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Model of nitrogen-phosphorus ratio and phytoplankton relationship in lake Laut Tawar, Indonesia

Saiful Adhar[1*], Munawwar Khalil[1], Erlangga[2], Muliani[1], Rachmawati Rusydi[1], Mainisa[1], Imanullah[2], Yudho Andika[2]

[1] Deparment of Aquaculture, Agriculture Faculty, Universitas Malikussaleh, Jalan Cot Teungku Nie, Kampus Utama Reuleut, Muara Batu, Aceh Utara, 24355, Indonesia
[2] Deparment of Marine Science, Agriculture Faculty, Universitas Malikussaleh, Jalan Cot Teungku Nie, Kampus Utama Reuleut, Muara Batu, Aceh Utara, 24355, Indonesia

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ABSTRACT

Phytoplankton blooms in the lake cause ecological, economic, health, energy, and aesthetic losses. It reduces water quality and biota diversity, creates toxins in the waters, and changes the structures and functions of the ecosystem. The essential nutrients for the growth of phytoplankton are nitrogen and phosphorus. Controlling phytoplankton growth can be managed by controlling the limiting nutrient input. This study aims to identify the limiting nutrient, analyze variations in TN:TP ratio spatially and temporally, and model TN:TP ratio and chlorophyll-a relationship. This study used secondary data from previous studies, namely TN, TP, and chlorophyll-a observed monthly in seven stations purposively during a year. Rainfall data was also obtained from the previous study. Limiting nutrients were determined by Redfield theory, and data were analyzed by Spearman correlation, One-way ANOVA, Kruskal-Wallis, and regression analysis. The results showed phosphorus was a limiting nutrient for phytoplankton growth in Lake Laut Tawar. TN:TP ratio and chlorophyll-a did not vary spatially, indicating the lake surface waters were evenly mixed. The parameters varied temporally, expressing the influence of hydroclimatological factors, especially rainfall. Rainfall increases nutrient input to the lake, but only rain below 200 mm/month causes an increase in the concentration of nutrients in the lake. The rainfall above 200 mm/month increases lake water volume significantly, thereby reducing nutrient concentrations. TN:TP ratio and chlorophyll-a related negatively and formed a non-linear relationship with an empirical model Chlorophyll-a = 2770.285 $(TN/TP)^{-1.871}$. Eutrophication of Lake Laut Tawar should be anticipated by controlling the anthropogenic phosphorus input.

Introduction

Phytoplankton is the aquatic organisms that dominate the primary productivity in the water column (Ikhsan, *et al*., 2020; Abubakar, *et al*., 2021; Florescu, *et al*., 2022), and function as the basic link in the food chain (Dwirastina & Makri, 2012; Fakioglu, 2013). It produces oxygen and organic matter through photosynthesis in lake ecosystems (Li, *et al*., 2020). Phytoplankton growth/cycles take place in the presence of sunlight and nutrients, especially nitrogen and phosphorus (Turner & Rabalais, 2013; Mamun & An, 2017; Filstrup & Downing, 2017), suitable water temperatures are around 23°C–29°C, and pH is about 8.2-8.4 (Zhou, *et al*., 2018). Phytoplankton biomass is usually measured as chlorophyll-a (Brezonik, *et al*., 2019). Chlorophyll-a is used widely as an indicator of phytoplankton biomass, water quality, and eutrophication status (Ninčević Gladan, *et al*., 2015; Lins, *et al*., 2017; Florescu, *et al*., 2022).

The presence of phytoplankton in the aquatic system positively impacts aquatic biotas and can also be detrimental to the ecosystem. The detrimental impact will arise when the phytoplankton experiences fast growth and bloom. Phytoplankton blooming occurs when the aquatic environment provides favorable conditions for rapid growth (Jasmine, *et al*., 2013). The rapidly increasing phytoplankton population is usually experienced by toxic species that potentially spread toxins into the

* Corresponding author.
Email address: saifuladhar@unimal.ac.id

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waters (Davis, *et al*., 2009; Ge, *et al*., 2014). The phytoplankton death will consume dissolved oxygen in the water, releasing nitrogen and phosphorus, and even certain species produce toxic substances when decomposed (Todeschini, *et al*., 2011; Pilotti, *et al*., 2021). This condition will result in the death of other aquatic biotas and disrupt the ecological balance of the environment (Lim & Choi, 2015).

