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Physico-chemical and biological characteristics of water and sediment in the mariculture zone park of Sto. Tomas, La union

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Abstract

Mariculture Park Program launched by DA-BFAR in the early 2000 primary aimed to promote sustainable supply of food, ensure job generation, and strengthen local development. In La Union, one of the two mariculture parks established is the Sto. Tomas MZP situated in Sto. Tomas Cove, Sto. Tomas, La Union. Formally launched in October 2002 with 60 HDPE fish cages maintained, the MZP has been a source of significant volume of quality milkfish. This study was designed to assess the effect of the mariculture activity on water quality and sediment. Specifically, it aimed to determine the physical, chemical, and biological characteristics of water and sediment in MZP Sto. Tomas and correlate water and sediment parameters with chlorophyll and phytoplankton. Samplings were conducted in the three established stations in MZP Sto. Tomas from February to May 2020. Water quality parameters (temperature, dissolved oxygen, salinity, pH, ammonia, nitrite, arsenic, cadmium, lead, mercury, fecal and total coliform count, chlorophyll, and phytoplankton density and composition) were analyzed for three months and sediment quality (color, organic matter, phosphorous, potassium, moisture content, pH, arsenic, mercury, lead, mercury) was analyzed for one month. Results showed spatial and temporal variability among selected water quality and no spatial variability among sediment quality from different stations. Of the twelve physico-chemical and biological parameters, ten passed the Philippine Standards. Twenty-eight species belonging to five phytoplankton groups were recorded. Sediment quality of the MZP Sto. Tomas is within range of the different International environmental standards. Correlation analysis revealed significant differences ($p>0.05$) in phytoplankton density and temperature, and strong correlation between temperature and chlorophyll.

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Introduction

Aquaculture has been developing rapidly for the previous decades and now dominates the fisheries sector. It contributes a significant supply of quality food for the consuming public and considered at the front line of the national government's programs to sustain food security and alleviate poverty. In the Philippines, top two (2) commodities produced which are commercially important are seaweeds and milkfish, among other aquaculture commodities such as shrimp, grouper, tilapia, siganids, and mussels. In 2020, the estimated total volume of fisheries production was 4,403.71 metric tons (MT), with total aquaculture production recorded at 2,324 MT contributing 52.7% in the total fisheries production (Philippine Statistics Authority, 2020).

The intensification of aquaculture was conceptualized by the government in partnership with private sectors due to the declining catch of marine fishes from small-scale or municipal fisheries and commercial fishing boat operators. From 2002 to 2010, commercial fisheries grew slightly from 1.042 million MT in 2002 to 1.24 million MT in 2010; however, it declined thereafter to 1.094 million MT in 2015 and 0.975 million MT in 2020. Aquaculture on the other hand, constantly and significantly contributes to fisheries production, similarly in terms of volume and value. Production from aquaculture since 2005 has been contributing 46%–52% to the total fisheries production, and accounts to 34%–39% to total production value (Ferrer *et al.*, 2017). As such, the importance of aquaculture as a major source of food and generates employment today and in the future was given emphasis. It then became as one of the main programs of the government to increase the incremental fisheries production in the country. Nevertheless, owing to various aspects of planning, implementation, and monitoring, along with weak local fishery regulations, aquaculture practices particularly in fish cages in some areas, faced environmental degradation thereby resulting to fish kill occurrences. The coastal environment and the socio-economic welfare of the marginalized group still remain as major concerns.

Among the sectors of aquaculture, marine fish farming or mariculture of finfish in pens and cages, shellfish particularly oyster and mussel, and seaweed, contributes to about 73% of aquaculture production, and about 63% shares of seaweed farming (PSA, 2020). Fresh, brackish, and marine water cultures using fish pens and cages contribute 10%–12% in the total aquaculture production, but it has potential to increase rapidly. In the year 2010 for instance, only 2,700ha from the 50,150 ha of the 62 mariculture parks in the country was developed by a 2,199 investors and the Bureau of Fisheries and Aquatic Resources (BFAR) (Salayo *et al.*, 2012).

