Reproductive and morphometric characteristics of climbing perch *Anabas testudineus* in Sigi, Central Sulawesi, Indonesia

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Abstract. This study was part of a program oriented towards domestication of native freshwater fishes in Central Sulawesi, Indonesia, in particular the climbing perch (*Anabas testudineus*, Bloch 1972). Previous studies have shown considerable variation between climbing perch populations, including in characters of importance for domestication. This study focussed on reproductive and morphological characters of the climbing perch population in Sigi District, specifically gonad maturity stage, gonadosomatic index (GSI), fecundity, length-weight relation ($W = aL^b$), length-length relationship (SL = $a+b$·TL), Fulton's condition factor K and the meristic formula. Specimens (n = 503) were collected in 2014, 2015 and 2019. Total length varied from 42 to 208 mm total length with body weight from 1.2 to 209.9 g. Overall sex ratio was balanced (1:1). The smallest specimens with mature gonads were: male TL = 72 mm; W = 8.1 g and female TL = 84 mm, W = 10.4 g. The condition factor K of males (mean≈1.68) was generally lower than for females (mean≈1.84); however the difference was not significant ($p > 0.05$). Fecundity, estimated using a gravimetric method, varied from 1,556 to 70,973, correlated positively and significantly with size ($p < 0.001$). The GSI of females in gonad maturity stage IV was high (mean 11.56%), significantly correlated with Fulton's condition factor K ($p < 0.05$) but not length or weight ($p > 0.05$). Gonad development patterns indicate a spawning peak during July-August. The meristic formula was D, XVIII+9; A, X+9; P, 13; V, I+5; C, 16. The length-weight relation showed isometric growth ($b \approx 3$). The length-length relation (SL≈0.56+0.806·TL) was highly significant ($p < 0.001$, $R^2 = 0.984$).
Key Words: Anabantidae, gonad maturity, fecundity, meristic formula, length-weight relation.

Introduction. Sulawesi is the largest island in Wallacea, a region renowned for its biodiversity, including freshwater fishes. However, to date freshwater aquaculture has largely concentrated on introduced species, rather than local (native) fishes. Many of these introduced species have proven capable of adapting to local conditions and can be considered invasive alien species. A program oriented towards the domestication of native fishes was initiated in the province of Central Sulawesi, Indonesia in 2013 (Ndobe et al 2013, 2014). Sigi District is the only land-locked district/city in Central Sulawesi, and has adopted freshwater aquaculture as a key development sector.

The climbing perch (*Anabas testudineus* Bloch, 1972) is a fish with a wide distribution in Asia (Froese & Pauly 2019), with Sulawesi thought to be the easternmost extremity of its natural range in Indonesia (Kottelat & Whitten 1996). It has suggested that the climbing perch was introduced to at least some inland waters (especially lakes) in Sulawesi by humans (Herder et al 2012; Kartamihardja 2014; Parenti et al 2014). However, the review by Thakur & Das (1986) considered it more likely that this fish crossed the Wallace Line naturally, aided by its tolerance to salt water, air breathing ability, and tendency to migrate between water bodies. It is possible that each of these hypotheses could apply to some Sulawesi climbing perch populations, as found in Japanese common carp (Mabuchi et al 2008) using mitochondrial DNA (mtDNA). The timing and mechanism(s) of climbing perch arrival in Sigi (and other regions within

Sulawesi and across its wide distribution) could possibly be elucidated using mtDNA or other genetic markers.

The wealth of local names and traditions (culinary and other) associated with the climbing perch in the culture of several ethnic groups in Central Sulawesi indicate that this fish has been present for many centuries at the very least, and has long been part of the local wetland ecosystem fish communities. Once a favourite traditional source of protein for several indigenous peoples in Central Sulawesi, the climbing perch is now regaining popularity as a food fish (Ndobe et al 2014, 2019). This revival in interest is at least partly due to increased awareness of the high nutritional quality of climbing perch flesh (Paul et al 2017; Mohd-Khairi et al 2018).

An obligate air breather, the climbing perch is capable of surviving, even thriving, in harsh conditions such as higher temperatures, lower dissolved oxygen and pH (Perera et al 2013), which are predicted to become increasingly prevalent due to climate change and other human impacts (Ficke et al 2007). In addition, as predators on mosquito larvae, climbing perch can be effective in mosquito control (Bhattacharjee et al 2009). Domestication of this native fish could thus contribute to regional climate change adaptation and food security, as suggested *inter alia* in Bangladesh (Chowdhury et al 2014). However, recent surveys indicated declining populations of the once common air breathing fishes *Channa striata* and *A. testudineus* in Central Sulawesi, and in particular in Sigi District (Ndobe et al 2014). Observed threats included loss or modification of wetland habitat (development of residential areas or infrastructure, paddy fields and aquaculture ponds, and in some areas palm oil plantations), increasing fishing pressure, and the introduction of non-native fishes, including invasive alien species (Ndobe et al 2014, 2019). These considerations highlight the need for management of wild climbing perch stocks as well as the advisability of aquaculture development.

Population characteristics such as reproductive and growth parameters are important as a basis for the development of aquaculture, in particular domestication, as well as for the management of wild fish populations. The climbing perch does not exhibit external sexual dimorphism; although on average females tend to be somewhat larger than males (Jacob 2005; Zworykin 2012), and during the breeding season ripe females may exhibit a reddish colouration around the vent (Behera et al 2015). Existing data on climbing perch populations indicate between-population variability in several important parameters. For example reported sizes at first maturity range from total length (TL) ≈ 8 cm (Thakur & Das 1986) and ≈10 cm (Jacob 2005; Marimuthu et al 2009) to ±15 cm TL (Amornsakun et al 2005), with reported fecundity ranging from hundreds to tens of thousands of eggs. Spawning tends to be seasonal; however, the timing and length of the season can vary between sites (Thakur & Das 1986; Jacob 2005; Behera et al 2015; Froese & Pauly 2019). Growth pattern can be influenced by environmental parameters at the broodstock place of origin and in the rearing environment (Jacob 2005; Murjani 2011). While a predominantly isometric growth pattern has been reported from some populations, particularly for smaller (juvenile) fish, allometric negative patterns are common in adult climbing perch (Ahmadi 2019). Between population variation in the climbing perch has been reported in morphometric and meristic characters (Thakur & Das 1986; Biswas & Shah 2009; Bungas 2014), genetic characters (Jamsari et al 2010), or both (Slamat et al 2011; Alam et al 2014).