Phytoplankton blooms indicate the waters have undergone eutrophication (Prasad & Siddaraju, 2012). Eutrophication causes a substantial adverse impact on the water resources for domestic use, livestock, and recreation (Rafiee & Jahangiri-Rad, 2015). Eutrophication causes an imbalance condition between biological components, decreased diversity, and ecosystem instability (Fu-Liu, *et al*., 2014). Eutrophication also has an impact on human health through increased exposure to cyanobacteria toxins (Hudnell, 2010; Ge, *et al*., 2014), increasing the cost of drinking water treatment, a decrease in quality of life, and environmental stigma (Cunha, *et al*., 2016; Wolf & Klaiber, 2017). It will affect the communities that depend on the results of fisheries and aquatic tourism activities (Tasnim, *et al*., 2021).

The most important factors influencing the growth of phytoplankton are nutrients (Cao, *et al*., 2018; Li, *et al*., 2020) and the intensity of light (Onyema, 2013; Çelik, 2013). Nutrients are substances that play a significant role in the process and growth of phytoplankton (Wang, *et al*., 2015; Wisha & Maslukah, 2017). The key elements for the growth of phytoplankton in water bodies are nitrogen and phosphorus as essential nutrients (Turner & Rabalais, 2013; Mamun & An, 2017). Excessive nitrogen and phosphorus loading can stimulate phytoplankton growth and is the primary cause of algal blooms in lakes (Paerl, *et al*., 2016; Mamun & An, 2017; Liang, *et al*., 2018).

The primary productivity of lake waters is often constrained by nitrogen (N) and phosphorus (P) generally (Filstrup & Downing, 2017). The limitations of N and P are benchmarks for studying phytoplankton interactions (Hofmann, *et al*., 2021). The significance of the relationship of N and P to phytoplankton growth informs decisions about whether N, P, or both should be managed (Turner & Rabalais, 2013). Phosphorus is widely considered the primary limiting factor for phytoplankton growth and chlorophyll-a concentration in reservoir and lake systems (Rangel, *et al*., 2012; Widyastuti, *et al*., 2015; Jin, *et al*., 2020; Zhou, *et al*., 2022). It is assessed based on the nutrient limit index (nitrogen and phosphorus), concentration, and ratio (Rangel, *et al*., 2012). However, several lakes have N as a limiting factor for phytoplankton growth (Xu, *et al*., 2010; Ma, *et al*., 2020).

The ratio of total nitrogen (TN) and total phosphorus (TP) plays a vital role in phytoplankton growth (Putri, *et al*., 2014) and is the most frequently selected variable from a variety of biological, chemical, and physical variables (Yuan & Pollard, 2014). The N:P ratio can be used, as an approach, to determine the limiting factors in phytoplankton growth (Downing & McCauley, 1992). Phytoplankton growth in waters requires a TN:TP ratio between 10 to 20 (Grahame, 1987). A strong relationship between TP and chlorophyll-a was obtained in P-limited waters, and N-limited waters would show a close relationship between N and chlorophyll-a.

Nitrogen and phosphorus used as limiting elements for phytoplankton growth are known as the Redfield ratio (Lusiana, *et al*., 2021). The Redfield ratio is well known for the N:P ratio of 16 for phytoplankton (Redfield, *et al*., 1963). Marine phytoplankton contains a molecular C:N:P ratio of 106:16:1 or requires N and P in a molar ratio of about 16:1 (Redfield, 1934; Redfield, 1958), the use of ratios has become widespread in marine and freshwater phytoplankton studies (Ekholm, 2008). In addition, TN:TP ratio of 16 is often used as an indicator of nutrient limiting and aquatic ecosystem status (Li, *et al*., 2012; Widyastuti, *et al*., 2015).

The current conditions of Lake Laut Tawar are increasingly encouraging eutrophication. Increased nutrients from catchment areas are a threat to lake water quality. This phenomenon is caused by population growth around the lake, thereby increasing domestic activity. Increased agricultural and plantation activities in catchment areas increase nutrient input to the lake. Nowadays, tourism activities show an increase, which will also impact increasing a pollutant. In addition, global warming poses a threat to the lake ecosystem (O'Reilly, *et al*., 2015).

