Phytoplankton and the correlation to primary productivity, chlorophyll-*a*, and nutrients in Lake Maninjau, West Sumatra, Indonesia

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Abstract. Intensive freshwater fish farming using floating-net-cages in Lake Maninjau has been conducted since 1992. Fish farming intensification can reduce water quality and affect aquatic biotic communities. This research aims to study the impact of floating-net-cages activities on the phytoplankton communities, and its correlation to primary productivity, chlorophyll-*a*, and water quality of Lake Maninjau. Five representative sampling sites from Lake Maninjau were chosen purposively. Primary productivity, chlorophyll-*a*, and water quality were analyzed using the oxygen method, chlorophyll extract from autotrophic organisms and the tropical index respectively, then all parameters were analyzed using principal component analysis (PCA) to present the pattern. Water quality parameters such as temperature, pH, total suspended solids (TSS), total dissolved solids (TDS), light intensity, dissolved oxygen (DO), biological oxygen demand (BOD), chemical oxygen demand (COD), total P, and total N were also measured. From the results, we found 17 species of phytoplankton from 5 classes. Phytoplankton abundance ranged from 1980 to 3540 individual L^{-1}, with the lowest abundance found in Sigiran Site (incubation zone) and the highest in Kubu Baru Site (surface waters). The biomass estimation value of chlorophyll-*a* ranged from 0.415 to 0.104 mg C m^{-3}, with the highest value found on the surface water in Sigiran Site and the lowest in incubation zone in Tanjung Sani Site. From the water quality assessment, the trophic index of Lake Maninjau is categorized as eutrophic. The results of the analysis indicate the surface water tends to have higher productivity than in the incubation zone. Although in Sigiran and Tanjung Sani sites, the incubation zone has higher productivity than the surface water. Physico-chemical assessment results in surface water and incubation zone for DO ranged from 5.93 to 6.82 mg L^{-1} and 5.74 to 7.06 mg L^{-1}, pH ranged from 8.0 to 9.8 and 8.1 to 9.7, BOD ranged from 0.97 to 2.36 mg L^{-1} and 0.84 to 2.44 mg L^{-1}, COD ranged from 7.10 to 25.27 and 6.72 to 27.93, total P ranged from 0.13 to 0.33 mg L^{-1} and 0.12 to 0.42 mg L^{-1}, total N ranged from 1.13 to 1.82 mg L^{-1} and 0.52 to 3.07 mg L^{-1} respectively, and light intensity ranged from 1.3 to 1.6 m. Residual feed due to floating-net-cages activity causes water quality impairment in Lake Maninjau which is known by water quality and eutrophic status.

Key Words: floating-net-cages, intensive fish farming, nutrient, water quality.

Introduction. Lake Maninjau is a type of volcanic lake, one of five big lakes in West Sumatra, Indonesia. Lake Maninjau supports a large amount of floating-net-cages activity. Besides that, Lake Maninjau also supports hydroelectric power generation, agriculture, tourism, and other fisheries activities. There are more than 16,210 units of floating-net-cages since it began in 1992, sedimentation occurred with values of about 9,324.98 tons per year and causing declining in water quality (Junaidi et al 2014). Intensive fish farming using floating-net-cages was enhancing the nitrogen and phosphate source from the fish feed residues in cages, which induce mass mortality of fishes (Syandri et al 2014). Also, this condition disrupts the balance of organisms and the occurrence of phytoplankton population outbursts that impacted aquatic organisms (Abuka 2012).

The enrichment of nitrogen and phosphate elements in the waters can cause eutrophication. Lake Maninjau is in the eutrophic status (Junaidi et al 2014). Eutrophication under certain conditions is harmful because it can stimulate the growth of aquatic plants which will cover the waters and impaire aquatic ecological conditions (Glibert 2017). Eutrophication status is analyzed from the water quality, phytoplankton or chlorophyll-*a* distribution and primary productivity (Qin et al 2012).

Several studies about phytoplankton in Lake Maninjau have been carried out including the distribution of the epilithic diatom distribution in the lake (Afrizal 1988), epilithic diatom in the littoral zone of the lake (Hayati 1988), the composition and structure of the phytoplankton community (Sasmita 2001; Merina 2014). Sasmita (2001) reported that the phytoplankton composition in Lake Maninjau consists of five classes (Bacillariophyceae, Chlorophyceae, Cyanophyceae, Dinophyceae, and Euglenophyceae). Bacillariophyceae class is dominating in the Lake Maninjau (Sasmita 2001; Merina 2014). Abundance and species distribution of phytoplankton in Lake Maninjau are fluctuated due to water quality and the impact of floating-net-cages activity and other factors (Hayati 1988; Sasmita 2001; Merina 2014).

Phytoplankton distribution and fluctuations of primary productivity are related to temperature, light intensity, nutrients, and other limiting factors. The productivity rate is related to water quality and aquatic biotic communities (Nuzapril et al 2017). If environmental factors were suitable, the productivity rate will be high. This study aims to analyze the impact of floating-net-cages activities on the distribution and abundance of phytoplankton and its correlation to primary productivity, chlorophyll-*a*, nutrients, and the water quality of Lake Maninjau.

Material and Method

Description of the study sites. Lake Maninjau (0^{o}12'26.63" - 0^{o}25'02.80" S and 100^o 07'43.74 - 100^{o}16'22.48" E) is located in Tanjung Raya sub-district, Agam Regency, approximately 140 kilometers north of Padang (Figure 1). This study was conducted in September 2017 - March 2018 from 5 observation sites in Lake Maninjau (Muko-muko, Koto Kaciak, Kubu Baru, Tanjung Sani, and Sigiran villages) (Table 1).

