INTERNATIONAL JOURNAL
OF
CONSERVATION SCIENCE

ISSN: 2067-533X Volume 14, Issue 1, January-March 2023: 281-294 www.ijcs.ro

POPULATION DYNAMIC OF ENDEMIC RICEFISH IN LAKE POSO IMPLICATIONS FOR CONSERVATION

Novalina SERDIATI [1,*], Muh. Saleh NURDIN[1], Veryl HASAN[2], Daniel Fikri MOKODONGAN[3], Muhammad SAFIR[1]

[1] Faculty of Animal Husbandry and Fisheries, Tadulako University, Palu, Central Sulawesi, 94118, Indonesia
[2] Aquaculture Department, Fisheries and Marine Faculty, Airlangga University, Surabaya, Indonesia
[3] Museum Zoologicum Bogoriense, Research Center for Biosystematics and Evolution, National Research and Innovation Agency, Cibinong, Indonesia

Abstract

The aim of this study is to assess the population dynamics of medaka fish (Oryzias nigrimas) in Lake Poso. Three habitats of this fish were surveyed, including Watudilana waters, Tolambo village waters and Taipa village waters. Samples were collected at night using a petromax lamp to attract fish. The fishing gear used nets of 8 by 3 meters with a mesh size of 3 by 3 millimeters. A total of 685 individuals of medaka fish (Oryzias nigrimas) were used for population dynamics analysis. Standard length was used to compare the current size of the endemic medaka fish Oryzias nigrimas with its size 28 years ago, while total length was used to examine data on growth, mortality, exploitation rate, recruitment yield and potential reproductive ratio. The male to female sex ratio of this type of fish fluctuated each month, where females tended to be more abundant than males. The average length of this fish is smaller than the standard length in 1993. However, its average size is larger than the freshwater medaka species Oryzias asinua, Oryzias wolasi and Oryzias woworae from Southeast Sulawesi and Oryzias matanensis from Lake Sulaw Towuti. The mortality rate of the medaka fish Oryzias nigrimas is mainly caused by the presence of introduced species and overexploitation. Selectivity of fishing gear, especially by catching fish measuring more than 50.70 millimeters, is strongly recommended for the conservation effort of this fish species.

***Keywords**: Conservation; Endemic fish; Fishing strategy; Over exploitation*

Introduction

The medaka fish (family: *Adrianichthyidae*, genus: *Oryzias*) is widespread in Asia, particularly Thailand, Cambodia, China, Hong Kong, Vietnam, Japan, the Philippines, and Indonesia [1-5]. Each of the 35 species of the genus *Oryzias*, of which 17 are unique to Sulawesi Island, exhibits morphological, physiological, and ecological adaption characteristics [6-7]. However, in 2020, a new endemic medaka species, *O. kalimpaaensis*, was identified in Lake Kalimpa'a, Central Sulawesi [8]. The discovery of this new species brings the total number of endemic medaka fish on Sulawesi Island to 18, distributed throughout three provinces: South Sulawesi, Southeast Sulawesi, and Central Sulawesi [9-10].

There are eight endemic medaka fish species in Central Sulawesi Province, and three of them are found in Lake Poso, Central Sulawesi. These are *O. nebulosus* [10], *O. nigrimas* [11],

*Corresponding author: novalinaserdiati@untad.ac.id

and *O. orthognathus* [12-14]. *O. nigrimas*, one of the three species, belongs to the celebensis group [15]. The endemic medaka fish *O. nigrimas* was found in the early 1990s by Swiss researcher Maurice Kottelat [16]. This ornamental fish is primarily studied for species diversity, evolution, and ecology [17-19].

The population of the endemic *O.nigrimas*, is threatened, according to a 2019 survey [20]. This further verifies the status of the fish population as Near Threatened, as previously determined by the International Union for the Conservation of Nature and Natural Resources (IUCN). This means that the fish population is facing imminent extinction [21]. Previously, surveys conducted in 2012 and 2017 found that invasive species and lake pollution (habitat degradation) were a potential threat to the survival of the endemic population of *O. nigrimas* in Lake Poso [21-22].

Of the 10 characteristics of species that are vulnerable to extinction according to the criteria of *M. Indrawan et al.* [23], four have been experienced by the endemic *O. nigrimas*, including a restricted geographic distribution, small population size, declining population size, and exploitation by humans [10, 17, 21]. The threat to the extinction of the endemic *O. nigrimas*, has not been fully recognized by all relevant stakeholders. Prior to the extinction of the fish population in Lake Poso, it is essential to take precautions as soon as possible. According to *L. Syafei* [24] and *N. Serdiati* [25], the basic information required for the conservation of the endemic *O. nigrimas* comprises physical traits, distribution and population dynamics, reproduction and growth, behavior, biotic interactions, and habitat. Population dynamics data are the only information that is not yet available. Additional information has been published by *N. Serdiati* [25], *N. Serdiati et al.* [26], *N. Serdiati et al.* [27], *N. Serdiati et al.* [28] and *N. Serdiati et al.* [29].

In order to protect and conserve the endemic *O. nigrimas* in Lake Poso, population dynamics data and information are required. The population dynamics of the endemic *O. nigrimas* require thorough data on sex ratio, size at initial gonad maturity, growth, mortality, exploitation rate, yield per recruit, and spawning potential ratio [30-32]. In order to initially determine the population status of *O. nigrimas*, it is necessary to collect data and information regarding population dynamics. Therefore, the aim of this study is to asses the population dynamic of medaka fish *Oryzias nigrimas* in Lake Poso

Experimental part

Field location and sample collection

The study was conducted from January to December of 2021 in Lake Poso, Poso Regency, Central Sulawesi Province. Three habitats of the endemic *O. nigrimas* were surveyed: (1) Station 1: Watudilana Waters, located in the northern part of the lake; (2) Station 2: Tolambo Village Waters, located in the eastern part of the lake; and (3) Station 3: Taipa Village Water Station 3, located in the southwest part of the lake (Fig. 1). Fish sampling were carried out by boat. The fishing gear utilized 8 by 3m gillnets with a 3 by 3mm mesh size [33]. The purpose of nighttime fishing using a petromax lamp is to attract fish to the light. The fish captured at each observation station were placed in a refrigerated box before being transported to the Tadulako University Water Productivity Laboratory for further analysis.

