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Phytoplankton Abundance and Distribution in Selected Sites of Boracay Island, Malay, Aklan, Central Philippines

ABSTRACT

This study investigated the impacts of natural and anthropogenic factors on the coastal water quality dynamics in the Island of Boracay, Malay, Aklan, Central Philippines particularly the effects of nutrient pollution on phytoplankton population. The samples were gathered at two month interval for a total of five samplings by filtering 10 liter buckets of surface water through a net with 25µm mesh bag. There were 35 identified genera of phytoplankton belonging to four taxonomic groups. Diatoms had 26 genera, cyanophycean and silicoflagellate and dinoflagellates had one and seven genera, respectively. Diatoms were the dominant group with the highest mean density of 1,588 ind.L^{-1}, followed by silicoflagellate at 399 ind.L^{-1} represented by Tintinnopsis, cynophycean was represented by Trichodesmium at 204 ind.L^{-1}, while the dinoflagellates had 132 ind.L^{-1}. Genera richness was high when N and P concentrations were relatively lower. Phytoplankton density was highest in Lugotan Cove and Long Beach where nutrients readings were relatively high. This research clearly demonstrated that the growth of Trichodesmium reaching carrying capacity is an indication that the island ecosystem is near its ecological thresholds. The level of nitrate N acts as the limiting nutrient in the coastal water of the island controlling the growth of Trichodesmium and phytoplankton diversity. Changes in phytoplankton assemblages and density in the coastal waters were associated to variations on intensity and frequency of water mixing along with nutrient loading coming from anthropogenic activities and land uses in the island.

Key words: *phytoplankton, diversity, anthropogenic activities, Boracay Island, tourism*

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INTRODUCTION

Phytoplankton is among the primary producers in shallow coastal areas and factors that affect them will most likely affect overall productivity of a given site (*Reynolds 2006*). Sensitive to environmental change, its relative and absolute abundances in pelagic and littoral systems would indicate the level of eutrophication in a water body (*Round et al. 1990*).

This study aimed at determining the impacts of anthropogenic activities and nutrient inputs to the phytoplankton diversity and abundance in the coastal waters of Boracay Island, Malay, Aklan, Central Philippines. The island is known for its tourism industry with growing concern on an impending ecological disaster as indicated in its declining water quality. Boracay as internationally renowned tourism destination showed a high recorded tourist population of 556,084 in the year 2006 (*LGU Malay, Aklan 2012*), ascribed to its enticing and pristine environment particularly the powdery white sand beaches.

In 2015, tourist arrivals reached a much higher record of 1.5 M (*LGU, Malay, Aklan 2016*). As the number one tourist attraction of the country, private sector and government agencies have strong concerns for sustaining the island's top position in the world's tourism industry. In 2015, tourism contributes 8.2% to the Gross Development Product (GDP) of the country (*Recide 2016*). Therefore, it is very important to maintain a healthy and clean environment for the island to sustain the industry.

The massive influx of tourists has visibly exerted too much pressure on the sustaining capacity of the island and has amplified the risks of environmental degradation, destruction of vital coastal habitats, loss of marine biological diversity, and deterioration of near shore water quality. Coliform counts, biochemical oxygen demand

and dissolved oxygen levels beyond the Department of Environment and Natural Resources (DENR) regulatory standards were noted in some water quality monitoring sites of the DENR- Environmental Management Bureau (EMB) (*DENR, EMB Water Quality Monitoring Report 2012*). Presence of thick mass of green algae was observed on the shore of the island particularly in summer indicates high nutrient level in water.

The determination of the abundance and composition of phytoplankton population in the coastal waters of an island open for mass tourism is impacted. The effects of land use and anthropogenic activities on the coastal water quality dynamics are associated to phytoplankton population dynamics. Analysis on the relationship between water quality and phytoplankton can provide knowledge on the causes and possible solutions to the water pollution problem of the island. As such, it can serve as basis in coming up with policies, and strategies on how to effectively protect and rehabilitate the coastal water quality to support and sustain the tourism industry in Boracay Island.

The genera diversity index implied that the changes in genera composition can be attributed to the sensitivity response of diatoms and other planktons to environmental change (*van Dam 1982; Bukry et al. 2013, Mcginnis et al. 1997*). The variations in the chemical composition of natural marine waters, geographical characteristics of the area, and wind action that affect the distribution of nutrients in water (*Goreau 2003; Mouritsen and Richardson 2003*) were believed to be the important factors in regulating the abundance, composition and influence the growth of diatoms. The high nutrient concentrations and loading resulted in increased production and changes in the species composition of phytoplankton (*Colijn et al.2002; Burford and Pearson 1998*). Land use at adjacent areas of the different study sites probably provides an important nutrient load, leading some species to grow, reproduce and diversify, restructuring the phytoplankton assemblage as a whole (*Ferrareze and Nogueira 2006; Khan and Ansari 2005*).

Materials and Methods

The Study Area and Sampling Sites

Boracay Island is located between 11°57' – 12°00' (latitude) and 121°56' - 121°57' (longitude) off the north-western tip of Panay, Western Visayas, Philippines. It consists of three villages namely Manoc-Manoc, Balabag and Yapak, municipality of Malay, Aklan (**Figure 1**). The uncontrolled and rapid tourism development in the island resulted in severe space limitations and conversion of mangrove swamps into built-up areas by local and transient residents (*DENR, VI, Wetland assessment Report 2009*).

The sampling stations were selected based on the existing land uses such as presence of business establishments and households anthropogenic activities and the presence of other coastal and marine ecosystems particularly noting its ecological role in the community (i.e. mangrove ecosystem, seagrass ecosystem). Physical survey was conducted on the current land use and anthropogenic activities of the terrestrial areas adjacent to the sampling areas. The reckoning point was 150 m from the shoreline, since a Karstic soil characterizing Boracay Island (*DENR Environmental Master plan Boracay 2008*) has a hydrological chain of 150 meters (*O'driscoll 2003*). Houses and other establishments were observed and estimated within the 150 meter radius, which were classified in terms of its sewerage system connection (Boracay Integrated Waters, Inc. (BIWC) or they have waste water treatment facilities based on the record of DENR-EMB, Region VI).

The Puka Beach is near to the coastal area of the mangrove swamp 1 in Brgy. Yapak with an area of 5.31 ha containing 51% (2.73 ha) mangrove cover (*DENR VI, PAWCZMS Assessment Report 2009*). It is located in 381829 E; 1326423 N. The Puka Beach is still free of establishments except for some native cottages, souvenir shops and a restaurant.

The Bulabog Beach also known as the 'back beach' situated at Brgy. Balabag is dominantly covered by seagrass. Two drainage outfalls containing untreated and partially treated sewage are being discharged to adjacent coastal water. It is the island's docking area of pump boats, numerous hotels, resorts and big establishments engaged in water sports are found.

