Management of Mystacoleucus padangensis population by the determination of the optimum length at first capture for its exploitation in Lake Singkarak, West Sumatara-Indonesia

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Abstract. The Lake Singkarak locates on Solok and Tanah Datar Regency, West of Sumatra-Indonesia which has 10,908.2 ha surface area and 178 m average of depth. The fish biodiversity in this lake was high among of them was the native fish species of bilih (Mystacoleucus padangensis) which pose an important economic value. The population of bilih has been decreasing caused by the overexploitation and habitat degradation. The resource management effort on the bilih fish was conducted through a determination on the needed conservation area as well as regulation on the location for capturing and restocking of the fish. The objective was to determine the optimum length of the fish at the first capture (Lc_opt) as a function of F/M for conducting a sustainable exploitation. The primary and secondary data were used in this study. The fish samples were caught on four stations using several experimental fishing gears in July 2019. The biological obtained data (population parameters, growth pattern, and reproduction) were collected from the secondary data. The length at first mature of male and female of bilih were 7.5 cm and 8.2 cm, respectively. The value of Lc_opt for F=3.86 M was 11.2 cm, while it would be of 10.0 cm for F=M and 9.5 cm for F=0.5M. Those values were larger than the first size of the mature gonads which suggested that bilih enable to reproduce. The exploitation conducted on the value of Lc_opt would give the maximum yield per recruitment and maintain population size above half of the natural abundance.

Keywords: Exploitation, Lake Singkarak, Management, Mystacoleucus padangensis

1. Introduction
Lake Singkarak is located on Solok and Tanah Datar Regency, West Sumatra-Indonesia with 10,908.2 ha surface area and 178 m of average depth. The lake has been used for many purposes including of drinking water source, aquaculture and capture fisheries, irrigations, tourism, and hydropower. Fish diversity of the lake is high [1] and among of them is bilih (Mystacoleucus padangensis), the endemic species of Sumatra which pose a high economic value (Rp50.000/kg) and being a main target for fishers at Lake Singkarak.

The Bilih fish at Lake Singkarak is a planktivore fish which eat phytoplankton, zooplankton, and detritus as natural food [2]. The Bilih fish was successfully introduced in Lake Toba, North Sumatra as
an effort for enhancing fisheries which gave a high productivity [3]. However, the production and body size of bilih has decreasing because of overexploitation and unselective fishing gear use [4]. The Bilih management efforts have been conducted by determination the conservation area and fishing zone, regulation of quota, and restocking [5]. Nevertheless, management of bilih resources by determining the legal size for exploitation has not been performed. Determination of the optimum length at first capture (Lc_opt) is must be obtained and evaluated for providing data to develop a management rule on bilih sustainability. The sustainable management on bilih population can provide a better income for fisher. Management of Nile perch (Lates niloticus), Nile tilapia (Oreochromis niloticus), and perch (Perca fluviatilis) at Lake Victoria was done by setting length at first capture (Lc) [6, 7, 8]. The Lc_opt is calculated based on the fish biological aspects which include growth parameters, reproduction, and growth pattern [9]. The aim of this research was to determine the optimum length at first capture (Lc_opt) to minimize the negative impact of bilih exploitation at Lake Singkarak, West Sumatra, Indonesia.

2. Methods
2.1. Data collection
The primary and secondary data were used in this study. The primary data were obtained through a single fish sampling conducted on July 2019 at four stations, namely Batang Sumpur River, Sumpur Village, Paninggahan, and Singkarak Village (figure 1). Fish was sampled using gillnet (of 5/8 and 3/4 inch mesh size), cast net (of 5/8 inch), and trap known as alahan. The fish sample was measured to determine the total length/TL (cm) and then dissected to determine the gonadal maturity stage of each fish. The classification of morphological maturity stage of bilih referred to Suryanti et al [10]. The total length and maturity stage data were used to estimate length at first captured (Lc) and length at first maturity (Lm), respectively. Subsequently, some of the parameters used in further analysis to estimate optimum length at first captured (Lc_opt) as shown in table 1 which are based on the previous studies [11,12]. They consist of growth pattern (length-weight relationship) and parameters of von Bertalanffy growth equation namely infinity length (L∞, cm), growth constant (K, year⁻¹), natural mortality (M, year⁻¹), fishing mortality (F, year⁻¹), and length at recruitment (Lr, cm).

