Sumatran major lakes: limnological overviews

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Abstract. Sumatra’s major lakes are uniquely interesting because they were formed mainly by the Great Sumatra Fault and also affected by volcanic processes. Eight large Sumatran lakes, as major lakes, have played important roles for local people and been part of a significant study of Limnology in Indonesia. These lakes include Laut Tawar, Toba, Maninjau, Singkarak, Diatas, Dibawah, Kerinci, and Ranau. The utilization of lakes can be for several purposes: fisheries, tourism, and other activities that have developed rapidly in the last decade, such as aquaculture in floating net cages. Activities in the waters and the surrounding areas of the lake have had impacts on the trophic status and the decrease of native fish populations. In this paper, the environmental conditions of the lake were comprehensively reviewed.

1. Introduction
Sumatra Island is one of the large islands in Indonesia, located in the tropical climate region with high rainfall. Sumatra Island was influenced by the Indian and Australian plate movement, and the collision between both of which formed a unique geological mosaic. The Great Sumatran fault (Semangko zone) divided the island from Gulf Semangko in the southeastern part to Banda Aceh in the northwestern part of the island. Sumatran major lakes are uniquely interesting that they were formed especially by Great Sumatran Fault, such as Ranau, Singkarak, and Laut Tawar. Whereas, volcanic processes also played a role in the formation of several large lakes, including Lake Toba and Lake Maninjau. Toba is the largest lake in Indonesia and listed as the largest volcanic lake in the world. Lake Toba is the site of a massive super-volcanic eruption estimated to occur 69,000 to 77,000 years ago [1]. The formation of lakes scattered along Sumatra Island is not only formed due to tectonic or volcanic processes but also as part of the flood systems of big rivers. The flood plain lakes, located in the down part of the river, are recognized as small lakes.

The Limnological study of Sumatran lakes, as the pioneer scientific study of inland water in Indonesia, was initiated by a German Researcher, Ruttner, who led the historical expedition known as the Sunda Expedition [2].

Utilization of lake waters in Sumatra for fishing and other activities, such as tourism, have been sufficiently developed in large lakes. The activity in the lake waters that have been developed rapidly in the last decades is aquaculture in floating net cages. These fish farming activities draw major attention, especially in Lake Toba and Maninjau which have caused the lake waters to deteriorate and negatively impact other activities i.e. tourism.

Several policies have been developed to address the problems that occur in the Sumatran major lakes, specifically Lake Toba, Singkarak, Maninjau, and Kerinci which are part of the 15 national
priority lakes I (period 2014 - 2019) in Indonesia regarding its management [3]. Other lakes such as Lake Laut Tawar include in national priority lakes II period (2019-2024) period.

Activities in the waters and the surrounding area of the lake have had any impacts on the elevated trophic status of the lake, a decrease of fish populations, and other negative impacts. In this paper, the environmental conditions of the lake were comprehensively reviewed.

2. Methodology
This paper is based on a literature study. Some information is displayed in the form tables and graphs, raw or analyzed data, and then an evaluation is carried out. Some of the water quality data shown in seasons I and II refer to the measurement period, which is respectively the first and second semester. An analysis is also carried out for the prediction of several parameters using formulations available on the references.

3. Results and Discussion
3.1. Physical characteristics
With a variety of types and sizes, Sumatra island has quite a lot of lakes and many of them have not been classified (table 1) with sizes from very small to quite large, but they appear to be dominated by small lakes (table 2) [4]. The flood plain lakes are significant in number and may have a relatively small size, this is related to river flow in the lowland zone, especially on the eastern side of Sumatra Island. In the flood plain area of the Batanghari river, one of the major rivers in Sumatra island, there are 47 lakes having a size of more than 0.04 km² [5].

| Lake type          | Total |
|--------------------|-------|
| Volcanic           | 9     |
| Tectonic           | 3     |
| Tecto-volcanic     | 2     |
| Flood plain        | 98    |
| Unclassified       | 150   |
| Reservoir          | 24    |

Sumatran major lakes stretch from south to north parallel to fault formation or mainly located in a series of mountain ranges (figure 1). The morphology of Sumatran major lakes evolved from a combination of tectonic activity and volcanic.

| Lake size (km²) | Total |
|-----------------|-------|
| Large (>1000)   | 1     |
| Big (101 – 1000)| 2     |
| Middle (10 - 100)| 10    |
| Small (0.01 – 10)| 259   |
| Very small (<0.01)| 14    |

Lake Laut Tawar was formed by tectonic process [6], Lake Singkarak is a part of the Sumatran fault zone with frequent uplift geothermal fluid in which this still contains sulfide causing fish death mass [7]. Lake Kerinci located in the Kerinci valley was formed by the formation of tectonic graben between two active faults, namely Sungai Penuh Fault and Sungai Abu Fault. Both of these faults are the segment of the Great Fault of Sumatra [8].

Generally, Sumatran major lakes are in the mountainous region, at altitudes > 300 above sea level (asl) to an altitude of 1521 m asl. The area of the lakes is in the range > 11 km² with a maximum depth
of between 47 to 508 m, and the longest retention time of water is, for instance, Lake Toba can be up to 81 years (table 3).