Lugotan Cove is characterized of having a three-hectare seagrass bed adjacent to a mangrove swamp containing 10% mangrove cover and inhabited by many informal settlers (*DENR VI, PAWCZMS Wetlands Assessment Report 2009*). It is a cove where untreated and partially treated sewage of domestic and commercial establishments were directly discharged (**Figure 1**).

Long Beach is characterized of having a four-kilometer powdery white sand and the most populated area in Boracay Island. Untreated wastewater from D'Mall is being discharged here. These establishments may beconnected to the sewerage system or had installed their own wastewater treatment facilities.

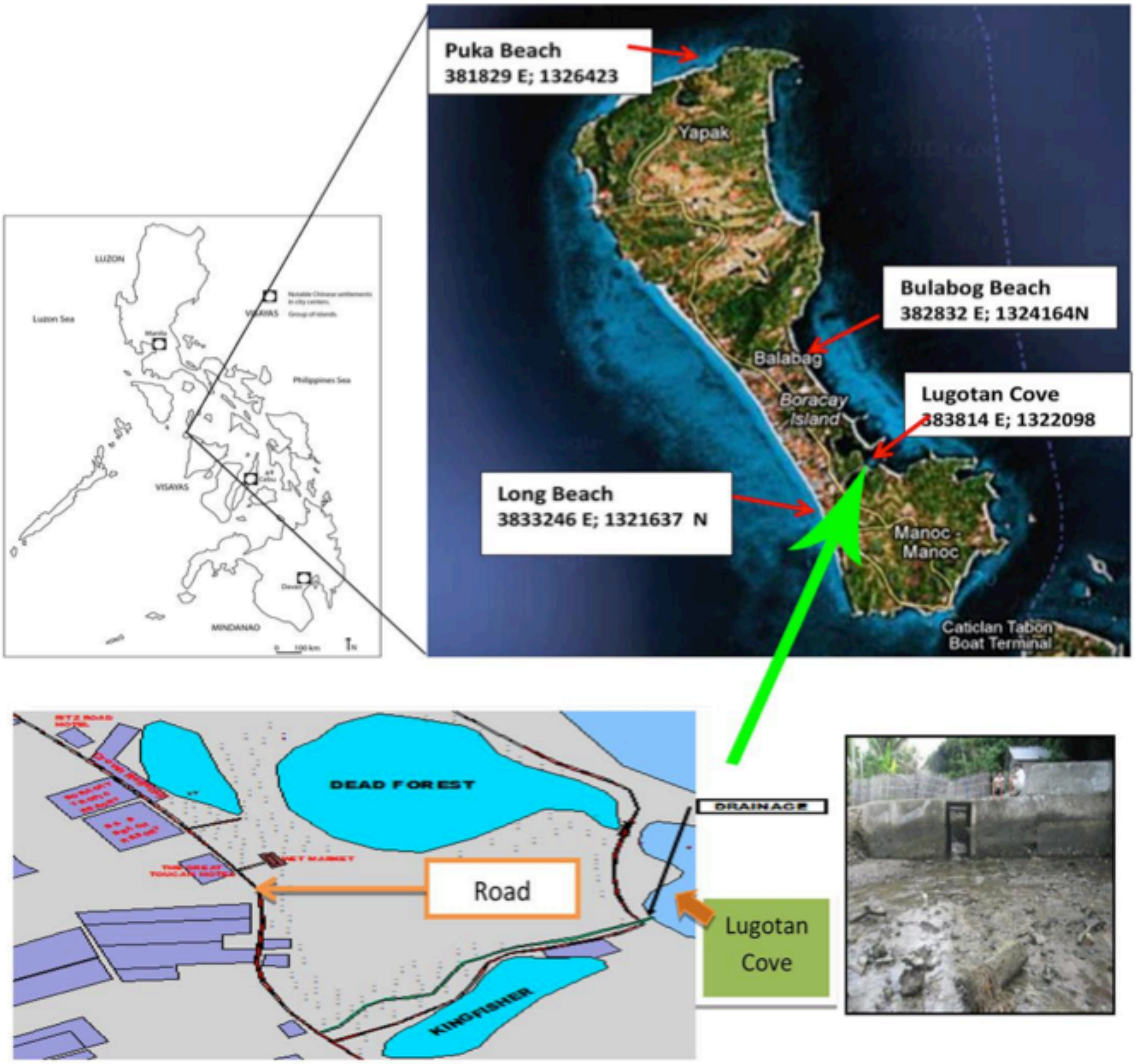

Figure 2. Sketch map of mangrove swamp (Dead Forest) and drainage canal of Brgy. Manoc-manoc showing its relative location to Lugotan Cove.

Table 1. Summary of the descriptions of the four study sites in Boracay Island (2012).

Study Sites	Description
Puka Beach	Adjacent to mangrove swamp 1 with an area of 5.31 ha with 51% mangrove cover. Named after "puka" shells abundantly found on the beach. No big establishments.
Bulabog Beach	Also called the "back beach". Covered with vast area of seagrass beds Discharge area of two drainage outfalls of Brgy. Balabag, and Brgy. Manoc-manoc BIWC outfall of treated sewage, 850 m away from the beach.
Lugotan Cove	Located in Brgy. Manoc-manoc. Referred to as the repository area of waters from "Dead Forest" (tree- impoverished mangrove swamp). It is an embayment. Mangrove forest lined the mouth area of the cove. Approximately covered by 3 hectares of seagrass bed. Outfall of drainage canal of Brgy. Manoc-manoc.
Long Beach	Four kilometers fine white sand starting from Angol Point in Manoc-manoc to Fridays area in Brgy. Yapak Divided into stations 1, 2, and 3, respectively Frequently visited by tourists. Most populated portion of Boracay Island

Phytoplankton sample collection and Laboratory analysis

Samples were collected both the wet season, (September- December 2012), which is the lean season of tourist arrivals; and also during the dry season, (April and June 2012) the peak season of tourism in the island (*LGU Malay 2012*).

Ten liters of surface water were collected in each of the four study sites using 2 L container and were filtered through a 25µm mesh plankton net (*Asis et al. 2006*). Water samples were collected 3 - 20 m from the lowest tide level at the shoreline, using a properly labelled container bottles and fixed in Lugol's iodine (*Eaton et al. 1998*).

The volume of collected samples from each station was standardized to 20 ml. Three replicates of 1- ml aliquot were used for the species identification. Phytoplankton cells were examined under a compound microscope at 40x magnification and were identified to genera (lowest level possible) and were further grouped into major taxa: blue-green algae (Cyanophyceae), diatoms (Bacillariophyceae), Dinoflagellates (Dinophyceae) and Silicoflagellates. The taxonomic identification was based on references including *Gran and Angst* (*1931*), *Yamaji* (*1962*), *Shirota* (*1966*), *Ferguson* (*1968*) and *Smith* (*1977*) .