Data collection

The total number of samples of the endemic *O. nigrimas* used for the analysis of population dynamics parameters was 685 individuals, while the number of samples utilized for the analysis of sex ratio was 645 individuals. Each sample of the endemic *O. nigrimas* was divided by sexes and measured for total length and gonad maturity. Determination of sex using sexual dimorphism features, where the male fish is bluish gray and tends to be black all over the body (except for the white belly), whereas the female is grayish brown and the belly is light [11]. Using a digital caliper with an accuracy of 0.01 mm, the body length of the endemic *O. nigrimas* was measured using standard length and total length (Fig. 2). The standard length was utilized to compare the current size of the endemic *O. nigrimas* to its size 28 years ago, while the total length was utilized to examine data on growth, mortality, exploitation rate, yield per recruitment, and spawning potential ratio.

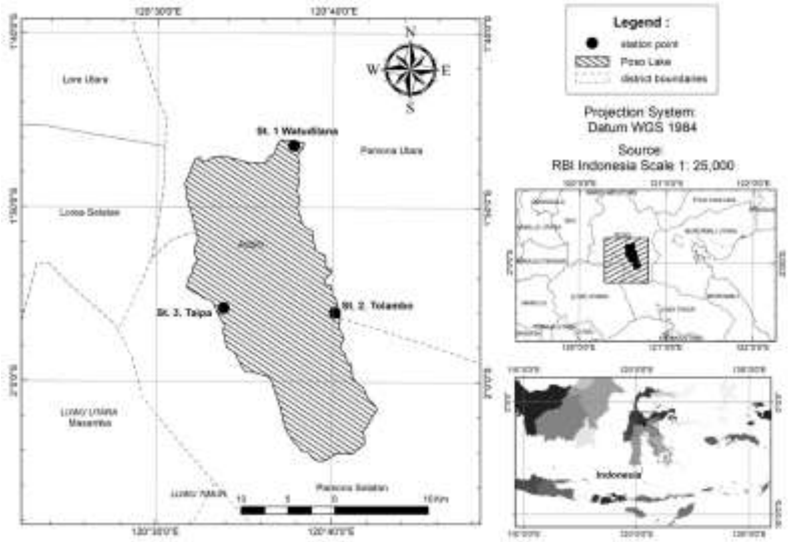

Fig 1. Fishing ground of endemic medaka fish, Oryzias nigrimas, in Lake Poso

Fig. 2. Endemic medaka fish, Oryzias nigrimas in Lake Poso (above: male, below: female)

Observation of gonadal maturity level was performed visually based on the characteristics of the gonads and ovaries with reference to the modification of *N. Serdiati* [25], namely the immature phase: the gonads are in the form of a pair of clear-colored threads with a smooth surface; male gonads are milky white while female gonads are yellowish white; mature phase: male gonads are milky white and partially cover the peritoneum; female gonads are brownish green and dark; eggs are visible with bigger granules; anal gonads grow empty and softer during the spent phase. The average yearly temperature of the waters of Lake Poso was measured to be 27.56°C using a thermometer with a protected reversing probe.

Using the *Chi-Square test* [34], the monthly difference in the sex ratio of males and females of the endemic *O. nigrimas* was studied using formulae as follows:

$$\chi^2 = \sum_{i=1} \frac{(O_i - E_i)^2}{E_i} \qquad (1)$$

where: Oi refers to the value of observation, and Ei refers to the value of expectations. To determine whether there was a difference between the average length of fish in this study and the average length of fish in 1993, the one-sample t-test was utilised using formula as follows:

$$t = \frac{\overline{X} - \mu_o}{S/\sqrt{n}} \quad (2)$$

where: X refers to the mean average of samples, μ_o refers to the mean average of tested, S refers to the sample population's standard deviation, and n is the number of samples. The size of the first gonadal maturity (Lm) was analyzed using a logistic function [35] with the equation:

$$P = \frac{1}{(1+\exp^{-r(L-Lm)})} \quad (3)$$

where: P is the proportion of fish that have reached sexual maturity, Lm is the average length of fish that reach 50% reproductive maturity, L is the length of the fish, and r is the angle of the curve's inclination. The growth was analyzed using the exponential growth equation by *Von Bertalanffy* [36] as follows:

$$Lt = L\infty \left\{1 - \exp^{-K(t-t0)}\right\} \quad (4)$$

where: Lt is the length of the fish at time-*t*, L∞ is the maximum length, K is the growth coefficient [37-39], t0 is the theoretical age at which the fish length is zero. Estimation of the theoretical age of *Oryzias nigrimas* when the length is equal to zero (t0) follows the *formulation from Pauly* [37], i.e:

$$\mathrm{Log}\,(-t0) = -0.3922 - 0.2752 \log\, L\infty - 1.038 \log K \quad (5)$$

where: L∞ is the asymptotic length (mm) and K is the growth coefficient. The natural mortality rate (M) was calculated using *Pauly's empirical* formula [40] as follows:

$$\mathrm{Log}\, M = -0.0066 - 0.279 \log\, L\infty + 0.6543 \log K + 0.4634 \log T \quad (6)$$

where: L∞ is the asymptotic length, K is the intrinsic growth coefficient, and T is the annual mean temperature (°C). Relative yield per recruitment (Y/R) was estimated using the analytical equation of *R.J. Beverton and S.J. Holt* [41] as follows:

$$\frac{Y'}{R} = E(1-c)^{M/K} x \left[1 - \frac{3(1-c)}{1+\frac{1-E}{M/K}} + \frac{3(1-c)^2}{1+\frac{2(1-E)}{M/K}} - \frac{(1-c)^2}{1+\frac{3(1-E)}{M/K}}\right] \quad (7)$$

where: c refers to fish = 0.05. Spawning Potential Ratio (SPR) was analyzed using input parameters such as M/k and Lm/L∞ [42] as follows:

$$SPR = \frac{\sum(1-\widetilde{L_x}^{(M/k[F/M)+1])}\widetilde{L_x^b}}{\sum(1-\widetilde{L_x})^{M/k} L_x^b} \text{ for } x_m \le x \le 1 \quad (8)$$

where: L_x is fish length, M is natural mortality, k is Von Bertalanffy growth, F is fishing mortality, and b is constant. The value of SPR is grouped into three categories, namely: (1) < 20% (over exploitation); (2) 20–25% (full exploitation); and (3) > 30-50% (under fishing) [43].

