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MORPHOLOGICAL CHARACTERISTICS AND REPRODUCTIVE ORGANS ASSESSMENT OF BLUE-SPOTTED MUDSKIPPER *Boleophthalmus boddarti* IN PENINSULAR MALAYSIA

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ABSTRACT

Mudskippers have a unique adaptation allowing them to live on the land and commonly inhabit the mangrove ecosystem. A fundamental study on the Blue-spotted mudskippers, *Boleopthalamus boddarti* were purposely to identify the species through morphometric and meristic characteristics, observation on the gonad organs as well as to correlate with their length-weight relationship. Collection of *B. boddarti* (n = 72) from Matang Perak, Pendas Johor and Pekan Pahang was conducted using hand and net. Data collection on sixteen morphometric and five meristics characters, length and weight, and pictorial documentation on male and female gonads were conducted. The means of each characteristic were estimated by using Analysis of Variance (ANOVA) with $P < 0.05$. The morphometric analysis found eye diameter and posterior dorsal fin ray count characteristics were significantly different ($P < 0.05$), followed by five meristics characteristics except for anterior dorsal fin ray count and upper jaw teeth characteristics (F value $\geq$ 1.0). The mature gonad of female *B. boddarti* was found with an ovary in bright yellow coloration, turgid, firm and visible presence of eggs. Male gonads were identified with a testis having two lobes, a swollen structure at the top of the elongated shape and appear pale pink and thicker than the immature testes that generally exist in string-like structures. The length and weight of the fish were found directly proportional to the regression curve displayed $b \neq 3$. Morphometric and meristic characteristics were a reliable method in the identification of fish in general and for *B. boddarti* in specific. The observation of gonads differentiation helps understand the mature and immature state of the sex organs. This study offered an easy, quick, and low-cost approach in determining species and sexes of mudskipper, compared with the molecular method.

Keyword: blue-spotted mudskipper, gonads differentiation, length-weight correlation, meristic, morphometric

INTRODUCTION

The Blue-spotted mudskippers, *Boleophthalamus boddarti* (Pallas 1770) belong to family Gobiidae and subfamily Oxudercinae, living on the mudflats of mangrove areas in many countries, including Vietnam (Dinh 2014), Southeast Coast of India (Ravi 2013; Ramanadevi *et al.* 2013), Malaysia (Khaironizam & Norma-Rashid 2002) and throughout Indo-West Pacific (Rainboth 1996). In Malaysia, the mudskippers including *B. boddarti,* are locally known as *"Belacak"* or *"Tembakul"* and for this blue-spotted mudskipper, it can be characterized by an elongated and laterally compressed body with the cycloid scales covering the external body. The Boddart's goggle-eye gobi is marked by the lighter color of the first dorsal fin, dark edge of the pectoral fins, large blue spots on the head and several darker dorso-ventrally stripes along the body.

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The mudskippers in general are the largest amphibious teleost fish, which are divided into four genera, *Boleophthalmus, Periophthalmodon, Periophthalmus* and *Scartelaos* (You *et al.* 2014). There are eight species reported from six genera that can be found in Peninsular Malaysia (Murdy 1989). In Malaysia, the densities of *B. boddarti* are abundant in the brackish water of estuaries, mangrove swamps and intertidal mudflats (Daud *et al.* 2005). This species is able to dig burrows up to one and a half meters deep inside each walled compound (Al-behbehani & Eberahim 2010) and always stay within the mud walls, an area that is enclosed like a pasture having sufficient food for each individual to survive. Detritus accumulation in the mangrove areas supplies food sources for species that inhabit the area, including shrimp, fishes, molluscs, birds and other marine organisms which contribute to fisheries stock (Takita *et al.* 1999; Tse *et al.* 2008).

Mudskippers are an important food source (Tsang 2007) to some countries and a source of income to fishermen. In Malaysia, mudskippers are famously utilized as a cure to asthma and are considered an aphrodisiac if taken with several spices, however, printed information regarding this matter is still lacking. Apart from that, mudskippers are a good bioindicator to environmental stress caused by natural disaster, such as tsunami (Ravi 2005). Mudskippers can detect pollution as they manage to accumulate the pollutants that have been released into the coastal environment by industrial, agricultural, domestic and transportation activities (Ansari *et al.* 2014).

