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Research Article

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Length-weight Relationship, Condition Factor and DNA Barcoding of Bonylip Barb, *Osteochilus vittatus* (Valenciennes, 1842) in Dampelas Lake, Central Sulawesi, Indonesia

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ABSTRACT

Dampelas Lake, also known as Talaga Lake, in Central Sulawesi Indonesia, lacks data on fish communities, especially biological aspects, including a wild population of bonylip barb *Osteochilus vittatus (Valenciennes, 1842).* Locally known as ikan nilem, this freshwater fish commodity is not native to Sulawesi. The purpose of this research was to analyze the length-weight relationship, condition factor and DNA barcode of the bonylip barb population in Dampelas Lake. Bonylip barb specimens (101 males and 78 females) were collected from Lake Dampelas during July 2023 using fish traps. The total length and weight ranges were 57-211 mm and 3-107 g. Length-weight relationships were $W = 3\times10^{-5}\ L^{2,8219}$ (males); $W = 3\times10^{-6}\ L^{3,2574}$ (females); and $W = 1,1\times10^{-5}\ L^{3,0176}$ (both sexes combined), indicating an isometric growth pattern. Condition factor ranged from 0.471-1.652 with similar mean values for males (1.01) and females (1.02). DNA barcodes for Lake Dampelas bonylip barbs nested in one of four *O. vittatus clades,* indicating a need for reviewing *Osteochilus* taxonomy. Most adult females had spent gonads, indicating seasonal spawning, with implications for developing an economically viable fishery which could also help control this non-native species in Dampelas Lake*.*

Keywords: Cyprinidae, freshwater fisheries, growth pattern, introduced fish, mitochondrial DNA

ABSTRAK

Danau Dampelas, juga dikenal sebagai Danau Talaga, di Sulawesi Tengah, Indonesia, masih minim data komunitas ikan, terutama aspek biologis, termasuk khususnya populasi liar ikan nilem *Osteochilus vittatus* (Valenciennes, 1842). Dengan nama umum *bonylip barb*, komoditas air tawar tersebut tidak bersifat asli di Sulawesi. Tujuan penelitian ini adalah untuk menganalisis hubungan panjang-berat, faktor kondisi dan barcode DNA populasi nilem di Danau Dampelas. Spesimen ikan nilem (101 ekor jantan dan 78 ekor betina) dari Danau Dampelas tertangkap menggunakan bubu selama bulan Juli 2023. Kisaran panjang total 57-211 mm dan kisaran berat 3-107 g. Hubungan panjang-berat ikan nilem, $W = 3\times10^{-5}\ L^{2,8219}$ (jantan); $W = 3\times10^{-6}\ L^{3,2574}$ (betina); dan $W = 1,1\times10^{-5}\ L^{3,0176}$ (gabungan jantan dan betina), menunjukkan pola pertumbuhan isometrik. Faktor kondisi berkisar 0,471-1,652 dengan nilai rata-rata yang mirip antar ikan jantan (1,01) dan betina (1,02). Barcode DNA ikan nilem Danau Dampelas masuk pada salah satu diantara 4 clades *O. vittatus*, menunjukkan bahwa taksonomi *Osteochilus* perlu ditinjau kembali. Gonad ikan betina dewasa umumnya dalam kondisi *spent*, sebuah indikator pola pemijahan bermusim, dengan implikasi bagi pengembangan pemanfaatan yang layak secara ekonomis sekaligus membantu dalam pengendalian jenis ikan asing tersebut di Danau Dampelas.

Kata kunci: Cyprinidae, perikanan perairan tawar, pola pertumbuhan, ikan introduksi, *mitochondria*l DNA

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1. Introduction

Sulawesi in eastern Indonesia is the largest island in the Wallacea region, a zone with complex biogeographical patterns at the meeting between Asia, Australia and Pacific tectonic plates with their specific biota (Ambo-Rappe & Moore, 2019; Clewing *et al.,* 2020; Hutama *et al.,* 2016). Sulawesi is home to diverse flora and fauna (Pusparini *et al.,* 2023), including many native and endemic aquatic species (Hutama *et al.,* 2016; Miesen *et al.,* 2016; Mokodongan & Yamahira, 2015; Pomua, 2018; Stelbrink *et al.,* 2014; von Rintelen *et al.,* 2012, 2014). Within this biodiversity hotspot, the province of Central Sulawesi has many rivers and lakes that are rich in freshwater and diadromous fish and important sources of fisheries produce for local consumption, as well as nationally and globally traded food and ornamental commodities (Aoyama *et al.,* 2018; BPS, 2023; Gani *et al.,* 2021; Herjayanto *et al.,* 2019; Miesen *et al.,* 2016; Ndobe *et al.,* 2020, 2023; Ndobe, Gani, *et al.,* 2022; Serdiati *et al.,* 2013; Swiyanto *et al.,* 2018). Dampelas Lake close to the west coast in Donggala Regency (approximately 0° 11’ 57.54" S and 119° 51’ 13.1" E), also sometimes called Talaga Lake, has a surface area of around 542.6 ha, an average depth of around 20 m, and is one of the freshwater bodies in Central Sulawesi with fisheries potential (Herjayanto *et al.,* 2019; Putri *et al.,* 2015).

Indonesian lakes in general, and Sulawesi lakes in particular, are in general subjected or vulnerable to a wide range of threats and, with few exceptions, tend to be poorly managed, undervalued and understudied (Sunardi *et al.,* 2016). The increasing number of non-native fish in freshwater bodies, especially lakes, is a worldwide problem (Dudgeon, 2020) and one of the major threats to Sulawesi freshwater biodiversity and to fisheries based on native species (Herder *et al.,* 2012, 2022; Herjayanto *et al.,* 2019; Miesen *et al.,* 2016; Ndobe *et al.,* 2020, 2023; Serdiati *et al.,* 2020, 2021; Yanuarita *et al.,* 2020). Dampelas Lake is illustrative of these paradigms, as the few references available highlight the presence of introduced species (Herjayanto *et al.,* 2019; Muryanto & Sumarno, 2018; Putri *et al.,* 2015). In this context, the terms alien and introduced are considered synonymous and refer to a species or subspecies “moved by human activities beyond the limits of its native geographic range, or resulting from breeding or hybridization and being released into an area in which it does not naturally occur, and includes any part, gametes or propagule of such species that might survive and subsequently reproduce” (Pagad *et al.,* 2018).

