Water quality of Puerto Princesa Bay in relation to the presence of informal settlers in its coastal areas

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ABSTRACT

In this study, the water quality of four coastal areas in Puerto Princesa Bay, with and without informal settlers, were compared in terms of the phytoplankton composition and density, fecal coliform and physicochemical parameters during a 12-month sampling period. Microscopic examination and identification using phytoplankton monographs showed five harmful algal blooms (HABs) genera (*Alexandrium, Dinophysis*, *Nitzschia*, *Pseudo-nitzschia*, and *Pyrodinium*) with *Dinophysis* spp. as the most abundant in coastal areas with informal settlers and *Pseudo-nitzschia* spp. in areas without informal settlers. Eight phytoplankton genera (*Coscinodiscus*, *Proboscia*, *Rhizosolenia*, *Skeletonema*, *Ceratium*, *Prorocentrum*, *Protoperidinium*, and *Oscillatoria*) reported to have caused algal blooms were also observed with *Coscinodiscus* spp. as the most abundant in both groups of coastal areas. Multiple-tube fermentation technique showed fecal coliform count ranging from 4 to >1600 most probable number (MPN)/100 ml in the coastal areas with informal settlers and from <1.8 to 295 MPN/100 ml in areas without informal settlers. Multiprobe measurements showed that both groups of coastal areas have similar physicochemical characteristics with only the dissolved oxygen failing to meet the Philippine standards for class SB waters. There was a significant difference ($P < 0.05$) in water quality between the coastal areas with and without informal settlers in terms of fecal coliform and the density of four phytoplankton genera (*Pseudo-nitzschia*, *Skeletonema*, *Alexandrium* and *Ceratium*). However, there is no significant difference in terms of the physicochemical parameters. Regression analysis indicates that the presence of informal settlers could affect water quality in terms of fecal coliform and the five phytoplankton genera (*Coscinodiscus*, *Pseudo-nitzschia*, *Skeletonema*, *Alexandrium* and *Ceratium*).

Keywords: blue-green algae, diatoms, dinoflagellates, fecal coliform, physicochemical properties, phytoplankton

INTRODUCTION

Puerto Princesa Bay, situated in the capital city of Palawan, is one of the major fishing grounds in the province. Because of its strategic location, the bay was subjected to influx of migrants who built their homes in the coastal areas (Gonzales 2004). The study of Cuebillas et al. (2016) stated that 4,680 households in Puerto Princesa City (9.8% of its total household population) are informal settlers, with 3,260 households living along the coastal areas of the city. The largest contributor of these informal settlers is Barangay Bagong Silang with 729 households (73.2% of its total household population), followed by Barangay San Pedro with 491 households (13.3% of its total household population). In addition, Barangay Bagong Silang has the highest number of households (60.8%) without access to sanitary toilet facility, while Barangay San Pedro comes fourth (7.5% of its total household).

Coastal communities with no sanitary toilets, directly discharge their wastes into the surface or coastal waters (DENR EMB-XI 2022). This discharge of untreated sewage wastewater may lead to water pollution problems such as eutrophication, algal growth, decrease in recreational uses of water, pathogen-causing diseases, excessive loss of dissolved oxygen, and undesirable changes in the population of aquatic resources (Owili 2003; Akpor and Munchie 2011).

Changes in water quality in the coastal areas can negatively affect the biotic components of the surrounding environment in various ways. First, many phytoplankton, including diatoms, dinoflagellates, and

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cyanobacteria can produce toxins or grow excessively resulting in harmful algal blooms (HABs). These blooms may harm humans, causing illness or death from eating contaminated shellfish or fish, and may also cause massive mortalities of fish, seabirds and other marine mammals (Borja et al. 2019). Secondly, pathogenic bacteria from anthropogenic sources, can affect the quality of both wild fish and aquaculture resources, and consequently the health of the consumers (Raña et al. 2017). Lastly, the physical properties of water can influence the distribution of aquatic organisms while its chemical properties can affect the type of organisms' present (Shilpa et al. 2012).

Puerto Princesa Bay has been categorized as class SB by the DENR-EMB (2022) which indicates that its waters are suitable for commercial propagation of shellfish, as spawning grounds for milkfish and similar species, for ecotourism, and for primary contact recreation (DENR 2016). These intended uses of the bay were compromised when the Bureau of Fisheries and Aquatic Resources (BFAR) declared Puerto Princesa Bay to be positive for red tide toxin in 30 January 2017. This was the first recorded incidence of toxic red tide in the bay which lasted for five weeks. In the same year, the second incidence was reported in 03 July 2017, which lasted for twenty weeks. The red tide in Puerto Princesa Bay continued to recur in the following years, with the latest occurring from July 2019 until early February 2020 (BFAR 2017, 2018, 2019, 2020). The reported causative organism was *Pyrodinium bahamense* (Palawan News 2018).

This study was conducted to determine the water quality on the coastal areas of Puerto Princesa Bay, with the presence and absence of informal settlers, in terms of phytoplankton density and composition, fecal coliform, and physicochemical parameters. This study also determined if there is a significant difference between the water quality in the coastal areas with the presence and absence of informal settlers and whether the presence of informal settlers in the coastal areas could affect the water quality in Puerto Princesa Bay.

METHODS

Research Areas

This study was conducted at four coastal areas in Puerto Princesa Bay (Figure 1). Two areas, Purok Abanico (Brgy. San Pedro) and Quito (Brgy. Bagong Silang) are inhabited by informal settlers with houses built on stilts in the coastal waters. The other two areas, Caña Island (Brgy. Tiniguiban) and Brgy. Mangingisda, have no informal settlers living in its coastal waters. Caña Island is known for its abundant shells while Brgy. Mangingisda has a fish port and many fish pens.

Water Sampling

Water sampling was conducted once a month for 12 months from April 2018 to March 2019. The water samples were collected at 100 to 200 m from the shoreline between 08:00 to 12:00.

Phytoplankton composition and density determination. Three water samples were collected by towing horizontally below the water surface a 20 µm mesh size plankton net securely tied in a motorboat moving at low speed for 5 min. A flow meter (General Oceanic Inc., USA) was tightly bound to the plankton net. Water samples were placed in clean bottles, fixed with 3 to 5 ml of 10% formalin, and stored in a cooler.