Table 1

Description of each observation sites

No	*Site*	*Lat/Long*	*Description*
1	Muko-muko	S: 00^{o}17'15" E: 100^{o}09'08"	Intensive fish farming, surface water dominated by hyacinth (*Eichhornia crassipes*), settlement and tourism area, conservation area, sandy-mud substrate, littoral zone.
2	Koto Kaciak	S: 0^{o}15'32" E: 100^{o}11'09"	Intensive fish farming, settlement area and paddy fields, dominated by hyacinth and *Hydrilla*, mud substrate, sloping littoral zone.
3	Kubu Baru	S: 0^{o}18'09" E: 100^o 13'13"	Intensive fish farming, settlement area and hospitals, sandy substrate, littoral zone.
4	Tanjung Sani	S: 0^{o}21'20" E: 100^{o}12'54"	Intensive fish farming, sandy-rock substrate, benthic vegetation dominated, littoral zone.
5	Sigiran	S: 0^{o}20'03" E: 100^{o}09'54"	Intensive fish farming, settlement area, mud substrate.

Sampling method. Sampling sites were chosen purposively referring to Sitorus (2009), based on several different water characteristics such as substrate and surrounding anthropogenic activities (Table 1). In each location, water samples were taken from the surface water (0 m depth) and incubation zone (Secchi depth) during optimal sunlight (9.00 am to 2.00 pm). Surface water samples were collected from 45 liters of water using a 15-liter bucket (three replications). The incubation zone water sample was taken out using a 2250-mL Lamotte Water tube with twenty replications.

The water sampling method for phytoplankton observation refers to Vollenweider (1974). Determination of phytoplankton communities and physico-chemical parameters from waters sample were conducted on the Laboratory of Ecology, Department of

Biology, Andalas University. Phytoplankton samples were observed with a Zeiss Primo Star iLED Microscope with 10x40 and 10x60 magnification. Species identification was done according to Yamaji (1980), Prescott et al (1978), Bold & Wynne (1985), Krammer & Lange-Bertalot (1986), Biggs & Kilroy (2001), and Botes (2001). Online databases (Algaebase.org) were also used for identification.

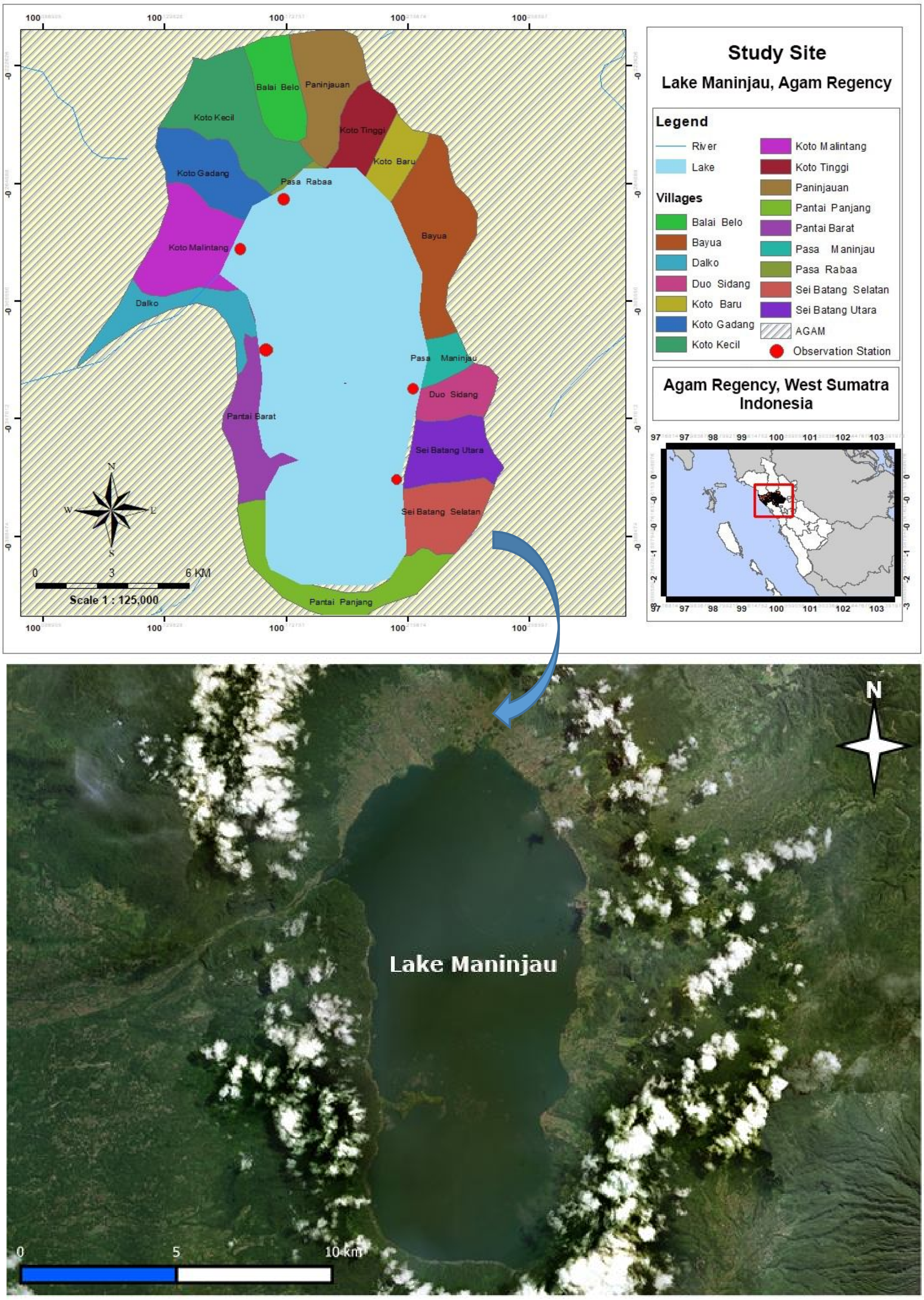

Figure 1. Lake Maninjau, sampling sites and satellite photos from Bing Satellite (QGIS).

