Assessing stock status of tilapia (*Oreochromis niloticus*) and Midas cichlid (*Amphilophus citrinellus*) in Batur Lake, Indonesia

[1]Tirtadanu, [1]Umi Chodrijah, [1]Prihatiningsih, [2]Sri Turni Hartati, [3]Tri Retnaningsih Soeprobowati, [4]Agus Heri Purnomo, [5]Syarif Prasetyo, [6]Jumari, [4]Ari Wahyono

[1] Research Center for Fishery, National Research and Innovation Agency (BRIN), Cibinong, Indonesia; [2] Research Center for Conservation of Marine and Inland Water Resources, National Research and Innovation Agency (BRIN), Cibonong, Indonesia; [3] School of Postgraduate Studies, Diponegoro University, Semarang, Indonesia [4] Research Center for Society and Culture, National Research and Innovation Agency (BRIN), Jakarta, Indonesia; [5] Faculty of Mathematics and Natural Science, State University of Surabaya, Surabaya, Indonesia; [6] Faculty of Science and Mathematics, Diponegoro University, Semarang, Indonesia. Corresponding author: Tirtadanu, tirtadanu91@gmail.com

Abstract. As the target species of fishermen in Lake Batur, tilapia (*Oreochromis niloticus*) population has declined, threatening the economic loss of the fisheries community. Furthermore, Midas cichlid (*Amphilophus citrinellus*), which has low economic value, has also dominated the fisher's catch in Lake Batur, reducing the catch of the target species. Stock assessment for both species is needed to develop proper management. This study aimed to assess the stock status of tilapia and Midas cichlid for fisheries management recommendations. Some population characteristics were obtained based on monthly data in 2023, and the stock status was determined by the yield per recruit and spawning potential ratio analysis. This study revealed that *A. citrinellus* in Lake Batur is more resistant than *O. niloticus*, indicated by the faster growth, better fatness and larger spawning stock biomass of *A. citrinellus* than *O. niloticus*. The current stock status of *O. niloticus* is in a recruitment overfishing condition, while the status of *A. citrinellus* is underfished. Several management measures are needed to increase tilapia's spawning stock biomass, improve the ecosystem's quality, limit the population of *A. citrinellus* and raise the economic value of *A. citrinellus* through processing and market development.
Key Words: market development, recruitment overfishing, spawning potential ratio, stock assessment.

Introduction. As a caldera lake with an area of 16.05 km^2, Lake Batur contributes to the local community's economy in the Bangli district primarily through capture fisheries, aquaculture, and tourism. Capture fisheries sustain the livelihoods of several local communities in Lake Batur, particularly for fishers who do not own agricultural land. Tilapia (*Oreochromis niloticus*) is a target species of fishers in Lake Batur, and a decline in the tilapia population will lead to the economic loss of fisheries communities. It resulted from various factors, including overfishing, heavy pollution, habitat degradation, and invasive species blooming.

Studies related to tilapia (*Oreochromis niloticus*) fisheries have been reported in Lake Batur, where the stock status was overfished in 2011 (Suryati & Samuel 2018). Moreover, increased pollution can degrade habitat and hasten ecosystem degradation, resulting in poor habitat quality and disruptive fish populations. Budiasa et al (2018) further noted that net floating cage aquaculture is a major cause of heavy pollution in Batur Lake, indicated by the higher biochemical oxygen demand (BOD), total phosphorus (total P), and total Ammonia (NH_3). Degradation of habitat and overfishing will lead to the decline of the fish population, threatening the fisheries' sustainability in Lake Batur.

Therefore, studies related to population characteristics in Lake Batur are also crucial to indicate habitat suitability for the fish stock.

Tilapia and Midas cichlid are introduced fish species in Batur Lake, and have negatively impacted the ecosystem, particularly in competition with native species for food (Syah et al 2023). Nevertheless, tilapia fisheries have significantly contributed to the main livelihoods of some local communities, raw materials for food industries, and essential protein sources. Meanwhile, Midas cichlid tends to be detrimental due to its dominating characteristics, which reduces the main catch and also has low economic value. Several studies have reported that *Amphilophus* spp. is one of the biggest threats to native fish populations in several lake waters in Indonesia, such as Lake Sentani and Sermo Reservoir (Ohee et al 2018; Hedianto et al 2022). Tilapia and Midas cichlid are the most dominant catch from gillnet fishers in Lake Batur, and stock assessment of both species is necessary for developing proper management of sustainable fisheries.

The research on the Lake Batur ecosystem has been reported from previous studies, including the overfishing of tilapia in 2011, as well as the study on water quality and potential fish production estimates of about 250 kg/ha/year (Wijaya et al 2012; Budiasa et al 2018; Suryati & Samuel 2018). This study used updated data to assess the stock status for tilapia (*O. niloticus*) as a target species and Midas cichlid (*A. citrinellus*) as a non-target species. Moreover, this study investigated biological reference points in Lake Batur that will provide information on optimal effort and selectivity through the analysis of yield per recruit and spawning stock biomass per recruit, which have never been reported in previous studies. This research aimed to assess the stock status of tilapia (*O. niloticus*) and Midas cichlid (*A. citrinellus*) as a basis for sustainable fisheries management in Lake Batur.

Material and Method

Description of the study sites. Samples of tilapia (*Oreochromis niloticus*) and Midas cichlid (*Amphilophus citrinellus*) were collected from the catch of gillnet fishers in Batur Lake, Bangli Regency, Bali Province, Indonesia, from March to June 2023 (Figure 1). The traditional fishers conducted the gillnet fishing using a mesh size of 2.8 inches. There were 1027 samples of tilapia and 1089 samples of Midas cichlid. Biological characteristics have been measured, including total length (cm), weight (kg) and gonad maturity stage.