Table 3. Physical characteristics of Sumatran major lakes.

| Lakes         | Level (a.s.l) (m) | Area (km²) | Catchment area (km²) | Volume (10⁶ m³) | Mean depth (m) | Maximum depth (m) | Length of shore line (km) | Retention time (years) | Ratio of catchment to lake area |
|---------------|------------------|------------|----------------------|-----------------|----------------|-------------------|--------------------------|------------------------|-------------------------------|
| Laut Tawar    | 1230             | 57         | 194⁠[¹⁰]              | 2.5⁠[¹²]        | 51             | 84                | 43.9                     | 3.4                    | 3.4                           |
| Toba          | 903              | 1124       | 2486                 | 256.20          | 228            | 508               | 428.7                    | 81                     | 2.2                           |
| Maninjau      | 461              | 97         | 133                  | 10.23           | 105            | 168               | 52.7                     | 25                     | 1.3                           |
| Singkarak     | 362              | 109        | 1290                 | 19.49           | 179            | 271               | 55.8                     | 17                     | 12.0                          |
| Diatass       | 1521             | 12         | 41                   | 0.30            | 24             | 47                | 20.0                     | 8                      | 3.3                           |
| Dibawah       | 1462             | 11         | Nd                   | 0.25            | 23             | 309               | nd                       | 72                     | nd                            |
| Kerinci       | 787              | 46         | 1005                 | 1.60            | 36             | 97                | 31.5                     | 11                     | 21.8                          |
| Ranau         | 539²⁰          | 128²¹      | 363²⁰                | 19.9²⁰         | 155²¹          | 221²¹             | 63.8²¹                   | 27²¹                   | 2.8²¹                         |

Note: nd: No data.

The existence of Sumatra major lakes at high elevations creates upstream or the water source of large rivers in Sumatra Island. Lake Laut Tawar is upstream of Peusangan River (Krueng), Lake Singkarak is upstream of Ombilin River, Lake Toba as upstream the Asahan River, and Lake Kerinci is upstream of the Batanghari River.

One of the physical factors of the lake to be considered is the ratio of catchment area and lake volume which determine the level of sedimentation or allochthonous material loads from land entering the waters. The catchment area and lake volume ratios are relatively high in Lake Singkarak [12] and Lake Kerinci [22]. The catchment characteristics are associated with determining allochthonous material apart from atmospheric factors. In Finnish lakes, it showed that 72–83% of large lakes (>10 km²) explained the loading of Total Nitrogen (TN), Total Phosphorus (TP), and Total Organic Carbon (TOC) in which attributed by catchment characteristic [22]. The trophic state of water bodies across a wide range of lentic ecosystems related to catchment condition especially land use and vegetation

Figure 1. Major Lakes distribution in Sumatra Island [9].
cover. Geographical features and land cover of the catchment influence the nutrient loading and water clarity of a water body [23].

The theoretical lake water retention time (in years) is defined as the ratio between the lake volume ($V$) and the mean annual water discharge ($Q_{mv}$). The water retention time controls the concentration and accumulative capacity of all the substances entering a lake basin. The high precision of measuring water retention time is needed for estimating the real impact of many chemical and biological processes in the ecosystem [24]. The longer Hydraulic Residence Times (HRT; another similar terminology of water retention time) of the water body will retain more external phosphorus loading. The novel finding of a study by Koiv et al. [25] showed that the impact of HRT on phosphorus retention coefficient in large lakes is much stronger than that in smaller lakes. In one observation in Ibitinga Reservoir (Sao Paula, Brazil), found that increased HRT of the reservoir had an impact on increasing surface waters covered by phytoplankton blooming [26].

3.2. Trophic status condition

Trophic status of lakes that refers to a single parameter, is commonly evaluated by the Secchi depth, chlorophyll-$a$, Total Phosphorus (TP), and Total Nitrogen (TN) content [27, 28, 29, 30]. In Indonesia, the trophic status of lake waters is officially determined through the Minister of Environment Regulation No. 28/2009. With a constant increase of human activity in Sumatran major lakes both in the waters and catchment area, this contributes significantly to drive the trophic status of the lakes which is marked by the change of trophic parameters condition.

| Lakes      | Range (average) | References |
|------------|-----------------|------------|
| Laut Tawar | 3.3 – 8.0 (5.7)  | [31]       |
|            | 3.4-4.9 (4.3)   |            |
| Toba       | 9.0 – 15 (11.6) | [32]       |
|            | 7.0 - 11 (9.2)  |            |
| Maninjau   | 1.8 – 3.2 (2.2) | [33]       |
|            | 1.8 - 5.6 (2.7) |            |
| Singkarak  | 1.7 – 2.6 (2.2) | [34]       |
|            | 3.2 – 7.2 (4.9) |            |
| Diatas     | 5.0 – 8.4 (6.4) | [35]       |
|            | 3.9 – 7.0 (5.5) |            |
| Kerinci    | 5.1 – 8.5 (6.7) | [36]       |
|            | 7.2 – 8.3 (7.6) |            |
| Ranau      | 4.2 – 6.5 (5.3) | [37]       |
|            | 4.0 – 6.0 (5.3) |            |

Secchi depth of Sumatran major lakes has a very wide range, on the other hand, the season might also influence the Secchi depth. The lowest Secchi depth was found in Lake Maninjau and Singkarak (<2.0 m) and the highest in Lake Toba which was still observable to a depth >10 m (table 4). Morphometric characteristic is one factor that determines the Secchi depth in a lake [38]. This is related to the dynamics of water mass in it, which will affect the diffusion and re-suspension of materials transferring in and out of the water. By ignoring typical lake conditions such as Maninjau and Singkarak there was a low relation between Secchi depth and the maximum depth (figure. 2).
Figure 2. Relationship between the maximum depth and Secchi depth of major Sumatran lakes
(Left: Includes Lake Maninjau and Singkarak; Right: Without Lake Maninjau and Singkarak)
(Results of the data processing from table 3 and 4).