Data analysis. Phytoplankton abundance was estimated by multiplying the mean total of phytoplankton observed in 1 mL subsamples with plankton concentrate volume in water samples (Michael 1984).

Chlorophyll-*a* content was estimated using the following formula (Boyd 1979):

$$\text{Chlorophyll} - \text{a}\,(\text{mg/m}^3) = 11.9(A665 - A750)\,x\,\frac{V}{L}\,x\,\frac{1000}{S}$$

where: A665 = absorbance at wavelength of 665 nm;
A750 = absorbance at wavelength of 750 nm;
V = acetone extract obtained (mL);
L = length of light path in liquid of cuvette (1 cm);
S = filtered sample volume (mL).

Primary productivity is equal to gross primary productivity value (GPP) minus respiration value (R) (Barus 2004). Respiration value was calculated from initial dissolved oxygen (DO) value minus DO value at the end of incubation in the dark bottle, GPP is equal to DO value in the light bottle minus DO value in the dark bottle at the end of incubation. DO units (mg L^{-1}) were converted into mg C m^{-3} by multiplying the value with conversion factor (375.36) (Barus 2004).

Statistical analysis*.* The principal component analysis (PCA) was used to find patterns and correlations of all parameters observed. PCA was performed using XLstat 2019 and SPSS Graduate PackTM 14.0 program for windows (SPSS 2005).

Nutrients and water quality parameters*.* Water quality evaluation in the field included the measurement of the following parameters: light intensity, temperature, pH, DO. Then measurements of the total dissolved solids (TDS), total suspended solids (TSS), biological oxygen demand (BOD), chemical oxygen demand (COD), N-nitrate, N-nitrite, N-ammonia, and phosphate from the water samples were conducted in the laboratory (Table 2).

Table 2

Nutrients and water quality parameters observed

No	*Parameter*	*Unit*	*Method*	*Tools*	*Analysis*
			Physical parameters		
1	Light intensity	meter	-	Secchi disc	In situ
2	Temperature	^{o}C	Thermal expansion	Thermometer	In situ
3	TDS	NTU	Nephelometric	Turbidimeter	Lab
4	TSS	mg L^{-1}	Gravimetric	Oven	Lab
			Chemical parameters		
1	pH	-	Potentiometric	pH meter	In situ
2	BOD	mg L^{-1}	-	-	Lab
3	COD	mg L^{-1}	-	-	Lab
4	DO	mg L^{-1}	-	-	In situ
5	N-nitrate	mg L^{-1}	Brucine	spectrophotometer	Lab
6	N-nitrite	mg L^{-1}	Sulfanilat	spectrophotometer	Lab
7	N-ammonia	mg L^{-1}	Phenate	spectrophotometer	Lab
8	Phosphate	mg L^{-1}	Stannous chloride	spectrophotometer	Lab

Trophic status*.* Trophic status of Lake Maninjau was analyzed using Trophic Index (TRIX) method with values range from 0 to 10 (Giovanardi & Vollenweider 2004) (Table 3) based on the following formula:

$$\text{TRIX} = [\log 10\ (PO_4 \times TN \times Chl\text{-}a \times DO\ saturation) + a] / b$$

where: PO_4 = total phosphate (micrograms per liter);
TN = total nitrogen (micrograms per liter);
Chl-*a* = chlorophyll-*a* concentration (micrograms per liter);
DO saturation = percentage of saturated oxygen;
Variables a = 1.5 and b = 1.2 are coefficient scales.

Table 3

Trophic index scale value (Vollenweider et al 1998)

TRIX value	Trophic status
0 < TRIX < 4	Oligotrophic
4 < TRIX < 5	Mesotrophic
5 < TRIX < 6	Eutrophic
6 < TRIX < 10	Hypertrophic

Results

Composition. We identified 17 species of phytoplankton from all sites, belonging to Bacillariophyceae (9 species), Chlorophyceae (3 species), Cyanophyceae (2 species), Zygnematophyceae (2 species), and Euglenophyceae (1 species) (Table 4). Bacillariophyceae class has the highest species and individuals number in general compared to other classes. *Nitzschia sigma* (Bacillariophyceae) was found as the main species of the phytoplankton community in Lake Maninjau with an enormous number and widely distributed in all sampling sites.

Table 4

Composition of phytoplankton in Lake Maninjau

Class	*Species*	*Presence (location)*				
		I	*II*	*III*	*IV*	*V*
Bacillariophyceae	*Cymbella tumida*	√	√	√	√	√
	Gomphonema elongatum	√	√	√	√	√
	Melosira granulata	√	√	√	√	√
	Synedra ulna	√	√	√	√	√
	Pinnularia viridis	√	√	√	√	√
	Nitzschia sigma	√	√	√	√	√
	Navicula cuspidata	√	√	√	√	√
	Epithemia sp.	√	√	√	√	√
	Fragillaria sp.	√	√	√	√	-
Chlorophyceae	*Oedogonium mitratum*	-	-	√	√	-
	Cosmarium sp.	√	-	-	√	-
	Pediastrum duplex	√	√	√	√	√
Cyanophyceae	*Oscillatoria* sp.	√	√	√	-	√
	Rivularia haematites	√	√	√	√	√
Euglenophyceae	*Phacus* sp.	√	-	√	√	-
Zygnematophyceae	*Closterium* sp.	√	√	-	√	-
	Spirogyra micropunctata	√	√	√	√	√

Information: √ (found); - (not found).

Abundance. The average abundance of phytoplankton on surface water and incubation zone were estimated as follows: Kubu Baru - 3540 and 2760 cells L^{-1}; Muko-muko - 3300 and 2940 cells L^{-1}; Tanjung Sani - 3180 and 3180 cells L^{-1}; Koto Kaciak - 2580 and 2350 cells L^{-1}; Sigiran - 2220 and 1980 cells L^{-1}, respectively (Table 5).

