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Nutrient Limiting Factor for Enabling Algae Growth of Rawapening Lake, Indonesia

✉Agatha Sih Piranti[1], Diana Retna Utarini Suci Rahayu[1], Gentur Waluyo[2]

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[1]Faculty of Biology, Universitas Jenderal Soedirman, Indonesia
[2]Faculty of Engineering, Universitas Jenderal Soedirman, Indonesia

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Abstract

Two important issues for establishment of nutrient criteria are identifying which nutrient limits algal growth and determining the concentration of that nutrient enabling nuisance growths. The purposes of this research were: 1) to examine the nutrient (TN, TP, ratio of TN/TP) dynamic in Rawapening Lake spatially and temporally, 2) to identify Nutrient Limiting of Algal Growth in Rawapening Lake, and 2) to determine the nutrient criteria for enabling algae growth in Rawapening Lake. The research was conducted using a survey method in 7 sites from February to August 2016. The result showed that spatially Total Nitrogen (TN) and Total Phosphor (TP) in the lake were not evenly distributed and temporally influenced by the inflow. The development of algae biomass in Rawapening Lake determined ratio of TN/TP. Nutrient criteria as follow: oligotrophic was 5.96 - 14.39, mesotrophic was 14.39 - 42.15, eutrophic 42.15 - 51.65, and hyper-eutrophic > 51.65. These criteria could be used in designing controlling eutrophication problem by arranging nutrient input from both external and internal sources in order to meet those limit. The benefits of research contributes to the development of environmental monitoring methods to assess the trophic status using more appropriate in accordance with the conditions of the tropics region. It also could be used for consideration in policy direction and orientation of land use in catchment areas in relation to water quality of the lake.

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✉ Correspondence Author:
Jl. HR Boenyamin 708, Grendeng, Purwokerto Banyumas, Jawa Tengah 53122
E-mail: agatha.piranti@gmail.com

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INTRODUCTION

The purpose of waters ecosystem management is to protect the ability of aquatic ecosystems against the pressure of changes and negative impacts caused by activity to remain capable of supporting functional integrity according to the carrying capacity of the ecosystem. Naturally, a lake ecosystem has the bio-capacity in absorbing nutrients in certain concentrations to support the metabolism process of organisms. The carrying capacity of the lake to nutrient input is reflected in the trophic level showing the level of water fertility and also indicates the water quality status. Nutrient criteria widely used for trophic status assessment in Indonesia are based on Organization for Economic Cooperation Development (1982), and Mason (1991) derived from eutrophication studies in subtropical region (4 seasons). So far, the assessment of trophic status for waters in Indonesia uses the same criteria as those. There are no nutrient criteria to assess the trophic level especially for Indonesia, so the monitoring trophic status of lakes in Indonesia using nutrient criteria derived from the temperate region (4 seasons).

The use of temperate criteria is less precise due to the biocapacity of lakes and reservoirs in Indonesia might be different from those of temperate regions and the responses generated will be different, so the use of its nutrient criteria for assessment of eutrophication of lakes in Indonesia is not appropriate. The concept of nutrient criteria based on the combined concept of Liebig Minimum Law and the Law of Tolerance by Shelford (*Horne & Goldman, 1994*). A state that is approaching or exceeding the tolerance threshold of a condition that includes the minimum or maximum range of determinants of organism growth is called the limiting factor of growth of the organism. The nutrient concept of eutrophication criteria was guided by the idea of the limiting factor. Therefore, determining which nutrients limit phytoplankton growth is an essential step in the development of effective lake and watershed management strategies (*Walker et al.*, 2007).

Rawapening Lake is a natural lake located in Semarang regency of Central Java, Indonesia, designated as one of the national priority lakes because of its existence provides the value of strategic benefits, but experiencing serious environmental problems and must be addressed. Rawapening Lake experiences ecological degradation related to the eutrophication process due to the entry of nutrients (nitrogen and phosphorus) from uncontrolled external and internal sources of the lake. Based on these problems it is necessary to examine the criteria of nutrient determinants of eutrophication in Rawapening Lake. Nutrient criteria showing the relationship between nutrient concentration and trophic status in the lake are expected to be used for the determination of trophic status not only for Rawapening Lake but also for other lakes in tropical regions, especially Indonesia which has the same morphometric characteristics. The research objectives were:1) to examine the nutrient (TN, TP, the ratio of TN/TP) dynamic in Rawapening Lake spatially and temporally, 2) to identify Nutrient Limiting Algal Growth in Rawapening Lake, and 3) to determine the Nutrient Criteria for Enabling Algae Growths in Rawapening Lake.