Published data on the characteristics of climbing perch populations in Sulawesi is minimal (Ndobe et al 2019). This study on the reproductive and morphometric characters of climbing perch from the Sigi District population aimed to provide data to support the sustainable management, including domestication, of the climbing perch in Central Sulawesi, as well as contributing to the body of knowledge on this important freshwater species.

Material and Method

Description of the study site. This study was conducted in Sigi District, Central Sulawesi, Indonesia, in the Palu valley south of Palu City, the capital of Central Sulawesi Province. The study area (Figure 1) naturally comprised extensive wetlands associated with the meandering Palu River, and is traversed by the Palu-Koro fault. Over recent decades much of the natural wetland area has been converted to irrigated paddy fields and aquaculture ponds, which were functioning and in use in 2014. After the triple tectonic disaster (earthquake, tsunami and liquefaction) on 28th September 2018 (Socquet et al 2019), much of the irrigation and domestic water supply infrastructure was still inoperative during the sampling period in 2019, with some wetlands reverting to a more natural state and others drying up.

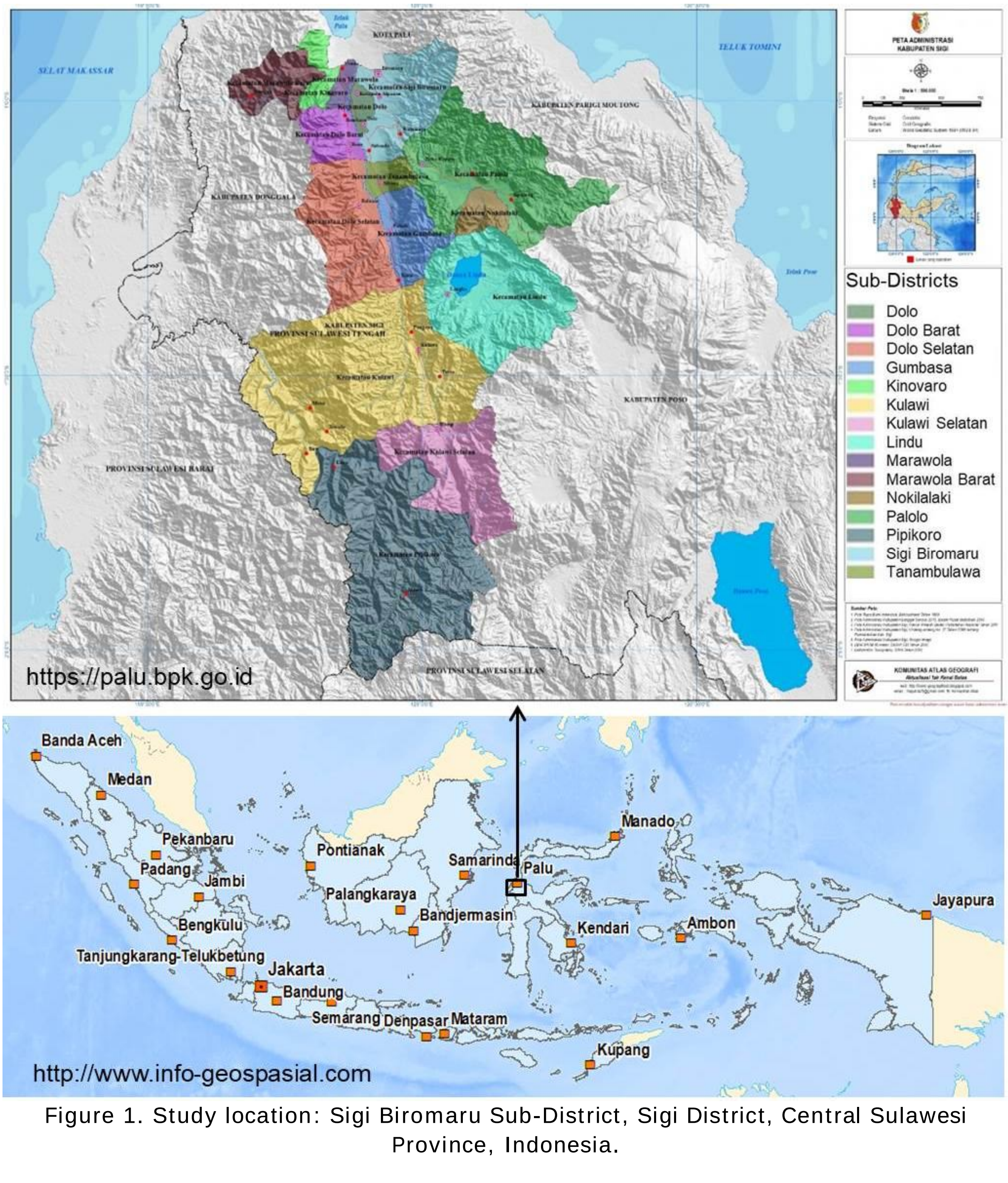

Figure 1. Study location: Sigi Biromaru Sub-District, Sigi District, Central Sulawesi Province, Indonesia.

Sample collection and measurement. Climbing perch were collected in 2014, 2015 and 2019 from wetland habitat in Sigi Biromaru Sub-District, Sigi District, Central Sulawesi Province, Indonesia (Figure 1 and Table 1). The climbing perch specimens were transported live and humanely euthanized in the laboratory. A plastic tag labelled with a unique code (using a 2B pencil) was attached (with raffia) to each specimen after euthanasia and temporarily removed when necessary (e.g. to take measurements or examine gonads). Total length (TL) and standard length (SL) were measured to the nearest millimetre (mm) using a standard fish measurement board (Cadwell ruler), and total body weight (W) measured to the nearest 0.1 g using digital scales (Adam CQT1501). Samples were preserved in 70% alcohol prior to meristic analysis.

Table 1

Climbing perch samples collected in Sigi District

Sampling			*n*	*Length range*		*Weight range*	*Analysis**		
No	*Year*	*Month*		*SL (mm)*	*TL (mm)*	*W (g)*	*Rp*	*Me*	*LW*
1	2014	June	71	32-144	42-163	1.3-88.6	70	71	71
2	2014	July	80	40-132	43-154	2.3-66.7	70	80	80
3	2015	September	114	33-105	40-126	1.2-39.9	-	-	114
4	2019	March	121	40-139	51-197	2.5-91.7	-	121	121
5	2019	August	49	110-165	135-208	45.3-209.9	49	49	49
6	2019	September	68	83-148	98-180	19.6-105.4	48	68	68
Total			503	32-165	42-208	1.2-209.9	238	389	503

* Rp = reproductive biology; Me = meristic analysis; LW = length-weight relation.