Philippine mariculture is defined as the culture or rearing of finfishes, shellfish, seaweeds and other commodities in marine environment using different structures such as cages, pens, stakes and rafts (Salayo *et al.*, 2012). Usually, cages or pens are used for fin fishes adopting either monoculture (single species) or polyculture (multiple species) system. In the country, mariculture has been practiced for more than 600 years, but only in the year 1965 when fish cages were first introduced for the culture of common carp in Laguna de Bay seconded by milkfish culture in fish pens in the early 1970s. Milkfish culture in fish pens spread to Lingayen Gulf in the early 1990s whereas fish cages proliferate in Taal Lake. HDPE cages otherwise known as Norwegian cages were introduced in Sual Bay, Pangasinan in 1996 purposely for salmon culture (Ferrer *et al.*, 2017). However, the development of mariculture has been difficult to monitor, and at times unregulated, especially on the aspect of stocking and feeding practices.

Fish farmers are not monitored during the installation of structures, thus, cages of any number and size are installed simply anywhere. The situation inevitably led to mass fish kills in cages and other environmental problems in some areas (Ferrer *et al.*, 2017). But with technological innovations, mariculture of seafood in coastal and open marine areas is now reliably supplying increasing amounts of protein. Based on PSA Report (2020), marine aquaculture production has reached 81,850.56 MT and 102,294.57 MT in 2019 and 2020 respectively.

In the early 2000, the DA-BFAR introduced the Program on Mariculture Park so as to promote sustainable supply of food, ensure job generation, and improved income in order to encourage development in local level. It is a community-based marine type of project with the involvement of the organized fisherfolk within a coastal community through the assistance of the Municipal Fisheries and Aquatic Resources Management Councils (MFARMC). In La Union, there are two (2) mariculture parks established, one in Rosario and one in Sto. Tomas. Rosario Mariculture Zone Park is located in Barangay Bani and established in 2007. The Sto. Tomas MZP is situated in Sto. Tomas Cove located along the western side of Sto. Tomas, La Union.

The Cove was chosen to be the site of the Mariculture Zone Park (MZP) because it is a sheltered area that could protect the mariculture structures from strong winds, waves and currents during the southwest monsoon. Formally launched in October 2002, the mariculture zone is complimentary to make the area attractive to tourists. The ten (10) hectare mariculture area is covered by the Agoo-Damortis Protected Landscapes and Seascape (ADPLS), hence, it is managed by the Protected Area Management Board (PAMB) of the Department of Environment and Natural Resources (DENR).

The actual and possible effects of marine fish farming in cages on the environment, especially in water quality, are of utmost concern of the government agency in particular, to develop an ecologically responsible industry. A suitable water quality is required to sustain a feasible aquaculture production and the growing aquaculture industry. Unsuitable water quality may have led to less profit from poor quality of the product and potential risks to human health. There is a reduced production when the water contains contaminants which may lead to impaired growth and development, reproduction, or even mortality to the cultured species. Some of the contaminants can accumulate up to the point whereit threatens human health even in low quantities and cause no evident adverse effects. The environmental quality of water and the associate components of an aquatic ecosystem cannot be evaluated without learning the bottom sediment characteristics (Avramidis *et al.*, 2013). The sediment stratum is an important habitat for the benthic macro invertebrates whose metabolic activities contribute to aquatic productivity.

Recognizing the importance of Sto. Tomas Cove as a resource area and the critical role of its water quality in sustaining intensive aquaculture enterprises in the mariculture park, it is the paramount concern of the researcher to analyze the current status of the water and sediment quality in terms of its physical, chemical, and biological characteristics, and to correlate these parameters to the primary productivity of the MZP.

Materials and methods

Research design

This study is an experimental type of research using Complete Randomized Design (CRD) to determine the different variables of water and sediment. Likewise, a correlation research design was applied to determine the relationship between primary productivity (chlorophyll-a and phytoplankton density) and water and sediment quality.

Collection site

Water and sediment samples were collected in identified sampling sites. The first station situated in 16°14' 54.43"N and 120°22'47.24"E has Norwegian cage stocked with milkfish which is approximately 760meters away from the next site. The second station has the same structure with the first site situated in 16°14'35.28"N and 120°23'3.60"E. The third station has no cages in the area, which is approximately 1.1km away from the second site, has coordinates 16°14'11.61"N and 120°23'31.62"E (Figs 1&2).