Figure 1. Research location at Lake Singkarak.
Table 1. Population parameters of bilih at Lake Singkarak 2009.

| Parameters          | Singkarak |
|---------------------|-----------|
| $L_\infty$ (cm)     | 11.6      |
| K (year$^{-1}$)     | 0.5       |
| M (year$^{-1}$)     | 1.46      |
| F (year$^{-1}$)     | 1.56      |
| Z (year$^{-1}$)     | 3.02      |
| E (year$^{-1}$)     | 0.52      |
| a                   | 0.0093    |
| b                   | 2.8920    |
| Lc male (cm)        | 5.4       |
| Lc Female (cm)      | 5.8       |
| Lr (cm)             | 2.3       |

Sources: [2]

2.2. Data analysis
Length at first mature (length at 50% maturity, $L_m$) was estimated using a logistic curve [13, 14]. Total length at maturity stage IV was a data for this equation. The logistic equation used is as follows:

$$P = \frac{1}{1 + \exp[-r(L - L_m)]} \quad \text{.......................................................... (1)}$$

Where:

- $P$ = The proportion of fish mature (%)
- $L_m$ = Length at first maturity (cm)
- $L$ = Total length (cm)
- $r$ = Slope

Length at first capture ($L_c$) of bilih was calculated using the cumulative frequency curve [15] with an equation:

$$L_c = \bar{L} - k(L_\infty - \bar{L})/Z \quad \text{.......................................................... (2)}$$

Where:

- $\bar{L}$ = Length at first capture (cm)
- $K$ = Growth coefficient (year$^{-1}$)
- $L_\infty$ = Asymptotic of total length (cm)
- $Z$ = Total mortality rate (year$^{-1}$)

Froese et al. [16] method was used to minimize the impact of fishing with determination of the size of fish which allowed to exploitation. It has three simple rules for fulfil to the method requirements, namely 1) fishing mortality is less than natural mortality 2) population size remains above half of the natural abundance and 3) the fish still grow and reproduce. The analysis was done by followings steps:

1. Optimal length at first capture ($L_{c\_opt}$) was calculated using the formula

$$L_{c\_opt} = \frac{L_\infty(2 + 3F/M)}{(1 + F/M)(3 + M/K)} \quad \text{.......................................................... (3)}$$

Maximum length ($L_{c\_max}$) was estimated using solver as add in from MS-excel$^\text{TM}$ software version 2016.

2. An index of yield per recruitment ($Y'/R$) as a function of length at first capture was calculated using the formula:
\[
Y' = \frac{F/M}{1 + F/M} (1 - 3(1 - Lc/L\infty) + \frac{3(1 - Lc/L\infty)^2}{1 + \frac{F/M}{K(1+F/M)}} + \frac{(1 - Lc/L\infty)^3}{1 + \frac{3M}{K(1+F/M)}}) \tag{4}
\]

3. The relative biomass per recruitment (Bo'/R) in the exploited phase was calculated using the formula:
\[
\frac{B_o'}{R} = (1 - Lc/L\infty)^{M/K} \left( 1 - \frac{3(1 - Lc/L\infty)}{1 + \frac{1}{M/K}} + \frac{3(1 - Lc/L\infty)^2}{1 + \frac{2}{M/K}} - \frac{(1 - Lc/L\infty)^3}{1 + \frac{3}{M/K}} \right) \tag{5}
\]

4. The relative mean body in the caught and in the exploited phase of the population (Wmean/W) was calculated using the formula:
\[
\frac{W_{\text{mean}}}{W_{\text{Wo}}} = \left( 1 - \frac{3(1 - Lc/L\infty)}{1 + \frac{1}{M/K}} + \frac{3(1 - Lc/L\infty)^2}{1 + \frac{2}{M/K}} - \frac{(1 - Lc/L\infty)^3}{1 + \frac{3}{M/K}} \right) \tag{6}
\]

5. Mean body weight above Lc in the unexploited population was calculated using the formula:
\[
\frac{W_{\text{mean}}}{W_{\text{Wo}}} = \left( 1 - \frac{3(1 - Lc/L\infty)}{1 + \frac{1}{M/K}} + \frac{3(1 - Lc/L\infty)^2}{1 + \frac{2}{M/K}} - \frac{(1 - Lc/L\infty)^3}{1 + \frac{3}{M/K}} \right) \tag{7}
\]

Economic calculation as a function of F, M, and Lc was analysed using King method [13]. The calculation was done on F=0.5M, F=M, and F=1.56.

