Phosphorus load base carrying capacity estimation for fish culture in Lake Ranau in Indonesia

L Lukman*, R Dina, A Ibrahim and A Waluyo

Research Centre for Limnology, Indonesian Institute of Sciences (LIPI), Cibinong Science Centre-Botanical Garden, Jalan Raya Bogor Km 46, Cibinong, Indonesia, 16911

*Corresponding author email: lukman@limnologi.lipi.go.id

Abstract. Carrying capacity is the ability of waters to accommodate pollutant load inputs without reducing the water quality. For aquaculture in floating net cages (FNC), the carrying capacity is a criterion to achieve the maximum fish production based on the level of total phosphorus (TP) released from the activity, which is still acceptable according to utilisation purposes. Lake Ranau in Sumatra is essential in supporting the socio-economic needs of the people in the surrounding areas, including FNC activities. The development of FNC as an aquaculture model in open waters will have a positive value as long as it is within the limits of water carrying capacity. Thus, the carrying capacity of Lake Ranau waters needs to be estimated to provide optimal direction for FNC development in line with other activities such as tourism. The carrying capacity was estimated using the Beveridge (1987) formulation that has also been adopted into the Ministry Regulation of Environment number 28/2009. As a limiting factor for tourism purposes, the status trophic of waters should be oligotrophic or oligo-mesotrophic. Therefore, the fish production that can be achieved is between 0 tons/year (oligotrophic scale) to 1,662 tons/year (oligo-mesotrophic scale).

1. Introduction
Carrying capacity is the ability of the environment to support human life, other living things, and balance between the two. The concept of the carrying capacity, in general, can be seen in terms of availability and needs. The term availability is to look at the regional characteristics and the potential of their natural resources. The needs of humans and other living creatures are principal to be identified and should be considered in the priority policy directions in a region [1]. According to [2] the waters carrying capacity is the ability to accommodate the pollutant load inputs without reducing the water quality. For the cage aquaculture in Floating Net Cages (FNC), carrying capacity is a criterion to achieve the maximum fish production based on the level of total phosphorus (TP) released from fish culture activity which is still acceptable according to the waters use interests [3].

The phosphorus concentration is considered for waters carrying capacity calculation due to the element of phosphorus is required for fish growth, metabolism, and formation of phospholipids. Phosphorus enters the fish body through the feed. However, some parts of phosphorus are released into the waters from the uneaten feed, residual metabolites, and faeces (Rismeyer, 1998 in [4]). The balance of input and output phosphorus formulation to the waters was firstly proposed by [5]. The excessive loads of phosphorus in the waters will accumulate and eventually change the water trophic status from oligotrophic to hypereutrophic.
Lake Ranau is the second largest lake in Sumatera Island, some parts of which are located in South Sumatra Province exactly in South Ogan Komering Ulu Regency, and some others are in Lampung Province is the West Lampung Regency [6]. Lake Ranau is important in supporting the people socio-economic needs in the surrounding areas. This lake functions as a tourist destination, especially for water recreation and nature tourism. Besides, it is also utilized for fisheries activities, consists of fishing and aquaculture using the FNC system, especially for the culture of carp and tilapia [7][8].

The FNC activities in Lake Ranau have been conducted since 2006. It was an alternative for the community's business due to the declining coffee price, the primary source of their income. The activities are centralized in South Ogan Komering Ulu. The fish production recorded in 2016 reached 565.918 tons, where the highest was in Warkuk Ranau Selatan District, which up to 93.580 tons. The development of FNC activities seems to be related to the low risk of this particular business [9].

The development of the FNC as an aquaculture model in open waters will have a positive value as long as it is within the limits of their carrying capacity and the selected location does not conflict with other interests. An excessive increase of FNC will have adverse effects; thus, the policy of utilizing natural resources by humans without regard to their carrying capacity will lead to environmental damage in the future [10]. According to [11], the rapid and uncontrolled growth of FNC has caused various problems that disrupt the sustainability of aquatic resources and the fishery business itself. Meanwhile, the development of FNC in a lake that functions as a tourism destination such as Lake Ranau is highly risked, considering that tourism requires clean, clear, and not slum water conditions.

Thus, the estimation of the carrying capacity of Lake Ranau waters is required in the development of fish culture with FNC, as the direction of optimal lakes utilization.

2. Materials and Methods
2.1. Location
Lake Ranau is a tec-tvonac lake type, as an ancient caldera of Mount Ranau, and was formed as part of the tectonic fault of Sumatra Island. Mount Seminung, located in the southeast of Lake Ranau, was formed as the last caldera (post-caldera). The lake is in the convergence area between the fault segment of Kepahiang-Makakau and Ranau-Suoh [12]. The Lake Ranau is located at an elevation of 538.7 m above sea level, with the main inlet is the Warkuk River, and the outlet is the Selabung River. The flow rate of the Warkuk River is 20.12 m$^3$/s, and the total inflow from the catchment is 23.67 m$^3$/s. The Lake Ranau has an area that reaches 128.13 km$^2$, the maximum depth is 221 m, and the volume is 19.92 x 10$^9$ m$^3$. The water retention time of Lake Ranau, based on the total inflow, is about 26.7 years [13].

