Water quality, plankton community and primary productivity of Langiran Lake in Bayambang, Pangasinan, Philippines

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Abstract. The importance of water quality, plankton community and primary productivity has long been recognized in fish propagation under confinements and management of surface waters. Hence, this study was conducted to generate salient information that could help the local government of Bayambang, Pangasinan, Philippines to its plan in maximizing the services provided by the Langiran Lake. Qualitative and quantitative analyses were conducted in-situ and ex-situ to determine the level of important water quality variables, plankton composition and abundance and primary productivity of the lake. Water transparency, turbidity, dissolved oxygen (DO) and PO_4 did not conform with the standards set by the Department of Environment and Natural Resources of the Philippines. A total of 14 genera belonging to 5 groups of phytoplankton and were identified. In terms of zooplankton, there were 9 identified and 2 unidentified genera under 5 groups. Chlorophytes had the highest number of representatives. However, bacillariophyte is the most abundant group in the phytoplankton division, while copepod dominates in the zooplankton community. The net primary productivity (NPP) of the lake ranged from 6.34 mg C m^{-3} hr^{-1} (Station 4) to 12.72 mg C m^{-3} hr^{-1} (Station 2), with a mean of 8.55 mg C m^{-3} hr^{-1}. DO, salinity and total coliform showed highly significant relationship ($p<0.01$) with ciliates, copepods and rotifers, respectively. Meanwhile, TAN showed significant positive relationship with NPP ($p<0.05$). With regard to trophic status, the lake is already eutrophic. This suggests that the lake is presently not favorable for aquaculture activities and it is recommended for the implementation of such management actions.

Key Words: eutrophication, Langiran Lake, phytoplankton, trophic status, zooplankton.

Introduction. The province of Pangasinan located in the northwestern part of Luzon Island in the Philippines is the third biggest province of the country with a total land area of 5451.01 km^2, with a coastline of 285.66 km. The province devoted more than 44% of its land area to crop production and is considered one of the top producers of agricultural products, especially rice in the country (RealPhil.com 2019). In addition, it is also endowed with rich natural resources within its vast mountains and aquatic environments. The coastal areas, especially the Lingayen Gulf, is a major site for capture and culture fisheries (Pangasinan Provincial Planning and Development Office 2019). Freshwater resources on the other hand also play an important role ecologically and economically.

The province is drained by 9 major river systems, of which the most important is Agno River, with a length of 270 km. These river systems supply household and agricultural waters. Moreover, the province harbors 3 major lake habitats, including Danao in Burgos, Mangabol and Langiran in Bayambang (PhilAtlas). There are also smaller lakes like Lalwan and Pacao in San Carlos City and Laloog in Mangatarem (Mapcarta). Although not as extensive as the coastal and riverine habitats, the lakes still provide significant contributions to the locality by supporting tourism, fishing and farming activities. However, studies conducted regarding these lakes are still limited. Hence, information is scarce, particularly on their water quality and productivity. In the municipality of Bayambang, only Mangabol Lake has been assessed for water quality and some of its associated ichthyofauna

(Sunga & Pridas 2015). Langiran Lake remains unassessed. Based from the report of Austria (2018), the Langiran Lake is eyed as a tourism spot by the municipal government. Moreover, development efforts also target the maximization of the resource through the production of fish using floating cages.

In accordance with these objectives, this study aims to produce a clear description of water quality conditions and primary productivity of the lake in order to prevent irreversible consequences. In addition, such information could also be used in managing existing lake resources to maintain ecological equilibrium.

Material and Method

Sampling sites. The study was conducted in Langiran Lake, one of the major inland water bodies of Bayambang, Pangasinan on October 14-18, 2022. Four sampling sites were established in the study area, specifically in the nearshore (near houses and rice paddies) and limnetic zones (open area and near water hyacinth mats) of the lake. The geographic position (Table 1) of these sampling sites was determined using a built-in phone GPS receiver and a map (Figure 1) was generated using a computer software.

Table 1

Geographic position and description of the sampling sites in Langiran Lake

Sampling site	*Coordinates*		*Description*
	Latitude	*Longitude*	
Station 1	15°49’55.05”N	120°24’7.02”E	Littoral zone; near the road and houses.
Station 2	15°49’58.71”N	120°24’7.38”E	Littoral zone; rice paddies.
Station 3	15°49’55.34”N	120°24’11.67”E	Limnetic zone; open area.
Station 4	15°49’58.53”N	120°24’5.19”E	Limnetic zone; near water hyacinth infested area.

Figure 1. Map showing the sampling stations in Langiran Lake (exported from Google Earth).

Water quality assessment. Water quality parameters were assessed (with triplicates) using digital equipment and laboratory techniques. The depth was measured using a digital depth meter (Hondex PS-7). The measurement was recorded to the nearest meter (m). Transparency was measured using a Secchi disc and also expressed to the nearest meter (m). The turbidity, water temperature, salinity, dissolved oxygen (DO), and pH were also assessed on-site using a handheld multi-parameter water quality checker (Horiba Advanced Techno Co., Ltd., Japan). Other chemical parameters such as ammonia (TAN), nitrite (NO_3) and total phosphate (PO_4) were analyzed at the Bureau of Fisheries and Aquatic Resources – National Fisheries Development Center (BFAR-NFDC). 1 L of water samples was collected from each sampling site using polyethylene plastic (PE) containers and transported to the laboratory at low temperature. Samples were processed in accordance with standard laboratory procedure of the BFAR–NFDC. The absorbance of the processed samples for TAN, NO_2 and PO_4 was read in spectrophotometer (UVS-2700 model of Labomed, Inc., Los Angeles, USA) using 625 and 885 wavelengths. The concentrations were calculated using the following equation:

Concentration = [Concentration of standard solution x (SV – BV)]/(SSV – BV)

Where: SV is the absorbance of the standard solution, BV is the absorbance of the blank and SV is the absorbance of the sample.