Secchi depth in Lake Maninjau and Lake Singkarak is slightly anomalous, supposedly, this is related to the following things. The Lake Maninjau indicated on eutrophic condition both based on TP and chlorophyll a levels. However, the high number of floating net aquaculture (FNA) in the lake has an impact on high levels of organic matter (35.1 – 75.5 mg/L) [33]. It is suspected that the Secchi depth in Lake Maninjau is not only due to the chlorophyll a concentration but also because of the high organic matter. The condition of Lake Singkarak was also eutrophic, which was influenced by the water level as a result of incoming water discharge. The total suspended solids entering the lake along with the incoming water is thought to provide an added impact on the low of Secchi depth.

The resuspension material from the bottom to the water column would be related to the depth of a lake. In deep lakes, temperature stratification forms a barrier to material resuspension. The water column in Lake Toba (max. depth of 508 m) estimated undergoing mixing between 1 -100 m depth but the subsequent depth is relatively stable [39]. This can be stated that Lake Toba is oligomictic or monomictic waters. Meanwhile, in Lake Kerinci (max. depth of 97 m), water temperature profiles vertically in December 1993 and October 1999 were evenly from the surface to the bottom and showed no indication of thermal stratification [40]. The absence of thermal stratification allows the mixing of water mass in all columns, which will encourage the process of material resuspension from the bottom of the lake.

The trophic status of Sumatran major lakes based on Secchi depth, referring to the Ministry of Environment Republic of Indonesia Regulation No. 28/2009, shows that most of the lakes were mesotrophic. Lake Toba was still oligotrophic, Lake Maninjau was eutrophic and also in a certain season, Lake Singkarak was eutrophic (figure 3).

Autochthonous material production, input of allochthonous material, and resuspended material from the bottom of the lake both due to wind or other activity can be roughly determined by Secchi depth [41, 42,43], besides morphometric condition. Plankton is the main autochthonous production in lake waters, especially phytoplankton.
Figure 3. Trophic status of Sumatran major lakes based on Secchi depth (Referring to the Ministry of Environment (Republic Indonesia) Reg.No.28/2009) (Results of the data processing from table 4).

Chlorophyll \( a \) reflects of phytoplankton biomass. In Sumatran major lakes, the concentration of chlorophyll \( a \) ranged from 0.47 mg/m\(^3\) to 38.77 mg/m\(^3\). The lowest was in Lake Toba and the highest was in Lake Maninjau (table 5).

Table 5. Range and average of chlorophyll \( a \) concentration in Sumatran major lakes.

| Lakes     | Season I (mg/m\(^3\)) | Season II (mg/m\(^3\)) | Reference |
|-----------|------------------------|-------------------------|-----------|
| Laut Tawar| 4.98 - 11.11           | 1.98 – 2.78             | [31]      |
|           | 7.3                    | 2.46                    |           |
| Toba      | 0.47 – 1.28            | 0.53 - 1.42             | [32]      |
|           | 0.83                   | 0.99                    |           |
| Maninjau  | 9490 - 2377            | 10820 – 38770           | [33]      |
|           | 15.790                 | 20.531                  |           |
| Singkarak | 4.0 - 16               | <5                      | [34]      |
|           | 9.2                    | <5                      |           |
| Diatas    | 0.93 – 1.97            | 0.85 - 2.96             | [35]      |
|           | 1.13                   | 1.93                    |           |
| Kerinci   | 0.018 – 0.048          | 0.017 – 0.023           | [36]      |
|           | 0.03                   | 0.02                    |           |
| Ranau     | 35 -51                 | 30 – 60                 | [37]      |
|           | 42.1                   | 42.5                    |           |

At certain lakes in the temperate region, the minimum Secchi depth can take place two times. Firstly, when tributaries enter carrying an accumulation of suspended sediments during snowmelt in June, and secondly in December which is due to the chlorophyll upward mixing from the bottom as an impact of the thermocline disappearance [44,45].
In Sumatran major lakes, chlorophyll $a$ seems to contribute to the Secchi depth of lakes. The lakes with relatively long water residence times (table 3), the Secchi depth is likely to be more influenced by chlorophyll $a$ than the input of suspended material from tributary discharge. The pattern of the relationship between the Secchi depth and chlorophyll $a$ shows that the increase in chlorophyll $a$ concentration is followed by a decrease in the Secchi depth (figure 4).

![Figure 4](image)

**Figure 4.** Relationship between chlorophyll $a$ abundance and Secchi depth. (Results of the data processing from tables 4 & 5)

In Sumatran major lakes, total phosphorus (TP) levels are recorded in the range of 0.005-0.350 mg/L, with annual averages of 0.010-0.265 mg/L. The lowest was in Lake Singkarak and the highest was in Lake Laut Tawar (table 6).