Tilapia, cichlid fishes with natural ranges confined to Africa (especially strains of the Nile tilapia *Oreochromis niloticus*) are considered the most widespread alien species in Sulawesi freshwaters (Herjayanto *et al.,* 2019). However, a 2016 checklist of fishes in Sulawesi freshwaters reported 22 alien species introduced mainly for food production or through the aquarium trade, but also for other reasons, such as pest control programs (Miesen *et al.,* 2016), and it is likely that more have been released into the wild since then. According to the International Union for Conservation of Nature (IUCN), alien invasive species are defined as species that “are introduced by humans, either intentionally or accidentally, into places outside of their natural range, negatively impacting native biodiversity, ecosystem services or human economy and well-being” (IUCN, 2021), while the term invasive is defined under the Convention on Biological Diversity and applies to a “taxon whose introduction and/or spread threatens biological diversity” (Pagad *et al.,* 2018). Most of the alien fish introduced to Sulawesi freshwaters are widely recognized as invasive, *inter alia* the pacu (piranha relatives of the Serrasalmidae), armored catfish (family Locariidae) and other catfishes (genera *Clarias* and *Pangasius*), tilapias (genus *Oreochromis*), hybrid flowerhorn cichlid and other Cichlidae (Herder *et al*., 2012; Serdiati *et al*., 2020; Yanuarita *et al*., 2020). However, not all alien species are necessarily invasive, and some may become invasive under certain conditions but not in other instances (Colautti & MacIsaac, 2004).

One of the alien species found in Sulawesian freshwaters, the bonylip barb *Osteochilus vittatus* (Valenciennes, 1842), is a cyprinid fish native to southeast Asia, with a distribution including the Malay Peninsula, Sumatra, Java and Borneo (Froese & Pauly, 2023). With the Indonesian name ikan nilem, the bonylip barb is a popular fisheries and aquaculture species in Java and Sumatra, and can readily become the dominant species in freshwater bodies (Syamsuri *et al.,* 2018). Although not listed in the Global Register of Introduced and Invasive Species (Kraus *et al.,* 2020), *O. vittatus* is considered an alien invasive species in Poso Lake, where it is thought to have been released by migrants from Java (Serdiati *et al.,* 2020).

Native or long-established species reported from Dampelas Lake include valuable food fish such as the catadromous eels of the genus *Anguilla* (Herjayanto *et al.,* 2019) and the

Anabantiformes *Anabas testudineus* and *Channa striata* (Ndobe *et al.,* 2020; Putri *et al.,* 2015). However, these species are outnumbered by the list of recently introduced species, which include tilapia, common carp, and the barb *Osteochilus hasseltii* (Putri *et al.,* 2015). *Osteochilus hasseltii* is now considered an unaccepted synonym of *O. vittatus*, the bonylip barb (Froese & Pauly, 2023). Although there does not seem to be an official record of the introduction of *Osteochilus* sp. to Dampelas Lake, the introduction is thought to have been unintentional. Juvenile barbs were probably introduced together with juveniles of other, deliberately stocked alien species such as tilapia (Putri *et al.,* 2015). As in Poso Lake (Serdiati *et al.,* 2020), the people living around Talaga Lake do not favor the bonylip barb as a food fish (Putri *et al.,* 2015). Consequently, due to the lack of fishing pressure, the bonylip barb was able to establish a wild population that, by 2013, was sufficiently abundant to raise concern regarding the ecological balance of the lake ecosystem, including the native species present in Dampelas Lake.

In order to manage the fisheries resources of Dampelas Lake, it is important to study and monitor fish stocks, including the potentially invasive alien species that could negatively impact aquatic biodiversity. A study on some aspects of the population biology of the bonylip barb in 2013 (Putri *et al.,* 2015) provides useful information; however, data on the bonylip barb population in Dampelas Lake are still limited and can be considered out-of-date. Furthermore, it is important to ensure the identity of the species present and to evaluate the kinship with other populations of the same species (Mochamad et al., 2020). In view of the importance of accurate and up-to-date data on stock characteristics for fisheries management, the purpose of this research was to study key characteristics of the bonylip barb (*O. vittatus*) in Dampelas Lake, in particular the length-frequency, length-weight relationship, growth pattern, and condition factor (overall and disaggregated by sex), sex ratio, DNA barcoding and phylogenetic analysis, and to evaluate the implications for the management of the introduced *O. vittatus* population in Dampelas Lake.