2.2. Estimation of phosphorus load
The source of phosphorus [P] that is considered and estimated as the load to Lake Ranau, apart from FNC, comes from rainwater and the catchment which derives from land use, domestic, and livestock. The data for each land use and human activity that potentially provides a phosphorus load refers to the secondary data.

A load of phosphorus from the catchment area was assumed to come from domestic activities and existing land uses. The pollutant load from the former was calculated using an equation referring to WHO (1993) in [14] as follows:

$$PL_{domestic} = [P] \times f[L] \times Qp$$ .........................................................(1)

$$[P] = Pollution \ [P] \ load \ from \ domestic \ activities \ (kg/year)$$

$$f[L] = Pollution \ [P] \ load \ factor \ from \ domestic \ activities \ (gr/cap/day)$$

$$Qp = Coefficient \ of \ runoff$$

A load of phosphorus from land use was calculated using an equation referring to WHO (1993) in [14] as follows:

$$PL_{land} = A \times Qp \times C_j$$ .........................................................(2)
\[ PL_{\text{land}} = \text{Pollution [P] load from land use (kg/year)} \]
\[ A = \text{Area of each land use (km}^2) \]
\[ Q_p = \text{Coefficient of run off} \]
\[ C_j = \text{Contribution of phosphorus in run off (kg/km}^2\text{/year)} \]

The contribution of load phosphorus from livestock activity was calculated using an equation referring to WHO (1993) in [14] follows:

\[ PL_{\text{livestock}} = \sum_{\text{livestock}} x Q_p x C_j \]

\[ PL_{\text{livestock}} = \text{Pollution [P] load from each livestock species} \]
\[ \sum_{\text{livestock}} = \text{Number of livestock species in the catchment area} \]
\[ Q_p = \text{Coefficient of runoff} \]
\[ C_j = \text{Contribution of pollution [P] load from each livestock species (kg/km}^2\text{/year)} \]

The factor of pollution [P] load from domestic referred to [15], the runoff flow coefficient \((Q_p)\), \(C_j\) referred to [16] and [17], and the value of \(Cl\) referred to Asaad (2005) in [14]. The phosphorus load from FNC activities was estimated by referring to Rismeyer (1998) formulation in [4] based on fish production data from [6], by the feed conversion ratio (FCR; Food Conversion Ratio) was 1.5 [18] and the phosphorus level in feed was 3.85% [19].

2.3. Calculation of carrying capacity

Calculation of the carrying capacity of Lake Ranau for the FNC development referred to the balance phosphorus model [3] that was adopted into the Ministry Regulation of Environment number 28/2009 concerning the Capacity of Pollution (P; Phosphorus) Loads for Lake and or Reservoirs [20]. This study was supported by secondary data, including the physical condition of the waters [13] and fish production data from FNC in Lake Ranau [6]. The formulation for determining the carrying capacity is as follows:

\[ \Delta P = [P]_f - [P]_I - [P]_{CA} \]  
\[ \Delta P = \text{Allowable [P] load from FNC} \]
\[ [P]_f = \text{Desired [P] concentration related to acceptable trophic state} \]
\[ [P]_I = \text{Prior [P] concentration from data monitoring} \]
\[ [P]_{CA} = \text{Load of [P] from the catchment area} \]

Meanwhile, \(\Delta P\) is related to phosphorus load from FNC \((L_{fish})\), the lake size (mean depth \([z]\), the flushing rate \([\rho]\)), and the fraction of \(L_{fish}\) retained by sediments \([R_{fish}]\):\n
\[ \Delta P = L_{fish} (1-R_{fish})/z \rho, \text{ therefore:} \]
\[ L_{fish} = \Delta P z \rho/(1-R_{fish}) \]  

The flushing rate of the lake \((\rho)\) obtained from the formula:

\[ \rho = Q/V \]  
\[ Q = \text{The amount of water discharge out of the lake per year (}10^6\text{ m}^3\text{/year)} \]
\[ V = \text{Volume of the lake (}10^6\text{ m}^3) \]

The fraction of \(L_{fish}\) retained by sediments \([R_{fish}]\) was obtained from:

\[ R_{fish} = x + f(1-x) R \]  
\[ x = \text{The net proportion of P loss permanently to the sediment as a result of solid deposition} (0.45-0.55 \approx 0.5; [3]) \]
\[ R = \text{The proportion of dissolved lost to the sediment} \]
The value of $R$ was calculated using the formula Larsen & Mercier (1976) in [3]:

$$ R = \frac{1}{1 + 0.747 \rho^{0.507}} \quad \text{............................................................. (8)} $$

The acceptable limits of phosphorus concentration of a lake depending on the trophic status criteria that following the needs and interests in the other utilizations of the lake (Table 1).