The work of *Asis et al.* (*2006*) on the computation of average cell density in study of phytoplankton abundance and composition in Coron, Palawan was also adopted in this study. Thirty random grids of the Sedgewick-Rafter were evaluated. The average cell density estimations were done on a 1-ml aliquot part of the sample in a Sedgewick-Rafter counting chamber. A raising factor (RF) was first obtained by dividing the total number of grids in the Sedgewick-Rafter (50 grids) by the number of grids analyzed (30 grids) and multiplied by 20. The raising factor was used in order to compute the phytoplankton present at a given exact volume of water that was sampled. The identified organisms were grouped into major taxa and the percent composition was calculated. The average densities (indivL^{-1}) were obtained using the formula:

$$\text{Average density} = \frac{\text{RF x average count}}{\text{Total volume filtered}}$$

In understanding the structure of the community, the relative abundance of genera was determined using the formula:

$$\text{Relative density} = \frac{\text{Total \# of cells per species}}{\text{Total \# of cells for all species}} \times 100$$

Species diversity

Simpson Index of Dominance (*Simpson 1949*) was used in calculating and measuring the dominance of the identified genera of phytoplankton, while the Shannon-Weiner Index (*Shannon 1948*) was used in determining the genera overall diversity.

Simpson Index of Dominance

$$C = (ni/N)^2$$

where:
ni = average density of each genus
N= total density values of all genera

Shannon-Weiner Index of Genera Diversity

$$H' = -\sum pi\ (\ln pi)$$

where:
pi = the proportion of individuals of genus (Relative density)
ln = natural logarithms of individual species i

The chlorophyll *a* concentration was analyzed to determine the phytoplankton biomass (*Cloern 2001*) in each of the four study sites. Five hundred ml unfiltered and unstrained marine surface water samples were placed in collection bottles wrapped with carbon paper to prevent the influence of light. The bottles were lowered few centimeters from the water surface and capped underwater. Water samplings were done bi-monthly from February to December 2012 for six samplings in the same site for phytoplankton analysis. The water samples were stored in a cooler under a temperature of at least 4^{o}C. The chlorophyll *a* concentration was analyzed at the South East Asian Fisheries Development Center (SEAFDEC) in Tigbauan, Iloilo.

The physicochemical properties which include the Dissolved Oxygen (DO), Biochemical Oxygen Demand (BOD), Total Suspended Solids (TSS), pH, temperature, ortho-phosphates and nitrates; which were obtained at the same schedule with phytoplankton and chlorophyll *a* analyses (*APHA, AWWA, WEF 1995*) (**Table 2**).

Mean total cell density and relative density of each of the genera identified were computed to determine percent contribution of the different genera to the phytoplankton community. Mean total cell density of the different genera comprising the major phytoplankton groups were used in correlation analyses. The BOD, TSS, Nitrate and ambient water temperature were correlated with major groups of phytoplankton. The phytoplankton groups were also

Table 2. Summary of parameters analyzed for coastal water quality in Boracay Island.

Parameters	Method	Reference or Manufacturer
Nitrate (mgL^{-1})	Closed Reflux Cell Test	MERCK
Phosphate (mgL^{-1})	Closed Reflux Cell Test	MERCK
Biochemical Oxygen Demand (BOD) (mgL^{-1})	Respirometric	5210 B 5-Day BOD Test ,APHA AWWA, Standard Method for the examination of water and waste water
Dissolved Oxygen (DO) (mgL^{-1})	Glass Electrode	4500-O G, APHA AWWA, Standard Method for the examination of water and wastewater
Total Suspended Solids (TSS) (mgL^{-1})	Gravimetric Method	2540 D, APHA AWWA, Standard Method for the examination of water and wastewater
pH (range)	Electrometric	4500-H+ , APHA AWWA, Standard Method for the examination of water and wastewater
Temperature (°C)	Mercury-filled Thermometer	APHA AWWA, Standard Method for the examination of water and wastewater
Chlorophyll *a*	Spectrophotometry	10200 I, APHA AWWA, Standard Method for the examination of water and wastewater

correlated with each other and with the physicochemical parameters analyzed, sampling periods and sampling sites.

All correlation analysis used Pearson *r* correlation which analyzed the association between the coastal water physicochemical parameters to the genera richness, abundance, diversity and distribution of phytoplankton. The physicochemical characteristics of the coastal water were the function of the land use and nutrient inputs from anthropogenic activities in the adjacent terrestrial ecosystem.

Discriminant analysis using the Statistical Analysis System (SAS) software was employed to determine the circumstances for phytoplankton growth and proliferation. The factors and parameters considered in this study that are predicted to have an effect to phytoplankton growth and proliferations are physicochemical, anthropogenic and hydrological. Likewise t-test was conducted to determine the effect of season to phytoplankton growth. Logistic growth curve (sigmoid curve) and quadratic equations were used to describe the growth of phytoplankton while, the Goodness of fit test used chi-square test. These were all done using Excel.

RESULTS AND DISCUSSION

Phytoplankton density, composition and growth pattern in relation to nutrients inputs in coastal waters

Thirty-five phytoplankton genera were identified. The mean total density among the different groups of phytoplankton for the entire sampling months was 2,322.8 indivL^{-1} (**Table 3**). The *Tintinnopsis* (Silicoflagellates) was the most abundant with mean cell density of 399 indivL^{-1} and relative cell density of 17.17% followed by *Coscinodiscus* (Diatoms) with 323 indivL^{-1} and relative density of 14%, and *Chaetoceros* (Diatoms) with 276 indivL^{-1} and relative density of 11.87%. The least abundant was the diatom *Hemidiscus* with a mean cell density of 4 ind.L^{-1} and a relative density of 0.19% (**Table 4**). Genus *Trichodesmium* that represented cyanophycean had a comparatively high density of 204 indivL^{-1} with a relative density of 9%. Other genera with equally higher average cell density were *Rhizolenia*, *Nitzschia* and *Biddulphia* all from Class Bacillariophyceae with mean cell density of 196 indivL^{-1}, 178 indivL^{-1}, 133 indivL^{-1}, and relative density of 8.45%, 7.65% and 5.73%, respectively.

Table 3. Mean density (ind.L^{-1}) and percentage composition (%) of major taxa of phytoplankton in selected sites in Boracay Island, Malay, Aklan (2012).