Chlorophyll-a concentration was analyzed following the methods of Aminot & Rey (2001). A 150 mL water sample was collected in the study site. Upon arrival at the laboratory, the samples were filtered using a Whatman no. 42 filter paper. The filter was removed and subsequently folded once with the algae inside, blotted in absorbent paper, and kept in a clean and properly labelled container. The filters with the algae were cut into small pieces and macerated in 8 mL of 90% acetone in subdued light. The extract was placed in a 10 mL capacity centrifuge tube. 2 mL of 90% acetone were added to the tube to obtain an extract volume of 10 mL The extract was centrifuged for 10 min at 500xg (Kubota KS-5000P). The sample extract was pipetted, carefully transferred to the cuvettes, and placed in the UV-VIS Dual Beam and Auto Cell UVS 2700 spectrophotometer (Labomed, Inc., California, USA). The absorbance of the extract was measured at 750, 664, 647, and 630 nm against 90% acetone (blank). The chlorophyll-a concentration was calculated using the equation given by Jeffrey & Humphrey (1975):

$$\text{Chl a} = [(11.85 * (E664–E750)–1.54 * (E647–E750)–0.08 * (E630–E750)) * Ve]/L * Vf$$

Where: L is the cuvette light-path in cm, Ve is the extraction volume in mL, Vf is filtered volume in L. Concentrations were expressed in mg m^{-3}.

Bacterial load was assessed using the modified procedures of Reyes et al (2019). Water samples were collected simultaneously with the collection of samples for ammonia, phosphate and chlorophyll-a analysis. The samples were stored in 100 mL capacity PE containers and transported to the laboratory at low temperature. A series of serial dilutions (10^{-10}) was made to prepare an aliquot for bacterial counting. 1 mL of water sample was added to the first test tube containing 9 mL of physiological saline solution (PSS). The solution was vigorously mixed and 1 mL was transferred to another test tube containing the same amount of PSS. The process was repeated in succeeding test tubes. From the tenth test tube, 0.1 mL aliquot was streaked in McConkey agar plates for the total bacterial count. The plates were incubated for 18-24 h and the number of coliform colonies was counted with the aid of a smartphone installable Microbial Colony Counter application (MLTool Technologies, New Delhi, India). The colony forming units (CFU) per unit of an aliquot streaked was estimated using the formula:

Coliform count (CFU mL^{-1}) = (number of colonies x dilution factor)/Volume plated

Collection and preservation of water samples. Water samples for plankton analysis were collected using a plankton net with a 45-micron mesh size. Collection of water was aided with a 5 L pail and filtered using the plankton net. This process was repeated 5 times until a 50 mL sample was obtained. The filtered water was stored in PE containers and was fixed by adding 0.15 mL of Lugol’s iodine solution for phytoplankton samples (APHA 1998) and 4% commercial formalin for zooplankton samples (Pollupuu 2007). The samples were transported to the laboratory at low temperatures. Upon arrival, the samples were placed in a dark room to allow the settlement of plankton.

Plankton identification and counting. A drop (1 mL) of stored sample was transferred to a Sedgewick Rafter Counting Chamber for identification and counting. The sample-filled chamber was observed under a binocular microscope (40x) (Hund Wetzlar). Plankton (phytoplankton and zooplankton) was identified using the taxonomic keys of: Reynolds (1984), Witty (2004), van Vuuren et al (2006), Petersen et al (2020) and Dang et al (2015). The representative from each identified group/genus were counted. The recorded number of individuals per unit of sample was used for the calculation of density. The method of Limates et al (2016) was adopted for the computation of average cell density. Thirty random grid squares of the Sedgewick-Rafter were evaluated. 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. This raising factor was used to determine the density in the exact volume of sample. Computation of density was based on the group of major taxa and the percentage of each representative taxa was calculated. The formula to obtain average density (AD) and relative density (RD) are as follows:

AD = RF x average count/total volume filtered

RD = Total # of cells per group/Total # of cells for all group x 100%

Assessment of primary productivity. The primary productivity of Langiran Lake was assessed using the light (clear) and dark (blackened) container technique. The initial level of oxygen was measured using a handheld multi-parameter water quality equipment (prior to the collection of 500 mL water for incubation). Then light and dark containers with a capacity of 500 mL were submerged at a depth of 30 cm from the surface to collect water for incubation. The containers were tightly closed after being filled with water while still submerged to ensure that there was no bubble formation. Collection was conducted in designated sampling stations with triplicates. Then water from the light and dark containers was immediately incubated for 24 h using the on-deck incubation method (Balch et al 2022). The phytoplankton primary productivity was expressed as the quantity of carbon assimilated per time unit. Thus, the changes in oxygen concentration were converted as corresponding changes in carbon. The photosynthetic quotient and respiratory quotient from Strickland & Parsons (1960), which are ratios describing the relative amounts of oxygen and carbon involved in photosynthesis and respiration were integrated to the equation of Britton & Greeson (1987). The calculations for gross primary productivity (GPP), net primary productivity (NPP) and respiration (R) were made using the following formulas:

$$\text{GPP (mg C m}^{-3}\text{ h}^{-1}) = [(LB–DB) * 1000 * 0.375] / (PQ*\Delta T)$$

$$\text{NPP (mg C m}^{-3}\text{ h}^{-1}) = [(LB–IB) * 1000 * 0.375] / (PQ*\Delta T)$$

$$\text{R (mg C m}^{-3}\text{ h}^{-1}) = [(IB–DB) * 1000 * 0.375] / (RQ*\Delta T)$$

Where LB, IB, DB refer to the concentrations of DO in the "Light" container, "Initial" container and "Dark" container, respectively. ΔT, PQ and RQ refer to the time of incubation, photosynthetic quotient and respiratory quotient, respectively. Strickland & Parsons (1960) suggested a PQ value of 1.2 (PQ=molecules of oxygen liberated during photosynthesis/molecules of CO_2 assimilated) and a RQ value of 1 (RQ=molecules of CO_2 liberated during respiration/molecules of oxygen consumed). The constant value 0f 0.375 converts mass of oxygen to mass of carbon and is a ratio of moles of carbon to moles of oxygen (12 mg C / 32 mg O_2). The value 1000 converts liters (L) to cubic meters (m^3).