**Table 6.** Range and average content of Total Phosphorus (TP) in Sumatran major lakes

| Lakes     | Total Phosphorus (TP) (mg/L) | References |
|-----------|-----------------------------|------------|
|           | Season I                    | Season II  |           |
| Laut Tawar| 0.010 – 0.200               | 0.170 – 0.350 | [48]     |
|           | 0.102                       | 0.265      |           |
| Toba      | 0.005 – 0.045               | 0.008 – 0.021 | [49]     |
|           | 0.019                       | 0.017      |           |
| Maninjau  | 0.010 – 0.093               | 0.004 – 0.065 | [33]     |
|           | 0.042                       | 0.029      |           |
| Singkarak | 0.008 -0.015                | 0.002 – 0.083 | [34]     |
|           | 0.010                       | 0.018      |           |
| Diatas    | 0.007 – 0.050               | 0.005 – 0.080 | [35]     |
|           | 0.023                       | 0.035      |           |
| Kerinci   | 0.051 – 0.085               | 0.072 – 0.083 | [36]     |
|           | 0.067                       | 0.076      |           |
| Ranau     | 0.078 – 0.127               | 0.070 – 0.125 | [37]     |
|           | 0.105                       | 0.094      |           |
Phosphorus balance approach in the lakes as proposed and argued that supply of phosphorus into the waters related to the lake catchment, and morphometric conditions and supported by population density that inhabits those areas [46]. Naturally, phosphorus originates from natural activities like from weathering of rocks [47], but nowadays, human activity in catchment areas, modification or agriculture greatly contributes to the phosphorus load into the water body [22,23].

In Lake Laut Tawar, the TP levels were highest if compared to other lakes with a very wide range. The concentration of phosphorus component (phosphates) has also been reported by the local environmental authority, the measured phosphate level was 0.21 mg/L. The lake exhibited water quality degradation problems. Additionally, water quality status in certain locations shows heavily polluted conditions (Environmental Boar of Central Aceh District, 2012. Unpublished). The phosphorus loading entering Lake Laut Tawar waters especially from agricultural activities on catchment was 126 tons/year [48]. In Lake Toba waters, the content of TP was quite varied but still low. It is related to lake physic conditions which are quite large and deep. Lake morphometric characteristics affect the dynamics of water mass and further have an impact on diffusion and resuspension material in lake waters [38]. In Lake Toba distribution of TP varies according to the location, while the vertical distribution of TP showed that the higher levels were at 100 m depth [49]. It seems that relatively permanent temperature stratification in Lake Toba [39] prevents TP resuspension from the bottom part of the lake.

Furthermore, Total Phosphorus (TP) concentration in Lake Maninjau is likely influenced by lake physical condition and activity of fish culture in the lake. The homogeneous temperature stratification pattern (December 2011) has shown a tendency of the turnover process [50], this condition enables vertical mixing in the water column which encourages material resuspension from the bottom part of the lake. Furthermore, the strong wind conditions in December to February period across the narrow lake are more encouraging a turnover process. On the other hand floating cages for aquaculture activity, with the level of fish production in 2011 has reached 36218 tones supplied phosphorus components to the lake about 381 tons [33].

Lake Kerinci shows high TP content, apparently the high of catchment to lake area ratio (21.8, table 3) contributed to the TP loading from the land, which was supported by utilization land for paddy fields which quite extensive (15.6% of lake catchment) [51]. The lake morphometric conditions (maximum depth 97 m; table 3) and disappearing temperature stratification [40] allowed TP resuspension to occur and enter the water column.

The high concentration of TP in Lake Ranau is very unique due to the deep lake condition (maximum depth of 221 m) and the ratio of catchment to lake area is only 2.83. In the water column, the temperature tends to be stratified [52] without the possibility of mixing, and the lake has categorized as meromictic [6]. Since Lake Ranau is a tecto-volcanic lake which was a proto caldera from Mount Ranau, this might be one reason that TP levels in Lake Ranau are quite high.

Based on the average value of TP content in each season and referring to Regulation of Ministry of Environment Republic of Indonesia No. 28/2009, Sumatran major lakes were in the oligotrophic - hypertrophic range. Most of the lake was mesotrophic, except Lake Singkarak on one season was recorded oligotrophic and Lake Laut Tawar also at one season was in hypertrophic condition (figure 5).

The availability of phosphorus as the most important determinant of productivity and water quality in lakes and reservoirs is a major paradigm in limnology [53], and the eutrophication on inland surface waters is considered mainly caused by excessive input of phosphorus [54].

It appears that almost all of the lake has undergone eutrophication and was suggested most of them have received a waste load of anthropogenic activities, especially phosphorus. Even so, various physical conditions of the lake have responded differently, so that the impacts are very diverse. As an example, the phosphorus load entering the Lake Toba as a whole, both from activities in the catchment and in waters have exceeded the permissible loading levels and changes in the trophic status of the Lake Toba waters [55], however, lake condition is not as severe as Lake Maninjau.
3.3. Fish and fisheries characteristic

The fish communities in inland waters such as lakes are important biological components that become a chain of energy and material transfer and are often be the main bioindicator of the environmental conditions. Fish as a population is a potential target of the most utilized natural biological resources. Fishing in a lake is the most preferable activity in utilizing biological natural resources and might be the first resource utilized by humans.

