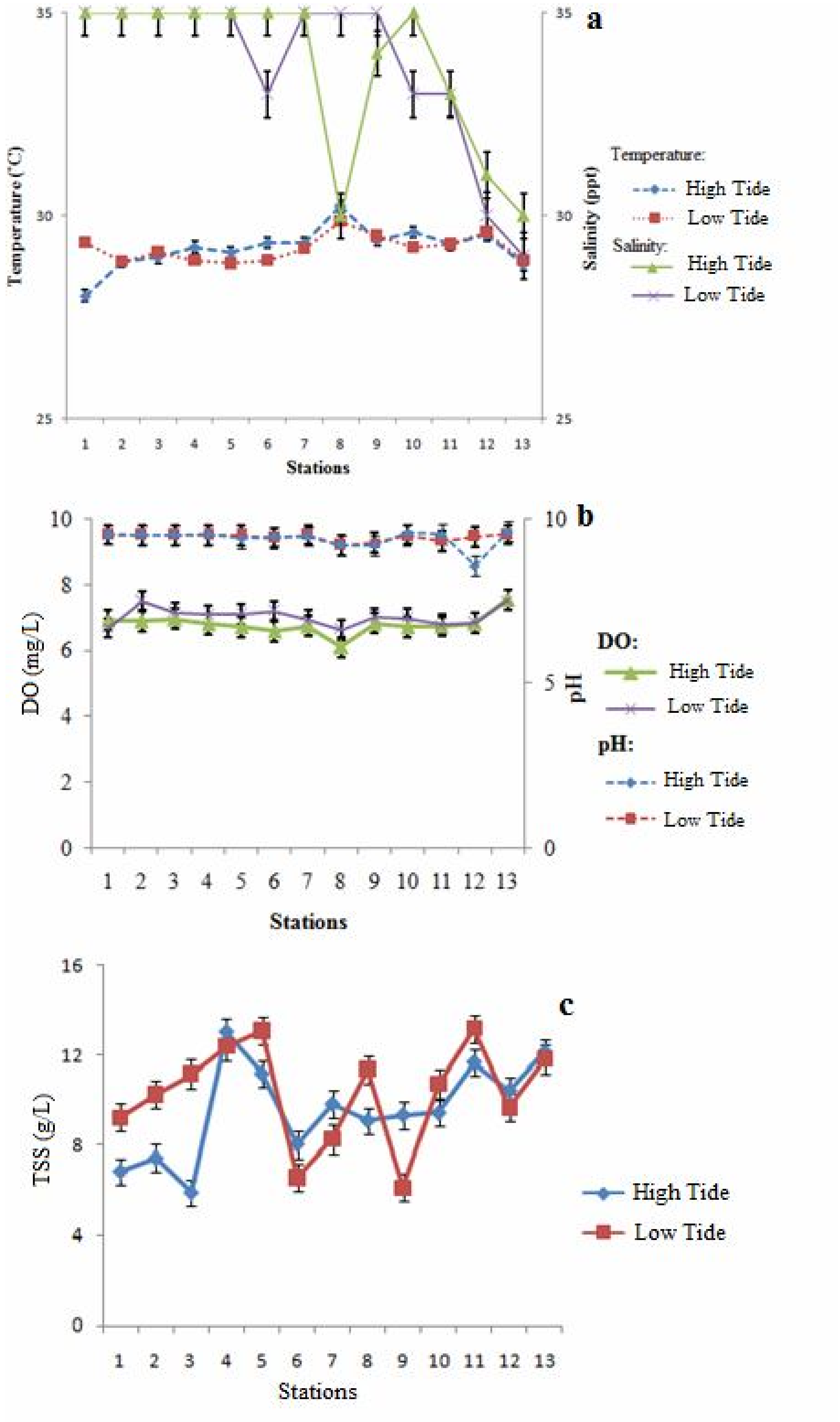

Figure 6. Mean values of (a) water temperature (°C), (b) DO (mg/L), and (c) TSS (g/L) in the thirteen sampling stations during high and low tides in Casiguran waters, Aurora Province, Philippines.