The phytoplankton was quantified using a Sedwick-Rafter counting chamber with the aid of an inverted microscope (Cole-Parmer, USA) and photographed using android phone camera. Photographs of phytoplankton presented in this paper such as the identified and considered as harmful based on the following taxonomic monographs for diatoms, dinoflagellates, and blue-green algae (Al-Kandari et al. 2009; Okolodkov 2010; Kim et al. 2013) were taken using android phone camera and an LB-243 Biological Trinocular Microscope (USA) with digital camera from different water samples obtained throughout the 12-month sampling period. The harmful species were verified using the IOC-UNESCO Taxonomic Reference List of Harmful Micro Algae (Lundholm et al. 2009 onwards).

Phytoplankton density was calculated using the equation below:

$$N = n \; x \; \frac{v}{V}$$

where N = total number of phytoplankton cells L^{-1} of water filtered; n = number of phytoplankton cells in 1 ml sample; v = volume of phytoplankton concentration (ml); V = volume of water (L) filtered thru plankton (obtained from flow meter reading).

Fecal coliform analysis. A 350 ml water sample was collected by direct scooping in duplicate. The water samples were collected one foot below the water surface, placed in sterilized bottles, stored in a cooler, and delivered to the Department of Science in Technology–Mindoro Marinduque Romblon Palawan Regional Standards and Testing Laboratory (DOST-MIMAROPA RSTL) in Puerto Princesa City, with 4 to 7 h holding time. The Multiple-Tube Fermentation Technique was used to estimate the fecal coliform density which was expressed in most probable number (MPN)/100 ml.

Physicochemical analyses. Measurement on subsurface water were done in triplicate. The physicochemical parameters measured *in situ* were pH, temperature, dissolved oxygen, and salinity. The pH was determined by dipping a pH meter (Lutron PH-223, Taiwan) on subsurface water while the temperature, dissolved oxygen and salinity were measured using a YSI Professional Plus Multiparameter Meter (USA). The total dissolved solid was measured *ex situ* at the Palawan State University–Marine Science laboratory (PSU-MSL) using HORIBA LACQUAact PC110 (Japan).

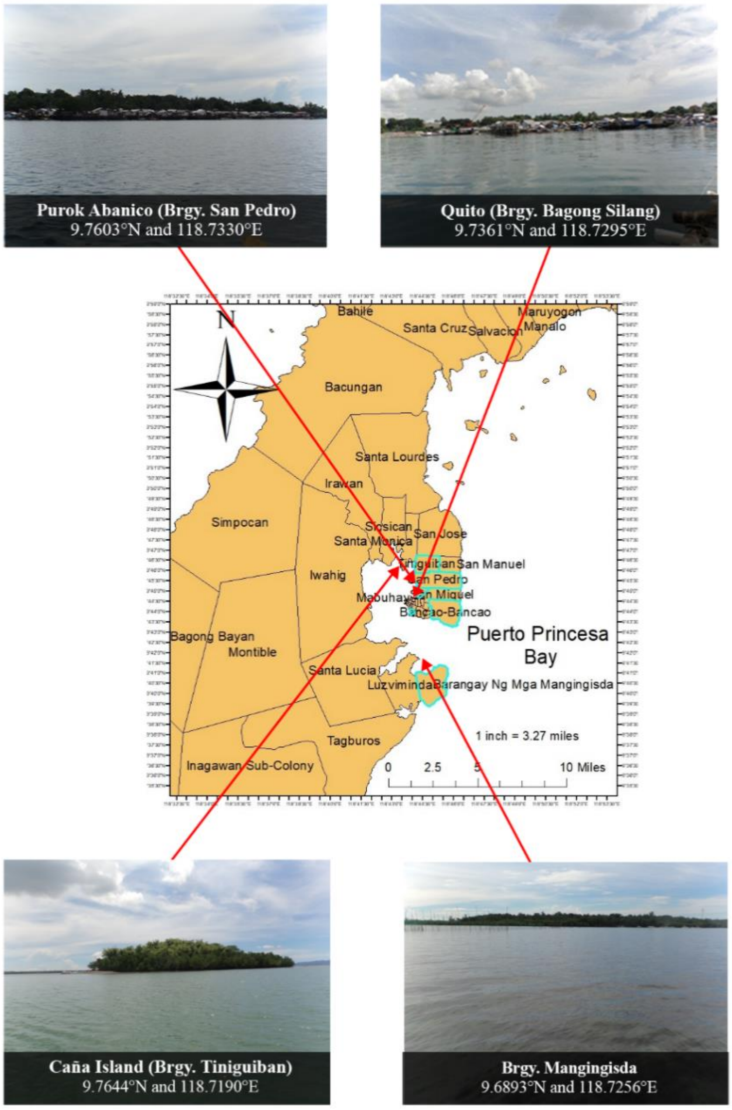

Figure 1. A map showing Puerto Princesa Bay and the four coastal areas as sampling sites.

Statistical Analysis

Kruskal Wallis was used to determine the significant difference between the water quality on the coastal areas with and without informal settlers. Logistic regression was employed to determine if the presence or absence of informal settlement in the coastal areas could affect the water quality. Both statistical methods were tested in terms of phytoplankton composition and density, fecal coliform, and physicochemical parameters.

RESULTS

Phytoplankton Composition and Density

The phytoplankton found in four coastal barangays fall under 13 genera. Of which, six were diatoms, six were dinoflagellates, and one was a blue-green alga (Table 1). The diatoms *Coscinosdicus* spp., *Nitzschia* spp., *Proboscia* spp., *Pseudonitzschia* spp., *Rhizosolenia* spp., and *Skeletonema* spp., and the blue-green alga *Oscillatoria* spp. were observed in both coastal areas with the presence and absence of informal settlers. Four dinoflagellate genera were also present in both sites which include *Ceratium* spp., *Dinophysis* spp., *Prorocentrum* sp., and *Protoperidinium* spp. However, *Pyrodinium* sp. along with *Alexandrium* spp. were found only in coastal areas with informal settlers.

In the first coastal area inhabited by informal settlers, Purok Abanico (Table 2), *Coscinodiscus* spp. had the highest total density among the 11 species observed while *Proboscia* spp. and *Nitzchia* spp. had the lowest. In addition, *Coscinodiscus* spp. and *Ceratium* spp. were consistently present for 10 months (June 2018 to March 2019.) The highest phytoplankton density (23,086 cells L^{-1}) in Purok Abanico occurred in June 2018 while the next highest density was observed in January 2019. Four HABs genera were observed which were present from August to December 2018, with *Alexandrium* spp. as the most abundant (Table 2).

