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Trophic States and Fishery Potential of Tidal Lakes, Lake Siombak, Medan, Indonesia

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Abstract

Siombak Lake is one of the tropical coastal lakes in Indonesia, which is unique and distinctive because it is directly influenced by the tidal dynamics of the Malacca Strait (7 km away) through the Belawan estuary. Therefore, Lake Siombak is brackish in its extensive pool. This lake functions as a water catchment, fishing area, and recreation area. This research aims to determine the fertility level and fisheries potential of Lake Siombak waters. The research was conducted from September 2018 to August 2019, but chlorophyll data was only taken for 4 months, namely November 2018, February, June, and August 2019. Water samples were taken during high tide and low tide conditions. Data taken to determine water fertility includes water brightness, phosphate concentration, and chlorophyll a. The fertility of lake waters is determined using various methods, namely the trophic State Index (TSI) method, Trix method, Trophic State Index Lamp (TSI Lamp), and Tropical Level Index (TLI). The brightness of Lake Siombak's waters ranges from 0.6–1.1 m. Phosphate concentrations ranged from 0.05-14.16 mg/L. The chlorophyll content in Siombak Lake ranges from 0.019 – 0.445 mg/m^3. The fertility level of Lake Siombak waters is eutrophic-hypereutrophic with a TSI value of 52.0-71.9; Trix index of 2.8-4.9; TSI lamp is 53.7-68.4; and TLI of 4.76-6.32. Spatially, the most fertile lake location is Station 1 (southern region), and temporally the dry season (February) is more fertile than the rainy season (November). The fisheries potential in Lake Siombak ranges from 320 – 773 kg/ha/month. The potential for fisheries production in Lake Siombak is highest in March.

Keywords: Fisheries potential, Lakes, Tidal lakes, Trophic status.

1. Introduction

Trophic status is the enrichment of water due to the input of nutrients in the form of inorganic materials needed by plants or algae which results in an increase in the primary productivity of water. The nutrients referred to in this case are nitrogen (N) and phosphorus (P) (Muhtadi, 2017; Pratiwi et al., 2020a,b; Adhar et al., 2022). Fertilization (enrichment) of water is a problem faced throughout the world, including land waters, especially lake or reservoir waters (McDowell et al., 2020). The trophic status of lake waters shows the impact of a load of nutrient waste entering the lake water (enrichment) (KLH, 2008; Muhtadi et al., 2018; Syawal et al., 2022).

Siombak Lake is one of the tidal lakes in Indonesia. Siombak Lake is located on the coast of Medan City, North Sumatra Province. This lake is very unique and distinctive. The uniqueness and peculiarity of this lake is that the lake's water system is an estuary. The river flow that enters the 7 km long lake from the Belawan River Estuary (Malacca Strait) is still influenced by the tides of seawater (Muhtadi et al. 2017; 2020a; 2023a). On the edge of the lake, there are mangroves that grow on the edge of the lake (Muhtadi et al., 2020b). The aquatic biota in Lake Siombak consists of groups of fresh, brackish, and marine organisms (Leidonald et al., 2019;

Yulianda et al., 2020; Muhtadi et al., 2022; 2023b). Siombak Lake functions as an water catchment, flood control, a fishing area for fish, shellfish, and crabs, as well as a tourist attraction (Muhtadi, 2022).

The location of Siombak Lake, which is at the mouth of the Belawan River, receives a lot of input from domestic or urban and industrial waste so the water quality is moderately polluted to heavily polluted (Muhtadi et al., 2023a). Apart from waste, the water quality of Lake Siombak also affects the amount of waste from offices, domestic, industrial, and community activities such as ponds. The entry of organic material into these waters will sooner or later affect the quality of the waters. This will then affect the existence of aquatic organisms, especially phytoplankton as the organisms that are the first to respond to changes in water quality (Muhtadi et al., 2020c; Pratiwi et al., 2020a, b).

