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Stock assessment using spawning potential ratio in data poor fisheries for mahseer *Tor tambroides* (Bleeker, 1854) in Aceh Province, Indonesia

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Abstract. *Haser TF, Nurdin MS, Supriyono E, Prihadi TH, Febri SP, Persada AY, Wibowo TH, Sari HPE, Putri KA, Antoni. 2023. Stock assessment using spawning potential ratio in data poor fisheries for mahseer* Tor tambroides *(Bleeker, 1854) in Aceh Province. Biodiversitas 24: 6039-6047.* Overexploitation of mahseer has led to a decline in population, posing a threat to its sustainability in the wild. Therefore, this study aimed to compare the length-based spawning potential ratio of the fish from Atu Suasah and Lawe Melang Rivers in Aceh Province. The experiment was conducted from January to August 2023, and the population dynamics parameters were calculated through Response Surface Analysis using Electronic Length Frequencies Analysis in the Fish Stock Assessment Tools program. Meanwhile, the spawning potential ratio (SPR) was analyzed based on data uploaded to the Barefoot Ecologist's Toolbox. The results showed that the asymptotic length ($L\infty$) at Atu Suasah and Lawe Melang Rivers was 750 mm and 759 mm, respectively, with K coefficients of 1.40 year^{-1} and 1.55 year^{-1}. The length at first maturity (Lm_{50}) of mahseer in these rivers was 372.52 mm and 438.88 mm. Total mortality (Z) is 3.88 year^{-1} and 3.24 year^{-1}, while natural mortality (M) values are 1.06 year^{-1} and 0.91 year^{-1}, with corresponding fishing mortality (F) rates of 2.82 year^{-1} and 2.33 year^{-1}. The Beverton and Holt analyzes of per recruitment results showed that mahseer in Lawe Melang and Atu Suasah River have exceeded E_{max}, where the current E values were 0.73 year^{-1} and 0.72 year^{-1} respectively. These implied that mahseer stock was overfished with SPR 9% and 16% respectively, falling below the standard biological reference point. To ensure sustainability, conservation efforts should be put in place, including establishing a capture size limit and reducing fishing gear by 42%.

Keywords: Fisheries management, mahseer, overfishing, spawning potential ratio

INTRODUCTION

Mahseer is a highly economic aquatic resource widely distributed in South Asia and Southeast Asia (Arjamand et al. 2013; Esa and Abdul Rahim 2013; Iqbal et al. 2013; Nath et al. 2016; Laskar et al. 2018), including in Indonesia (Cahyanti et al. 2019; Muchlisin et al. 2022). In Indonesia, the distribution of this fish species is limited to the Sunda Shelf, which includes Sumatra, Java, and Borneo (Hutama et al. 2016; Roesma et al. 2019; Hendrik et al. 2021). Locally, it is referred to as *tambra* and *dewa* in Java, *sapan* in Borneo, and *semah* and *keureling* in Sumatra (Akmal et al. 2018; Andriyanto 2019; Zulfahmi et al. 2019; Abinawanto et al. 2023). Mahseer is renowned for its delicious taste and is commonly sold fresh, live, and occasionally as smoked fish (Chasanah et al. 2021; Lim et al. 2021), which has spurred an increase in fishing efforts (Pinder et al. 2015).

Aceh Province provides a conducive freshwater system for mahseer production in the wild, but the stock in the area has experienced a significant decline over the past decade (Muchlisin et al. 2015a; 2016a; 2016b). Mahseer fisheries in Aceh are primarily small scales, dominated by gillnet and handlines as the main gear (Nugroho et al. 2021). Currently, the market supply relies on captured fish due to the impracticality of cultivation (Haser et al. 2022). The limited advancement in breeding technology has hindered the development of mahseer aquaculture (Muchlisin et al. 2014, 2015b; Prihadi et al. 2022). Furthermore, aquaculture activities are highly sensitive to changes in water quality, leading to increased costs (Mohd Nosi et al. 2018; Hasan and Tamam 2019; Tiwari and Tiwari 2022).

Several studies showed that the exploitation rate of mahseer exceeded its optimum threshold, as observed in *Tor tor* Hamilton 1822 (E = 0.71-0.84 year^{-1}) in Vindhyan Region of India (Dwivedi and Nautiyal 2012), *Tor putitora* Hamilton 1822 (E = 0.67 year^{-1}) in Western Himalayan (Rana and Nautiyal 2023), and *Tor khudree* Sykes 1839 (E = 0.34-0.84 year^{-1}) in Peninsular India (Raghavan et al. 2011). In the case of *T. putitora*, the exploitation rate has drastically increased over 15 years, from E = 0.37 $year^{-1}$ to E = 0.70 $year^{-1}$ (Nautiyal et al. 2008), showing a rapid decline in populations (Sah et al. 2021).

Overexploitation of mahseer fisheries has not only resulted in environmental degradation but also led to population decline, reduced distribution, diminished abundance, and a loss of genetic diversity. This has consequently led to the unsustainability of this species in the wild (Ali et al. 2014; Arifin et al. 2015; Bhatt and Pandit 2016; Wibowo and Dwirastina 2016; Safitri et al. 2021; Imron et al. 2022). Other anthropogenic forces such as pollution, dam construction and illegal fishing have put stress on the wild mahseer population (Sharma et al. 2019; Pinder et al. 2019; Nautiyal and Dwivedi 2020; Everard et al. 2021). Addressing this situation poses a challenge in implementing effective fisheries management (Hestirianoto et al. 2021). In the absence of immediate management measures, this species may face a high risk of extinction (Pinder et al. 2018).

Important information for mahseer fisheries management includes an assessment of stock availability. This information provided a genuine depiction of the current status of the wild fish resource (Sarkar et al. 2015). The spawning potential ratio (SPR) method proves valuable in assessing mahseer stock (Hordyk et al. 2015; Miethe et al. 2019; Ault et al. 2022). It is particularly well-suited for stock evaluation in cases of limited data, a common scenario in small-scale fisheries (Hordyk et al. 2016; Ault et al. 2019; Serdiati et al. 2023) such as mahseer in Aceh Province. Therefore, this study aimed to compare and analyze mahseer stock in Lawe Melang River, South Aceh District, and Atu Suasah River, Aceh Tamiang District. The stock assessment included an estimation of the length-based spawning potential ratio.

MATERIALS AND METHODS

Study area

This study was conducted from January to August 2023 in Lawe Melang River (3º12’54.01’’ N and 97º22’50.33” E), South Aceh, and Atu Suasah River (4º13’42.96” N and 97º58’39.41” E), Aceh Tamiang, Aceh (Figure 1). Both locations were known as mahseer habitats, located upstream and downstream of Amount Leuser (Figure 2) (Haser et al. 2022). The characteristics of the ecosystems in these sites reflect unique and intriguing conditions. The waters are clear, allowing sunlight to penetrate the bottom of the river. Furthermore, the strong currents flowing through created a dynamic and oxygen-rich environment, supporting the life of mahseer. The substrates in both waters were diverse, consisting of rocks, gravel, and sand. This combination of ecosystem characteristics was highly suitable for mahseer, facilitating activities such as feeding, sheltering, and spawning (Haser et al. 2022; Raghavan et al. 2017).