2. Material and Methods

2.1. Study site and sample collection

The study site was Dampelas Lake, in Talaga Village, Dampelas District, Donggala Regency, Central Sulawesi Province, Indonesia (Figure1). The lake is generally calm with little or no current and a sandy substrate. Sago palms grow around the lake margins, and the lake is a local tourist attraction. Bonylip barb samples were collected by local fishermen using fish traps (35 cm wide, 110 cm long, and 50 cm high). The fish traps were set in the morning around 7 a.m. and collected in the late afternoon, around 5 p.m. The

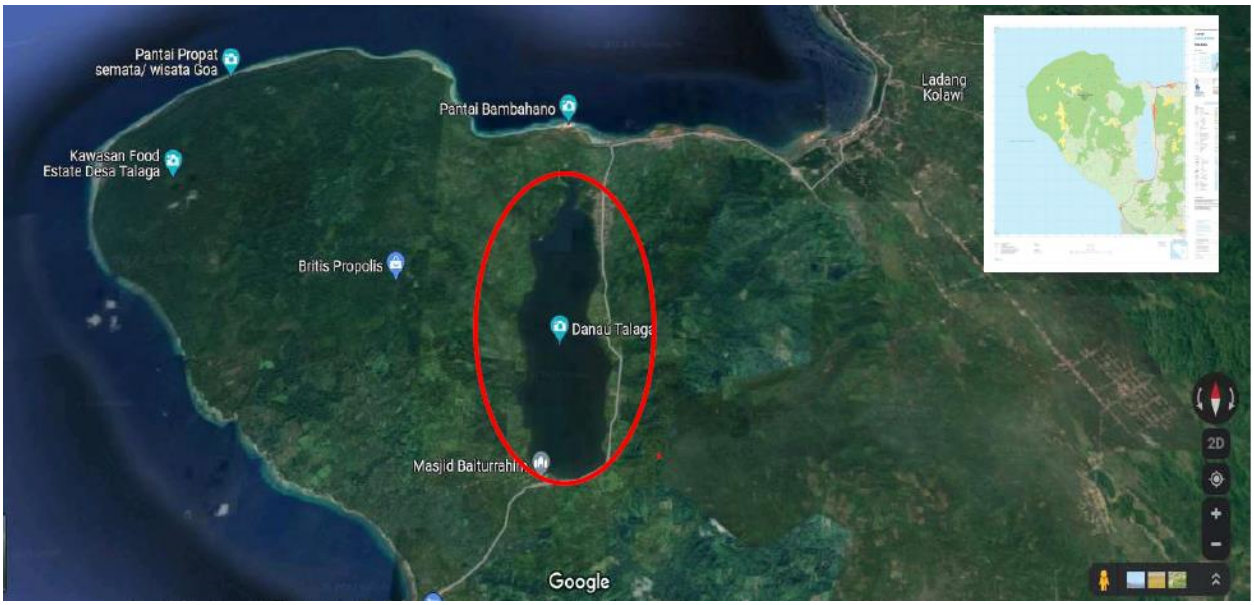

Figure 1. Map of the study site: Dampelas Lake (within the red oval) in Donggala Regency, Central Sulawesi Province, Indonesia (Source: https://www.google.com/maps/; teal marker “Danau Talaga” at 0° 10' 48.58" S, 119° 51' 0.21" E)

specimens collected (n = 179) were euthanized and measured before being carefully placed in an insulated cool box with crushed ice to keep the fish in good condition during transport to the Water Quality, Aquatic Biology, and Aquaculture Pathology Laboratory, Faculty of Animal Husbandry and Fisheries, Tadulako University in Palu City. Tissue samples were taken from two bonylip barb specimens as well as from one tilapia and one blue panchax specimen. Each sample was placed in a labelled Eppendorf tube filled with 96% absolute ethanol for molecular (genetic) analysis.

2.2. Data collection

Measurements collected in the field were total length (TL) and weight. A fish ruler with 1 mm precision was used to measure TL (from the tip of the snout to the tip of the tail). Each specimen was weighed on digital scales with 0.01 precision. Sex was determined in the laboratory through dissection and observation of the gonads and for mature females the gonad condition was noted.

2.3. DNA Barcoding

A sample of approximately 10 g was taken from the preserved tissue of each specimen for DNA extraction using Qiagen blood and tissue kits following the Qiagen protocols. The target DNA barcode was a portion of the cytochrome oxidase I mitochondrial DNA gene (COI mtDNA) which was amplified through Polymerase Chain Reaction (PCR) on an Applied Biosystems™ 2720 Thermal Cycler machine following BIONESIA laboratory protocols. The primer pair used to amplify the target DNA was FISH F1 (5'-TCA ACC AAC CAC AAA GAC ATT GGC AC-3') and FISH R1 (5'-TAG ACT TCT GGG TGG CCA AAG AAT CA -3') (Ward et al., 2005). Each PCR reaction tube (26 µL volume) contained the following mix: 2 µL DNA template, 1.25 µL of each primer (10 mM concentration), 9 µL ddH2O, and 12.5 µL Ready mix. The PCR profile was as follows: initial denaturation at 94 °C for 3 min; 38 cycles of denaturation (94 °C for 30 s), annealing (50 °C for 30 s), extension (72 °C for 60 s); and final extension at 72 °C for 2 min. The PCR results were then visualized on 1% Agarose gel with Nucleic Acid Gel Stain (GelRed®) staining. Samples that were positive (luminescent DNA bands) were then sent to PT. Genetic Science, Jakarta for Sanger dideoxy sequencing. The DNA barcode sequences received in the form of chromatogram trace files (.abi files) were edited to trim ambiguous nucleotides and to combine the forward and reverse sequences for each specimen in MEGA 11 (Tamura *et al*., 2021)

2.4. Data Analysis

Morphological and biological data were tabulated and data analyses were conducted in Microsoft Excel 365. Length-frequency histograms were produced in RStudio (RStudio Team, 2016) using the ggplot2 package (Wickham, 2016). Average values were shown as mean ± standard deviation (SD). Statistical significance was evaluated at the 95% confidence level (α = 0.05) throughout. Sex ratio was calculated as the ratio of males to females (M:F) in the sample. The chi-square test was used to test whether the sex ratio was significantly different from 1:1. The length-weight relationship can be used to determine the growth pattern. The relationship was determined for the sample as a whole and disaggregated by sex from the total length and weight data based on the following equation in (Froese, 2006):

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

where:
W = fish body weight (g)
L = total length (mm)
a = intercept
b = regression coefficient

The growth pattern is isometric if $b = 3$, allometric positive or hyperallometric if $b > 3$ and allometric negative or hypoallometric if $b < 3$. After logarithmic transformation, the quadratic regression method was applied to calculate the values of the constants *a* and *b*, giving the equation:

$$\log W = \log a + b \log L \quad (2)$$

To determine whether *b* was significantly different from 3, the t-test was applied using the following equation:

$$T_{val} = |(b-3)\ Sb^{-1}| \quad (3)$$

where:
t_{val} = t-value
b = regression coefficient
Sb = standard error of *b*

The t-test was also used to compare the regression coefficient *b* values for male and female bonylip barbs. The regression coefficient b value was considered to differ significantly between the sexes if $t_{val} > t_{tab}$, and vice-versa.