Table 1. Location and description of sampling station in Mariculture Zone Park of Sto. Tomas, La Unio

Station	GPS coordinates		Description
	Latitude (N)	Longitude (E)	
1	16°14' 54.43"N	120°22'47.24"E	Norwegian cage owned by Mr. Medriano, stocked with milkfish Approximately 760 meters away from Station 2
2	16°14'35.28"N	120°23'3.60"E	Norwegian cages owned by Mr. Hilario, stocked with milkfish Approximately 105 meters away from BFAR Station
3	16°14'11.61"N	120°23'31.62"E	No cages in the area, approximately 1.1 km away from Station 2

Fig. 1. Map showing the sampling stations

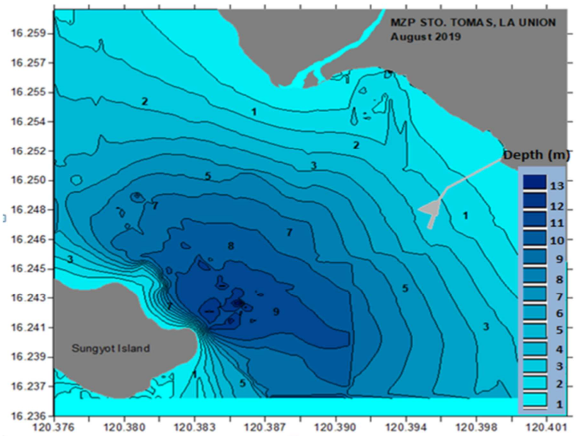

Fig. 2. Bathymetric profile of MZP Sto Tomas, La Union

Sample collection

Three (3) liters of water samples were collected in the sub surface of every sampling stations using water sampler. The collected samples were properly labelled and placed in a cooler box with coolant and brought to the laboratory for chemical (ammonia and nitrite), biological (chlorophyll-a), and heavy metal (arsenic, mercury, lead, cadmium) analysis. Separate water samples for microbiological analysis were collected in the sub surface using a sterilized glass sampling bottles covered with aluminum foil. Water samples were collected using the water sampler. The water samples were placed in a separate cooler box with coolant to avoid contamination and brought to the laboratory for the analysis of total and fecal coliform bacteria. A 20 µm mesh size plankton net with water collector was used in the collection of water sample for plankton density and composition.

A total of three (3) samples of sediment were gathered using a soil grabber to about 10 meters depth. The grab has a hinge and lockable inspection flaps constructed with 0.5 mm mesh. The grab was slowly released to the water until it reaches the bottom part of the sites. Once it reaches the seabed, the rope connecting the grab was carefully pulled up allowing the grab to enclose with the collected sediment inside. One-two grab samples were taken at each site to complete the desired quantity for laboratory analysis and was placed in a plastic container with wide opening and labelled with site identification.

Data gathered

Physico-chemical characteristics of the water such as temperature, dissolved oxygen, salinity, and pH were gathered *in situ* at sub-surface level. The water ammonia and nitrite was analyzed using BFAR-NIFTDC's procedures, whereas chlorophyll-a was analyzed using the extraction fluorescence method of Guo *et al.* (2008). Total and fecal coliform content of collected water samples were analyzed using the Most Probable Number (MPN) method of bacteriological analysis. Water samples collected and submitted to CRL Environmental Corporation Laboratory were analyzed using Inductively Coupled Plasma – Optical Emission Spectroscopy (ICP-OES) for arsenic, cadmium and lead determination and Manual Cold Vapor Atomic Absorption Spectrophotometry for mercury determination. Plankton density was computed based on the description of the Photo Guide to cyanobacteria (IOC- IOC-Danida Advanced

Workshop on HAB. Workshop IV: Cyanobacteria, 2004) using the formula of: D= (N×V1)/Vs.

Sediment samples were analyzed following the Walkley and Black Spectrophotometric method for organic matter, Olsen method for available phosphorous, Cold Sulfuric Acid Extraction Flame Atomic Emission Spectroscopy method for available potassium, Feel method for texture, Gravimetric method for moisture content, and Potentiometric/Conductimetric method for pH and electrical conductivity for heavy texture samples. The method for arsenic determination followed the procedure of the Inductively Coupled Plasma – Optical Emission Spectroscopy, Flame Atomic Absorption Spectrophotometry (AAS) for cadmium and lead, and Manual Cold Vapor Atomic Absorption Spectrophotometry for mercury.

Data analysis

Data recorded on physico-chemical and biological characteristics of water and sediment quality were analyzed using Kruskal-Wallis Test and Pairwise Comparisons at 5% level of significance.