Data collection

Mahseer samples were obtained from local fishermen using gillnet. The installation of gillnets was conducted from 09:00 to 15:00, and each was lifted every 2 hours. This fishing gear had a length and height of 10 and 1 meter, with a mesh size of 1-1.5 inches. Mahseer length was measured in total length, from the mouth to the edge of the caudal fin, using a standard 1 mm scale. The specimens were collected through observations over a period of 8 months, with sampling intervals of 2 times a month. The sampling was conducted by a census method due to the relatively low catch volume each month.

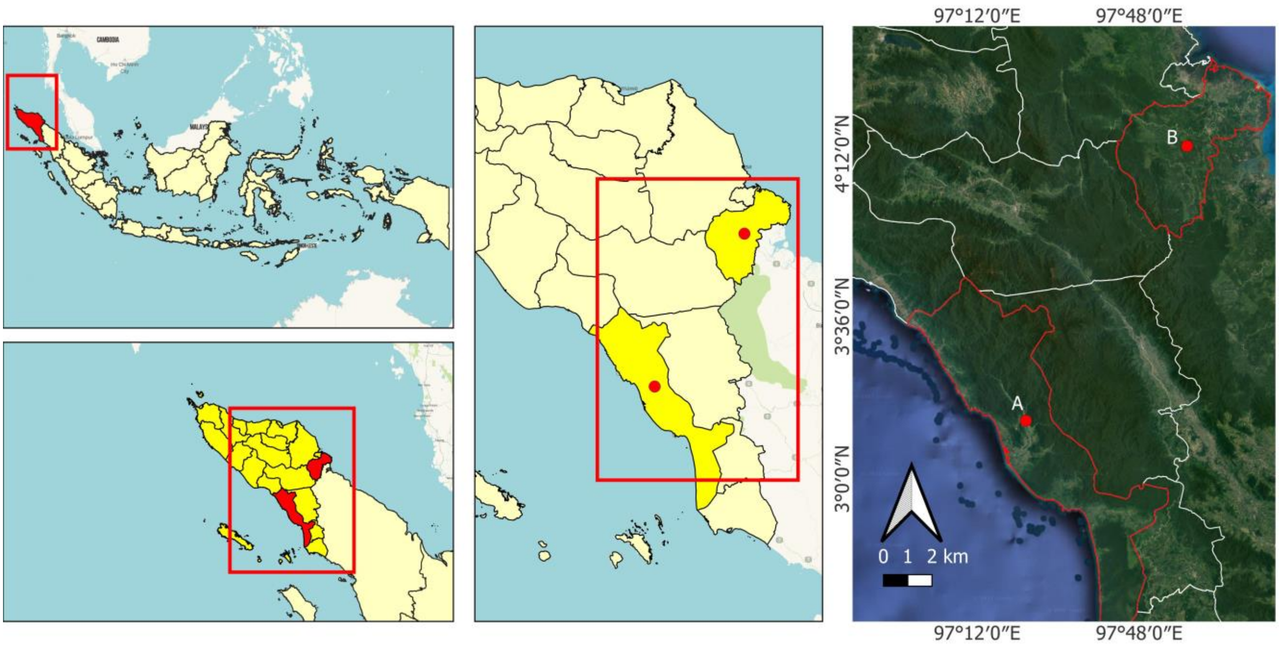

Figure 1. Fishing ground of mahseer in Aceh. A. Lawe Melang River, South Aceh; and B. Atu Suasah River, Aceh Tamiang, Aceh, Indonesia

Figure 2. Habitat of mahseer in Atu Suasah (above) and Lawe Melang River (middle); and morphology of mahseer (below)

Gonad maturity was observed visually following the modified Desai (1973) guideline. The immature characteristic included slim ovarium, thin short ribbon-like, transparent, and unobservable by the naked eye. Maturing ovarium was characterized by the larger yolk; the eggs turned yellow, blurred, and easily observable. In the mature phase, the ovarium was in the form of a plastic bag packed with big yellow eggs, while during the spent phase, the ovarium was softened.

Data analysis

The input parameters used for SPR estimation were fish length frequency, length at first maturity (Lm_{50}), length at first captured (SL), Von Bertalanffy growth and asymtotic length ($L\infty$), as well as natural mortality (M). Mahseer length difference was calculated using the following T-student test (Zar 2010) formula:

$$t = \frac{x - \mu_0}{S/\sqrt{n}}$$

Where: x, μ_0, S, and n represent the sample average, tested average, the standard deviation of a sample, and sample size, respectively.

First length at maturity (Lm_{50}) was analyzed using a logistic function based on the following equation (King 2007):

$$Lm_{50} = \frac{1}{(1 + \exp^{[-r(L-Lc)]})}$$

Where: Lm_{50} is the proportion of matured mahseer, Lc is the length average when 50% of mahseer were at the reproductive stage, L is fish length, and r is the slope.

Mahseer growth was analyzed using the following Von Bartalanffy exponential growth (Sparre and Venema 1998):

$$Lt = L\infty\left\{1 - \exp^{-K(t-t0)}\right\}$$

Where: Lt is mahseer length at the age of t, L∞ is asymptotic length, K is growth coefficient, and t0 is theoretical length at age 0, estimated using Pauly (1980):

$$\text{Log}\,(-t_0) = -0.3922 - 0.2752\log L\infty - 1.038\log K$$

Where: L∞ is asymptotic length, K is intrinsic growth coefficient, and T is average annual temperature (°C).

Total mortality (Z) of mahseer was estimated from the length converted catch curve in FISAT II (Sparre and Venema 1998) as:

$$Z = K\,\frac{(L_\infty - L)}{L - L'}$$

Where: Z is total mortality (per year), K is the growth coefficient, L∞ is the asymptotic length (mm), L is the mean length at capture (mm), and L' is the smallest length at capture (mm).

Rate of natural mortality was computed using Pauly (1980) empirical formula:

$$\text{Log}\,M = -0.0066 - 0.279\log L\infty + 0.6543\log K + 0.4634\log T$$

Fishing mortality (F) was estimated using the equation by (Sparre and Venema 1998):

$$F = Z - M$$

Where: F is fishing mortality, Z is total mortality, and M is natural mortality.

Exploitation rate (E) was estimated using the following equation (Pauly 1980):

$$E = \frac{F}{Z}$$

Where: E is exploitation rate, F is fishing mortality, and Z is total mortality.

The relative yield per recruit (Y/R) was estimated using the following analytic equation from Beverton and Holt (1964):

$$\frac{Y'}{R} = E(1-c)^{\frac{M}{k}}\,x\left[1 - \frac{3(1-c)}{1+\frac{1-E}{\frac{M}{k}}} + \frac{3(1-c)^2}{1+\frac{2(1-E)}{\frac{M}{k}}} + \frac{(1-c)^2}{1+\frac{3(1-E)}{\frac{M}{k}}}\right]$$

Where: c = 0.05 for Lawe Melang and Atu Suasah. SPR was analyzed using input parameters such as M/k and Lm/L∞ (Hordyk et al. 2015; Prince et al. 2020) based on uploaded data in Barefoot Ecologist's Toolbox (LBSPR Version: 0.1.9).