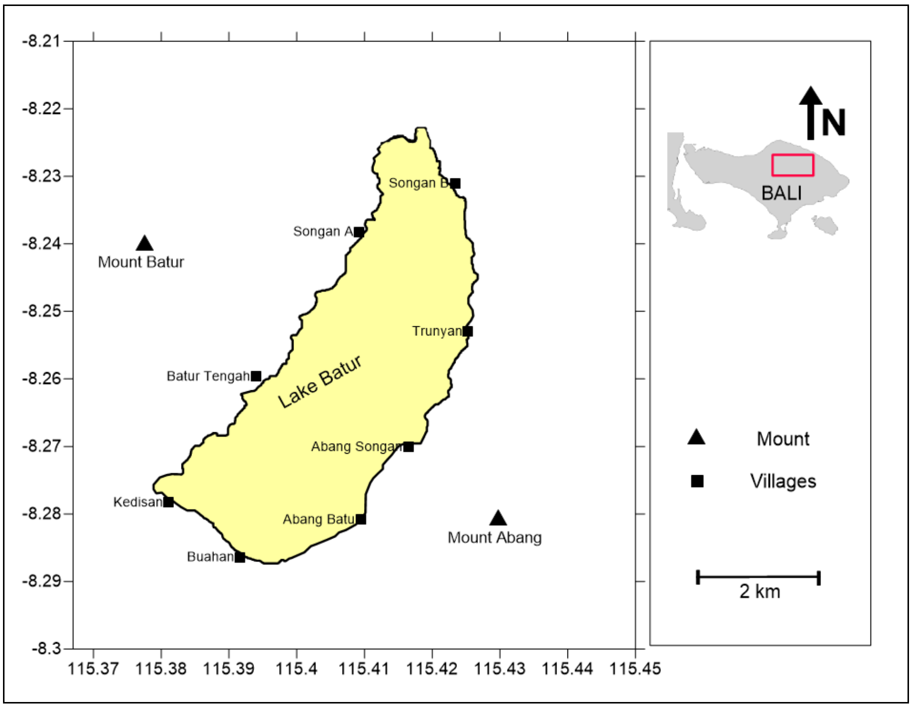

Figure 1. Lake Batur's study area (yellow) as a habitat for *Oreochromis niloticus* and *Amphilophus citrinellus* (map generated using Surfer software).

Data analysis. The data were analyzed to study the population ecological characteristics and stock status of *O. niloticus* and *A. citrinellus*. The population's ecological characteristics include the following: the length distribution, growth, length-weight relationship, mortality parameters, length at first capture (Lc) and length at first maturity (Lm).

Histograms with a class interval of 1 cm were employed. The growth of fish followed the von Bertalanffy equation (Sparre & Venema 1992):

$$L_t = L_\infty\left[1 - e^{-K(t-t_0)}\right]$$

Where Lt is the total length at age t, L_∞ is the asymptotic length, K is the annual growth rate, and t_0 is the point in time when the fish has zero length. Electronic length frequency analysis (ELEFAN) from TropFishR software package was used to estimate the asymptotic size (L_∞) and growth rate (K) using the R program with a Simulated Annealing package (Mildenberger et al 2017; Xiang et al 2013). The point in time when the fish has zero length (t_0) was estimated based on the following equation (Pauly 1983):

$$\text{Log}_{(-t0)} = (-0.3922) - 0.2752\log_{L\infty} - 1.038\log_{K}$$

The empirical natural mortality (M) was performed by using Then et al (2015) equation:

$$M = 4.188K^{0.73}{L_\infty}^{-0.33}$$

Total mortality (Z) was estimated from the linearized length-converted catch curve equation (Sparre & Venema 1992):

$$ln\frac{C(L1,L2)}{\Delta t(L1,L2)} = C - Zt(\frac{L1+L2}{2})$$

Where Z represents total mortality, C represents the frequency of length class, Δt represents the time it takes an average fish to grow from L1 to L2, L1 represents the length at age t, and L2 represents the length at age t+Δt. The following equation was used to calculate fishing mortality (F) and exploitation rate (E):

$$F = Z - M \; and \; E = \frac{F}{Z}$$

The logistic equation was performed to estimate the length at first capture (Lc) and the length at first maturity (Lm) by using the following equations (Sparre & Venema 1992; Schnute & Richards 1990):

$$S_t = \frac{1}{1+exp\,(T1-T2(t))}$$

$$P_i = \frac{G}{1 + e^{A-B(x_i)}}$$

Where T1 and T2 are the intercept and slope of the linear regression between the observed selection ogive and age (t), respectively. P is the proportion of mature fish at length or age Xi, and G is the maximum attainable mature fish proportion. A and B are the constants in the logistic curve.

Stock status was determined by employing yield per recruit and spawning potential ratio analysis. The yield per recruit used the following equation (Beverton & Holt 1957):

$$\frac{Y}{R} = F(\alpha {L_\infty}^{\beta})\left[\frac{L_\infty - L_c}{L_\infty}\right]^{\frac{M}{K}}\left[\frac{L_\infty - L_r}{L_\infty}\right]^{\frac{M}{K}}\sum_{n=0}^{3}\frac{U_n\left[\frac{L_\infty - L_c}{L_\infty}\right]^n}{F+M+nK}$$

Where Y/R is yield per recruit (g recruit^{-1}), a and b are the constants from the length weight relationship, F is the fishing mortality (year^{-1}), L_∞ is the asymptotic length (cm), Lc is the length at first capture (cm), M is natural mortality (year^{-1}) and K is growth rate (year^{-1}). U_n includes U_0=1, U_1=-3 and U_3=-1.