High values in salinity are expected in most of the stations that are located furthest from the inner bay due to the influence and mixing of more saline waters of the Pacific Ocean. High alkaline pH range values (8.33-9.63) have been recorded in all stations for both high and low waters (Figure 6b), much higher than the slightly alkaline seawater (pH 7.5-8.5). This may imply the influence of the intrusion of the waters of the neighboring Pacific Ocean which may contain high concentrations of calcium carbonate.

It has been reported that the alkaline pH values are almost always determined by the buffering effect of dissolved salts or seawater (Schmieglow 2004; Costa et al 2009) and from a high concentration of free CO_2, carbon-based mineral molecules suspended in the water, specifically calcium carbonate that comes from rocks like limestone or can be leached from calcite in the soil (George et al 2012).

Dissolved oxygen is the amount of oxygen dissolved in the water. It is an important constituent of water and its concentration is an indicator of prevailing water quality and ability of water body to support a well-balanced aquatic life (George et al 2012). Among the 13 stations, only stations 8 and 13 showed fluctuations in DO values during the two tidal cycles. High DO values were noted in station 13 (high tide: 7.54 mgL^{-1}; low tide: 7.53 mgL^{-1}), whereas low DO values were observed in station 8 (high tide: 6.10 mgL^{-1}; low tide: 6.63 mgL^{-1}) (Figure 6b). High DO values in station 13 might be due to the influence of freshwater runoff coming from the four nearby rivers that carries oxygen which may diffused from the atmosphere into these rivers.

Turbidity (total suspended solids) is a measure of the attentuation of light in the water column and can be caused by the light adsoprtion properties of the water, the number of planktonic organisms in the water, and with the amount of suspended particulate organic and inorganic matter (Parr et al 1998). It has been stressed out that suspended particulate matter is often the primary cause of turbidity of the water (Dawes 1981). TSS value (Figure 6c) during high tide waters was highest in station 4 (12.15 mgL^{-1}) but lowest in station 3 (5.90 mgL^{-1}). During low tide, stations 5 (12.93 mgL^{-1}) and 11 (13.07 mgL^{-1}) showed highest values, whereas lowest value was observed in station 9 (6.15 mgL^{-1}).

For the nutrient contents of the water, NO_3 values (Figure 7a) during high tide were high in station 2 (1.24 μM), while low value was noted in station 7 (0.08 μM). During low tide, high value was observed in station 9 (1.70 μM), whereas low NO_3 value was recorded in station 12 (0.11 μM). For NH_3 values (Figure 7b), during high tide waters, high mean value was apparent in station 2 (3.08 μM), while low in station 6 (0.37 μM). During low tide, high mean values were recorded in stations 5 and 6 (1.02 μM), while low NH_3 value was observed in station 11 (0.11 μM). For PO_4 (Figure 7c), during high tide, value was high in station 8 (2.64 μM) but low in station 11 (1.88 μM). During low tide, high mean value was recorded in station 5 (2.81 μM), while low NO_3 value was noted in station 11 (1.93 μM). Despite such differences reflected in Figures 6 and 7), the values for all surface water quality parameters in all thirteen sampling stations are within the range for any marine faunistic assemblage to thrive and be fairly abundant (DENR 1990).

In order to know if phytoplankton species and their abundances are similar between the thirteen sites during high and low tides, cluster analysis using Ward's method was employed. Results revealed two different or distinct clusters where the thirteen stations were separately grouped (Figure 8). In these two distinct clusters, the diagram showed similarities in the composition and abundance of phytoplankton species between stations 1, 4, 5, 6, 7, which belong to Group I, and between stations 2, 3, 8, 9, 10, 11, 12, 13 belonging to Group II, for both tides. It is interesting to note that stations 2 and 3 although both located within Casiguran Sound, did not cluster with the rest of the stations (1, 4, 5, 6, 7) in Casiguran Sound, but instead clustered together with all the stations that are located in the inner Casiguran Bay (8, 9, 10, 11, 12, 13). Casiguran waters in Aurora Province comprises of Casiguran Sound where stations 1-7 are established, which directly connects itself into the open sea or pacific ocean, and Casiguran Bay (stations 8-13), which is located in the innermost part of the area where it often receives freshwater runoffs from the nearby rivers.