This study aims to determine the limiting nutrient, analyze the variation in TN:TP ratio spatially and temporally, and model the relationship between TN:TP ratio and chlorophyll-a at Lake Laut Tawar. Phytoplankton blooms are a common problem in the waters of the world (Minaudo, *et al*., 2015; Smith, 2016; Paerl, *et al*., 2016; Zhang, *et al*., 2017), studies on limiting nutrients have been discussed decades before (Schindler, 1974; Hecky & Kilham, 1988; Nixon, 1995; Dzialowski, *et al*., 2005; Lv, *et al*., 2011). However, limiting nutrients in Lake Laut Tawar have never been studied, while a limiting nutrient assessment in lake management for a healthy environment is urgently needed (Fukushima & Matsushita, 2021). Given the importance of the role and function of Lake Laut Tawar in ecology, economy, public health, energy, and aesthetics (Adhar, *et al.*, 2021a; Adhar, *et al.*, 2022), this study is feasible and significant as an effort to provide scientific information in the formulation of policies for the management of Lake Laut Tawar.

Materials and Methods

Location and time of research

Study site

Lake Laut Tawar is a tectonic-type lake (Lehmusluoto & Machbub, 1997) located in the eastern part of Takengon Town, the capital of Aceh Tengah Regency, Indonesia, at an elevation of about 1230 meters above sea level (Adhar, *et al.*, 2020). Geographically, it is between 4˚38'34"- 4˚34'46" N and 96˚51'25"- 96˚59'48" E, with a coastline of 49.75 km, a surface area of 58.62 Km^2 (Adhar, *et al.*, 2021a), an average depth of 25.19 meters and a maximum depth of 84.23 meters (Husnah & Fahmi, 2015). Lake Laut Tawar has a water catchment area of 18878 hectares with five land use types, residentials, plantations, rice fields, shrubs, and forests (Adhar, 2020).

Sampling

This study uses secondary data from previous studies, namely (Adhar, 2020) and (Adhar, *et al.*, 2023). The data are Total Nitrogen (TN), Total Phosphorus (TP), Chlorophyll-a (Chl), and rainfall monthly collected from October 2016 - September 2017 (Adhar, 2020). The observations used sampling points in seven stations purposively. A sampling of water for analysis of phytoplankton (chlorophyll-a), TN, and TP was carried out from 8 a.m. to 4 p.m. Sampling depth was approximately 30 cm. In detail, the study location and the sampling site are presented in Figure 1 (Adhar, 2020).

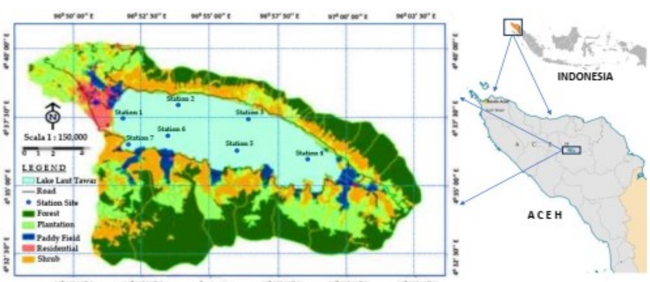

Figure 1. Map of Study Area

Figure 1 shows the study sites, land use, and observation stations. Observation stations were selected purposively based on land use in the sub-catchment area where the inlet flows into the lake and activities in the lake water. Table 1 presents the positions and criteria for observation stations. The data used in this study are total nitrogen (TN), total phosphorus (TP), and chlorophyll-a concentration (Chl).