Waters rich in nutrients are characterized by high nutrient availability. Increased water fertility (eutrophication) due to the input of nutrients, especially nitrogen and phosphate, will trigger the growth of phytoplankton (Muhtadi et al., 2020c; Hasani et al., 2022). The presence of nutrients is very important for the fertility level of water, because the large content of nutrients, especially nitrate (NO_3) and phosphate (PO_4), will affect the phytoplankton population in waters (Muhtadi et al., 2016; Adhar et al., 2018; Abobi and Wolff 2020; Pratiwi et al., 2020a; Muhtadi, 2022). The fertility level of water can be determined from the abundance and diversity of phytoplankton as well as the nutrient content in the waters (Timur & Abraham 2017; Pratwi et al., 2020b). The fertility level of lake and reservoir waters can be calculated based on several parameters that greatly influence lake fertility (Carlson, 1977; Timur & Abraham 2017).

Determining the trophic states and fertility level of water is important for lake management. Trophic states is useful for monitoring water quality (Leitão, 2012) through understanding nutrient cycles and their interactions with food networks in an ecosystem (Timur & Abraham, 2017). The importance of this aspect is the background for conducting this research. This study aims to assess the trophic states of Lake Siombak through several fertility index approaches. The hope is that it can be used as reference material for planning the development and management of Lake Siombak in a sustainable manner.

2. Methods

2.1 Time and Location

This research was carried out in November 2018, February, June, and August 2019. The sampling location was Lake Siombak, Medan City, North Sumatra Province. Testing of water samples and identification of phytoplankton was carried out at the Medan Class 1 Environmental Health and Disease Control Engineering Center and the Medan Industrial Research and Standardization Center.

2.2 Study Site

Siombak Lake has an area of 29.72 ha with an average lake depth ranging from 1.63–4.53 m when it rains (average tide about 3.27 m) and 1.61–4.38 when it dries (average tide about 3.25 m) (Muhtadi et al., 2020a). There are 11 observation stations (Figure 1). The distribution of sampling points represents activities around the lake (points 1-8) including 3 locations on the river (points 9-11).

2.3 Measurements of Water Tranparency, Phosphate, and Chlorophyll-A

Measurements and data collection were carried out during the full moon, at high tide and low tide. The brightness of the water is measured using a Secchi disk. The water sample for phosphate is a mixed sample of the surface, middle, and bottom. Phosphate analysis in the laboratory is carried out based on the Ascorbic Acid method (APHA, 2017).

Chlorophyll-a concentration measurements were carried out at the Medan Class 1 Environmental Health and Disease Control Engineering Center. The working method for measuring chlorophyll-a concentration is to take 1000 mL of water sample, filter it using 0.45

µm Whatman CNM filter paper, then add the extract to 10 mL of acetone solution, stir until the mixture is green, measure the absorbance of chlorophyll-a with a spectrophotometer at ƛ = 664, 647 and 630 nm.

Production potential data consists of morphometric data, water quality, and primary water productivity. Morphometric data were taken from Muhtadi et al. (2020a), water quality was obtained from the research results of Muhtadi et al. (2023a), and water productivity data was taken from Pakpahan et al. (2017).