Major Taxa	Mean Density	Percentage Composition
Cyanophycean	203.8	8.8
Diatoms	1588.2	68.4
Dinoflagellates	132.0	5.7
Silicoflagellates	398.8	17.2
TOTAL	2322.8	100.0

The Bacillariophyceae (Diatoms) was found dominant constituting 68.4% of the total taxa (**Table 3**). *Moore* (*1974*) and *Round* (*1984*) pointed out that diatoms are usually the most common element of shallow communities. It is well-known that diatoms are sensitive to a wide range of limnological and environmental variables, and its community structure may quickly respond to changing physical, chemical and biological conditions in the environment (*Mooser et al. 1996*). Moreover, they are generally abundant in nutrient-rich nearshore waters and are considered as the chief component of phytoplankton in the marine environment (*Sverdrup et al. 1942*). Generally, diatoms were found to be dominant in mangrove waters can tolerate the widely changing hydrographical conditions (*Kannan and Vasantha 1992; Rajasegar et al. 2002*).

Table 4. Relative density (%) and mean cell density (ind.L^{-1}) of phytoplankton genera collected from sampling sites at all sampling periods in Boracay Island, Aklan (2012).

Class/Genera	Average Density ($Ind^{-1}L$)	Relative Density (%)
Silicoflagellates	398.81	17.17
Tintinnopsis		
Cyanophyceae		
Trichodesmium	203.81	8.77
Bacillariophyceae		
Coscinodiscus	323.08	13.91
Chaetoceros	275.64	11.87
Rhizosolenia	196.31	8.45
Nitzschia	177.67	7.65
Biddulphia	133.10	5.73
Thalassionema	68.36	2.94
Navicula	67.21	2.89
Pleurosigma	58.95	2.54
Guinardia	57.03	2.46
Thallasiotrix	44.65	1.92
Lauderia	33.81	1.46
Dactyliosolen	29.36	1.26
Climacodium	21.05	0.91
Licmophora	12.58	0.54
Skeletonema	12.03	0.52
Stephanophyxis	11.40	0.49
Leptocylindricus	10.44	0.45
Eucampia	9.52	0.41
Fragilaria	7.96	0.34
Dithylum	6.12	0.26
Cocconeis	6.59	0.28
Melosira	6.07	0.26
Asterilla	5.71	0.25
Hemiaulus	4.54	0.20
Bacteriastrum	4.52	0.19
Hemidiscus	4.45	0.19
Dinophyceae		
Favella	35.87	1.54
Peridinium	30.72	1.32
Undella	22.06	0.95
Gymnodinium	20.70	0.89
Ceriatium	8.71	0.37
Gyrosigma	8.63	0.37
Amphora	5.30	0.23
N 35 Mean 2,322 Max 398.1	**Sd 99.88**	

Across the sampling periods, the water temperature remained fairly constant ranging from 27°C to 30.0°C. Temperature is an important factor which regulates the biogeochemical activities in the aquatic environment. Generally, there was an increasing trend of number of genera and classes per sampling months (**Figure 2**).

Phytoplankton genera increased (**Figure 2**) with the decreasing trend of BOD (**Figure 3**). Low BOD meant less amount of organic matter in coastal water which implied reduced inputs of waste water particularly sewage. The high level of BOD value could be attributed to the discharge of pollutants from washing, sewage contamination, and other domestic wastes. Lower BOD was recorded from September, October and December sampling periods. Lower tourist influx was recorded for September (70,527) and October (79,686) but there was a 30-40% increase in tourist arrivals in December (125,986) compared to the lean previous months. This entailed a cleaner water quality compared to February, April and June sampling periods. March (118,177), April (161,504) and May (130,452) (LGU, Malay 2013) had also higher tourist arrivals. The lower number of genera in the month of April maybe further attributed to the proliferation of macro algae that inhibited the growth of certain species of phytoplankton (*Yang et al. 2008*). The reason for the lower BOD in December with high tourist arrivals was unclear as this may be affected by rainfall, prevailing temperature, currents and decomposition of organic matters which this study did not cover.

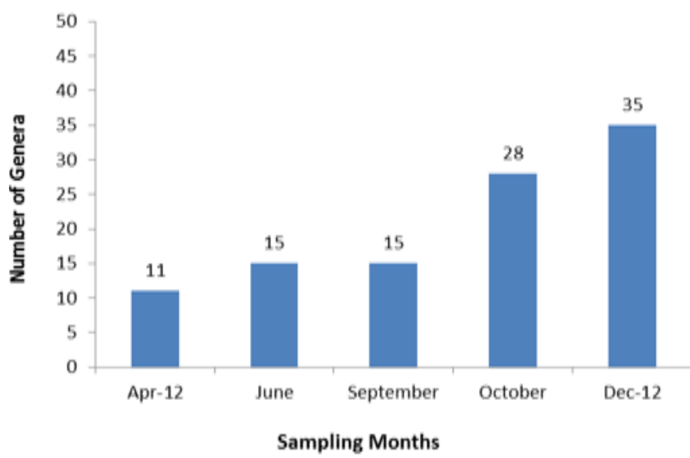

Figure 2. Total number of different genera of phytoplankton in the selected sites of Boracay Island, April-December 2012.

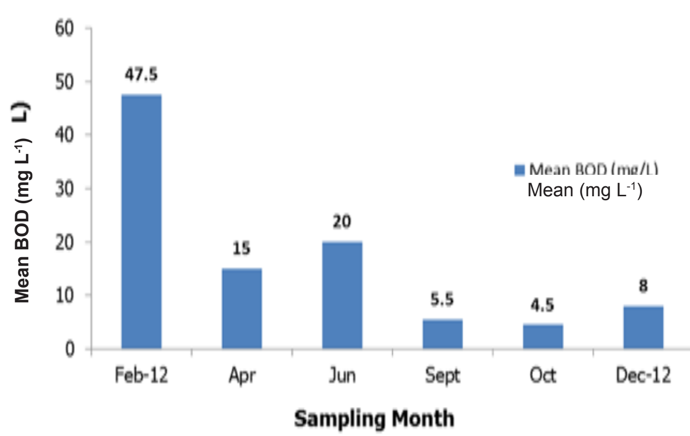

Figure 3. Mean BOD (mg L^{-1}) readings from four sampling sites in Boracay Island in all sampling periods.

The highest genera richness observed in December (**Figure 2**) can be attributed to the decreasing water temperature which favored phytoplankton growth (Yang, 2008), and improved water quality such as low BOD and nitrate level (**Table 5**). On the other hand, the standard level of phosphate and nitrate in marine water is not yet determined by EMB, DENR. However, in a related study, *Yang et al.* (*2008*), noted that phosphate concentration of 0.1 mgL^{-1} in lakes is the maximum acceptable level to avoid accelerated eutrophication, and phosphate of > 0.1 mgL^{-1} could result accelerated growth and other consequent problems. Total nitrogen (TN) of 1.0-2.0 mgL^{-1} in water indicates eutrophy (*Kan 2005; Richardson et al. 2003*). There are sites in the island reaching very high levels of phosphate (up to 99.0 mgL^{-1}) and nitrate N (8 mgL^{-1}) which are indicators of eutrophication of the island's coastal waters (**Table 5**).