Input factors such as asymptotic length, M/K, length at 50% and 95% selectivity, and length at 50% and 95% maturity were used to perform the length-based spawning potential ratio (Hordyk et al 2015). The spawning potential ratio (SPR) was defined as the ratio of spawning stock biomass per recruit in the exploited stock ($SSBR_{exploited}$) to spawning stock biomass per recruit in the absence of fishing ($SSBR_{F=0}$) (Goodyear 1993):

$$SPR = \frac{SSBR_{exploited}}{SSBR_{F=0}}$$

Results and Discussion

Population ecological characteristics. Tilapia (*Oreochromis niloticus*) had a length 57.82% larger than Midas Cichlid (*Amphilophus citrinellus*). The length of *O. niloticus* ranged from 13 to 36.3 cm with an average size of 19.71 ± 3.4 (mean ± stdev). The length of *A. citrinellus* ranged from 9.2 to 23 cm with a mean size of 15.15 ± 2.25 (mean ± stdev). Several other waters have also reported similar sizes where *A. citrinellus* in Jatiluhur reservoir ranged from 12-22 cm and in Ir. Haji Juanda waters of 7-21 cm (Tampubolon et al 2012; Purnamaningtyas et al 2010). *O. niloticus* and *A. citrinellus* were most commonly caught at 18 cm (14.4%) and 15 cm (15.4%), respectively (Figure 2).

O. niloticus in Lake Batur has an asymptotic length of 37.59 cm and a growth rate of 0.58 year^{-1}. The von Bertalanffy growth curve of *O. niloticus* in Lake Batur followed the equation $L_t = 37.59\left[1 - e^{-0.58(t+0.26)}\right]$ (Figure 3). Based on the finding, the current asymptotic length of *O. niloticus* in 2023 (37.59 cm) is smaller than the asymptotic length in 2011 (41.45), indicating a decline in Tilapia size (Suryati & Samuel 2018). Overfishing and habitat degradation can influence the declining size of *O. niloticus* in Batur Lake. Net floating cage aquaculture and tourism were some commercial activities that influenced Lake Batur's rising pollution (Budiasa et al 2018; Agustina & Aprinica 2022). Habitat protection based on local wisdom can be crucial to maintaining Lake Batur's ecosystem's sustainability.

The growth rate of *A. citrinellus* is faster (K=1.18 year^{-1}) than that of *O. niloticus* (K=0.58 year^{-1}). The asymptotic length of *A. citrinellus* is 24.87 cm, and the Von Bertalanffy growth curve of *A. citrinellus* in Batur Lake follows the equation $L_t = 24.87\left[1 - e^{-1.18(t+0.14)}\right]$. With its higher growth rate than *O. niloticus* and colonial population characteristics, *A. citrinellus* has the potential to dominate the ecosystem as an invasive species. Moreover, Umar et al (2015) noted that the impact of *A. citrinellus* invasion includes a decrease in biodiversity and a decline in commercially important fish. *A. citrinellus* has also reduced the catch of *O. niloticus* in Batur Lake, so limiting the population of *A. citrinellus* is important in maintaining the sustainability of Tilapia fisheries.

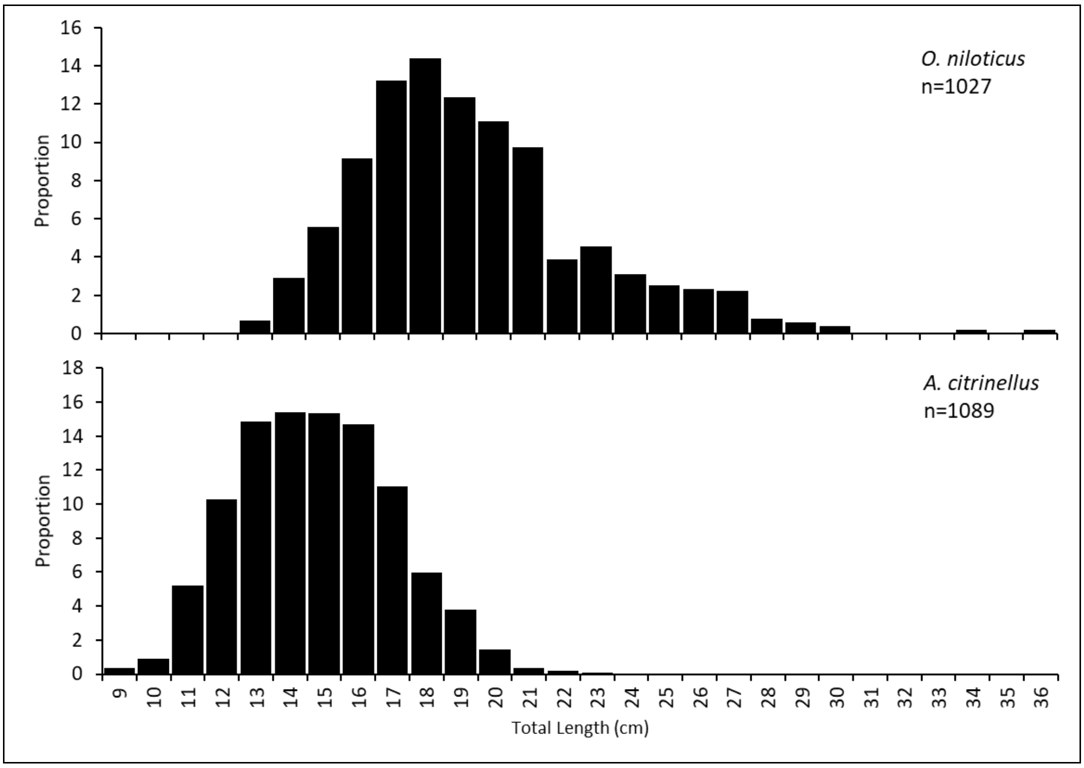

Figure 2. Length frequency data of *Oreochromis niloticus* and *Amphilophus citrinellus* in Batur Lake, 2023.