Table 1. Description of the observation station

Station	Positions	Criteria of Inlet Sources
Station 1	N 4°37'26.00" and E 96°51'50.00"	Dominated by settlements and plantations
Station 2	N 4°37'54.00" and E 96°53'51.00"	Dominated by shrubs
Station 3	N 4°37'25.00" and E 96°56'25.00"	Water springs
Station 4	N 4°35'56.00" and E 96°58'36.00"	Dominated by plantations and paddy fields
Station 5	N 4°36'15.00" and E 96°56'00.00"	Dominated by forests and paddy fields
Station 6	N 4°36'47.00" and E 96°53'28.00"	Dominated by forests, scrubs, and paddy fields
Station 7	N 4°36'28.50" and E 96°52'01.50"	Floating net cage culture area

Data Source (Adhar, 2020)

Data analysis

The TN:TP ratio was calculated by dividing the TN values by the TP values. The obtained TN:TP ratio was compared with the Redfield theory to determine the limiting nutrients. Besides, the limiting nutrients were by comparing the correlation coefficient value between TN-Chl and TP-Chl. The limiting nutrients were by a higher correlation coefficient value. The Spearman correlation test analyzed the correlation coefficient between nutrients and chlorophyll-a. The Chl was compared among stations by using One-way ANOVA, and the comparison of the TN:TP ratio among stations was by using the Kruskal-Wallis test. A comparison of Chl and the TN:TP ratio among observation times was done by using the Kruskal-Wallis test and the Tukey Post Hoc Test. The One-way ANOVA test was used for normally distributed and homogeneous data, but if these assumptions were not a requirement, then the Kruskal-Wallis test was used.

The effect of rainfall on TN:TP ratio and Chl was analyzed by using regression analysis. Previously, correlation and linearity were analyzed to determine the regression analysis to be used on the relationship between both rainfall - TN:TP ratio, and rainfall – Chl. The linearity test was also used for the relationship between TN:TP ratio and Chl. A suitable relationship model between the two parameters was confirmed using regression analysis. The entire data analysis process used SPSS 22 software, and the graphs were using the Excel version 2016 software.

Results

The parameters observed during October 2016-September 2017 showed that TN was detected between 580 – 810 µg/L, with an average of 715.60 ± 68.73 µg/L. The TP showed an average of 36.04 ± 7.56 µg/L, ranging from 22 – 47 µg/L. The Chl was between 5 – 19 µg/L with an average Chl of 10.73 ± 3.94 µg/L. Based on the TN and TP values, the TN:TP ratio values range from 15.71 to 32.17 with an average of 20.52 ± 3.63. Figure 2a and 2b shows the averages of the TN:TP ratio and Chl from October 2016 to September 2017.

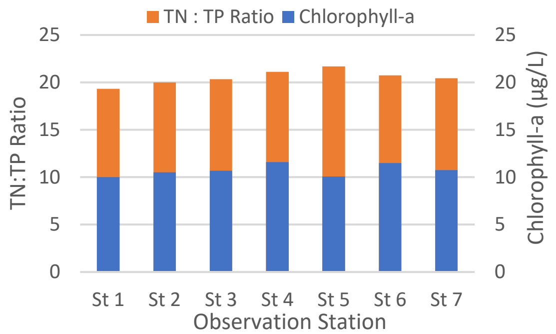

Figure 2a. TN:TP ratio and Chlorophyll-a of Observation Station in Lake Laut Tawar

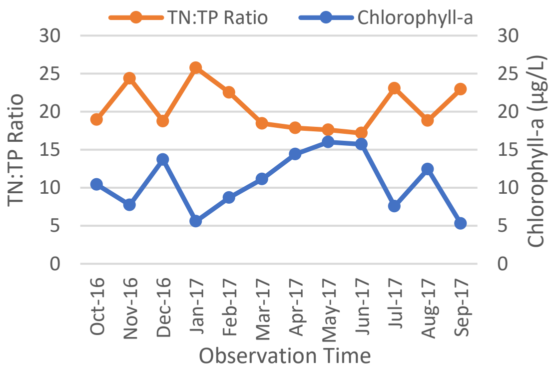

Figure 2b. TN:TP ratio and Chlorophyll-a of Observation Time in Lake Laut Tawar

Rainfall in the Lake Laut Tawar area ranged from 42 – 419 mm/month with an average of 197.58 mm/month (Adhar, 2020). In detail, the rainfall during October 2016 – September 2017 was described in Figure 3 which shows the lowest rain occurred in July 2017, and the highest rain occurred in September 2017.