Diatoms and silicoflagellates population densities were positively correlated with sampling periods (r= 0.901, p= 0.037; r= 0.969, p= 0.006), respectively (**Table 6**). Likewise, these two groups occurred together as an assemblage indicated by their positive correlation with each other (r= 0.557, p= 0.006) (**Table 6**). The correlation between sampling period and density means that at each sampling period there was change in population densities of the two major groups. This can be attributed to water quality changes (i.e. BOD level, presence of other autotrophs, etc.) as discussed above that influenced the population densities. These data therefore, further confirmed what *Mooser et al.* (*1996*) pointed, that diatoms are sensitive to environmental variables and its community structure respond to changing physical, chemical and biological conditions. These data also supported what *Round et al.* (*1990*) stated that phytoplankton population can indicate the level of eutrophy in a water body. Thus, these data support our recommendation that regular phytoplankton population sampling is a cheap and evidence-based way of water quality monitoring.

Phytoplankton population were positively correlated with pH (r=0.98; p=0.01, **Table 6**), they prefer alkaline water. Boracay Island has Karstic soil (*DENR VI Environmental Master Plan, Boracay 2008*) contains large quantities of calcium carbonate ($CaCO_3$) tends to have higher pH. Diatoms was the only group that was correlated with DO (r=0.592; p=.008) (**Table 6**), the higher DO the more diatoms were present. Higher pH and DO favored the growth of phytoplankton, as shown by the highly positive correlation of total phytoplankton with pH and DO (r= 0.95; p=0.01 and 0.98; p=0.01), respectively (**Table 6**). Thus, the Karstic soil of Boracay may have contributed to the population structure of phytoplankton in the Island, a natural resource that provides cleansing mechanism in the Island.

On the other hand, the presence of fast-growing centric diatoms like *Chaetoceros* and *Rhizosolenia* over pennates diatoms could be an indicator of stressed environment (*Verlecar et al. 2006*). The study conducted by *Hallare et al.* (*2010*) after the oil spill incident in Guimaras Island, Philippines showed that these two genera of centric diatoms *Chaetoceros* and *Rhizosolenia* together with *Skeletonema* and *Bacteriastrum* became the dominant genera after the oil spill. Similarly, fast growing centric diatoms were considered as biological indicators of organic pollution and nutrient enrichment and suggest a moderately high environmental stress (*Verlecar et al. 2006*). In the study of *Sabater* (*2000*), diatoms abundance indicated a poor water quality.

Genus *Tintinnopsis* (Silicoflagellates) was observed in all study sites at all sampling periods and they were present in all sampling sites with different nutrient levels. This genus is considered cosmopolitan (*Marshall 1969*) and neritic that can survive in unfavorable environmental conditions (*Dolan et al. 2006*). Moreover, tintinnids are euryhaline as well as eurythermal nature organism both in coastal and oceanic waters (*Edward et al. 1995*).

Silicoflagellates are associated with nutrient rich water (*Bukry and Cheshire 2013*). Tintinnopsis, the only Silicoflagellate monitored had the highest density compared to other genera of phytoplankton identified in the coastal water of Boracay and with recorded higher density in Lugotan Cove, Long Beach and Bulabog Beach compared to Puka Beach (**Table 2**). This phenomenon may be due to high phosphate and nitrate readings in the previously mentioned study sites (**Table 5**). Records from *DENR VI-EMB* (*2012*) and *BIWC* (*2012*) showed that there were numerous illegal and informal settlers in the 'Dead Forest' (tree-impoverished mangrove swamp) with only 10% mangrove cover adjacent to Lugotan Cove, string of resorts and houses along the Bulabog Beach that were not connected to the sewerage system. On the other hand, Long Beach was the most populated area in the Island in which drainage from wet market (D'Mall) was being discharged. Furthermore, the peak season of tourists arrival in summer months and Christmas season (*LGU Malay 2012*) may have triggered the discharged of high nitrate and phosphate sewage (*EMB 2012; BIWC 2012*).

The higher abundance of *Tintinopsis* in the Lugotan Cove, Long Beach and Bulabog Beach compared to Yapak Beach (**Figure 5**) indicates that the water quality in the said areas exhibited a higher level of nutrients indicating a more stressful environmental condition (*Cloern 2005*). On the other hand the Puka Beach was being protected by the adjacent mangrove swamp. The mangrove swamp with an area of 51,531 m^2 has 51% mangrove forest cover and 49%

Table 5. Summary of BOD, N and P readings in four sampling sites in Boracay Island (2012).

Sampling Sites	29-Feb-12			27-Apr-12			27-Jun-12			4-Sep-12			18-Oct-12			19-Dec-12		
	BOD	N	P	BOD	N	P	BOD	N	P	BOD	N	P	BOD	N	P	BOD	N	P
	(mgl^{-1})			(mgl^{-1})			(mgl^{-1})			(mgl^{-1})			(mgl^{-1})			(mgl^{-1})		
Puka Beach	20	3	0.8	10	2	32.6	20	3	19.3	9	1	27.5	0	2	11.3	6	1	66.7
Bulabog Beach	50	1	34.3	10	3	79	20	1	21.1	3	3	10.6	2	2	1.1	4	1	3.4
Lugotan Cove	100	1	63.5	20	8	72.5	20	1	16.9	8	8	36.3	11	2	2.8	19	1	72.5
Long Beach	20	2	20.5	20	6	99.1	20	0	83.6	2	3	23.3	5	1	8.6	3	1	2.8

Table 6. Summary of correlation values between variables that showed significant results.

Variables Correlated	*r* Values	*p* Values
Diatoms and Silicoflagellates	0.557	0.006
Blue green algae and nitrates	-0.99	0.01
Diatoms and sampling periods	0.901	0.037
Silicoflagellates and sampling period	0.969	0.007
Dinoflagellates and TSS	0.941	0.017
Chlorophyll a and Diatoms in Site 6 only	0.995	0.011
Diatoms and DO	0.590	0.008
Phytoplankton and DO	0.95	0.01
Phytoplankton with pH	0.98	0.01
Diatoms and phytoplankton	0.98	0.018
Dinoflagellates and nitrates	0.398	0.091
Chlorophyll a and phytoplankton (combined all sites)	0.593	0.01

was converted into residential areas (*DENR VI-PAWCZMS Wetland Assessment Report 2009*).