Likewise, correlation analysis on primary productivity (chlorophyll-a and phytoplankton density) between water and sediment quality was done using Bivariable Analysis of data using Inter-Basal Statistical Product and Service Solutions (version 27).

Results and discussion

Water physico-chemical and biological characteristics

There was no observed spatial variability among water quality like temperature, dissolved oxygen, salinity, pH, ammonia, arsenic, cadmium, lead, mercury, fecal coliform, chlorophyll, and phytoplankton density, from the different monitoring stations which means that fewer but more evenly-spaced monitoring stations are recommended for the MZP (Table 2a-b, Figs 3, 4&5). Dissolved oxygen and pH have exceeded the DENR-DAO directive for Class SC waters, while others (temperature, salinity, ammonia, arsenic, cadmium, lead, mercury, fecal and total coliform, chlorophyll, and phytoplankton density) are all within desirable level as compared to standards. Fecal coliform was not detected in all stations, whereas total coliform was detected only at Station 1.

Table 2a. Mean values of water parameters in MZP Sto. Tomas

Water parameters	Station 1	Station 2	Station 3	Mean	DENR standard*
Temperature (°C)	28.89±1.39	28.93±1.48	28.92±1.52	28.84±1.29	25-31
DO (ppm)	5.03±0.43	4.73±0.52	5.32±0.42	5.07±0.47	5
Salinity (ppt)	36.00±2.36	35.83±2.04	35.00±3.162	35.70±2.39	None
pH	8.64±0.15	8.68±0.09	8.71±0.10	8.68±0.11	6.5-8.5
Ammonia (mg/L)	0.032±0.024	0.027±0.03	0.04±0.03	0.037±0.027	0.05
Nitrite (mg/L)	0.013±0.009 [b]	0.009±0.006[a]	0.012±0.007 [b]	0.011±0.006	<0.1***
Arsenic (mg/L)	< 0.008	< 0.008	< 0.008	0.008±0.00	0.02
Cadmium (mg/L)	<0.001	<0.001	<0.001	0.001±0.00	0.005
Lead (mg/L)	<0.005	<0.005	<0.005	0.005±0.00	0.05
Mercury (mg/L)	<0.0002	<0.0002	<0.0002	0.0002±0.00	0.002
Fecal Coliform (MPN/100ml)	0.00±0.00	0 .00±0.00	0.00±0.00	0.00±0.00	200**
Total Coliform (MPN/100ml)	0.79±1.36 [a]	0.00±0.00[b]	0.00±0.00 [b]	0.26±.851	5,000**
Chlorophyll (mg/m3)	0.006±0.008	0.006±0.006	0.005±0.008	0.005±0.007	None
Phytoplankton density (cells/Li)	3.8945×10^3 ±6608.05	2.494×10^3 ±3947.23	4.6×10^3 ±8724.53	3.655×10^3 ±6278.82	None

References: *DAO 2016-08, ** DAO 1990-34 (Class SB & SC), ***PHILMINAQ, 2006

[a] Mean values in a column having superscripts differ significantly at .05 level of significance.

Phytoplankton density is most abundant at Station 3 and least at Station 2 which is composed mainly of diatoms (Bacillariophyceae) and dinoflagellates (Dinophyceae). Twenty eight (28) phytoplankton species were identified from the three (3) stations, covered by five (5) classes namely, Bacillariophyceae, Dinophyceae, Oligotrichea, Mediophyceae, and Raphidophyceae.

Table 2b. Mean values of water parameters in the MZP Sto. Tomas per sampling (February to May 2020)