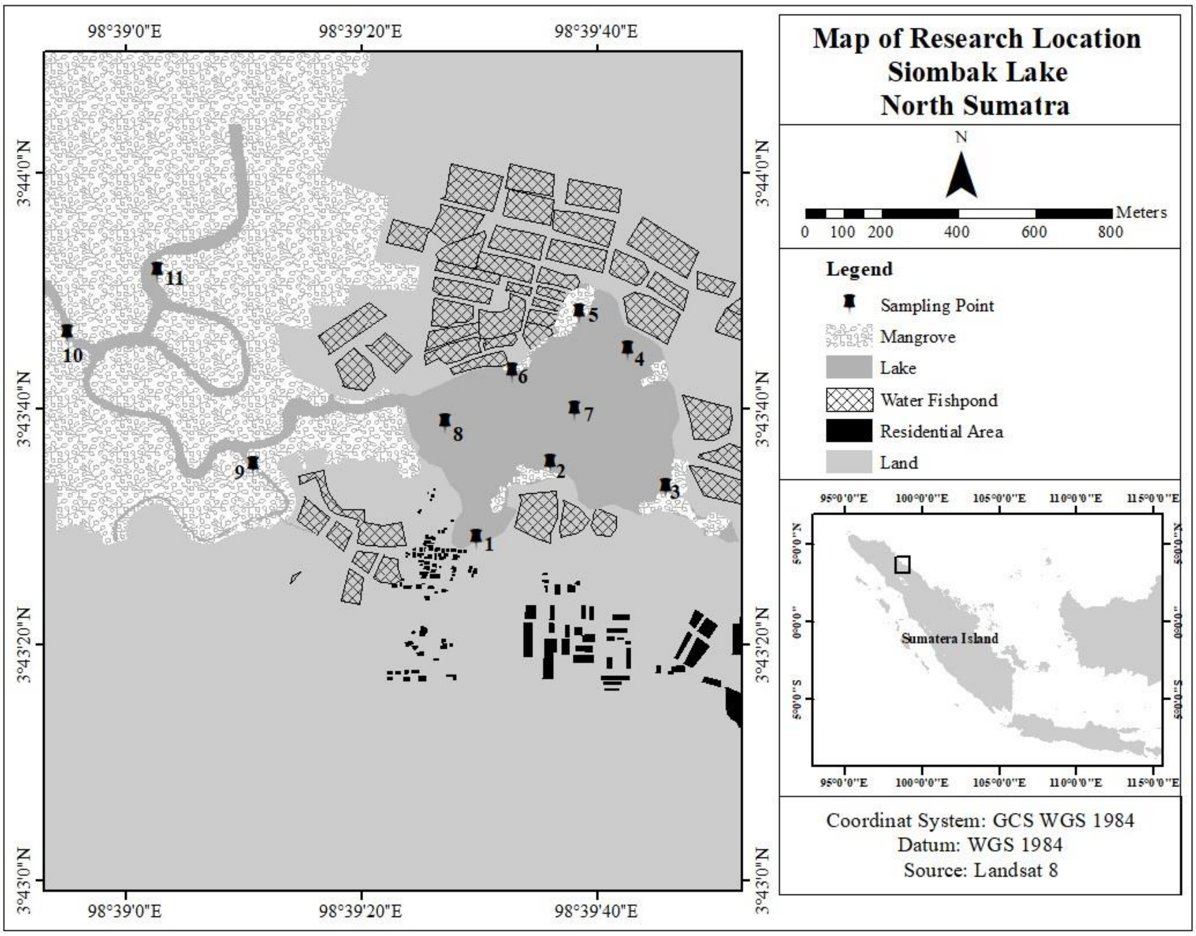

Figure 1. Data collection location at Siombak Lake

2.4 Data Analysis

Carlson (1977) developed the Tropical Status Index (TSI) with 3 fertility parameters, namely: total phosphate, chlorophyll-a, and brightness (Sechi disc). Vollenweider et al., (1998) developed a fertility index (Trix) with 4 water quality parameters: chlorophyll, oxygen, total nitrogen, and total phosphate. Another index is the trophic level index (TLI) (Burns et al., 2005) with 4 parameters: nitrogen, phosphorus, chlorophyll and brightness. Even Bucci et al., (2015) stated that for surface water in tropical waters, chlorophyll and total phosphate parameters are sufficient. The classification of trophic status includes hypertrophic, eutrophic, mesotrophic, oligotrophic and dystrophic (Welcomme, 2001, Wetzel, 2001, Jorgensen, 1980). However, in general there are three categories, namely eutrophic, mesotrophic and oligotrophic.

