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First and recurrent records of *Stiphodon surrufus* Watson & Kottelat, 1995 (Gobiiformes, Gobiidae, Sicydiinae), a naturally rare amphidromous goby, in Sulawesi, Indonesia

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Abstract

Stiphodon surrufus Watson & Kottelat, 1995, with its recent synonym *S. birdsong* Watson, 1996, is recorded from widely separated locations in the Western Pacific, including Papua and Halmahera in eastern Indonesia. We collected a single specimen of male *S. surrufus* from the Bohi River, Banggai District, Central Sulawesi Province, Indonesia in 2019; this represents the first record of *S. surrufus* from Sulawesi, the largest island in the Wallacea biodiversity hotspot. Three additional specimens were collected in 2020, one in 2021, and two in 2022, all from the same site. These records expand the known distribution of a naturally rare but widespread sicydiine goby and contribute to the underexplored but increasingly threatened Sulawesian riverine ichthyofauna.

Keywords

Bohi River, Gobiidae, Luwuk Banggai, range extension, Sicydiinae, Wallacea

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Introduction

Sicydiine gobies of the genus *Stiphodon* M.C.W. Weber, 1895 are distributed in subtropical and tropical freshwater streams from Sri Lanka to French Polynesia, and from the Ryukyu Islands, Japan to north-eastern Australia, including the Indonesian Archipelago (Keith et al. 2011). Many sicydiine gobies have an amphidromous life cycle (McDowall 1999; Ebner et al. 2011; Keith and Lord 2012). The adults of several genera, including *Stiphodon*, are generally confined to clear, often fast-flowing streams (Ebner et al. 2011; Keith and Hadiaty 2014; Keith et al. 2015a). Amphidromous gobioid post-larvae recruiting to freshwater typically form multi-species shoals which can include *Stiphodon* species (Nurjirana et al. 2019; Sahami and Habibie 2020). These post-larval shoals are heavily fished for human consumption in some areas (Keith and Lord 2012), including Sulawesi (Ambo-Rappe and Moore 2019; Sahami and Habibie 2020). Furthermore, a growing number of sicydiine gobies, including the genus *Stiphodon*, are increasingly sought for an expanding niche market in the freshwater aquarium trade (Ebner et al. 2011; Maeda and Tan 2013; Seriously Fish 2021). Like the post-larval fisheries, the emerging fisheries for ornamental amphidromous gobies in Sulawesi are at present unregulated and mostly unreported. Responsible fisheries management relies on knowledge of, in particular, species' distributions (Caddy 1996).

Riverine gobies in the Indo-Pacific, including Indonesia, are understudied, as reflected by recent surveys of Indonesian riverine ichthyofauna which have resulted in the description of new species (Keith and Hadiaty 2014; Keith et al. 2015b, 2020), as well as range extensions for previously described species (Keith et al. 2015c; Gani et al. 2021a). Conversely, some nominal species are now regarded as synonyms; for example *Stiphodon birdsong* Watson, 1996 is now considered a junior synonym of *Stiphodon surrufus* Watson & Kottelat, 1995 based on morphological (Keith et al. 2015a) and genetic (Lor 2016) characters. Incorporating reports for *S. surrufus* and *S. birdsong*, this taxon is known from regions with a latitudinal range from Yukushima Island (Ryuku Islands), southern Japan (Yonezawa et al. 2010) to north-eastern Australia (Ebner et al. 2011) and a longitudinal range from Leyte Island, Philippines (Watson and Kottelat 1995) to the Solomon Islands (Boseto et al. 2007). The known range of *S. surrufus* also includes Palau (Lor 2016), Halmahera, Papua and Biak in eastern Indonesia, and Papua New Guinea (Watson 1996; Watson et al. 1998).