RESULTS AND DISCUSSION

Size structure and length at first maturity

Length frequency distribution of fish captured in Lawe Melang and Atu Suasah ranges from 110-711 mm and 111-680 mm with total lengths average of 379.19±141.16 mm and 393.30±147.43 mm (Figure 3). In Lawe Melang, 29% of the total catch belonged to the size class of 301-400 mm, while in Atu Suasah, the majority, 34%, fell in the size class of 401-500 mm. Mahseer captured in Atu Suasah did not exceed 70 mm in length. However, a t-test shows that there is no significant difference in the total length of fish captured in both rivers (p>0.05). Asymptotic length (L∞) of samples captured at both Atu Suasah and Lawe Melang were 750 mm and 759 mm respectively. The Von Bertalanffy equations for these two species, include $Lt = 750\left\{1 - e^{-1.40(t+0.0462)}\right\}$ and $Lt = 759\left\{1 - e^{-1.55(t+0.0415)}\right\}$ respectively (Figure 4), and the K coefficients were 1.40 year^{-1} and 1.55 year^{-1}.

The length at first maturity (Lm_{50}) for mahseer in Lawe Melang and Atu Suasah were 372.52 mm and 438.88 mm (Figure 5). The results showed a dominance of young mahseer that had not reached gonadal maturation, with percentages of 68.20% and 47.30% in the respective locations. This suggests the occurrence of growth overfishing, which has the potential to disrupt the stability of mahseer stock in the wild by inhibiting their spawning ability.

Figure 3. The size structure of mahseer caught in Aceh, Indonesia

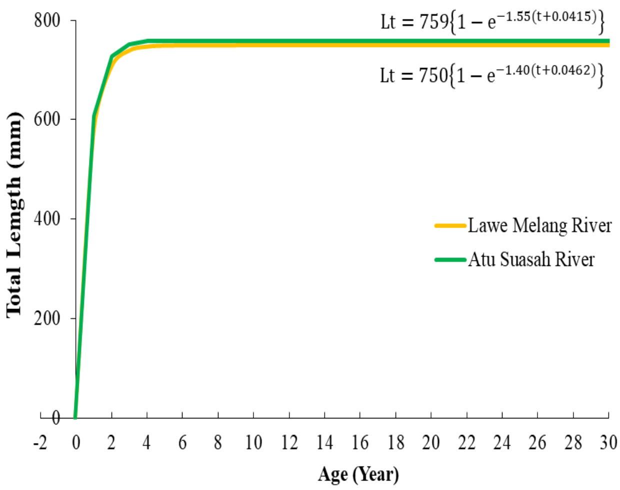

Figure 4. Length-frequency based growth curves for mahseer generated in FISAT II

Mortality and exploitation rate

The total mortality of fish captured at Lawe Melang and Atu Suasah were 3.88 $year^{-1}$ and 3.24 $year^{-1}$, respectively. Natural mortality values were calculated as 1.06 $year^{-1}$ and 0.91 $year^{-1}$, while fishing mortality was estimated at 2.82 $year^{-1}$ and 2.33 $year^{-1}$. This indicated that the mortality resulting from fishing activities for both mahseer caught in Lawe Melang and Atu Suasah, surpasses natural mortality. According to the Beverton and Holt yield per recruit analysis, mahseer in both waters have been overexploited, with current E values of 0.73 $year^{-1}$ (Figure 6) and 0.72 $year^{-1}$ (Figure 7), respectively, exceeding the respective E_{max} values of 0.47 and 0.46.

Spawning potential ratio (SPR)

SPR analysis yielded values of 9% and 16% for Lawe Melang and Atu Suasah (Figure 8). These values were associated with F/M ratios of 2.80 and 1.59. The obtained SPR values fell below the biological limit reference point (BRP) of 20%, showing that mahseer in both waters has been overexploited. The estimation below 20% was attributed to the high proportion of the immature catch. Meanwhile, the current estimation showed that only about 9% of the mahseer population in Lawe Melang and 16% in Atu Suasah have the opportunity to spawn or experience recruitment. Overexploitation of mature and spawning mahseer led to a decline in recruitment, resulting in a depletion of the stock over time.

Discussion

Mahseer (*Tor tambroides* Bleeker 1854) is widely distributed in Southeast Asia, including Indonesia (Java, Borneo, Sumatra), Malaysia (Peninsular Malaysia, Sabah, Sarawak), Thailand, Brunei Darussalam, Vietnam, and extending to China (Esa and Abdul Rahim 2013; Kottelat et al. 2018; Sharma et al. 2019; Hasan et al. 2022). The average size in this study was bigger (Muchlisin et al. 2015a) compared to those captured in Nagan and Sikundo Rivers in Aceh, as well as Manna and Tarusan in West Sumatra (Wibowo and Dwirastina 2016). However, it was smaller than those captured in Bundelkhand Region, Central India, where the length reached 820 mm (Nautiyal and Dwivedi 2020).

The caught samples in Atu Suasah and Lawe Melang have experienced a decrease in size. This was in line with previous studies, which reported a reduction in the size of mahseer population. According to Muchlisin et al. (2015a), the search for a big-size *Tor tambra* Valenciennes 1842 is very difficult in Nagan and Sikundo River, Aceh. Additionally, mahseer wild population is significantly declining and has been classified as threatened (Kottelat et al. 2018; Sah et al. 2021). Kottelat et al. (2018) stated that the decline in the population of mahseer was attributed to illegal fishing and habitat fragmentation (Lau et al. 2021; Everard et al. 2021).