The benefits of research comprised in two aspects including of scientific development and management development. Regarding in the scientific development, especially in Environmental Sciences, this study contributes to the development of environmental monitoring methods to assess the alignment of the interrelationships between environmental components, as reflected in the trophic status of waters using a more appropriate nutrient criteria in accordance with the conditions of the tropics region. Regarding in the development of lake management, it is providing quantitative information that explains the causal relationship between human activity (anthropogenic process) and the biological response of water which can then be used in the planning, control, and improvement of a body of water. It also could be used for consideration in policy direction and orientation of land use in catchment areas in relation to water quality of the lake.

METHODS

This study used a survey method in Rawapening Lake from February to August 2016. The samples were taken monthly in 7 sites in stagnant water of the lake: 1) site of Brebesan (Mouth of Torong and Galeh river), 2) the tourism area of Bukit Cinta, 3) the water springs area, 4) Mouth of Muncul river, 5) Floating net area (Mouth of Legi river), 6) Mouth of Kedungringin river, and 7) the outlet of Rawapening lake (the Tuntang river). The sampling sites scheme is shown in Figure 1.

The main parameters include the concentration of Total Nitrogen (TN), Total phosphor (TP) andalgae biomass (chlorophyll). To assess the nutrient dynamics in Rawapening lakes performed descriptive analysis using graphs to describe nutrient concentrations between locations (spatial) and between times (temporarily). To determine the nutrients are limiting factor of eutrophication in Rawapening lakes analyzed using correlation and regression of Minitab computer program version 14. Determination of the nutrient criteria for the assessment of the trophic status of Lake Rawapening performed a quantitative analysis using a model. The best empirical results of regression analysis between nutrients and algae biomass was extrapolated to find the range of criteria of specified nutrient based on maximum chlorophyll in each trophic level according to trophic level classification based on *OECD (1982)* and *Mason (1991),* ie Oligotrophic waters containing chlorophyll 0,0 - 4,0 mg.m^{-3}, Mesotrophic 4.0 - 10.0 mg.m^{-3}, Eutrophic 10.0 - 25.0 mg.m^{-3}, and Hyper-eutrophic $\geq$ 25.0 mg.m^{-3}. Plotting prediction and extrapolation of the regression line to the nutrient concentration determinant to trophic status was performed using the computer program "Mapple version 14" (Bluman, 2000).