The highest average phytoplankton abundance on the surface water and incubation zone was found in Kubu Baru and Tanjung Sani, while the lowest average of phytoplankton found in Sigiran. These results indicate the highest phytoplankton abundance found on the surface water in Kubu Baru is not followed by incubation zone, while the lowest abundance of phytoplankton is found at the same location on surface water and incubation zone (Figures 2 and 3).

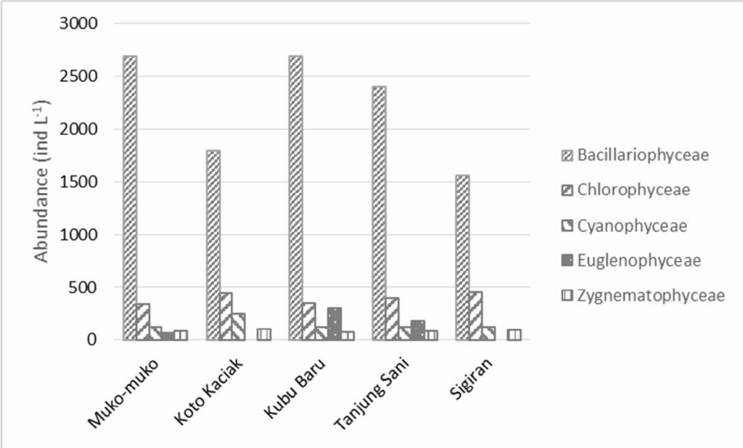

Figure 2. Average phytoplankton abundance (ind L^{-1}) on the surface water of Lake Maninjau.

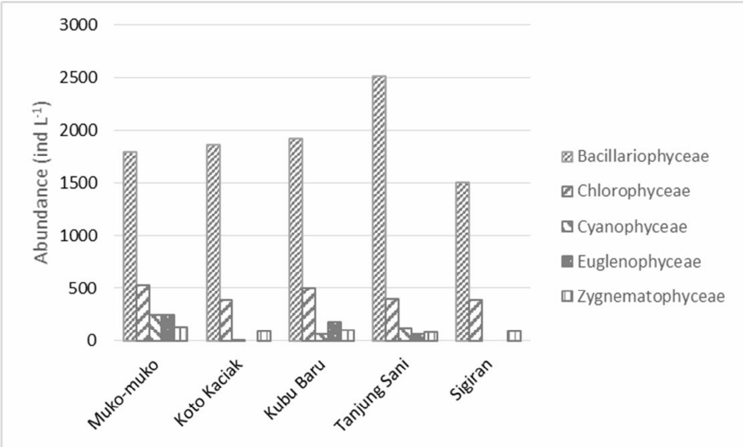

Figure 3. Average phytoplankton abundance (ind L^{-1}) in the incubation zone of Lake Maninjau.

Phytoplankton biomass (chlorophyll-a). Chlorophyll-*a* average value (conversion to mgC m^{-3} unit) on surface water and incubation zone found in Muko-muko were 0.250 and 0.204 mgC m^{-3}, Koto Kaciak 0.155 and 0.132 mgC m^{-3}, Kubu Baru 0.298 and 0.257 mgC m^{-3}, Tanjung Sani 0.104 and 0.104 mgC m^{-3}, Sigiran 0.415 and 0.411 mgC m^{-3}, respectively (Table 5). The average value of chlorophyll-*a* tended to be higher on surface water than in incubation zone (Figure 4). The highest chlorophyll-*a* average value on surface water and incubation zone were found in Sigiran (0.415 and 0.411 mgC m^{-3}, respectively) while the lowest found in Tanjung Sani (0.104 and 0.104 mgC m^{-3}, respectively).

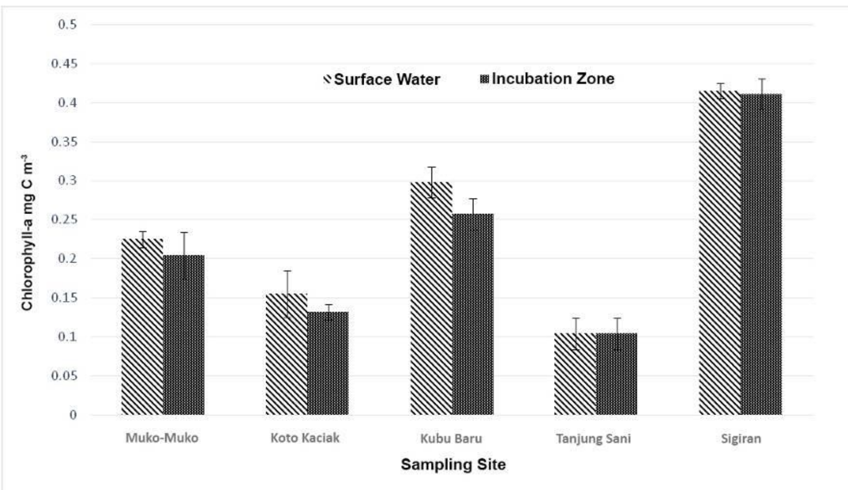

Figure 4. Chlorophyll-*a* concentration in Lake Maninjau.

PCA analysis showed that chemical-physical factors influenced the phytoplankton community and the chlorophyll-*a* value in Lake Maninjau (Figure 5). From the analysis, it is known that the increase in DO, phosphate, BOD, total nitrogen and light intensity values will increase the chlorophyll-*a* value. While the changes in temperature, COD, TSS, and TDS values have no relationship with chlorophyll-*a* value in the waters.