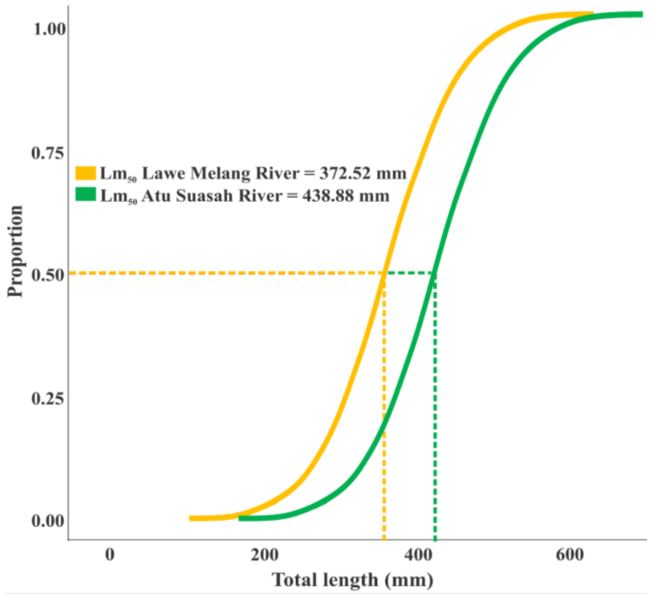

Figure 5. Lm_{50} of mahseer caught in Aceh, Indonesia

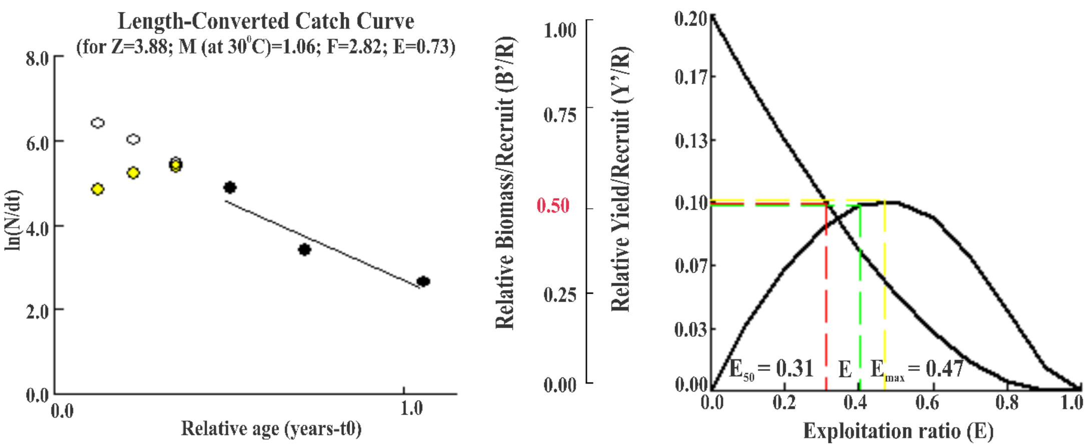

Figure 6. Length-converted catch curve (*left*) and yield per recruit versus exploitation rate (*right*) for mahseer in Lawe Melang River, Aceh, Indonesia

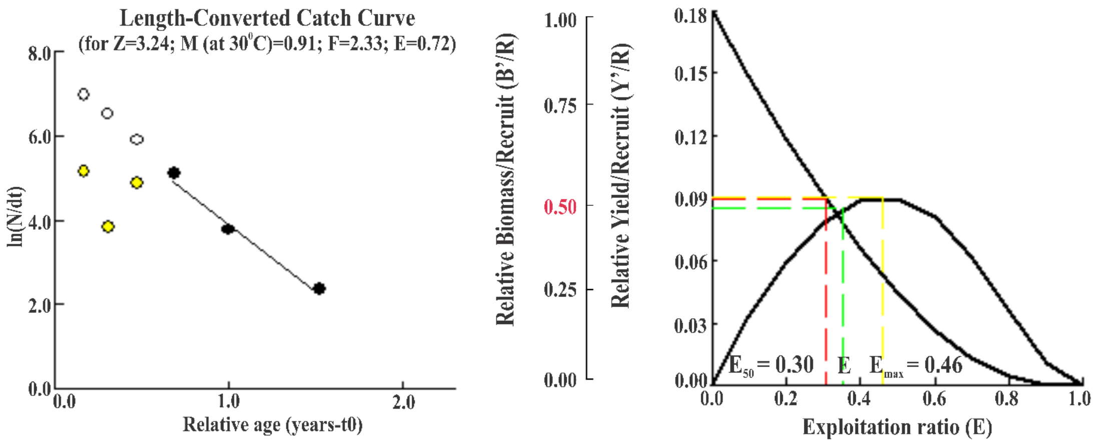

Figure 7. Length-converted catch curve (*left*) and yield per recruit versus exploitation rate (*right*) for mahseer in Atu Suasah River, Aceh, Indonesia

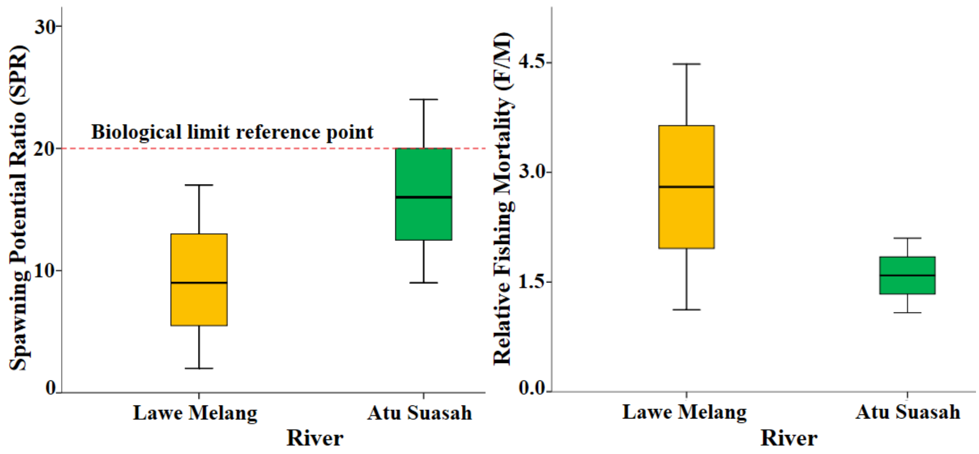

Figure 8. Spawning potential ratio (*left*) and relative fishing mortality of mahseer (*right*)

Implementing policies that regulate gear size to allow fish to reach reproductive maturity is a crucial aspect of responsible fisheries management (Ilkyazi et al. 2018; Achmad et al. 2020). The parameter Lm_{50} can serve as a threshold for determining the appropriate mesh size of gillnets, thereby enabling fish to spawn (Sabrah et al. 2017; Udoh and Ukpatu 2017). The results from this study showed that the length at first maturity was bigger than the selectiveness of fishing gears. Therefore, the mesh size of the gillnet used in both rivers (1 to 1.5 inches) was inadequate to ensure the sustainability of mahseer fisheries. Irpan et al. (2018) reported a maximum length of mahseer captured with an inch mesh size of 227.50 mm. Continuous fishing practice in this current state may lead to growth overfishing (Joshi et al. 2018), resulting in reduced populations and diminished productivity (Raghavan et al. 2011; Lappalainen et al. 2016).

The K coefficient of mahseer in Atu Suasah and Lawe Melang was lower compared to 1.90 year^{-1} and 1.70 year^{-1} of Manna and Tarusan River, West Sumatra, respectively (Wibowo and Dwirastina 2016). Raghavan et al. (2011) reported a K coefficient of 0.19 year^{-1} for mahseer from *T. khudree* Sykes 1839 in India, while Nautiyal et al. (2008) discovered a K coefficient of 0.04 year^{-1} for *T. putitora* in Gangga River, India. The K coefficients showed significant differences between Indian and Indonesian mahseer. Most of the values for Indian mahseer were below one (<1), while in Indonesia, they exceeded 1. According to Sparre and Venema (1998), fish with K coefficients smaller than one grow faster and reach the maximum size more quickly.