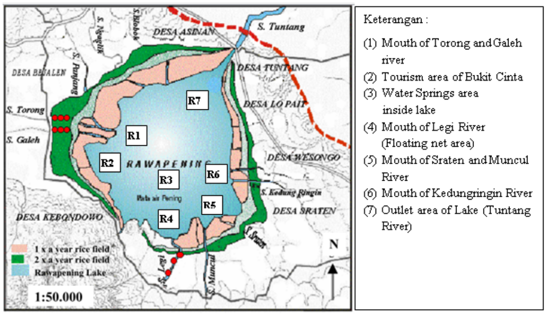

Figure 1. The sampling Sites in Stagnant Water of Rawapening Lake

RESULTS AND DISCUSSION

Nutrient (TN, TP and TN/TP) dynamic in Rawapening Lake

The lake ecosystem consists of two unit of landscapes that is Catchment Area (CA) and the stagnant water, so all human activity in CA have an impact on the lake. Human activities in the CA will affect the conditions in the lake. *Hart et al.* (2004) state that the nutrient content of rivers entering the lake is a reflection of land use conditions and activities occurring in its catchment areas (forests, agriculture, industry, settlements) and determines water quality and fertility status (trophic) lakes *(McFarland & Hauck, 2001).* The presence of erosion in the CA coupled with the use of high fertilizers can increase the rate of N and P transported into the lake in soluble form or bonded with soil particles in suspended sediments that cause cultural eutrophication (*McDowell & Wilcock, 2004*). Many circumstances, such as multiple combinations of land use, household impacts, and physical geographical factors may be responsible for variation in nutrient export into the lake (*Buhvestova et al., 2011*). The water catchment area of Rawapening Lake called Tuntang watershed consists of 9 sub-watersheds with several rivers that empty into Rawapening Lake as inlet and one river as outlet Tuntang River. Those nine sub-watersheds are formed of Legi, Parat, Galeh, Torong, Panjang, Sraten, Kedungringin, Rengas, and Muncul) Rivers. The inclusion of nutrients from catchment area into reservoirs through their inflow is not directly reflected in the increased trophic status of the lake because the lake response to nutrients will be modified by the addition of nutrients derived from the internal lake *(Kwang-Guk-An & Dong-Su-Kim, 2003).* Nutrients derived from internal and external sources of the lake can cause spontaneous or temporal fluctuations of nutrients in the lake, which will then be responded by algae in the lake. Therefore, the nutrient conditions in the lake will differ spatially and temporally.

Nutrient (TN and TP) Dynamic Spatially

Nutrient dynamic spatially distribution showed that the highest concentration of nitrogen (TN and TP) was coming from the Muncul River that was R1, R3, R5. The high nutrients entering into the lake were derived from the CA carried by each river. Total input TN to Rawapening Lake was very high up to 154.62 mg.sec$^{-1,}$ and TP was up to 10.32 mg.sec^{-1} *(Piranti et al.,* 2016*).* The high concentrations of TN and TP were also present in the floating net area. This was due to the fish feed residue, and fish feces that fall into the bottom of the waters caused increasing the nutrient content of the waters. Total nutrient in lakes especially TP derived from floating net activities has also exceeded its carrying capacity due to the amount of feed given has doubled more than the provision feed amount based on the load capacity of phosphorus contamination. Even the number of floating net in the waters has crossed to the threshold, so they needed to be a reduction in the number of floating net up to 307 units *(Samudra et al., 2013).*

The Springs Water is a source of water coming from the groundwater resulting from fracturing rocks that appears as a spring. It is located in the middle of the lake so that the area around the spring was not affected by human activities yet. The discharge of the springs is around 10 liters.sec^{-1}, so the water quality of surrounding area was still relatively of good quality. Therefore, the nutrient content (TN and TP) was lowest compared to other sites because it is diluted by the springs (Figures 2 and 3).

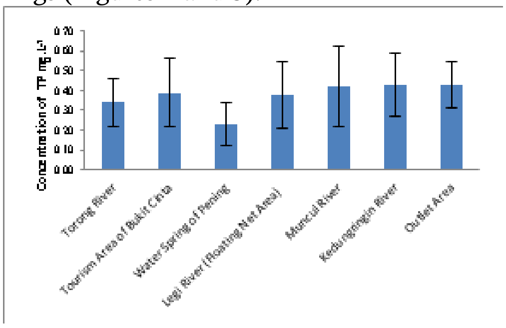

Figure 2. Spatial Distribution of TP in Rawapening Lake

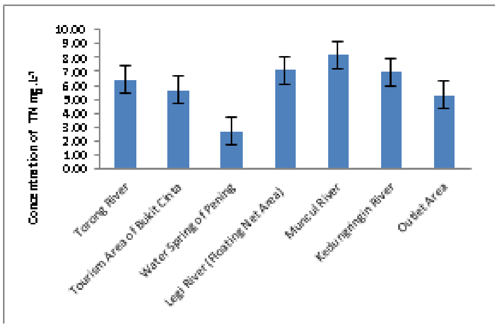

Figure 3. Spatial Distribution of TN Rawapening Lake

Tuntang River was the only outlet of the lake so that the TN and TP from the lake were carried out of the lake to the environment.