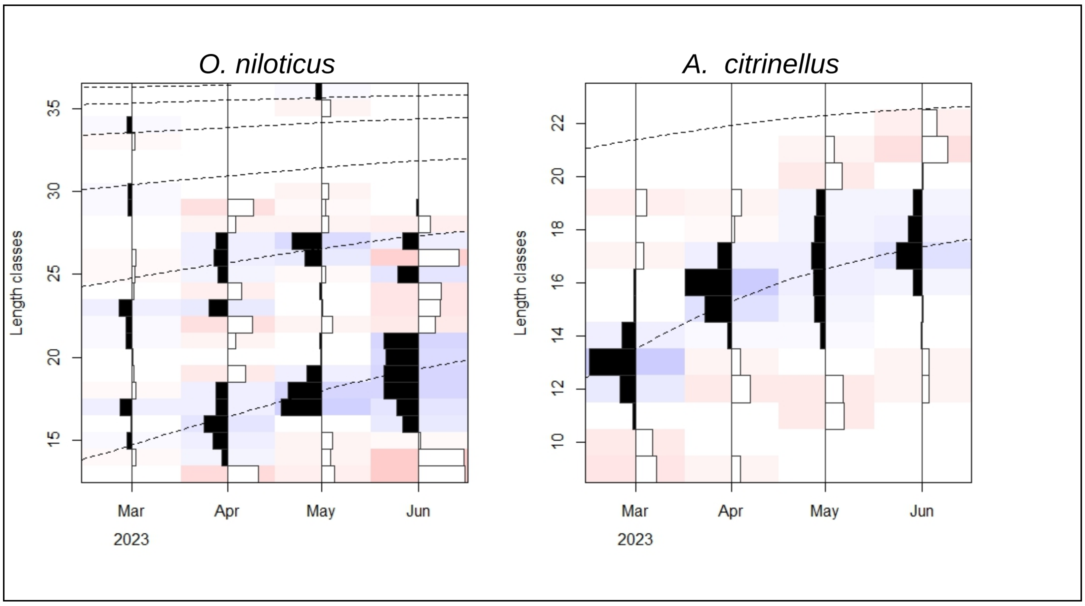

Figure 3. Von Bertalanffy growth curve of *Oreochromis niloticus* and *Amphilophus citrinellus* in Batur Lake, 2023.

The weight of *O. niloticus* ranged from 41 to 850 g, while *A. citrinellus* ranged from 12 to 236 g. The average weight was 156.42 ± 96.88 (mean ± stdev) for *O. niloticus* and 53.55 ± 23.05 for *A. citrinellus*. *O. niloticus* was 3.6 times heavier than *A. citrinellus*. As a target species with high economic value, the rise in the tilapia population will significantly contribute to the biomass and economy of local communities in Lake Batur.

O. niloticus in Lake Batur has a negative allometric growth pattern with a growth coefficient (b) of 2.9387 ± 0.04 (± SE) (Figure 4). In contrast, *A. citrinellus* has a positive allometric growth pattern with a growth coefficient (b) of 3.12 ± 0.05. These conditions mean that *A. citrinellus* in Lake Batur has better fatness than *O. niloticus*, indicating the better resistance and adaptation of *A. citrinellus* than *O. niloticus*. A positive allometric growth pattern was found in *A. citrinellus* in Ir. H. Juanda reservoir (Tampubolon et al 2012). Ohee et al (2018) also stated that *Amphilophus* spp. is adaptable and has a colonizing pattern, making it invasive and endangering the survival of endemic and economically important species.

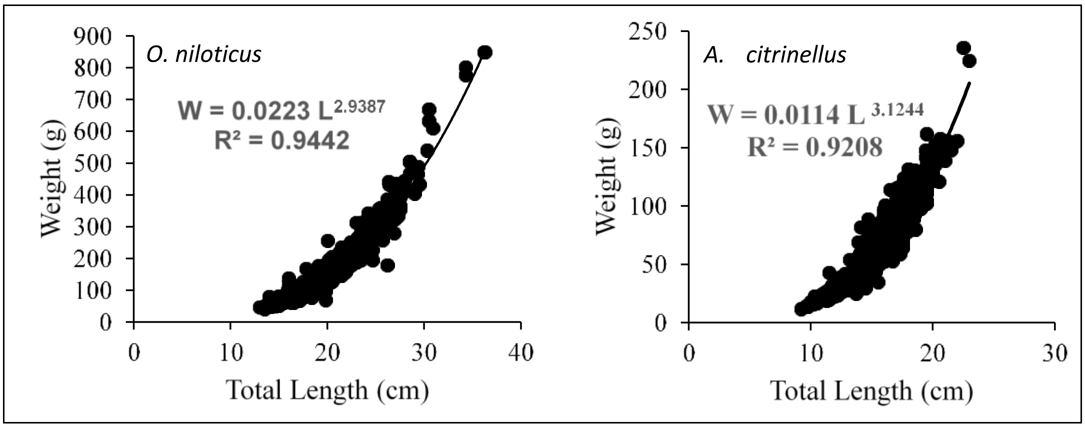

Figure 4. Length-weight relationship of *Oreochromis niloticus* and *Amphilophus citrinellus* in Batur Lake, 2023.

The length at first maturity of *O. niloticus* and *A. citrinellus* in Lake Batur waters was 16 cm and 13 cm, respectively (Figure 5). Several studies have reported the length at first maturity of tilapia, including in Coatetelco Lake, Mexico, at 14 cm and in a tropical reservoir in Ethiopia at 18.9 cm (Gómez-Marquez et al 2023; Hailu 2014). The selectivity of gill net gear on both fish species is lower than their length at first maturity, indicating that the immature fish dominate the catch. Low selectivity in tilapia can reduce spawning biomass and disrupt the fish reproduction cycle. Fishing control for small tilapia is necessary to maintain the recruitment and sustainability of the tilapia fishery in Batur Lake.