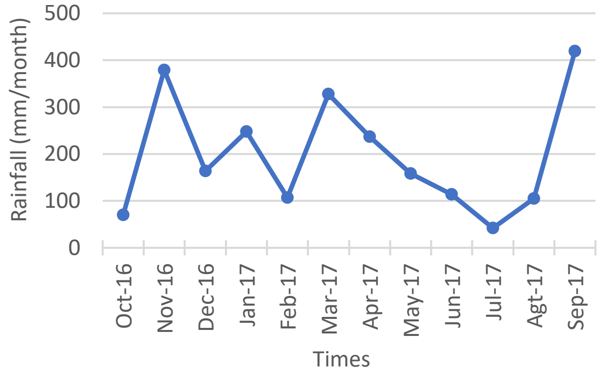

Figure 3. Rainfall in Lake Laut Tawar Area

Limiting Nutrient

The ratio of Total Nitrogen and Total phosphorus in Lake Laut Tawar during the study ranged from 15.71 to 32.17 with an average of 20.52 ± 3.63. TN:TP ratio and Chl varied quantitatively by station and sampling time. The average parameter values at each observation station describe values spatially, while the average values at each observation time exhibit the values temporally.

Figure 2(a) displays the average TN:TP ratio and Chl by stations and times. The highest average TN:TP ratio was at Station 5 at 21.67 ± 3.77. The lowest average Chl of 10.00 ± 3.30 µg/L was at Station 1, where the lowest average TN:TP ratio was also found with a value of 19.34 ± 3.59. The highest average Chl of 11.58 ± 4.58 µg/L was at Station 4. Figure 2(b) shows the average TN:TP ratio and Chl based on the observation times. The highest average TN:TP ratio was in January 2017 at 25.77 ± 4.40. September 2017 showed the lowest average Chl at 5.29 ± 0.49 µg/L. The lowest average TN:TP ratio obtained in June 2017 was 17.17 ± 0.69. The highest average Chl was in May 2017 at 16.00 ± 2.71 µg/L.

The normality test of TN, TP, TN:TP Ratio, and Chl on all observations showed that they were not normally distributed. It caused the correlation of TN, TP, and TN:TP ratio with Chl to be examined by the Spearman test. The TN - Chl correlation coefficient is 0.78, TP - Chl is 0.92, and TN:TP ratio - Chl is -0.77.

Spatio-temporal Variation of Chlorophyll-a and TN:TP Ratio

The chlorophyll-a data were normally distributed and homogeneous in nature. A one-way ANOVA test was used to observe the mean difference of Chl between observation stations. The analysis showed that the mean difference of Chl was not significantly different (sig = 0.942). The TN:TP ratios at each observation station have a homogeneous variant, but are not normally distributed. The difference test of the mean TN:TP ratio was used in the Kruskal-Wallis test which showed it was not significantly different between observation stations (Asymp. Sig = 0.742).

Chlorophyll-a at each observation time showed no homogeneous variance and at several observations, times were not normally distributed. Chl transformed to logarithm did not also show normally distributed data at observation times, which only showed homogeneous variance. Due to the failure to meet the requirements for parametric testing, so the Kruskal-Wallis test was used to analyze the difference in mean of Chl without data transformation between observation times. The result showed that Chl was significantly different between observation times (Asymp. Sig = 0.000). The Post Hoc Test also showed results confirmed that Chl was affected by variations in measurement time.

During the observation time, the TN:TP ratio did not have a homogeneous variance, and was not normally distributed. The normality and homogeneity test of the data transformed to logarithms showed that the data were not normally distributed and not homogeneous. The comparison test was carried out with the Kruskal Wallis Test which showed that the TN:TP ratio was significantly different between observation times (Asymp. Sig = 0.000). The Post Hoc Test to TN:TP ratio also revealed the same results as Chl which was affected by time variations.

Model of TN:TP Ratio and Chlorophyll-a Relationship

The normality test conducted on all Chl and TN:TP ratio data indicated that they were not normally distributed (Chl, KS sig = 0.004, TN:TP ratio, KS sig = 0.001). Similarly, when data transformed to logarithms also showed not normally distributed (log Chl, KS sig = 0.001, log TN:TP ratio, KS sig = 0.000). Because it did not meet the requirements of the parametric test, TN:TP ratio and Chl correlation were examined by Spearman's correlation test. The result showed a significant correlation with the correlation coefficient (r, Spearman's of -0.77).