3. Results and Discussion
The TL of female and male bilih in this study were ranged of 4.2 to 10.8 cm (averagely of 7.1 cm) and 4.2 to 9.5 cm (averagely of 6.4 cm), respectively. The highest frequency of female and male were 7.0 cm and 6.0 cm, respectively. These results showed that the size of bilih in this study was relatively similar to a study which conducted in 2010 and 2019 (figure 2), except of the highest frequency of male bilih has decreased by 1.0 cm. Furthermore, each fishing gear caught bilih with different size range, for instance, the alahan and cast net have caught bilih with a wider size range than gillnet which was more selective, as shown in table 2. On the other hand, the highest frequency (mode) and average of bilih caught using gillnet of 3/4 inch was relatively bigger than other gears. The estimated length at first capture (Lc) for all gears were 5.4 and 5.8 cm for male and female, respectively.

Table 2. Total length range, mode, mean, and standard deviation of bilih based on the fishing gear.

| Fishing gear | Total length range | Mode (cm) | Mean (cm) |
|--------------|-------------------|-----------|-----------|
| Gillnet 5/8" | 5.3–8.0           | 7.0       | 6.7±0.5   |
| Gillnet 3/4" | 6.6–8.9           | 8.0       | 7.8±0.4   |
| Cast net 5/8 "| 5.0–10.0          | 7.0       | 6.7±1.1   |
| Alahan       | 4.2–10.8          | 6.0       | 6.4±1.3   |
Limited information about the fishing activities, legal size for capture, and the fish stock have been an obstacle in the freshwater resource management [17]. Alternatively, management based on biological parameters of the fish population have been used. The biological aspects consist of growth pattern, growth parameter, and length at first mature as fundamental information for sustainable fisheries management [19]. For example, the management effort based on the biological information and selectivity of the use of fishing gear could prevent recruitment overfishing at the juvenile phase [18].

The estimated length at first mature ($L_m$) of bilih at Lake Singkarak was 7.5 cm for male and 8.2 cm for female (figure 3). Combining the obtained value of $L_m$ with the size distribution of caught bilih (figure 2), it revealed that 60.5% of female and 83.0% of male bilih were smaller than the length found at the first mature ($L_c<L_m$). The nile tilapia ($Oreochromis niloticus$) at Lake Abu-zabal, Egypt has been exploited at a bigger size than its length at first mature [20] and this gives a chance for the fish to reproduce [21].
The determination of legal size increased the economic value for fishers [22]. This is an effective way for conducting a sustainable management [23]. The Bilih population at Lake Singkarak has been overexploited with an exploitation rate (E) of 0.52 year\(^{-1}\) which was accompanied by the symptom of the decreasing of maximum length from 18.6 cm to 11.6 cm [2]. The yield of bilih in 2013 was 720 kg/year or 67% more than the maximum sustainable yield (230 kg/year) [24]. Every mortality in fishing was correspond to the measured length at first capture. The result of the analysis showed that in the area between F=0.5M and F=M (which represent sustainable exploitation area) the value of Lc\(_{\text{opt}}\) exceeded to Lc\(_{\text{max}}\) value by 4.4 and 12.0%, respectively and the difference was decreasing as F increasing (figure 4). At the maximum fishing pressure (F=M), the value of Lc\(_{\text{opt}}\) was equal to 54% of L\(_\infty\) while F=0.5M was correspond to 50.5% of L\(_\infty\) (rule 1). At that size, the proportion of mature bilih was 92.0%. Instead, the actual fishing mortality of bilih in 2009 was F=3.86M. The Lc\(_{\text{opt}}\) for F=3.86M was 11.2 cm, while it would be of 10.0 cm for F=M and 9.5 cm for F=0.5M. The optimum length at first capture (Lc\(_{\text{opt}}\)) was bigger than the length at first mature of bilih (Lc\(_{\text{opt}}\)>Lm) (rule 3).