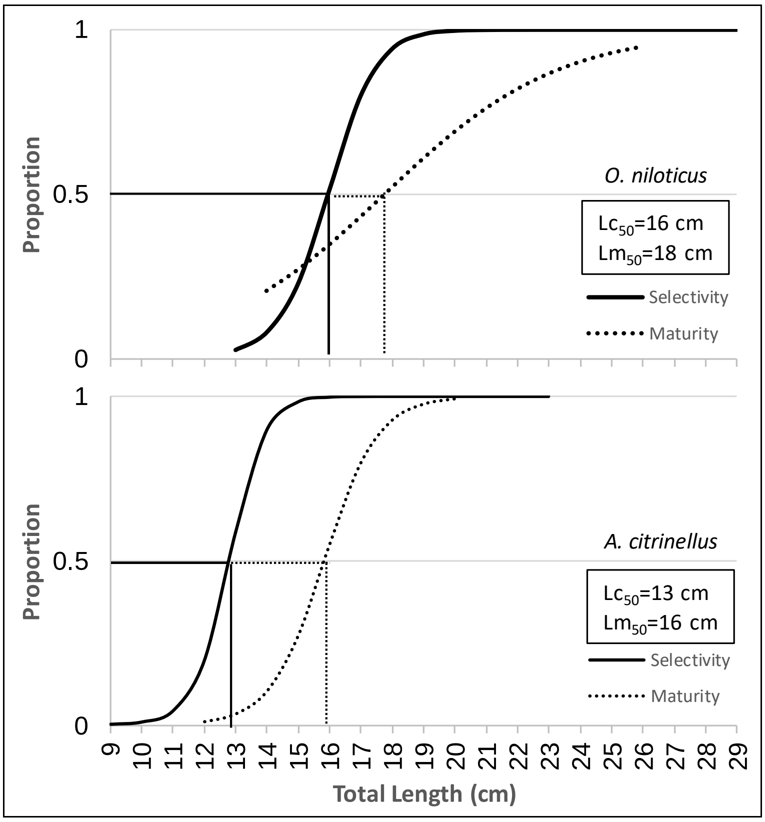

Figure 5. Logistic curve for length at first maturity and length at first capture for *Oreochromis niloticus* and *Amphilophus citrinellus* in Batur Lake, 2023.

Total mortality (Z), natural mortality (M) and fishing mortality (F) of *O. niloticus* were 2.78 $year^{-1}$, 0.85 $year^{-1}$ and 1.93 $year^{-1}$, respectively (Figure 6). Total mortality (Z), natural mortality (M) and fishing mortality (F) of *A. citrinellus* were 3.57 $year^{-1}$, 1.64 $year^{-1}$ and 1.93 $year^{-1}$, respectively. The current exploitation rate of *O. niloticus* (E_{2023}=0.68) has exceeded its optimum point suggested by Gulland (1983) of 0.5, while the exploitation rate of *A. citrinellus* (E=0.54) is still under optimum conditions. To ensure the sustainability of tilapia stock, the target species of fishers in Batur Lake, some management actions related to increasing biomass are required. On the other hand, *A. citrinellus* requires a limitation on its population. Hedianto et al (2022) proposed a high catch rate for *Amphilophus* spp. to limit its population in inland waters.

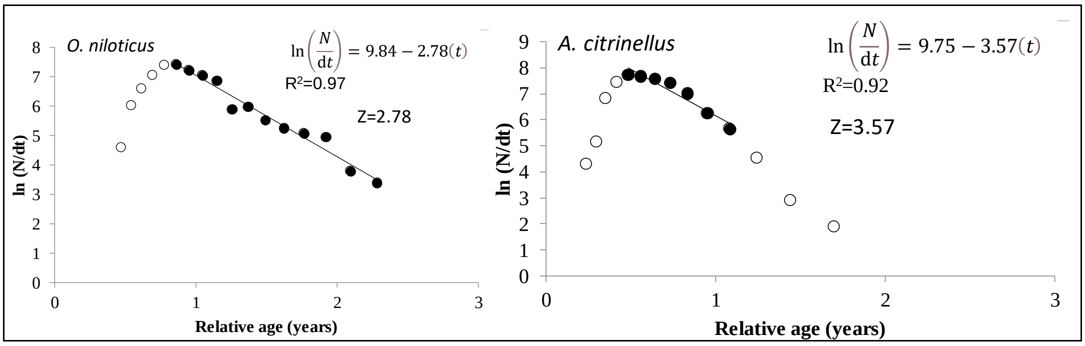

Figure 6. Length-converted catch curve to estimate the total mortality of *Oreochromis niloticus* and *Amphilophus citrinellus* in Batur Lake, 2023.

Stock status. Overfishing status has been found for *O. niloticus* based on the current fishing mortality (F_{2023}=1.93 $year^{-1}$), which is higher than the fishing mortality that produces maximum yield per recruit (F_{max}=1.4 $years^{-1}$) (Figure 7). The current length at first capture of *O. niloticus* by gillnet is 16 cm with a yield per recruit of 85.44 g $recruit^{-1}$ (Table 1). Yield per recruit would increase by 15.4% if the selectivity were increased to 22 cm, meaning that increasing the selectivity of tilapia to 22 cm would be more beneficial for fishers in Lake Batur. Warsa et al (2019) suggested using a mesh size larger than 3 inches for Tilapia fisheries in the Jatilihur reservoir. Hailu (2014) found that using a mesh size of 3.1 inches produces a selectivity of 22 cm for tilapia. The current mesh size of gill nets used by fishers in Batur Lake is 2.8 inches, so adjusting the size to above 3 inches is expected to increase yield per recruit and fisher's income.

In contrast to the status of *O. niloticus*, the current fishing mortality of *A. citrinellus* (F_{2023}=1.93 $year^{-1}$) is still less than the fishing mortality that produced maximum yield per recruit (F_{max}=4.5 $year^{-1}$). This condition indicates the status of the *A. citrinellus* fishery, which is underfished. Fishing efforts for *A. citrinellus* must be increased to limit its population in the ecosystem. An increase of up to 1.3 times from the current effort can still be done to reach the optimum fishing mortality point of *A. citrinellus*. Several studies noted that *A. citrinellus* can be processed as a source of plant nutrition and an alternative diet for tilapia aquaculture (Fatma 2017; Putra et al 2022). Studies related to fish processing need to be carried out to increase the economic value and market development of Midas cichlid.