The Fulton's condition factor (K) for each individual fish is obtained by comparing the weight measured to the cube of the length (Froese, 2006). The Fulton's condition factor (K) was calculated and the t-test was used to

determine the significance of the between-sex difference. The following equation was used to determine the Fulton's condition factor K:

$$K = 10^5 W L^{-3} \quad (4)$$

where:
K = Fulton's condition factor
W = body weight (g)
L = total length (mm)

The phylogenetic analysis involved the four DNA barcodes obtained from this study as well as 40 homologous COI-mtDNA barcode sequences obtained from the NCBI GenBank using the BLAST-n routine with default parameters. The sequences were aligned and trimmed (to 630 positions) and a Neighbor-Join (Saitou & Nei, 1987) tree was produced in MEGA 11 (Tamura et al., 2021) and edited in the interactive tree of Life (iToL) (Letunic & Bork, 2021). Evolutionary distances (number of base substitutions per site) were computed using the Maximum Composite Likelihood method (Tamura et al., 2004) with 1000 bootstrap replicates (Felsenstein, 1985).

3. Result and Discussion

3.1. Sex ratio and length-frequency distribution

The specimens collected (n = 179) comprised 101 male and 78 female bonylip barbs giving a sex ratio (M:F) of 1.295:1 and mean length 118 ± 19 mm. Although male-biased, the sex ratio was not significantly different from 1 (chi-square test, p = 0.19 > 0.05). On average, female bonylip barbs were larger (both longer and heavier) than males (Figure 2). The total length ranges were 57-180 mm (mean 114 ± 19 mm) for males and 86-211 mm (mean 123 ± 20 mm) for females. Weight ranges were 3-100 g (mean 16 ± 10 g) for males and 5-107 g (mean 21 ± 13 g) for females. The between sex differences were significant for both length (p = 0.001 < 0.05) and weight (p = 0.004 < 0.05). The overall and sex-aggregated length-frequency distributions were approximately normal, with similar mean, median, and mode values for total length and weight. The maximum size Lmax in this study was 211 mm, relatively small compared to an Lmax of 320 mm given in FishBase (Froese & Pauly, 2023), and close to the common length given for this species (200 mm).

The sex ratio observed in this study was not significantly different to 1:1, although the sample was numerically male-biased. According to (Jusmaldi *et al.,* 2020b), the sex ratio of bonylip barbs can be affected by environmental factors, especially temperature, with lower temperatures encouraging female bias and higher temperatures encouraging male bias. In this context, the male bias in this study could be due to higher temperatures in Dampelas lake, both due to its position closer to the equator than other sites in Table 1 (Figure 1) and the general increase in global and local temperatures (Lee & Romero, 2023; Ningsih *et al.,* 2023), with many temperature anomaly records broken in 2023 (Cheng *et al*., 2024), and a range of likely impacts on freshwater ecosystems and fishes (Armitage, 2023; Scherer *et al*., 2023).

Compared to data from 10 years ago at the same site (Putri *et al.,* 2015), on average the size of bonylip barb in Dampelas Lake appears to have declined, and can also be considered low compared to the majority of other populations with size range data in Table 1. However, the size range in this study was similar to that reported from a reservoir (Waduk Benanga) in East

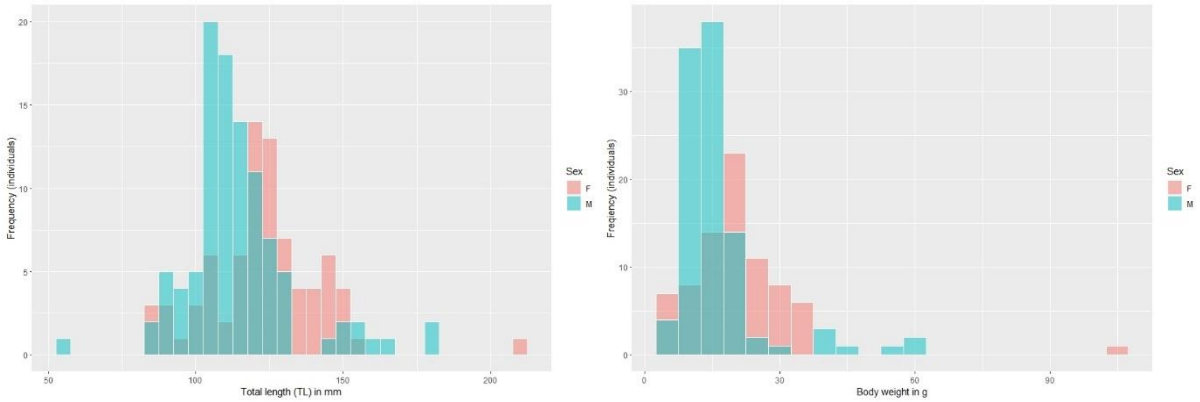

Figure 2. Histogram of Dampelas lake bonylip barb *Osteochilus vittatus* total length (a) and weight (b) disaggregated by sex

Table 1. Population parameters of bonylip barbs (*Osteochilus vittatus*) from Dampelas Lake and other populations