Reproductive parameters. Sex and gonad maturity stage (GMS) were determined through dissection of the abdominal cavity and visual observation of the gonads based on the qualitative scale in Table 2. Gonads were removed and weighed (W_g in g) using high precision digital scales (OHAUS Pioneer PA214, accuracy 0.0001 g).

Table 2

Gonad maturity stage (adapted from Effendie (2002))

Gonad maturity scale		*Description*	
		Female gonads (ovaries)	*Male gonads (testes)*
I	Immature	Gonads very small and transparent can be slightly rounded and coloured.	Gonads very small and transparent, thread-like.
II	Maturing	Gonads fill up to half of body cavity, roundish, pinkish/yellowish No discernable oocytes/eggs.	Gonads fill up to half of body cavity, off-white/milky, narrower than ovaries.
III	Ripening	Fill about 2/3rds length of body cavity, round section, pinkish-yellow to pale orange, granular texture.	Fill about 2/3rds length of body cavity, whitish to creamy, smooth texture, some veining.
IV	Ripe	Fill 2/3rds to full length of body cavity, yellowish orange to orange-pink, conspicuous blood vessels. Large transparent ripe ova visible.	Fill 2/3rds to full length of body cavity, whitish-creamy, soft, smooth velvety texture.
V	Spent	Ovaries shrunken (1/2 length of body cavity or less), can contain remnants of disintegrating or ripe ova, darkened or translucent.	Testes shrunken, flabby, darker in colour, can be bloodshot.

The sex ratio was calculated as the ratio of male to female specimens (M:F). Gonadosomatic index (GSI) was calculated for female fish in GMS III and IV using the equation (Bernal et al 2015):

$$GSI = Wg \cdot We^{-1} \cdot 100 \text{ (in \%)}$$

where: Wg = gonad weight (g);
W = total body weight (before dissection, g);
We = gutted body weight (g) = W-Wg.

Fecundity was estimated using a gravimetric method (Murua et al 2003), using high precision digital scales (OHAUS Pioneer PA214, accuracy 0.0001 g). Three samples were removed from the anterior, central and posterior portions of one gonad from each specimen and placed on a petri dish (Pyrex Iwaki) which had just been weighed. Sample weight was determined by subtracting the empty petri dish weight from the weight of the same dish with the sample. The eggs were visible to the naked eye and were counted with the aid of a handheld magnifying glass (lens magnification x 2). Egg count was divided by sample weight to obtain egg count per gram for each sample. Egg count/g was averaged for the three samples to obtain estimated egg count per gram and multiplied by total gonad weight (W_g) to obtain the estimated fecundity *Fe* of the specimen. Thus the equation used for estimating fecundity *Fe* was:

$$Fe = W_g \cdot (\Sigma n_i \cdot w_i^{-1}) \cdot 3^{-1}$$

where: W_g = total gonad weight (both ovaries, g);
n_i = number of eggs in the i^th^ sample;
w_i = weight of the i^th^ sample (g);
I = number from 1 to 3.

Length-weight relation and L_{max}. The length–weight relation is usually expressed in the form $W = a \cdot L^b$ where *W* is the wet weight, *L* is the length, and the parameters *a* and *b* are constants (Froese 2006). The parameters *a* and *b* were determined through linear regression of the (natural) log-transformed variables (TL in mm and W in g) using the lm function in R, leading to an equation of the form:

$$\log(W) = a' + b \cdot \log(L)$$

where: *W* = total body weight (g);
L = total length TL (in mm);
a' = intercept of the log-transformed regression log*W* ~logTL = log(*a*);
b = slope of the log-transformed regression;
a = is the constant *e* raised to the power of *a'*.

This analysis was performed for all specimens (n = 503) and on subsets comprising specimens identified as female (n = 118) and male (n = 107). Values of *b* were used to determine the growth pattern of the Sigi District population: isometric if $b \approx 3$, allometric positive for $b > 3$ and allometric negative if $b < 3$. L_{max} was, by definition, the length of the longest specimen within the total sample.

Fulton's condition factor K. The Fulton's condition factor *K* (Froese 2006) was calculated as:

$$W \cdot L^{-3} \cdot 10^5$$

where: *W* = total body weight (g);
L = total length (mm).

Higher values of *K* indicate better fish condition, though other factors such as gonad development and gut fullness can affect the value of *K*; therefore, it is noted that all specimens were weighed as caught (i.e. guts were not emptied and the gonads were not removed before weighing).

Meristic characters. For each specimen (n = 389), the number of spines and rays (dorsal, anal, pectoral, ventral and caudal fins) were counted through visual inspection. Where necessary, a magnifying glass (magnification × 2) was used. Mean and median values of each meristic variable were computed for the sample as a whole and by sex. The meristic formula (D = dorsal fin, V = ventral fin, A = anal fin, P = pectoral fin, C = caudal (tail) fin; spine counts in Roman numerals, ray counts in Arabic numerals) was determined using median values for each parameter.

Data analysis. The data were tabulated in Microsoft Excel 2007 and statistical analyses were conducted in R version 3.6.0 (R Core Team 2017) in the RStudio version 1.1.456 environment (RStudio Team 2016). All analyses were conducted under the Windows 10 operating system. Unless otherwise stated, the 95% confidence level of statistical significance ($\alpha = 0.05$; $p < 0.05$) was used in the analyses. The results were compared with the scientific literature.

The chisq.test function in R was used to test whether the sex ratio (number of male fish:number of female fish) was balanced (not significantly different from 1:1) or skewed (significantly different from 1:1). The lm function in R was used to conduct regression analysis and to determine the significance of relationships between numerical and categorical parameters. These included the correlations of GSI and fecundity with each other, with length (TL) and with weight (*W*), and the variation of the condition factor *K* with sampling period, sex, and gonad maturity stage (GMS).

Results

Sex ratio and gonad maturity stage. Total length and body weight ranges of the specimens for which sex could be determined (*n* = 225) were 42-208 cm and 1.3-209.9 g. Gonad observation identified 118 females and 107 males (Table 3). The Chi-squared test results ($p > 0.05$) indicate a balanced sex ratio (1:1) overall and for the two sampling years with sex data (2014 and 2019). Male and female specimens in all gonad maturity stages were found (Table 3). The proportion of specimens in each gonad maturity stage (GMS I to V) varied between months (2014 and 2019 data combined) for both female (Figure 2a) and male (Figure 2b) climbing perch.

