International Journal of Sustainable Development and Planning
Vol. 18, No. 9, September, 2023, pp. 2695-2701
Journal homepage: http://iieta.org/journals/ijsdp

Sustainable Fishing Yields of Commercial Fish in Jatibarang Reservoir, Indonesia

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https://doi.org/10.18280/ijsdp.180908

Received: 12 April 2022
Revised: 7 June 2023
Accepted: 27 June 2023
Available online: 26 September 2023

Keywords:
NILE tilapia, virtual population analysis, growth, mortality, exploitation rates

ABSTRACT

The Nile tilapia (*Oreochromis niloticus*) is a predominant species that commercially fished in Jatibarang Reservoir. About 72% of the total catch from the Reservoir consists of the Nile tilapia. Fishing activity is intense since a substantial number of fishers, both local and outsiders, have engaged in the fishery for decades. Although restocking of the species has regularly been conducted annualy, the indication of decreasing Nile tilapia stock still exists and has become a concern of the local management authorities. This research aims to evaluate and determine the sustainable potential yield of Nile tilapia in the Jatibarang Reservoir using the Length-Based Thomson & Bell prediction model as part of the improvement of previous studies on carrying capacity and economic beneficiary. A series of observations on biological data of individual species, such as the length-weight, gonadal maturity stage, and sex differentiation, were collected daily for nine months, from March to December 2018 were performed as a database for the analysis. The predicted population parameters indicated that the asymptotic length (L) and growth rate (K) are 58.2 cm and 0.51/year, respectively. The relative fishing mortality (F/M) is 0.39, indicating a relatively low harvest rate. The estimated Maximum Sustainable Yield for the Nile tilapia in Jatibarang Reservoir is about 9.76 tons/yr. This result would contribute to developing the baselines for the local fisheries management plan of Jatibarang Reservoir by the local authority to support the alternative source of income for surrounding communities.

1. INTRODUCTION

A Reservoir is a man-made lake intended to store water for several purposes, such as agricultural irrigation, natural water reserve, water transport arena, or hydroelectricity. Besides that, functionality, a Reservoir, particularly in Indonesia, has also played multiple roles for the local community, one of them is to support an alternate livelihood through, fishing activity based on culture-based fisheries (CBF) practice for small-scale fishers. Therefore, a Reservoir has huge potential for improving community livelihoods for freshwater reserves and fisheries [1].

The Ministry of Marine Affairs and Fisheries (MMAF) has actively promoted culture-based fisheries practice to lift the capture fisheries production in inland waters while promoting non-native and introduced species to fill the protein needs without compromising the conservation and protection of the native species. The Jatibarang Reservoir is one of the pilot projects among several other Reservoirs that practice CBF with non-native species and has become a lesson-learned project for developing an inland capture fishery model in Indonesia.

The Jatibarang Reservoir, with an area of 189 ha, was firstly operated on May 11th, 2015, and has a water storage capacity of 20.4 million metric cubics [2]. Several commercial entities run around the Reservoir, including boat rent for tourism, a local restaurant, a fishery, and a homestay business unit. For the fishery, small-scale handline fishing is the most common fishing activity recently found in the Reservoir. The fishers originated from both local and outside areas of the Reservoir. Previous study [3] reported that 50 to 150 kg of fish could be caught daily in the Reservoir from small-scale handline fishery.

This sign of high fishing pressure, along with the human activity surrounding the Reservoir, may have an impact on exacerbating the resources, especially the sustainability of the Nile tilapia stock. A stocking fish is one of the best ways that can be implemented to overcome the diminishing fish stock in a Reservoir [4]. In Jatibarang, several species have been introduced into the waters, such as Nile tilapia, milkfish, gourami, catfish, goldfish, and giant catfish. Still, the Nile tilapia is the dominant restocked fish consisting of 64.79% of the total released fish, followed by 12.49% milkfish. The number of restocked fish is directly proportional to the catch, where 68% of the catch consisted of the Nile tilapia [3].

In the long run, this intense fishing activity could potentially decrease the catch per unit effort and the total production of the Nile tilapia in Jatibarang Reservoir. Therefore, assessing the sustainable potential yield of this commercial species is urgent to ensure the sustainability of the stock. This research is aimed to provide information on the stock status of Nile tilapia in Jatibarang Reservoir by providing its harvest reference point (VPA), the Maximum Sustainable Yield (MSY). Both VPA reference points and the MSY would define the proper management strategy of the fishery. In many tropical countries, length-based VPA is often used rather than aged-based VPA due to the difficulties of collecting the age information of the species based on the annuli reading [5].