Nutrient (TN and TP) Dynamic *Temporarily in Rawapening Lake*

The amount of nutrient input (TN and TP) to the reservoir related to the amount of inflow discharge to the reservoir. The high inflow is the high TN Input and vice versa. With the increase of inflow discharge to the reservoir, the input of nutrients (TN and TP) from CA into reservoir also increases and vice versa. Temporal distribution of nutrients (TN and TP) showed that TN and TP concentrations were highest in March and subsequently decreased in July and August (Figures 4 and 5).

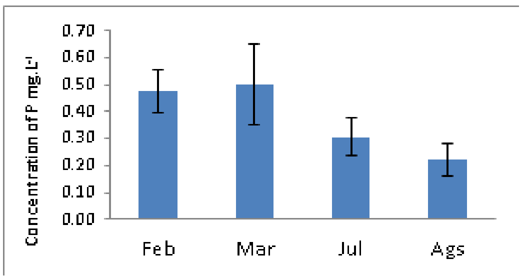

Figure 4. Concentration of TP Temporarily

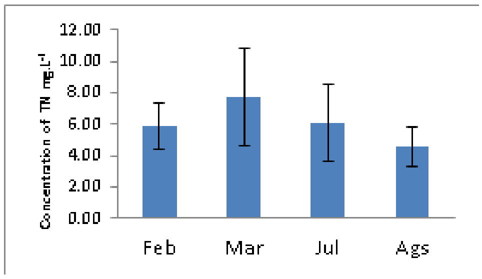

Figure 5. Concentration of TN Temporarily

The result of this observation showed that the input of nutrients that enter the lake has increased along with increasing rainfall. Based on data from the Tuntang River Basin Management Center *(Kementrian Lingkungan Hidup, 2011)* that the rainy season (wet months) occurred for six months (November to April), dry season for six months (May to October). There was a very strong positive correlation between the number of input nutrients both TP and TN with an inflow of lake discharge (*Piranti et al., 2014*). Surface water flowing through residential and agricultural areas will carry the materials containing TN and TP that eventually enter the Rawapening Lake. The highest nutrient loading into Rawapening Lake was occurring during March (TN of 205.3 $mg.sec^{-1}$ and TP 13.64 $mg.sec^{-1}$ compared to other months (February - August) (*Piranti et al., 2016*). The high nutrient also relates to land use type in CA due to the highest coefficient export of TP was generated respectively by land uses of rice field, settlement, agricultural field, forest and plantation (*Piranti et al., 2010; Hussian et al., 2016; Piranti et al. 2015*). The topography form of Rawapening Lake varied from flat to mountainous landscape. The flat topography area with a slope of 0% -15% located around Lake Rawapening in the form of rice fields. Slopes between 8% - 25% are at the foot of Mount Merbabu. A steep slope of > 45% found around Mount Gajah Mungkur. This land uses in Rawapening Lake of CA with those topography forms resulted in the high nutrient load into the lake.

***Dynamic of Ratio TN/TP in Rawapening Lake* Spatially and Temporarily**

Spatially ratio of TN/TP in Lake Rawapening ranged between 11 - 20 and temporal ranges between 12 - 20 (Figure 6 and Figure 7). Based on these assessments, the growth of algae in the waters of Lake Rawapening be determined by TP and at times determined by the ratio TN/TP (Florida Lakewatch, 2000). In conditions where nitrogen is the limiting factor in the growth of aquatic algae, in general, the types of algae that grow are a group of blue algae are capable of nitrogen fixation from the air (Suryono, 2006). The range of ratio TN/TP in Rawapening Lake presented in Figure 6 and Figure 7.