Table 3

Sex and Gonad Maturity Stage of *Anabas testudineus* specimens from Sigi (n = 236)

Year	*Sex*	*Gonad maturity stage (GMS)*					*Total*
		I Immature	*II Maturing*	*III Ripening*	*IV Ripe*	*V Spent*	
2014	Female	1	3	10	55	2	71
	Male	9	20	39	1	1	70
2019	Female	2	1	12	25	7	47
	Male	3	11	8	8	7	37
Total	Female	3	4	22	80	9	118
	Male	12	31	47	9	8	107

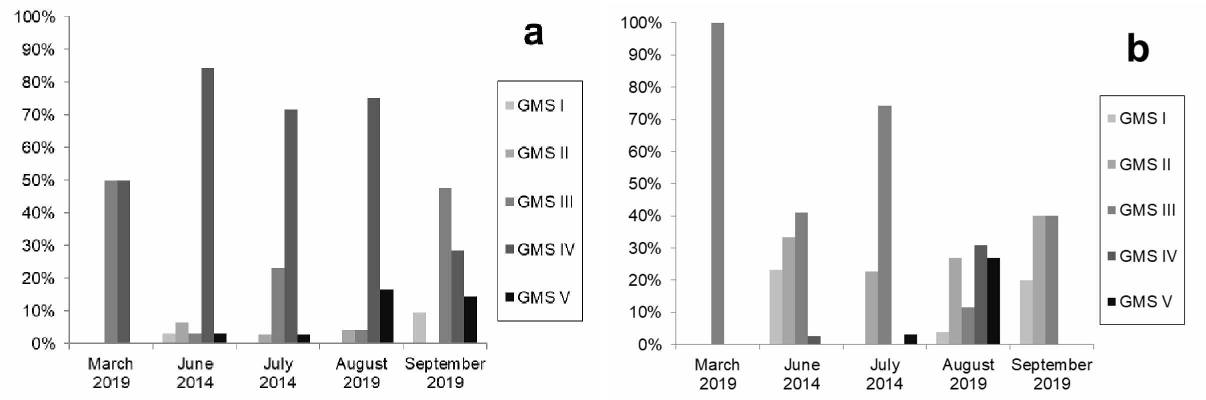

Figure 2. Climbing perch gonad maturity stage (GMS) by month/year:
a. females (n = 118); b. males (n = 107).

Gonadosomatic index GSI. The gonadosomatic index (GSI) of female climbing perch varied from 0.48 to 23.50 g, with a mean of 10.23 g (Figure 3c). GSI was significantly different between gonad maturity stages (Figure 3a) and by month (Figure 3b). The mean values of GSI by GSI were: 0.82 for GMS II; 3.48 for GMS III; and 11.56 for GSI IV. GSI was also weakly but significantly correlated with Fulton's condition factor *K* ($p < 0.05$) with the regression equation $GSI = -2.712 + 6.982 \cdot K$ (Figure 3d).

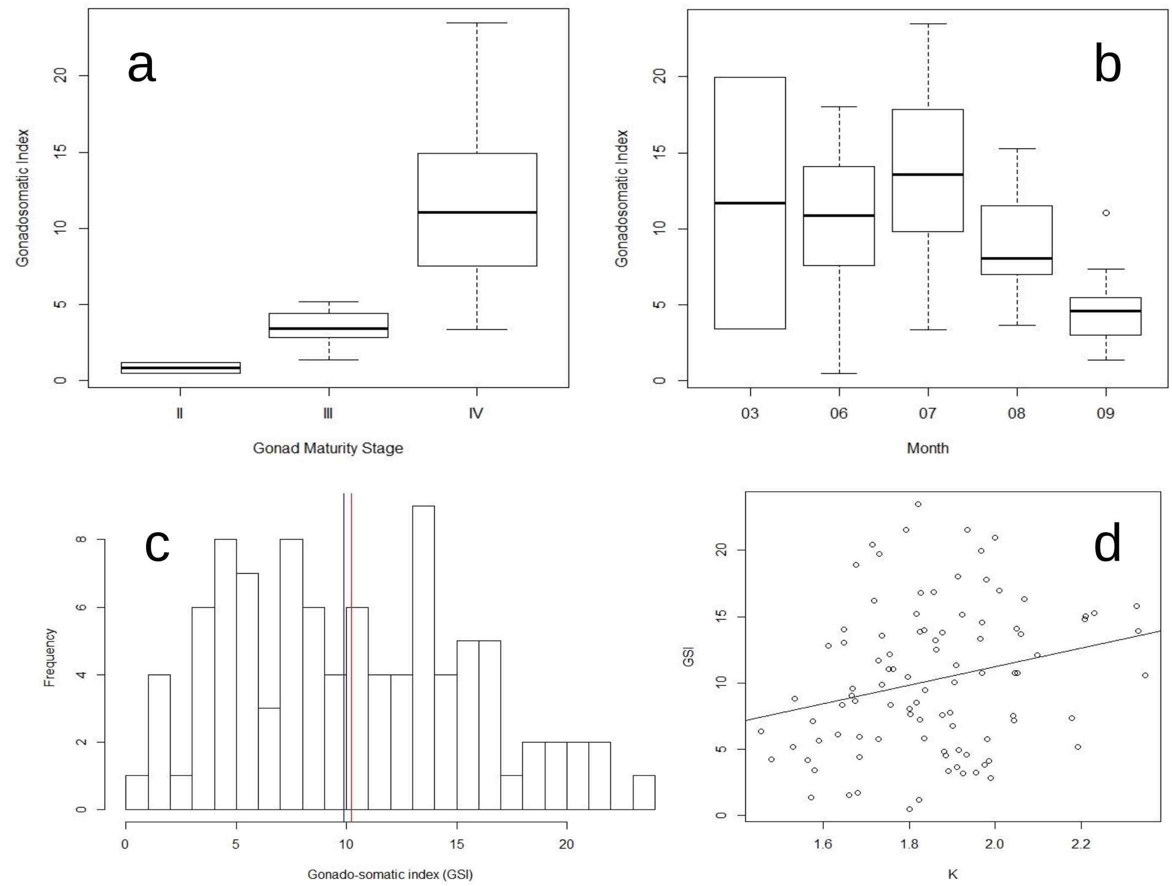

Figure 3. Gonadosomatic index (GSI) of female climbing perch (n = 95): a. by gonad maturity stage (GMS IV significantly different, $p < 0.01$); b. by month (September, month 09, significantly different, $p < 0.05$); c. histogram of GSI (red line = mean, blue line = median); d. correlation with Fulton's condition factor *K* ($R^2 = 0.05$).