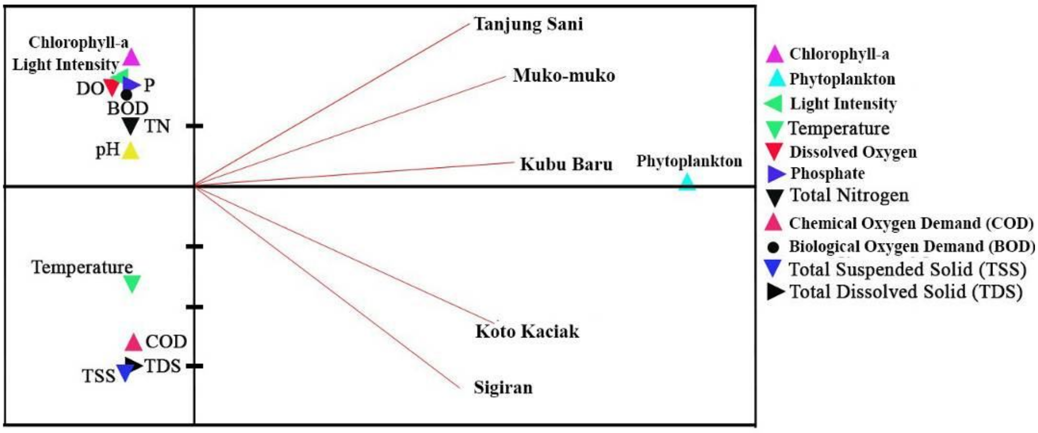

Figure 5. Chlorophyll-*a* and phytoplankton abundance groups with nutrients.

Primary productivity. Net primary productivity (NPP) value on surface water and incubation zone found in the sampling stations are: Muko-muko (1.37 and 1.17 mgC m^{-3} day^{-1}), Koto Kaciak (1.43 and 1.48 mgC m^{-3} day^{-1}), Kubu Baru (0.61 and 1.47 mgC m^{-3} day^{-1}), Tanjung Sani (0.11 and 0.89 mgC m^{-3} day^{-1}), and Sigiran (2.30 and 2.25 mgC m^{-3} day^{-1}) respectively (Figure 6 and Table 5).

Comparison of gross primary productivity (GPP) values is shown in Figure 6, where the highest primary productivity is at the Kubu Baru site (0.8 mgC m^{-3} day^{-1} in surface water) and Muko-muko site (0.6 mgC m^{-3} day^{-1} in incubation zone) and the lowest GPP values were found in the Koto Kaciak and Sigiran sites (0.03 mgC m^{-3} day^{-1} in surface water) while for the incubation zone the lowest values were found in Kubu Baru, Koto Kaciak and Tanjung Sani sites (0.02 mgC m^{-3} day^{-1}).

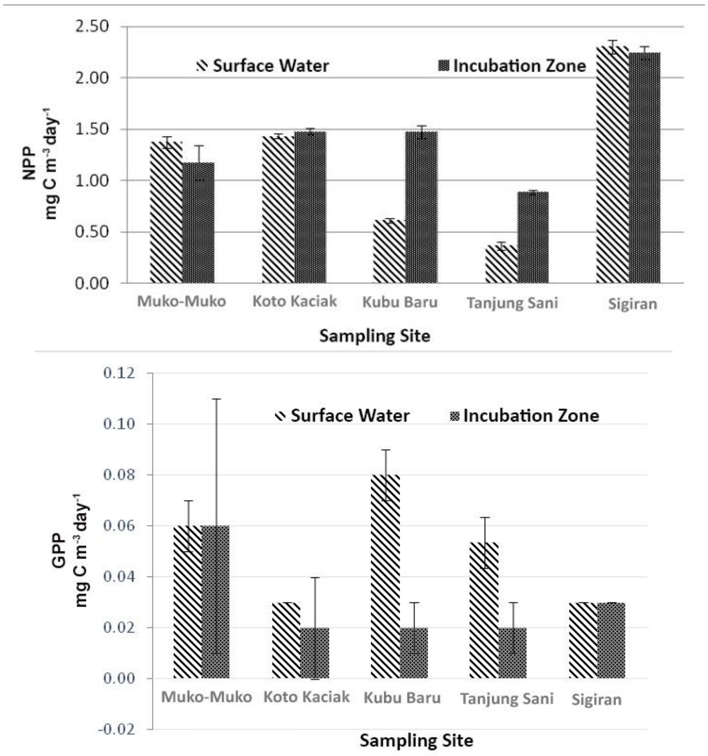

Figure 6. Primary productivity value of Lake Maninjau.

Based on Principal Component Analysis (Figure 7) we concluded that there is a relationship between GPP and NPP and the physico-chemical factors of water, namely GPP and NPP are positively correlated with light intensity, BOD, total nitrogen, DO and P. While TSS, TDS, COD are negatively correlated, with temperature, pH of waters having no correlation to GPP and NPP value.

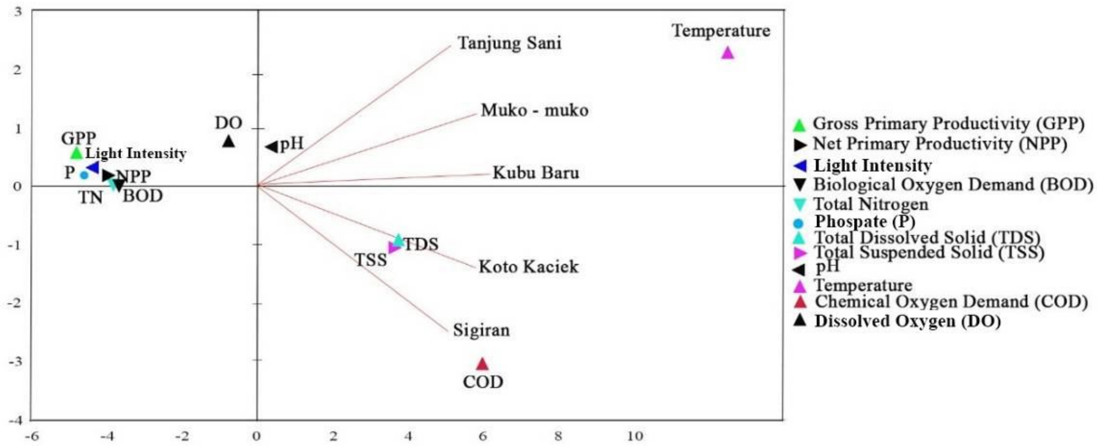

Figure 7. Net primary productivity and gross primary productivity group with nutrients.