No	Location	n	Sex	Size range (to nearest integer)		Length-weight parameter *b*	Growth pattern[a]	Sex ratio (M:F)	Fulton's Condition factor	Source
				Length (mm)	Weight (g)					
1	Dampelas Lake, Central Sulawesi (2023)	179	Both	57-211	3-107	3.015	IS	1.3:1	1.016 ± 0.139	This study
		101	M	57-180	3-100	2.818	IS			
		78	F	86-211	5-107	3.257	IS			
2	Dampelas Lake, Central Sulawesi (2013)	413	Both	110-227	16-171	2.838	AN	0.55:1	No data	(Putri *et al*., 2015)
		105	M	No data	No data	2.590	AN			
		192	F	No data	No data	2.888	AN			
3	Waduk Benanga, East Kalimantan	92	M	77–194	5–79	No data	No data	0.49:1	No data	(Jusmaldi *et al*., 2020a)
		186	F	72–197	4–89					
4	Waduk Benanga, East Kalimantan	278	Both	72-197	4-89	3.126	AP	0.49:1	1.026±0.150	(Jusmaldi *et al*., 2020b)
		92	M	77–194	5–79	2.967	IS		1.181±0.117	
		186	F	72–197	4–89	3.199	AP		0.949±0.094	
5	Sidenreng Lake, South Sulawesi	143	M	124-191	19-85	No data	No data	0.26:1	No data	(Omar, 2010)
		549	F	118- 256	22-237					
6	Temengor Reservoir, Malaysia	357	Both	108 - 252 (191±30)	16 - 232 (95±102)	3.038	IS	No data	1.215 ± 0.162	(Hamid *et al*., 2015)
7	Singkarak Lake, Sumatra	27	F	162 - 283	No data	3.338	AP	0.41:1	No data	(Froese & Pauly, 2023)
		11	M	145 - 226		3.480	AP			
8	Various locations in Malaysia and Thailand	>800	Both	50 - 283	No data	2.85-3.31 (mean 3.13 ± 0.156)	IS	No data	No data	(Froese & Pauly, 2023)

[a] IS = Isometric; AN = Allometric negative; AP = Allometric positive

Kalimantan (Jusmaldi *et al.,* 2020a,b) and not much lower than in Sidenreng Lake, South Sulawesi (Omar, 2010). The relatively small size could be related to environmental factors, including temperature, as predicted by the gill oxygen limitation theory (Pauly, 2021), which also explains how population density can affect the size attained by fish when oxygen is limited, such as in a lake.

Water quality data collected at five points around Dampelas Lake over 4 months (July-October 2023) and from other bonylip barb population sites in Indonesia (Table 2) indicate that, in 2023, water temperatures in Dampelas Lake were consistently in excess of 30^{o} C, higher than for any of the other sites. DO levels fluctuated but were mostly below 5 ppm, and in general lower than for any of the other sites. Salinity ranged from 0 to 3 ppt, indicating some marine influence in this coastal lake. The pH was close to neutral at one station, with mostly acidic and mostly basic conditions at two stations each, but was generally within the range reported from other sites. No references were found on the thermal niche or tolerance to low DO of *O. vittatus*. However, the abundant population indicates that water quality parameters in Dampelas Lake are within tolerances for *O. vittatus*, although they may not be optimal for this species.

Similar to this study, in 2013 the smallest *O. vittatus* specimens were males and the largest females, even though there was a wide overlap in size between the sexes (Putri *et al.,* 2015). A similar pattern has also been observed at several other sites, including Singkarak Lake in Sumatra, within the native range (Froese & Pauly, 2023), and the introduced population in Sidenreng Lake, South Sulawesi (Omar, 2010). Despite their relatively small average size, most of the fish sampled appeared mature based on observation of the gonads, indicating a lower length at first

maturity (Lm) compared to values given in FishBase (Lm ≈ 192 mm, range 180-202.35 mm). The substantially lower Lm values compared to FishBase (Froese & Pauly, 2023) for the introduced population in Sidenreng lake, South Sulawesi (Omar, 2010) and Waduk Benanga, East Kalimantan (Jusmaldi *et al.,* 2020a) support the likelihood of lower Lm values in Dampelas Lake. Furthermore, Omar (2010) found that males tend to mature at a smaller size (Lm ≈ 147 mm, range 140-154 mm) than females (Lm ≈ 150 mm, range 137-164 mm), consonant with the general trend of smaller average size and size range values for males compared to females, although Jusmaldi *et al*. (2020a) found similar values for males (Lm ≈ 136, range 129-142 mm) and females (Lm ≈ 137, range 129-142 mm).

The ovaries of the adult females were mostly in spent condition, indicating recent spawning. According to Omar (2010), *O. vittatus* is a total spawner, meaning that each individual spawns once in each reproductive cycle, with females releasing all their eggs at once or over a short period of time. The spent condition in late July in this study is consonant with the data from 2013 (Putri *et al.,* 2015) where the proportion of individuals with matured ovaries increased from very few individuals in March to most individuals in June, indicating that *O. vittatus* in Dampelas Lake most likely spawn in late June/early July. A similar pattern was observed in the Sidenreng lake introduced population, with the proportion of mature gonads increasing from march to May and mainly spent gonads in both sexes observed in June (Omar, 2010), slightly earlier than in Dampelas Lake. This indicates possible interannual or between-site variability in the timing of *O. vittatus* spawning.

3.2. Length-weight relationship

The length-weight relationship (Figure 3) yielded values of the regression coefficient *b* for male (*b* = 2.8175) and female (*b* = 3.2574) bonylip barb, with *b* = 3.0151 for the combined data set. None of the three *b* values differed significantly from 3 (t-test, $p > 0.05$), indicating isometric growth for both sexes.