***Fecundity**.* The fecundity of female climbing perch in gonad maturity stage III (*n* = 6) varied from 1,556 to 5,437 (mean = 3,903), and for GMS IV (*n* = 59) from 3,848 to 70,973 (mean = 18,060). Single factor models (lm) indicated that mean fecundity was significantly different ($p < 0.01$) between GMS III and IV (Figure 4a) but not between time periods, despite a considerably lower mean value in September compared to the other months (Figure 4b). Fecundity was strongly correlated with body weight W ($p < 0.001$, $R^2 = 0.333$), with a regression equation of $Fe = 3903 + 14157 \cdot W$ (Figure 4c) and total length TL ($p < 0.001$, $R^2 = 0.207$), with a regression equation of $Fe \approx -12846 + 226 \cdot TL$ (Figure 4d). Thus, approximately 57% of the observed variation in fecundity can be explained by individual body weight, and 45% by body length. A multiple regression model (lm) of *Fe* against (GMS + W + month) had an R^2 of 0.668, thus potentially explaining up to 81.7% of the observed variation in fecundity, and showed significant effects of month ($p < 0.01$ for August and $p < 0.05$ for September).

***Meristic characters**.* The meristic characters measured varied considerably between individuals (*n* = 389), but there was no significant correlation between meristic character values and any other parameters measured in this study. The meristic formula (based on median values) was: D, XVIII+9; A, X+9; P, 13; V, I+5; C, 16. The variability in meristic characters is visible in Figure 5.

***Length-weight and length-length relationships**.* The length–weight relation obtained was $W = 1.49 \cdot 10^{-5} \cdot L^{3.0361}$, where W is in g and *L* is TL in mm (*n* = 503, $R^2 = 0.979$). This indicates that total length explains nearly 99% of the variation in weight. The log-transformed regression plot is shown in Figure 6. The length-weight relationship was not significantly different from isometric for male or female climbing perch, despite a higher value of b for females (b = 3.0396, n = 118, R^2 = 0.977) than for males (b = 2.9693, n = 107, R^2 = 0.99). The length-length relation (SL≈0.56+0.806·TL) was highly significant ($p < 0.001$, R^2 = 0.984).

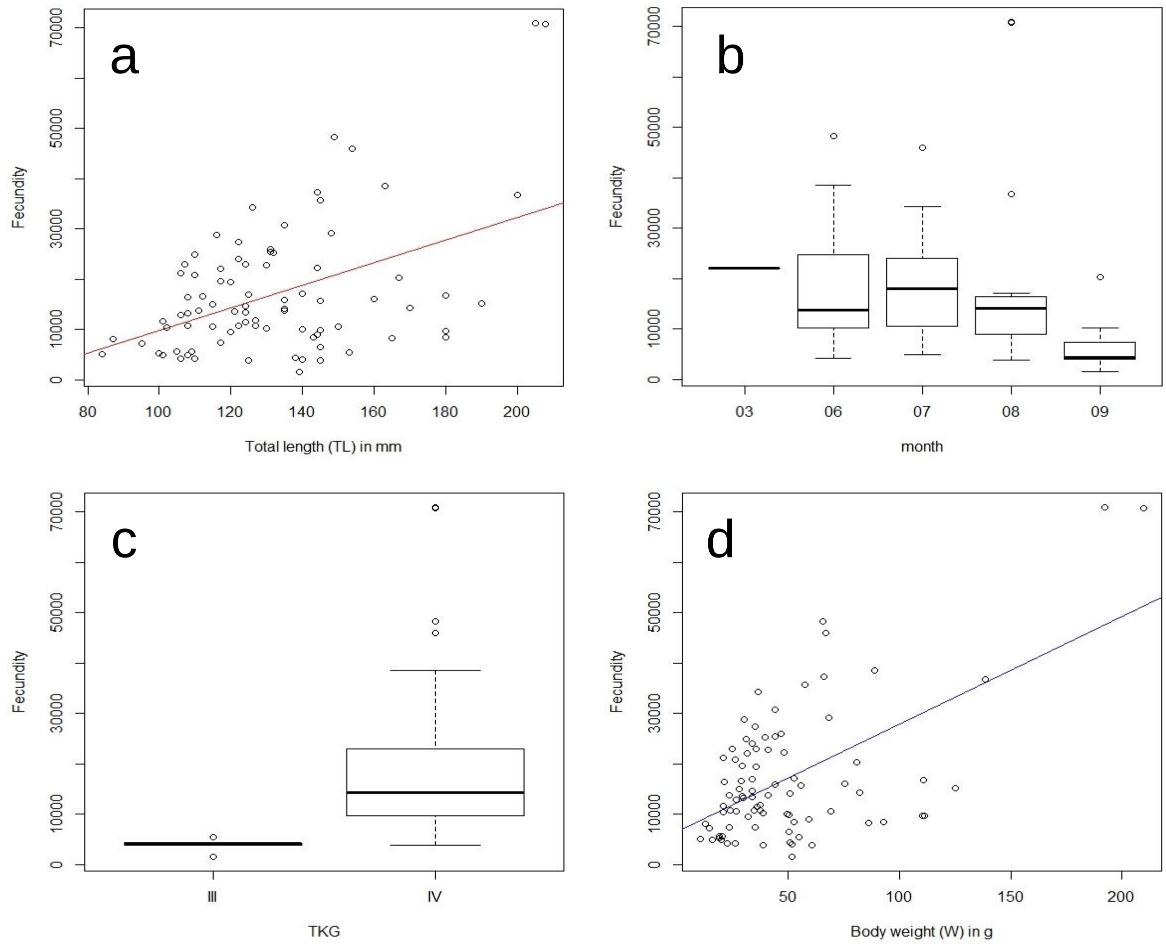

Figure 4. Fecundity of climbing perch Fulton's condition factor K (R^2 = 0.05): a. boxplot of fecundity by gonad maturity stage (GMS); b. boxplot of fecundity by month; c. Plot of fecundity Fe against bodyweight W (in g).