1. *Tropik Status Index (TSI)*

TSI is calculated using the following formula (Carlson, 1977):

1. TSI_K = 9.81 ln Chlorophyll-a (µg/l)+30.6
2. TSI_{WT} = 60-14.41In depth water tranparency (m)
3. TSI_P =14.42 ln Total Phosphates (µg /L) + 4.15
4. TSI $= \frac{TSI_k+TSI_{wt}+TSI_P}{3}$

Trophic Status of lake according to the following categories: <30 (oligotrophic), 30–40 (Hypolymnas), 40–50 (mesotrophic), 50–70 (eutrophic), >70 (hypertrophic).

2. *Indeks trophic (Trix)*

Vollenweider *et al.*, (1998) developed a index trophic (Trix) with a formula:

$$Trix = \frac{(log_{10}[ChA + aD\%O + \min N + TP] + k)}{m}$$

Where:
ChA = chlorophyll-a (µg/L)
aD%O = percent oxygen saturation
min N = Total N (µg/L)
TP = total phosphate (µg/L)
Coefficient k = 1.5 and m = 1.2.

Trophic Status of lake consist of < 4 (Low trophic level), 4–5 (Middle trophic level), 5–6 (High trophic level), 6–10 (Very high trophic level).

3. *Trophic Level Index (TLI)*

TLI is calculated using a formula (Burns *et al.*, 2005):

1. TL_N = -3.61+3.01log (N_{total})
2. TL_P = 0.218+2.92log (P_{total})
3. TLK_{WT}= 5.10+2.27log (1/water transparency -1/40)
4. TL_K = 2.22+2.54log (Chl*a*)
5. TLI = $\frac{TL_N + TL_P + TL_{WT} + TL_{Kl}}{4}$

Trophic Status of lake consist of: 0.0–1.0 (Ultramicrotrophic), 1.0–2.0 (Microtrophic), 2.0–3.0 (Oligotrophic), 3.0–4.0 (Mesotrophic), 4.0–5.0 (Eutrophic), 5.0–6.0 (Surpertrophic), and >6.0 (Hypertrophic).

4. *Trophic Level Index Lamp (TLI_{lamp})*

Bucci *et al.*, (2015) modifying TSI with the name TSI_{Lamp} for tropical waters with only 2 parameters, namely chlorophyll and total phosphate. The TSI_{Lamp} formula is:

1. TSI_K $= 10x\left(6 - \left[\frac{0.92 - 0.34 x \ln klorofil{-}a}{\ln 2}\right]\right)$
2. TSI_{TP} $= 10x\left(6 - \left[\frac{1.77 - 0.42 x \ln TP}{\ln 2}\right]\right)$
3. TSI_{lamp} $= \frac{TSI_{klorofil-a} + TSI_{TP}}{2}$

Status trophic of lake categories are: TSI ≤47 (ultraoligotrophic), 47 < TSI ≤ 52 (oligotrophic), 52 < TSI ≤ 59 (mesotrophic), 59 < TSI ≤ 63 (eutrophic), 63 < TSI ≤ 67 (supereutrophic), and TSI > 67 (hypereutrophic).

Analysis of potential fishery production based on water quality data and/or other morphometric parameters. There are several methods used in analyzing fisheries potential, consisting of:

1. *Morpho Edaphic Index Model* (MEI)

Morpho Edaphic Index (MEI) is a parameter used to predict the potential yield of a body of water (Henderson dan Welcomme 1974) with the formula:

$Y = 13.313 \times MEI^{0.4681}$

where, Y is potential (kg/ha/year) and MEI is calculated by Eq:

$$MEI = \frac{conductivity}{average\ depth}$$

2. ***Toews dan Griffith Model (1979):***

This model is a modification of the MEI model (Toews dan Griffith 1979). This model is calculated by a formula:

$$log\, Y = 1.4071 + 0.3697 log MEI - 0.00004565 A_0$$

A_0 = surface area (Ha); Y is potential (kg/ha/year)