Determining trophic status. The trophic status of the lake was determined using the conventional trophic state index (TSI) criteria based on chlorophyll-a (CHL-a), total phosphate concentration (TP) and Secchi disc visibility (SDV). The formulas are:

$$\text{TSI (CHL-a, μg L}^{-1}) = 10 \times [6 - (2.04 - 0.68 \ln(\text{CHL-a}))/\ln 2]$$

$$\text{TSI (TP, μg L}^{-1}) = 10 \times [6 - \ln(48/\text{TP})/\ln 2]$$

$$\text{TSI (SD, m)} = 10 \times [6 - \ln(\text{SD})/\ln 2]$$

The values obtained from the computation of TSI (CHLa), TSI (TP) and TSI (SD) were used to determine the average TSI using the Carlson (1977) equation:

$$\text{ATSI} = [\text{TSI (CHLa)} + \text{TSI (TP)} + \text{TSI (SD)}]/3$$

Based on the computed ATSI, the lake could be classified based on trophic level. In previous studies, the TSI for oligotrophic conditions was in the range of 30-40, mesotrophic conditions have a TSI range of 40-50, and eutrophic conditions range between 50-70 (Mamun et al 2021).

Data treatment and analysis. The data collected during the assessment was processed using descriptive statistics and tabulated for better presentation of results. The degree of association between water quality parameters (depth, turbidity, transparency, temperature, DO, pH, salinity, conductivity, ammonia, nitrite, phosphate, chlorophyll-a and coliform count) and the density of plankton in Langiran Lake was ascertained using the Pearson Product Moment Correlation.

Results and Discussion

Water quality variables. The summary of result on the assessment of water quality is presented in Table 2.

Table 2

Summary of the level of water quality variables in Langiran Lake

Parameter	*Sampling site*				*Mean*
	Station 1	*Station 2*	*Station 3*	*Station 4*	
Water depth (m)	1.90	1.40	2.40	2.00	1.92
SDV (m)	1.30	0.50	1.20	1.30	1.07
Turbidity (NTU)	821.0	807.0	634.3	631.3	723.4
Temperature (^{o}C)	30.8	30.8	31.1	31.1	30.9
Dissolved oxygen (mg L^{-1})	2.6	2.5	2.6	2.1	2.4
pH	8.5	8.4	8.4	8.1	8.4
Salinity (ppt)	0.2	0.2	0.1	0.1	0.15
TAN (mg L^{-1})	0.052	0.055	0.026	0.020	0.038
Nitrite (mg L^{-1})	0.008	0.009	0.009	0.011	0.009
Total Phosphate (mg L^{-1})	0.036	0.090	0.053	0.191	0.093
Chlorophyll-a (mg m^{-3})	2.727	2.563	1.647	1.517	2.113
Total Coliform (CFU/mL), (MPN/100 mL)	2.90x10^{12}, >1800	1.27x10^{12}, >1800	0.67x10^{12}, 980	1.27x10^{12}, >1800	1.52x10^{12}, >1500

Note: SDV - Secchi disc visibility; TAN - total ammonia nitrogen; CFU - colony forming units; MPN - most probable number.

Assessing water quality is an integral component of any development activity in natural bodies of water. In aquaculture, the level of water quality sets the foundation for the establishment of aquaculture systems and in creating appropriate lake management programs. In comparison with the standards prescribed by DAO 2016-08 (DENR) as major guidelines implemented in the Philippines and several studies (detailed below), it can be said that the water quality of the lake in general is in relatively poor condition.

The mean water depth of the lake was recorded at 1.92 m, with station 3 (open water area) having the deepest portion (2.4 m). SDV had a mean reading of 1.07 m and the turbidity recorded a mean of 723.4 NTU. Water transparency describes the transmission intensity of light in water, its quantity and nature of the matter and substances that play significant role in supporting the primary productivity (Robert B. Annis Water Resources Institute 2020). Transparency has an important implication for aquatic diversity. The transparency of freshwater bodies varies substantially, and has a range of 1.3-5 m for some lake sites worldwide (Teubner et al 2020). Most shallow inland lakes were observed to have a narrow range below 1.5 m (Bai et al 2020). The mean water transparency observed in Langiran Lake is below this range, suggesting its conformation with the common transparencies in shallow lakes. According to Jones & Bachmann (1978), it is closely associated with algal biomass. However, it is commonly measured as a function of chlorophyll-a concentration, total suspended solids, and colored dissolved organic matter (Bai et al 2020). Algae is often regarded as a main driving factor that influences the transparency of lake waters (Angagao et al 2017). The transparency of deep lakes is determined by phytoplankton biomass instead of sediment resuspension (Liu et al 2020). Meanwhile, a decrease in transparency could imply water quality deterioration. This condition could be a function of natural and anthropogenic factors through time. Eutrophication can strongly influence the lake ecosystem and the services that it can provide. Reductions in water transparency are due to the formation of turbid sediments and excessive growth of phytoplankton (Bunnel et al 2021). Turbidity is sometimes used interchangeably with water transparency. In this study, the turbidity of lake was expressed as a maximum concentration in nephelometric units (NTU) following the US EPA (2022). In comparison with the standard turbidity level in some parts of the United States for lake water (under 25 NTU), the observed mean turbidity in Langiran Lake is excessive. Moreover, it is outside the range of annual mean turbidity recorded in seven crater lakes in the Philippines (Zapanta et al 2008). However, there is no established criterion for turbidity in the country at present. From an aquaculture viewpoint, the level of turbidity is relatively high when converted to milligram per liter (241.13). The turbidity of water usually describes the amount of suspended particulate matter (SPM). These SPMs are playing important roles in the transport and transformation of organic pollutants (He et al 2021). High levels of particulate matter in natural and aquaculture waters may negatively affect the physiological state of fish populations and other members of the aquatic community.