Morphometric studies are important in measuring traits and relationships among taxa, while meristics are often applicable in identifying species as they are less affected by the environmental changes. Generally, sex determination involves the study of primary development of sex organs in the organism. In some studies, sex determination provides an understanding of the plasticity of vertebrates' sex determination mechanism. However, the sex differentiation among the variety of finned-ray species plays an important role in two types of regulation, i.e., genetic regulation and endocrine regulation (Nishimura & Tanaka 2014).

Sex determination of an animal can come easy in some cases, as it is possible to be detected by looking at their genetic level where the sex-determining gene managed to determine the orientation of bipotential gonadal development (Matsuda 2005). In mammals, the male determining system is identified with the presence of the SRY gene that is generally found at the Y chromosome (Sinclair *et al.* 1990). However, the mammal's sex determination is not the same as the non-mammalian vertebrates which depended on heredity, environment or even both. Devlin and Nagahama (2002) proclaimed that sex determination process in fish is very complex as many genes are known to influence the process.

Since there is no recent record on the mudskippers in Malaysia, this study is expected to focus on the morphological characteristics, meristics count, allometric growth, and sex determination of *B. boddarti*. Observation on the morphology and allometric growth of *B. boddarti* eventually reflect the health of mangrove ecosystem in Peninsular Malaysia.

MATERIALS AND METHODS

Study Area

A study on Blue-spotted mudskippers was done between January and September 2017 at three selected mangrove areas in Peninsular Malaysia namely, Matang Perak, Pendas Johor and Pekan Pahang (Fig 1). The Matang Forest Mangrove Reserve is located on the northwest coast of Peninsular Malaysia having an area of 40,711 ha at the 4° to 5° N latitude and 100°2' E longitude, and it is known as the largest mangrove forest in Peninsular Malaysia (Ahmad 2009). The Pekan Pahang sampling site is located at the delta of the Pahang River and the coastal plain represented as one of the largest coastal deposits in Malaysia (Ali 2002). The length of Pahang River is 50 km with the latitude of 3°29'31.54' N and longitude of 103°23'22.36' E. The mangrove ecosystem in Pendas Johor is located at the coordinates of 1°23'0" N, 103°38'0" E and the area is densely populated by human settlements.

Figure 1 Matang Forest Mangrove Reserve located at the northwest coast of Peninsular Malaysia

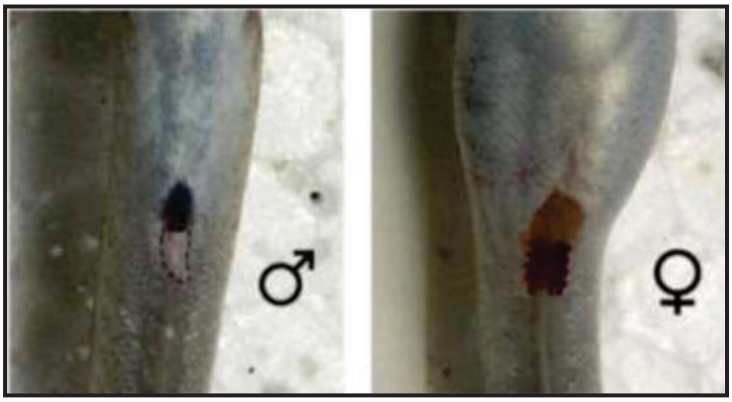

Figure 2 The external genitalia of male and female *Periophthalmus gracilis*
Source: Polgar (2006).

Sample Collection

A total of 72 samples of *B. boddarti* were collected by using casting nets, hand nets and bare hands. The mudskippers were collected at night-time, especially when the tide was low. Sampling activity was focused on the mudflat region of the mangrove where the mudskippers usually resided. Specimens were firstly identified morphologically using Murdy (1989) and the sex of *B. boddarti* was determined by observing the external morphology of the genital papilla (Daud *et al.* 2005) (Fig 2), i.e., oval shape is a female and triangle shape is a male (Dinh *et al.* 2015), before being preserved in -20 °C storage for further analysis.