The linearity test result showed that the relationship between the TN:TP ratio and Chl was not linear (Deviation from Linearity = 0.000). Therefore, when the model of the relationship was analyzed with a Non-linear Regression model. Several non-linear regression models were tried, such as logarithmic, power, and exponential, showing a significant relationship. The regression test showed that the highest R-square is the Power Model, namely 0.621. Figure 4 illustrates the graphic of the Power Model that explains the relationship between the TN:TP ratio and Chl.

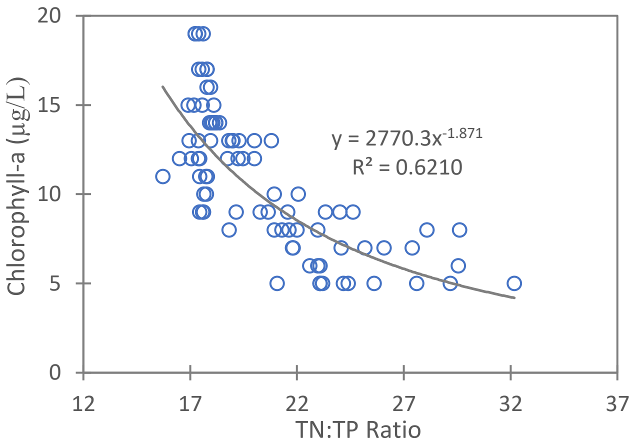

Figure 4. TN:TP ratio and chlorophyll-a relationship of Lake Laut Tawar

Figure 4 displays the TN:TP ratio and chlorophyll-a relationship with the empirical equation is Chl = 2770.285 $(TN/TP)^{-1.871}$, where Chl is chlorophyll-a (µg/L), TN is total nitrogen (µg/L), and TP is total phosphorus (µg/L). This equation has a Standard Error Estimate of 0.242.

Discussion

Limited Nutrient

The TN:TP ratio was applied to determine the limiting nutrient for phytoplankton growth (Li, *et al.*, 2012) and is commonly employed as an approach to determining the limiting factors for phytoplankton growth (Downing & McCauley, 1992; Putri, *et al.*, 2014; Yuan & Pollard, 2014). Based onthe average TN:TP ratio obtained in Lake Laut Tawar of 20.52 ± 3.63, decided that phosphorus was the limiting nutrient. It is regarding TN:TP ratio is greater than 16 (Redfield, 1958; Redfield, *et al.*, 1963; Sulastri, *et al.*, 2007; Indrayani, *et al.*, 2015; Widyastuti, *et al.*, 2015). These conditions indicate that the Lake Laut Tawar ecosystem has excess nitrogen availability. The utilization of nitrogen for phytoplankton growth only follows the availability of phosphorus nutrients (Poxleitner, *et al.*, 2016).

The decision that phosphorus is a limiting nutrient can also be from the excess nitrogen in Lake Laut Tawar. The observation showed that TN values were much higher than TP. In addition, TP has a higher correlation with Chl than TN (Lv, *et al.*, 2011). The result showed that Chl and TP were significantly correlated. The excess availability of nitrogen and phosphorus in lake waters originated from anthropogenic activities (Smith, *et al.*, 2016), both in the lake waters and the catchment area. The water quality of Lake Laut Tawar waters is influenced by floating net cage activities (Iriadi, *et al.*, 2015), which produce nutrient waste from excess feed (Adhar, *et al.*, 2021b). Floating net cage activities in Lake Laut Tawar produced about 170.16 tons N/yr and 77.83 tons P/yr (Adhar, 2020).