The temperature of the lake surface water is 30.9^{o}C. Water temperature is considered a controlling factor for all aquatic life (Devi et al 2017). It measures the intensity of heat in the system. Many biological, physical and chemical processes are affected by this variable. The recorded mean temperature is higher compared to the findings of several assessments conducted in different freshwater bodies in Luzon Island (Reyes et al 2019; Fajardo et al 2022). This condition could be linked to the area and depth of Langiran Lake, where smaller and shallow waters tend to warm rapidly than large and deep ones (Mooji et al 2008). However, the recorded level is within the recommended range of 25-31^{o}C (DAO 2016).

In terms of DO, low values have been recorded across stations with a mean of 2.4 mg L^{-1}. DO is another variable that reflects water quality in lakes. This variable is virtually needed for the survival of aquatic organisms. It can be noted that the DO of Langiran Lake during the assessment is relatively low compared to the ideal level of DENR (DAO 2016), which is above 5 mg L^{-1}. According to Angagao et al (2017), low concentrations of DO may indicate high oxygen consumption of lake-associated organisms. It is evident by the presence of dead fish during the assessment. The presence of a dense mat of water hyacinth could be a primary factor influencing low oxygen levels. Dense mats prevent transfer of atmospheric oxygen to the surface water and restrict light penetration, which is essential for photosynthesis (Villamagna & Murphy 2010). Shallow lakes can be heavily infested by the plant as observed in Langiran Lake, where complete deoxygenation may occur in its deeper water and sediments (Osumo 2001). The obtained results imply that the lake cannot sustain the oxygen demands of organisms within it and it is not suitable for aquaculture unless actions will be implemented to manage the DO level of the lake.

The pH did not vary greatly across sampling sites, having a mean value of 8.4. The pH of a water body indicates the acidity or basicity of a water. Acidic water contains extra hydrogen ions (H^+) and basic water contains extra hydroxyl (OH^-) ions (Alley 2007). The mean pH value observed in Langiran Lake conforms to the standard pH range of 6.5-9, set by the DENR for freshwater Class C category. Moreover, the level of pH is within the favorable range of 7-8.5 for biological productivity (Bhatnagar & Devi 2013). Therefore, the lake is suitable for fish propagation, recreation and industrial uses in terms of pH.

Salinity had a mean value of 0.15 ppt. This parameter measures the concentration of dissolved salts in water. Most of these salts are comprised of chloride. According to Elbein (2017), the salinity of freshwater lakes is typically within the range of 0-0.1 ppt. The small deviation of salinity of the lake's water from this range could be attributed to its proximity to residential and agricultural areas. Müller & Gächter (2011) linked the increasing chloride concentration in a lake from the agricultural and industrial inputs. Moreover, prolonged dry periods could elevate chloride concentrations (Webster et al 2000).

Chemical parameters such as TAN, nitrite and phosphate have mean values of 0.038 mg L^{-1}, 0.009 mg L^{-1} and 0.093 mg L^{-1}, respectively. TAN is a parameter that measures both the unionized and ionized ammonia. The TAN of lake water is relatively low compared with the reported level from other freshwater bodies such as Lake Lanao (Angagao et al 2017), Nabao Lake (Reyes et al 2019) and Pantabangan Reservoir (Fajardo et al 2022). It is surprising that despite the heavy infestation with water hyacinth and low oxygen levels, the TAN level is still within the acceptable range. The mean nitrite concentration of the lake is also in conformity with the level set by PHILMINAQ (<0.5 mg L^{-1}) for aquaculture. The low concentration of TAN and NO_2 could be attributed to the monotypic mat of water hyacinth. Akinbile & Yusoff (2012) reported that the macrophytes can efficiently reduce nitrogen in waters with constant solar radiation, temperature and DO levels. However, decaying materials from this macrophyte could negatively affect water quality that may result in DO depletion (Sikawa & Yakupitiyage 2010).

The recorded mean phosphate level is beyond the permissible limit of 0.05 mg L^{-1} set by DENR for Class C waters (DAO 2016). Phosphorous is regarded as a limiting factor for algal growth in most freshwater bodies. However, even a modest increase in its level could result in eutrophication (Bhateria & Jain 2016). Although there are several sources of phosphorous, the high concentration in Langiran Lake could be attributed to its closeness to rice paddies. Fertilization during land preparation increases the phosphorous level and transport of phosphorous from rice paddies can be generally associated with runoff events (Cui et al 2020; Guan et al 2022).