Trophic status. The trophic index value of Lake Maninjau ranged from 5.1 to 5.6. Based on the trophic index (TRIX) category, Lake Maninjau belongs to eutrophic status (Table 6). Eutrophic conditions may have an impact on reducing water light intensity, the anoxic hypolimnetic zone, aquatic plant domination, and phytoplankton populations outburst.

Table 6

Trophic index and trophic status in all sites of Lake Maninjau

Location	*Index*	*Status*
Muko-muko	5.4	Eutrophic
Koto Kaciak	5.5	Eutrophic
Kubu Baru	5.1	Eutrophic
Tanjung Sani	5.1	Eutrophic
Sigiran	5.6	Eutrophic

Water quality parameters. The water quality parameters at Lake Maninjau are quite varied (Table 7) and significantly different ($p < 0.05$) between surface and incubation zone (Figure 8). The average value of DO on the surface water and incubation zone of each location ranged from 5.93±0.07 to 6.82±0.01 mg L^{-1} and 5.74±0.19 to 7.06±0.02 mg L^{-1}, respectively. Overall, the average DO value is higher in the incubation zone, although in Muko-muko and Sigiran site DO in the surface area was higher than the incubation zone.

Overall, the water quality parameters of Lake Maninjau observed on the surface water and incubation zone range from 28.13-29.20 to 28.20-29.17^{o}C for temperature; pH ranged from 8.0-9.8 to 8.1-9.7, TSS ranged from 5.41-18.49 to 8.20-18.49 mg L^{-1}, TDS ranged from 5.41-18.49 to 8.21-18.49 mg L^{-1}, respectively. Light intensity was 0 m and 1.30-1.60 m, BOD 0.97-2.36 and 0.84-2.44 mg L^{-1}, COD 7.10-25.27 and 6.72-27.93 mg L^{-1}, total P 0.13-0.42 and 0.12-0.42 mg L^{-1}, total N 1.13-1.82 and 0.52-3.07 mg L^{-1}, respectively (Table 7). Total P and total N were quite high in Lake Maninjau due to increases in floating-net cage activity, which produces many nutrient residues, such as at the Kubu Baru site.

Table 5

Primary productivity, chlorophyll-*a*, and phytoplankton abundance from all sites in Lake Maninjau

Parameter	*Sampling site*									
	Muko-muko		*Koto Kaciak*		*Kubu Baru*		*Tanjung Sani*		*Sigiran*	
	SW	*IZ*	*SW*	*IZ*	*SW*	*IZ*	*SW*	*IZ*	*SW*	*IZ*
Net primary productivity (mgC L^{-1})	1.37 ± 0.06^{a}	1.17 ± 0.17^{ai}	1.43 ± 0.02^{ac}	1.48 ± 0.03^{ac}	0.61 ± 0.02^{d}	1.47 ± 0.06^{ac}	0.11 ± 0.43^{e}	0.89 ± 0.02^{f}	2.30 ± 0.07^{g}	2.25 ± 0.06^{g}
Gross primary productivity (mgC L^{-1})	0.06 ± 0.01^{a}	0.06 ± 0.05^{a}	0.03 ± 0.00^{a}	0.02 ± 0.02^{a}	0.08 ± 0.01^{a}	0.02 ± 0.01^{a}	0.05 ± 0.01^{a}	0.02 ± 0.01^{b}	0.03 ± 0.00^{a}	0.03 ± 0.00^{a}
Chlorophyll-*a* (mg L^{-1})	0.23 ± 0.01^{a}	0.18 ± 0.03^{b}	0.14 ± 0.03^{c}	0.12 ± 0.01^{ac}	0.28 ± 0.02^{d}	0.24 ± 0.02^{d}	0.09 ± 0.02^{d}	0.08 ± 0.02^{d}	0.40 ± 0.01^{e}	0.40 ± 0.02^{e}
Abundance (ind L^{-1})	3300 ± 0.06^{a}	29400.17^{ai}	2580 ± 0.02^{ac}	2350 ± 0.03^{ac}	3540 ± 0.02^{d}	2760 ± 0.06^{ac}	3180 ± 0.43^{e}	3180 ± 0.02^{f}	2220 ± 0.07^{g}	1980 ± 0.06^{g}

Note: SW = surface water; IZ = incubation zone. Average±SD (n = 3). The alphabet notation in the table explains the significance of the data from Duncan's test ($p < 0.05$).