3. ***Marshall Model (1985)***

This model uses data on the area (morphometry) of the lake (Marshall 1985). This model is calculated by a formula:

$Ln\ Y = 3.57 + 0.76 Ln(A_0)$

A_0 surface area (Ha); Y is potential (kg/ha/year)

4. ***Moreau dan De Silva Model (1991)***

This model combines area data with the number of fishermen who use the lake ecosystem (Moreau dan De Silva 1991). This model is calculated by a formula:

$Y = 436.2 + 0.336 A_0 + 0.745E$

A_0 is the surface area (Ha), E is the number of fishermen, Y is the potential (kg / ha / year)

5. ***Model of Downing et al., (1990)***

This model uses primary productivity data (Downing *et al.*, 1990). This model is calculated by a formula:

$log_{10}FP = 0.6 + 0.575\ log_{10}PP$

FP = potential of fisheries (kg/ha/year); PP = Primary productivity (µg/L)

6. ***Crul* Model *(1992)***

Just like Marshall's (1985) model, this model also uses area data (Crul 1992). This model is calculated by a formula:

$Y = 8.32 x A_0^{0.92}$

A_0

surface area (Ha); Y is potential (kg/ha/year)

7. **Model *Abobi dan Wolff (2020)***

Just like the Marshall model (1985) and the Crul model (1992), this model also uses area data (Abobi dan Wolff 2020). This model is calculated by a formula:

$Y = 17.3 \times A_0 (km^2)^{0.8626}$

A_0

surface area (Ha); Y is potential (kg/ha/year)

3. Results and Discussion

3.1 Trophic Status of Lake

Based on the results of trophic status calculations, Lake Siombak is classified as mesotrophic (Trix) to hypereutrophic (TSI, TLI, and TSILamp). However, if we look at the average value, in general, Lake Siombak is fertile (eutrophic) to very fertile (hypertrophic) waters (Figure 2). Eutrophic conditions according to Carlson (1977) can have impacts including decreasing water clarity, the hypolimnetic zone being anoxic, problems with aquatic plants, and only fish being able to live in warm water, dominated by blue-green algae. According to Minister of Environment Regulation No. 28 of 2009, the trophic status of lake and reservoir water contains high levels of nutrients. The trophic status of Lake Siombak shows that the water has been polluted by increased levels of N and P. Thus, in line with the water quality status of Lake Siombak which is classified as moderate to heavily polluted (Muhtadi et al., 2023a), Lake Siombak has experienced organic pollution containing N. and P. This nutrient enrichment will directly or indirectly change the biological processes that stimulate algae blooms (Yilmaz et al., 2018; Cutrim et al., 2019; Pérez-Ruzafa et al., 2019).