As to biological variables, chlorophyll-a has a mean of 2.113 mg m^{-3} and the mean coliform count is 1.52×10^{12} CFU mL^{-1}, or >1500 MPN/100 mL. Chlorophyll-a concentration is an important parameter in evaluating water quality. It is the most common parameter to characterize trends in algal biomass (Huot et al 2007; Adams et al 2021). Moreover, it can be used as an indicator of nutrient loading and extent of pollution in a body of water (Cheng et al 2013). The recorded mean level of chlorophyll-a in this study is considerably lower than the reported levels in seven crater lakes in the Philippines namely: Bunot, Calibato, Mohicap, Palakpakin, Pandin, Samplaoc and Yambo (Zapanta et al 2008). In terms of chlorophyll-a concentration, the lake can be considered as oligotrophic when compared to a threshold of >40 mg m^{-3} as an indicator of algal bloom (Bachmann et al 2003). Other authors also used higher and lower thresholds such as 100 μg L^{-1} (Tett 1987) and 5 μg L^{-1} (Jonsson et al 2009) to define a bloom. The level of water transparency and turbidity of the lake could be largely contributed by suspended sediments and not by the phytoplankton community. This could also be supported by the recorded level of oxygen suggesting the sparsity of primary producers. Lastly, the concentrations of coliforms suggest that the water of the lake is contaminated by this bacterium. However, the total coliform counts did not exceed the standard values specified by the Department of Environment and Natural Resources in the Philippines for Classes C waters (5000 MPN/100 mL). Although mean values are still within the standard limit of total coliform, the presence in high numbers may suggests higher risk of contracting disease-causing organisms (Rana et al 2017). The obtained results may imply that the lake has a direct contact with several risk factors such as animal manure and household effluents. Contaminated soil, wildlife feces, agricultural water, dust, and the household communities present and near the lake are considered as potential sources of heavy coliform contamination (Beuchat 2006; Matthews 2013). Anthropogenic activities and improper waste disposal can also lead to the spread of this bacterium in water (Paragamac et al 2021). Furthermore, storm event runoffs may hasten the transport of coliform-contaminated materials (Oporto-Bensig et al 2014). Previous studies showed that coliforms can survive in the environment for up to four months depending on the type of manure, temperature, pH, oxygen level, ammonia, concentration and presence of competing organisms (Guan & Holley 2003; El Saidy et al 2015).

Plankton composition and abundance. Based on the results indicated in Table 3, a total of 14 genera belonging to 5 groups of phytoplankton were identified in Langiran Lake which include charophytes, chlorophytes, cyanophytes, bacillarophytes and euglenophytes. Among the identified phytoplanklton genera are *Closterium*, *Ankistrodemus*, *Actinastrum*, *Monoraphidium*, *Pediastrum*, *Scenedesmus* and *Tetrahedron*. In terms of zooplankton composition, it was found that 5 groups which include rotifers, cladocerans, copepods, heliozoans and ciliates are present in the lake, with 9 identified and 2 unidentified genera.

Table 3

Summary of the assessment of plankton composition Langiran Lake

Plankton group	*Genus*	*Sampling site*			
		Station 1	*Station 2*	*Station 3*	*Station 4*
Phytoplankton					
Charophytes	*Closterium*	+	+	-	-
Chlorophytes	*Ankistrodesmus*	-	-	+	-
	Actinastrum	-	+	-	-
	Monoraphidium	-	-	+	+
	Pediastrum	+	+	+	+
	Scenedesmus	+	-	-	-
	Tetraedron	+	+	-	-
Cyanophytes	*Anabaena*	+	-	-	+
	Merismopedia	+	-	-	-
Bacillarophytes	*Navicula*	-	+	-	-
	Nitzschia	+	+	+	+
	Synedra	+	+	+	+
Euglenophytes	*Euglena*	+	+	+	+
	Phacus	+	+	+	-
Zooplankton					
Rotifers	*Brachionus*	+	+	+	+
	Trichocera	+	+	-	-
	Keratella	+	+	+	-
	Hexartha	-	-	+	+
Cladocerans	*Diaphanosoma*	+	+	+	+
Copepods	*Eucyclops*	-	-	+	+
	Mesocyclops	+	+	+	+
	Tropocyclops	-	-	+	-
	Filinodaptomus	+	+	+	+
Heliozoans	Unidentified	-	-	-	+
Ciliates	Unidentified	-	-	-	+

As revealed, chlorophytes dominated the phytoplankton community of the lake with 6 identified genera, while rotifers and copepods both have 4 representative genera dominating the zooplankton community. These are *Brachionus*, *Trichocera Keratella*, *Hexartha*, *Diaphanosoma*, *Eucylcops*, *Mesoscyclops*, *Tropocyclops*, and unidentified genera of both heliozoan and ciliate. In comparison with previous studies conducted in lake systems of different areas of the Philippines, the structure of the plankton community may vary significantly due to a number of biotic and abiotic factors. However, the richness of chlorophytes among algal groups is similar with the findings of studies conducted in Nabao Lake (Reyes et al 2019) and Lake Tikub (Torreta et al 2020). Meanwhile, the richness of rotifers and copepods was also reported in Paoay Lake, Ilocos Norte (Aquino et al 2008).

In terms of abundance, microscopic assessment revealed that the phytoplankton community had a mean density of 8.28 ind L^{-1}, while the zooplankton had a mean density of 10.40 ind L^{-1} (Table 4).

Table 4

Summary of the assessment of plankton density in Langiran Lake

Plankton group	*Plankton density in the sampling site*				*Mean*
	Station 1	*Station 2*	*Station 3*	*Station 4*	
Phytoplankton (ind L^{-1})	12.32	8.32	6.88	5.6	8.28
Charophytes (%)	2.31	2.56	0.00	0.00	1.22
Chlorophytes (%)	6.13	4.71	6.55	6.67	6.02
Cyanophytes (%)	6.06	0.00	0.00	4.76	2.71
Baciliariophytes (%)	79.22	85.03	82.55	83.16	82.49
Euglenophytes (%)	5.48	7.69	10.90	5.41	7.37
Zooplankton (ind L^{-1})	17.76	14.08	3.04	6.72	10.40
Rotifers (%)	31.46	27.25	27.50	35.71	30.48
Cladocerans (%)	17.47	12.24	4.17	8.99	10.72
Copepods (%)	51.07	60.50	68.33	49.34	57.31
Heliozoans (%)	0.00	0.00	0.00	3.17	0.79
Ciliates (%)	0.00	0.00	0.00	2.78	0.69