The isometric growth pattern of the bonylip barbs in Dampelas Lake indicates that the fish grow proportionately in all three dimensions and therefore retain a similar body shape throughout the life-cycle phases represented within the sample collected. The values of *b* obtained were well within the range observed in other studies where *b* was generally close to 3, even for cases reported as allometric (Table 1). However, as the sample did not include early life-stages, the growth pattern may differ for juveniles.

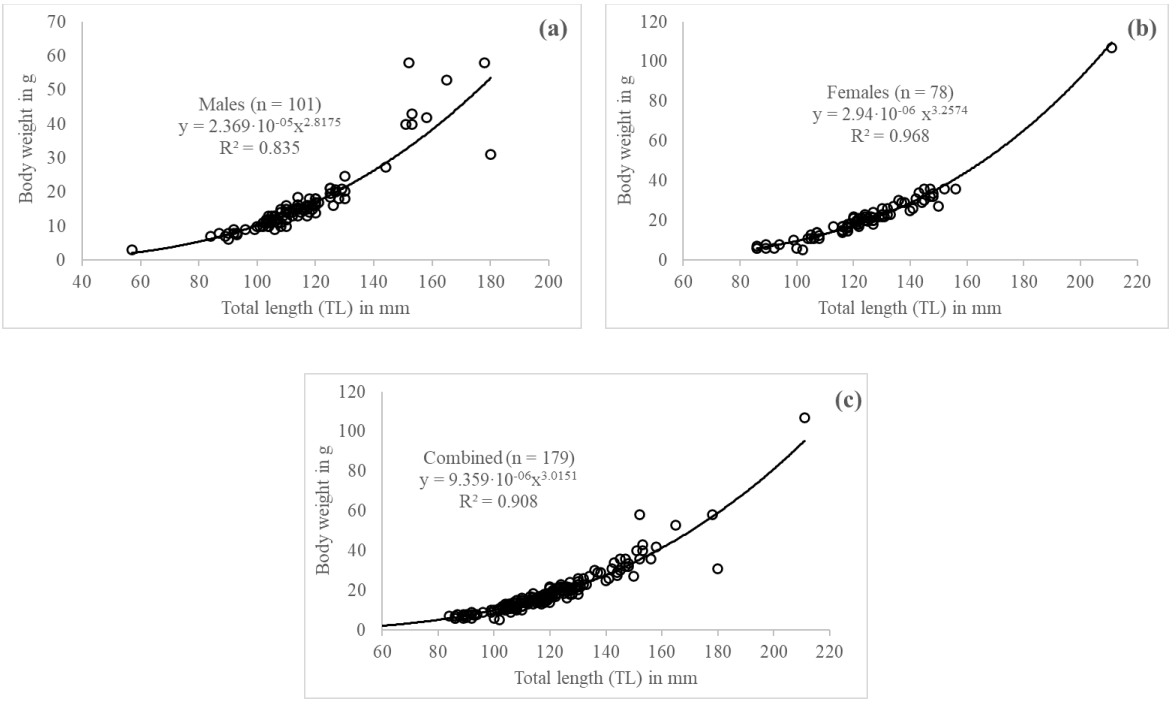

Figure 3. Length-weight relationship of bonylip barb *Osteochilus vittatus* from Dampelas Lake: males (a), females (b) and both sexes combined (c).

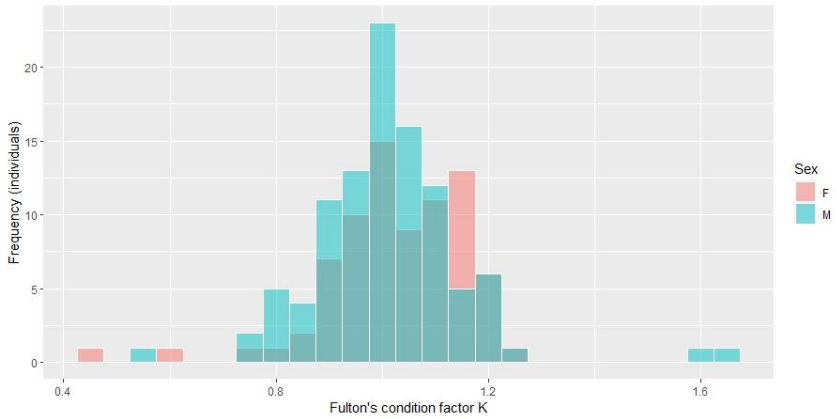

Figure 4. Fulton's condition factor of Dampelas Lake bonylip barb *Osteochilus vittatus* (n = 179) by sex

3.3. Condition factor

The overall Fulton's condition factor K range was 0.471-1.652 (mean 1.016 ± 0.139), with an approximately normal distribution (Figure 4). Condition factor for males was, on average, slightly lower (1.01 ± 0.15) than for females (1.02 ± 0.13), but the difference was not statistically significant (p = 0.55 > 0.05). The condition factor of most individuals was close to 1, indicating that the majority of individuals sampled were in a good or healthy condition, as also indicated by the isometric growth pattern of the population. Condition factor can vary between individuals and populations and over time for the same individual or population. Factors affecting fish condition factor include internal factors such as life-cycle and reproductive stage, sex, and general health issues as well as eternal factors such as food availability, water quality, and any environmental stress factors (Froese, 2006). Higher mean condition factor values in female fish compared to males have been reported in other *O. vittatus* populations (Jusmaldi *et al.,* 2020b) and in other fishes (Ahmadi, 2019; Panicker & Katchi, 2021). The similar condition factor of female bonylip barbs compared to males in this study may be due to the reproductive cycle, while the value close to or above 1 indicates that the environment in Dampelas Lake is conducive for the continued

Table 2. Water quality data from Dampelas Lake and other *Osteochilus* populations in Indonesia