Human activities and land use types in the catchment area contribute to an increased nutrient entry into the lake (Gorman, *et al.*, 2014; Sobolewski, 2016). The catchment area of Lake Laut Tawar is for plantations, rice fields, forests, shrubs, and settlements (Adhar, 2020; Adhar, *et al.*, 2023), which produce N and P inputs into the lake (Adhar, *et al.*, 2023). Additionally, tourism activities in Lake Laut Tawar also increase pollutant inputs (Iriadi, *et al.*, 2015; Sieńska, *et al.*, 2016). Nutrients N and P in catchment areas are from agricultural activities, mainly from fertilizers and cultivation practices (Crooks, *et al.*, 2021; Tanaka, *et al.*, 2021), residential or urban areas (Camara, *et al.*, 2019; Tanaka, *et al.*, 2021), forest areas, and shrubs (Camara, *et al.*, 2019). The total N and P from the catchment area of Lake Laut Tawar were 195.64 tons N/year and 7.76 tons P/year (Adhar, 2020).

Based on this analysis, it concluded that Lake Laut Tawar is a lake limited in phosphorus and has excess nitrogen. Eutrophication of Lake Laut Tawar can be anticipated by controlling phosphorus input. Such anticipation measures are necessary to be applied because the phytoplankton growth in Lake Laut Tawar is limited only by the nutrient phosphorus, whereas the nutrient nitrogen is abundant but does not affect the phytoplankton growth.

Spatio-temporal Variation of TN:TP Ratio dan Chlorophyll-a

Statistical analysis showed that the mean TN:TP ratio and Chl did not vary between observation stations. It shows TN:TP ratio and Chl have relatively identic values in all sites of Lake Laut Tawar. Given that the lake inlets are from different land uses, they also input different concentrations of nutrients, which should result in different phytoplankton abundances. However, this did not happen, which indicates an influence on the hydrological conditions of the lake. Previous studies have shown that the nutrient inputs differ from the inlet, but the nutrient concentrations in Lake Laut Tawar were not spatially different (Adhar, 2020; Adhar, *et al.*, 2023). There were 43 types of phytoplankton in Lake Laut Tawar are classified into 5 classes, namely Chlorophyceae, Bacillariophyceae, Cyanophyceae, Dinophyceae, and Euglenophyceae (Nurfadillah, *et al.*, 2012). Similarly, a study at Lake Sentani also showed that the nitrite concentration in the inlet zone was significantly different from that in the center of the lake and the outlet, while the nitrite concentration in the middle of the lake and the outlet was not significantly different (Indrayani, *et al.*, 2015). Assumed, any input material from one part of the lake will flow to other sites, so form a stable and homogeneous concentration throughout the lake.

The relatively homogeneous mixing of the surface waters of Lake Laut Tawar (Adhar, *et al.*, 2021a; Adhar, *et al.*, 2022; Adhar, *et al.*, 2023) induces there is no variation in the mean TN:TP ratio and Chl spatially. The mixing and drainage of the lake's surface water are influenced by the winds in the area. The wind is a factor that drives hydrological disturbances (Ribeiro, *et al.*, 2014; Sulastri, *et al.*, 2019). Field observations at the study site showed the wind always occurs every afternoon, which causes the influence of the wind daily in Lake Laut Tawar, so the lake waters are relatively homogeneous spatially (Adhar, *et al.*, 2021a; Adhar, *et al.*, 2023). In addition, the morphology of Lake Laut Tawar is a shallow lake making it susceptible to disturbance by the wind that induces internal mixing by wind pressure on the lake surface (Andersen, *et al.*, 2020).

Temporally, it showed a significant difference in the mean TN:TP ratio and Chl between observation times. These differences indicate that the condition of Lake Laut Tawar waters varies monthly. The variations were affected by hydro-climatological factors, especially rain (Adhar, *et al.*, 2023) and fluctuations in water level and nutrient input (Sulastri, *et al.*, 2019; Florescu, *et al.*, 2022). Varied rainfall fluctuates in water level and nutrient input variations in Lake Laut Tawar (Adhar, *et al.*, 2023), so it variated in TN:TP ratio and phytoplankton biomass (chlorophyll-a). The effect of rainfall on variations in TN:TP ratio and Chl was by a graph that explains the relationship between rainfall and these parameters. Figure 5 describes the relationship.