**Table 1.** Criteria for the trophic status of a lake based on several water quality parameters.

| Trophic state    | Total N (mg/m$^3$) | Total P (mg/m$^3$) | Chlorophyll a (mg/m$^3$) | Transparency (m) |
|------------------|--------------------|--------------------|--------------------------|------------------|
| Oligotrophic     | $\geq 650$         | $< 10$             | $< 2.0$                  | $\geq 10$        |
| Mesotrophic      | $\geq 750$         | $< 30$             | $< 5.0$                  | $\geq 4$         |
| Eutrophic        | $\leq 1900$        | $< 100$            | $< 15$                   | $\geq 2.5$       |
| Hypertrophic     | $\geq 1900$        | $\geq 100$         | $\geq 200$               | $\leq 2.5$       |

Source: [20]

3. **Results and Discussion**

3.1. **Lake Ranau condition**

The trophic status of Lake Ranau has shown eutrophic to hypertrophic conditions (average TP levels of 0.092 – 0.110 mg/L) [21].

**Table 2.** Data of Total Phosphorus (TP) in Lake Ranau

| Time            | Location (Stations) |
|-----------------|---------------------|
|                 | I   | II  | III | IV  | V   | VI  |
| April 2013      | 0.078 | 0.120 | 0.097 | 0.092 | 0.085 | 0.090 |
| June 2013       | 0.112 | 0.116 | 0.112 | 0.127 | 0.113 | 0.122 |
| August 2013     | 0.092 | 0.092 | 0.096 | 0.072 | 0.112 | 0.072 |
| October 2013    | 0.087 | 0.087 | 0.133 | 0.099 | 0.125 | 0.097 |
| Average         | 0.092 | 0.104 | 0.110 | 0.098 | 0.109 | 0.095 |

Source: [21]

The phosphorus in the waters is externally sourced from the catchment area and internally from the resuspension processes coming from the sediment [22]. The high TP levels of Lake Ranau have also been previously reported by [23]. The high TP levels on this lake are unique because of the relatively deep waters with a maximum depth is 221 m [13] and the catchment area to lake area ratio as the primary source of phosphorus is only 2.83 [24].

Deep lakes, such as Lake Ranau, tend to experience stratification when viewed from the vertical temperature profile [23]. As stated by [25], the stratification of the lakes obviously depends on their depth apart from the wind shelter factor. The permanent stratification will impact the distribution of both biological and chemical parameters. It is contradicting to the shallow lakes that often have high phosphorus concentrations related to the resuspension process. Resuspension is a significant factor in the transport mechanism of materials from the bottom part of shallow lakes [26].

3.2. **Phosphorus sources**

Rainwater contains various types of pollutants, including nutrient components such as nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), and sodium (Na). In a study of rainwater chemistry in Indian forest areas, it was found that the mean inputs of the components of N, P, K, Ca, and Na were 1.01 mg/L, 0.05 mg/L, 0.56 mg/L, 0.62 mg/L, and 3.40 mg/L, respectively [27]. Rainwater appears to
be a source of phosphorus to the waters. Referring to [28], the TP concentration in rainwater at Lake Maninjau area is approximately 1 mg/m³. The contribution of TP from rainfall to the lake does not seem significant (Table 3).

**Table 3. The potency of phosphorus load from rainfall in Lake Ranau.**

| Parameters                                         | Quantity                                      |
|----------------------------------------------------|-----------------------------------------------|
| Average of rainfall annual (ARA)<sup>1)</sup>     | 2775 mm (2.775 m)                            |
| Area of Lake Ranau (ALR)<sup>2)</sup>              | 128.13 km² (128.13 x 10⁶ m²)                 |
| Volume of annual rainfall (VAR)<sup>3)</sup>       | 355.56 x 10⁶ m³                              |
| Concentration of TP in rain water (CPR)<sup>4)</sup> | 1 mg/m³                                      |
| Phosphorus load from rain water<sup>5)</sup>       | 355.56 x 10⁶ mg/year (0.356 tons/year)       |

Sources: <sup>1)</sup> [6]; <sup>2)</sup> [13]; <sup>3)</sup> ARA x ALR; <sup>4)</sup> [28]; <sup>5)</sup> VAR x CPR

The contribution of phosphorus from rainfall is globally low and insignificant. However, the atmospherically transported anthropogenic phosphorus may play an important role mainly from incinerators and biomass burning especially will impact to the lake oligotrophic condition [29].

A catchment area is the primary source of pollution loads that enter the lake, related to land use, domestic and farm activities. The land use in the catchment area greatly affects the supply of allochthonous phosphorus to the lake, such as organic matter. The land use in the Lake Ranau watershed is dominated by plantation (45.0%) and relatively large shrubs (34.7%), while the forest area is very small (8.1%). The estimation of phosphorus load from land use activities in the Lake Ranau catchment was 1,397.9 kg/year or 1.398 tons/year (Table 4). The land that is used for extensive agriculture is characterized by high concentrations of phosphorus and nitrogen [30]. The phosphorus concentration on a water body can reflect its land-use profile so that attention to the phosphorus load from the catchment area is important.