Results and discussion

Sex ratio

The study collected a total sample size of 645, composed of 137 males and 508 females. The sex examination of the endemic *O. nigrimas* in Lake Poso revealed that 21.2% were males and 78.8% were females (1:3.71). (Table 1). During the study period, the overall sex ratio of male and female of *O. nigrimas* fluctuated every month, with the maximum captures occurring in August, with 21 males and 61 females (Table 1). Female *O. nigrimas* tended to be more abundant than males, as shown by a Chi-Square test (x_2 = 1.13; df = 1; $p < 0.05$).

Table 1. Sex ratio percentage of endemic *O. nigrimas*, in Lake Poso

Month		Sex		Total
		Male	Female	
January	Count	16	35	51
	Percentage	31.4%	68.6%	100%
February	Count	10	46	56
	Percentage	17.9%	82.1%	100%
March	Count	7	43	50
	Percentage	14%	86%	100%
April	Count	11	28	39
	Percentage	28.2%	71.8%	100%
May	Count	11	36	47
	Percentage	23.4%	76.6%	100%
June	Count	9	48	57
	Percentage	15.8%	84.2%	100%
July	Count	9	43	52
	Percentage	17.3%	82.7%	100%
August	Count	21	61	82
	Percentage	25.6%	74.4%	100%
September	Count	11	55	66
	Percentage	16.7%	83.3%	100%
October	Count	13	32	45
	Percentage	28.9%	71.1%	100%
November	Count	9	49	58
	Percentage	15.5%	84.5%	100%
December	Count	10	32	42
	Percentage	23.8%	76.2%	100%
Total	Count	137	508	645
	Percentage	21.2%	78.8%	100%

Sex ratio is thought to influence sexual behavior, environmental conditions, and fishing activities [44]. If the sex ratio is balanced or close to 1:1, it indicates that roughly equal numbers of male and female fish were captured [32]. However, some species, notably *O. nigrimas*, may depart from these optimal conditions [45]. During the study, the sex ratio of *O.nigrimas* in Lake Poso was not balanced between males and females; female *O. nigrimas* tended to predominate. As reported by *N. Hasanah* [46] in the endemic medaka fish of *O. celebensis* in the Leang-Leang River and the Pattunuangasue River, South Sulawesi, previous studies on sex ratios in endemic medaka fish found that the female population was larger than the male population.

The imbalance between male and female populations in *O. nigrimas* is part of the fish's reproductive strategy to ensure that there is no competition between male fish during the spawning process, allowing for optimal spawning [47]. *M.A. Firmasnyah et al.* [48] demonstrated that one male medaka fish male can produce optimal sperm and fertilization in three female broods simultaneously. Moreover, according to *M.A. Firmasnyah et al.* [48] endemic medaka fish with a sex ratio of 1:3 can produce the optimal number of eggs and larvae throughout the spawning period.

Initial gonadal maturity

The total length of *O. nigrimas* captured in Lake Poso ranged from 34.67–59.83mm (mean±SD = 50.50±3.87mm), whereas the standard length ranged from 32.75–52.48mm (mean±SD = 43.20±4.24mm). The 51–55mm size class yielded the highest total catch with 310 individuals, or 45.26% of the total population, while the 31–36 mm size class yielded the lowest total catch with 2 fish, or 0.29% of the total population (Fig. 3).

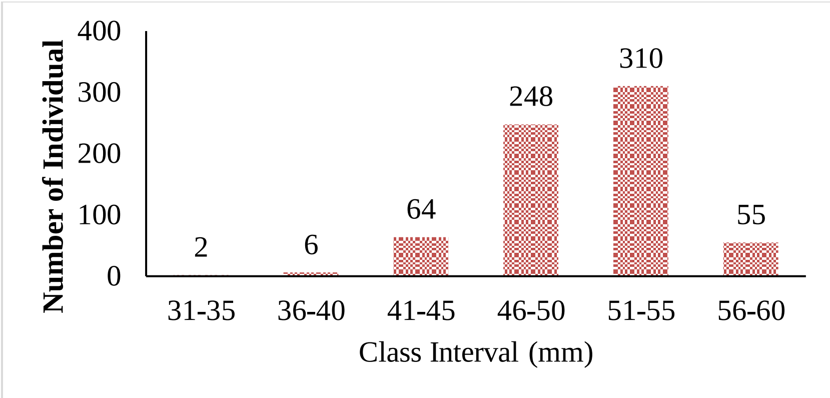

Fig. 3. Size structure based on class interval (mm) of endemic *O. nigrimas*, in Lake Poso

The findings of the *t*-test indicated that the current average standard length (42.20mm) differed substantially from the average standard length in 1993 (47mm; $p < 0.05$). After 28 years of exploitation, this investigation reveals a decline in the average length of *O. nigrimas* fish. A length size of 50.70mm was determined to be the initial gonadal maturity size (Lm) of *O. nigrimas* in Lake Poso (Fig. 4). These results suggested that 49.78% of the collected *O. nigrimas* had attained gonadal maturity, whereas 50.22 % had not.

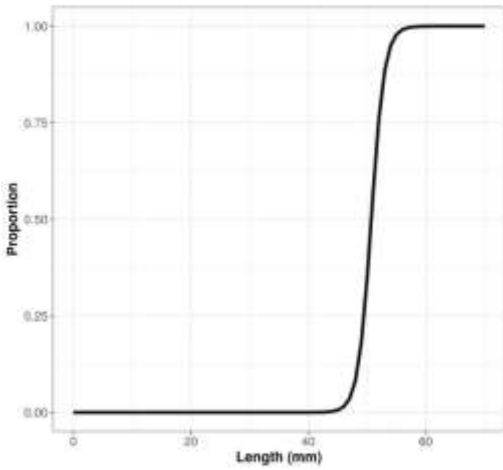

Fig. 4. Initial gonadal maturity of endemic medaka fish, Oryzias nigrimas, in Lake Poso

As a measure of the constraints imposed on fish populations, it is crucial to assess fish size frequently. Occasionally, the average size of fish that exhibit more catch symptoms will drop [49]. The average size of the endemic *O. nigrimas* from Lake Lindu, Central Sulawesi, is still larger than that of the endemic *O. soerotoi* from Lake Lindu [50]. The endemic *O. nigrimas* is larger than the endemic medaka fish species of *O. asinua*, *O. wolasi*, and *O. woworae* from freshwater Southeast Sulawesi and *O. matanensis* from Lake Towuti, South Sulawesi [6, 51]. However, the endemic *O. nigrimas* is smaller than the newly discovered endemic medaka fish (*O. kalimpaaensis*) in 2020, the species from Lake Kalimpa'a, Central Sulawesi [8]. When compared to the average length of the endemic *O. nigrimas* in 28 years ago, the average length of this endemic species has decreased. This symptom is a biological indicator of overfishing of the endemic *O. nigrimas*, as the average size of the fish captured tends to be smaller.