Parameters	Sampling					
	Initial (February 18)	First (March 3)	Second (March 17)	Third (March 31)	Fourth (April 14)	Final (May 14)
Temperature (°C)	27.53 ±0.13[ab]	27.30 ±0.084[a]	28.85 ±0.093[b]	29.13 ±.0.04[bc]	29.26 ±.0.05[cd]	31.38 ±.0.15[d]
DO (ppm)	5.00±0.25[a]	5.35±0.18[a]	4.99±0.487[b]	5.46±0.312[a]	5.17±0.225[b]	4.28±0.29[bc]
Salinity (ppt)	34.29±2.45[a]	39.33±0.48[b]	37.36±0.496[b]	35.00±0.00[a]	35.00±0.00[a]	32.64±0.501[a]
pH	8.70±0.027[ab]	8.66±0.060[b]	8.66±0.022[b]	8.819±0.062[cd]	8.70±0.084[a]	8.52±0.133[e]
Ammonia (mg/L)	0.048±0.004[a]	0.052±0.0067[a]	0.043±0.038[a]	No data	No data	0.00±0.00[b]
Nitrite (mg/L)	0.016±0.003[a]	0.013±0.003[a]	0.0014±0.0012[b]	No data	No data	0.016±0.005[a]
Arsenic (mg/L)	0.008±0.00	-	-	-	-	-
Cadmium (mg/L)	0.001±0.00	-	-	-	-	-
Lead (mg/L)	0.005±0.00	-	-	-	-	-
Mercury (mg/L)	0.0002±0.00	-	-	-	-	-
Fecal Coliform (MPN/100ml)	0.00 ±0.00	0.00 ±0.00	No data	0.00 ±0.00	No data	0.016 ±0.0046
Total Coliform (MPN/100ml)	1.05 ±1.48	0.00 ±0.00	No data	0.00±0.00	No data	0.016 ±0.0046
Chlorophyll-a (mg/m³)	0.017 ±0.001[a]	0.0016 ±0.0004[bc]	0.001 ±0.000[b]	No data	No data	0.003 ±0.002[cd]
Plankton density (cells/Li)	1.6937 × 10⁴ ±4963.24[a]	5.856 × 10² ±86.014[b]	7.7749 × 10² ±302.354[bc]	7.812 × 10² ±608.11[b]	1.4409 × 10³ ±240.012[cd]	1.6632 × 10³ ±228.611[ac]

* Mean values in a column having different superscripts differ significantly at .05 level of significance. Arsenic, Cadmium, Lead, and Mercury were sampled only once, during the initial sampling

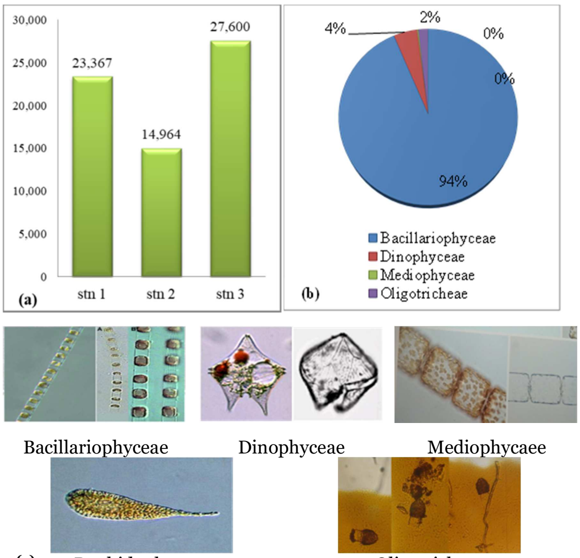

Fig. 3. Plankton density (a), over all species composition (b), and representative genera (c) in MZP Sto.Tomas

Significant differences (p<0.05) were noted on nitrite and total coliform in all stations. Temporal variations in water quality parameters like temperature, dissolved oxygen, salinity, pH, ammonia, nitrite, chlorophyll, and phytoplankton density were detected. The highest temperature was recorded during the final sampling on May 2020, whereas the lowest temperature was recorded during the first sampling on the month of March.

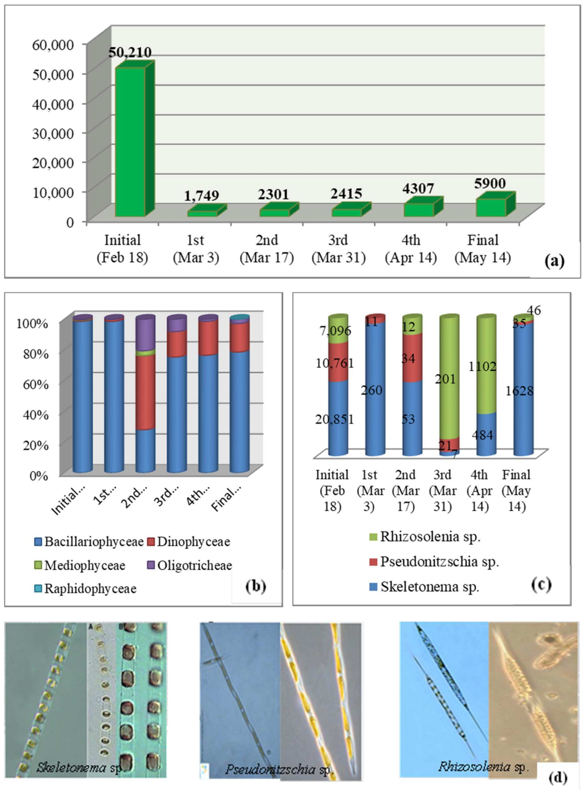

Fig. 4. Plankton density (a), composition (b,c), and abundant species (d) per sampling