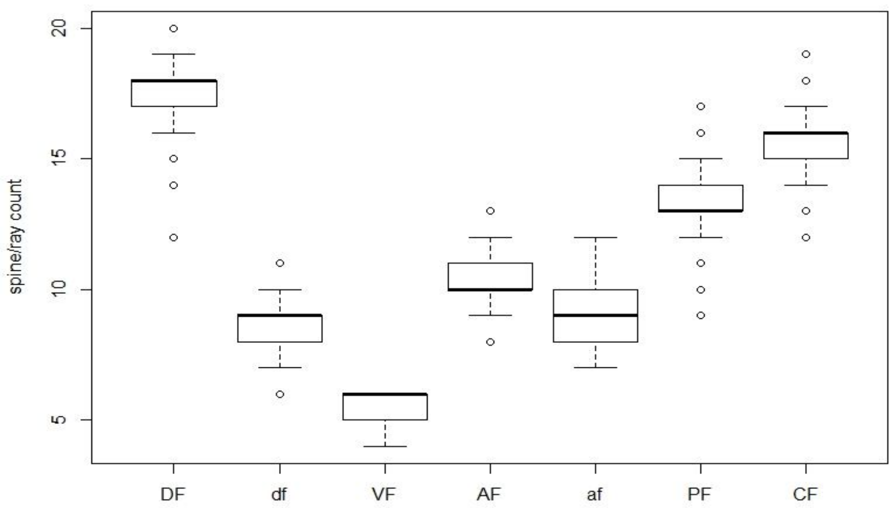

Figure 5. Box plot of Sigi climbing perch meristic characters (n = 389).

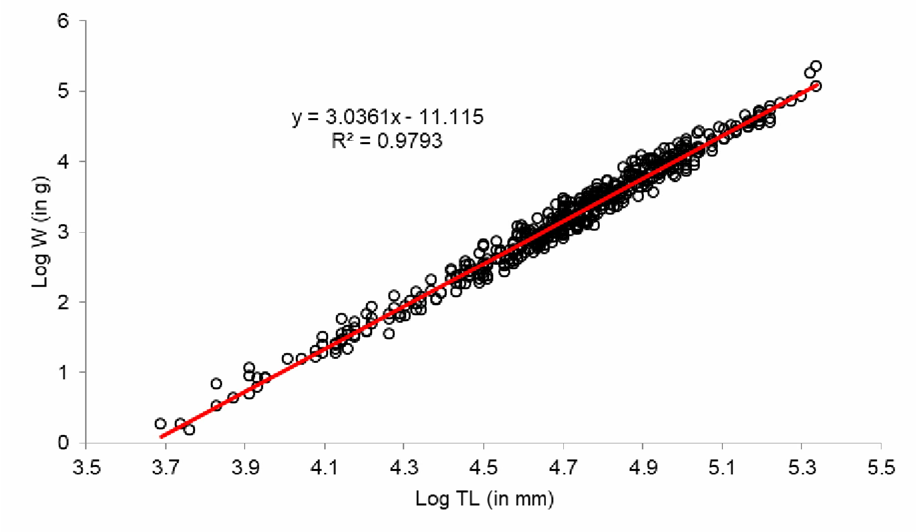

Figure 6. Log-transformed length-weight relation of Sigi climbing perch (n = 503).

Fulton's condition factor K. The Fulton's condition factor K showed a right-skewed distribution (Figure 7a), with the median value (1.740) less than the mean value (1.779). The mean values of K were significantly different for male (1.679) and female (1.836) climbing perch ($p < 0.001$), despite considerable overlap in range (Figure 7b). Condition factor K was higher for fully mature males (Figure 7c) and females (Figure 7d) in GMS IV (ripe) than those in GMS III (ripening) or GMS V (spent). However the differences were not significant ($p > 0.05$). There was no significant difference in K between sampling periods (months or years).