This high nitrate levels in the Lugotan Cove (**Table 5**) could be attributed to the presence of two sewage canals coming servicing the houses, small restaurants and establishments in Barangay Manoc manoc and voluminous waste water and sewage discharged by informal settlers within and adjacent the dead forest (**Figure 1**). Evidence of siltation with TSS readings ranging from 25 to 799 mgL^{-1} were observed in the cove, which resulted to a turbidity and smothering of some seagrasses. According to *Calumpong and Menez* (*1997*), the green algae (Chlorophyta) can beused as bioindicators of a highly polluted or contaminated area. Thus, presence of green algae (e.g. *Ulva reticulate, Chaetomorpha crassa* and *Ulva intestinales*) observed in the seagrass beds within the cove indicated polluted coastal water. Likewise, said authors emphasized that the green algal bloom in shallow intertidal zones indicates high concentration of nutrients, while the presence of profuse epiphytes on species of seagrass like *Enhalus acoroides* may also signify unhealthy seagrass condition.

The appearance and abundance of autotrophs– seagrass, phytoplankton and macroalgae generally affectedby the levels of nutrients in water (NO_3), light condition and possibly by their competitive interactions. In the months of October to early December where number of tourists in the island was low, no macroalgae were observed. On this period, nitrate level was also relatively low (**Table 5**) wherein a high number of genera of phytoplankton were observed. Thus, it can be hypothesized that at this time of the year, only phytoplankton and seagrass present in Lugotan cove were withdrawing nutrients from the water column. As the number of tourists increased with a peak in the month of April, more nitrates are released in the water (**Table 5**). This coincided with the high light penetration in the region as evidenced by minimum cloudiness of only four to five (*recorded in PAGASA, Roxas City 2012*). All these environmental conditions triggered the proliferation of macroalgae (**Figure 4**) which were observed yearly in Lugotan Cove and Long Beach to appear particularly during the month of April.

The major three groups of autotrophs present in the island synergistically interact with each other on the withdrawal of nutrients from the water which in turn helps in the maintenance of clear water quality. It was observed that among the sampling areas, Bulabog Beach has the least density of Diatoms (340 ind. L^{-1}). This may be due to the presence of wide seagrass beds in the area along the beach and seagrass may have competed with the diatoms for the resources.

Genus *Trichodesmium* is one of the most well-known marine nitrogen fixers. They have enzyme complex, called nitrogenase, to break gaseous nitrogen's tough triple bond and convert it into a form other creatures can use (*Lee 2008*). They are often found in low-nutrient waters (*Lin et al. 1998*). They occur during periods of low wind stress and warm temperatures (*Lenes et al. 2005*) hence; they appeared in areas not so exposed to wind influence. The cyanophycean represented by genus *Trichodesmium* has an erratic abundance across sampling periods and study sites. This phytoplankton was found to be negatively correlated with nitrates, (r=-0.99; p=0.01) (**Table 6**). They appearedin period and sites withlesser concentrations of nitrogen, such as in October. It also appeared only in Puka Beach and Bulabog Beach.

Figure 4. Three abundant species of macro-algae observed in Boracay Island in the month of April 2012. a. *Enteremorpha flexuosa*, b. *Chaetomorpha crassa* and c. *Ulva intestinales*.

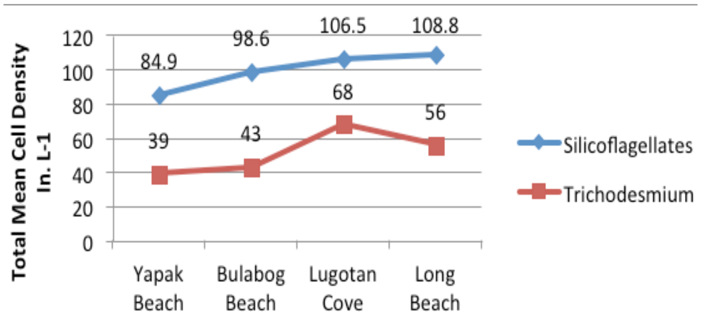

Figure 5. Mean total density of Silicoflagellates and *Trichodesmium* (average of all sampling periods) in the four selected sites of Boracay Island (2012).

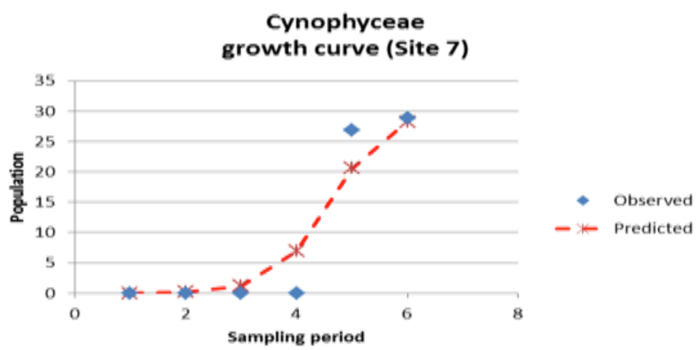

Figure 6. *Trichodesmium* sigmoid curve growth rate and pattern in Long Beach in the coastal water of Boracay Island, during sampling periods (2012).

Trichodesmium population increased in October and was registered in the sampling when precipitation was 300 mm/month. Its highest population appeared during December with a recorded rainfall of 200 mm, which was the start of the dry season (12.55 vs 0.881, t=2.84, p<.009). This organism increased its population only when the nitrate concentration was low. It can be deduced that one of the factors that affected the lower concentration of nitrate was dilution effect of precipitation. The rainy season was also a lean season of tourist arrivals at the same time.

The cyanophycean followed a different growth pattern exhibited by a logistic function. The population level starts slowly then increases similar to the exponential or J-curve, and levels off after sometime (**Figures 6** and **7**). As such, the growth rate is not constant.

The data for Long Beach was used for the goodness of fit test to the logistic growth curve using chi-square test with parameters: K=30 K/No =10000a r=2. The population showed a downward trend at the 6th sampling period. The predicted population was between the populations of the 5th and 6th sampling periods. The predicting equation was:

$$N(t) = K/ [1+(K/No-1)e^{-rt}$$

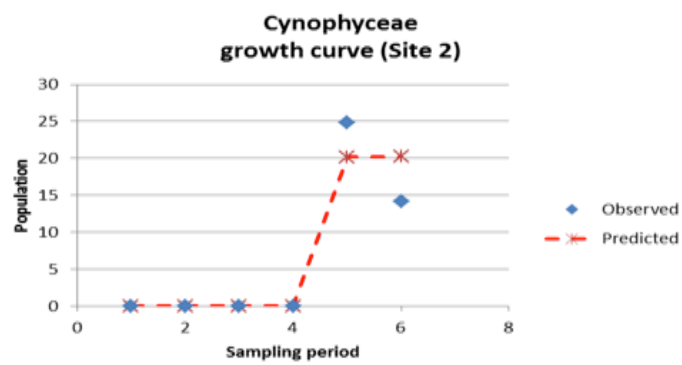

Figure 7. *Trichodesmium* sigmoid curve growth rate and pattern in Puka Beach in the coastal water of Boracay Island during sampling periods (2012).

$$N(t) = 20.20/[1+(1.11E+26-1)\ e^{-13.26}$$

Lower initial nitrate level in February resulted in higher intrinsic rate of increase (r) and lower carrying capacity (K). Puka Beach and Bulabog Beach had higher r and lower K, while Lugotan Cove and Long Beach had higher K and a lower r (**Table 7**). This relationship can be described by a quadratic equation in **Figure 8**.