2. MATERIALS AND METHODS

This study strengthened the baseline for Reservoir capture fisheries management in previous studies on the economic beneficiary and carrying capacity in the exact location [6, 7]. The stock status with particular reference to Nile tilapia as a dominant species was performed in this study.

Samples were collected throughout 9 months, from March to December 2018, in the Jatibarang Reservoir, Indonesia (Figure 1). Individual fish biological data such as length and weight and the daily landing catch were recorded by the field enumerators**.** The length-based Virtual Population Analysis (VPA) was used to determine the natural mortality [8]. All the computation uses FISAT II (FAO-ICLARM Stock Assessment Tool), which can be downloaded from the FAO website. The alpha (a) and beta (b) parameters are derived from the length-weight relationship model, while the asymptotic length (L_∞) and the growth rate parameters are computed by ELEFAN I analysis in FISAT II software, as well as the natural mortality (M) and fishing mortality (F) [8]. All of these population parameters were then added to the VPA analysis.

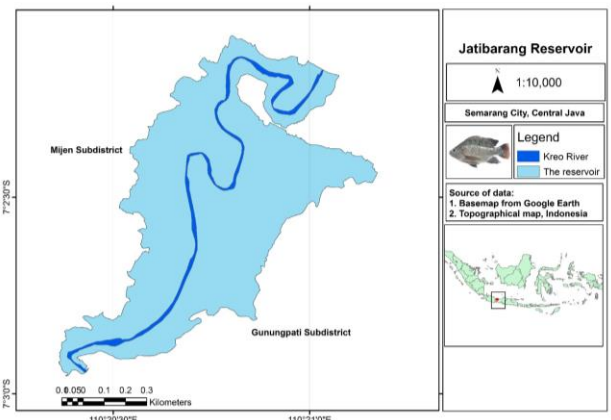


Figure 1. Map of the Jatibarang Reservoir, Semarang Indonesia

The computation of alpha (a) and beta (b) parameters in length and weight relationship can be modelled [9] below:

$$W = aL^b \quad (1)$$

where, W is the weight of each individual fish (gram), L is the body length (cm), a is the intercept, and b is the regression model's slope. A t-test was used to test whether the b value equals 3 with a p-value of 0.05.

The length at first captured (Lc) is computed based on the formula [8].

$$S_L = \frac{1}{1+\exp(S1 - S2 \ x \ C)} \quad (2)$$

$$\ln\left[\left(\frac{1}{S_L}\right) - 1\right] = S_1 - S_2 \times L \quad (3)$$

where, S_L is the logistic curve, while S_1 and S_2 are constant values derived from the logistic curve.

The growth parameter is estimated using length-frequency analysis that computes the growth coefficient (K) and length infinity (L_∞). Both parameters are estimated by using FISAT II (FAO-ICLARM Stock Assessment Tool) software. Both two parameters have been estimated, Pauly's formula [10] then applied to estimate t_0 dan t_{max} as expressed below:

$$Log(-t_0) = 0.3922 - 0.2752(LogL_\infty) - 1.038(LogK) \quad (4)$$

$$t_{max} = \frac{3}{K} + t_0 \quad (5)$$

The parameters K, L_∞ and t_0 then be used to calculate the Von Bertalanffy growth curve [8] below:

$$L_t = L_\infty(1 - \exp\,(K(t - t_0))) \quad (6)$$

If t=t+1, then the equation can be expressed as below:

$$L_{t+1} = L_\infty(1 - \exp\,(K(t + 1 - t_0))) \quad (7)$$

where, L_t is the length at age of t, K is the growth coefficient, and t_0 is the theoretical age of the individual fish once its length is zero.

Natural mortality (M) and fishing mortality (M) were included in the mortality rate (F). A linear model of the catch curve based on length composition can be used to estimate total mortality (Z) [8]. This computation can be executed as follow:

(1) Converting length to age:

$$t_{(L)} = t_0 - \left(\frac{1}{K} * ln\left(1 - \frac{L}{L_\infty}\right)\right) \quad (8)$$

(2) calculating the average required time of individual fish to grow from L1 to L2 (Δt).