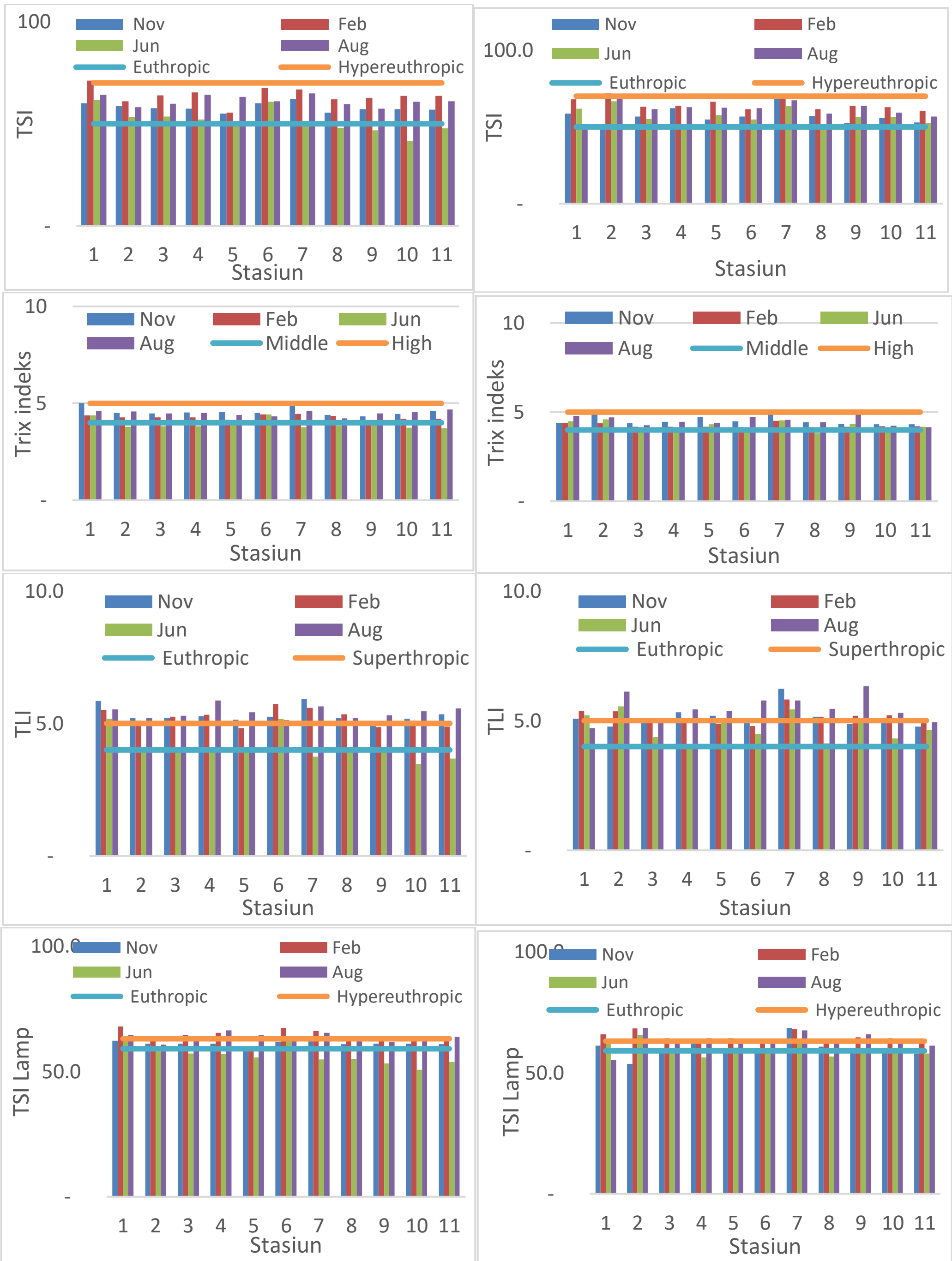

Figure 2. Trophic Status of Siombak lake at high tide (left) and low tide (right)

The fertility of Lake Siombak's waters is greatly influenced by the very high concentration of phosphate in the waters. Several studies on inland lakes illustrate that phosphate is an important element causing eutrophication (Zulfiah and Aisyah 2016; El-Serehy et al., 2018). However, it turns out that in coastal lakes the presence of N and the N/P ratio will trigger phytoplankton blooms (Tew et al., 2010; Tew et al., 2014; O'Neill et al., 2015). Phosphate concentrations of more than 0.1 mg/L (Muhtadi et al., 2020a) by Wetzel (2001) are categorized as fertile (eutrophic) environments. Likewise, a nitrate concentration of more than 0.2 mg/L constitutes eutrophic waters.