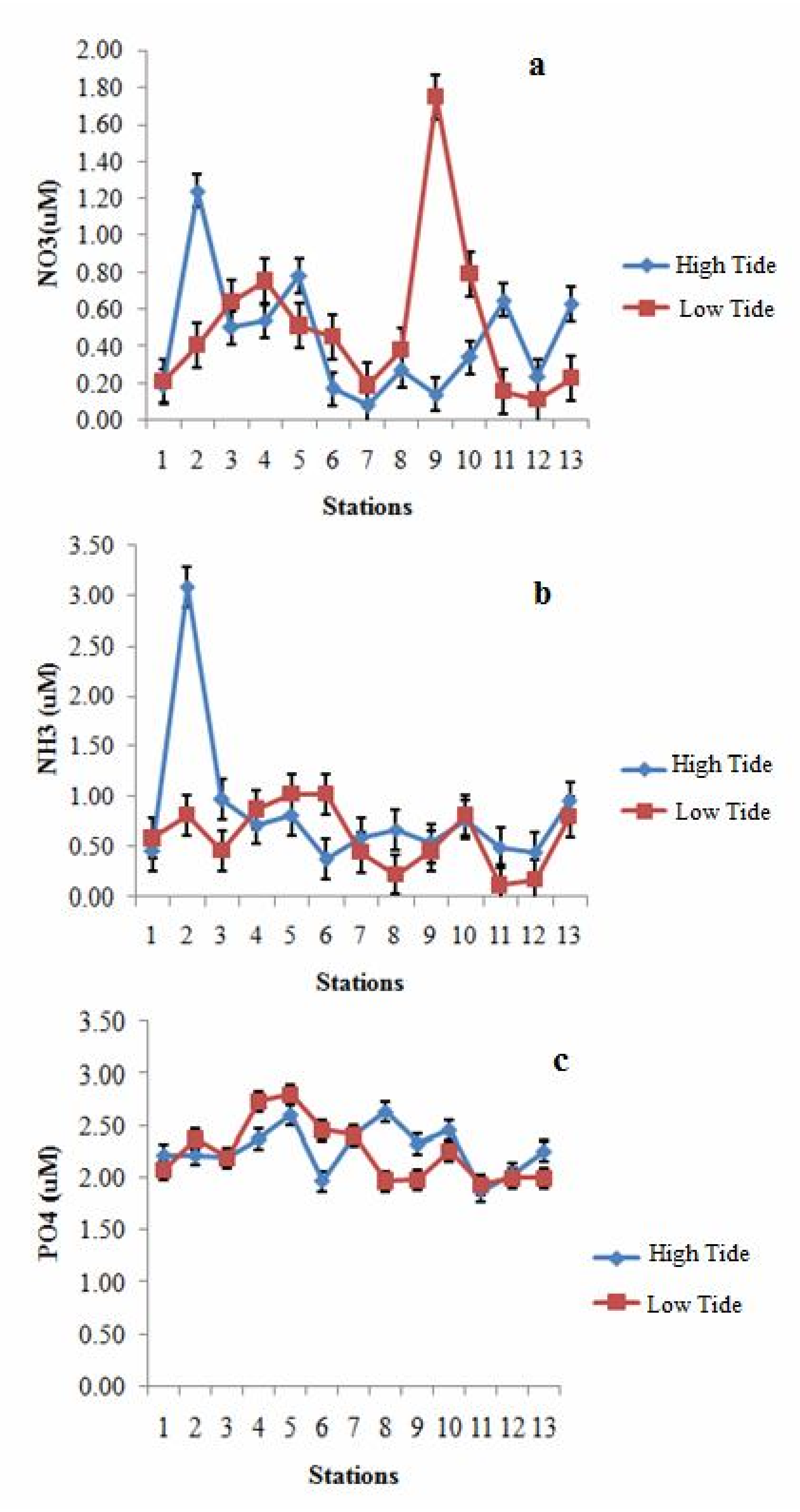

Figure 7. Mean values of (a) NO_3 (μM), (b) NH_3 (μM), and (c) PO_4 (μM) in the thirteen sampling stations during high and low tides in Casiguran waters, Aurora Province, Philippines.