(3) The average length of time:

$$\Delta t = t(L_2) - t(L_1) = \frac{1}{K} * ln\left(\frac{L_\infty - L_1}{L_\infty - L_2}\right) \quad (9)$$

$$t\frac{L_1 - L_2}{2} = t_0 - \left(\frac{1}{K} * ln\left(1 - \frac{L_1 + L_2}{2L_\infty}\right)\right) \quad (10)$$

(4) Calculating the catch curve linear model that is converted to a length:

$$n\frac{C(L_1 - L_2)}{\Delta t(L_1 - L_2)} = C - D\frac{L_1 - L_2}{2} \quad (11)$$

The equation above is linear with a slope that is derived from the following:

$$B = -D \quad (12)$$

where, B is biomass, and D is the slope of the Eq. (11).

The natural mortality (M) is estimated based on Pauly's equation [10] that incorporates the average sea surface temperature (T) as below:

$$LogM = -0.0066 - 0.279Log(L_\infty) + 0.6543Log(K) + 0.4634Log\ (T)) \quad (13)$$

where, M represents natural mortality, L represents asymptotic length, K represents growth rate, and T represents annual average sea surface temperature.

Total mortality (Z) is calculated in FISAT II using the length converted catch curve [11, 12], whereas fishing mortality (F) and exploitation rate (E) are calculated using Pauly's formula (1983) as follows:

$$F = Z - M \quad (14)$$

$$E = \frac{F}{Z} \quad (15)$$

The Maximum Sustainable Yield (MSY) was estimated using Cadima's formula for exploited stocks [8]:

$$MSY = 0.5 * (Y + MB) \quad (16)$$

where, B=biomass, Y=annual yield and M=natural mortality rate.

3. RESULT

3.1 The Reservoir fisheries

The gap between the increasing demand for fish, the high utilization rate, and the increasingly limited natural resource or potential production in marine capture fisheries has given rise to the need for various approaches to stock enhancement-based systems globally. Shifts in fisheries typology include efforts to increase natural production in water bodies such as natural lakes and man-made Reservoirs [13].

Tilapia is a freshwater fish native to the Africa continent belonging to the family Cichlidae. However, Nile tilapia (*Oreochromis niloticus*) is the most widely tilapia species intended for cultivation and wild release as part of the non-native species introduced in the freshwater body. The program was initiated to increase its economic value for an optional protein supply for the community [14].

The Reservoir fisheries data are limited. Therefore, we use 2 subsequent years of one data from the Ministry of Marine Affairs and Fisheries in 2020 and 2021 (https://statistik.kkp.go.id/). The number of fishers households for the last two years was around 75 (2020) and slightly decreased to 50 (2021) households. All fishers can harvest the fish resource using only the handline with and without motorized fishing boats. The annual landing was reported at 3 to 4 tons with a 91 to 112 million IDR value.

Previous studies on the carrying capacity of fish resources in the Jatibarang Reservoir ranged from 3.57-6.3 tons/year, with a negative relationship with the depth of the waters. The carrying capacity value is lower at water depths of more than 20m and relatively high at depths of more than 10m [7]. The fertility level of Jatibarang Reservoir waters was mesotrophic-eutrophic [15]. The primary focus of utilizing Reservoirs is on tourism rather than fisheries. Extensive research has been conducted on the tourism sector at Jatibarang Reservoir, including studies on the significant economic benefits to the region [16, 17] and the economic value of tourism-related businesses around the Reservoir [18]. On the other hand, the economic benefits of the fisheries sector have not been thoroughly examined, despite the positive impact it has on the community's economy through additional income from fishing.

3.2 The landing of Nile Tilapia

The species composition that has been introduced into the Jatibarang Reservoir consisted of the Nile tilapia (*Oreochromis niloticus*), milkfish (*Chanos chanos*), freshwater pomfret (*Colossoma macropomum*), gourami (*Osphronemus goramy*), catfish (*Clarias*), bony lip barb (*Osteochilus vittatus*), giant catfish (*Pangasius pangasius*), and freshwater prawn (*Macrobrachium rosenbergii*). However, the Nile tilapia is the predominant species, as they restocked and target fish. The released species consisted of 64.79% of the Nile tilapia, then followed by milkfish 12.49% (Figure 2). On the other hand, the majority of species caught from Jatibarang Reservoir, is also the Nile tilapia which is 72.14% of the total catch. Therefore, the catch composition is commensurate with the composition of restocked fish (Figure 3).