In the second coastal area with informal settlers, Quito (Table 3), *Rhizosolenia* spp. had the highest total density among the 12 species seen while *Pyrodinium* sp. had the lowest. *Ceratium* spp. was seen throughout the 12-month sampling period, while *Coscinodiscus* spp. and *Rhizosolenia* spp. appeared for a period of ten months. Similar with Purok Abanico, four HABs genera were observed in Quito which were present for six months, with *Dinophysis* spp. as the most abundant (Table 3).

In the first coastal area with the absence of informal settlers, Caña Island (Table 4), *Coscinodiscus* spp. had the highest total density among the 10 species found while *Proboscia* spp. had the lowest. *Coscinodiscus* spp. and *Ceratium* spp. appeared all throughout the 12-month sampling period. Two HABs genera were observed, with *Pseudo-nitzschia* spp. as the more abundant and was present for eight months (Table 4).

In the second coastal area without informal settlers, Brgy. Mangingisda (Table 5), *Coscinodiscus* spp. had the highest total density among the 11 species identified while *Oscillatoria* spp. had the lowest. *Coscinodiscus* spp. was seen throughout the 12-month sampling period while *Ceratium* spp. appeared in the water samples for a period of eleven months. June 2018 exhibited the densest phytoplankton species (23,479 cells L^{-1}) for this site followed by 3,768 cells L^{-1} in July 2018. Similar with Caña Island, the same two HABs genera were observed, with *Dinophysis* spp. as the more abundant but was only present for two months (Table 5).

Comparing the harmful phytoplankton species, three HABs genera (*Nitzschia*, *Pseudo-nitzschia*, *Dinophysis*) were present in both groups of coastal areas with *Dinophysis* spp. as the most abundant in the coastal areas with informal settlers and *Pseudo-nitzschia* spp. in the coastal areas without informal settlers. Two other HABs genera (*Alexandrium* and *Pyrodinium*) were observed only in the coastal areas with informal settlers with *Alexandrium* sp. as the more abundant.

The species of diatoms, dinoflagellates, and blue-green algae found in four coastal areas of Puerto Princesa Bay were presented in Figures 2,3, and 4, respectively.

Table 1. Composition of phytoplankton genera of four coastal areas in Puerto Princesa Bay. Harmful species (Lundholm et al. 2009 onwards) are written in bold. Note: √ (present); - (absent).

	Coastal areas with informal settlers		Coastal areas without informal settlers	
Phytoplankton Taxa	**Abanico**	**Quito**	**Caña**	**Mangingisda**
Diatom				
Coscinodiscus spp.	√	√	√	√
Nitzschia spp.	√	-	√	√
Proboscia spp.	√	√	√	√
Pseudonitzschia spp.	√	√	√	√
Rhizosolenia spp.	√	√	√	√
Skeletonema spp.	√	√	√	√
Dinoflagellate				
Alexandrium spp.	√	√	-	-
Ceratium spp.	√	√	√	√
Dinophysis spp.	√	√	√	√
Prorocentrum sp.	-	√	-	√
Protoperidinium spp.	√	√	√	√
Pyrodinium sp.	-	√	-	-
Blue-Green Algae				
Oscillatoria spp.	√	√	√	√

Table 2. Composition and density of phytoplankton in the coastal area of Purok Abanico. Harmful species (Lundholm et al. 2009 onwards) are written in bold.

Taxa	Density (Total number of phytoplankton cells L^{-1} of water filtered)												
	2018									2019			Total
	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	
Diatom													
Coscinodiscus spp.			23,069	512	341	1,671	767	341	409	6,172	648	341	34,271
Nitzschia spp.					17								17
Proboscia spp.		17											17
Pseudo-nitzschia spp.							68		239				307
Rhizosolenia spp.				2,285	34	17	136						2,472
Skeletonema spp.		1,961									648		2,609
Dinoflagellate													
Alexandrium spp.						324							324
Ceratium spp.			17	239	17	2,046	341	154	307	85	870	495	4,571
Dinophysis spp.						17	17	102					136
Protoperidinium spp.							102						102
Blue- Green Algae													
Oscillatoria spp.					34		375						409
Total		1,978	23,086	3,036	443	4,075	1,806	597	955	6,257	2,166	836	45,325

Table 3. Composition and density of phytoplankton in the coastal area of Quito. Harmful species (Lundholm et al. 2009 onwards) are written in bold.

Taxa	Density (Total number of phytoplankton cells L^{-1} of water filtered)												
	2018									2019			Total
	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	
Diatom													
Coscinodiscus spp.	1,773	17	495	1,535	682	972	341		341	8,372		3,223	17,751
Proboscia spp.		205	801	1,569									2,575
Pseudo-nitzschia **spp.**					239								239
Rhizosolenia spp.	699	2,864	1,091	1,790	290		392		1,552	2,080	938	13,248	24,944
Skeletonema spp.				699		136	580		307			1,859	3,581
Dinoflagellate													
Alexandrium spp.	51		324				17						392
Ceratium spp.	205	1,125	2,268	2,080	68	17	443	136	154	6,735	631	1,091	14,953
Dinophysis spp.	17		392		34	801				1,756			3,000
Prorocentrum sp.						68							68
Protoperidinium spp.	68		426		17		17	17		1,790			2,335
Pyrodinium sp.							34						34
Blue-Green Algae													
Oscillatoria spp.					188		1,876						2,064
Total	2,813	4,211	5,797	7,673	1,518	1,994	3,700	153	2,354	20,733	1,569	19,421	71,936

Table 4. Composition and density of phytoplankton in the coastal area of Caña Island. Harmful species (Lundholm et al. 2009 onwards) are written in bold.

Taxa	Density (Total number of phytoplankton cells L^{-1} of water filtered)												
	2018									2019			Total
	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	
Diatom													
Coscinodiscus spp.	188	222	801	1,790	119	870	733	699	7,485	7,928	801	9,088	30,724
Nitzschia spp.	750	1,790	205										2,745
Proboscia spp.	205			17	290		17						529
Pseudo-nitzschia **spp.**	1,586	818	904	154	921	136	136			51			4,706
Rhizosolenia spp.	597	870	171	34	136	17	51		4,331	4,075	1,279	2,933	14,494
Skeletonema spp.	477	1,074	222	938	119	51		375			921	1,807	5,984
Dinoflagellate													
Ceratium spp.	597	580	580	7,093	512	1,500	256	1,040	1,057	5,644	1,074	1,944	21,877
Dinophysis spp.		85		34			34	341		256			750
Protoperidinium spp.								495	716	580	836	307	2,934
Blue-Green Algae													
Oscillatoria spp.	921	6,360	2,200	392		102							9,975
Total	5,321	11,799	5,083	10,452	2,097	2,676	1,227	2,950	13,589	18,534	4,911	16,079	94,718

Table 5. Composition and density of phytoplankton in the coastal area of Brgy. Mangingisda. Harmful species (Lundholm et al. 2009 onwards) are written in bold.