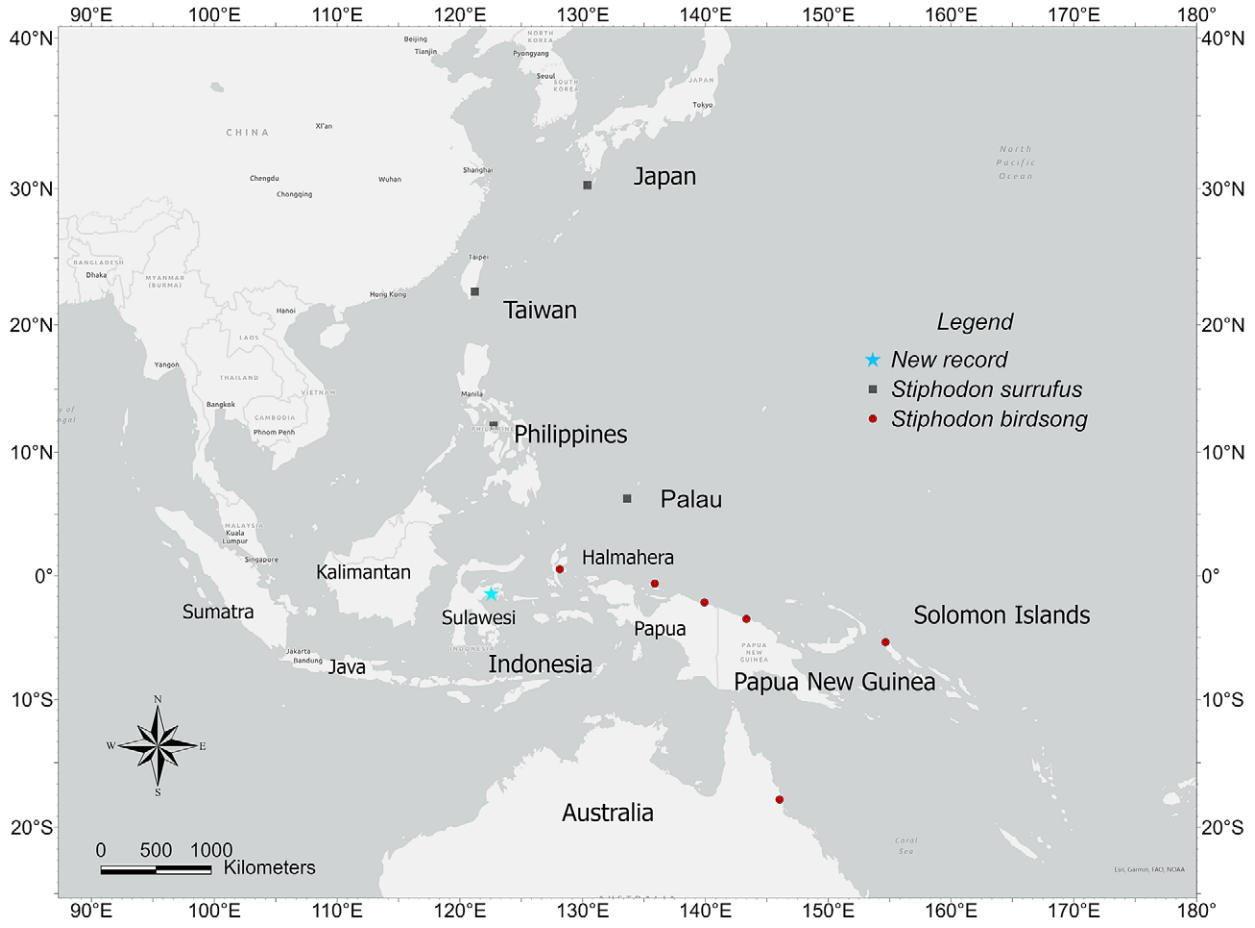

Figure 1. Recorded distribution of *Stiphodon surrufus* in the Western Pacific region. The blue star denotes the recent record from Central Sulawesi, Indonesia; black squares indicate previous records originally reported as *S. surrufus* and red circles indicate records originally recorded as *S. birdsong*. Data sources: Boseto (2012); Ebner et al. (2011); Keith et al. (2015); Lor (2016); Sakaue (2007) in Jaafar (2018); Watson and Kottelat (1995); Watson (1996); Watson et al. (1998); Yonezawa et al. (2010); Zhou and Gao (2011) in Jaafar (2018).

During an expedition to explore the gobioid ichthyofauna of the Luwuk Banggai region in Central Sulawesi Province on the eastern side of Sulawesi Island, Indonesia, on 15 November 2019 we collected a specimen of *S. surrufus* from the Bohi River. This specimen represents the first record of *S. surrufus* from Sulawesi, the largest island in Wallacea, and a westward extension of the known geographic range of this species (Fig. 1). Six additional specimens were subsequently collected from the same site.