As observed, there is low density of phytoplankton in the area that can be attributed to the limitations brought about by the infestation of water hyacinth. Moreover, the grazing pressure of zooplankton could have reduced their biomass. Bacillariophytes, also known as diatoms, showed the highest relative density (82.49%) in the community. Diatoms can thrive in almost all types of surface waters, but the composition of the community may depend on various environmental factors (Martin & Fernandez 2012). In the study of Effendi et al (2016), diatoms are considered the most abundant algae because of their ability to adapt in a wide range of environmental condition. Similar findings have been reported by Fajardo et al (2022) in Pantabangan Reservoir in Nueva Ecija, Philippines. The abundance of diatoms in a body of water implies a certain level of pollution gradients in water. According to Akinyemi et al (2007), a 40% relative abundance or occurrence of diatoms in a phytoplankton community may be a good indicator of pollution, as these algae can tolerate polluted waters. With regard to zooplankton abundance, the copepods exhibit some sort of dominance as they outnumbered other identified members of the community. These organisms comprised 57.31% of the zooplankton community of Langiran Lake. Fajardo et al (2022) stated that copepods are generally abundant in freshwater ecosystems, but require longer periods to establish their population compared to other groups of zooplankton. The dominance of copepods indicates that there is low level of fish predation in Langiran Lake that could substantially decrease their population. The large size of copepods and cladocerans made them more vulnerable to predation compared with rotifers that are considerably smaller (Karus et al 2014). Moreover, despite low phytoplankton density, copepods still dominate the community, which can be linked to the selective consumption of these organisms to plant detritus (Harfmann et al 2019). Detritus materials produced by water hyacinth in Langiran Lake may have been used by these organisms to survive and proliferate. Rotifers are the second most abundant group, comprising 30.48% of the overall zooplankton density. According to Ceirans (2007), rotifers are better biological indicators than crustaceans (copepods and cladocerans), as they are sensitive to environmental changes. High abundance indicates that the lake is eutrophic (Ismael & Adnan 2016). Emam (2006) described that a shift in the zooplankton community structure from larger species to smaller ones is a direct effect of eutrophication. This condition could be attributed to several factors such as domestic discharges, animal wastes and fertilizers leaching to a water body (Fajardo et al 2022).

Relationships between water quality variables and plankton abundance. The correlation analysis of environmental parameters such as depth, water transparency or SDV, turbidity, temperature, pH, DO, salinity, TAN, NO_3, PO_4, chlorophyll-a, and total coliform with the plankton density in the Langiran Lake showed the following findings: ciliates from the zooplankton taxa are negatively correlated with pH and DO, while they are positively correlated with phosphate level; the salinity level was positively correlated with charophytes, rotifers, cladocerans, and copepods; depth was negatively correlated with copepods; TAN showed a moderately positive correlation with bacillarophytes and copepods; a positive correlation was also observed between phosphate level and ciliates; surprisingly, chlorophyll-a had a positive correlation with bacillarophytes; coliform count had a significantly high correlation with rotifers (Table 5).

Ciliates comprise the majority of living organisms in the aquatic environment next to bacteria (Shukla & Gupta 2001). Some studies had shown correlation of the pH with the growth, cell density, species composition, and species richness of ciliates (Noland 1925; Lackey 1938; Weisse & Stadler 2006). Extensive changes in pH in the natural environment may make ciliates die out or perhaps encyst if they are not be able to tolerate such conditions (Lackey 1938). In the present study, the mean pH level recorded in the lake was 8.4, which is slightly alkaline. As compared to the study of Noland (1925), the observed minimum and maximum levels of pH were 6 and 9.8, concluding that pH has no direct influence on ciliate distribution. Meanwhile, the laboratory experiment of Weisse & Stadler (2006) indicated that pH has a minor ecological significance for freshwater ciliates. Freshwater ciliates showed positive growth rates for pH values ranging from 6.5 to 8, but *Urotricha farcta*, the model ciliate species used to quantify the potential significance of seasonal pH changes had showed reduction in growth rates with increasing pH, from 7.4 to 8.4. Therefore, in this study, it could be assumed that the density of ciliates in the lake may be affected by other factors rather than pH.

The DO concentration in the aquatic environment is mainly influenced by four factors: temperature, the abundance of chlorophyll-bearing organisms, the number of oxygen-consuming organisms, and the amount of aeration in the water, which is influenced by wave actions, currents, and the ratio of depth to surface exposed (Noland 1925). In the present study, the recorded mean DO level was low, having 2.4 mg L^{-1}. The significant high negative correlation of ciliates to DO may not be conclusive. Based on Noland (1925), DO is a necessity for the life of ciliates, even if some ciliated thrive in most concentrated infusions, where oxygen is almost or totally depleted. These organisms rise in the surface water, where they can access a very small amount of available free oxygen. DO is important for the growth and survival of zooplankton, as its concentration affects the rate of metabolic reactions of organisms (Badjoeri 2020).

The positive significant correlation of salinity to zooplankton taxa such as rotifers, cladocerans, and copepods is in accordance to their euryhaline characteristics that permit them to live in both freshwater and saline environments (Zsuga et al 2021).

The inverse relationship of depth to copepod groups in the present study was also observed in the study of Yamaguchi et al (2015). Thermocline and the oxygen minimum zone are environmental factors that influence the vertical distribution of zooplankton (Sameoto 1986). The zone below the thermocline is characterized by a lack of oxygen (Karpowicz & Ejsmont-Karabin 2018). Hence, zooplankton may tend to move upward to access available oxygen necessary for their metabolic processes. Furthermore, increasing density of zooplankton with decreasing depth may be also affected by the presence of phytoplankton in the water column (Khalifa et al 2015), which serve as their food. Phytoplankton, like other land plants, needs photon light energy along with inorganic carbon for photosynthesis (Utami et al 2021), tending to stay in the upper layers of the water where the sunlight penetrates.