Morphometric and Meristics Characteristics Measurement

A total of sixteen morphometric characteristics was selected and measured (Fig 3), which were the total length (TL), standard length (SL), body depth (BD), eye diameter (ED), head depth

(HD), head length (HL), head width (HW), snout length (SNL), predorsal length (PDL), first dorsal fin length (FDFL), second dorsal fin length (SDFL), pectoral fin length (PFL1), pelvic fin length (PFL2), caudal fin length (CFL), caudal peduncle fin length (CPL) and anal fin ray length (AFL). Five meristic characteristics measured were the anterior dorsal fin ray count (ADF), posterior dorsal fin ray count (PDF), anal fin ray count (AF), number of stripes (NOS) and lateral line scales count (LLS). The sample was measured by using a digital calliper to the nearest 0.01 cm and digital balance to the nearest 0.1 g.

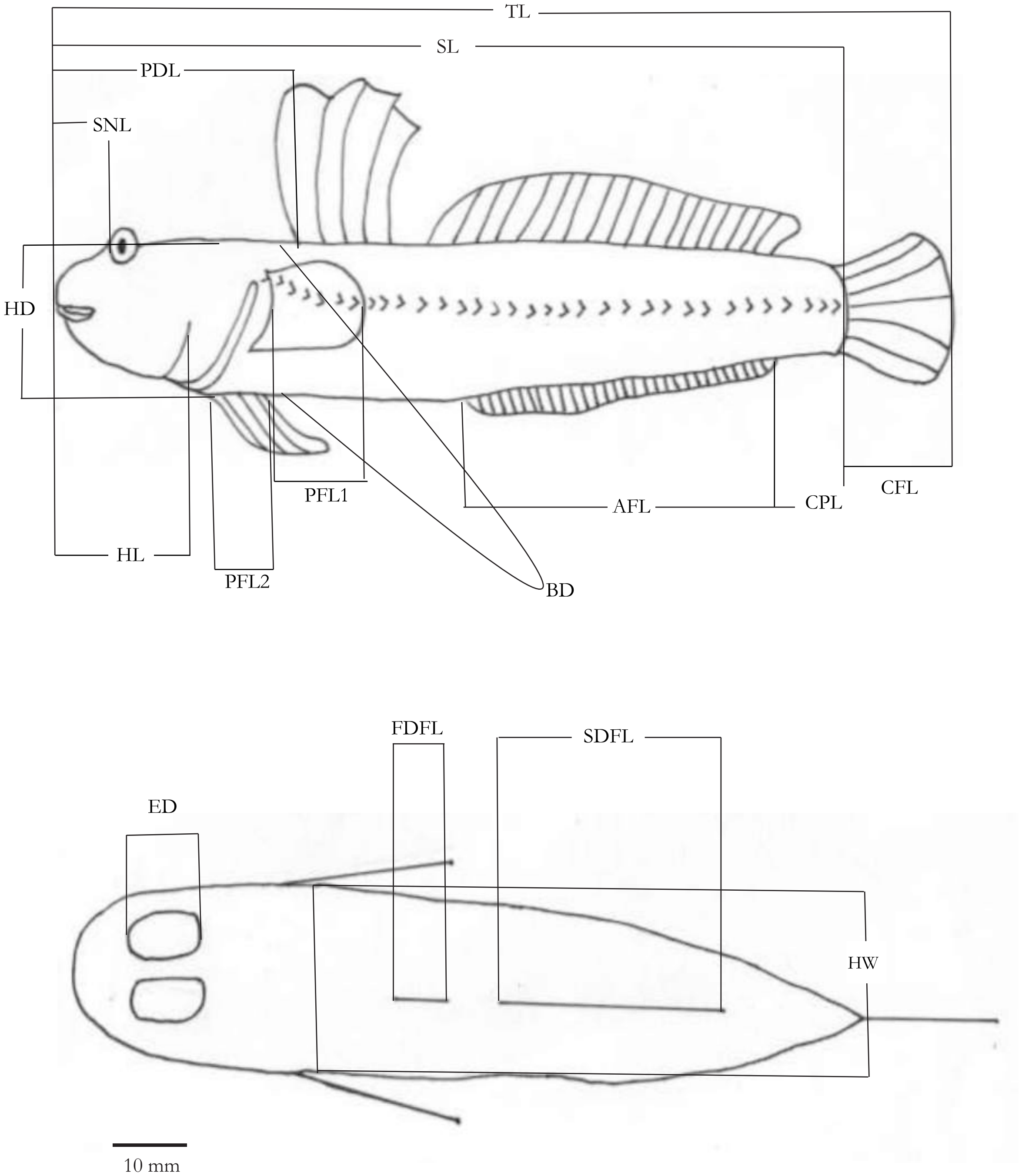

Figure 3 Morphometric characteristics used for characterizing *Boleophthalmus boddarti*
Notes: TL = Total length, SL = standard length, BD = body depth, ED = eye diameter, HD = head depth, HL = head length, HW = head width, SNL = snout length, PDL = predorsal length, FDFL = first dorsal fin length, SDFL = second dorsal fin length, PFL1 = pectoral fin length, PFL2 = pelvic fin length, CFL = caudal fin length, CPL = caudal peduncle fin length, and AFL = anal fin ray length.

Gonads Differentiation