Methods

Specimens of *S. surrufus* were caught with a scoop net in the upper reaches of the Bohi River, about 6 km from the sea (Gulf of Tolo) in Luwuk Subdistrict, Banggai District, Central Sulawesi Province, Indonesia (Fig. 2). Here, the Bohi River is a swiftly flowing stream with crystal clear waters running over a mixed rocky and sandy substrate through dense rainforest (Fig. 3). All specimens were euthanized with MS222, preserved in 96% ethanol (Hasan and Tamam 2019), and deposited at the Dry Laboratory, Fish Quarantine, Quality Control and Fisheries Product Safety Station, Luwuk Banggai, Indonesia (FCLB).

Diagnostic morphological and meristic characters of the specimens were examined following Watson and Kottelat (1995) and Keith et al. (2015a); however, scales were counted only for the first specimen (FCLB 068/SKILB/SP.I/IV/2019). Morphological examination was complemented with photographs of the live colouration taken immediately after capture. Measurements and counts were obtained from the left side of the first specimen collected from the Bohi River. Measurements were taken from point to point using digital callipers with a precision of 0.1 mm and reported as a percentage of the standard length (SL) giving the range with the mean value in brackets. Fin rays/spines and scales were counted under a stereomicroscope (Leica MZ6). Counts were reported as a range, with mean values in brackets.

Results

***Stiphodon surrufus* Watson & Kottelat, 1995**
Figure 4; Table 1

New records. INDONESIA – Central Sulawesi • Banggai District, Luwuk, upper reaches of the Bohi River; 01°01′39″S, 122°42′40″E; 15.XI.2019; A. Gani, A.A. Bakri and D.T. Adriany leg.; 1 ♂, 41.0 mm SL, FCLB 068/SKILB/SP.I/IV/2019 • same locality as the preceding; 07.III.2021; A. Gani, Afif leg.; 3 ♂, 40–42 mm SL, FCLB 152a/SKILB/SP.I/VI/2020, 152bSKILB/SP.I/VI/2020, 152cSKILB/SP.I/VI/2020 • same locality as the preceding; 13.II.2021; A. Gani, Afif leg.; 1 ♂, 26 mm SL, FCLB 143/SKILB/SP.I/III/2021 • same locality as the preceding; 26.I.2022; A. Gani, Afif leg.; 2 ♂, 30–37 mm SL, FCLB 167/SKILB/SP.I/I/2022, 168/SKILB/SP.I/I/2022.

Identification. Diagnostic characters for *S. surrufus* within the genus *Stiphodon* observed in our specimens include: a naked predorsal midline; absence of gill rakers on the inner edge of the gill arch; absence of filamentous rays on the first dorsal fin; first dorsal fin same height as second dorsal fin, dorsal fin spine not elongate or filamentous; posterior margin of caudal fin rounded; strong cup-like pelvic disc formed by joined pelvic fin rays, adherent to belly at base between fifth rays; anal fin directly below second dorsal fin. Colouration in fresh specimens: lateral sides of head, body, and tail vivid orange; belly whitish; dorsal region brownish; dark scale margins in caudal region; first and second dorsal fins pale reddish brown with 3–5 black spots along each ray. Caudal fin orange proximally with hyaline margins and 3–5 black spots along several rays. Pectoral fin without remarkable markings. Anal fin reddish brown with a dusky submarginal band (Fig. 3). Meristic characters of the male *S. surrufus* and from the original descriptions of *S. surrufus* (Watson and Kottelat 1995) and *S. birdsong* (Watson 1996), as well as from several subsequent records (Keith et al. 2015a), are given in Table 1.