Taxa	Density (Total number of phytoplankton cells L^{-1} of water filtered)												
	2018									2019			Total
	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	
Diatom													
Coscinodiscus spp.	614	853	23,069	1,398	614	1,228	136	563	546	409	597	136	30,163
Nitzschia spp.		102											102
Proboscia spp.	102			648			34						784
***Pseudo-nitzschia* spp.**	34	17						136					187
Rhizosolenia spp.	68						409				1,023	1,177	2,677
Skeletonema spp.	102	68	256	256	818	460		392	375	307			3,034
Dinoflagellate													
Ceratium spp.	358	750	154	1,449	1,790	529	239	2,148		426	307	188	8,338
***Dinophysis* spp.**					51	188							239
Prorocentrum sp.								171					171
Protoperidinium spp.	85	392		17	68	34	290	85					971
Blue- Green Algae													
Oscillatoria spp.							85						85
Total	1,363	2,182	23,479	3,768	3,341	2,439	1,193	3,495	921	1,142	1,927	1,501	46,751

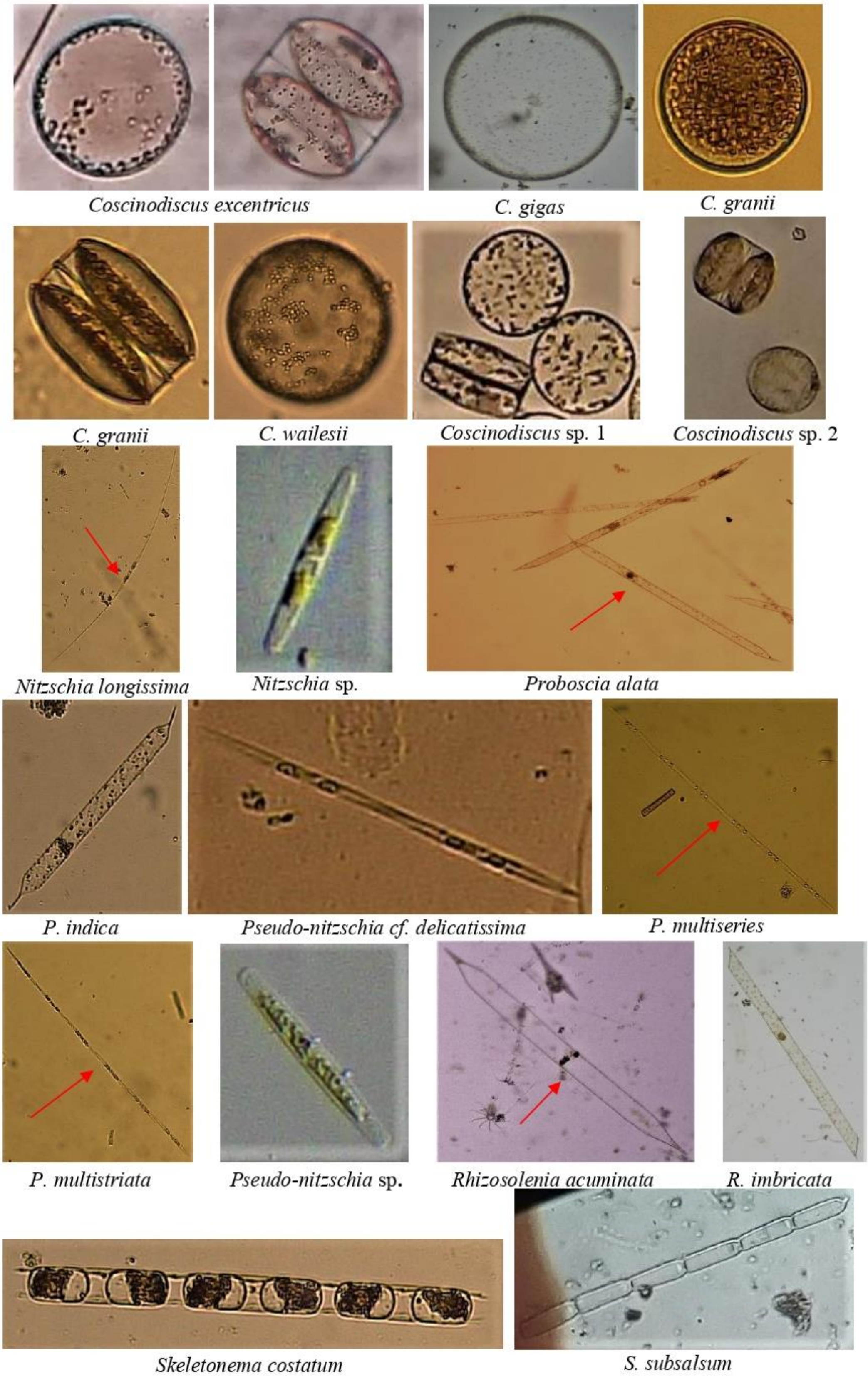

Figure 2. The diatoms species found in the coastal areas of Puerto Princesa Bay.

Figure 3. The dinoflagellate species found in the coastal areas of Puerto Princesa Bay.

Figure 4. The blue-green algae species found in the coastal areas of Puerto Princesa Bay.

Fecal Coliform

The highest fecal coliform count (> 1600 MPN/100 ml) was recorded in September 2018 in the coastal areas with the presence of informal settlers (Table 6). Moreover, this month gave the highest readings for all sampling sites. The lowest fecal coliform count (< 1.8 MPN/100 ml) was recorded in April 2018 in the two coastal areas without informal settlements, and again in Brgy. Mangingisda in January 2019.