Natural mortality of the stuck is directly associated with the K coefficient (Beverton and Holt 1957), signifying that it is a dynamic parameter subject to change due to predation. Consequently, the size structure will also be subjected to alterations (Powers 2014). The rate of natural mortality is classified as normal when its ratio to the K coefficient falls in the range of 1.5-2.5 (Beverton and Holt 1957; Rahangdale et al. 2016). The ratio of M/k for the two populations of Lawe Melang and Atu Suasah River is 0.62 and 0.68, respectively. Therefore, the natural mortality rate for both populations was significantly low. This low result is suspected to stem from the limited number of individuals that survive fishing activity until they reach maturity (Permatachani et al. 2017). The high fishing mortality is evident in the exploitation rate, which has surpassed E_{max}, showing overfishing of mahseer in Lawe Melang and Atu Suasah. The exploitation rate surpassing E_{max} leads to a decline in the recruitment of mahseer populations in Lawe Melang and Atu Suasah.

Overexploitation of mahseer in Lawe Melang and Atu Suasah was a pressing concern, with a predominant capture of undersized fish indicative of growth overfishing. This alarming trend has been corroborated by studies from Hendrik et al. (2021) and Abinawanto et al. (2023), highlighting a critical stage in mahseer population in Indonesia, potentially leading to extinction. The adverse effects of overexploitation were manifested in size reductions and a dearth of genetic diversity (Arifin et al. 2015; Muchlisin et al. 2015a). These impacts were attributed to the sustained overharvesting driven by high market value, along with habitat degradation, pollution, and alterations in water usage patterns that disrupt the reproduction and life cycle of the species (Arjamand et al. 2013; Sarkar et al. 2015; Bower et al. 2017; Pinder et al. 2019).

SPR is identified through modeling to predict the number of mature mahseer capable of maintaining reproductive capacity or spawning stock biomass (SSB) (Bunnell and Miller 2005). The data for mahseer in Lawe Melang and Atu Suasah indicated that only about 9% and 16% of the remaining breeding stock in nature were capable of reproduction. These assessments were based on Lm_{50} measurements of 372.52 mm and 438.88 mm, respectively. This disruption in the mahseer recruitment process had a pronounced impact on both water bodies. To ensure the reproductive sustainability of the stock, it was imperative to set the SPR at a minimum of 20% (Prince 2014). Consequently, concerted efforts were required to be implemented for the conservation of mahseer (Bhatt and Pandit 2016; Pinder et al. 2018). Additionally, the imposition of gear restrictions, specifically aimed at preventing the capture of fish below 439 mm in Atu Suasah and 373 mm in Lawe Melang River through the establishment of minimum legal sizes, held significant potential for reducing the likelihood of capturing young fish.

To ensure the sustainability of mahseer fisheries, careful monitoring and regulation of the number of fishing efforts operating in both waters, including fleets and fishing gear, was necessary (Achmad et al. 2022; Azmi et al. 2022). According to the Beverton and Holt yield per recruit analysis at 50%, a reduction of 42% in fishing effort is required in Lawe Melang and Atu Suasah Rivers from the current exploitation rate to reach E_{50} 0.31 and E_{50} 0.30. Another management action is the application of the “no-take zone” in areas identified as spawning grounds. It appears that you are providing information from a study about mahseer fish and their spawning behavior. Dash et al. (2021) categorized mahseer as part of the lithophils group due to their tendency to spawn in river banks characterized by sand substrates, shallow depths, and high water clarity. Consequently, the ideal spawning grounds for mahseer are shallow river banks (Subagja et al. 2017; Saxena et al. 2022).

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REFERENCES

Abinawanto A, Lestari S, Bowolaksono A, Dwiranti A, Lestari R, Gustiano R, Kristanto AH. 2023. The effect of different honey concentrations on the ultrastructure profile of spermatozoa in Dewa Mahseer (*Neolissochilus soro*). Biodiversitas 24: 1025-1031. DOI: 10.13057/biodiv/d240243.

Achmad DS, Gani S, Ardiansyah W, Mokoginta MM, Nurdin MS, Jompa J, Indrianti MA, Achmad N. 2022. Population dynamics of reef fish in the Kwandang Bay, Sulawesi Sea, Indonesia. Biodiversitas 23: 5217-5226. DOI: 10.13057/biodiv/d231030.

Achmad DS, Sudirman, Jompa J, Nurdin MS. 2020. Estimating the catchable size of orange-spotted grouper (*Epinephelus coioides*) in Kwandang Bay, Gorontalo Utara District, Indonesia. IOP Conf Ser: Earth Environ Sci 473: 012133. DOI: 10.1088/1755-1315/473/1/012133.

Akmal Y, Zulfahmi I, Rahardjo MF. 2018. Morphology of appendicular skeleton of the Thai mahseer’s *Tor tambroides* (Bleeker, 1854). Jurnal Iktiologi Indonesia 18: 261-274. DOI: 10.32491/jii.v18i3.443. [Indonesian]

Ali S, Barat A, Kumar P, Sati J, Kumar R, Haldar RS. 2014. Study of the length-weight relationship and condition factor for the golden mahseer, *Tor putitora* from Himalayan Rivers of India. J Environ Biol 35: 225-228.

Andriyanto. 2019. Studi populasi dan habitat ikan semah (*Tor* sp.) di Sungai Napal Licin Kabupaten Merangin. Biocolony: Jurnal Pendidikan Biologi dan Biosains 2: 1-7. [Indonesian]

Arifin OZ, Subagja J, Hadie W. 2015. Biometric characterization three population of semah mahseer *Tor douronensis* (Valenciennes, 1842) in support to conservation of genetic resources. Jurnal Iktiologi Indonesia 15: 143-154. DOI: 10.32491/jii.v15i2.68. [Indonesian]

Arjamand S, Dar SA, Desai AY, Sayani AN, Yusufzai SI, Ashfaq M, Bhola DV, Fofandi MD. 2013. Reproductive biology of an endangered coldwater fish golden mahseer, *Tor putitora* (Ham.) from anji mahseer hatchery reasi (J&K). IOSR J Pharm 3: 13-16. DOI: 10.9790/3013-0310013-16.

Ault JS, Smith SG, Bohnsack JA, Luo J, Stevens MH, DiNardo GT, Johnson MW, Bryan DR. 2019. Length-based risk analysis for assessing sustainability of data-limited tropical reef fisheries. ICES J Mar Sci 76: 165-180. DOI: 10.1093/icesjms/fsy123.

Ault JS, Smith SG, Johnson MW, Grove LJ, Bohnsack JA, DiNardo GT, McLaughlin C, Ehrhardt NM, McDonough V, Seki MP, Miller SL. 2022. Length-based risk analysis of management options for the southern Florida USA multispecies coral reef fish fishery. Fish Res 249: 106210. DOI: 10.1016/j.fishres.2021.106210.

Azmi F, Mawardi AL, Sinaga S, Nurdin MS, Febri SP, Haser TF. 2022. Population dynamics of *Anadara antiquata* of East Coast of Aceh, Indonesia. Biodiversitas 23: 436-442. DOI: 10.13057/biodiv/d230145.

Beverton RJH, Holt SJ. 1957. On the Dynamics of Exploited Fish Populations. Chapmann and Hall, London. DOI: 10.2307/1440619.