Discussion

Central Sulawesi is the third region in Indonesia from which the presence of *S. surrufus* has been reported; the two previous regions were Papua and Halmahera (Watson 1996; Watson et al. 1998). Our new records of *S. surrufus* extend the known geographic range of *S. surrufus* in the equatorial region westwards to Sulawesi, a major island with many clear streams providing extensive potential habitat with conditions similar to sites where *S. surrufus* has been reported in other areas (Ebner and Thuesen 2010; Donaldson et al. 2013; Ebner et al. 2021). The Bohi River site in Sulawesi is around 700 km (in a straight line) south-west from the Halmahera site, while the sites in the Philippines, Papua, and Palau are approximately 1,200 km, 1,500 km, and 1,600 km, respectively, from our newly recorded site in Sulawesi. The western shore of Halmahera faces Sulawesi across the Molucca Sea; however, the collection site of the *S. birdsong* specimen from Halmahera in Watson (1996) was the Ifis River, in Wasile Utara Subdistrict, Halmahera Timur District, at the tip of the north-east branch of Halmahera. This river flows into the Halmahera Sea on the eastern side of Halmahera, facing Papua. In terms of seaways and potential connectivity, data from Ocean Surface Current Analysis Real-time (OSCAR; accessible through the NASA on-line portal https://podaac.jpl.nasa.gov) show highly variable and complex currents in the seas east of Sulawesi. These data suggest that larval dispersal to the eastern coast of Sulawesi from any of the known sites would likely be a rare event, whether from Palau or the three nearer sites (Halmahera, Philippines, and Papua). Unusual patterns of connectivity have been reported in this region for other taxa (Umar et al. 2019). A multi-taxon concordant phylogeographic break