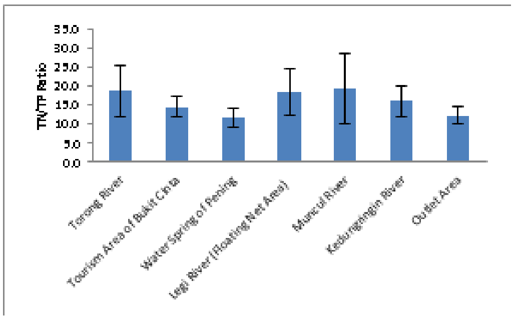

Figure 6. Ratio of TN/TP spatially

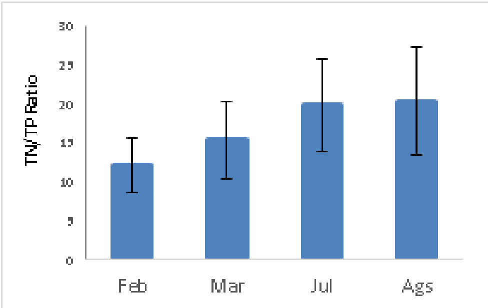

Figure 7. Ratio of TN/TP temporarily

Identification of Nutrient Limiting for Algal Growth in Rawapening Lake

The nutrient content of a water body is used to express the trophic status of waters, and it is reflecting the fertility of the water body. The trophic status of waters are classified as oligotrophic (poor nutrient, infertile/low productivity), mesotrophic (medium nutrient/medium productivity) and eutrophic (rich in nutrients, highly fertile/ high productivity), hyper-eutrophic (very rich/very fertile/highly productive) (*Horne & Goldmann, 1994)*. Various observations on correlations between algal biovolume and chlorophyll-a concentration have led to an acceptance of chlorophyll analysis as an indirect measure of algae biomass (Voros & Padisak, 1991).

The concentration of chlorophyll in Rawapening Lake during the study presented in Table 8 and 9. It is showed that the highest chlorophyll concentration was in the outlet area of the lake (Tuntang River) and the lowest in the spring water of the lake. In general, the abundance of algae in Lake Rawapening is very low (2.19 - 4.80 $mg.l^{-1}$). It was likely due to the abundance of water hyacinth species (*Eichornia crassipes*) that reduce the light penetration to the lake water. As much as 70% ake rawapening surface covered by water hyacinth The development of algae in waters was determined by the availability of nutrients (N and P) but also determined by other environmental condition such as the intensity of light, oxygen, temperature and water retention *(Onyema, 2013).*

Seasonal differences may lead to differences in these nutritional limitations and determine the phytoplankton taxa that dominate due to each Phytoplankton taxa of nutritional needs varies depending on seasonal changes Dzialowski et al. (2005). Furthermore, Under N-limiting conditions will be dominated by cyanobacteria which further would be dominance by the cyanobacteria. It leads to changes in some environmental variables including pH, grazing pressure by zooplankton, increase in water temperature and fluctuations in light intensity to the influence of the composition and dominance of phytoplankton species *(Paerl & Otten, 2013).*

The result of this research showed that chlorophyll concentrations representing phytoplankton assemblage increased during the study from February to August (Figure 9). It was influenced by lake water discharge. During February and March, the rainfall was still high and in July to August entering the period of the dry season. For the power generating purpose, during the dry season the turbine did not operate so the volume of water increase in level. This condition gave a chance to grow in the lake because not carried out the flow of water out and resulted in the phytoplankton density was increasing.

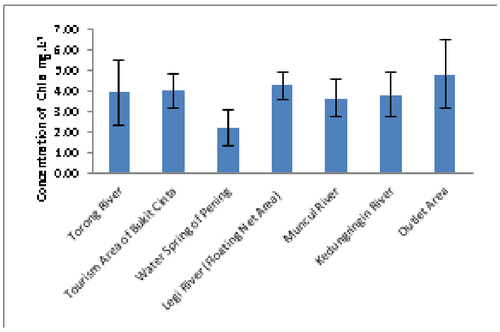

Figure 8. Concentration of Chlorophyll temporally

Nutrients (nitrogen and phosphorus) entry into the waters is the main factor that determines the number of algae *(Horne & Goldman, 1994).* The concentration of chlorophyll in the water samples can be used to estimate the number of algae or algae biomass in the waters *(Kom & Pan, 2013)* as well as a trophic status indicator (water fertility). The result of the correlation analysis between nutrients (TP, TN, TN/TP) and chlorophyll presented in Table 1.