Physicochemical Characteristics

The water temperatures in Puerto Princesa Bay ranged from 25.2 to 32.1ºC (Table 7). The mean temperature of water varies closely between the coastal areas with the presence and absence of informal settlers. The pH values ranged from 7.6 to 9.2. The highest observed pH was in Quito (April 2018) and the lowest in Brgy. Mangingisda (September 2018). The dissolved oxygen (DO) in the four coastal areas ranged from 3.2 to 6.8 mg L^{-1}. The mean DO values for both sites with the presence and absence of informal settlers do not vary much. The salinity ranged from 14.2 to 48.9 ppt, with the lowest value observed in Caña Island in December 2018 and the highest value measured in Quito in April 2018. The total dissolved solids (TDS) ranged from 8.2 to 24.2 ppt in the four sampling sites. The lowest TDS value was observed in Quito (November 2018) and the highest in Brgy. Mangingisda (April 2018).

Water Quality in Relation to the Presence of Informal Settlers

Kruskal-Wallis statistical analysis identified four phytoplankton genera which are significantly different in terms of their density between the coastal areas with the presence and absence of informal settlers at $P < 0.05$ (Table 8). These include *Pseudo-nitzschia*, *Skeletonema*, *Alexandrium*, and *Ceratium*. There is also a significant difference in the fecal coliform in the coastal areas with and without informal settlers. On the other hand, there is no significant difference observed in the physicochemical characteristics of the coastal areas with the presence and absence of informal settlers.

Regression analysis indicates that the presence of informal settlements in the coastal areas can affect both the fecal coliform and the composition and density of five phytoplankton genera - *Coscinodiscus*, *Pseudo-nitzschia*, *Skeletonema*, *Alexandrium*, and *Ceratium* (Table 9).

DISCUSSION

Phytoplankton Composition and Density

The five phytoplankton genera – *Nitzschia, Pseudo-nitzschia, Dinophysis, Alexandrium,* and *Pyrodinium* – present in the coastal areas with informal settlers are included in the IOC-UNESCO Taxonomic Reference List of Harmful Micro Algae (Lundholm et al. 2009 onwards). Incidentally, the first three genera were also observed in coastal areas without informal settlers. Both the diatom genera *Nitzschia* and *Pseudo-nitzschia* are capable of producing the neurotoxin domoic acid (DA), the causative agent of amnesic shellfish poisoning (ASP) (Sahraoui et al. 2011; Su et al. 2017). The toxin accumulates in shellfish and consumption of such results in intoxication including memory loss, disorientation, gastrointestinal and respiratory distress, and ataxia, which may lead to death via respiratory paralysis (Kadiri and Isagba 2018).

The remaining three HABs genera - *Dinophysis*, *Alexandrium*, and *Pyrodinium* - are dinoflagellates. Many *Dinophysis* species are capable of producing diarrhoetic toxins and pectenotoxins, the causative agents of diarrhetic shellfish poisoning (DSP). Gastrointestinal illness may occur immediately after consumption of contaminated shellfish, even at low cell densities (Reguera et al. 2014). On the other hand, several species of the genus *Alexandrium* and a single species of *Pyrodinium* (*P. bahamense*) can cause paralytic shellfish poisoning through the production of saxitoxin which accumulates in shellfish. Eating contaminated mollusks such as clams, oysters, and mussels can lead to various gastrointestinal and neurologic symptoms, which in extreme cases, is fatal (Band-Schmidt et al. 2019). Both *Alexandrium*, and *Pyrodinium* were only observed in coastal areas inhabited by informal communities.

Both the coastal areas with the presence and absence of informal settlers were found to have high densities of two diatom genera (*Coscinodiscu*s and *Rhizosolenia*) and a dinoflagellate genus (*Ceratium*). Although these phytoplankton are not included the IOC-UNESCO Taxonomic Reference List of Harmful Micro Algae (Lundholm et al. 2009 onwards), reports were found that these genera caused fish and shellfish mortalities. In Omani waters, blooms of *Coscinodiscus* species caused a massive fish kill (13,000 t0 27,000 kg of fish) in 2000 while *Ceratium* species triggered a mass mortality of marine organism in 1998 (Gheilani et al. 2011). In 1987, a bloom *Rhizosolenia chunii* in Port Phillip Bay, southeastern Australia, caused the mussels, scallops and flat oysters to develop an unpleasant and persistent bitter taste which eventually led to high shellfish mortality 3 to 8 months after the bloom had ended (Parry et al. 1989).

Table 6. Fecal coliform count of four coastal areas in Puerto Princesa Bay. Note: nd = no data due to unavailability of media and other reagents for fecal coliform analysis.

Sampling Site	Fecal Coliform (MPN/100 ml)											
	2018									2019		
	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar
Coastal areas with informal settlers												
Abanico	12.35	920	183.5	195	nd	>1600	1600	10.4	390	445	74.5	67.5
Quito	67.2	186.5	19	32.5	nd	>1600	6.4	19.5	30	4	185	17
Coastal areas without informal settlers												
Caña Island	<1.8	41	3.2	5.4	nd	295	5.6	7.8	6.2	71.8	4.9	10.8
Mangingisda	<1.8	8.8	1.9	1.9	nd	71	4.8	8.6	4.9	<1.8	22.5	110.9

Table 7. Physicochemical characteristics of four coastal areas in Puerto Princesa Bay.

Sampling Site	Physicochemical Parameters									
	Temperature (°C)		pH		DO (mg L^{-1})		Salinity (ppt)		TDS (g L^{-1})	
	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean
Coastal areas with informal settlers										
Quito	27.4-31.5	29.3	8.2-9.2	8.38	3.5-6.5	5.4	14.2-48.8	40.9	9.5-16.7	12.5
Abanico	28.0- 32.1	29.7	8.0-8.7	8.38	4.0-6.6	5.3	28.8-48.6	40.9	8.2-23.6	12.2
Coastal areas without informal settlers										
Caña Island	27.7-31.6	29.6	8.1-8.5	8.29	3.3-6.5	4.9	14.2-48.8	40.9	9.5-16.7	12.5
Mangingisda	25.2-31.2	28.3	7.6-8.8	8.44	3.2-6.8	5.1	28.9- 48.3	43.4	8.4-24.2	13.0

Table 8. Significant difference between the water quality of four coastal areas in Puerto Princesa Bay with and without informal settlers. Note: ** significant at $P < 0.01$; * significant at $P < 0.05$.