Location/ Island	Species	Temperature (°C)	DO (mg/L)	pH	Reference (remarks)
Dampelas Lake, Sulawesi	*Osteochilus vittatus*	30-32.8 (31.3±0.8)	3-7.7 (4.6±1.4)	5-8.3 (6.9±1.0)	Unpublished data[a] (July-October 2023)
Poso Lake, Sulawesi	*Osteochilus vittatus*	26-28.5	6.0-6.9	8.0-8.5	Serdiati *et al*. (2020)[b] (May 2017 - April 2018)
Leuser watershed, Sumatra	*Osteochilus vittatus*	24-28	5.2-6.7	5.8-9.1	Hidayat *et al*. (2023)
Wampu watershed, Sumatra	*Osteochilus hasseltii*	24.6-27.5	7.1-8.45	7.2-8.3	Desrita *et al*. (2018) (2017)
Grow-out ponds, Java	*Osteochilus hasseltii*	22-28	5.2-5.7	6.2	Syamsuri *et al*. (2018) (2017)

[a] Data from a survey and monitoring program for Dampelas Lake. Data were collected from July to October 2023 at five sites around the lake.
[b] Historical data from 2007-2013 record temperatures up to 30.4° C and show lower DO and pH associated with higher temperatures in 2010-2012.

Table 3. DNA barcode (COI mtDNA) sequences from Dampelas Lake

Dampelas Lake Specimen Code	GenBank	Nearest GenBank Accession(s) Species	Accession	Origin	% cover	%ID
2023DAMP001	OR742018	*Osteochilus vittatus*	KU692714.1	Central Java [a]	99	100
and	and	*Osteochilus vittatus*	OR674043.1	Poso Lake [b]	99	100
2023DAMP003	OR742020	*Osteochilus vittatus*	AP013320.1	Unknown [c]	100	98.78
		Osteochilus vittatus	MN243482.1	Sumatra [d]	100	98.78
2023DAMP002	OR742019	*Aplocheilus panchax*	KU692268.1	East Java [a]	97	100
2023DAMP004	OR742021	*Oreochromis niloticus*	MG438454.1	Thailand [e]	100	100

[a] Dahruddin *et al*. (2016); [b] Ndobe *et al*. (2023, unpublished); [c] Miya *et al*. (2013, unpublished); [d] Ariyanti *et al*. (2021); [e] Panprommin *et al*. (2019).

presence and even possibly further growth of the bonylip barb population, despite the comparatively highwater temperatures associated with lower pH and DO compared to other bonylip barb habitat (Table 2).

3.4. DNA Barcoding

The DNA barcodes (COI mtDNA sequences) obtained from this study and the closest GenBank accessions for each of our sequences (Table 3) confirm the morphological identification of each specimen. GenBank accession numbers allocated to our sequences are also shown in Table 3. The DNA barcodes were 672 bp in length, and the two *O. vittatus* sequences were identical. There was very high cover and 100% identity with a sequence recently obtained from the introduced population in Poso Lake (OR674043.1), also in Central Sulawesi, and a sequence from the native distribution in Central Java (Dahruddin *et al*., 2016). Sequences with 100% cover and relatively high identity included a sequence from the native distribution in Sumatra (Ariyanti *et al*., 2021) and a sequence deposited by a Japanese team, from a specimen of unknown origin. The other two taxa had high or 100% coverage and 100% identity with sequences from several other introduced populations of Nile tilapia (*O. niloticus*) and blue panchax (*A. panchax*), with a representative accession for each taxon shown in Table 3.

3.5. Phylogenetic Analysis

The Neighbor-Join phylogenetic tree (Figure 5) was constructed using *O. niloticus* and *A. panchax* as outgroups and comprised four nominal species of the genus *Osteochilus* (*O. hasseltii*, *O. kahajanensis*, *O. microcephalus*, *O. vittatus*) as well as sequences labelled as *Osteochilus* sp. and a sequence deposited as *Neolissochilus hexagonolepis* (OQ151823.1). Sequences submitted as *O. vittatus* and *O. hasseltii* were all labelled *O. vittatus* as these taxa are currently considered as synonyms with *O. vittatus* as the valid name (Froese and Pauly, 2023).

Among the *Osteochilus* and related taxa, only *O. microcephalus* formed a single well-defined clade. *Osteochilus vittatus* formed multiple clades, most of which included sequences deposited under both synonyms (*O. vittatus* and *O. hasseltii*). The two Dampelas lake specimens nested with 100% bootstrapping confidence within one clade, together with two of the GenBank accessions in Table 3. The other two accessions in Table 3 nested within the sister clade labelled as *Osteochilus* spp. clade, together with accessions labelled as *N. hexagonolepis* (OQ151823.1), *O. kahajanensis* (HM345943.1 and HM345944.1), and *Osteochilus* sp. (e.g. JX074151.1 and AP013320.1). These two sister clades were separated from all other clades by distances consonant with different species. These results indicate widespread taxonomic confusion within the genus *Osteochilus* and possibly even at the genus level, given the inclusion of *N. hexagonolepis* in one of the *Osteochilus* clades. Which clade(s) actually represent the taxon *O. vittatus*/*O. hasseltii* could probably be determined if it is possible to examine and sequence type or paratype material (Chen *et al*., 2022) or, alternatively, as for sweetlips (Haemulidae), based on specimens from the type locality of each species (Damadi *et al*., 2023). Further studies integrating classical taxonomic and molecular biology methods are required to determine the number of species in the genus *Osteochilus*, their respective taxonomic identity, and diagnostic characters.