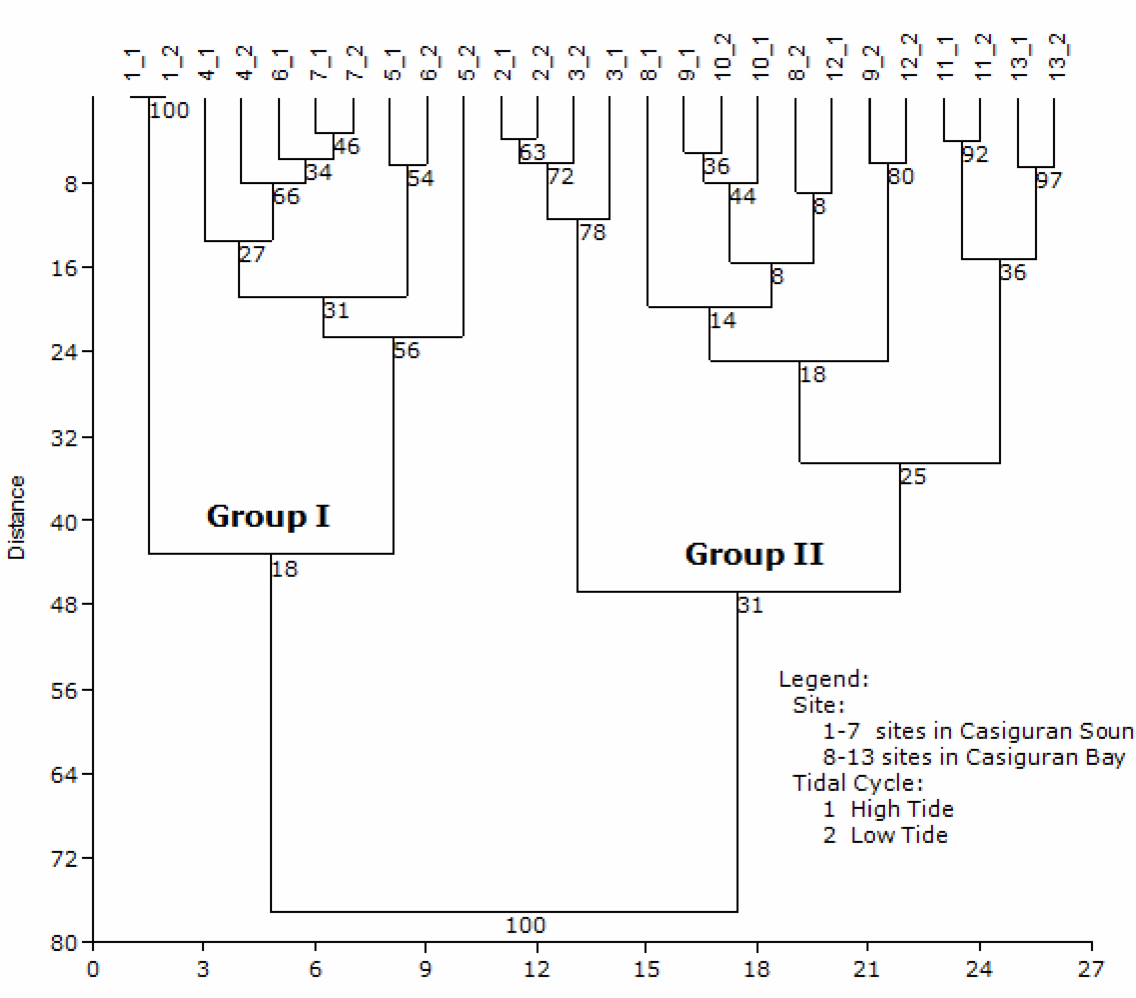

Figure 8. Cluster diagram showing similarities in the relative abundance of phytoplankton species between thirteen sites. The diagram was computed by Ward's method analysis using Euclidean distance measure (Boot N:100).