Parameter	Kruskal-Wallis	
	Computed Value	Significant Value
Phytoplankton		
Diatoms		
Coscinodiscus spp.	1.616	0.204
Nitzschia spp.	2.185	0.139
Proboscia spp.	0.859	0.354
Pseudo-nitzschia spp.	7.694	0.006 **
Rhizosolenia spp.	0.006	0.940
Skeletonema spp.	6.912	0.009 **
Dinoflagellates		
Alexandrium spp.	4.265	0.039 *
Ceratium spp.	7.985	0.005 **
Dinophysis spp.	0.153	0.696
Prorocentrum sp.	0.001	0.976
Protoperidinium spp.	2.201	0.138
Pyrodinium sp.	0.000	1.000
Blue-Green Algae		
Oscillatoria spp.	0.207	0.649
Fecal Coliform	12.075	0.001 **
Physicochemical		
Temperature (ºC)	1.407	0.236
pH	0.254	0.614
DO (mg L^{-1})	1.358	0.244
Salinity (ppt)	0.011	0.918
TDS (g L^{-1})	0.310	0.578

Table 9. Water quality in relation to the presence of informal settlers in four coastal areas of Puerto Princesa Bay. Note: ** significant at $P < 0.01$; * significant at $P < 0.05$.

Parameter	Logistic Regression (df=1)	
	Statistical Value	Significant Value
Phytoplankton		
Diatoms		
Coscinodiscus spp.	4.092	0.043*
Nitzschia spp.	2.860	0.091
Proboscia spp.	0.690	0.406
Pseudo-nitzschia spp.	8.145	0.004 **
Rhizosolenia spp.	0.000	1.000
Skeletonema spp.	8.043	0.005 **
Dinoflagellates		
Alexandrium spp.	4.181	0.041*
Ceratium spp.	6.063	0.014 *
Dinophysis spp.	0.222	0.637
Prorocentrum sp.	0.080	0.777
Protoperidinium spp.	2.037	0.154
Pyrodinium sp.	-	-
Blue-Green Algae		
Oscillatoria spp.	0.315	0.575
Fecal Coliform	5.199	0.023 *
Physicochemical		
Temperature (ºC)	2.111	0.146
pH	0.006	0.940
DO (mg L^{-1})	1.003	0.317
Salinity (ppt)	0.193	0.660
TDS (g L^{-1})	0.094	0.760

The less abundant phytoplankton genera found in Puerto Princesa Bay include *Proboscia*, *Skeletonema*, *Prorocentrum*, *Protoperidinium*, and *Oscillatoria*. There were also reports that these genera produced either toxic or nontoxic blooms. One study showed that a bloom of the diatom *Proboscia alata* occurred in 2009 in the coastal sea off Bekal, India resulting in pale brown discoloration of water (Thomas et al. 2014). Another study showed that a dense bloom of diatoms *Skeletonema costatum* and *Thalassiosira* species in British Columbia, Canada resulted in gill lesions and mortality in Atlantic salmon reared in the area. This was the first report of fish kill caused by these diatoms (Kent et al. 1995). Moreover, studies showed that *Prorocentrum minimum* and *P. cordatum* cause mass aquaculture fish kills in Japan, Philippines and Singapore while *P. rhathymum* can cause DSP, similar with *Dinophysis* species (Yñiguez et al. 2021). In 2019, a brownish-red dense bloom of *Protoperidinium steinii* was observed in the tropical Indian waters, but did not cause mortality in marine organisms (Sathishkumar et al. 2021). Lastly, *Oscillatoria acutissima* was reported to have caused massive fish mortality in the Alexandrian waters in Egypt (Ismael 2012).

The months that exhibited the highest density of toxic and potentially toxic phytoplankton in Puerto Princesa Bay were June 2018 and January 2019. The next highest density of these phytoplankton was observed in July 2018, January 2019, and March 2019. Interestingly, the recorded incidences of red tide in Puerto Princesa Bay for the last three years occurred during these months (BFAR 2017, 2018, 2019, 2020; Puerto Princesa 2017) or close to these periods.

Fecal Coliform

The coastal areas with the absence of informal settlers passed the Philippine standard for Class SB waters in terms of fecal coliform, which is 100 MPN/100 ml (DENR 2016), throughout the sampling period with the exception of Caña Island in the month of September (295 MPN/100 ml) and Brgy. Mangingisda in the month of March (110.9 MPN/100 ml).

On the other hand, coastal areas with the presence of informal communities exceeded the limit of Philippine standard for Class SB waters for fecal coliform for most months, with the highest count at > 1600 MPN/100 ml. Only in the months of March, April, and November did these areas have fecal coliform counts within the limit set by DENR (2016). As previously stated, these sites have many houses built on stilt with residents that directly discharge human wastes on coastal areas.

The fecal coliform count was found to be highest (> 1600 MPN/100 ml) in September, during the rainy season and lowest (< 1.8 MPN/100 ml) in April, a dry season. These findings are parallel with Latha and Mohan (2013) that explained that the presence of fecal coliform bacteria in water indicates water pollution. These pathogenic microorganisms from human and animal wastes can contaminate fish and other marine organisms which in turn can pose serious health threat to human consumers, particularly in cases of extreme fecal contamination in seawater. Such situation can also affect the environmental quality and the over-all economy of the country (Echapare et al. 2019).

Physicochemical Characteristics

The average temperature in the four coastal areas is within (or close to) the limit set by the Philippine standard for Class SB waters, which is 26° to 30°C (DENR 2016). In addition, the temperature range (25.2 to 32.1 ºC) in the four coastal areas is good for phytoplankton growth which requires an optimum temperature ranging from 20° to 30ºC (Veronica et al. 2014). Similarly, the pH average values for all sampling sites (8.29 to 8.44) are within the permissible limits of the Philippine standard for Class SB waters, which is 7.0 to 8.5 (DENR 2016).

The average dissolved oxygen (4.9 to 5.4 mg L^{-1}) in the four coastal areas is below the permissible limits of the Philippine standard for Class SB waters, which is 6.0 mg L^{-1} (DENR 2016). Puerto Princesa Bay is a harbor for fishing and commercial boats. The water has domestics rubbish and oil spills from boats, in addition to untreated sewage and domestic waste from coastal communities surrounding the bay (Yap et al. 2011). According to Bozorg-Haddad et al. (2021), the introduction of organic wastes, such as domestic and animal sewage, can greatly reduce the DO in water. This is alarming since most aquatic organisms need oxygen to survive; in particular, fish cannot survive for long in water with DO < 5 mg L^{-1}. Thus, low DO in water is a sign of contamination. In addition, Seo et al. (2019) explained that DO and pH have a negative relationship with fecal coliform. The proliferation of coliform bacteria leads to consumption of DO and the production of carbon dioxide results in a decrease in pH.