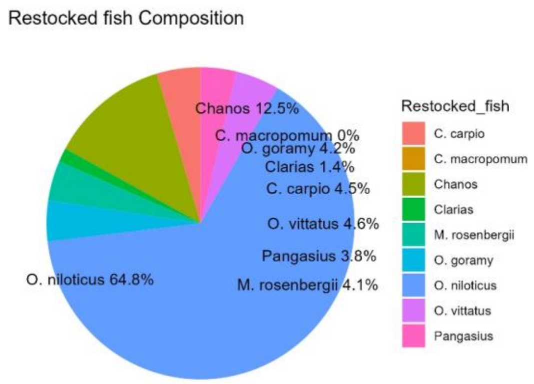


Figure 2. Composition of restocked fish

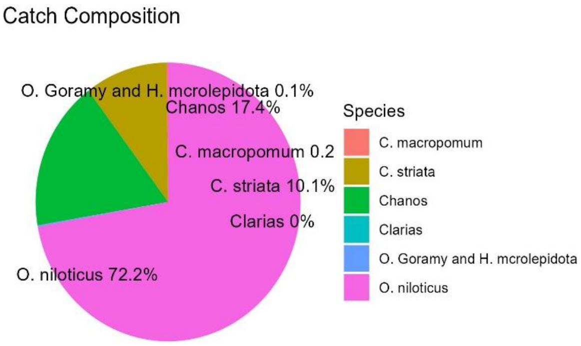


Figure 3. Catch composition in the Jatibarang Reservoir

The total catch from Jatibarang Reservoir from April to December 2018 fluctuated slightly. The average catch of the Nile tilapia is 403.89 kg/month, with the lowest catch that occurred in June, as many as 140 kg. The maximum catch occurred during April and December, as many as 525 kg (Figure 4).

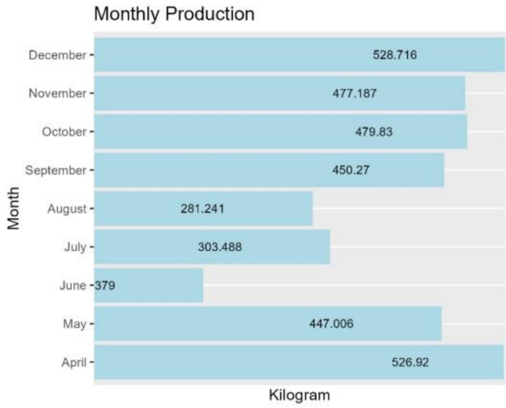


Figure 4. The monthly fish landing in Jatibarang Reservoir from April to December 2018

3.3 Virtual population analysis (VPA)

The samples were then grouped according to their length distribution, which varies for each month of the sampling period. Each group's length mode shift reflects the individual fish growth, and growth is a biological process influenced by various elements such as physiological, behavioral, dietary, genetic, and environmental factors [19]. The growth performance of Nile tilapia can be affected by sex, age, and production system [20].

Age data is crucial for determining growth, mortality, and productivity, this is one of the most significant population parameters. Whether basic calculations like growth rate or a more intricate one like virtual population analysis, all calculations depend on age information. Therefore, any rate calculation, regardless of its simplicity or complexity, necessitates the inclusion of an age or elapsed time component [21].

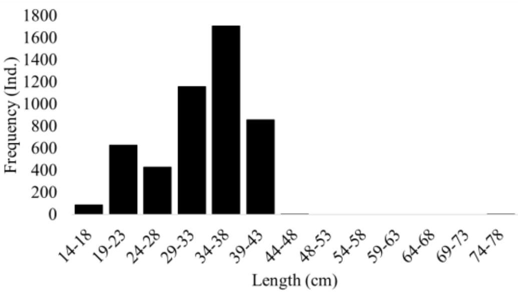


Figure 5. The length group of the fish sampled in Jatibarang Reservoir from April to December 2018