At least 90 species of fish have been recorded from Sumatran major lakes, with various types. There are types of migration, introduction, and limited species to rare species (Table 7). The number of fish species found on the island of Sumatra reached 272 species, consisting of primary fish species (232 species), secondary species (1 species), and diadromous and vicarious fish (39 species), and 30 species of them are endemic fish [56]. Thus, in Sumatran major lakes, approximately 30% of fish species belong in all inland fish in Sumatra.

Table 7. Types and the distribution of fish in Sumatran major lakes.

| No. | Species                  | 1  | 2  | 3  | 4  | 5  | 6  | 7  | 8  | Type          |
|-----|--------------------------|----|----|----|----|----|----|----|----|---------------|
| 1   | *Anabas testudineus*     | +  | -  | +  | +  | -  | -  | +  | +  | Migratory     |
| 2   | *Anguilla* spp.          | -  | -  | +  | -  | -  | -  | -  | -  |               |
| 3   | *Aplocheilus panchax*    | +  | +  | -  | -  | -  | +  | -  | -  |               |
| 4   | *Colossoma macropomum*   | -  | -  | -  | -  | -  | -  | +  | -  | Introduction  |
| 5   | *Carassius auratus*      | +  | -  | -  | -  | -  | -  | -  | -  |               |
| 6   | *Channa gachua*          | +  | +  | -  | -  | -  | -  | +  | -  |               |
| 7   | *C. lucius*              | -  | -  | +  | -  | -  | -  | -  | -  |               |
| 8   | *C. striata*             | +  | -  | -  | -  | -  | -  | -  | +  |               |
| 9   | *Chanos chanos*          | +  | -  | -  | -  | -  | -  | +  | -  | Introduction  |
| 10  | *Ctenopharyngodon idella*| +  | +  | -  | -  | -  | -  | +  | -  | Introduction  |
| 11  | *Cyclocheilichthys apocon*| -  | -  | +  | +  | -  | -  | -  | -  |               |
| 12  | *C. dezaani*            | -  | -  | +  | +  | +  | -  | -  | -  |               |
| 13  | *C. siaja*              | -  | -  | +  | -  | -  | -  | -  | -  |               |
| 14  | *Clarias batrachus*      | +  | +  | +  | -  | -  | -  | -  | -  | Introduction  |
| 15  | *C. gariepenus*         | +  | -  | -  | -  | -  | -  | -  | -  |               |
| 16  | *C. nieuhofi*           | -  | +  | -  | -  | -  | -  | -  | -  |               |

Figure 5. Total Phosphorus (TP) content and trophic status of Sumatran major lakes (Data processing from table 6).
| No. | Species                                      | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | Type               |
|-----|---------------------------------------------|---|---|---|---|---|---|---|---|--------------------|
| 17  | *C. teysmanni*                              |   |   |   |   |   |   |   |   |                   |
| 18  | *Crossochilus gnathopogon*                  |   |   | + | + | + | + | + | + |                   |
| 19  | *Cyprinus carpio*                           | + | + | + | + |   |   |   |   | Introduction       |
| 20  | *Dermogenys pusillus*                       |   | + |   |   |   |   |   |   |                   |
| 21  | *D. sumatrana*                              |   | + |   |   |   |   |   |   |                   |
| 22  | *Glyptocephalus platygonoides,*             |   |   | + |   |   |   |   |   |                   |
| 23  | *Gobiopeterus brachypterus*                 |   | + |   |   |   |   |   |   |                   |
| 24  | *Hampala ampalong*                          |   |   |   |   |   |   |   | + |                   |
| 25  | *H. binaculata*                             |   |   | + |   |   |   |   |   |                   |
| 26  | *H. macrolepida*                            |   | + | + | + | + | + | + | + |                   |
| 27  | *Helostoma temmincki*                       |   |   |   |   |   |   |   | + |                   |
| 28  | *Homaloptera gymnogaster*                   | + | + | + | - | - |   |   |   | Limited            |
| 29  | *Lepisosteus reticulatus*                   | + | + |   |   |   |   |   |   |                   |
| 30  | *Liposarcus pardalis*                       | + | - | + |   |   |   |   |   | Introduction       |
| 31  | *Mastacembelus erythrotaenia,*              |   |   | + |   |   |   |   |   |                   |
| 32  | *M. maculatus*                              |   |   |   |   | + | + | + | + |                   |
| 33  | *M. unicolor*                               | + | + | + | + | + | |   |   |                   |
| 34  | *Monopterus albus*                          | + | + | + | + | + |   |   |   |                   |
| 35  | *Mystacoleucus marginatus*                  | + | + | + | - | - |   |   |   | Declining pop.     |
| 36  | *N. olivaceus*                              | + | + | + | + | + | + | + | + |                   |
| 37  | *Neolipisochilus thienemanni*               |   |   |   |   |   |   |   |   | Rare              |
| 38  | *N. vittatus*                                | + |   | + | + | + | + | + | + |                   |
| 39  | *N. waandersi*                              |   |   | + | + | + | + | + | + |                   |
| 41  | *N. planiceps*                              |   |   |   |   |   |   |   |   |                   |
| 42  | *N. olivacea*                               |   |   |   |   |   |   |   |   |                   |
| 43  | *N. barensis*                               |   |   |   |   |   |   |   |   |                   |
| 44  | *N. baturinus*                              |   |   |   |   |   |   |   |   |                   |
| 45  | *N. brevis*                                 |   |   |   |   |   |   |   |   |                   |
| 46  | *O. marmorata*                              |   |   |   |   |   |   |   |   |                   |
| 47  | *O. micropeltes*                            |   |   |   |   |   |   |   |   |                   |
| 48  | *O. teysmanni*                              |   |   |   |   |   |   |   |   |                   |
| 49  | *O. fasciatus*                              |   |   |   |   |   |   |   |   |                   |
| 50  | *O. lineatus*                               |   |   |   |   |   |   |   |   |                   |
| 51  | *O. maculatus*                              |   |   |   |   |   |   |   |   |                   |
| 52  | *O. maculatus*                              |   |   |   |   |   |   |   |   |                   |
| 53  | *O. politus*                                |   |   |   |   |   |   |   |   |                   |
| 54  | *O. sp*                                     |   |   |   |   |   |   |   |   |                   |
| 55  | *O. striatus*                                |   |   |   |   |   |   |   |   |                   |
| 56  | *O. maculatus*                              |   |   |   |   |   |   |   |   |                   |
| 57  | *P. belinka*                                |   |   |   |   |   |   |   |   |                   |
| 58  | *P. catenatus*                              |   |   |   |   |   |   |   |   |                   |
| 59  | *P. lineatus*                               |   |   |   |   |   |   |   |   |                   |
| 60  | *P. maculatus*                              |   |   |   |   |   |   |   |   |                   |
| 61  | *P. maculatus*                              |   |   |   |   |   |   |   |   |                   |
| 62  | *P. olivacea*                               |   |   |   |   |   |   |   |   |                   |
| 63  | *P. olivacea*                               |   |   |   |   |   |   |   |   |                   |
| 64  | *P. lineatus*                               |   |   |   |   |   |   |   |   |                   |
| 65  | *P. maculatus*                              |   |   |   |   |   |   |   |   |                   |
| 66  | *P. maculatus*                              |   |   |   |   |   |   |   |   |                   |
| 67  | *P. maculatus*                              |   |   |   |   |   |   |   |   |                   |
| 68  | *P. maculatus*                              |   |   |   |   |   |   |   |   |                   |
| 69  | *Pristolepis grotch*                        |   |   |   |   |   |   |   |   |                   |
| 70  | *Rasbora argyrotaenia*                      |   |   |   |   |   |   |   | + | Declining pop.     |
| 71  | *R. elegans*                                |   |   |   |   |   |   |   | + |                   |
Rasbora. The introduced fish types of Lake Toba such as others introduced fishes, *Nogaster* and *Homaloptera gymnopterum* are known only found in Lake Toba, *Tylocheilos falcifer* and *Trichogaster pectoralis* are known only found in Lake Singkarak, which were first distributed in 2003 by the Ministry of Maritime Affairs and Fisheries [37].