The Philippine standards for water quality did not set a limit for both salinity and total dissolved solids in coastal waters (DENR 2016). The wide range of salinity (14.2 to 48.9 ppt) in the four coastal areas may be due to freshwater runoff during rainy season resulting in low salinity and high evaporation rate near shallow areas during summer leading to high salinity (AMSAT 2008). On the other hand, the total dissolved solids in the coastal waters may have come from agricultural runoff and leaching of soil contaminants (Yap et al. 2011).

Water Quality in Relation to the Presence of Informal Settlers

Two water quality parameters showed significant difference at $P < 0.05$ between the coastal areas with and without informal settlers. These include fecal coliform and the density of the four phytoplankton genera – *Pseudo-nitzschia*, *Skeletonema*, *Alexandrium*, and *Ceratium*. In addition, the positive statistical values in Kruskal-Wallis indicate that the density of all phytoplankton genera is higher in the coastal areas with the presence of informal settlers, but the difference is not significant in some phytoplankton. Likewise, there is no significant difference in the physicochemical parameters between the coastal areas with the presence and absence of informal settlers.

In regression analysis, the higher the statistical value and the lower the significant value ($P < 0.05$), the higher is the tendency for a particular parameter to be affected by the presence of informal settlement in the coastal areas. The parameters that could be affected by the presence of informal settlers in coastal areas include fecal coliform and the five phytoplankton genera (*Coscinodiscus*, *Pseudo-nitzschia*, *Skeletonema*, *Alexandrium* and *Ceratium*) which are all significant at $P < 0.05$. It can be deduced from the result of linear regression that these five phytoplankton genera will thrive in water contaminated with fecal coliform.

Based on the results of this study and in light of the recurring incidence of red tide in Puerto Princesa Bay, it is highly recommended that the local government should provide policies for the management of human-caused sources of pathogenic bacteria, to keep the fecal contamination within a range considered safe for human health and to prevent its contribution to harmful or potentially harmful algal blooms. Relocation programs of the local government unit may be strengthened and information campaigns may be organized to increase the awareness of the local residents on the impacts of informal settlements on the water quality of Puerto Princesa Bay.

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REFERENCES

Akpor OB and Munchie M. 2011. Environmental and public health implications of wastewater quality. African Journal of Biotechnology, 10(13): 2379-2387. https://doi.org/10.5897/AJB10.1797

Al-Kandari M, Al-Yamani FY and Al-Rifaie K. 2009. Marine Phytoplankton Atlas of Kuwait's Waters. Kuwait Institute for Scientific Research, Safat. Kuwait. 351pp.

AMSAT (Australian Marine Science and Technology Ltd). 2008. ASEAN Marine Water Quality: Management Guidelines and Monitoring Manual. https://environment.asean.org/wp-content/uploads/2015/07/ASEAN-MarineWater QualityManagementGuidelinesandMonitoringManual.pdf. Accessed on 20 July 2020.

Band-Schmidt CJ, Durán-Riveroll LM, Bustillos-Guzmán JJ, Leyva-Valencia I, López-Cortés DJ, Núñez-Vázquez EJ, Hernández-Sandoval FE and Ramírez-Rodríguez DV. 2019. Paralytic Toxin Producing Dinoflagellates in Latin America: Ecology and Physiology. Frontiers in Marine Science, 6(42): 1-39. https://doi.org/10.3389/fmars.2019.00042

Borja VM, Furio EF, Gatdula NC and Iwataki M. 2019. Occurrence of harmful algal blooms caused by various phytoplankton species in the last three decades in Manila Bay, Philippines. Philippine Journal of Natural Sciences, 24: 80-90.

Bozorg-Haddad O, Delpasand M and Loáiciga HA. 2021. Water Quality, Hygiene, and Health. In: Bozorg-Haddad O (ed). Economical, Political, and Social Issues in Water Resources, Elsevier, pp. 217-257. https://doi.org/10.1016/B978-0-323-90567-1.00008-5

BFAR (Bureau of Fisheries and Aquatic Resources). 2017. Bureau of Fisheries and Aquatic Resources Shellfish Bulletin, Series of 2017. https://www.bfar.da.gov.ph/redtide. Accessed on 28 July 2020.

BFAR (Bureau of Fisheries and Aquatic Resources). 2018. Bureau of Fisheries and Aquatic Resources Shellfish Bulletin, Series of 2018. https://www.bfar.da.gov.ph/redtide. Accessed on 28 July 2020.

BFAR (Bureau of Fisheries and Aquatic Resources). 2019. Bureau of Fisheries and Aquatic Resources Shellfish Bulletin, Series of 2019. https://www.bfar.da.gov.ph/redtide. Accessed on 28 July 2020.

BFAR (Bureau of Fisheries and Aquatic Resources). 2020. Bureau of Fisheries and Aquatic Resources Shellfish Bulletin, Series of 2020. https://www.bfar.da.gov.ph/redtide. Accessed on 28 July 2020.

Cuebillas AMD, Defensor CKC, Esguerra JLC, Falcon FEB, Mejico MSF and Padilla MJDP. 2016. ECAN Resource Management Plan of Puerto Princesa City, Palawan (2017-2022). University of the Philippines Los Baños and Palawan Council for Sustainable Development. 276pp.

DENR (Department of Environment and Natural Resources). 2016. Water Quality Guidelines and General Effluent Standards of 2016. DENR Administrative Order No. 2016-08. https://emb.gov.ph/wp-content/uploads/2019/04/DAO-2016-08.pdf. Accessed on 08 March 2022.

DENR-EMB (Department of Environment and Natural Resources - Environmental Management Bureau). 2022. Region 4B list of waterbodies. DENR EMB Environmental Quality Management Division, Water Quality Management Section. https://water.emb.gov.ph/?page_id=765/. Accessed on 08 March 2022.

DENR-EMB XI (Department of Environment and Natural Resources Environmental Management Bureau - XI). 2022. Water Quality Management. http://r11.emb.gov.ph/water-quality-management/. Accessed on 19 January 2022.