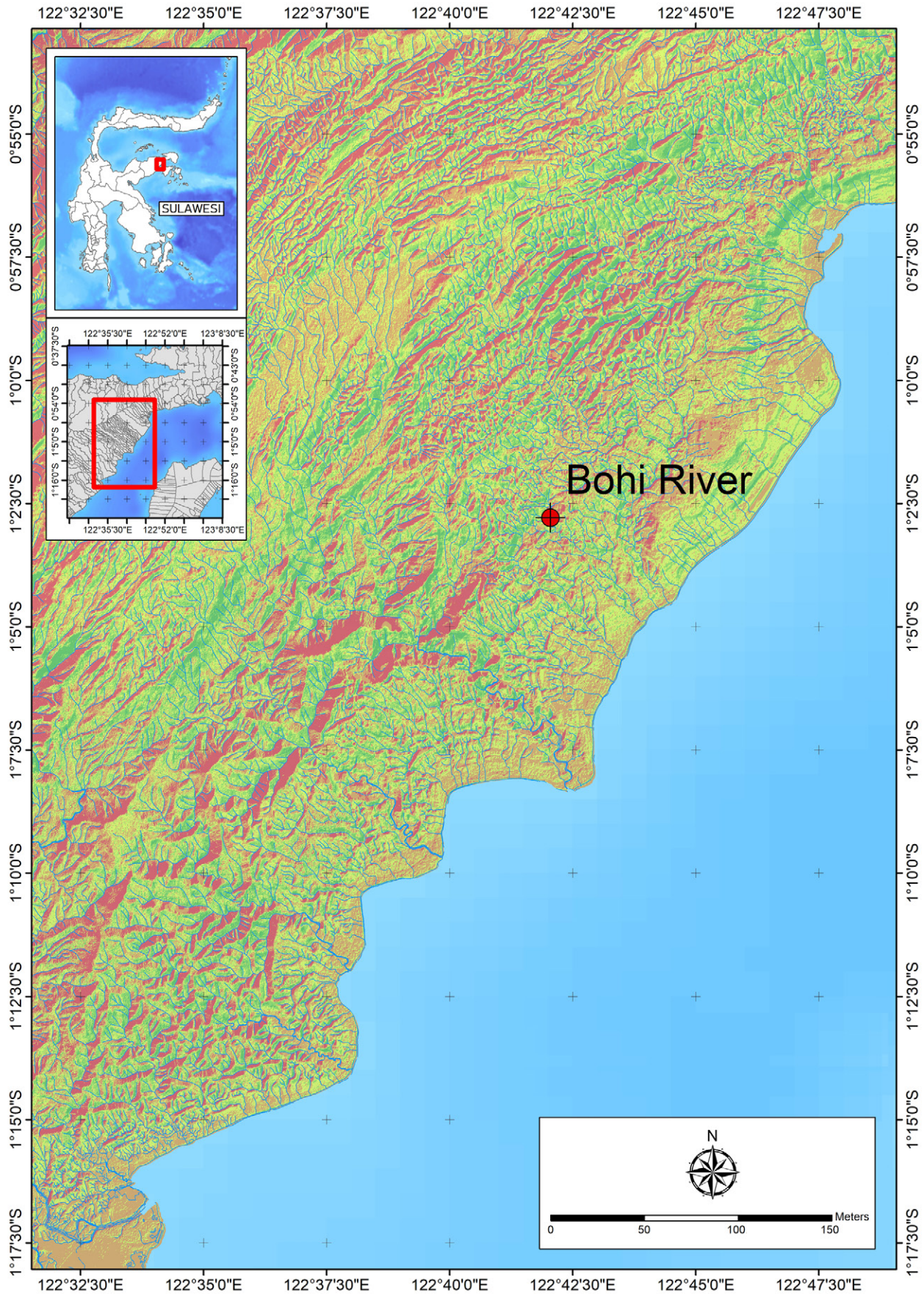

Figure 2. The *Stiphodon surrufus* collection site on the Bohi River in Banggai District, Central Sulawesi Province, Indonesia.

Figure 3. Bohi River, collection site of *Stiphodon surrufus* in Central Sulawesi, Indonesia.

between Halmahera and Sulawesi has been proposed (Carpenter et al. 2011), and potential barriers to dispersal have been identified between Sulawesi and the locations of all other *S. surrufus* records (Treml et al. 2015). However, amphidromous gobies present in one or more of these regions have been reported in the Luwuk Banggai region and/or other regions of Sulawesi (Gani et al. 2021a; Keith and Mennesson 2020). Further exploration to discover as yet unrecorded populations and studies using molecular (DNA) markers could help to clarify the phylogeography of this rare and patchily distributed but widespread species.

Some sicydiine goby species are considered highly vulnerable to extirpation or even extinction (Keith 2003; Walter et al. 2012; Ebner et al. 2016). Their amphidromous nature can render them vulnerable to environmental changes (Yamasaki and Tachihara 2006; Keith et al. 2009), especially during the riverine, estuarine, and marine larval and post-larval stages (Keith and Lord 2012; Teichert et al. 2021). IUCN Red List assessments are available for 30 *Stiphodon* species: seven species (23.3%) are classified in one of the at-risk categories, 12 (40%) are Least Concern, and 11 (37%) are Data Deficient. Population trends are unknown for 22 species (73.3%), including *S. surrufus* (IUCN 2021). *Stiphodon surrufus* was originally classified as Vulnerable under the IUCN Red List criteria, with threats identified including the likelihood of anthropogenic disturbance to critical habitats (Kottelat 1996). The recently synonymised *S. birdsong* (Keith et al. 2015a) was assessed as Least Concern in 2011 (Boseto 2012) due to its widespread distribution and lack of known major threats, with the caveat that the species appears to be naturally rare over most of its distribution (Papua, Indonesia; Papua New Guinea; Solomon Islands) and extremely rare in Australia (Queensland). A revised assessment of *S. surrufus* in 2020 reclassified the species as Least Concern, based on the consideration that the wide geographic spread of *S. surrufus* populations means that stochastic events may lead to local extirpations but unlikely to cause global extinction (Jaafar 2019). However, the paucity of data on the biology, ecology, and population trends was noted, with a recommendation for further research on this species.

Our collection of this species in four consecutive years strongly suggests an established population rather

Figure 4. Specimen of male *Stiphodon surrufus* (FCLB 168/SKILB/SP.I/I/2022) from the Bohi River, Central Sulawesi, Indonesia.

Table 1. Meristic characters of male *Stiphodon surrufus* from the Bohi River, Central Sulawesi, Indonesia (present study); Leyte, Philippines (Watson and Kottelat 1995); Halmahera and New Guinea (Watson 1996); and several sites (Keith et al. 2015a).

Character	Present study	Watson and Kottelat 1995	Watson 1996[a]	Keith et al. 2015[b]
First dorsal fin rays	VI	VI	VI	VI
Second dorsal fin rays	I+9	I+9	I+9	I+9
Anal fin rays	I+10	I+10	I+10	I+10
Caudal fin rays	13	11–13	12–13	11–13
Pectoral fin rays	14	14	14	13–15
Scales in lateral series	33	19–36	16–21	12–36
Scales in transverse backward series	14	10–14	2–12	2–15

[a] As *Stiphodon birdsong*.