Based on Domestic Wastewater Quality Standards in the State Minister of the Environment Decree No. 112 of 2003, domestic wastewater comes from businesses, residential complexes, and office activities. The humans who inhabit an area are also other sources of phosphorus load to the waters, both inorganic and organic forms. In the catchment area of Lake Ranau, there are communities with a total population of 33,382 people spread in two sub-districts. The estimation of phosphorus load from domestic in Lake Ranau catchment was 15.2 tons/year (Table 5).

The phosphorus load from FNC activities will depend on the fish culture intensity that will determine the feed supply, ultimately, the amount of phosphorus released into the waters either from uneaten feeds or metabolites. Based on the calculation, the loading of phosphorus from FNC activity to the Lake Ranau can reach 150.4 tons/year which is released through the faeces (50.7 tons/year) and wastes as solutions (99.7 tons/year) (Table 6).

Livestock and farm activities will contribute to the waters as a source of phosphorus. Each livestock animal will provide a different supply of phosphorus. In the Lake Ranau catchment, the most common livestock species are goats (86235 animal units), followed by ducks, cows, buffalos, and horses. The estimation of phosphorus load from livestock and farm activities in the Lake Ranau catchment was 45.1 tons/year (Table 7).

**Table 4. Land use in the Ranau Lake catchment area and its phosphorus load.**

| District/Land use | Area (ha)<sup>1)</sup> | %     | Phosphorus load factor (kg/ha/year) | Runoff coefficient<sup>2)</sup> | Phosphorus load (kg/year) |
|-------------------|------------------------|-------|-----------------------------------|-------------------------------|---------------------------|
| Lombok Seminung   | 844.50                 | 21.8  | 0.196<sup>6)</sup>                 | 0.15                          | 24.83                     |
| District/Land use | Area (ha) | % | Phosphorus load factor (kg/ha/year) | Runoff coefficient | Phosphorus load (kg/year) |
|------------------|-----------|---|-----------------------------------|-------------------|--------------------------|
| Plantation       | 2,683.24  | 69.3 | 0.302<sup>2)</sup> | 0.4              | 324.13                  |
| Settlement       | 53.77     | 1.4  | 0                                  |                   | 0                        |
| Paddy field      | 273.20    | 7.1  | 0.346<sup>3)</sup> | 0.35             | 33.08                   |
| Shrubs           | 6.95      | 0.2  | 0.246<sup>4)</sup> | 0.3              | 0.51                     |
| Pond             | 0.60      | 0.0  | 0                                  |                   | 0                        |
| Dry land farming | 9.96      | 0.3  | 0.302<sup>5)</sup> | 0.4              | 1.38                     |
| **Sub Total**    | **3,872.23** |     |                                    |                   | **383.94**               |

**Sukau**

| District/Land use | Area (ha) | % | Phosphorus load factor (kg/ha/year) | Runoff coefficient | Phosphorus load (kg/year) |
|------------------|-----------|---|-----------------------------------|-------------------|--------------------------|
| Forest           | 337.54    | 3.2  | 0.196<sup>4)</sup> | 0.15             | 9.92                     |
| Plantation       | 3,864.00  | 36.2 | 0.302<sup>5)</sup> | 0.4              | 466.77                   |
| Settlement       | 137.78    | 1.3  | 0                                  |                   | 4                        |
| Paddy field      | 757.23    | 7.1  | 0.346<sup>3)</sup> | 0.35             | 91.70                    |
| Shrubs           | 5,048.76  | 47.3 | 0.246<sup>4)</sup> | 0.3              | 372.60                   |
| Pond             | 0.94      | 0.0  | 0                                  |                   | 0                        |
| Dry land farming | 527.15    | 4.9  | 0.302<sup>5)</sup> | 0.4              | 72.96                    |
| **Sub Total**    | **10,673.39** |     |                                    |                   | **1013.95**              |

**Total** 14,545.60 1,397.89

Source: 1<sup>)</sup> [6]; 2<sup>)</sup> Adopted from [14]; 3<sup>)</sup> Middle value 4<sup>)</sup> [17]; 5<sup>)</sup> [16]; 6<sup>)</sup> Adopted from the grassland value.

**Table 5.** The population in the Lake Ranau catchment area and their phosphor load.

| Districts               | Capita (cap.)  | Phosphorus<sup>3)</sup> load factor (gr/cap/day) | Runoff coeisien<sup>3)</sup> | Phosphorus load (g/day) | Phosphorus load (tons/year) |
|------------------------|----------------|-----------------------------------------------|-----------------------------|-------------------------|-----------------------------|
| Lumbok Seminung        | 8,191          | 2.5                                           | 0.5<sup>4)</sup>             | 10.239                  | 3.737                       |
| Sukau                  | 25,191         | 2.5                                           | 0.5<sup>4)</sup>             | 31.489                  | 11.493                      |
| **Total**              | **33382**      |                                               |                             | **41.728**              | **15.231**                  |