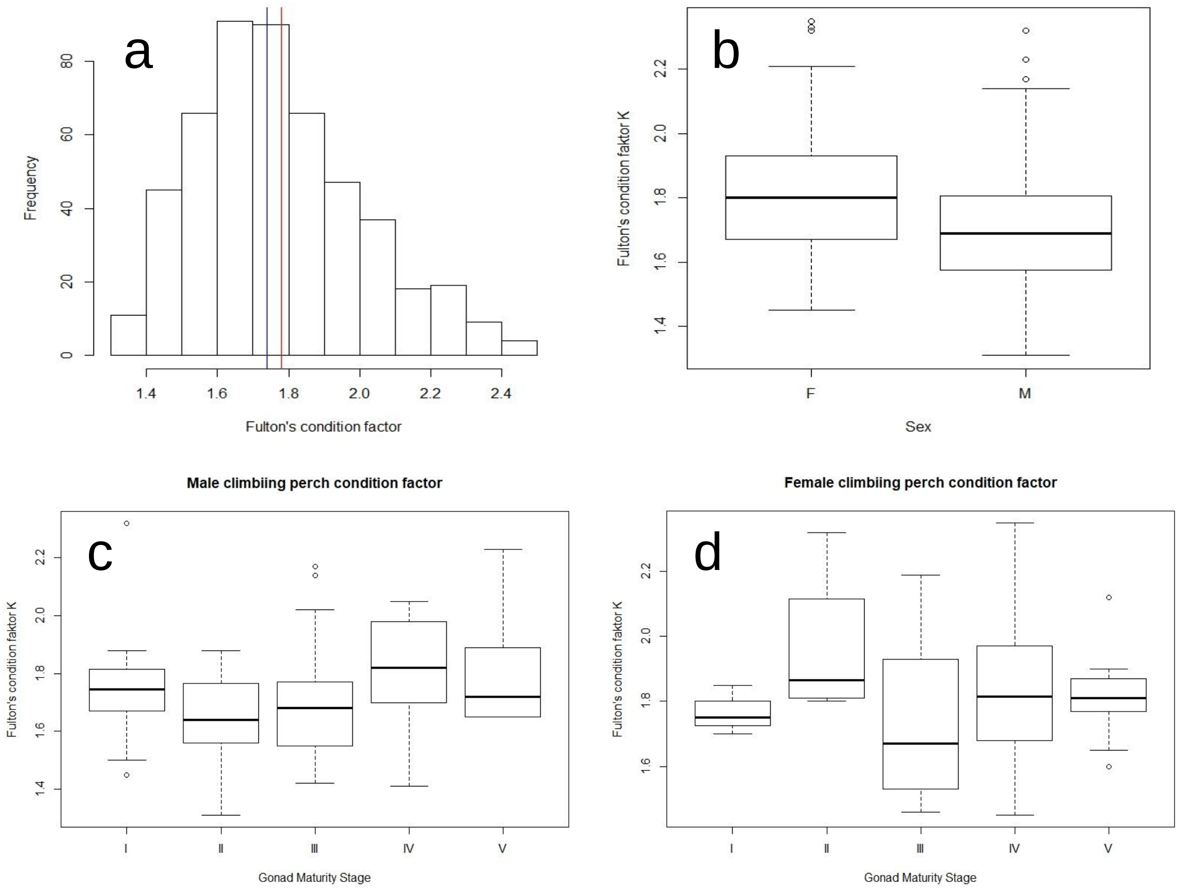

Figure 7. Fulton's condition factor K: a. Histogram of K distribution (red line = mean, blue line = median; n = 503); b. boxplot of K by sex (n = 225); c. boxplot of K by gonad maturity stage (GMS) for male fish (n = 107); d. boxplot of K by GMS for female fish (n = 118).

Discussion

Reproductive biology. The balanced sex ratio of the Sigi climbing perch population can be considered as a positive result, as this species is reported to form pairs before spawning (Thakur & Das 1986), and a balanced sex ratio is generally considered normal. However ex-situ experiments by Zworykin (2012) suggest that climbing perch can engage in promiscuous or sequential spawning patterns with more than one partner, and can reproduce successfully with a wide range of sex-ratios, whether male- or female-skewed. There is also doubt as to whether individual climbing perch spawn once (Thakur & Das 1986) or multiple times (Zworykin 2012) during the spawning cycle.

With respect to size at maturity, the smallest specimens with mature gonads were: male TL = 72 mm; *W* = 8.1 g and female TL = 84 mm, *W* = 10.4 g, both from the 2014 sample. Maturing gonads (GMS II) were found in individuals as small as 62 mm TL (*W* = 4.1 g, male) and 72 mm TL (*W* = 6.8, female); together with the low maximum length L_{max} (163 mm) in 2014, these figures potentially indicated a population under pressure, as suggested by Ndobe et al (2019). The higher minimum length of mature/maturing individuals (minimum 95 SL for males and 108 mm SL for females) and higher L_{max} (208 mm) in 2019 could be artefacts of sampling, but may be related to (possibly temporary) changes in land use and exploitation after the September 2018 triple disaster (tsunami, earthquake and liquefaction) in the Palu region.

The GSI range of Sigi climbing perch specimens in this study was relatively high compared to that reported by several other studies (Table 4). Bearing in mind that in some studies the gonad maturity stage of the samples is not reported, in some cases this could be related to sampling methods.

Table 4

Gonadosomatic index (GSI) for climbing perch in Sigi District and several other climbing perch populations (SD = standard deviation)

Location/Source	*n**	*GSI**			*Reference*
		Range	*Mean*	*SD*	
Sigi District,	66	1.38-19.03	9.78	4.66	This study – stage III and IV
Indonesia	55	3.26-19.03	11.11	3.87	This study – stage IV
	10	1.38-5.90	3.13	1.44	This study – stage III
Malaysia	70	1.28-15.97	-	-	Marimuthu et al (2009)
India	-	-	9.84	3.52	Jacob (2005) – stage IV
			2.95	2.01	Jacob (2005) – stage III
India	-	-	3.25	0.43	Pandit & Gupta (2019)
Bangladesh	-	1.53-8.33	male		Hafijunnahar et al (2016)
	-	3.29-14.91	female		
Thailand	-	-	10.4	2.5	Amornsakun et al (2005)
Philippines**	20	-	10.9**	-	Bernal et al (2015)
Vietnam (July)	-		12.71**	0.73	Uddin et al (2017)
Vietnam (October)	-		1.13	0.10	

* Data not available indicated by "-"; ** Mean value during peak spawning season, thus comparable to Sigi sample. Lower GSI values were reported at other times of the year.

Fecundity of the Sigi climbing perch samples was within the range reported from other populations (Table 5), however the standard deviation was larger than in most other studies, indicating a high level of variability between individuals. One reason could be a greater variation in the size-range and relatively high number of individuals sampled.

Unlike Uddin et al (2017) who found a very close linear relationship between log-transformed body weight and fecundity ($R^2 \approx 0.96$), in this study log-transformation resulted in a lower value of R^2 (0.145) than the untransformed relation ($R^2 = 0.333$). However, the two specimens with the highest fecundity and GSI were exceptionally large, outliers for size and weight as well as reproductive parameters, and indicate that fecundity may increase exponentially at larger sizes. Such a phenomenon has been reported in several species, and led to the concept of big old fat fecund female fish (BOFFFFs) as disproportionally important to reproduction at the population level, and hence population dynamics (Hixon et al 2014). Thus reserves where such BOFFFFs could contribute to the replenishment of climbing perch in nearby exploited areas seems advisable as part of precautionary approach to the management of this freshwater fisheries resource, as advocated by Marshall et al (2019).

Table 5
Fecundity for climbing perch in Sigi District and several other climbing perch populations. Where available, range given above and mean±SD below

Location/Source	*n**	*Fecundity**			*Reference*
		Range	*Mean*	*SD*	
Sigi District, Indonesia	85	1,556-70,973	17.061	13,084	This study (GMS III & IV)
Malaysia	70	3,120-84,690	36,804	2289	Marimuthu et al (2009)
India	-	5324-68,640	-	-	Ramaseshaiah (1985)
India	25	575-59.022	-	-	Jacob (2005)
Bangladesh**		50,610-227,378	-	-	Hafijunnahar et al (2016)
Thailand		-	24,121	3328	Amornsakun et al (2005)
Vietnam (April)	42	-	16,833	673	Uddin et al (2017)
Vietnam (July)		-	46,186	2219	

* Data not available indicated by "-"; ** Large fish, TL 190 to 240 mm.

The condition of fish can be influenced by many factors, and can vary significantly, as reflected in the ranges of Fulton's condition factor *K* reported from other climbing perch populations (Table 6), including other Indonesian populations studied, predominantly from Kalimantan. As in this study, where data disaggregated by sex are available, the condition factor is generally higher for females than males (Ernawati et al 2009; Ahmadi 2019; Mustakim et al 2019); however Ahmadi (2019) also found that the difference was not statistically significant, and the difference in Mustakim et al (2019) is so small that it is almost certainly not statistically significant either at the 95% confidence level.