Table 5

Correlation coefficient of environmental variables and plankton density in Langiran Lake, Bayambang, Pangasinan

	Charophytes	*Chlorophytes*	*Cyanophytes*	*Bacillarophytes*	*Euglenophytes*	*Rotifers*	*Cladocerans*	*Copepods*	*Heliozoans*	*Ciliates*
Depth	-0.311	-0.028	0.005	-0.187	-0.146	-0.474	-0.408	-0.685*	0.063	0.063
SDV	-0.072	0.054	0.330	-0.054	0.043	-0.088	-0.080	-0.396	0.203	0.203
Turb	0.426	0.195	0.174	0.076	0.009	0.571	0.478	0.832	-0.285	-0.170
Temp	-0.327	-0.198	0.004	-0.498	-0.341	-0.124	-0.504	-0.388	0.392	0.129
pH	0.288	0.267	0.216	0.298	0.075	0.382	0.548	0.535	-0.233	-0.594*
DO	0.227	-0.007	0.305	0.208	0.155	0.424	0.233	0.228	0.274	-0.771**
Sal	0.577*	0.241	0.211	0.424	0.321	0.620*	0.703*	0.879**	-0.302	-0.302
TAN	0.571	0.430	0.004	0.598*	0.523	0.189	0.445	0.596*	-0.479	-0.054
NO_2	-0.176	-0.081	0.557	-0.410	-0.411	0.152	0.292	0.097	0.566	-0.131
TPO_4	-0.317	0.118	-0.015	-0.049	-0.253	-0.253	-0.372	-0.260	0.384	0.702*
Chl-a	0.100	0.242	0.055	0.594*	-0.092	0.458	0.536	0.590	-0.388	-0.145
TC	-0.047	-0.148	0.029	0.016	-0.188	0.776**	0.196	0.367	0.093	-0.005

Note: SDV - Secchi disk visibility; Turb - turbidity; Temp - temperature; DO - dissolved oxygen; Sal - salinity; TAN - total ammonia nitrogen; TPO_4 - total phosphate; Chl-a - chlorophyll-a concentration; * - significant at p<0.05; ** - significant at p<0.01.

The direct relationship of TAN with bacillarophytes may probably be linked to the adaptability of this phytoplankton genus to a wide range of environmental variables (Effendi et al 2016). Shen et al (2018) found that NH_3-N is one of the main environmental factors that affect the distribution of benthic diatoms. Also, the genera *Nitzschia* and *Navicula* were found in the Langiran Lake, where these diatoms were considered eutrophic indicators of the aquatic environment. This is in accordance with the findings of the present study, where the lake was classified as eutrophic based on the calculated mean trophic status index (TSI).

Diatoms are utilized in monitoring water quality in waterways as they are powerful bioindicators of freshwater quality (Shen et al 2018). The copepods' linear relationship with TAN may associate with the active excretion of nitrogen in the form of ammonium into the water (Valdes et al 2017). Valdes et al (2017) revealed that copepods excrete nitrogen at an excretion rate reaching 2.6 µmol L^{-1} h^{-1}.

The strong relationship of PO_3 with ciliates is because phosphorous is among the major drivers influencing ciliate biomass, indicating a potential impact of eutrophication in the animal's growth. In particular, nutrients in the water directly affect the photosynthetic activity of photosynthetic ciliates, whilst indirect impact is experienced in heterotrophic ciliates due to the effect on the growth of phytoplankton which serve as their food (Wang et al 2014).

Diatoms are the most species-rich autotrophic algae found in fresh, brackish, and marine waters (Mann et al 2017). This group also has chlorophyll-a as a light-harvesting pigment (Kucynska et al 2015). In ecology, chlorophyll-a concentration is used to quantify the abundance of algae proliferating in certain bodies of water (US EPA 2022). As such, the high abundance of diatoms clearly reflects on its significant positive relationship with the chlorophyll-a concentration in the lake.

The high degree of association on the total coliform bacteria and rotifers may be linked to the taxon's feeding habit. Based on the study of Somani et al (2012), this group generally feeds on particulate organic matter and bacteria. The high level of coliform count recorded in the lake may be attributed to animal manure, household effluents, wildlife feces, and agricultural wastes that discharge in the lake, tending to increase the abundance of rotifers.

Primary productivity. As shown in Table 6, the GPP of the lake has a computed mean of 15.58 mg C m^{-3} hr^{-1}, NPP of 8.55 mg C m^{-3} hr^{-1} and a respiration rate of 8.44 mg C m^{-3} hr^{-1}.

Table 6

Summary of the level of phytoplankton primary productivity in Langiran Lake

Parameter	*Sampling site*				*Mean*
	Station 1	Station 2	Station 3	Station 4	
GPP (mg C m^{-3} h^{-1})	12.59	25.95	12.76	11.02	15.58
NPP (mg C m^{-3} h^{-1})	7.47	12.72	7.68	6.34	8.55
R (mg C m^{-3} h^{-1})	6.15	15.89	6.09	5.63	8.44

Note: GPP - gross primary productivity; NPP - net primary productivity; R - respiration.