3.6. Fisheries management considerations

The characteristics of bonylip barbs (*O. vittatus*) in Dampelas Lake in July 2023 are mostly within the ranges reported in past studies on this population and in studies on other populations (Table 1). The non-native bonylip

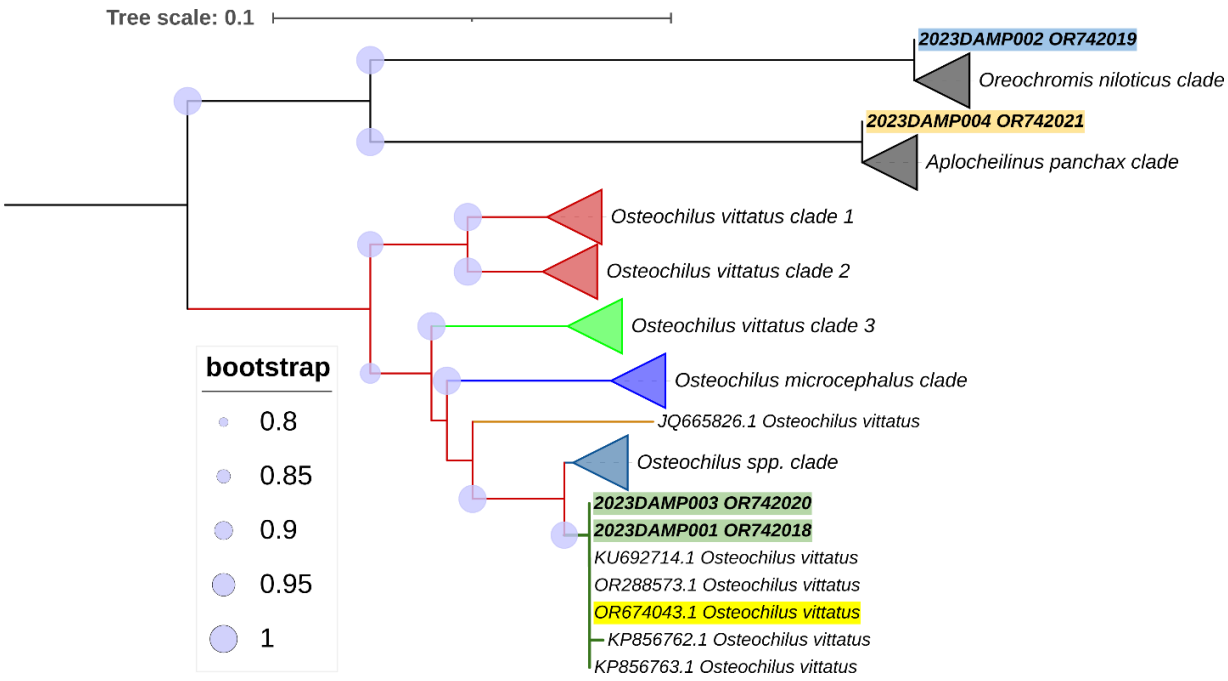

Figure 5. Phylogenetic tree of *Osteochilus* and related taxa (COI mtDNA barcode, Neighbor-Join with X 1000 bootstrapping, *O. niloticus* and *A. panchax* as outgroups, 630 nucleotide positions). Colored highlighting indicates sequences from this study or other Sulawesi lakes

barb *O. vittatus* has become the most abundant fish in Dampelas Lake, comprising the majority of the catch in the fish traps used during this study. This was already the case in 2013, when bonylip barbs comprised 57-88% of experimental fishing catches over five months (Putri *et al.,* 2015). Once established, wild populations of invasive fish such as *O. vittatus* are extremely hard to eradicate, and effective eradication methods can also lead to the eradication of native species (Sorensen, 2021); therefore, in many cases, the best option is to control the population through fishing. Ideally fishing pressure should meet or even exceed sustainable limits to control or ideally reduce the population abundance.

However, at present fishing pressure on bonylip barbs in Dampelas lake is low, and limited to unvalued or even rejected or released by-catch. Like most Central Sulawesi residents, the people living around Dampelas Lake prefer a range of freshwater and marine fishes. These include the other species found in the lake such as the native or long-established striped snakehead (*Channa striata*) and climbing perch (*Anabas testudineus*) as well as other (also invasive) alien species such as tilapia (*Oreochromis niloticus*, *O. mossambicus*) and common carp (*Cyprinus carpio*) (Ndobe *et al.,* 2020; Putri *et al.,* 2015).

Although popular in Java and Sumatra within its native range, there has been insufficient economic incentive to fish bonylip barb in Dampelas Lake as a commodity for inter-island trading. This situation raises the challenge of developing market demand to drive fishing in order to control the introduced population. Fish gonads, often called roes, are generally very nutritious (Ma *et al.,* 2020). Many are considered delicacies, and roe products from many fish and aquatic invertebrates can contribute to sustainable global and local food security (Mouritsen, 2023). In Indonesia, one example of a fishery targeting fish eggs is the collection of flying fish eggs (Halim *et al.,* 2020), indicating the potential for market acceptance. As a total spawner, shortly before spawning bonylip barb gonads are quite large, and anecdotal information indicates that they could be developed as a premium food product. Based on the data from this and previous studies, a seasonal fishery could then be developed to target pre-spawning bonylip barb, with the potential to provide economic benefits to the Dampelas Lake fishing community while reducing pressure on native fish in the lake.

4. Conclusions

The introduced bonylip barb *Osteochilus vittatus* population in Dampelas Lake, Central Sulawesi, appears well established as a wild population of an alien invasive species. The sex ratio was balanced. The relatively small average

size was possibly due to environmental factors, in particular relatively high water temperature and low dissolved oxygen levels compared to other *O. vittatus* populations, and/or population density. Nonetheless, the bonylip barbs were generally in good condition with isometric growth and Fulton's condition factor close to 1. DNA barcoding and phylogenetic analysis indicate that *O. vittatus* in Dampelas Lake are closely related to at least one Javanese population and to the introduced population in Poso Lake, and highlights the need for research to resolve taxonomic uncertainties within the genus *Osteochilus*. Based on the oviparous total spawner reproductive pattern of the bonylip barb, developing a seasonal fishery together with processing and market chains to exploit the mature gonads could have both environmental and economic benefits.

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