Fishing pressure on the endemic *O. nigrimas* is evident in the large proportion of gonadally immature fish caught, which is also indicative of the low number of adult-sized fish [52-53]. Smaller endemic and juvenile gonadal medaka fish have been caught in recent years than gonadally mature fish, as was the case with *O. celebensis* in the Leang-Leang and Pattunuangsue rivers [54] and *O. matanensis* in Lake Towuti [55].

In endemic fishing activities in Lake Poso, nets of a length of 20 m or even 70 m and fishing aids in the form of a petromax lamp are utilized, with the net being one modification of fishing nets [33]. In addition, *Gundo* [33] discovered that the mesh size is so fine that many immature gonads are caught. This is compounded by the use of petromax lamps, which attract fish of various sizes, including juveniles and adults. This kind of fishing is certainly damaging because young fish are not given the opportunity to breed before being captured, hence limiting the likelihood of future recruitment.

Increased fishing pressure on fish that have not yet spawned and that will spawn, along with a decline in the average size of fish captured, will reduce fish stocks [56]. It is likely that the enormous number of endemic *O. nigrimas* taken with immature gonads may reduce the population of fish resources in the future, since it is probable that the fish caught have not yet spawned but will do so in the future. Therefore, the length of the captured endemic *O. nigrimas* must exceed the size of the first mature gonad, assuming the fish have spawned at least once [45].

Mortality and relative yield per recruitment (Y/R)

The endemic *O. nigrimas* population in Lake Poso can attain an average maximum length of $L\infty$ = 64.67mm with a growth coefficient (K) of 0.88 $year^{-1}$ (Fig. 5). With a negative allometric growth trend, the average maximum weight of the endemic *O. nigrimas* in this lake varies between 1.56–2.21 grams [22]. Compared to other endemic fish in Lake Towuti, South Sulawesi, such as Paratherina striata with a growth coefficient of 2 $year^{-1}$ [57] and *Glossogobius matanensis* with a growth coefficient of 1.2 $year^{-1}$ [57], the growth coefficient of the endemic *O. nigrimas* is relatively low [58]. Using *Musick's criteria* [59], the growth of indigenous fish on Sulawesi Island exhibits the same pattern, which is highly resilient because the growth coefficient is more than > 0.30. Due to its high growth coefficient, this also suggests that the endemic *O. nigrimas* has a relatively short lifespan [60].

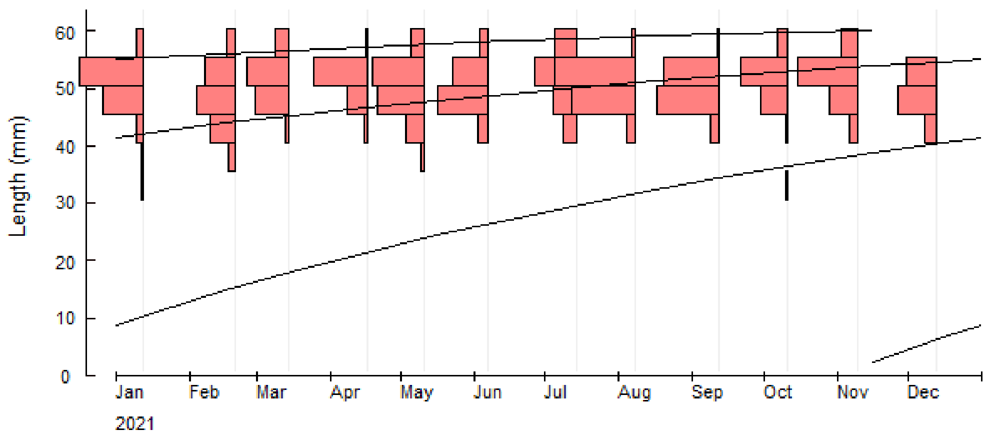

Fig. 5. Growth curve of endemic *O. nigrimas*, in Lake Poso

Total, natural, and fishing mortality values as well as exploitation rates were estimated using the conversion curve method of catches with total length using FISAT II software using $L\infty$ and K coefficient values as inputs. Total mortality (Z) was 3.16 $year^{-1}$, natural mortality (M) was 1.67 $year^{-1}$, fishing mortality (F) was 1.49 $year^{-1}$, and the exploitation rate was 0.47 $year^{-1}$ (Fig. 6).

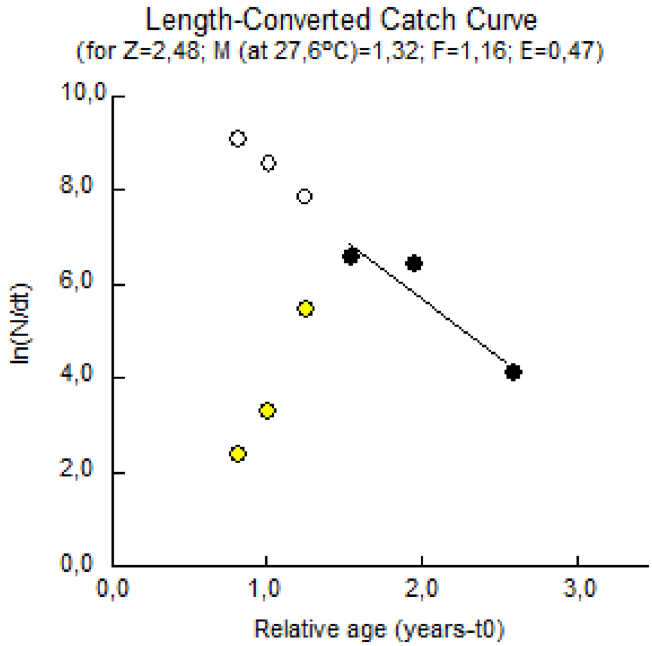

Fig. 6. Mortality and exploitation rate of endemic medaka fish, Oryzias nigrimas, in Lake Poso

The results of the Beverton and Holt yield per recruit analysis indicate that the endemic *O. nigrimas* has been overfished, as the current E value of 0.47 year^{-1} exceeds the Emax value of 0.38 year^{-1} (figure 7). If the exploitation rate hits 0.25 per year^{-1}, virgin stock will be reduced by 50% (E50).