Our results implies that Group I, comprising stations 1, 4, 5, 6, 7, hosts species that are different in terms of composition and abundance from those that were recorded in Group II, comprising of stations 2, 3, 8, 9, 10, 11, 12, 13. For instance, data shows that *Bacteriastrum elongatum* (8.01 %), *Chaetoceros decipiens* (9.85 %) and *C. didymus* (6.98 %) were the most abundant phytoplankton species in Group I, whereas *B. delicatum* (5.47 %), *B. hyalinum* (16.09 %), *C. affinis* (17.36 %), *C. compressus* (3.76 %), *C. diversus* (3.25 %), *Thalassionema nitzschoides* (14.13 %), *Neoceratium fusus* (4.50 %) and *Trichodesmium* sp. (4.28 %) were the dominant species in Group II. Moreover, among the 115 phytoplankton species recorded in the entire Casiguran waters during high and low waters (Table 1), 103 species were noted to be present in the stations belonging to Group II compared to 89 species in Group I.

The results reflected in the cluster diagram (Figure 8) is more or less supported by the results of the Canonical Correspondence Analysis (Figure 9) where the plots of the sites or stations along the first two canonical axes are shown for samples collected during (a) high tide and (b) low tide. Results in Figure 9a show different community structures of phytoplankton during high and low tides.

During high tide (Figure 9a), the stations 4 to 7 hosts several species of phytoplankton that are absent from stations 1 to 3 and 8 to 13. The differences in the species composition and their abundances among the stations may be explained by the observed disparity in some physico-chemical factors of the water. For instance, stations 2 (1.24 μM) and 3 (0.50 μM) registered high NO_3 values whilst low in station 7 (0.08 μM).

Likewise, NH_3 were highest in stations 2 (3.08 µM) and 3 (0.97 µM), while low in station 6 (0.37 µM).

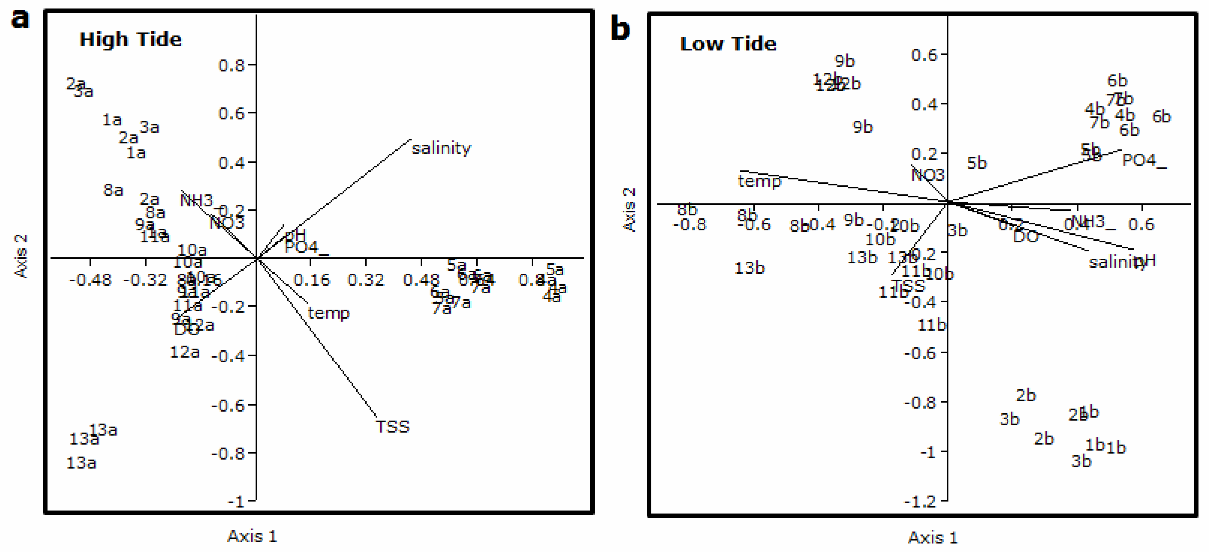

Figure 9. Results of the Canonical Correspondence Analysis (a) biplot showing the distance among the sampling stations during high tide and (b) during low tides and the physico-chemical factors that influence the abundance of phytoplankton in Casiguran, Aurora Province.