Table 7

Water quality parameters of Lake Maninjau in November 2017

Parameter	*Site*									
	Muko-muko		*Koto Kaciak*		*Kubu Baru*		*Tanjung Sani*		*Sigiran*	
	SW	*IZ*	*SW*	*IZ*	*SW*	*IZ*	*SW*	*IZ*	*SW*	*IZ*
Temperature (°C)	28.13 ± 0.15^{a}	28.20 ± 0.10^{a}	29.13 ± 0.06^{b}	29.13 ± 0.06^{b}	29.13 ± 0.06^{b}	29.17 ± 0.10^{b}	29.20 ± 0.06^{b}	29.17 ± 0.06^{b}	29.17 ± 0.06^{b}	29.13 ± 0.06^{b}
pH	9.8 ± 0.058^{a}	8.1 ± 0.058^{b}	8.9 ± 0.058^{c}	9.7 ± 0.058^{d}	8.5 ± 0.058^{e}	8.8 ± 0.000^{c}	8.0 ± 0.058^{f}	8.1 ± 0.058^{f}	8.6 ± 0.000^{e}	8.1 ± 0.058^{b}
TSS (mg L^{-1})	10.31 ± 0.02^{a}	15.48 ± 0.03^{b}	18.06 ± 0.01^{c}	18.45 ± 0.01^{d}	13.34 ± 0.01^{e}	16.04 ± 0.02^{f}	5.41 ± 0.03^{g}	8.20 ± 0.01^{h}	18.49 ± 0.02^{i}	18.49 ± 0.01^{j}
TDS (mg L^{-1})	10.30 ± 0.01^{a}	15.47 ± 0.01^{b}	18.06 ± 0.02^{c}	18.43 ± 0.01^{d}	13.34 ± 0.01^{e}	16.04 ± 0.03^{f}	5.41 ± 0.02^{g}	8.21 ± 0.01^{h}	18.49 ± 0.02^{i}	18.49 ± 0.02^{j}
Light intensity (m)	0.00 ± 0.00^{a}	1.50 ± 0.00	0.00 ± 0.00^{a}	1.30 ± 0.00	0.00 ± 0.00^{a}	1.45 ± 0.00	0.00 ± 0.00^{a}	1.60 ± 0.00^{a}	0.00 ± 0.00^{a}	1.55 ± 0.00
DO (mg L^{-1})	6.73 ± 0.06^{a}	5.74 ± 0.19^{b}	6.27 ± 0.02^{c}	6.30 ± 0.02^{c}	6.82 ± 0.01^{a}	7.06 ± 0.06^{d}	6.60 ± 0.43^{a}	7.06 ± 0.02^{d}	5.93 ± 0.07^{e}	5.88 ± 0.06^{e}
BOD_5 (mg L^{-1})	1.31 ± 0.02^{a}	1.94 ± 0.01^{b}	2.16 ± 0.02^{c}	2.44 ± 0.04^{d}	2.36 ± 0.02^{e}	2.37 ± 0.03^{e}	0.97 ± 0.02^{f}	0.84 ± 0.03^{g}	1.18 ± 0.02^{h}	0.91 ± 0.03^{i}
COD (mg L^{-1})	17.14 ± 0.01^{a}	24.20 ± 0.01^{b}	24.14 ± 0.03^{c}	27.93 ± 0.02^{d}	25.27 ± 0.02^{e}	25.27 ± 0.03^{e}	7.10 ± 0.02^{f}	6.72 ± 0.02^{g}	13.55 ± 0.03^{h}	10.81 ± 0.03^{i}
Total P (mg L^{-1})	0.21 ± 0.02^{a}	0.31 ± 0.02^{b}	0.33 ± 0.02^{b}	0.42 ± 0.02^{c}	0.42 ± 0.03^{d}	0.41 ± 0.01^{d}	0.13 ± 0.02^{e}	0.12 ± 0.01^{e}	0.22 ± 0.02^{a}	0.16 ± 0.02^{f}
Total N (mg L^{-1})	1.46 ± 0.43^{a}	1.72 ± 0.45^{b}	1.75 ± 0.49^{b}	1.86 ± 0.48^{c}	1.82 ± 0.66^{c}	3.07 ± 0.62^{d}	1.13 ± 0.42^{d}	0.52 ± 0.16f	1.22 ± 0.36^{g}	1.01 ± 0.31^{h}

Note: SW = surface water; IZ = incubation zone. Average±SD (n = 3). The alphabet notation in the table explains the significance of the data from Duncan's test ($p < 0.05$).

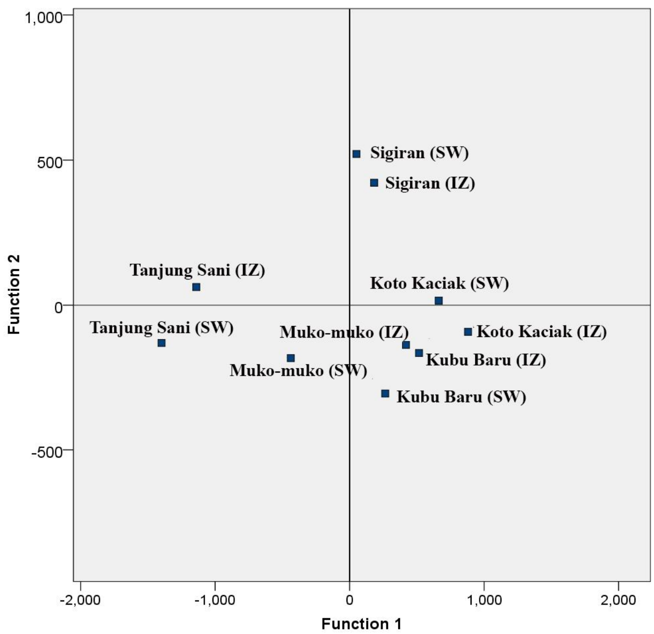

Figure 8. Water quality of Lake Maninjau (SW: surface water, IZ: incubation zone).

Discussion. Ruttner (1963), Odum (1971), Barus (2004), Persada (2013), and Samudra et al (2013) reported that the Bacillariophyceae community was dominant in the water body and characterized only by variations of species and individuals number. Arinardi et al (1994) and Hatta (2007) explained that Bacillariophyceae have rapid growth and development rate, also well-adapted to the stress of environmental factors. The high frequency of *Nitzschia sigma* was thought to be caused by a high concentration of nutrients, fast reproduction, and wide distribution in freshwaters, according to Odum (1971), Sachlan (1982), Arifin (2009), and Tjitrosoepomo (2011).