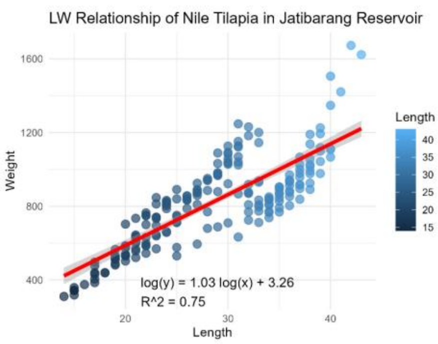
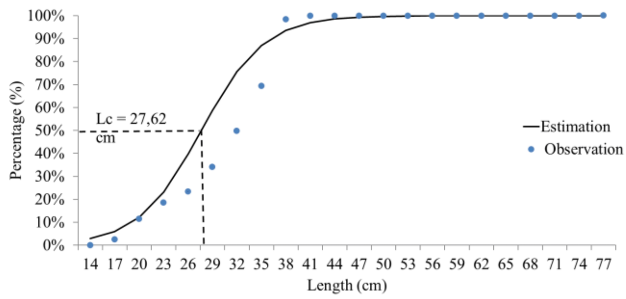


Figure 6. The length-weight relationship of Nile tilapia from Jatibarang Reservoir

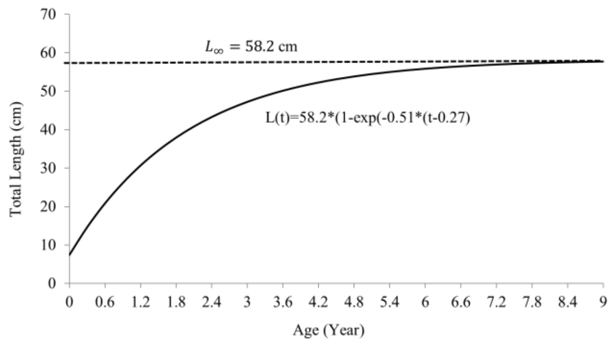
Series measurements of field observation showed that fish length distribution ranged from 14 to 77 cm, and 29.45 cm of mean length (Figure 5).

Nile tilapia's length and weight relationship can be used to determine its growth pattern. The Nile tilapia length-weight relationship is $W=26.111\ L^{(1.0261)}$ with a determinant coefficient is 74.75% (Figure 6). The t-test demonstrates that the species' growth pattern is allometrically negative ($b < 3$), meaning the growth length of the fish is slightly faster than its weight. This result has similarity to the previous studies [22] in Djuanda Reservoir as well as the study that conducted by Ramadhani et al. [23] in Cacaban Reservoir, reporting that the Nile tilapia from these two Reservoirs follow the negative allometric growth model. However, a different result has been reported by Wahyuni et al. [24] confirming that Nile tilapia in the Cirata Reservoir has an isometric growth pattern. An isometric growth means the fish grow in all dimensions simultaneously.

The length data of the Nile tilapia was analyzed. The length at first captured (L_c) is 27.62 cm (Figure 7a). Meanwhile, the asymptotic length (L_∞) is 58.2 cm, growth rate coefficient (K) is 0.51/year, and the age of fish theoretically at a length of zero (t_0) is -0.27. By putting these population parameters, the von Bertalanffy growth curve equation can be expressed as $L(t) = 51.8 * (1 - \exp(-0.51 * (t - 0.27)))$. Figure 7b shows the growth curve of the von Bertalanffy calculation.



a)



b)

Figure 7. a) Length at first captured and b) Von Bertalanffy's growth curve of the Nile tilapia in Jatibarang Reservoir

The asymptotic length (L_∞) of the Nile tilapia from the Jatibarang Reservoir is larger than the asymptotic length of the species caught in other Reservoirs (Table 1). As reported by Duponchelle and Panfili [25], a difference in growth in any fish mostly depends on the environment in which fish grow, unfavourable conditions like a decreased water level or overfishing. Another study, as conducted by Welcomme in 2001, argues that internal factors like genetics, directly impact the growth and longevity of the fish and external factors such as food availability [26]. Another population parameter, the t_{max} (the maximum age of the fish), correlates with the food availability that could support the growth of the fish. The highest number, the longest the fish could survive in their natural habitat [27].

The different habitats may also cause different population parameters of a species. Environmental factors such as the seasonality of food, the size of the specimens, and food availability are substantial to the growth of the cohort [28]. On the other hand, Tilapia growth performance is influenced by several factors, such as stocking density, feed, and water quality. The water quality parameters include dissolved oxygen, salinity, water temperature, pH, ammonia concentration, nitrite (NO_2) and nitrate (NO_3) concentration [29].