The range of dissolved oxygen during the sampling was 4.28 ppm to 5.46 ppm, with the highest mean value recorded during the third sampling and lowest during the final sampling on May. Highest salinity value of 39.33 ppt was recorded during the first sampling period, and lowest value of 32.64 ppt during the final sampling. The third sampling had the highest pH mean value of 8.81, and lowest value of 8.52 during the final sampling on May 2020. Ammonia level ranged from 0.00 mg L^{-1} to 0.052±0.03 mg L^{-1}, highest level was recorded during the first sampling period and lowest during the final sampling. Highest nitrite level is recorded during the initial and final sampling (0.016 mg L^{-1}) and lowest during the second sampling. Fecal coliform is not detected in all sampling. On the other hand, total coliform was only recorded during the initial sampling on February.

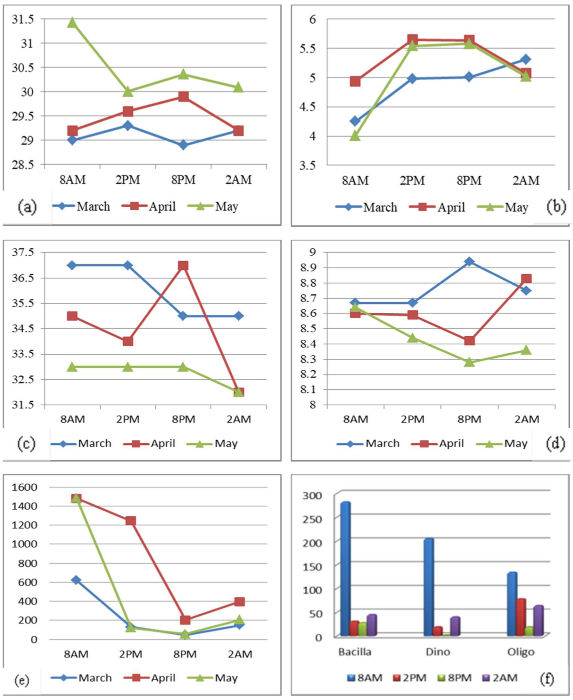

Fig. 5. Water quality (a-temperature, b-DO, c – Salinity, d-pH, e-Phytoplankton density, f-species composition) of Station 2, MZP Sto. Tomas during diurnal sampling

Chlorophyll mean values were recorded at a range of 0.0016 mg m^3 to 0.017 mg m^3, wherein the highest value was recorded during the initial sampling and lowest on the first sampling on the month of March. Phytoplankton was most abundant during the initial sampling on a hot, sunny day of February and lowest during the first sampling. *Skeletonema* sp. belonging to Class Bacillariophyceae is highest at 20,851 cells L^{-1} during the initial sampling, whereas *Pseudonitzschia* sp. was lowest during the first sampling at 11 c cells L^{-1}. Statistical analysis using Krukal-Wallis test showed that temperature, DO, salinity, pH, ammonia, nitrite, chlorophyll, and phytoplankton density are statistically significant ($p<0.05$). These variations are attributed to natural causes such as tidal fluctuations and rainfall. As regard to the diurnal sampling in Station 2, temporal variability (6 hours interval) was not observed among water quality (temperature, dissolved oxygen, salinity, pH, and phytoplankton density) from different monitoring time. However, temporal variability was detected across sampling of water quality (temperature, salinity, pH) for the 3-month diurnal sampling. Highest temperature was noted in 8:00 AM sampling on the final sampling and lowest on 8:00 PM of the initial sampling on March. Significant differences ($p<0.05$) was observed in temperature across the sampling periods from March to May. DO was lowest in 8:00 AM of the final sampling, and highest during 2:00 PM of the first sampling on April. Same salinity was recorded during sampling in the morning (8:00 AM), evening (8:00 PM), and dawn (2:00 AM) at 35.00±2.00 ppt. pH value is highest at 8:00AM and lowest in the evening and dawn. A significant difference ($p<0.05$) was observed in pH ($p=0.048$) across the sampling periods from March to May. Highest density of phytoplankton ($1.201 \times 10^3 \pm 494.54$) is recorded in the morning (8:00 AM) sampling period and lowest in the evening (8:00 PM) sampling ($1.016 \times 10^2 \pm 87.85$). Phytoplankton density was highest when the temperature is highest at the same time of 8:00 AM, during the final sampling. Twenty three (23) phytoplankton species were identified from the diurnal sampling. These species cover three (3) classes namely, Bacillariophyceae, Dinophyceae, and Oligotricheae.