Beverton RJH, Holt SJ. 1964. Table of yield functions for fishery management. FAO, Rome.

Bhatt JP, Pandit MK. 2016. Endangered Golden mahseer *Tor putitora* Hamilton: a review of natural history. Rev Fish Biol Fish 26: 25-38. DOI: 10.1007/s11160-015-9409-7.

Bower SD, Danylchuk AJ, Raghavan R, Danylchuk SC, Pinder AC, Alter AM, Cooke SJ. 2017. Involving recreational fisheries stakeholders in development of research and conservation priorities for mahseer (*Tor*

spp.) of India through collaborative workshops. Fish Res 186: 665-671. DOI: 10.1016/j.fishres.2016.05.011.
Bunnell DB, Miller TJ. 2005. An individual-based modeling approach to spawning-potential per-recruit models: An application to blue crab (*Callinectes sapidus*) in Chesapeake Bay. Can J Fish Aquat Sci 62: 2560-2572. DOI: 10.1139/f05-153.
Cahyanti W, Soelistyowati DT, Carman O, Kristanto AH. 2019. Artificial spawning and larvae performance of three Indonesian mahseer species. AACL Bioflux 12: 280-288.
Chasanah E, Fithriani D, Poernomo A, Jeinie MH, Huda N. 2021. The nutritional profile of Indonesian salmon van Java mahseer *T. soro* species. Slovak J Food Sci 15: 566-574. DOI: 10.5219/1552.
Dash P, Tandel RS, Pandey N, Sawant PB, Sarma D, Rawat KD, Chadha NK. 2021. Effects of rearing temperature on egg incubation, growth, standard metabolic rate, and thermal tolerance of chocolate mahseer, *Neolissochilus hexagonolepis*. J Therm Biol 98: 102942. DOI: 10.1016/j.jtherbio.2021.102942.
Desai V. 1973. Studies on the fishery and biology of *Tor tor* (Ham.) from River Narmada. II. Maturity, fecundity and larval development. Indian National Sci Acad 39: 228-248.
Dwivedi AC, Nautiyal P. 2012. Stock assessment of fish species Labeo rohita, *Tor tor* and *Labeo calbasu* in the rivers of Vindhyan region, India. J Environ Biol 33: 261-264.
Esa Y, Abdul Rahim KA. 2013. Genetic structure and preliminary findings of cryptic diversity of the Malaysian Mahseer (*Tor tambroides* Valenciennes: Cyprinidae) inferred from mitochondrial DNA and microsatellite analyses. BioMed Res Intl 2013: 170980. DOI: 10.1155/2013/170980.
Everard M, Pinder AC, Claussen JE, Orr S. 2021. Assessing the societal benefits of mahseer (*Tor* spp.) fishes to strengthen the basis for their conservation. Aquat Conserv: Mar Freshw Ecosyst 31: 2979-2986. DOI: 10.1002/aqc.3683.
Hasan V, Mamat NB, South J, Ottoni FP, Widodo MS, Arisandi P, Isroni W, Jerikho R, Samitra D, Faqih AR, Simanjuntak CPH, Mukti AT. 2022. A checklist of native freshwater fish from Brantas River, East Java, Indonesia. Biodiversitas 23: 6031-6039. DOI: 10.13057/biodiv/d231158.
Hasan V, Tamam MB. 2019. First record of the invasive nile tilapia, *Oreochromis niloticus* (Linnaeus, 1758) (Perciformes, Cichlidae), on Bawean Island, Indonesia. Check List 15: 225-227. DOI: 10.15560/15.1.225.
Haser TF, Nurdin MS, Supriyono E, Radona D, Azmi F, Nirmala K, Widanarni, Prihadi TH, Budiardi T, Valentine RY. 2022. Reproductive biology of mahseer (*Tor tambroides*) from Atu Suasah and Lawe Melang Rivers in Aceh Province to support sustainable fisheries management. Pak J Zool 54: 561-567. DOI: 10.17582/journal.pjz/20200831050805.
Hendrik H, Fauzi M, Ramadona T, Hendrizal A, Effendi I. 2021. Local wisdom and conservation status of tor Thai mahseer fish (*Tor tambroides* Blkr) in the Batang Haluan River, West Sumatra, Indonesia. Intl J Conserv Sci 12: 1547-1556.
Hestirianoto T, Wildan DM, Simanjuntak CPH, Rahardjo MF, Syafruddin D, Nugroho T, Ismanto AJ. 2021. Application of radiotelemetry in tracking the movement of mahseer fish (*Tor* spp.) in Batang Toru River, North Sumatera Province Indonesia. IOP Conf Ser: Earth Environ Sci 744: 012028. DOI: doi:10.1088/1755-1315/744/1/012028.
Hordyk A, Ono K, Sainsbury K, Loneragan N, Prince J. 2015. Some explorations of the life history ratios to describe length composition, spawning-per-recruit, and the spawning potential ratio. ICES J Mar Sci 72: 204-216. DOI: 10.1093/icesjms/fst235.
Hordyk AR, Ono K, Prince JD, Walters CJ. 2016. A simple length-structured model based on life history ratios and incorporating size-dependent selectivity: application to spawning potential ratios for data-poor stocks. Can J Fish Aquat Sci 73: 1787-1799. DOI: 10.1139/cjfas-2015-0422/.
Hutama AA, Hadiaty RK, Hubert N. 2016. Biogeography of Indonesian freshwater fishes: Current progress. Treubia 43: 17-30.
Ilkyazi AT, Metin G, Soykan O, Kinacigil HT. 2018. Effects of different commercial feeds and enrichments on biochemical composition and fatty acid profile of rotifer (*Brachionus plicatilis*, Müller 1786) and *Artemia franciscana*. Turk J Fish Aquat Sci 18: 211-216. DOI: 10.4194/1303-2712-v18_1_24.
Imron I, Asrori A, Umam K, Arifin OZ, Astuti DN. 2022. Cross-species amplification and variability of microsatellite DNA markers in domesticated Indonesian mahseer; A case study with *Tor soro*, *Tor douronensis* and their interspecific hybrids. HAYATI J Biosci 29: 409-416. DOI: 10.4308/hjb.29.3.409-416.
Iqbal Z, Pervaiz K, Javed MN. 2013. Population dynamics of *Tor macrolepis* (Teleostei: Cyprinidae) and other fishes of Attock region, Pakistan. Can J Pure Appl Sci 7: 2195-2201.
Irpan A, Djunaidi D, Hertati R. 2018. Pengaruh ukuran mata jaring (*mesh size*) alat tangkap jaring insang (*gill net*) terhadap hasil tangkapan di Sungai Lirik Kecamatan Jangkat Timur Kabupaten Merangin Provinsi Jambi. Semah Jurnal Pengelolaan Sumberdaya Perairan 2: 1-11. DOI: 10.36355/semahjpsp.v2i2.181. [Indonesian]
Joshi KD, Das SCS, Pathak RK, Khan A, Sarkar UK, Roy K. 2018. Pattern of reproductive biology of the endangered golden mahseer *Tor putitora* (Hamilton 1822) with special reference to regional climate change implications on breeding phenology from Lesser Himalayan Region, India. J Appl Anim Res 46: 1289-1295. DOI: 10.1080/09712119.2018.1497493.
King M. 2007. Fisheries Biology, Assessment and Management. Blackwell Publishing Ltd, Oxford. DOI: 10.1002/9781118688038.
Kottelat M, Pinder A, Harrison A. 2018. *Tor tambroides*. The IUCN Red List of Threatened Species 2018: e.T187939A91076554. DOI: 10.2305/IUCN.UK.2018-2.RLTS.T187939A91076554.en.
Lappalainen A, Saks L, Šuštar M, Heikinheimo O, Jürgens K, Kokkonen E, Kurkilahti M, Verliin A, Vetemaa M. 2016. Length at maturity as a potential indicator of fishing pressure effects on coastal pikeperch (*Sander lucioperca*) stocks in the northern Baltic Sea. Fish Res 174: 47-57. DOI: 10.1016/j.fishres.2015.08.013.
Laskar BA, Kumar V, Kundu S, Tyagi K, Chandra K. 2018. Taxonomic quest: validating two mahseer fishes (Actinopterygii: Cyprinidae) through molecular and morphological data from biodiversity hotspots in India. Hydrobiologia 815: 113-124. DOI: 10.1007/s10750-018-3555-6.
Lau MML, Lim LWK, Ishak SD, Abol-Munafi AB, Chung HH. 2021. A review on the emerging asian aquaculture fish, the Malaysian mahseer (*Tor tambroides*): Current status and the way forward. Proc Zool Soc 74: 227-237. DOI: 10.1007/s12595-021-00368-4.
Lim LWK, Chung HH, Lau MML, Aziz F, Gan HM. 2021. Improving the phylogenetic resolution of Malaysian and Javan mahseer (Cyprinidae), *Tor tambroides* and *Tor tambra*: Whole mitogenomes sequencing, phylogeny and potential mitogenome markers. Gene 791: 145708. DOI: 10.1016/j.gene.2021.145708.
Miethe T, Reecht Y, Dobby H. 2019. Reference points for the length-based indicator $L_{max5\%}$ for use in the assessment of data-limited stocks. ICES J Mar Sci 76: 2125-2139. DOI: 10.1093/icesjms/fsz158.
Mohd Nosi MZ, Syed Jamil Fadaak SNE, Muhammad MDD, Iehata S. 2018. Assessment of gut microbiota in different developmental stages of Malaysian mahseer (*Tor tambroides*). Aquac Res 2018: 1-11. DOI: 10.1111/are.13757.
Muchlisin ZA, Afrido F, Murda T, Fadli N, Muhammadar AA, Jalil Z, Yulvizar C. 2016a. The effectiveness of experimental diet with varying levels of papain on the growth performance, survival rate and feed utilization of keureling fish (*Tor tambra*). Biosaintifika: J Biol Biol Edu 8: 172-177. DOI:10.15294/biosaintifika.v8i2.5777.
Muchlisin ZA, Arisa AA, Muhammadar AA, Fadli N, Arisa II, Siti-Azizah MN. 2016b. Growth performance and feed utilization of keureling (*Tor tambra*) fingerlings fed a formulated diet with different doses of vitamin E (alpha-tocopherol). Arch Pol Fish 24: 47-52. DOI: 10.1515/aopf-2016-0005.
Muchlisin ZA, Batubara AS, Siti-Azizah MN, Adlim M, Hendri A, Fadli N, Muhammadar AA, Sugianto S. 2015a. Feeding habit and length weight relationship of keureling fish, *Tor tambra* Valenciennes, 1842 (Cyprinidae) from the western region of Aceh Province, Indonesia. Biodiversitas 16: 89-94. DOI: 10.13057/biodiv/d160112.
Muchlisin ZA, Fuadi Z, Munazir AM, Fadli N, Winaruddin W, Nanda DC, Hendri A. 2015b. First report on Asian fish tapeworm (*Bothriocephalus acheilognathi*) infection of indigenous mahseer (*Tor tambra*) from Nagan Raya district, Aceh province, Indonesia. Bull J Vet Med 18: 361-366. DOI: 10.15547/bjvm.877.
Muchlisin ZA, Munazir AM, Fuady Z, Winaruddin W, Sugianto S, Adlim M, Fadli N, Hendri A. 2014. Prevalence of ectoparasites on mahseer fish (*Tor tambra* Valenciennes, 1842) from aquaculture ponds and wild population of Nagan Raya District, Indonesia. Hum Vet Med 6: 148-152.
Muchlisin ZA, Nur FM, Maulida S, Handayani LS, Rahayu SR. 2022. Mahseer, the history of the king of the river. E3S Web Conf 339: 03006. DOI: 10.1051/e3sconf/202233903006.