Fishing activity in Lake Maninjau especially for *Tambroides* species, *maninjau* genus, is quite successful, which becomes valuable fish for the local community as *bilih*. In this lake also found a fish species that has been designated as a rare and endangered species, *Mystacoleucus padangensis* as an endemic fish of Lake Laut Tawar and its tributaries that its Lake Toba inlets, the *Depik* fish species have entered the critical endangered (vulnerable) category [70].

In Lake Toba, species *Neolissochilus (Lissochilus) thiemenanni*, are known only found in Lake Toba [56], but unfortunately, their existence is rarely to be found. The introduced fish types of Lake Toba such as *Oreochromis mossambicus* and *Cyprinus carpio* were introduced by the fisheries authorities into Lake Toba in 1940 and 1937, respectively [71]. In recent observations on some tributaries that its Lake Toba inlets, the *Neolissochilus (Lissochilus) c.f sumatrana* [72] species were found.

*Mystacoleucus padangensis* species inhabiting Lake Toba are introduced fish originating from Lake Singkarak, which were first distributed in 2003 by the Ministry of Maritime Affairs and Fisheries [73]. This introduction was carried out as an effort to restore fish populations, due to a crisis of native fish populations such as the decline in abundance of *Puntius binotatus* species as a result of the deterioration in environmental quality and biological impacts of the spread of other introduced fishes such as tilapia.

Lake Singkarak has a typical fish species, namely *Mystacoleucus padangensis* known to the local community as “bilih”. This fish was later introduced into Lake Toba and their population growth was quite successful, but subsequently, due to various factors, the population declined again. *Mystacoleucus padangensis* is an endemic species in Lake Singkarak and also is an economically valuable fish for the local community [74].

Moreover, in Lake Maninjau a special quite fish known by local name as “bada” is found. In this region, “bada” is a commercial fish, a unique commodity, and has become an icon of culinary that supporting tourism activities [75]. Some studies showed that “bada” is refer to some species of the genus *Rasbora* spp, namely *Rasbora lateristriata, R. argyrotaenia*, and *R. cf sumatrana* [76] and *R. maninjau*. In this lake also found a fish species that has been designated as a rare and endangered species, *Homaloptera gymnoaster*, or with the local name Selusur (Loach) Lake Maninjau [77].

Some of the fish which Sumatran major lakes inhabitants are quite special, such as fish (*Rasbora tawarensis*), which local name is Depik known as an endemic fish of Lake Laut Tawar and its population right now decline. In Lake Laut Tawar, the species *Rasbora tawarensis* and *Poropuntius tawarensis* are classified as threatened and red listed [69], and based on the latest evaluation these two fish species have entered the critical endangered (vulnerable) category [70].