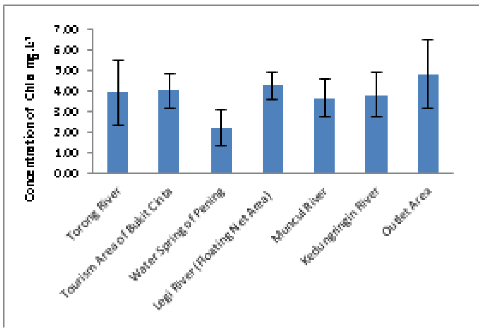

Figure 9. Concentration of Chlorophyll Spatially

Table 1. Correlation of nutrients and chlorophyll in Rawapening Lake

Correlation	Coeff of correlation (r)	Meaning
TN – Chlorophyll	0.135	no relationship
TP – Chlorophyll	0.200	very weak
TN/TP - Chlorophyll	0.487	significant

In the Table 1 showed that there was no correlation between TN and chlorophyll, but there was a correlation between TP and chlorophyll although the relationship was very weak. The relationship between TN/TP and chlorophyll ratio showed a significant relationship. It was said that the addition of TP alone less stimulates the growth rate of algae, while TN and TP more often limited the growth rate in the form of TN/TP ratio. It showed that how was the importance of the two nutrients (TN and TP) in regulating freshwater ecosystems *(Elser et al. 2007).*

Determination of Nutrient Criteria of Rawapening Lake

The primary purpose of establishing nutrient criteria is to prevent nuisance growths of algae causing eutrophication condition in the lake water. Two critical issues for establishment of nutrient criteria are by identifying which nutrient limits algal growth and determining the concentration of that nutrient enabling nuisance growths *(Suplee, 2012).* Based on the results of correlation analysis showed that the development of algae biomass (chlorophyll) was determined only by the ratio of TN/TP. In addition to the presence of nutrients, other environmental factors that influence the development of algae biomass among others is the presence of light, water mixing conditions and hydraulic residence time. Each of these environmental factors interacts with algae biomass, and its interaction is very complex resulting in a very specific model of relationship that reflects latitude, water catchment conditions, land use, and reservoir depth. Examination of the biochemical element content and environmental parameters in the algae community can be used as information on the influence of physicochemical conditions and nutrient composition to the algae community used as the algae bioindicators. Bacillariophyceae is an algae community that can be an early alarm against changes in water quality *(Hussian et al., 2016).*

Based on the statistical test results on the regression model shows that the best model that can describe the relationship between TN/TP and chlorophyll in Rawapening Lake was of the cubic regression model (Figure 10), with the following equation as follows.

$$\text{Chlorophyll} = -6.901 + 1.523\,(TN/TP) - 0.06695\,(TN/TP)^2 + 0.000957(TN/TP)^3$$

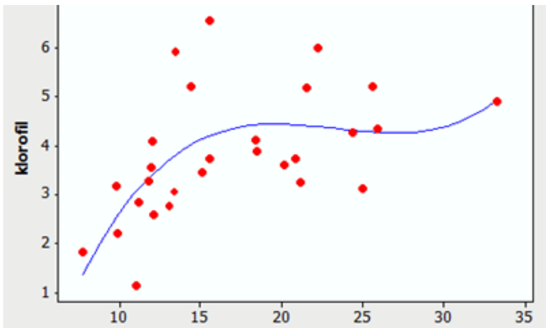

Figure 10. Relationship Model between TN/TP and Chlorophyll in Rawapening Lake

Nutrient criteria can be determined by extrapolation of the regression line results of the study the relationship between nutrient determinants of the growth of algae. The nutrient criteria of Rawapening Lake based on TN/TP were calculated by extrapolating to the best regression line equation presented in Figure 10. The relationship model can be explained that by increasing TN/TP ratio could increase the amount of algae biomass. The best regression line extrapolation results used as the basis for determining nutrient criteria are presented in Figure 11.