Nath R, Baruah D, Das P, Sarma D. 2016. Present status, threats and conservation measures of mahseer resources in the central rivers of Meghalaya. SKUAST J Res 18: 32-40.

Nautiyal P, Dwivedi AC. 2020. Growth rate determination of the endangered mahseer, *Tor tor* (Hamilton 1822) from the Bundelkhand region, Central India. J Fish Res 4: 7-11. DOI: 10.35841/fisheries-research.4.2.7-11.

Nautiyal P, Rizvi AF, Dhasmanaa P. 2008. Life- history traits and decadal trends in the growth parameters of golden mahseer *Tor putitora* (Hamilton 1822) from the Himalayan stretch of the Ganga River system. Turk J Fish Aquat Sci 132: 125-132.

Nugroho T, Simanjuntak CP, Sulistiono S, Rahardjo MF, Shafrudin D, Hestiranoto T, Ismanto AJ. 2021. Utility of Batang Toru River (North Sumatra, Indonesia) for fishery activities of the local communities: a study on fisheries socioeconomic condition. E3S Web Conf 322: 05013. DOI: 10.1051/e3sconf/202132205013.

Pauly D. 1980. On the interrelationships between natural mortality, growth parameters, and mean environmental temperature in 175 fish stocks. ICES J Mar Sci 39: 175-192. DOI:10.1093/icesjms/39.2.175.

Permatachani A, Boer M, Kamal MM. 2017. Kajian stok ikan peperek (*Leiognathus equulus*) berdasarkan alat tangkap jaring rampus di perairan Selat Sunda. Jurnal Teknologi Perikanan dan Kelautan 7: 107-116. DOI: 10.24319/jtpk.7.107-116. [Indonesian]

Pinder AC, Britton JR, Harrison AJ, Nautiyal P, Bower SD, Cooke SJ, Lockett S, Everard M, Katwate U, Ranjeet K, Walton S, Danylchuk AJ, Dahanukar N, Raghavan R. 2019. Mahseer (*Tor* spp.) fishes of the world: status, challenges and opportunities for conservation. Rev Fish Biol Fish 29: 417-452. DOI: 10.1007/s11160-019-09566-y.