Nitrate reading in all study sites in October and December sampling periods was relatively the same. However, *Trichodesmium* density is higher in Lugotan

Table 7. Relationship of initial nitrate to intrinsic rate of increase and carrying capacity in different sampling sites (2012).

Site	Nitrate	*K*	*R*
Puka Beach	1	20.19892	14.41231
Bulabog Beach	1	20.79545	14.58756
Lugotan Cove	2	30.54738	12.54679
Long Beach	3	28.90561	13.25816

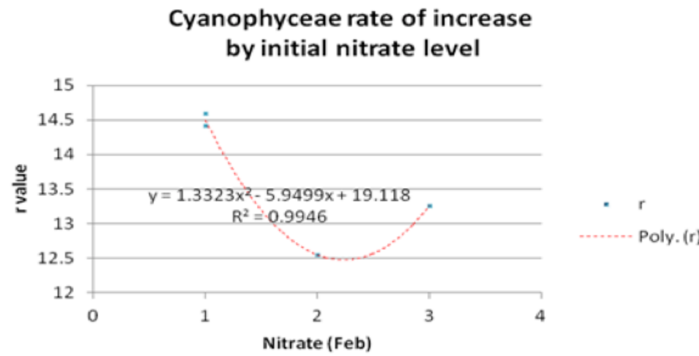

Figure 8. *Trichodesmium* rate of increase by initial nitrate level (mgL^{-1}) in coastal water of Boracay Island (2012).

Cove (**Figure 5**). This may be attributed to its geographic characteristic as a cove or embayment where there is low wind stress and warm temperatures that promote the growth of *Trichodesmium* (*Lenes et al.2005, Ghosal et al. 2011*).

The growth plateau of *Trichodesmium* has reached K or carrying capacity. This indicates that the island ecosystem is near its ecological thresholds. These data also showed that nitrate is the limiting nutrient factor. The level of this nutrient in the water column controlled the growth of the indicator species *Trichodesmium* and the phytoplankton genera diversity. Management and control of sources of this nutrient from anthropogenic activities could help in sustainably managing the tourism activity in the island.

Genera Diversity of phytoplankton as affected by nutrient inputs

The highest genera diversity was recorded in December with a Shannon-Weiner Index of 1.12. The least genera diversity of H^1=0.23 was noted in April, while June (H'=0.28) and September (H'=0.27) has a relatively the same level of diversity. Furthermore, October with H'=0.34 was a little higher than June and September. The diversity of phytoplankton were weakly negatively correlated with nitrate (*r*=-0.398; *p*=0.091). This means that nitrate concentration in water column was inversely associated with genera diversity (**Figure 9**). Furthermore, October with H'=0.34 was a little higher than June and September. The genera of phytoplankton were weakly negatively correlated with nitrate (*r*=-0.398; *p*=0.091). This means that nitrate concentration was inversely associated with genera diversity (**Table 6**).

The analysis of the diversity of phytoplankton for all the study sites and across the sampling periods showed that the Simpson Index of Dominance (1/D) was recorded at generic index of 2.0 and the Shannon Weiner Index (H') at 0.9. High 1/D would happen when a genus/genera dominates the phytoplankton community, which correspondingly, would result to low H' or index of diversity. The genera that dominated in all sites across all sampling periods were the *Tintinnopsis* (Silicoflagellates), *Coscinodiscus*

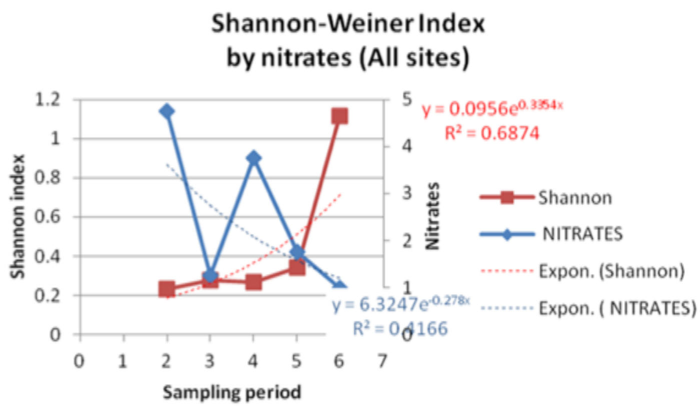

Figure 9. Graph showing the relationship of nitrates (mgL^{-1}) and genus diversity (Shannon-Weiner Index) reflecting the diversity of the different study sites in Boracay Island (2012).

(Diatoms), and Chaetoceros (Diatoms). *Trichodesmium* (cyanophycean) was also found abundant in the last three sampling periods (September, October and December).

On the other hand, when Shannon and Simpson Indices were analyzed in every sampling period covering all the study sites, it showed that the Shannon Index was relatively higher compared to Simpson Index (**Figure 10**). It revealed that the coastal water of Boracay Island was still inhabited by representatives of various species/genera of phytoplankton per sampling period. The higher diversity of phytoplankton in December can be attributed to lower average temperature that favors the growth of algae in the water column (*Yang et al. 2008*) with relatively lower nitrates (**Table 5**). There may be also other natural mechanisms in the Island that promoted the diversity and abundance of phytoplankton that futures studies may explain.

The genera diversity index implied that the changes in genera composition in every sampling period can be attributed to the sensitivity response of diatoms and other planktons to environmental change (*van Dam 1982*). The

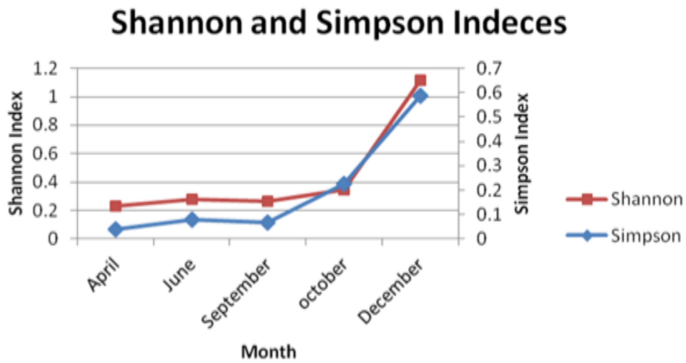

Figure 10. Shannon-Weiner Index and Simpson Index covering the four sampling sites for the 5 sampling periods in Boracay Island, Malay, Aklan (2012).

variations in the chemical composition of natural marine waters, geographical characteristics of the area, and wind action that affect the distribution of nutrients in water were believed to be the important factors in regulating the abundance, composition and influence the growth of diatoms as observed in this study. The high nutrient concentrations and loading resulted in increased production and changes in the species composition of phytoplankton (*Colijn et al. 2002*). Land use at adjacent areas of the different study sites probably provides an important nutrient load, leading some species to grow, reproduce and diversify, restructuring the phytoplankton assemblage as a whole (*Ferrareze and Nogueira 2006*).