Source: 3<sup>)</sup> [6]; 2<sup>)</sup> Middle value [15]; 3<sup>)</sup> Adopted from [14]; 4<sup>)</sup> Middle value between of 0.4 – 0.6

**Table 6.** The estimation of phosphorus load from FNC activity in Lake Ranau.

| Fish production (tons)<sup>1)</sup> | Estimated feed usage (tons)<sup>2)</sup> | Phosphorus content on the feed (tons)<sup>3)</sup> | Phosphorus retention on fish (tons)<sup>4)</sup> | Loss of phosphorus via faeces (tons)<sup>4)</sup> | Loss of phosphorus as a solution (tons)<sup>4)</sup> | Loss of total phosphorus in the lake waters (tons)<sup>4)</sup> |
|-----------------------------------|------------------------------------------|-----------------------------------------------|-----------------------------------------------|-----------------------------------------------|-----------------------------------------------|-----------------------------------------------|
| 4,179.5                           | 6,269.26                                 | 241.37<sup>3)</sup>                           | 91.61<sup>3)</sup>                             | 50.69<sup>3)</sup>                             | 99.68<sup>3)</sup>                             | 150.37                                        |

Source: 1<sup>)</sup> [6]; 2<sup>)</sup> [18]; 3<sup>)</sup> [19]; 4<sup>)</sup> Rismeyer (1998) in [4]. a<sup>)</sup> FCR of Nile tilapia = 1.5; b<sup>)</sup> 3.85% from feed weight; c<sup>)</sup> 37.7% of phosphorus on feed; d<sup>)</sup> 21.1% of phosphorus on feed; e<sup>)</sup> 41.3% of phosphorus on feed
Table 7. Types of reared livestock in the Lake Ranau catchment area and their phosphorus load.

| District/Type of livestock | ΣLivestock (unit) | Phosphorus loads factor (kg/unit/day) | Runoff coefficient (Qp) | Phosphorus load (kg/day) | Phosphorus load (tons/year) |
|---------------------------|-------------------|-------------------------------------|------------------------|-------------------------|---------------------------|
| Lombok Seminung           |                   |                                     |                        |                         |                           |
| Cows                      | 2,717             | 0.02                                | 0.25^4                 | 13.59                   | 4.959                     |
| Buffalos                  | 159               | 0.02                                | 0.25^4                 | 0.80                    | 0.290                     |
| Horses                    | 95                | 0.013                               | 0.25^4                 | 0.31                    | 0.113                     |
| Goats                     | 7,463             | 0.003                               | 0.25^4                 | 5.60                    | 2.043                     |
| Ducks                     | 2,717             | 0.00056                             | 0.35^5                 | 0.53                    | 0.194                     |
| Sub Total                 | 13,151            |                                     |                        |                         |                           |
| Sukau                     |                   |                                     |                        |                         |                           |
| Cows                      | 6,875             | 0.02                                | 0.25^4                 | 34.38                   | 12.547                    |
| Buffalos                  | 404               | 0.02                                | 0.25^4                 | 2.02                    | 0.737                     |
| Horses                    | 192               | 0.013                               | 0.25^4                 | 0.62                    | 0.228                     |
| Goats                     | 78,772            | 0.003                               | 0.25^4                 | 59.08                   | 21.564                    |
| Ducks                     | 33,547            | 0.00056                             | 0.35^5                 | 6.58                    | 2.400                     |
| Sub Total                 | 119,790           |                                     |                        |                         |                           |
| Total                     | 132,941           |                                     |                        |                         | 45.074                    |

Source: 1) [6]; 2) Assad (2005) in [14]; 4) Middle value of the grass land (0.05 – 0.25) adopted from [14]; 5) Middle value of the paddy field (0.1 – 0.6) adopted from [14].

Based on the fish production recorded in 2019 on FNC activity in Lake Ranau, the total phosphorus load released into the waters reached 150 tons (Table 6). The load of phosphor from the FNC far exceeded the phosphorus load from various activities in the catchment area from domestic, land use, and livestock activities (Table 8).

Table 8. Phosphorus load in Ranau Lake from various pollutant sources.

| Sources of phosphorus | Phosphorus load (tons/year) | %   |
|-----------------------|----------------------------|-----|
| 1. Rain water         | 0.356                      | 0.17|
| 2. Domestic activity  | 15.231                     | 7.17|
| 3. Land use           | 1.398                      | 0.66|
| i. Forest             | 0.035                      |     |
| ii. Plantation        | 0.791                      |     |
| iii. Paddy field      | 0.123                      |     |
| iv. Shrubs            | 0.373                      |     |
| v. Dry land farming   | 0.074                      |     |
| 4. Farm/livestock     | 45.074                     | 21.20|
| i. Cows               | 17.505                     |     |
| ii. Buffalos          | 1.027                      |     |
| iii. Horses           | 0.340                      |     |
| iv. Goats             | 23.607                     |     |
| v. Ducks              | 2.594                      |     |
| Total load from the catchment area | 62.012 | 29.20 |
| 5. Floating net cage (FNC) | 150.370 | 70.80 |
| Total                 | 212.382                    | 100 |