Spatially, the most fertile lake location is Station 1 (southern region) (Figure 2). This can be seen from the high levels of nutrients at station 1 (Muhtadi et al., 2023a) and the high abundance of phytoplankton at that location (Muhtadi et al., 2020c). However, the fertility of the lake at Station 1 is not as striking compared to other locations. Temporally, the dry season (February) is more fertile than the rainy season (November). This is influenced by the high abundance of phytoplankton so the chlorophyll value is high during that month. However, in the method that emphasizes nutrients (Trix), the rainy season (November) is more fertile than the dry season (February). This is caused by the higher levels of N and P nutrients in the rainy season compared to the dry season (Muhtadi et al., 2023a). Meanwhile, if you look at the highs and lows, the values are not that different. Trophic status of other lakes in Indonesia is reported to tend to fall into the eutrophic to hypereutrophic category (Muhtadi et al., 2018). Likewise other coastal lakes, such as Lake Chilika, India (Sarkar et al., 2019). Meanwhile, four coastal lakes in Tunisia are classified as supertropic (Trix method) (Abidi et al., 2018), including Jansen lagoon in Brazil (Cutrim et al., 2019).

3.2 Fisheries Production Potential

Based on analysis from various methods, it shows that the fisheries potential in Lake Siombak ranges from 6–603 kg/ha/year (Table 1). This striking difference in value is based on different method principles. Calculations using the MEI method (method 1 & 2) show high fisheries potential. This is caused by the high DHL value in Lake Siombak which is influenced by sea water. Fisheries potential using the MEI method ranges from 516–603 kg/ha/year. This value is very high when compared to lakes in Indonesia where the fisheries potential of lakes in Indonesia does not reach 100 kg/ha/year. Using primary productivity and chlorophyll shows lower production potential (119 kg/ha/year) compared to the MEI method. The fisheries potential of Lake Siombak using the primary productivity method is lower than Lake Kerinci which reaches 307 kg/ha/year (Samuel et al., 2015). Based on the morphometric method with extensive data (methods 4-7), it shows low fisheries production potential (6-16 kg/ha/year), except for the latest method released by Abobi and Wolff (2020) where the fisheries potential in Lake Siombak reaches 205 kg/ha/year.

Tabel 1. Fishing potential of Siombak Lake and other lakes/reservoirs in Indonesia

Metod	Fisheries potential (kg/ha/year)						
	SiombakLake[1]	Diatas Lake[2]	Laut tawar Lake[3]	Tempe Lake[4]	Paniai Lake[5]	Kerinci Lake[6]	West afica[7] Coastal lake)
1	603		34.12				
2	516	44		36-87	32.4		
3	119					307	
4	16						
5	14						
6	6						
7	205						30 - 634

[1]Results of this study, [2]Samuel dan Adiansyah (2016), [3]Adhar *et al.*, (2018), [4]Samuel *et al.*, (2012), [5]Samuel dan Ditya (2019), [6]Samuel *et al.*, (2015), [7]Abobi dan Wolff (2020)

The fisheries potential of Lake Siombak is classified as moderate when compared to lakes in West Africa with a potential reaching 30 – 634 kg/ha/year (Abobi and Wolff 2020). When compared with other coastal lakes in the world (Figure 4), it shows that the fisheries potential of Lake Siombak is above the average fisheries potential for coastal lakes in the world, namely 137.4 kg/ha/year (Pérez-Ruzafa and Marcos 2012). Areas of high fisheries potential in coastal lakes are in the northwest Atlantic (883.4 kg/ha/year), the Caribbean (302.6 kg/ha/year), the mid-eastern Atlantic (300.6 kg/ha/year), Japan (454.0 kg/ha /year), and Sri Lanka (406.3 kg/ha/year).

Referring to Downing et al. (1990), found that the most appropriate determination of fisheries production potential is the primary productivity method. Downing et al. (1990), found that the primary productivity variable can explain 79% of the actual situation with an acceptable p-value ($p<0.001$). Calculation of fisheries potential with DHL (MEI) only explains 20% with an unacceptable p-value ($p<0.593$), including other morphometric variables with a p-value<1. Thus according to Downing et al. (1990), that the potential for fisheries production in Lake Siombak is 119 kg/ha/year or 3,445.10 tons/year.