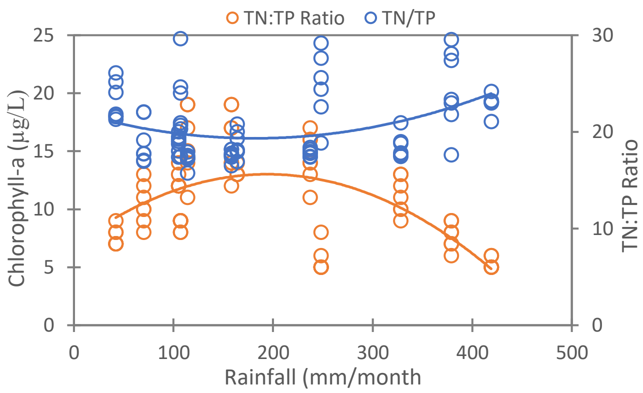

Figure 5. Relationship of Rainfall and TN:TP Ratio and chlorophyll-a in Lake Laut Tawar

Figure 5 illustrates a relationship between Rainfall and TN:TP and Chl that relationship model follows a quadratic equation. Regression analysis revealed that the relationship between rainfall and Chl has a determinant coefficient (R-square) of 0.43, which means that the precipitation factor affects the concentration of Chl in Lake Laut Tawar by 43 percent, and the relationship between rainfall and TN:TP ratio has a determinant coefficient (R-square) of 0.23, where the effect rainfall of 23 percent for TN:TP ratio value in Lake Laut Tawar.

The figure explains that increasing the rainfall to 200 mm/month increases the chlorophyll-a concentration in the lake waters. It is due to an addition in phosphorus input from the catchment area, driven by runoff due to increased rainfall. The phenomenon shown in the TN:TP ratio decreases with increasing rainfall up to 200 mm/month.

In this condition, TP increases more sharply than TN, thereby reducing the TN:TP ratio. It showed the opposite when the rain continued increasing over 200 mm/month. So, it might be considered that increased rainfall causes an increase in lake water volume, hence reducing phosphorus concentration in lake waters. The decrease in TP concentration in this condition was sharper than TN, thereby increasing the TN:TP Ratio.

It shows that the TP nutrient input decreases by rain of more than 200 mm/month. Previous rain events drained the TP to the lake from the catchment area. It was the opposite in TN, where as long as there was rain, it was still available and did not decrease significantly. This statement still requires proof, although it confirms that Lake Laut Tawar has excess TN and is limited by the TP.

Model of TN:TP Ratio and Chlorophyll-a Relationship

The relationship of TN:TP ratio and Chl were in Figure 3, which formed a non-linear relationship model as a Power Model. Figure 4 describes the interaction between nutrients (N and P) and phytoplankton in Lake Laut Tawar waters. The correlation coefficient (r, Spearman's) of the relationship about -0.77 indicated a negative relationship, where a decrease in TN:TP ratio is in line with an increase in Chl (Filstrup & Downing, 2017; Liang, *et al*., 2020). It is the condition of the absorption process of nutrients by phytoplankton, where the increase in phytoplankton is affected by a decrease in the TN:TP ratio caused by an increase in phosphorus without an increase in nitrogen.

The interaction showed that the growth of phytoplankton was controlled and dominated by phosphorus nutrients. The increase in nutrient nitrogen without increasing phosphorus in Lake Laut Tawar waters will increase TN:TP ratio values, and then it will decrease the phytoplankton growth because limited by phosphorus nutrients. TN:TP ratio influences the appearance of Chl as phytoplankton biomass in Lake Laut Tawar, by the determinant coefficient (R-square) of 0.621. This value means that the TN:TP ratio factor has an influence of 62.10 percent on changes in phytoplankton growth in Lake Laut Tawar waters, where other factors such as the light intensity (Onyema, 2013; Çelik, 2013), temperature, and pH (Zhou, *et al*., 2018).

Conclusion

This study concludes that (1) Lake Laut Tawar is a lake that has excess nitrogen, and the limiting nutrient is phosphorus (2) TN:TP ratio and Chl in Lake Laut Tawar did not vary spatially, but varied temporally, which was influenced by hydro-climatology factors, especially rainfall affecting directly or indirectly, (3) The relationship model of TN:TP ratio and Chl formed a non-linearly with the empirical model of Chl = 2770.285 $(TN/TP)^{-1.871}$. Controlling anthropogenic phosphorus inputs is a precise effort to anticipate eutrophication in Lake Laut Tawar.

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