Based on the analysis, the natural mortality (M) and fishing mortality (F) rates are 0.68 and 0.27, respectively. Total mortality (Z) is the product of natural and fishing mortality. As a result, the Z value is estimated to be 0.95/year. The exploitation rate (E) can be estimated using the ratio between F and M. Based on the ratio of F to M; the exploitation rate E can be estimated to be 28%. The result of VPA defines the number of survivors for each length group at different fishing mortality rates (F). The VPA estimates the total biomass of the Nile tilapia is about 26.2 tons, with MSY 9.8 tons per year.

Based on the analysis, the estimated natural mortality (M) of the Nile tilapia in the Jatibarang Reservoir is 0.68/year which is higher than its fishing mortality rate (F) of 0.27/year. As a result, the number of fish that died naturally in the Reservoir is higher than the number of fish exploited from fishing. These results are similar to the previous studies [22, 30, 31], as shown in Table 1.

Table 1. Population parameters of the Nile tilapia from several Reservoirs in Indonesia

Location	Growth Parameters	Mortality	Exploitation Rate (E)	Ref.
Djuanda Reservoir	L_∞=44.1 cm K = 0.72/year	M = 1.34/year F = 1.06/year	E = 0.44/year	[22]
Paniai Lake	L_∞=37.28 cm K = 0.50/year	M = 0.99/year F = 0.54/year	E = 0.35/year	[30]
Bilibili Reservoir	L_∞=43.00 cm K = 0.30/year	M = 0.74/year F = 0.42/year	E = 0.36/year	[31]

The VPA is a cohort analysis commonly used to estimate historical fish numbers at age using the information on the mortality rate of the species each year [32, 33]. The length group analysis shows that large-size specimen dominates the catch composition. This fact could facilitate the new recruitment process of the population and may produce a sustainable yield of the stock [8]. However, the biomass of the Nile tilapia in the Reservoir is estimated at around 26.24 tons meaning that the exploitation rate of the fish is less than 50% of its maximum yield. Therefore, it is suggested that the exploitation rate of the Nile tilapia in the Jatibarang Reservoir is still well below the optimum rate. Since we do not provide the maturity stages, another source of information on length at first maturity (Lm) in other man-made lakes was varied at around 15 cmTL [25, 34]. Meanwhile, Agumassie [35] found Lm of the same species in Ethiopia at 42 cmTL.

4. CONCLUSIONS

The length-weight relationship of Nile tilapia in Jatibarang Reservoir follows negative allometric growth, indicating that this species grows slowly and tends to be thinner. The growth parameters analysis resulted in the infinity length (L_∞) of this species 51.8 cm, the coefficient of growth 0.51/year, while the t_0 equals -0.27 year. Based on the von Bertalanffy growth curve, the fish grows faster during the first and the second year, with natural mortality (M) being 0.68/year, fishing mortality (F) 0.27/year, and total mortality (Z) 0.95/year. The exploitation rate (E) of 0.28 indicates that the stock has not yet been over-exploited (E<Eopt), but a precautionary approach should be taken in managing the fishing effort. According to the VPA analysis, the total biomass of the species in the Jatibarang Reservoir is estimated to be around 26.24 tons.

Using the 2020 and 2021 landing data with a volume of 3 – 4 tons indicate that the harvesting rates are still below the MSY. Implementing the precautionary approach helps prevent fish stocks' depletion and fisheries' collapse. We can reduce the risk of overfishing and maintain healthy population levels by taking precautionary measures, such as setting conservative catch limits and implementing protective measures. Reservoir fisheries are part of complex ecosystems, and their sustainability is closely linked to the health of the surrounding environment.

This finding is a suggested based line to develop a management plan for the local government and beneficiary community surrounding the Reservoir. Controlling the existing number of selective fishing gear would allow the fish growth and reproduce. Implementing the minimum size at length at first capture (27 cmTL) would allow for reaching reproductive maturity before being harvested. Further observation on reproduction parameters should be carried out to strengthen the bio-exploitation indicators to support the fisheries management plan of the dominant species in the Reservoir.

ACKNOWLEDGMENT

This paper is a part of the research project "The stocking introduced fish impact on fishery resources in the Inland Fisheries Management Area 434" of the Center for Fisheries Research for the fiscal year 2018. All writers act as major contributors.

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