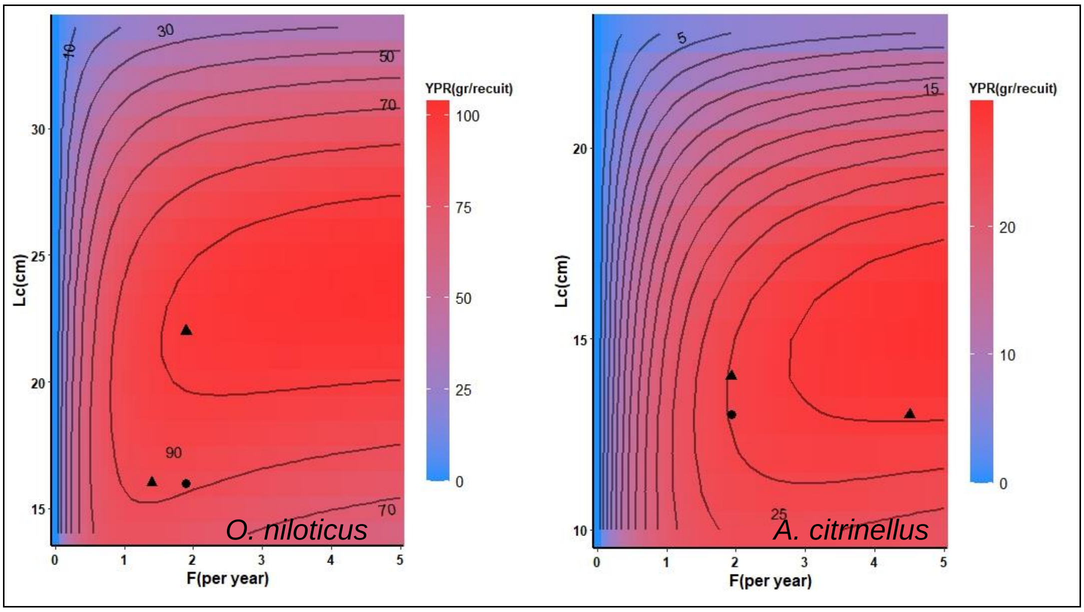

Figure 7. The isopleth of the yield per recruit as a function of length at first capture (Lc) and fishing mortality for *Oreochromis niloticus* and *Amphilophus citrinellus* in Batur Lake, 2023. The triangle symbols represent the reference point of F_{max} and Lc_{max}. The round dot represents the current condition of fishing mortality and selectivity.

The spawning potential ratio (SPR) of *A. citrinellus* in Batur Lake (SPR *A. citrinellus* = 33%) is much higher than that of *O. niloticus* (SPR *O. niloticus* = 15%) (Figure 8). Some studies suggest an SPR of 30% as the optimal spawning potential ratio (Gabriel & Mace 1999; Prince et al 2020). Thus, the current status of *O. niloticus* is already in recruitment overfishing condition, while *A. citrinellus* is still in underfishing conditions. These conditions indicate that *A. citrinellus* is more resistant than *O. niloticus* to fishing pressure and changes in the Lake Batur ecosystem.

Degradation of the aquatic environment in Batur Lake and continued fishing efforts can significantly reduce the population of *O. niloticus*, so that spawning stock biomass is incapable of replenishing its population. A management measure to increase the spawning stock biomass of *O. niloticus* needs to be carried out, including improving the habitat quality of the Batur Lake ecosystem and enlarging the selectivity of fishing gear to 22 cm for *O. niloticus*. Dewi et al (2019) suggested restocking tilapia in Batur Lake to increase its population. In addition, the capture of *A. citrinellus* in Batur Lake should be increased to limit its population. Hedianto et al (2022) also suggested a high fishing pressure on *A. citrinellus* to control its natural population. Studies related to *A. citrinellus* processing and market development are important to increase economic value. Habitat protection based on local wisdom is also needed to maintain the sustainability of the ecosystem in Batur Lake.

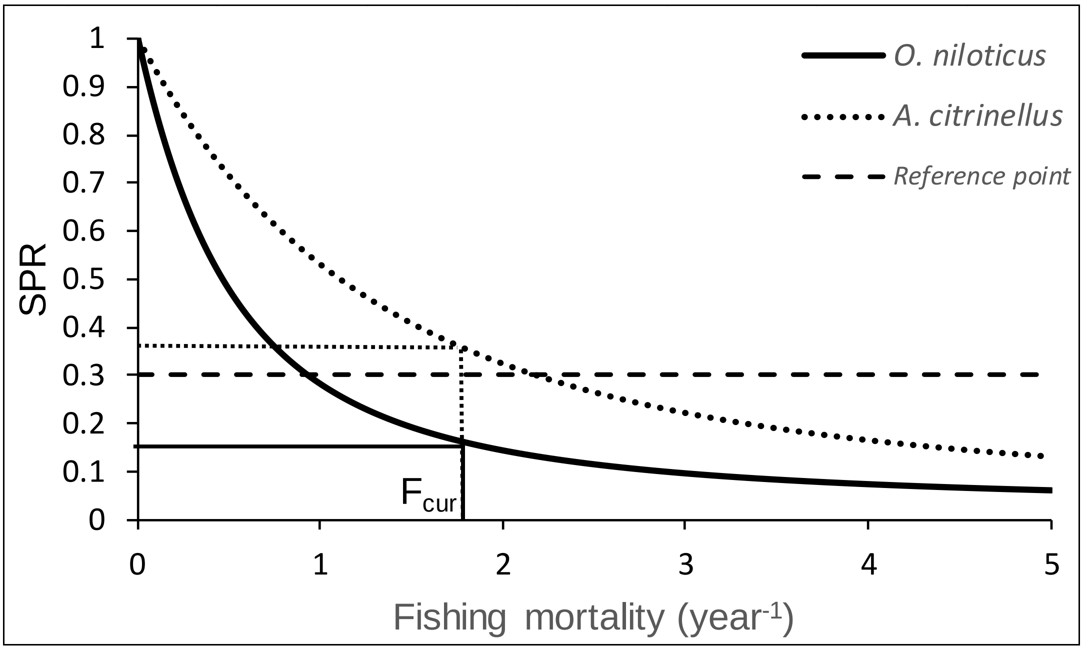

Figure 8. The spawning potential ratio as a function of fishing mortality for *Oreochromis niloticus* and *Amphilophus citrinellus* in Batur Lake, 2023.