Sediment physico-chemical and biological characteristics

In terms of sediment quality, Station 2 has black-colored sediment as compared to the other two (2) Stations wherein mariculture is minimal or absent. Data obtained for some parameters like organic matter content, phosphorous, and potassium are baseline data (Table 3). The highest organic matter content (%) is recorded at Station 2 with 3.05, followed by Stations 1 and 2. Station 1 has the highest available phosphorous with 37.93 ppm, followed by Station 2 and Station 3 with 33.66 ppm and 28.22 ppm, respectively. The highest available potassium was obtained at Station 2 with 1,375.87 ppm, followed by Station 1 with 968.65 ppm and Station 3 with 936.09 ppm. The highest recorded moisture content is at Station 3 with 9.06% and lowest moisture content of 7.64% in Station 2. Station 1 has the lowest pH values of 6.73 and highest pH values of 8.31 in Station 3. Stations 1 and 2 have the same electrical conductivity levels of 0.02 mS cm^{-1} while Station 3 is the lowest at 0.02mS cm^{-1}. Results of the initial analysis of composite sediment samples on 2016 shows the concentrations of Arsenic have greatly increased from 1.6 ppm to 3.58 ppm (mean of 2020). Cadmium (Cd) content of the surface sediment is highest at Station 2 with 1.2 ppm and lowest at Station 3 with 1 ppm. Stations 1 and 3 have the same Lead content of 11 ppm, Station 2 having the highest content of 12 ppm. The mercury content of sediment is not detected in the samples collected for this study. There was no observed spatial variability of different parameters such as organic matter, phosphorous, potassium, moisture content, pH, electrical conductivity, arsenic, mercury, lead, and mercury) from the three stations.

Table 3. Mean values of sediment parameters in MZP Sto. Tomas

Sediment parameters	Station 1	Station 2	Station 3	Mean	Guidelines
Color	Gray	Black	Gray		
Organic matter (%)	1.62	3.05	1.44	2.0±0.731	None
Phosphorous (ppm)	37.93	33.66	28.22	33.29±4.182	30-60ppm*
Potassium (ppm)	968.65	1,375.87	936.09	1083.75±203.14	None
Moisture Content (%)	8.02	7.64	9.06	8.25±0.619	None
pH	6.73	7.56	8.31	7.52±0.679	None
Electrical conductivity (mS/cm)	0.02	0.02	0.01	0.016±0.0049	None
Arsenic (mg/kg)	4.2	2.2	4.2	3.58±0.957	8.2**
Cadmium (mg/kg)	1.1	1.2	1	1.097±0.083	1.2**
Lead (mg/kg)	11	12	11	11.31±0.479	46.7**
Mercury (mg/kg)	ND	ND	ND	0.00±0.00	0.15**

ND – Not Detected * After Banerjea (1967) **NOAA ERL, 1999

Table 4. Correlation between water parameters and primary productivity

Parameters	Station	Mean Ranges	Chlorophyll	Phytoplankton density
Temperature (°C)	1	28.81±1.25	-0.358	-0.372[a]
	2	28.84±1.33	-0.169	-0.377[a]
	3	28.87±1.36	-0.407	-0.432[a]
DO (ppm)	1	5.06±0.38	0.216	0.163
	2	4.78±0.48	-0.069	-0.195
	3	5.35±0.38	-0.163	-0.329
Salinity (ppt)	1	36.12±2.25	-0.172	-0.076
	2	35.91±1.883	-0.384	-0.057
	3	35.12±2.89	0.713	-0.668
pH	1	8.65±0.13	0.242	0.081
	2	8.68±0.09	0.667	-0.044
	3	8.72±0.097	0.735	0.060
Ammonia (mg/L)	1	0.03±0.02	0.217	0.170
	2	0.029±0.027	0.368	0.441
	3	0.047±0.032	0.033	0.024
Nitrite (mg/L)	1	0.01±0.01	0.398	0.363
	2	0.009±0.005	0.359	0.201
	3	0.012±0.006	0.730	0.736
Total Coliform	1	0.79±1.357	1.000	0.998
	2	N/A	N/A	N/A
	3	N/A	N/A	N/A