Dissolved oxygen was also highest in station 13. Changes in the community structure can also be seen during low tide (Figure 9b), with stations 1 to 7 comprising phytoplankton species that are not recorded in stations 8 to 13. Ecological parameters that may have influence these variations may be due to the NO_3 and PO_4 content of the water, where stations 9 and 5 recorded highest values of NO_3 (1.70 µM) and PO_4 (2.81 µM), respectively. The high DO content in station 13 during high tide maybe due to the influence of freshwater runoff coming from the four nearby rivers that carries oxygen which may diffused from the atmosphere into these rivers, rather than the phytoplankton since they were not abundant in this station. This finding is in contrast with those reported by George et al (2012) who stressed out the role of phytoplankton in contributing more DO in the water.

Although our data may suggests the influence of the nutrients (NO_3 and PO_4) to the type and abundance of phytoplankton species in Casiguran waters during high and low tides, such impact is only minimal. Conversely, many authors reported maximal phytoplankton abundance in response to nutrient loadings (Uy et al 2006; Geetha & Kondalarao 2004; Ilyash & Matorin 2007; Hari Muraleedharan & Ramasubbu 2010; Coutinho et al 2012; George et al 2012), and it could be that other factors like internal tides (Haury et al 1983; Lande & Yentsch 1988), wind waves (Iverson et al 1974; Demers et al 1987), wind-driven surface currents (Harris & Trimbee 1986) and horizontal tidal advection (Cloern et al 1989) may have played an important role in phytplankton diversity and distribution in Casiguran waters.

Conclusions. The results of the study revealed that the level of phytoplankton diversity and abundance did not fluctuate with changes in the tide levels, suggesting that phytoplankton species were thus uniformly distributed by the alteration of high and low tides accompanied by intense horizontal and vertical mixing which are apparent during spring tide. Further, although our data may suggests the influence of the nutrients (NO_3 and PO_4) to the type and abundance of phytoplankton species in Casiguran waters during high and low tides, such impact is only minimal. It might be that other factors like wind and wave actions, wind-driven currents and horizontal tidal advection may have played an important role in phytplankton diversity and abundance in Casiguran waters. Since results of the study reflect the importance of physical and chemical factors of the water on the phytoplankton community structure in the said areas, the present records are essentially vital in order to assess further the relationship between environmental conditions of the water and the organisms and to evaluate future development towards conservation and management of the Casiguran sound and bay. It is recommended that the period of the study will be made in an annual basis in order to observe the trend and compare the distribution and abundance of phytoplankton communities during dry and wet seasons and during spring-neap tide cycles in these particular areas.

Acknowledgements. The study was supported by Senator Edgardo J. Angara, Aurora Provincial Government, the Philippines Department of Agriculture-Bureau of Fisheries and Aquatic Resources (DA-BFAR) Region III, Mindanao State University-Iligan Institute of Technology (MSU-IIT), Aurora State College of Technology, Zabali Campus, Aurora Province and University of the Philippines-Marine Science Institute (UP-MSI). M. L. D. G. Lacuna would like to acknowledge the marine biology students from the Department of Biological Sciences, Mindanao State University-Iligan Institute of Technology, Iligan City, Philippines and Ms. Arri Adajar and Mr. Rolly Caballero for assisting in the collections and analyses of the phytoplankton samples.

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Received: 20 April 2013. Accepted: 24 May 2013. Published online: 13 June 2013.

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How to cite this article:
Angara E. V., Rillon G. S., Carmona M. L., Ferreras J. E. M., Vallejo M. I., Amper A. C. G. G., Lacuna M. L. D. G., 2013 Diversity and abundance of phytoplankton in Casiguran waters, Aurora Province, Central Luzon, Northern Philippines. AACL Bioflux 6(4):358-377.