Sources: Table 3; Table 4; Table 5; Table 6; Table 7
The phosphorus load from FNC is generally quite high, as in the Lake Toba the fish production in 2016 was 62,023 tons and the total of phosphorus released to the lake waters was approximately 570.3 tons [31]. Further, fish production on FNC in Lake Maninjau in 2010 was about 36,219 tons it was estimated that the phosphorus released into the lake waters reached 387.1 tons [32]. Similar conditions also occurred on Lake Rupancos in Chile, where the FNC activities rearing salmon (*Oncorhynchus mykiss; O. salar*) produced a large phosphorus load to the waters. From the production of approximately 1,626 tons of salmon, the phosphorus released into the waters reached 12.1 tons [33].

### 3.3. Carrying capacity of Lake Ranau for the floating net cage based on phosphorus load
Various sources of phosphorus supply into the Lake Ranau came from rainwater, land use, domestic and farm activities in the catchment area, and fish culture in FNC. The total phosphorus load to the waters reached 212 tons per year, and it appears that the largest (71%) came from FNC activities (Table 7; Table 8).

#### 3.3.1. Carrying capacity approach. Considering that the FNC phosphorus load enter to the waters directly, so the determination of their carrying capacity is based on the water's capacity to accept phosphorus load residual from other sources like from the catchment.

The trophic status of Lake Ranau was already in a meso-eutrophic [23] and it has changed into hypertrophic condition (Table 3) [24], indicating that the \([P]i\) has exceeded. Since Lake Ranau becomes a tourist destination, it is not possible to establish the \([P]f\) on the eutrophic or hypertrophic level. For this reason, a scenario was required by setting assumptions so that \(\Delta P\) could be made and the carrying capacity for the FNC development could be determined [34].

Therefore, two scenarios, Scenario I and Scenario II, were built. Scenario I set an acceptable TP for waters \([P]f\) under oligotrophic (< 10 mg/m\(^3\) ≈ 10 mg/m\(^3\)) condition. Furthermore, Scenario II sets the \([P]f\) under oligo-mesotrophic conditions (< 20 mg/m\(^3\) ≈ 20 mg/m\(^3\)) (see Table 1), where it is assumed that the transparency will be high (Table 9).

Based on the calculation, the overall acceptable TP in Lake Ranau waters was 60.9 tons/year at Scenario I and 121.8 tons/year at Scenario II (Table 9). The TP level determined the carrying capacity of the Lake Ranau for FNC development after deducting the TP load from other sources (Table 8) except for the phosphorus load from FNC activity.

#### Table 9. Scenario for determining the carrying capacity of Lake Ranau to receive phosphorus load.

| Symbol | Formula/Description | Unit | Quantity |
|--------|---------------------|------|----------|
| \(\Delta P\) | \([P]f\) – \([P]i\) | mg/m\(^3\) | 10.0\(^1\) 20.0\(^3\) |
| \(\Delta P\) | Allowable phosphorus load from FNC activity | | |
| \([P]f\) | Desired P concentration related to acceptable trophic state | mg/m\(^3\) | 5.0\(^2\) 10.0\(^1\) |
| \([P]i\) | Prior P concentration from monitoring | mg/m\(^3\) | |
| \(\Delta P\) | | mg/m\(^3\) | 5.0 10.0 |
| \(L_{fish}\) | \(\Delta P z\rho/(1-R_{fish});\) | | |
| \(L_{fish}\) | Phosphor loading from FNC | | |
| \(V\) | Lake volume | m\(^3\) | 19.92 x 10\(^9\) 19.92 x 10\(^9\) |
| \(A\) | Lake area | m\(^2\) | 128.13 x 10\(^6\) 128.13 x 10\(^6\) |
| \(z\) | Lake depth average \((V/A)\) | m | 155.467 155.467 |
| \(\rho\) (rho) | Lake flushing rate/year \((Q/V)\) | | |
The 4th International Symposium on Marine and Fisheries Research  
IOP Conf. Series: Earth and Environmental Science 919 (2021) 012020  
doi:10.1088/1755-1315/919/1/012020

### Table 10. Allocation of phosphorus load \([P]\) from FNC activities and achievable fish production targets.

| Scenario (Trophic status) | \([P]_A\) \(^1\) (tons/year) | \([P]_{CA}\) \(^2\) (tons/year) | \([\Delta P]_{FNC}\) (tons/year) | Achievable fish production (tons/year) |
|---------------------------|-------------------------------|-------------------------------|---------------------------------|--------------------------------------|
| Oligotrophic             | 60.9                          | 62.0                          | -                               | -                                    |

### Equations

\[
\Delta P = [P]_f - [P]_i - [P]_{CA} \quad \text{(Equation 4)}, \quad \text{or} \quad \Delta P = [P]_A - [P]_{CA}
\]