Chlorophyll *a* Concentration as Affected by Nutrients and other Environmental Factors

In many ecosystems, phytoplankton biomass (chlorophyll *a* concentration) is correlated with the availability of N or P (*Cloern 2001; Bledsoe et al. 2004*). The chlorophyll *a* concentration in specific coastal water indicates the relative amount of nutrients utilized by phytoplankton for growth and reproduction. Knowledge of the changes of the photosynthetic activity of phytoplankton, primary production, biomass accumulation and communityassemblages provide important indicators in evaluating the effect of nutrients input into the aquatic system (*Rakocevic-Nedovic and Hollert 2005; Ekwu and Sikoki 2006; Uttah et al. 2008*). Nutrient inputs to the aquatic system favor phytoplankton growth and reproduction even in a small lotic environment like a stream (*Raji et al. 1996*).

There is positive correlation between chlorophyll *a* and groups of phytoplankton at different levels. It is attributed to its response to nutrient circulations which were responsible for the observed spatial distribution pattern, since diatoms, dinoflagellates and cyanophycean would have different nutrient requirements. nd cyanophytes would have different nutrient requirements. There were also other equally important factors in determining distribution, such as water exchange and currents. Data tended to show that with increasing chlorophyll *a*, there was increase in genera of diatoms (combined data). In Lugotan Cove, chlorophyll *a* was positively correlated with the genera of all identified groups of phytoplankton and particularly was highly significant with diatoms (*r*=.995; *p*=0.011) (**Table 6**).

The three study sites, except Lugotan Cove, had relatively similar concentration of chlorophyll *a* all throughout the sampling periods (**Figure 11**). Lugotan Cove showed an irregular concentration of chlorophyll *a* which had its peak level in April, October and December. The result of the chlorophyll *a* pattern in Lugotan Cove showed a close relationship with peak of tourist arrivals in the Island. It can be supported by the fact that the Lugotan Cove had shown a poor water quality based on the results of the biophysico-chemical analyses of water samples.

The relatively lower chlorophyll *a* concentration reading in Yapak Beach can be supported by the physicochemical condition of the coastal waters in this site where lesser nutrient inputs were recorded. High level of nutrients increased population or average density of phytoplankton thus the high recorded level of chlorophyll *a* in Lugotan Cove. It exhibited the assimilative capacity of the system where nutrients released were absorbed by the primary producers.

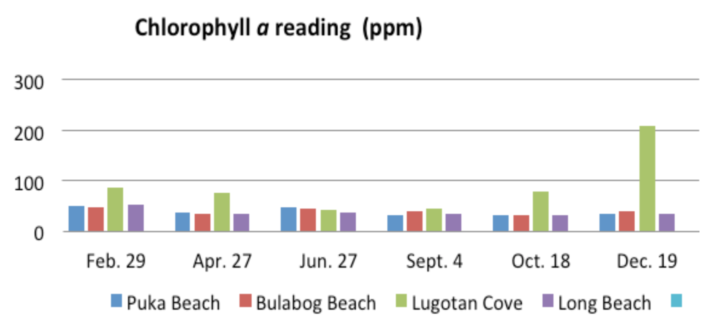

Figure 11. Chlorophyll *a* reading (in ppm) in study area Boracay Island (2012).

SUMMARY, CONCLUSION AND RECOMMENDATIONS

The distribution, diversity and abundance of phytoplankton in the coastal waters of Boracay Island were closely associated to the land use and anthropogenic activities of the adjacent terrestrial ecosystem. There were four major phytoplankton groups identified from samples taken in four coastal study sites in Boracay Island, Malay, Aklan. These were the Diatoms (Bacillariophyceae)

Silicoflagellates, Dinoflagellates (Dinophyceae) and Blue green algae (Cyanophyceae). Of these, diatoms were the most abundant, while the cyanophycean and Dinoflagellates were the least abundant. The Simpson Index of Dominance was recorded at slightly higher value of 2.0 and the Shannon-Weiner Index at 0.9 which implied that there was a group of phytoplankton genera that dominated the coastal waters of Boracay Island. These genera were *Tintinnopsis* (Silicoflagellates), *Coscinodiscus* (Diatoms) and *Chaetoceros* (Diatoms). Lugotan Cove can be considered as critical area because of its poor water quality considering that it has higher phytoplankton density and chlorophyll *a* concentration, while lowest in terms of phytoplankton genera diversity compared with other three study sites.

The occurrence of macro algal proliferation in Boracay was not uncommon. The recorded high level of nutrients indicated eutrophic waters. The three major autotrophs (seagrasses, phytoplankton, and macroalgae) absorbed the nutrients for their growth and reproduction. The data from this study showed that the primary producers of the coastal water, seagrass and phytoplankton were still capable of assimilating the nutrient inputs from the anthropogenic activities. However, the growth plateau of cyanophycean reaching K indicated that the Island ecosystem is near its ecological thresholds.

This study can serve as baseline data to determine if the threshold is already reached using phytoplankton as indicator. Phytoplankton monitoring can be used as biological indicator and can give feedback on the quality of water as influenced by land use and nutrient inputs contributed by anthropogenic activities. It must be given due attention so that proactive strategies will be formulated and implemented to curtail the possible sources of pollution and to rehabilitate and maintain the good water quality of the Island. As such, phytoplankton monitoring should be conducted and institutionalized to determine the impact of nutrient loading to the coastal water, and can provide feedback on the ecological status of the coastal ecosystem particularly the quality of the coastal waters of Boracay Island. Implementation of strong multi-sectoral monitoring system is deemed necessary. As such, parameters such as concentration of nutrients (phosphates and nitrates) must be included.

Strengthening of the governance system is necessary for people to follow the precepts and policies towards the discharge of waste water to the coastal waters. These necessitate the protection and conservation of existing mangrove swamps which purify water before going to the coastal waters (*Gearheart 1993*). The government should foster appropriate action with true partnership and collaboration with the private sector and other stakeholders. The existing management practices should be flexible enough to incorporate changes arising from results of scientific studies.

Implementers should strictly impose the proper land use plan and institute actions and policies to mitigate the pollution loading in the coastal waters such as complete connection of structures to the sewerage system or strictly require all establishments to establish their waste water treatment facilities. The LGU could pass an ordinance requiring all business entities to institute their waste water treatment system prior to the issuance of building permit.

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