**Figure 3.** Length at first mature of bilih.

**Figure 4.** Relative length at first capture (Lc/L\(_\infty\)) as a function of F/M (Equation 3).
Figure 5. A). Yield per recruitment relative to the theoretical maximum yield (Equation 2) B). Biomass per recruitment relative to the unexploited biomass, as a function of the F/M ratio (Equation 3). Lc_opt: (optimum length of fish at the first capture), Lc_max: (maximum length of the fish at the first capture), Lc (length of fish when captured at the existing condition), and L0.05 (no size limit scenario).

Fishing started at Lc_max and Lc_opt would result in the same maximum yield at a given value of F. Compared to yield at Lc and L0.05, the yield at Lc_max and Lc_opt would give the optimum yield (figure 5A). Biomass per recruitment at F0.1 measured as a sustainable management approach [25] falls below B0=0.5Bo (rule 2), while the value of Lc_opt for F0.1 with the catch resulted of 79% of the theoretical maximum catch. At the scenario of F=M, gave catch estimation of 82% of the theoretical maximum catch. The decreasing of fishing mortality by 50% or F=0.5M, the yield became decreasing of 63%. The lowest yield would be obtained when no size limitation (B=0.17Bo).

The fishing activity would have an impact on the fish resources in a water body. Maximum sustainable yield (MSY) should be between 37 and 50% of unexploited biomass (Bo) [26,27] and F=M as an optimal exploitation limit [28] (figure 5B). The fishing strategy showed that B=0.5Bo could be reached or occurs when F=0.66M and it fulfilled all three proposed rules [16] for fish resources management. The starting fishing at bilih length of 5.5 cm and actual fishing mortality F=3.86 M would keep the stock below of 7.0% of the unexploited biomass per recruitment, furthermore at F=0.5M and Lc_opt would keep the stock 60% of unexploited biomass per recruitment.
The length of capture at Lc_opt with F=0.5M to F=M reduced fishing impact for bilih population. The estimated mean body weight of the spawning fish in the unexploited stock is 22.0 g (Equation 4). For the exploitation scenario of 2009 (F=3.86M and Lc=5.5 cm), the predicted mean body weight of the spawning fish is 2.5 g or 11.0% of natural weight (Equation 5). However, if the bilih stock is exploited at F=0.5M and starting length for capture is Lc_opt the predicted mean body weight of the spawning fish would be 12 g or 60% of the natural weight. The estimated of the optimum length at first capture (Lc_opt) of bilih was 9.5 cm. The length at first capture of bilih at the survey in 2019, which is 5.4 for male and 5.8 for female, which were much smaller than the estimated Lc_opt. Therefore, to sustain the fisheries of bilih in Lake Singkarak, the fishing gears i.e. gillnet ¾/8 inch and alahan is not recommended to use. Based on the size profile (range, mode, and average) of bilih at each fishing gear, the catch of gillnet with mesh size bigger than of ¾ inch would be close to the Lc_opt value.

The economic simulation/estimation at sustainable of F (F= M and F=0.5 M) and Lc_opt showed that the total catch would be higher than of the actual F value in 2009 which up to 9 and 20 times. The bigger size of brood stock would give eggs and larvae with better quality and quantity than smaller brood stock [29]. Fecundity of a fish is affected by the environmental conditions, natural food availability, and the size of brood stock [30]. Protecting the mature fish would lead to successful of fish spawning for recruitment [31].

4. Conclusion
Determination of the optimum length at first capture (Lc_opt) is needed as a part of the population management effort of bilih fish (Mystacoleucus padangensis) in Lake Singkarak. The smaller size of exploited bilih fish indicated the stock decreasing tendency. The optimum length at the first capture (Lc_opt) was 9.5 cm. Regulation of fishing gears is one of the ways to achieve the value of the optimum length at first capture of bilih fish. The exploitation at Lc_opt would have fulfilled the three simple rules for sustainable management and minimizing the impact of bilih fish exploitation at Lake Singkarak.

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