* Mean values in a column having the same superscripts differ significantly at .05 level of significance. N/A Not analyzed

Correlation of water parameters and sediment quality on the productivity

Overall results revealed that temperature and primary productivity are inversely related. Temperature significantly influenced productivity in terms of chlorophyll and phytoplankton density (Table 4). In Station 1, dissolved oxygen is directly related with chlorophyll and phytoplankton density while in Stations 2 and 3, dissolved oxygen and chlorophyll and phytoplankton density are inversely related. In all stations, weak associations and insignificant correlation between the parameters were found. DO did not significantly influenced the primary productivity in the mariculture area. Weak negative correlation was noted between salinity and chlorophyll at Stations 1 and 2, and a strong positive correlation at Station 3. Phytoplankton density in all stations is negatively correlated to salinity, with weak correlation at Station 1 and Station 2, and moderate correlation at Station 3. pH has a positive weak correlation to chlorophyll at Station 1, moderate correlation at Station 2 and strong correlation at Station 3. Phytoplankton density in Stations 1 and 3 have direct correlation with pH, however, negatively correlated in Station 2. Phytoplankton density and pH have weak associations and insignificant correlation in all stations.

Ammonia is directly related with primary productivity indicators but weak association was found between the two parameters. In terms of correlation to chlorophyll, a weak association was recorded in all stations. Ammonia has positive weak to moderate correlation to phytoplankton density in all stations. Nitrite is positively correlated to chlorophyll and phytoplankton. A weak to strong correlation of nitrite to chlorophyll was observed. Phytoplankton has a positive weak and strong correlation recorded. Total coliform in Station 1 has a strong to perfect correlation to phytoplankton and chlorophyll.

Conclusion

Based on the results obtained in the study, the following conclusions are drawn:

1. Of the 12 physico-chemical and biological water quality parameters tested, 10 passed the standards (DENR-DAO and PHILMINAQ), namely: temperature, salinity, ammonia, nitrite, arsenic, cadmium, lead, mercury, fecal coliform, total coliform; while DO and pH exceeded the limit of criteria for water quality standard for Class SC waters. Spatio-temporal and diurnal variations on water quality in MZP Sto. Tomas were noted in some sites and parameters. Diurnal sampling revealed that DO level starts to decrease at dawn (2:00 AM) until 8:00 AM onwards. Desirable level of DO (5 ppm) was recorded at 2:00 PM sampling. Water quality and sediment are in good condition, thus, are able to sustain the intensive aquaculture enterprises in the Mariculture Zone Park Sto. Tomas.
2. There was an accumulation of heavy metals (arsenic, cadmium, lead) in the sediment of the MZP Sto. Tomas for the four (4) years of mariculture operations, but still within range of the different international environmental standards. Cadmium level in the sediments of MZP Sto. Tomas is classified under the Effect Range Low (ERL) of NOAA (1999).
3. Temperature significantly influenced the primary productivity (chlorophyll and phytoplankton density) of the MZP Sto. Tomas. Dissolved oxygen, salinity, pH, ammonia, nitrite, and total coliform has insignificant correlation with primary productivity variables, thus did not influence the chlorophyll and phytoplankton density in the MZP.

Recommendations

Based on the conclusions obtained in the study, the following recommendations are drawn:

1. Sustain continuous monitoring of water quality parameters (temperature, dissolved oxygen, salinity, pH, ammonia, nitrite), heavy metals, and coliform content. Intensive monitoring should be done during marketable size of the stocks to prevent mortalities.
2. Further study on the microbiota of the sediment to determine its possible impacts in the mariculture

area brought about by feeding practices and nutrient loading.

3. Sustain phytoplankton species identification to determine presence of harmful algal blooms (HABs) that may cause water quality deterioration in MZP Sto. Tomas.
4. Further study on the sediment quality to include other parameters such as grain size, hydrogen sulphide, carbon, nitrogen, etc. within MZP to investigate nutrient loading.
5. Strict implementation of good aquaculture practices of the mariculture investors to sustain their operations without causing environmental degradation.

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