Recent observations on some tributaries that its Lake Toba inlets, the *Neolissochilus (Lissochilus) c.f sumatrana* [72] species were found.

References:
[37, 57, 58, 59, 60, 61, 62, 63, 64, 65, 66, 67, 68]

| No. | Species                      | 1  | 2  | 3  | 4  | 5  | 6  | 7  | 8 Type          |
|-----|------------------------------|----|----|----|----|----|----|----|----------------|
| 72  | *Rasbora jacobsonia*         | -  | +  | -  | -  | -  | -  | -  |                |
| 73  | *R. lateristriata var. Sumatrana* | -  | -  | +  | -  | -  | -  | -  |                |
| 74  | *R. spilotaenia*             | -  | -  | -  | +  | -  | -  | -  |                |
| 75  | *R. sumaterana*              | +  | -  | -  | -  | -  | -  | -  |                |
| 76  | *T. tawarensis*              | +  | -  | -  | -  | -  | -  | -  |                |
| 77  | *Tetraodon mappa*            | -  | -  | +  | -  | -  | -  | -  |                |
| 78  | *Tetraodon sp*               | +  | -  | -  | -  | -  | -  | -  |                |
| 79  | *T. palembangensis*          | -  | -  | +  | -  | -  | -  | -  |                |
| 80  | *Tor soro*                   | +  | +  | -  | -  | +  | -  | -  |                |
| 81  | *T tambra*                   | -  | -  | -  | -  | -  | -  | +  |                |
| 82  | *T. tambroides*              | -  | -  | +  | +  | -  | -  | -  |                |
| 83  | *T. dourenensis*             | +  | -  | -  | -  | +  | -  | +  |                |
| 84  | *Trichogaster pectoralis*    | -  | -  | -  | -  | -  | +  | +  |                |
| 85  | *T. trichopterus*            | +  | +  | +  | -  | -  | -  | -  |                |
| 86  | *Trichopsis vittata*         | +  | -  | -  | -  | -  | -  | -  |                |
| 87  | *Tylognathus falcifer*       | -  | -  | +  | -  | -  | -  | -  |                |
| 88  | *Xiphophorus helleri*        | +  | -  | -  | -  | -  | -  | -  | Introduction   |
| 89  | *X. maculatus*               | +  | -  | -  | -  | -  | -  | -  | Introduction   |

Note: 1) Lake Tawar; 2) Lake Toba; 3) Lake Maninjau; 4) Lake Singkarak; 5) Lake Diatas; 6) Lake Dibawah; 7) Lake Kerinci; 8) Lake Ranau

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are increasingly rare. Current fishing of “bada” is mostly using lukah (trap) which has been found in several locations [76].

In Lake Kerinci, *Ctenopharyngodon idella* was introduced in 1995 to control the blooming of water hyacinth (*Eichornia crassipes*), which nearly 80% of the lake surface was covered by water hyacinth [78]. The species *O. niloticus*, *H. Macrolepidota*, and *O. waandersii* were dominant fish production from fishing activity in Lake Kerinci [79].

Water utilizations for fisheries activities that have taken place in the Sumatran major lakes are fishing and aquaculture. Fishing activity has been recorded since the 1950s, namely in Lake Toba [60], and aquaculture activities which carried out on Floating Net Aquaculture (FNA) was first tried in 1988 [80] also in Lake Toba, and at present, the activity has been quite extensive.

Efforts to increase fish productivity in Lake Toba to support fishing have also been carried out through the introduction of *O. mossambicus* and *C. carpio* species in 1940 and 1937, respectively [71]. The last introduction of a new species that is quite phenomenal is the *M. padangensis* from Lake Singkarak, as stated before, namely in 2003 [73].

Fish catch in Lake Toba before the introduction of *M. padangensis* was dominated by *O. mossambicus* (69.1%), followed by *O. niloticus* (22.4%), *O. hasselti* (3.0%), *C. carpio* (2.4 %) and *Trichogaster* spp. (3.0%) [81] while based on 2005 data, fishing production in Lake Toba reached 4,462 tons with *O. mossambicus* and *O. niloticus* as the most dominant fish catch[82].

Since the *M. padangensis* was introduced to Lake Toba, the fishing production increased sharply from 8,500 tons in 2007 to 45,000 tons in 2012. The increasing of fish production has had a positive impact on fishermen income and their welfare. But starting in 2013, the production of *M. padangensis* shows a decline caused by various factors, including the high pressure of fishing which using unfriendly fishing gear, the reserve area of fish has not been established, selling price games of small sized fish because high demand and increasing of invasive fish species population (*Siamensis parambassis*) [83].

Fishing activities in Lake Laut Tawar are mainly targeted for *O. mossambicus* and/or *O. niloticus*, but in certain areas, the fishing target is *R. tawarensis*, which is known locally as “depik” [84]. Based on data from the Board of Animal Husbandry and Fisheries Aceh Tengah District (2013: Unpublished), total fishing production from Lake Laut Tawar in 2012 was 215 tons, consisting of *R. tawarensis* (13 tons) and other fish such as tilapia and carp which reached 202 tons. From the same data source, it appears that there has been a production decline of *R. tawarensis* from 2007 (18.4 tons) to 2012 (13 tons) and the peak of production occurred in 2011 (32 tons).