[b] Includes data for the synonymised *S. birdsong*.

than stochastic recruitment of an isolated individual, as might have been inferred from the finding of a single specimen in 2019. The rarity of the species in other regions and the low number of specimens collected at the Bohi River site (one in 2019, three in 2020, one in 2021, and two in 2022) indicate that this goby is likely naturally present in low abundances. However, due to the amphidromous lifestyle of *Stiphodon*, it seems unlikely that *S. surrufus* would be restricted to just one stream along the eastern coast of Sulawesi. Tropical streams are diverse, ecologically important but often understudied environments, where anthropogenic impacts can cause rapid changes, often before baseline data have been collected (Smith et al. 2003). Although most rivers in eastern Indonesia, including Papua, Halmahera, and Sulawesi, are generally considered to be relatively free from industrial pollution compared to western Indonesia, mining and land conversion are increasing threats to many regions of Sulawesi, including Banggai District (Lasut et al. 2010; Muhammad et al. 2012; Ambo-Rappe and Moore 2019; Rijal et al. 2019; Kadir et al. 2020). No *S. surrufus* were found during ichthyological expeditions to 11 nearby rivers (Gani et al. 2019, 2020, 2021a, 2021b); however, sampling efforts to date represent limited stretches of a tiny proportion of the rivers and streams potentially providing suitable habitat in Central Sulawesi Province. Further data collection efforts are needed to assess the abundance and distribution of *S. surrufus* in the Bohi River and similar riverine habitat nearby, along the east coast of Sulawesi, and in other areas of Sulawesi, and to determine the threats facing each watershed.

No human uses are listed in the FishBase records for *S. surrufus* and *S. birdsong* (Froese and Pauly 2021). Similarly, the IUCN Red List assessment for *S. surrufus* makes no mention of any form of exploitation. The detailed threats section states that this species does not appear to have any direct threats "although impacts to its habitat, such as runoff, pollutants, barriers to migration, and development of riparian areas, affect populations" (Jaafar 2019: 5). However, collection of fishes from rivers in the Luwuk Banggai area for the freshwater ornamental fish trade appears to have begun around April 2021. Since then, the frequency and volume of mixed species consignments airfreighted from Luwuk to ornamental fish traders in Jakarta have increased. Regulation of this ornamental fishery and trade is at present limited to the statutory pre-flight procedures required by the Fish Quarantine, Quality Control and Fisheries Product Safety Station. While the manifests do not provide species-level data, we have seen consignments containing *S. surrufus* and other amphidromous gobies. This recent development highlights the urgency of exploring and managing Sulawesian freshwater biodiversity and, in particular, establishing the taxonomy and systematics of the species present. This is vital for understanding the ecology and biology of Sulawesian fishes, including determining species' distributions at a fine (e.g., watershed) scale and habitat needs throughout their respective life cycles as well as the composition and functioning of aquatic communities. Such knowledge and understanding are needed to evaluate the potential for sustainable ornamental fisheries and to inform conservation and fisheries management measures. In the current situation where data on target species are still extremely limited, a precautionary approach is highly recommended. At a minimum, this should include improved resolution of the data collected on freshwater/amphidromous taxa dispatched from regions such as Luwuk Banggai, and this could be achieved through regulations at subnational (district/city, provincial) and/or national levels, enabling *inter alia* the leveraging of existing fish health and quarantine procedures.

Understanding the distribution of sicydiine gobies is important in the context of amphidromous species diversity and biogeography (Ebner et al. 2011; Maeda and Palla 2015; Hasan et al. 2021). Our new distributional data on *S. surrufus* reinforces indications of historical and/or contemporary connectivity of amphidromous species between Sulawesi, in particular the Gulf of Tolo coast of eastern Sulawesi, and other islands in Wallacea and eastern Indonesia more generally, including the Sahul Shelf ecoregion. Irrespective of the extent of *S. surrufus* distribution around Sulawesi, our findings also reinforce the importance of Sulawesian inland waters, especially riverine habitat, as breeding areas and migration routes for amphidromous gobies.

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Authors' Contributions

Conceptualization: SN, AG. Data curation: SN, AMM. Investigation: AG, AAB, DTA, EW, LDK. Methodology: SN, MH, VH. Resources: AG, AAB, DTA, EW. Writing – original draft: SN, AG, AMM. Writing – review and editing: SN, AG, AAB, DTA, EW, LDK, MH, VH, AMM.

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