Variation of phytoplankton abundance on the surface water is due to the variation of light intensity, nutrients, floating-net-cages activity, and concentration of suspended particles through water flow. From the results, we found both sun type (Bacillariophyceae and Chlorophyceae) and shade type (Euglenophyceae) of phytoplankton (Sulawesty 2019). Sun type is the main group, referring to the number of species found and its abundance in the floating-net-cages area of Lake Maninjau. According to Goldman & Horne (1983), Barus (2004), Yuliana & Irfan (2018), and Niyoyitungiye et al (2020) the abundance and distribution of phytoplankton communities are influenced by the ability of phytoplankton to photosynthesize, physico-chemical condition, and anthropogenic activities.

From the analysis, we found that the average value of chlorophyll-*a* concentration was higher in the surface water than the incubation zone. Furthermore, the variation of chlorophyll-*a* average value among location is assumed to be influenced by variations of phytoplankton species, growth abilities, abundance and availability of nutrients. Goes et al (2004) state that the high concentration of chlorophyll-*a* indicates a growth season of phytoplankton. Welch (1980) states that the presence of chlorophyll can be used to estimate algal biomass and determine water productivity. Biomass of chlorophyll-*a* in Lake Maninjau ranged from 0.104 to 0.415 mgC m^{-3}, based on chlorophyll-a value indicating that Lake Maninjau is classified as oligotrophic status (Welch 1980). In conclusion, the distribution of chlorophyll-*a* is positively correlated with the light intensity, DO, TP, TN, BOD, and pH while the abundance of phytoplankton is negatively correlated with COD, TDS, and TSS (Figure 5).

The highest primary productivity means were found in surface water and incubation zone of Sigiran (2.30 and 2.25 mgC m^{-3} day^{-1} respectively) while the lowest found in Tanjung Sani (0.11 and 0.89 mgC m^{-3} day^{-1} respectively). Generally, primary productivity was found higher on surface waters, but in Sigiran and Tanjung Sani we found the primary productivity rate was higher in the incubation zone (Figure 6). This variation may be caused by position differences of optimum light intensity (light saturation) from surface waters to a certain depth, distribution of nutrients, and also differences of optimum productivity layer. Baksir (1999) explains that the highest productivity value is at a depth of 200 cm (239.58 mgC m^{-3} per 4 hours). According to Valiela (1984), Parsons et al (1984) and Neale (1987), generally the photosynthetic rate increases with gain in light intensity to a certain optimum value (saturation light point). Primary productivity is also influenced by temperature, nutrients, and plankton diversity (Odum 1971; Barus 2004). Nitrate and ammonia components influenced the growth and photosynthetic process of phytoplankton as autotrophic species (Nybakken 1988; Henriksen & Kemp 1988; APHA 2003).

Based on Figure 7, the distribution of GPP and NPP are positively correlated with chlorophyll-a, light intensity, DO, TP, TN, BOD, while the GPP and NPP are negatively correlated with COD, TDS, and TSS. Temperature and phytoplankton abundance are not correlated to NPP and GPP. Each nutrient highly affects primary productivity. Sanusi (1994) explained that primary productivity is strongly influenced by water trophic levels. Highly trophic status caused an enhance of plankton abundance (especially phytoplankton) (Sidabutar et al 2020). High turbidity and TSS value were found in locations, these conditions assumed to come from anthropogenic activities (including fish farming).

Eutrophic conditions in Lake Maninjau are thought to be caused by the influence of intensive fish farming and poorly feeding management, which correlates to reducing water quality. Intensive fish farming caused enhanced nitrogen and phosphate concentration (Gál et al 2011), organic material from fish feed residues and urea from fish excretion. Klug (2002) explains that organic material in waters can have a positive or negative impact on the phytoplankton population. Murthy et al (2008) and Wetzel (2001) also explained that eutrophic conditions caused the predominance of green-blue algae and anoxic hypolimnetic zones.

Variation of water quality in Lake Maninjau is influenced by the fluctuation of reduction and oxidation process of ammonia, nitrite, and nitrate, and also by the phytoplankton respiration process. Junaidi et al (2014) reported that DO in Lake Maninjau ranged from 5.70 to 6.77 mg L^{-1} in surface water, lower than this study. In a recent report from Lukman & Hidayat (2001), DO in Lake Maninjau ranged from 0.8 to 7.84 mg L^{-1} in December 2018 to January 2019. This variation was influenced by the intensity and quality of light penetration to water which depends on the solar angle. According to Junaidi et al (2014), TSS and TDS contents in Lake Maninjau are quite high as a result of increasing organic material intakes from feed residues in floating-net-cages. Marganof (2007) reported that the TSS concentration in Lake Maninjau in 2006 was 6.98 mg L^{-1}.

Conclusions. There were 17 species of phytoplankton which consist of 4 classes, namely Bacillariophyceae (9 species), Chlorophyceae (5 species), Cyanophyceae (2 species) and Euglenophyceae (1 species) with various phytoplankton abundance among sites.

The highest chlorophyll-*a* content was found in Sigiran site (0.415 mgC m^{-3}) and the lowest in Tanjung Sani site (0.104 mgC m^{-3}). Chlorophyll-*a* content was generally higher on surface water than incubation zone, induced by phytoplankton variation, phytoplankton growth, total abundance and nutrient availability at each site.

Primary productivity value in Lake Maninjau was generally higher in surface water than incubation zone, although in Sigiran (2.30 mgC m^{-3}) and Tanjung Sani (0.11 mgC m^{-3}) sites, incubation zone has higher productivity than the surface water. Current trophic status of Lake Maninjau from TRIX analysis is categorized as eutrophic.

Water quality parameters in Lake Maninjau are varied and significantly different ($p < 0.05$) between the surface waters and incubation zone. Within the current state of water quality and remaining intensive fish farming, the possibility of declining water quality and mass mortality of fishes in Lake Maninjau will continue every year.

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