- \(\Delta P\): Allowable phosphorus load from FNC activity
- \([P]_f\): Desired P concentration related to acceptable trophic state
- \([P]_i\): Prior P concentration from monitoring
- \([P]_{CA}\): Loading of P from catchment area
- \([P]_A\): Total phosphorus that can be accepted by lake waters

Assumptions:  
1. Prior formulation without load from the catchment;  
2. Maximum Total Phosphorus (TP) on oligotrophic conditions (Table 1);  
3. TP levels of lake waters before any activities in Lake Ranau (in reference to the phosphorus data of Lake Toba in 1929; Source: [35]);  
4. TP on oligo-mesotrophic condition (Table 1)
| Oligo-mesotrophic | 121.8 | 62.0 | 59.8 | 1661.8 |
|-------------------|-------|------|------|--------|

Table 9; Table 8; The formulation refers to the fish production level on FNC in Lake Ranau and the resulted phosphorus load.

4. Conclusions
The phosphorus load from the catchment area is relatively small (29%) compared to the FNC (71%) activities. However, the phosphorus level in Lake Ranau tends to be high, probably related to the condition or type of the lake as a tecto-volcanic lake, where the source of phosphorus comes from natural activities, including geological or volcanic processes. Criteria of allowable phosphorus load is a determinant of carrying capacity calculations based on conservative criteria. As Lake Ranau is utilized for tourism purposes, the trophic status of waters should be oligotrophic or oligo-mesotrophic. Therefore, fish production that can be achieved between 0 tons/year and 1,662 tons/year for oligotrophic scale and oligo-mesotrophic scale, respectively.

Acknowledgements
Authors wishing to acknowledge assistance or encouragement from colleagues, special work by technical staff or financial support from organizations should do so in an unnumbered

References
[1] KLH 2014 Pedoman penentuan daya dukung dan daya tampung lingkungan hidup. Deputi Bidang Tata Lingkungan Kementerian Lingkungan Hidup.
[2] Mullakkezhil Reghunathan V, Joseph S, Warrier C U, Hameed A S and Albert Moses S 2016 Factors affecting the environmental carrying capacity of a freshwater tropical lake system Environ. Monit. Assess. 188
[3] Beveridge, M C M 1987 Cage Aquaculture. Fishing News Books, Ltd. Farnham Survey-England 352 p
[4] Azwar Z I, Suhenda N and Praseno O 2004 Manajemen pakan pada usaha budi daya ikan dalam karamba jaring apung. Dalam: Sudradjat A, Wardoyo S E, Azwar Z I, Supriyadi H, and Priono B (Penyunting) Makalah dalam buku Pengembangan Budi Daya Perikanan di Perairan Waduk. Pusat Riset Perikanan Budidaya DKP 37 - 44
[5] Vollenweider, R A and Dillon P J 1974 The application of phosphorus loading concept to eutrophication research, NRC.Techn. Rep. 13690 42 pp
[6] Kelompok Kerja Pengelolaan Danau Ranau (Working Group for Lake Ranau Management) 2020. Rencana pengelolaan Danau Laporan Direktorat Kerusakan Perairan Darat. Direktorat Pengendalian Daerah Aliran Sungai dan Hutan Lindung. Kementerian Lingkungan Hidup dan Kehutanan
[7] Zaennudin A, Basuki A, Solikhin A and Saing U B 2011 Studi awal fenomena kematian ikan di Danau Ranau, Sumatra Selatan Jurnal Lingkungan dan Bencana Geologi 2 77 - 94
[8] Muthmainnah D, Atminarso D and Makmur S 2015 Fishing Activities and Fishermen Income Ind.Fish.Res.J. 21 19–26
[9] Permatasari F and Munajat 2018 Risk Analysis Income of Fish Business at Ranau Lake of South Sumatera Indonesia E3S Web Conf. 68 2016–9
[10] Lukman 2011 Pengembangan karamba jaring apung. Pertimbangan dayadukung dan ancamannya terhadap lingkungan perairan danau Makalah pada Buku “Perspektif terhadap kebencanaan dan lingkungan di Indonesia: Studi kasus dan pengurangan dampak resikonya. Editor: Anwar H Z and Harjono H. Sub Kegiatan Kompetitif Kebencanaan dan Lingkungan-LIPI 173 – 193
[11] Kartamihardja E S 1998 Pengembangan dan pengelolaan budidaya ikan dalam keramba jaring apung ramah lingkungan di perairan waduk dan danau serbaguna. Prosiding Simposium Perikanan Indonesia II Ujung Pandang 2 -3 Desember 1997
[12] Michaela P 1994. Pola regangan daerah Pull-Apart Danau Ranau. Prosiding Seminar of 30 Tahun Pusat Penelitian Geoteknologi -LIPI Puslit Geoteknologi-LIPI
[13] Harsono E, Wibowo H, and Ridwansyah I 2002. Karakteristik fisik Danau Ranau: Estimasi pola arus. *Dalam* Hartoto DI & Sulastri *Monografi Limnologi Danau Ranau* 1–13 Pusat Penelitian Limnologi–LIPI.