The mudskipper sample was dissected from the point of the external genitalia up to the operculum to split open the body cavity of the sample by using dissecting scissors and forceps. Gonads of the male and female mudskippers were observed and documented prior to being compared based on maturity stages (Gurgel *et al.* 2012) and gonads shapes (Fig 4). Basic organs, such as the stomach, intestines, gonads, liver, heart, and gills, were also observed. Photos of the basic internal organs were taken by using a DSLR camera (D3200) with the correct mode and lighting. The samples of internal organs anatomy were drawn on the A4 paper based on the picture taken.

Data Analysis

One-way ANOVA was applied for analyzing the meristic count and morphometric measurements (Holden & Raitt 1974). The length-weight relationships (LWR) of *B. boddarti* were calculated using the formula (1) to look at the linear regression of LWR, performed by SPSS 16. The body weight and the body length were then correlated with the sex of the mudskipper, *B. boddarti* represented by using linear regression.

$$W = aL^b$$
$$\log W = \log a + b \log L \quad \text{.............................} \quad (1)$$

where:
W = weight of the samples
L = total length of the samples
a, b = constants

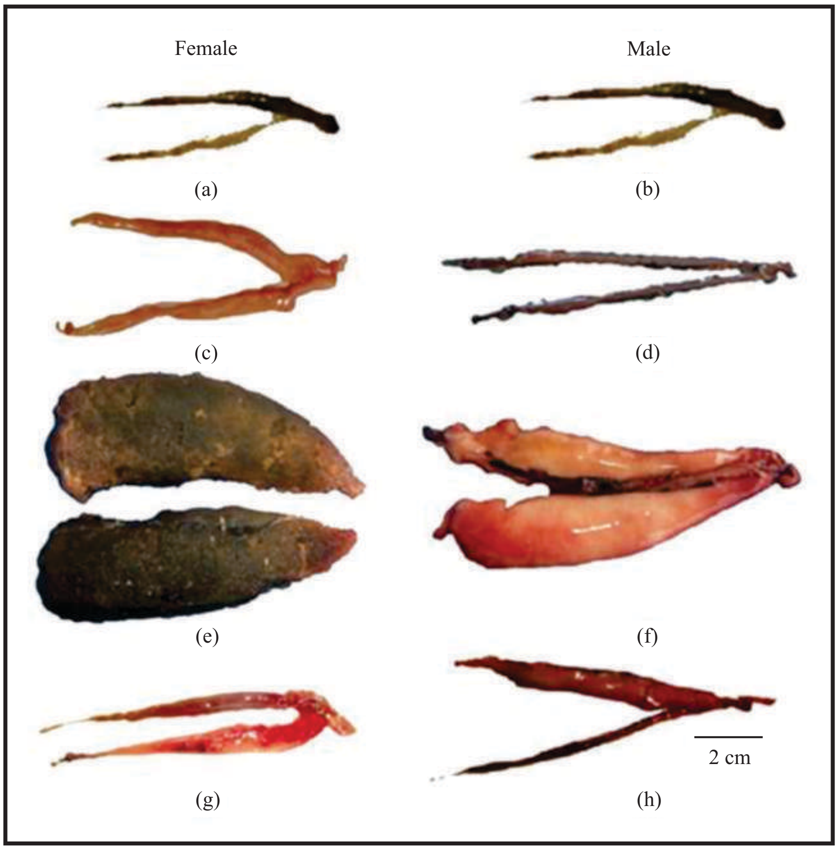

Figure 4 Gonad maturity stages of male and female of *Prochilodus brevis* obtained from a semi-arid area in Brazil
Source: Gurgel *et al.* (2012).
Notes: (a) and (b) show the immature states; (c) and (d) show maturing states; (e) and (f) represent the mature states of gonads; (g) and (h) represent the spent female and male gonads.