Table 1

The current exploitation level, yield per recruit, spawning potential ratio and some optimal reference points for *Oreochromis niloticus* and *Amphilophus citrinellus* in Batur Lake, 2023

Species	*Current condition*					*Reference point*			
	F_{2023} (year^{-1})	*Lc_{2023} (cm)*	*E_{2023}*	*YPR_{2023} (g recruit^{-1})*	*SPR_{2023}*	*F_{max} (year^{-1})*	*YPR at F_{max} (g recruit^{-1})*	*Lc_{max} (cm)*	*YPR at Lc_{max} (g recruit^{-1})*
O. niloticus	1.93	16	0.69	85.44	0.15	1.4	86.34	22	98.49
A. citrinellus	1.93	13	0.54	26.05	0.33	4.5	28.23	14	26.07

Conclusions. Based on the findings, it can be concluded that Midas cichlid (*Amphilophus citrinellus*) in Batur Lake is more resistant than tilapia (*Oreochromis niloticus*). The higher spawning potential ratio of *A. citrinellus* indicates this condition, as well as better fatness and faster growth than *O. niloticus*. The stock status of *O. niloticus* has already been in a recruitment overfishing condition, while the stock of *A. citrinellus* is underfished. Several management actions need to be carried out, including applying management measures to increase the spawning stock biomass of tilapia, improve the quality of the ecosystem with a local wisdom approach, limit the population of *A. citrinellus*, and increase the economic value of *A. citrinellus* through fish processing and market development.

Acknowledgements. This research received a fund from DIPA with Number: SP-DIPA-124.01.1.690501/2023 and Number: B- 2637/HK.01/III.4/PR.07.00/11/2022. The author would also like to thank the Bangli Department of Fisheries and the Bangli community for cooperating in coordination and data collection. All authors contributed equally to this research.

Conflict of interest. The authors declare that there is no conflict of interest.

References

Agustina A., Aprinica N. P. I., 2022 [The impact of tourism on water pollution in Lake Batur, Bangli Regency]. Jurnal Ilmiah Hospitality Management 12(2):81-89 [In Indonesian].

Beverton R. J. H., Holt S. J., 1957 On the dynamics of exploited fish populations. Fish Invest. U.K. Ministry of Agriculture, Food and Fisheries, London. 533 pp.

Budiasa I. W., Santosa I. G. N., Ambarwati I. G. A. A., Suada I. K., Sunarta I. N., Shchegolkova N., 2018 Feasibility study and carrying capacity of Lake Batur ecosystem to preserve tilapia fish farming in Bali, Indonesia. Biodiversitas 19(2):613-620.

Dewi S. A. I. S., Arthana I. W., Pratiwi M. A., 2020 [Management of natural tilapia (*Oreochromis niloticus*) populations in Lake Batur, Bangli, Bali]. Current Trends in Aquatic Science II(2):48-55 [In Indonesian].

Fatma R. A., 2017 [Processing red devil (*Amphilophus labiatus*) in Sermo Reservoir into amino acid as a source of plant nutrition Durian (*Durio zibethinus*)]. Jurnal Agroteknologi 5(1):42-46 [In Indonesian].

Gabriel W. L., Mace P. M., 1999 A review of biological reference points in the context of the Precautionary Approach. Proceedings 5th NMFS NSAW. NOAA. Tech. Memo. 34-45 p.

Gómez-Márquez J. L., Peña-Mendoza B., Salgado-Ugarte I. H., Guzmán-Arroyo M., 2003 Reproductive aspects of *Oreochromis niloticus* (Perciformes: Cichlidae) at Coatetelco Lake, Morelos, Mexico. Rev. Biol. Trop. 51(1):221-228.

Goodyear C. P., 1993 Spawning stock biomass per recruit in fisheries management: foundation and current use. p. 67-81. In Smith S. J., Hunt J. J. and Rivard D. (ed). Risk evaluation and biological reference points for fisheries management. Can. Spec. Publ. Fish. Aquat. Sci. 120 pp.

Gulland J. A., 1983 Fish stock assessment. A manual of basic method. Chicester: John Wiley and Sons. 233 pp.

Hailu M., 2014 Gillnet selectivity and length at maturity of Nile tilapia (*Oreochromis niloticus* L.) in a tropical reservoir (Amerti: Ethiopia). Journal of Agricultural Science and Technology A 4:135-140.

Hedianto D. A., Purnomo K., Kartamihardja E. S., Warsa A., 2022 [Population parameters of three spot cichlid (*Cichlasoma trimaculatum*, Gunther 1867) in Sempor Reservoir, Central Java]. J. Lit. Perikan. Ind. 20(2):81-88 [In Indonesian].

Hordyk A., Ono K., Valencia S., Loneragan N., Prince J., 2015 A novel length-based empirical estimation method of spawning potential ratio (SPR), and tests of its performance, for small-scale, data-poor fisheries. ICES Journal of Marine Science 72(1):217-231.

Mildenberger T. K., Taylor M. H., Wolff M., 2017 TropFishR: an R package for fisheries analysis with length-frequency data. Methods in Ecology and Evolution 8(11)1520-1527.

Ohee H. L., Sujarta P., Surbakti S. B., Barclay H., 2018 Rapid expansion and biodiversity impacts of the red devil cichlid (*Amphilophus labiatus*, Gunther 1864) in Lake Sentani, Papua, Indonesia. Biodiversitas 19(6):2096-2103.

Pauly D., 1983 Some simple methods for the assessment of tropical fish stocks. FAO Fisheries Technical Paper 254, 52 p.