Table 6
Fulton's condition factor for climbing perch in Sigi District and several other climbing perch populations

Location/Source	*n**	*Condition factor K**			*Reference*
		Range	*Mean*	*Remarks*	
Sigi District, Indonesia	107	1.31-2.32	1.68	male	This study
	118	1.45-2.35	1.84	female	This study
	503	1.39-2.49	1.78	overall	This study
Kalimantan, Indonesia	77	0.73-3.02	1.99	male	Ahmadi (2019)
	79	1.10-3.26	2.01	female	
	156	0.73-3.26	2.0	overall	
Kalimantan, Indonesia	122	-	1.07	male (swamp)	Ernawati et al (2009)
	87	-	1.82	female (swamp)	
Kalimantan, Indonesia	-	-	3.11	male	Mustakim et al (2019)
	-	-	3.14	female	
Indonesia	318	-	1.53	male	Ahmadi et al (2018)
	393	-	1.64	female	
Indonesia	-	-	1.01		Syahrir (2013)
Tripura, India	312	1.28-1.84	1.51	Lower in medium-sized fish (80-139 mm TL)	Maurya et al (2018)
India	-	-	1.09	Experimental control	Pandit & Gupta (2019)

* Data not available indicated by "-".

The reproductive biology parameters of the Sigi climbing perch population indicate that spawning can occur over at least four months (June to September), most likely over a longer period, with a spawning peak in July-August. This is similar to the findings of Hafijunnahar et al (2016) in Bangladesh, except that the spawning peak in Bangladesh occurred in May. Of the five sources cited in FishBase (Froese & Pauly 2019), four have shorter spawning periods (3-4 months, March or April to June), while one population from the Mekong Basin (Sokheng et al 2000) has a spawning period of eight months (March to October), which might well be similar to the Sigi population. Interestingly, the review by (Thakur & Das 1986) also indicates short spawning periods mostly before June, but quote a period from May to October for one source in India, and December to May for an unspecified location in Indonesia. The findings of this and other studies indicate a need for further research, ideally over at least one full calendar year, and ideally ongoing monitoring of the Sigi climbing perch population reproductive status.

Morphological parameters. With respect to size, the largest individuals in all time periods were female. Although length and weight distribution patterns were similar for male and females, the ranges and means were significantly different, with male climbing perch tending to be smaller than females, as well as maturing at a smaller size. A similar pattern has been reported from several other climbing perch populations (e.g. Thakur & Das 1986), and can thus be considered normal for this species. The growth pattern in this study was isometric. Most studies have found allometric negative growth patterns, especially for male climbing perch, however allometric positive growth has also been reported (Table 7). There seem to be very few studies reporting the length-length relationship of the climbing perch (Table 8); however these show a similar pattern to that observed in this study, with SL approximating 80% of TL.

Table 7

Reported values of the length-weight parameter *b* for Sigi District and some other climbing perch populations

Sample origin	*n**	*b**			*Growth pattern***	*Reference/Remarks*
		Value	*SE*	*R^2*		
Indonesia,	503				I	This study - all
Sigi District,	118				I	This study - female
Sulawesi	107				A^-	This study - male
Indonesia,	400	2.754	-	-	A^-	Ernawati et al (2009) - all
Kalimantan	165	2.818	-	-	I	female
	235	2.674	-	-	A^-	male
Idem	975	2.959	-	0.89	A^- to I	Mustakim et al (2019)
Indonesia	318	2.796	-	0.834	A^-	Ahmadi et al (2018) - male
	393	2.714	-	0.833	A^-	female
Philippines	-	2.84	0.16	0.97	A^-	Garcia (2010)
Thailand	34	2.507	0.112	0.951	A^-	Satrawaha & Pilasamorn (2009)
Thailand	155	3.015	0.113	0.988	I	Sidthimunka (1973)
Bangladesh	6 x 12	1.53-3.08	-	> 0.9	A^- to I	Begum & Minar (2012)
India	238	2.770	0.09	0.87	A^-	Kumar et al (2013)
India	-	3.205	-	-	A^+	Thakur & Das (1986) - adult
	-	3.711	-	-	A^+	juvenile
Bangladesh		3.09	-	0.96	I	Khatun et al (2019)
	319					Jacob (2005)
FishBase***	-	2.77[2]	0.06	-	A^-	Froese & Pauly (2019)

* Data not available indicated by "-"; ** I = isometric; A^- = allometric negative; A^+ = allometric positive;
*** mean of 6 values.

Table 8
Reported values of the length-length relationship (SL= $a+b$·TL) for Sigi District and other climbing perch populations

Sample origin	n	Linear regression parameters*			Reference/Remarks
		a	b	R^2	
Indonesia, Sigi District, Sulawesi	503	0.56	0.81	0.98	This study - all
Bangladesh	239	-0.25	0.82	0.97	Khatun et al (2019)
-	1	0	0.799	-	Froese & Pauly (2019)

* Data not available indicated by "-".

Genetic variation tends to be low within populations but high between populations (Jamsari et al 2010). Morphological and genetic differences between populations can co-occur (Bungas 2014), though causal links do not seem to have been demonstrated as yet. However, the unusually high meristic diversity within this population, first reported in Ndobe et al (2019) and further elaborated by this study, could indicate genetic diversity, which in turn could be an indication of potential for selective breeding as part of the domestication process.

Conclusions. The Sigi District climbing perch population had a balanced sex ratio. While observed threats in 2014 and 2015 included wetland habitat conversion, competition with alien species and unsustainable fishing practices, in 2019 conditions had changed and were in process of (unpredictable) further change in the aftermath of the September 2018 triple disaster in the Palu region. Fecundity and gonadosomatic index (GSI) values were within the range typically reported for this species, and significantly correlated with size, gonad maturity stage, and each other. The exceptionally high fecundity of the largest females highlights the importance of big old fat fecund female fish (BOFFFFs) in this species. The overall patterns of reproductive parameters indicate an extended spawning season, from June to October and possibly beginning earlier or continuing later, with a peak in July-August. A similar pattern has been reported for some other climbing perch populations, although most appear to have shorter spawning seasons. The findings from this study will be used to inform ongoing research and development on climbing perch culture, as well as sustainable management of the wild climbing perch population and habitat.

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