Pinder AC, Manimekalan A, Knight JDM, Krishnankutty P, Britton JR, Philip S, Dahanukar N, Raghavan R. 2018. Resolving the taxonomic enigma of the iconic game fish, the hump-backed mahseer from the Western Ghats biodiversity hotspot, India. PloS ONE 13: e0199328. DOI: 10.1371/journal.pone.0199328.

Pinder AC, Raghavan R, Britton JR. 2015. The legendary hump-backed mahseer *Tor* sp. of India's River Cauvery: an endemic fish swimming towards extinction?. Endanger Species Res 28: 11-17. DOI: 10.3354/esr00673.

Powers JE. 2014. Age-specific natural mortality rates in stock assessments: size-based vs. density-dependent. ICES J Mar Sci 71: 1629-1637. DOI: 10.1093/icesjms/fst226.

Prihadi TH, Haser TF, Pantjara B, Widyastuti YR, Arifin OZ, Cahyanti W, Kusmini II, Radona D, Kurniawan K, Subagja J, Saputra A. 2022. Determining oxygen consumption of Indonesian mahseer (*Tor soro*) fingerlings at different size and stocking density. J Hunan Univ Nat Sci 49: 60-67. DOI: 10.55463/issn.1674-2974.49.3.7.

Prince J, Creech S, Madduppa H, Hordyk A. 2020. Length based assessment of spawning potential ratio in data-poor fisheries for blue swimming crab (*Portunus* spp.) in Sri Lanka and Indonesia: Implications for sustainable management. Reg Stud Mar Sci 36: 101309. DOI: 10.1016/j.rsma.2020.101309.

Prince J. 2014. A technical report on an SPR size assessment of the blue swimmer crab fishery in Southeast Sulawesi. IMACS Project Report, USAID.

Raghavan R, Ali A, Dahanukar N, Rosser A. 2011. Is the deccan mahseer, *Tor khudree* (Sykes, 1839) (Pisces: Cyprinidae) fishery in the western ghats hotspot sustainable? A participatory approach to stock assessment. Fish Res 110: 29-38. DOI: 10.1016/j.fishres.2011.03.008.

Raghavan R, Dahanukar N, Britz R. 2017. The type locality of *Tor mosal* (Hamilton, 1822) (Teleostei: Cyprinidae). Zootaxa 4317: 593-596. DOI:10.11646/zootaxa.4317.3.12.

Rahangdale S, Chakraborty SK, Jaiswar AK, Shenoy L, Raje SG. 2016. Preliminary study on growth and mortality of *Escualosa thoracata* (Valenciennes, 1847) from Mumbai waters. Indian J Geo-Mar Sci 45: 290-295.

Rana P, Nautiyal P. 2023. Assessment of population dynamics of endangered *T. putitora* (Ham, 1822) in the breeding and nursery grounds of Western Himalaya. bioRxiv 2023: 1-15. DOI: 10.1101/2023.07.06.547904.

Roesma DI, Chornelia A, Mursyid A. 2019. Phenotype analysis of endemic mahseer fish (*Neolissochilus sumatranus*) from Batang Toru tributaries, North Sumatra, Indonesia. J Phys: Conf Ser 1317: 012099. DOI: 10.1088/1742-6596/1317/1/012099.

Sabrah MM, Heneish RA, Alwany ME, Ahmad MI. 2017. Sexual maturity, spawning activity, sex ratio and fecundity of two Mullidae species dwelling the Gulf of Suez, Red Sea. Egypt J Aquat Res 43: 83-91. DOI: 10.1016/j.ejar.2016.04.007.

Safitri FR, Sulistyono, Hariyadi S, Asmadi. 2021. Biodiversity and community of phytoplankton in the mahseer conservation area at Bungo and Kerinci Regencies, Jambi Province, Indonesia. IOP Conf Ser: Earth Environ Sci 744: 012068. DOI: 10.1088/1755-1315/744/1/012068.

Sah P, Mandal S, Singh RK, Dutta N, Sah R, Pathak A, Srivastava JK, Singh A, Lal KK, Mohindra V. 2021. Development of novel microsatellite marker panel in threatened tetraploid mahseer, *Tor tor* (Hamilton 1822) for insights into its genetic diversity and population structure. Meta Gene 28: 100880. DOI: 10.1016/j.mgene.2021.100880 .

Sarkar UK, Mahapatra BK, Roy Saxena S, Singh AK. 2015. Mahseer in India: An overview on research status and future priorities. J Ecophysiol Occup Health 15: 45-52. DOI: 10.15512/joeoh/2015/v15i1&2/91183.

Saxena S, Das R, Shrivastava P, Patil N. 2022. Conservation of mahseer fish in Madhya Pradesh by following M.I.R.A.C.L.E strategy. Sci Prog 2: 517-522. DOI: 10.52152/spr/2022.154.

Serdiati N, Nurdin MS, Hasan V, Mokodongan DF, Safir M. 2023. Population dynamic of endemic ricefish in Lake Poso implications for conservation. Intl J Conserv Sci 14: 301-314. DOI: 10.36868/IJCS.2023.01.19.

Sharma L, Ali S, Siva C, Kumar R, Barat A, Sahoo PK, Pande V. 2019. Genetic diversity and population structure of the threatened chocolate mahseer (*Neolissochilus hexagonolepis* McClelland 1839) based on SSR markers: implications for conservation management in Northeast India. Mol Biol Rep 46: 5237-5249. DOI: 10.1007/s11033-019-04981-7l.

Sparre P, Venema SC. 1998. Introduction to tropical fish stock assessment - Part 1. Manual FAO, Rome.

Subagja S, Wibowo A, Marson, M. 2017. Pertumbuhan ikan semah (*Tor tambra*, Valenciennes, 1842) di perairan Sungai Musi, Sumatera Selatan. BAWAL Widya Riset Perikanan Tangkap 2: 133-138. DOI: 10.15578/bawal.2.4.2009.133-138l. [Indonesian]

Tiwari P, Tiwari MP. 2022. Evaluation of water quality and dam for sustaining the fish population dynamics. Appl Water Sci 12: 233. DOI: 10.1007/s13201-022-01728-x.

Udoh JP, Ukpatu JE. 2017. First estimates of growth, recruitment pattern and length-at-first-capture of *Nematopalaemon hastatus* (Aurivillius, 1898) in Okoro River estuary, southeast Nigeria. AACL Bioflux 10: 1074-1084.

Wibowo A, Dwirastina M. 2016. Growth comparison of mahseer (*Tor tambroides*) from Manna and Tarusan River in Western Sumatera River. Indones Fish Res J 22: 1-8. DOI: 10.15578/ifrj.22.1.2016.1-8.

Zar JH. 2010. Biostatistical Analysis. Prentice Hall, Upper Saddle River, New Jersey.

Zulfahmi I, Akmal Y, Batubara AS. 2019. Morfologi tulang belakang (ossa vertebrae) ikan keureling, *Tor tambroides* (Bleeker, 1854). J Iktiologi Indones 18: 139-149. DOI: 10.32491/jii.v18i2.329. [Indonesian]