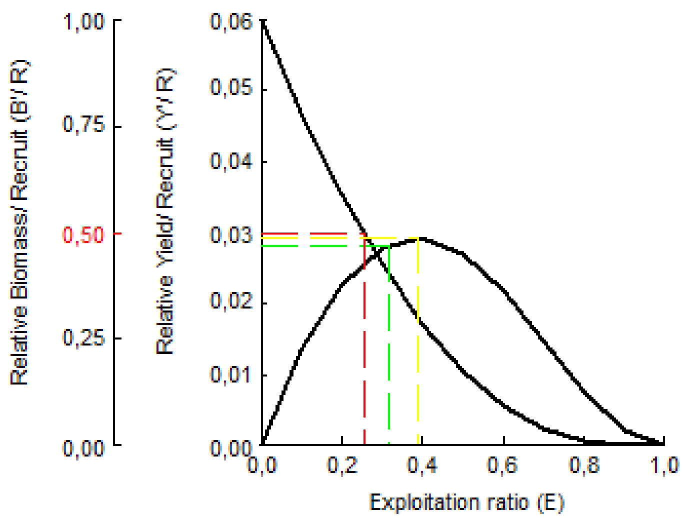

Fig. 7. Beverton and Holt relative yield/recruit curve of endemic *O. nigrimas*, in Lake Poso

The mortality value of the endemic *O. nigrimas* is not significantly different from natural mortality. This indicates that the demise of endemic medaka fish in Lake Poso is mostly caused by the presence of introduced species, in addition to fishing activities [10, 22, 61]. The high natural mortality of the endemic *O. nigrimas* in Lake Poso is caused by the presence of invasive species. The 2019 survey in Lake Poso identified seven introduced species, including *Anabas testudineus*, *Aplocheilus pancax*, *Channa striata*, *Cichlasoma* sp., *Oreochromis niloticus*, *Trichopodus trichopterus*, and *Melanochromis auratus* [20]. The presence of these invasive species in Lake Poso poses a serious danger to biodiversity and ecosystems [62].

Endemic fish cannot compete with introduced fish for food and breeding space, or endemic fish are preyed upon by introduced fish [63], like in the instance of *Melanochromis auratus* in Lake Poso, which is suspected of preying on fish larvae and eggs [64]. *F. Herder et al*. [64] claimed that the drop in the native fish population in Lake Poso was followed by an increase in the number of introduced *Melanochromis auratus* fish [64]. This process demonstrates that introduced fish turn into invasive species and are also known as biological contaminants [24].

A.J. Whitten et al. [65] observed that the introduction of *Channa striata* and *Oreochromis mossambicus* into Lake Poso in 1951 led to a decline in the population of endemic *Adrianichthys kruyti* and *Adrianichthys poptae* medaka fish. The population status of the two endemic medaka fish in Lake Poso is unknown, as they have not been sighted there since 1983 [11, 16], however according to the IUCN, they are critically endangered and endangered, respectively.

***Spawning Potential Ratio* (SPR)**

The results of the spawning potential ratio (SPR) analysis of the endemic medaka fish *Oryzias nigrimas* in Lake Poso were 18% when the F/M and Z/K ratios were 14.15 and 2.81, respectively (Table 2). The value of the F/M ratio that exceeds 1 and the Z/K ratio that exceeds 2 and the SPR value below the biological limit reference point value of 20% proves that there has been overexploitation of the endemic *O. nigrimas* in Lake Poso. The current SPR estimation of the endemic *O. nigrimas* also illustrates that only about 18% of the population of the endemic *O. nigrimas* in Lake Poso has the opportunity to spawn.

Table 2. Spawning Potential Ratio estimation of endemic *O. nigrimas*, in Lake Poso

SL_{95}	F/M	Z/K	M/K	SPR
63.76	14.15	2.81	1.5	18

SPR analysis is paired with modeling to anticipate the number of brooders with reproductive capacity or so-called spawning stock biomass (SSB). A SPR of less than 20 % as the minimum reference point (limit reference point or LRP) decreases the relative yield recruit and spawning stock biomass (SSB) from sustainable levels because of low broodstock and egg production [66-67]. Due to the low broodstock and egg production of endemic medaka fish, introduced fish have become an invasive species that feeds on broodstock, larvae, and eggs of endemic medaka fish [64, 68]. This is made worse by fishing activities that capture more fish that have not yet spawned but will soon do so.

Conservation implication

The overexploitation of the endemic *O. nigrimas* is reflected by three major factors: (i) a reduction in the size of the fish captured; (ii) an exploitation rate that exceeds Emax; (iii) an SPR value that falls below the biological limit reference point. The findings of this study confirm the findings of previous studies that reported the extinction of the endemic medaka fish in Lake Poso due to overexploitation [11, 65]. To increase the number of endemic medaka fish resources, stringent conservation measures must be implemented.

In relation to the correlation between the SPR value and the length of the fish, the conservation effort that can be applied so that the SPR value equals 20% (biological reference point limit) is to increase the selectivity of fishing gear, specifically by capturing fish measuring longer than 50.70 millimeters. This is to ensure that fishing activities do not interfere with the reproduction and recruitment of fish, hence ensuring their long-term viability. It is also necessary to control invasive fish species in order to boost the SPR value. The presence of invasive species in Lake Poso is heavily influenced by the absence of existing laws and restrictions, as well as the lack of public awareness. In addition to improving laws for the entry of fish into Lake Poso, education to community have an important impact.

In order to obtain E_{50} = 0.25 based on the Beverton and Holt yield per recruit study of 50%, it is necessary to lower the number of attempts by 22% from the current value of the exploitation rate (E_{50} = 0.47). However, the available information is confined to the characteristics of fishing gear; there is no information regarding the number of boats and fishing gear used to capture the endemic medaka fish in Lake Poso. For the goal of limiting the number of attempts that can be made to catch fish based on the availability of fish resource stocks in Lake Poso, it is required to gather annual data on the number of attempts with the production of endemic medaka fish resources in Lake Poso.