[14] Sugiatno I, Rizal, Sitanggang L U, Sitompul R, Wahyuni. Janatu and Sagala R 2017. Kajian daya tampung beban pencemaran dan daya dukung Danau Toba untuk budidaya perikanan. *Laporan Dinas Lingkungan Hidup Provinsi Sumatra Utara* 18 *(unpublished)*

[15] WHO 1993 *Assessment of Sources of Air, Water, and Land Pollution, Part I Rapid Invent. Tech. Environ. Pollut.*

[16] Harms L L, Dornbush J N and Andersen J R 1974 Physical and chemical quality of agricultural land runoff *Journal of Water Pollution Control Federation* 46.11

[17] Inamori Y & Fujimoto N 2010 *Non Point Sources of Pollution* Water Quality Standards-Volume II. Encyclopedia of Life Support Systems (EOLSS).

[18] Nur A 2007 Analysis of feeds and fertilizers for sustainable aquaculture development in Indonesia. In: Hasan M R, Hecht T, De Silva SS and Tacon A G J (Eds.). *Study and analysis of feeds and fertilizers for sustainable development*. *FAO Fisheries Technical Paper* 497 245-267 Rome

[19] Hidonis K 2014 Model pengelolaan waduk berbasis sistem KJA multispesies (Studi kasus Waduk Cirata) Tesis Sekolah Pasca Sarjana. IPB

[20] KLH 2009 *Daya Tampung Beban Pencemaran Air* Danau dan/atau Waduk 1–15

[21] Subagdja, Muthmainnah D, Sawestri S, Atminarso D, Makri Sulastri, Badjoeri M, Sudrajat A 2013 Ekologi, biologi dan kapasitas penangkapan sumberdaya ikan di Danau Ranau Provinsi Sumatra Selatan, Palembang, Indonesia. *Laporan Internal*. Balai Penelitian Perikanan Umum, Badan Litbang Kelautan dan Perikanan, Kementerian Kelautan dan Perikanan *(unpublished)*

[22] Leinweber P, Bathmann U, Buczko U, Bouhaine C, Eichler Krasznai E 2015 *Lake stratification in the Carpathian basin and its interesting biological consequences* *Inl. Waters* 5 173–86

[23] Sulastrri, Badjoeri M, Sudarso J, and Syawal M S 1999 Kondisi fisik, kimia dan biologi Perairan Danau Ranau Sumatra Selatan *Limnotek*, 61 25–38

[24] Lukman 2018 *Catalogue of Sumatran Big Lakes* LIPI Press 136 pp

[25] Borics G, Abonyi A, Várbiró G, Padisák J and T-Krasznaï E 2015 *Lake stratification in the Carpathian basin and its interesting biological consequences* *Inl. Waters* 5 173–86

[26] Niemisto J, Holmoos H and Horppila J 2011 *Handling the phosphorus paradox in agriculture and natural ecosystems: Scarcity, necessity, and burden of P*. *Ambio* 47 3–19

[27] Yadav A K and Mishra G P 1979 Chemistry of rainwater and its contribution to nutrient input in forests of central India. *Tellus* 31 463–4

[28] Lukman 2012 *Evaluasi keseimbangan fosfor di Danau Toba*. *Prosiding Seminar Nasional Limnologi IV*. Pusat Penelitian Limnologi LIPI

[29] Migon C and Sandroni V 1999 *Phosphorus in rainwater: Partitioning inputs and impact on the surface coastal ocean* *Limnol. Oceanogr.* 44 1160–5

[30] Rodríguez-Romero A J, Rico-Sánchez A E, Mendoza-Martínez E, Gómez-Ruiz A, Sedeño-Díaz J E and López-López E 2018 Impact of changes of land use on water quality, from tropical forest to anthropogenic occupation: A multivariate approach *Water (Switzerland)* 10

[31] Lukman L, Hidayat H, Subehi L, Dina R, Mayasari N, Melati I, Sudirian Y and Ardianto D 2019 Pollution loads and its impact on Lake Toba *IOP Conf. Ser. Earth Environ. Sci.* 299

[32] Lukman, Setyobudiandi I, Muchsin I and Hariyadi S 2015 Impact of cage aquaculture on water quality condition in Lake Maninjau, West Sumatera Indonesia *Int. J. Sci. Basic Appl. Res.* 23 120–37

[33] León-Muñoz J, Echeverría C, Marcé R, Riss W, Sherman B and Iriarte J L 2013 The combined impact of land use change and aquaculture on sediment and water quality in oligotrophic Lake Rupanuco (North Patagonia, Chile, 40.8°S) *J. Environ. Manage.* 128 283–91
[34] Lukman and Hamdani A 2011 Estimasi daya dukung perairan Danau Toba Sumatera Utara untuk pengembangan budidaya ikan dengan karamba jaring apung *Limnotek* 18 59-66

[35] Ruttner F 1931 Hydrographische und hydrochemische Beobachtungen auf Java, Sumatra and Bali *Arch.Hydrobiol. Suppl.* 8 197–454