Fishing activities in Lake Singkarak was more dominated by catching of “bilih” (*M. padangensis*), and production of “bilih” in 2003 could reach 71.2% from the total fishing production (1332 ton) [85]. However, there were indications that the population of “bilih” in Lake Singkarak began to extinction. This was characterized by reduced production and the smaller size of the fish caught. The threat of extinction is due to uncontrolled and excessive capture of fish, the use of fishing gear with relatively small mesh sizes, such as gill nets (¾ inches and 5/8 inches) as well as cast net (½ inches), and operation of fishing gear by intercepting spawn fish at mouth of the rivers [86]. It can be stated that the fishing rate of “bilih” has overfishing [74].

The fish commodity that is mostly caught in fishing activities in Sumatran major lakes is *O. niloticus*, the introduced species that is able to adapt to both fishing pressure and the environment condition of lakes. However, in some lakes, it appears that local fish are able to contribute to the fishing production of the lake, such as *R. tawarensis* (Lake Laut Tawar), *M. padangensis* (Lake Singkarak) and *Rasbora* spp., (Lake Maninjau) (table 8).
### Table 8. Performance of fisheries activities in Sumatran major lakes

| Lakes         | Area* (km²) | The fishing dominant species | Fishing production potential* (ton/ha/yr) | Fishing Production (ton) (yr) | Production of FNA (ton) (yr) | Reference    |
|---------------|-------------|------------------------------|----------------------------------------|-----------------------------|-----------------------------|--------------|
| Laut Tawar    | 57          | *O. niloticus; C.carpio; R. tawarensis* | 0.0339 193                             | 215 (2012)                  | 239 (2014)                  | [57]; [87];  |
|               |             |                              |                                        |                             |                             | [88]         |
| Toba          | 1124        | *O. massambicus; O. niloticus; M.padangensis.* | 0.0100 1127                           | 15729 (2010)               | 47478 (2011)               | [89]; [90]; |
|               |             |                              |                                        |                             |                             | [82]         |
| Maninjau      | 97          | *Rasbora spp; O. niloticus.* | 0.0143 139                             | 112 ton (2003)             | 36219 (2011)               | [91]; [92]  |
| Singkarak     | 109         | *M. padangensis; O. vitatus; C. dezwaani; H. macrolepidota.* | 0.0087 95                             | 500 (2000)                  | 97 (2011)                  | [93]; [94]; |
|               |             |                              |                                        |                             |                             | [95]; [96]  |
| Diatas        | 12          | nd                           | 0.0128 15                              | nd                          | nd                          |              |
| Dibawah       | 11          | nd                           |                                        | nd                          | nd                          |              |
| Kerinci       | 46          | *H. macrolepidota; O. niloticus; O. waandersii.* | 0.0207 95                             | 1092 (2011)                | 688 (2011)                 | [36]; [79]; |
|               |             |                              |                                        |                             |                             | [97]         |
| Ranau         | 128         | *H. macrolepidota; O.mossambicus; O. niloticus; O. vittatus.* | 0.0247 316                           | nd                          | nd                          | [37]         |

Note: FNA = Floating Net Aquaculture; nd = No data; 
*) Table 3 
**) Estimation value based on waters TP average content referred to [98] 
***) Total production

If comparing the potential of production and production achieved from fishing activities, the level of utilization of fish resources in general has exceeded the production potential that can be produced in the waters (Table 8). This shows that the condition of capture fisheries in Sumatran major lakes was overfishing.

The activities of floating net aquaculture (FNA) have grown in five of the eight Sumatran major lakes, namely in Lake Laut Tawar, Lake Toba, Lake Maninjau, Lake Singkarak, and Lake Kerinci. Considering the level of fish production from FNA, it appears that the highest is produced from Lake Toba and subsequently from Lake Maninjau (table 8). However, if considered the area of the two lakes, it appears that FNA activities at Lake Maninjau are far more intensive than those at Lake Toba.

The FNA becomes controversial because on one hand it gives additional value to the utilization of water resources and contributes to the economic activities of the community, on the other hand, it gives the impact of eutrophication on the waters. For this reason, the development of FNA in lake waters must refer to the carrying capacity and direction of its space utilization.

The fish production of FNA in Lake Toba refers to the carrying capacity based on oligotrophic status (the purposes of waters is for tourism) is 35 282 tons/year [99]. Thus, fish production that has been achieved at that time in Lake Toba has passed its carrying capacity. Similarly, fish production that has been achieved at FNA in Lake Maninjau, is thought to have exceeded its carrying capacity.
Referring to the carrying capacity of Lake Maninjau, the Government of Agam Regency, West Sumatra Province has set a regulation that the number of FNA can operate in the lake is only 6,000 units [100]. Assuming each unit of FNA produces 3 tons of fish/year (from three of production periods), the total production can be achieved is 18,000 tons/year. Fish production has been achieved from FNA activity in Lake Maninjau (36,219 tons in 2010; table 8) has exceeded the production determined by the regulation.

4. Closing Remarks
In line with the development of the community, utilization of the lakes, and their surrounding area, the condition of Sumatran major lakes is constantly changing. Management of lakes is needed in order to conserve the sustainability of the lake, both as an ecological point or as a medium of utilization for the human being.

Studies of Sumatran major lakes are still continued with various approaches recently. Therefore, the studies should be directed to deepening scientific aspects as well as management and sustainable use of resources aspects.

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