Conclusions

The endemic medaka fish (*Oryzias nigrimas*) in Lake Poso has been overfished, as demonstrated by the reduction in fish size, the exploitation rate value surpassing Emax, and the SPR value falling below the biological limit reference value. The endemic *O. nigrimas* can be conserved by establishing appropriate catch sizes, educating the public and improving restrictions relating to fish introductions, and collecting data on the number of activities associated with the endemic medaka fish resources.

Acknowledgments

The author would like to thank the Laboratory of Water Quality and Aquatic Biota, Faculty of Animal Husbandry and Fisheries, Tadulako University, which has provided facilities during the research. The author also thanks the fishermen from Lake Poso who have helped to catch the medaka fish.

References

[1] M. Kottelat, A.J. Whitten, **Freshwater Fishes of Western Indonesia and Sulawesi: Addition and Corrections**, Periplus, Hongkong: Periplus, 1996, 830 hal.

[2] L.R. Parenti, *Oryzias haugiangensis,* **The IUCN Red List of Threatened Species 2012: e.T181280A1716747,** International Union for Conservation of Nature, 2012.

[3] L.R. Parenti, *Oryzias curvinotus,* **The IUCN Red List of Threatened Species 2012: e.T181194A1708251,** International Union for Conservation of Nature. 2012.

[4] W. Magtoon, A. Termvidchakorn, *A Revised Taxonomic Account of Ricefish Oryzias (Beloniformes ; Adrianichthyidae), in Thailand, Indonesia and Japan*, **The Natural History Journal of Chulalongkorn University**, **9**, 2009, pp. 35–68.

[5] J. Gonzalez, R.S.P. Gaerlan, E.C. Ame, M.A.F. Cecilio, M.P.C. Garcia, R.S.I. Guino-o, *Oryzias luzonensis,* **The IUCN Red List of Threatened Species 2021: e.T162159966A162159994**, International Union for Conservation of Nature, 2021.

[6] L.R. Parenti, R.K. Hadiaty, D. Lumbantobing, F. Herder, *Two new ricefishes of the genus oryzias (Atherinomorpha: Beloniformes: Adrianichthyidae) augment the endemic freshwater fish fauna of southeastern Sulawesi, Indonesia*, **Copeia**, **3**, 2013, pp. 403–414.

[7] Y. Takehana, M. Zahm, C. Cabau, C. Klopp, C. Roques, O. Bouchez, *Genome sequence of the euryhaline Javafish Medaka, Oryzias javanicus: A small aquarium fish model for studies on adaptation to salinity*, **G3 Genes, Genomes, Genet**, **10**(3), 2020, pp. 907–915.

[8] A. Gani, N. Suhendra, F. Herder, J. Schwarzer, J. Möhring, J. Montenegro, *A new endemic species of pelvic-brooding ricefish (Beloniformes : Adrianichthyidae : Oryzias) from Lake Kalimpa ' a , Sulawesi, Indonesia*, **Bonn zoological Bulletin**, **71**(1), 2022, pp. 77–85.

[9] M. Kottelat, A.J. Whitten, S.N. Kartikasari, S. Wiroatmodjo, **Freshwater fishes of western**

Indonesia and Sulawesi, Periplus Editions Limited, Hongkong,1993.
[10] L.R. Parenti, B. Soeroto, *Adrianichthys roseni and Oryzias nebulosus, two new ricefishes (Atherinomorpha: Beloniformes: Adrianichthyidae) from Lake Poso, Sulawesi, Indonesia*, **Ichthyological Research**, **51**, 2004, pp. 10–19.
[11] M. Kottelat, *Synopsis of the endangered Buntingi (Osteichthyes: Adrianichthyidae and Oryziidae) of Lake Poso, Central Sulawesi, Indonesia, with a new reproductive guild and descriptions of three new species*, **Ichthyological Exploration of Freshwaters**, **1**, 1990, pp. 49–67.
[12] R.K. Hadiaty, *Status taksonomi iktiofauna endemik perairan tawar Sulawesi*, **Jurnal Iktiologi Indonesia**, **18**(2), 2018, pp.175–190.
[13] F.W. Miesen, F. Droppelmann, S. Hüllen, R.K. Hadiaty, F. Herder, *An annotated checklist of the inland fishes of Sulawesi*, **Bonn Zoological Bulletin**, **64**, 2015, pp. 77–106.
[14] L.R. Parenti, *A phylogenetic analysis and taxonomic revision of ricefishes, Oryzias and relatives (Beloniformes, Adrianichthyidae)*, **Zoological Journal of the Linnean Society**, **154**(3), 2008, pp. 494–610.
[15] Y. Takehana, K. Naruse, M. Sakaizumi, *Molecular phylogeny of the medaka fishes genus Oryzias (Beloniformes: Adrianichthyidae) based on nuclear and mitochondrial DNA sequences*, **Molecular Phylogenetics and Evolution**, **36**(2), 2005, pp. 417–428.
[16] L.R. Parenti, *Endemism and conservation of the native freshwater fish fauna of Sulawesi, Indonesia*, **Prosiding Seminar Nasional Ikan**, **1**(10), 2011, pp. 1–10.
[17] M. Herjayanto, A. Gani, Y.S. Adel, N. Suhendra, *Iktiofauna air tawar beberapa danau dan sungai inletnya di provinsi sulawesi tengah, indonesia*, **Journal of Aquatropica Asia**, **4**(1), 2019, pp. 1–9.
[18] D.F. Mokodongan, K. Yamahira, *Origin and intra-island diversification of Sulawesi endemic Adrianichthyidae*, **Molecular Phylogenetics and Evolution**, **93**, 2015, pp. 150–160.
[19] K. Inoue, Y. Take, *Diverse adaptability in Oryzias species to high environmental salinity*, **Zoological Science**, **19**(7), 2002, pp. 727–734.
[20] K.P. Bandjolu, E. Madiyono, M. Herjayanto, A. Gani, M. Nur, S. Laheng, *Checklist of endemic (Adrianichthyidae, Gobiidae, Zenarchopteridae) and introduced fish in Lake Poso, Sulawesi, Indonesia*, **IOP Conference Series Earth and Environmental Science**, **869**, 2021, Article Number: 012060.
[21] D.F. Mokodongan, *Oryzias nigrimas*, **The IUCN Red List of Threatened Species 2019: e.T15576A90980728**, International Union for Conservation of Nature, 2019.
[22] N. Serdiati, D. Arfiati, M.S. Widodo, T.D. Lelono, S. Ndobe, K. Mansyur, *Perspectives on sustainable management of the poso lake (Indonesia) endemic ricefish, oryzias nigrimas (actinopterygii: Adrianichthyidae)*, **Revista de Biología Tropical**, **69**(1), 2021, pp. 139–52.
[23] M. Indrawan, B.P. Richard, S. Jatna, **Biologi Konservasi, Yayasan Obor Indonesia**, Jakarta, Yayasan Obor Indonesia, 2012.
[24] L. Syafei, *Keanekaragaman Hayati dan Konservasi Ikan Air Tawar*, **Jurnal Penyuluhan Perikanan dan Kelautan**, **11**(1), 2017, pp. 48–62.
[25] N. Serdiati, **Karakterisasi ikan padi Oryzias nigrimas (Kottelat, 1990) sebagai upaya pengelolaan ikan endemik di Danau Poso, Sulawesi Tengah**, Universitas Brawijaya, 2019.
[26] N. Serdiati, D. Arfiati, M.S. Widodo, T.D. Lelono, B.A.J. Gosari, *Food habits of the endemic ricefishes (Oryzias Nigrimas, Kottelat 1990) in Poso Lake, Central Sulawesi of Indonesia*, **Russian Journal of Agricultural and Socio-Economic Sciences**, **87**(3), 2019, pp. 125–130.
[27] N. Serdiati, D. Arfiati, M.S. Widodo, T.D. Lelono, A.H.A. Toha, *Genetic characteristics of ricefish from Lake Poso, Central Sulawesi, Indonesia*, A**ACL Bioflux**, **12**(2), 2019, pp. 535–552.