Prince J., Creech S., Maduppa 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. Regional Studies in Marine Science 36:1-13. https://doi.org/10.1016/j.rsma.2020.101309

Purnamaningtyas S. E., Tjahjo D. W. H. 2010 [Some aspects of the biology of oscar fish (*Amphilophus citrinellus*) in the Ir Reservoir. H. Djuanda, Jatiluhur, West Java]. BAWAL 3(1):9-16 [In Indonesian].

Putra I. K. D., Sasmita P. G., Kartika G. R. A., 2022 [Utilization of red devil fish (*Amphilophus* sp.) as an alternative feed in cultivating tilapia (*Oreochromis niloticus*)]. Jurnal Bumi Lestari 22(1):32-40 [In Indonesian].

Schnute J. T., Richards L. J., 1990 A unified approach to the analysis of fish growth, maturity and survivorship data. Can. J. Fish. Aquat. Sci. 47:24-40.

Sparre P., Venema S. C., 1992 Introduction to tropical fish stock asseessment Part 1. Manual. FAO Fish. Tech. Pap. (306/1). Rev.1: 376 pp.

Suryati N. K., Samuel., 2018 [Habitat and biological characteristic of tilapia (*Oreochromis niloticus*) in Batur Lake]. Berkala Perikanan Terubuk 46(3):1-9 [In Indonesian].

Syah T., Pertami N. D., Perwira I. Y., Sari K. A. P., Pramana M. A. S., Bisma M., Suryaningtyas E. W., 2023 Ichthyo-diversity of Batur Lake, Bali: a preliminary study. E3S Web of Conferences 442:01027. https://doi.org/10.1051/e3sconf/202344201027

Tampubolon P. A. R. P., Rahardjo M. F., Krismono, 2012 [Growth of Midas cichlid (*Amphilophus citrinellus*, Gunther 1864) in Ir H. Djuanda Reservoir, West Java]. Jurnal Iktiologi Indonesia 12(1):1-11 [In Indonesian].

Then A. Y., Hoenig J. M., Hall N. G., Hewitt D. A., 2015 Evaluating the predictive performance of empirical estimators of natural mortality rate using information on over 200 fish species. ICES Journal of Marine Science 72(1):82-92.

Umar C., Kartamihardja E. S., Aisyah., 2015 [Invasive impact of red devil fish (*Amphilophus citrinellus*) to fish diversity in inland water in Indonesia]. J. Kebijak. Perikan. Ind. 7(1):55-61 [In Indonesian].

Warsa A., Tjahjo D. W. H., Astuti L. P., 2019 [Measurement first maturity and gillnet selectivity of Nile tilapia (*Oreochromis niloticus*) at Jatiluhur Reservoir, West Java]. Berita Biologi 18(3):283-293 [In Indonesian].

Wijaya D., Sentosa A. A., Tjahjo D. W. H., 2012 [Study of water quality and fish resource production potential in Lake Batur, Bali]. Prosiding Seminar Nasional Limnologi VI Tahun 2012. 386-399 p. [In Indonesian].

Xiang Y., Gubian S., Suomela B., Hoeng J., 2013 Generalized simulated annealing for efficient global optimization: the GenSA package for R. The R Journal 5(1):13-28.

Received: 17 July 2023. Accepted: 11 October 2023. Published online: 30 May 2024.

Authors:

Tirtadanu, Research Center for Fishery, National Research and Innovation Agency (BRIN), Indonesia, Bogor, Cibinong, Jl. Raya Bogor KM. 47 Nanggewer Mekar, e-mail: tirtadanu91@gmail.com

Umi Chodrijah, Research Center for Fishery, National Research and Innovation Agency (BRIN), Indonesia, Bogor, Cibinong, Jl. Raya Bogor KM. 47 Nanggewer Mekar, e-mail: umi_chodriyah@yahoo.co.id

Prihatiningsih,Research Center for Fishery, National Research and Innovation Agency (BRIN), Indonesia, Bogor, Cibinong, Jl. Raya Bogor KM. 47 Nanggewer Mekar, e-mail: nining.bppl@gmail.com

Sri Turni Hartati, Research Center for Conservation of Marine and Inland Water Resources, National Research and Innovation Agency (BRIN), Indonesia, Bogor, Cibinong, Jl. Raya Bogor KM. 47 Nanggewer Mekar, e-mail: sriturnihartati@gmail.com

Tri Retnaningsih Soeprobowati, School of Postgraduate Studies, Diponegoro University, Indonesia, 50241 Semarang, Jl. Imam Bardjo No. 3-5 e-mail: trsoeprobowati@live.undip.ac.id

Agus Heri Purnomo, Research Center for Society and Culture, National Research and Innovation Agency (BRIN), Indonesia, Jakarta, Widya Graha LIPI Buildings 6th floor Jl. Raya Gatot Subroto No. 10, e-mail: a_heri_p@yahoo.com.

Syarif Prasetyo, Faculty of Mathematics and Natural Sciences, State University of Surabaya, Surabaya, South Ketintang Street, Gayungan District, East Java 60231, email: syarifprasetyo@gmail.com

Jumari, Faculty of Science and Mathematics, Diponegoro University, Semarang, Indonesia, Jl. Prof. Soedharto, Tembalang, 50275 Semarang, e-mail: jumariundip@gmail.com

Ari Wahyono, Research Center for Society and Culture, National Research and Innovation Agency, Indonesia, Jakarta, Widya Graha LIPI Buildings 6th floor Jl. Raya Gatot Subroto No. 10, e-mail: ariw001@brin.go.id

How to cite this article:

Tirtadanu, Chodrijah U., Prihatiningsih, Hartati S. T., Soeprobowati T. R., Purnomo A. H., Prasetyo S., Jumari, Wahyono A., 2024 Assessing stock status of tilapia (*Oreochromis niloticus*) and Midas cichlid (*Amphilophus citrinellus*) in Batur Lake, Indonesia. AACL Bioflux 17(3):960-970.