Based on the concentration of nutrients during observation, the trophic status of the waters of Rawapening Lake was already on hyper-eutrophic status, but if it was based on the chlorophyll, it was still in oligotrophic status. However, when it was assessed visually, Rawapening lake productivity was very productive. It was characterized by the abundance of aquatic vegetation dominated by water hyacinth plant

(*Eichornia crassipes*). The low biomass of algae in Rawapening Lake likely due to inhibition of algae growth due to the presence of aquatic plants, especially the water hyacinth. It is because they can produce an anti-microbial substance that can kill (microbiocidal) or inhibit growth (microbiostatic) bacteria, fungi, protozoans and including microalgae *(*Baral &Vaidya, 2011*).*

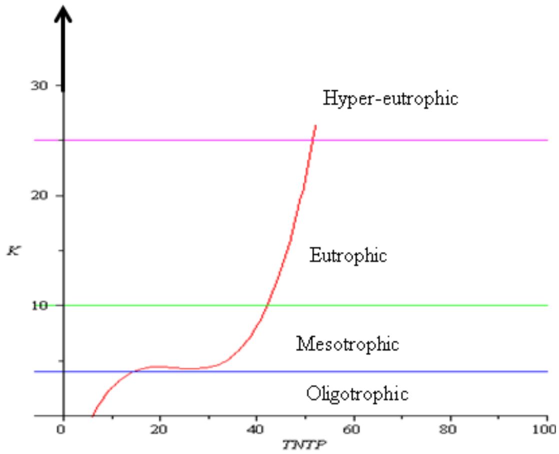

Figure 11. Extrapolation line of TN/TP and Chlorophyll in Rawapening Lake.

Historically, TP has been regarded as a primary nutrient that limits the growth of phytoplankton in freshwater ecosystems (Dzialowski *et al., 2005).* Some range of TN/TP ratios was used in the classification of nutritional limitations in lakes or reservoirs *Elser et al. (2007).* Therefore, the ratio of TN/TP can be used to determine the types of nutrients that act as a growth-limiting nutrient *(*Florida Lakewatch, 2000) and can be used to assess the type and or kind of population that may exist or dominate a body of water (Retnaningdyah *et al.,* 2010). By knowing the ratio of TN/TP can help anticipate and avoid the dominance of certain algae community that can degrade water quality as Cyanophyta.

The defining range of nutrient classification by N and P is commonly observed in lakes and reservoirs worldwide, highlighting the importance of N and P in regulating the growth of freshwater algae *(Ekholm, 2008).* Consequently, management efforts targeting P inputs alone will not effectively control algae disturbance and the associated negative impact of eutrophication. This suggests that the TN / TP ratio can be an effective tool for assessing nutritional limitations. The TN/TP criteria for algae growth in Rawapening Lake as shown in Table 2.

Based on Figures 11 and Table 2, it could be explained that the oligotrophic phase when the TN/TP ratio was in the range of 5.96 - 14.39, the mesotrophic phase was achieved when the TN/TP ratio range was 14.39 - 42.15, the eutrophic phase was achieved when the TN/TP ratio range was 42.15 - 51.65 And when the TN/TP ratio > 51.65 then the water was in the hyper-eutrophic phase

Table 2. Ratio TN/TP Criteria as determinant of algae growth in Rawapening Lake

Trophic State	Chlorophyll (mg.L^{-1})	Ratio of TN/TP
Oligotrophic	0 - 4	5.96- 14.39
Mesotrophic	4 - 10	14.39 – 42.15
Eutrophic	10 - 25	42.15 – 51.65
Hiper-eutrophic	≥ 25	≥ 51.65

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The characteristics of lakes in Indonesia are different from those of temperate lakes. If recently the assessment of trophic status of waters in Indonesia uses the nutrient criteria derived from the temperate region, then the result were inaccurate. Therefore, this research findings of this criteria could be used as a reference in the required nutrient control program to prevent eutrophication especially in Rawapening Lake. It is hoped that this nutrient criteria could be developed for other lakes so that further could be determined the nutrient criteria for tropical region especially for Indonesia water**.**

CONCLUSION

Spatially the concentrations of TN and TP was influenced by the nutrient load of each river and temporally were determined by the flow of water entering the lake. The rasio of TN/TP resulted in the development of algae biomass that representing the trophic status of Rawapening Lake. The mesotrophic phase was reached when the TN/TP ranged of 14.39 - 42.15. Over this range was in the eutrophic phase. Therefore, the lake water should be maintained in mesotrophic phase by controlling the TN/TP not exceeded than 42.

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