[28] N. Serdiati, D. Arfiati, M.S. Widodo, T.J. Lelono, S. Ndobe, R. Saranga, *Morphological variations and phylogenetic analysis of oryzias nigrimas kottelat, 1990 (Rice fish) from lake poso, Central Sulawesi, Indonesia*, **Biodiversitas**, **21**(3), 2020, pp. 882–888.
[29] N. Serdiati, D. Arfiati, M.S. Widodo, T.D. Lelono, A. Masyahoro, N. Hasanah, *Length-weight ratio and condition factor of endemic fish Oryzias nigrimas (Kottelat, 1990) in Poso Lake, Central Sulawesi*, **IOP Conference Series: Earth and Environmental Science**, **750**, 2021, Article Number: 012055.
[30] A. Halim, N.R. Loneragan, B. Wiryawan, A.R. Hordyk, M.F.A. Sondita, I. Yulianto, *Evaluating data-limited fisheries for grouper (Serranidae) and snapper (Lutjanidae) in the Coral Triangle, eastern Indonesia*, **Regional Studies in Marine Science**, **38**, 2020, Article Number: 101388.
[31] F. Azmi, A.L. Mawardi, S, Sinaga, M.S. Nurdin, S.P. Febri, T.F. Haser, *Population dynamics of Anadara antiquata of East Coast of Aceh, Indonesia*, **Biodiversitas**, **23**(1), 2022, pp. 436–442.
[32] T.F. Haser, M.S. Nurdin, E. Supriyono, D. Radona, F. Azmi, K. Nirmala, *Reproductive biology of mahseer (Tor tambroides) from Atu Suasah and Lawe Melang Rivers in Aceh Province to support sustainable fisheries management*, **Pakistan Journal of Zoology**, **54**(2), 2022, pp. 561–567.
[33] M.T. Gundo, *Daerah penangkapan dan status alat tangkap ikan rono (Xenopoecilus oophorus) di Danau Poso*, **Media Litbang Sulteng**, **3**(1), 2010, pp. 33–37.
[34] J.H. Zar, **Biostatistical analysis**, New Jersey, Prentice Hall, 2010.
[35] M. King, **Fisheries Biology, Assessment and Management,** Second edition, Blackwell Publishing, 1995, 382p.
[36] P. Sparre, S.C. Venema, **Introduction to tropical fish stock assessment - Part 1: Manual**, FAO, Rome, 1998.
[37] E. Ciornea, G. Dumitru, S. Vasile, *Morphological and biochemical study of the digestive tube in common carp, Prussian carp and bighead carp*, **Lucrări Ştiinţifice, Seria Zootehnie**, **53**(15), 2010, pp. 561 - 569
[38] G. Dumitru, E. Ciornea, S. Vasile, *The study of some morphological characters at the Aristichthys nobilis species in different stages of development*, **Lucrări Ştiinţifice, Seria Zootehnie**, **55**(16), 2011, pp. 276 - 282
[39] G. Dumitru, E. Todirascu-Ciornea, L. Hritcu, I.G. Sandu, *Studies of some morphological and biochemical parameters concerning the health condition of some fish species from Prut River, Romania*, **Revista de Chimie**, **69**(5), 2018, pp. 1194 - 1199.
[40] D. Pauly, *On the interrelationships between natural mortality, growth parameters, and mean environmental temperature in 175 fish stocks*, **ICES Journal of Marine Science**, **39**(2), 1980, pp. 175–192.
[41] R.J. Beverton, S.J. Hol, **Table of Yield Functions for Fishery Management,** FAO, Rome, 1964.
[42] J. Prince, S. Creech, H. Madduppa, A. Hordyk, *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**, 2020, Article Number: 101309.
[43] J. Prince, A. Hordyk, S.R. Valencia, N. Loneragan, K. Sainsbury, *Revisiting the concept of Beverton -Holt life- history invariants with the aim of informing data-poor fisheries assessment*, **ICES Journal of Marine Science**, **72**(1), 2015, pp. 194–203.
[44] D.V. Ball, K.V. Rao, **Marine fisheries**, New Delhi, Tata McGraw-Hill publishing company, 1984.
[45] D.S. Achmad, Sudirman, J. Jompa, M.S. Nurdin, *Estimating the catchable size of orange-spotted grouper (Epinephelus coioides) in Kwandang Bay, Gorontalo Utara District, Indonesia*, **IOP Conference Series: Earth and Environmental Science**, **473**, 2020, Article