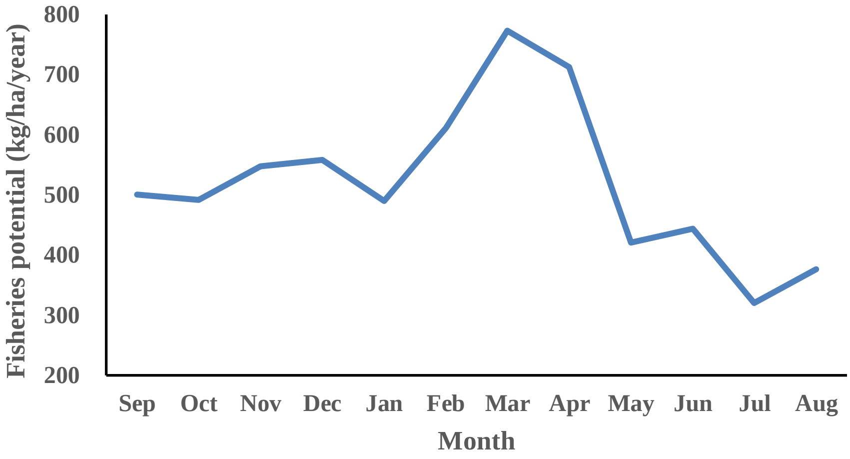

Figure 3. Potential fisheries production in Lake Siombak by month

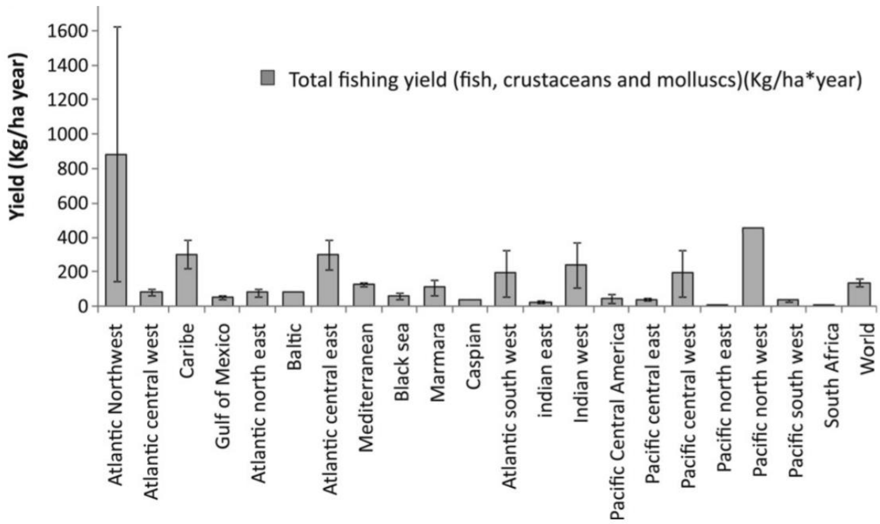

Figure 4. Potential fisheries production in the world's coastal lakes (Pérez-Ruzafa and Marcos 2012)

4. Conclusion

The trophic status of Lake Siombak waters is eutrophic–hypereutrophic with a TSI value of 52.0-71.9; Trix index of 2.8-4.9; TSI lamp is 53.7-68.4; TLI is 4.76-6.32. Spatially, the most fertile lake location is Station 1 (southern region). Temporally, the dry season (February) is more fertile than the rainy season (November). The fisheries potential in Lake Siombak ranges from 320 – 773 kg/ha/month. The potential for fisheries production in Lake Siombak is highest in March. The high production potential and eutrophic status of Siombak Lake require further management to sustain the Siombak Lake ecosystem.

5. Acknowledgement

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