The GPP and NPP obtained in this study are considerably low, corresponding to low levels of chlorophyll-a. It has been reported that shallow lakes are substantially productive compared with deeper ones, but could deviate from this when there is a dense mat of macrophytes on the surface (Feresin et al 2010). This could explain the low level of primary productivity in Langiran Lake, as it is heavily infested by water hyacinth. This macrophyte covers a large portion of the lake resulting in the reduction of light intensity and temperature, thereby restricting photosynthetic activity. Higher rates of GPP, NPP and R were observed in the sampling site near rice paddies (Station 2). The leaching or transport of nitrogen and phosphorous from these areas may have increased the primary productivity of the sampling site. However, the mean NPP of the lake is generally low. Moreover, mean R rate is almost the same with the NPP suggesting high consumption of DO by associated organisms. The level of net primary productivity of Langiran Lake is considerably lower compared with the reports on some freshwater bodies worldwide (Huq et al 1981; Feresin et al 2010; Koli & Ranga 2011; Lohani et al 2020). Hence, this could not favor aquaculture.

Relationship between water quality variables and primary productivity. The correlation analysis between water quality variables and primary productivity of Langiran Lake suggest that depth and SDV were negatively correlated with GPP and R, while TAN was positively correlated with NPP (Table 7).

Table 7
Correlation analysis of water quality variables and primary productivity in Langiran Lake

	GPP	*NPP*	*R*
Depth	-0.68*	-0.407	-0.715**
SDV	-0.824**	-0.514	-0.842**
Turbidity	0.254	-0.089	0.536
Temperature	-0.426	-0.514	-0.159
pH	0.282	0.2	0.261
Dissolved oxygen	0.209	0.137	0.206
Salinity	0.507	0.326	0.507
TAN	0.538	0.613*	0.242
Nitrite	-0.061	-0.228	0.15
TPO_4	-0.1	0.087	-0.269
TC	-0.181	-0.282	0.003

Note: SDV - Secchi disc visibility; TAN - total ammonia nitrogen; TPO_4 - total phosphate; TC - total coliform; GPP - gross primary productivity; NPP - net primary productivity; R - respiration; * - significant at $p<0.05$; ** - significant at $p<0.01$.

Negative associations of depth and SDV with GPP relate to the penetration of light into the water. Light along with nutrients are necessary for phytoplankton to proceed in their photosynthetic activity. According to Van Ruth et al (2020), phytoplankton production is influenced by depth layers in the ocean. The first is the layer with active turbulence caused by wind and tidal actions. In this region, the deeper the phytoplankton are mixed, the farther they will be taken away from the light. The second layer is the depth of the euphotic zone, where the sunlight could penetrate, thereby allowing the phytoplankton to photosynthesize. Lastly, in the third layer or the depth of maximum chlorophyll concentration, phytoplankton generally receives a lesser amount of light, which results in slower growth.

In terms of negative correlation of depth with respiration, the rate of respiration is typically high in the surface layers and decreases sharply below the base of the photic layer and often remains low throughout the thermocline (Del Giorgio & Duarte 2002). Respiration rates in lakes decline with increasing depths, being also associated to the decline in temperature and primary productivity (Pace & Praire 2004).

The positive relationship of TAN with NPP is associated with the phytoplankton growth due to the availability of nutrients in the surrounding water. Ammonia is a form of nitrogen that promotes eutrophication in the water (USGS 2016). The source of ammonia in the study site may come from the livestock wastes, effluents from households and hatchery facilities, wildlife feces, and agricultural wastes.

Temperature, turbidity, pH, DO, salinity, TAN, NO_3, TPO_4, and TC showed no significant relationships with primary productivity. This result is similar with the findings of Omondi et al (2016) in Kuinet Dam, Nigeria, where the insignificant relationship of temperature, pH, DO and TP has been linked to the effect of the dry period.

Trophic status. The trophic status of a lake system is an essential parameter in determining its environmental condition (El-Serehy et al 2018) and basically used as reference for dividing lakes into different categories such as oligotrophic, mesotrophic, eutrophic, and hypereutrophic lakes (Carlson 1977). In its conventional approach, it is calculated using a combination of water quality variables like water transparency, phosphorous level and chlorophyll-a concentration (Phillips et al 2013). The computed values of TSI are presented in Table 8. The lake has a mean TSI CHL-a of 38.96 μgL^{-1}, classifying the lake as oligotrophic. This means that the lake has low to moderate productivity. Meanwhile, in terms of TSI TP and TSI SDV, the lake exhibits high values, falling within eutrophic classification. The computed mean TSI suggests that the lake is already in a eutrophic condition. With reference to the findings of Omondi et al (2016), a water body having total phosphates greater than total nitrogen, with the dominance of chlorophytes and baciliariophytes, could indicate a eutrophic condition. As observed, the lake is shallow, with phosphate levels beyond the acceptable range and dominated by green algae and diatoms.

Table 8

Mean values of trophic state indices in Langiran Lake

Parameter	*Sampling site*				*Mean*	*Trophic class*
	Station 1	*Station 2*	*Station 3*	*Station 4*		
TSI CHL-a (μgL^{-1})	30.48	32.30	45.32	47.74	38.96	Oligotrophic
TSI TP (μgL^{-1})	55.98	69.12	61.34	79.90	66.59	Eutrophic
TSI SDV (m)	56.21	70.00	57.37	56.21	59.95	Eutrophic
ATSI	47.56	57.14	54.68	61.29	55.16	Eutrophic

Note: TSI CHL-a - trophic index chlorophyll-a; TSI TP - trophic index total phosphate; TSI SDV - trophic index Secchi disc visibility; ATSI - average trophic index.

Conclusions. Based on the findings of the study, the water quality of the lake is generally poor and only few genera of phytoplankton and zooplankton are present. The richness and abundance of green algae and diatoms indicate the presence of organic pollutants. Moreover, primary productivity is low and the lake can be categorized as a eutrophic body of water. Therefore, aquaculture in the lake is not recommended as of date and appropriate management actions are necessary to enhance the productivity of the lake, such as total removal of water hyacinths, dredging, construction of residential sewage system, regulating excessive fertilizer application in nearby farms, regular water quality monitoring, and proper information dissemination among resource users.

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