Number: 012133.
[46] N. Hasanah, S.B.A. Omar, J. Tresnati, *Sex ratio of endemic Ricefish Oryzias celebensis in South Sulawesi*, **Jurnal Ilmiah AgriSains**, **23**(2), 2022, pp. 1–8.
[47] M.A. Adel, *Effect of sex ratio on reproductive performance of broodstock Nile Tilapia (Oreochromis Niloticus) in suspended Earthen Pond Hapas*, **Journal The Arab Aquaculture Society**, **7**(1), 2012, pp. 19–28.
[48] M.A. Firmansyah, M. Mustahal, M.B. Syamsunarno, M. Herjayanto, *Optimization of reproduction of ricefish endemic to Southeast Sulawesi Oryzias woworae Parenti & Hadiaty, 2010 through different sex ratios in spawning*, **Jurnal Iktiologi Indonesia**, **21**(3), 2021, pp. 235–251.
[49] S.H. Nasution, S. Sulistiono, D. Soedharma, I. Muchsin, S. Wirjoatmodjo, *Kajian aspek reproduksi ikan endemik bonti-bonti (Paratherina striata) di Danau Towuti, Sulawesi Selatan*, **Indonesian Journal of Biologyry**, **4**(4), 2007, pp. 225–237.
[50] D.F. Mokodongan, R. Tanaka, K. Yamahira, *A new ricefish of the genus oryzias (Beloniformes, Adrianichthyidae) from Lake Tiu, Central Sulawesi, Indonesia*, **Copeia**, **3**, 2014, 561–567.
[51] A. Rinandha, S.B.A. Omar, J. Tresnati, D. Yanuarita, M.T. Umar, *Length-weight relationship and condition factors of matano medaka (Oryzias matanensis aurich, 1935) in towuti lake, south Sulawesi, Indonesia*, **AACL Bioflux**, **13**(4), 2020, pp. 1946–1954.
[52] A.R.P. Pane, H. Widiyastuti, A. Suman, *Parameter populasi dan tingkat pengusahaan rajungan (Portunus pelagicus) di perairan Asahan, Selat Malaka*, **BAWAL Widya Riset Perikanan Tangkap**, **9**(2), 2017, Article Number: 93.
[53] T. Noegroho, T. Hidayat, U. Chodriyah, M.P. Patria, B*iologi reproduksi ikan tenggiri (Scomberomorus commerson Lacepede, 1800) di perairan teluk kwandang, laut Sulawesi*, **BAWAL Widya Riset Perikanan Tangkap**, **10**(1), 2018, pp. 69–84.
[54] N. Hasanah, S.B.A. Omar, J. Tresnati, M.S. Nurdin, *Ukuran pertamakali matang gonad ikan medaka endemik Indonesia*, Jurnal Ilmiah Samudra Akuatika, **3**(2), 2019, pp. 31–35.
[55] A. Rinandha, S.B.A. Omar, J. Tresnati, D. Yanuarita, M.T. Umar, *Sex ratio and first maturity size of matano ricefish (Oryzias matanensis Aurich, 1935) at Lake Towuti, South Sulawesi, Indonesia*, **IOP Conference Series: Earth and Environmental Science**, **486**, 2020, Article Number: 012021.
[56] H. Widiyastuti, A. Zamroni, *Biologi reproduksi ikan malalugis (Decapterus macarellus) di Teluk Tomini*. **BAWAL Widya Riset Perikanan Tangkap**, **9**(1), 2017, pp. 63–71.
[57] S.H. Nasution, *Tingkat eksploitasi ikan endemik bonti-bonti (Paratherina striata) di Danau Towuti*, **Jurnal Biologi Indonesia**, **7(1)**, 2011, pp. 53–66.
[58] J.J. Mamangkey, S.H. Nasution, *Pertumbuhan dan mortalitas ikan endemik (Glossogobius matanensis Weber, 1913) Di Danau Towuti, Sulawesi Selatan*, **Berita Biologi**, **13**(1), 2014, pp. 31–38.
[59] J.A. Musick, *Criteria to define extinction risk in marine fishes: The American fisheries society initiative*, **Fisheries**, **24**(12), 1999, pp. 6–14.
[60] R.J. Beverton, S..J Holt, **On the Dynamics of Exploited Fish Populations**, Chapmann and Hall, 1957, 533p.
[61] S. Wargasasmita. *Ancaman invasi ikan asing terhadap keanekaragaman ikan asli*, **Jurnal Iktiologi Indonesia**, **5**(1), 2005, pp. 5–10.
[62] A.J. Reid, A.K. Carlson, I.F. Creed, E.J. Eliason, P.A. Gell, P.T.J. Johnson, *Emerging threats and persistent conservation challenges for freshwater biodiversity*, **Biological Reviews**, **94**(3), 2019, pp. 849–873.
[63] E.S. Kartamihardja, *Prospek pemanfaatan sumber daya ikan endemik di perairan umum daratan zona wallacea dalam mendukung pembangunan ekonomi masyarakat*, **Jurnal Kebijakan Perikanan Indonesia**, **6**(1), 2014, pp. 43–53.
[64] F. Herder, J. Möhring, J.M. Flury, L.V. Utama, L. Wantania, D. Wowor, *More non-native*

fish species than natives, and an invasion of Malawi cichlids, in ancient Lake Poso, Sulawesi, Indonesia, **Aquatic Invasions**, **17**(1), 2022, pp. 72–91.

[65] A.J. Whitten, K.D. Bishop, S.V. Nash, *Clayton L. One or More Extinctions born Sulawesi, Indonesia*? **Conservation Biology, 1**(1),1987, pp. 42–48.

[66] D.B. Bunnell, T.J. Miller, *An individual-based modeling approach to spawning-potential per-recruit models: An application to blue crab (Callinectes sapidus) in Chesapeake Bay*, **Canadian Journal of Fisheries and Aquatic Sciences**, **62**(11), 2005, pp. 2560–2572.

[67] A. Wujdi, H. Hartaty, B. Setyadji, *Estimasi parameter populasi dan rasio potensi pemijahan tongkol komo (Euthynnus affinis, Cantor 1849) di perairan selatan Lombok*, **Jurnal Penelitian Perikanan Indonesia**, **26**(2), 2020, pp. 93–107.

[68] F. Herder, U.K. Schliewen, M.F. Geiger, R.K. Hadiaty, S.M. Gray, J.S. McKinnon, *Alien invasion in Wallace's Dreamponds: Records of the hybridogenic "flowerhorn" cichlid in lake Matano, with an annotated checklist of fish species introduced to the Malili Lakes system in Sulawesi*, **Aquatic Invasions**, **7**(4), 2012, pp. 521–535.

Received: August 2, 2022
Accepted: February 10, 2023