Echapare EO, Pacala FAA, Mendańo RV, Araza JB. 2019. Physico-chemical and microbial analysis of water in Samar mussel farms. The Egyptian Journal of Aquatic Research, 45(3): 225-230. https://doi.org/10.1016/j.ejar.2019.05.007

Gheilani HMA, Matsuoka K, AlKindi AY, Amer S and Waring C. 2011. Fish kill incidents and harmful algal blooms in Omani waters. Agricultural and Marine Sciences, 16: 23-33. https://doi.org/10.24200/jams.vol16iss0pp23-33

Gonzales BJ. 2004. Puerto Princesa Bay and Honda Bay, Palawan: An ecological profile. Fisheries Resource Management Project Technical Monograph Series, No. 8, 28pp.

Ismael AA. 2012. Benthic bloom of cyanobacteria associated with fish mortality in Alexandria waters. The Egyptian Journal of Aquatic Research, 38(4): 241-247. https://doi.org/10.1016/j.ejar.2013.01.001

Kadiri MO and Isagba S. 2018. Amnesic Shellfish Poisoning (ASP) and Paralytic Shellfish Poisoning (PSP) in Nigerian Coast, Gulf of Guinea. Frontiers in Marine Science, 5: 1-6. https://doi.org/ 10.3389/fmars.2018.00481

Kent ML, Whyte JNC and LaTrace C. 1995. Gill lesions and mortality in seawater pen-reared Atlantic salmon *Salmo salar* associated with a dense bloom of *Skeletonema costatum* and *Thalassiosira* species. Diseases of Aquatic Organisms, 22: 77-81.

Kim HY, Kim SH, Jung MM and Lee JB. 2013. New record of dinoflagellates around Jeju Island. Journal of Ecology and Environment, 36(4): 273-291. https://doi.org/10.5141/ecoenv.2013.273

Latha N and Mohan MR. 2013. Microbial pollution- total coliform and fecal coliform of Kengeri lake, Bangalore region Karnataka, India. International Journal of Scientific and Research Publications, 3(11): 1-3.

Lundholm N, Churro C, Fraga S, Hoppenrath M, Iwataki M, Larsen J, Mertens K, Moestrup Ø and Zingone A. 2009 onwards. IOC-UNESCO Taxonomic Reference List of Harmful Micro Algae. https://doi.org/10.14284/362

Okolodkov YB. 2010. Ceratium Schrank (Dinophyceae) of the National Park Sistema Arrecifal Veracruzano, Gulf of Mexico, with a key for identification. Acta Botánica Mexiň, 93: 41-101. https://doi.org/10.21829/abm93.2010.275

Owili MA. 2003. Assessment of Impact of Sewage Effluents on Coastal Water Quality in Hafnarfjordur, Iceland. The United Nations University - Fisheries Training Programme, Iceland, 39pp.

Palawan News. 2018. Red tide explained. https://www.pressreader.com/Philippines /palawan-news/20180708/281560881550342. Accessed on 01 July 2020.

Parry GD, Langdon JS and Huisman J. 1989. Toxic effects of a bloom of the diatom *Rhizosolenia chunii* on shellfish in Port Phillip Bay, Southeastern Australia. Marine

Biology, 102: 25-41. https://doi.org/10.1007/BF00391320

Puerto Princesa. 2017. Puerto Princesa Bay Positibo sa Red Tide, Pagkain ng Shellfish Ipinagbabawal. http://puertoprincesa.ph/?q=articles/puerto-princesa-bay-positibo-sa-red-tide-pagkain-ng-shellfish-ipinagbabawal. Accessed on 15 March 2018.

Raña JA, Domingo JE, Opinion AGR and Cambia FD. 2017. Contamination of coliform bacteria in water and fishery resources in Manila Bay aquaculture farms. The Philippine Journal of Fisheries, 24(2): 98-126. https://doi.org/10.31398/tpjf/24.2.2016A0015

Reguera B, Riobó P, Rodríguez F, Díaz PA, Pizarro G, Paz B, Franco JM and Blanco J. 2014. *Dinophysis* toxins: causative organisms, distribution and fate in shellfish. Marine Drugs, 12: 394-461. https://doi.org/10.3390/md12010394

Sahraoui I, Bates SS, Bouchouicha D, Mabrouk HH, Hlaili AS. 2011. Toxicity of *Pseudo-nitzschia* populations from Bizerte Lagoon, Tunisia, southwest Mediterranean, and first report of domoic acid production by *P. brasiliana*. Diatom Research, 26(3): 293-303. https://doi.org/10.1080/0269249X.2011.597990

Seo M, Lee H and Kim Y. 2019. Relationship between coliform bacteria and water quality factors at Weir Stations in the Nakdong River, South Korea. Water, 11(6): 1-16. https://doi.org/10.3390/w11061171

Sathishkumar RS, Sahu G, Mohanty AK, Arunachalam KD and Venkatesan R. 2021. First report of *Protoperidinium steinii* (Dinophyceae) bloom from the coastal marine ecosystem – an observation from tropical Indian waters. Oceanologia, 63(3): 391-402. https://doi.org/10.1016/j.oceano.2021.04.003

Shilpa P, Chonde S, Aasawari J and Raut PD. 2012. Impact of Physico-Chemical Characteristics of Shivaji University lakes on Phytoplankton Communities, Kolhapur, India. Research Journal of Recent Sciences, 1(2): 56-60.

Su SNP, Nasur DM and Usup G. 2017. Screening of toxic marine *Nitzschia* species (Bacillariophyceae) in Malaysia. Indonesian Journal of Marine Science and Technology, 10(1): 97-102.

Thomas AM, Sanilkumar M, Vijayalakshmi K, Abdulla MH and Saramma AV. 2014. *Proboscia alata* (Brightwell) Sandström bloom in the coastal waters off Bekal, Southwest India. Current Science, 106(12): 1643-1645.

Veronica E, Leksono AS, Soemarno and Arfiati D. 2014. Effect of water quality on phytoplankton abundance in Hampalam River and fish pond of Batanjung Village. Journal of Environmental Science, Toxicology and Food Technology, 8(1): 15-21.

Yap CK, Chee MW, Shamarina S, Edward FB, Chew W and Tan SG. 2011. Assessment of surface water quality in the Malaysian coastal waters by using multivariate analyses. Sains Malaysiana, 40(10): 1053–1064.

Yñiguez AT, Lim PT, Leaw CP, Jipanin SJ, Iwataki M, Benico G and Azanza RV. 2021. Over 30 years of HABs in the Philippines and Malaysia: What have we learned? Harmful Algae,102. https://doi.org/10.1016/j.hal.2020.101776

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