RESULTS AND DISCUSSION

Morphometric and Meristic Measurements in *B. boddarti*

This study showed the morphometric, meristic and sex determination methods practiced for species identification purposes and these approaches were considered as the authentic and the earliest methods (Kolar *et al.* 2007; Soliman *et al.* 2018). Among the 16 morphological characters, caudal peduncle fin length, pectoral fin length and eye diameter were significantly different ($P < 0.05$), while among the 5 meristic characters, 4 were significantly different (posterior dorsal fin ray count, anal fin ray count, number of stripes and lateral line scales count) (Table 1). These findings provided evidence of heterogeneity among mudskipper populations in Peninsular Malaysia. Meanwhile, there were no significant differences ($P > 0.05$) in the following morphometric measurements, namely total length (TL), standard length (SL), head length (HL), head depth (HD), body depth (BD), head width (HW), snout length (SNL), predorsal length (PDL), first dorsal fin length (FDFL), second dorsal fin length (SDFL), pelvic fin length (PFL2), caudal fin length (CFL), anal fin ray length (AFL), and anterior dorsal fin ray count (ADF) for meristic measurements.

The total length (TL) of 72 samples of *B. boddarti* collected from three sampling sites of Matang Perak (n = 24), Pendas Johor (n = 24) and Pekan Pahang (n = 24) ranged from 70.14 - 160.45 mm with mean of 113.73 ± 5.67 (Table 1). The range of standard length (SL) was 59.92 - 137.02 mm with mean of 97.20 ± 4.81 (Table 2).

Table 1 ANOVA results for morphometric and meristic measurements of *B. boddarti* from three selected mangrove areas

Morphometric and meristic measurements	F value	P value
Total length (TL)	0.498	0.610
Standard length (SL)	0.478	0.622
Eye diameter (ED)	9.511	0.000
Head length (HL)	0.476	0.624
Head depth (HD)	0.098	0.907
Body depth (BD)	1.668	0.196
Head width (HW)	0.586	0.559
Snout length (SNL)	1.327	0.272
Predorsal length (PDL)	0.224	0.800
First dorsal fin length (FDFL)	0.634	0.534
Second dorsal fin length (SDFL)	0.060	0.942
Pectoral fin length (PFL 1)	3.334	0.041
Pelvic fin length (PFL2)	0.439	0.646
Caudal fin length (CFL)	0.154	0.858
Caudal peduncle fin length (CPL)	5.547	0.006
Anal fin ray length (AFL)	0.797	0.455
Anterior dorsal fin ray count (ADF)*	0.000	1.000
Posterior dorsal fin ray count (PDF)*	3.463	0.037
Anal fin ray count (AF)*	6.734	0.002
Number of stripes (NOS)*	68.019	0.000
Lateral line scales count (LLS)*	28.703	0.000

Table 2 Morphometric characteristics of *B. boddarti* in three selected mangrove areas

MC	Matang (n = 24)			Pendas (n = 24)			Pekan (n = 24)		
	Range (mm)		Mean ± SE	Range (mm)		Mean ± SE	Range (mm)		Mean ± SE
	Min	Max		Min	Max		Min	Max	
TL	86.95	145.66	114.18 ± 3.05	79.63	157.95	108.67 ± 3.85	70.14	160.45	113.73 ± 5.67
SL	71.11	124.11	97.72 ± 2.84	66.04	136.75	92.61 ± 3.41	59.92	137.02	97.20 ± 4.81
ED	1.85	5.54	3.61 ± 0.15	3.05	5.60	4.10 ± 0.14	3.04	5.83	4.50 ± 0.14
HL	16.82	31.05	24.05 ± 0.71	16.69	33.52	23.59 ± 0.84	14.68	34.95	24.92 ± 1.29
HD	10.74	19.59	14.81 ± 0.48	11.28	22.35	15.00 ± 0.54	8.82	22.14	15.19 ± 0.73
BD	11.81	21.29	16.75 ±0.57	10.96	23.54	15.25 ± 0.60	9.85	28.00	16.89 ± 0.89
HW	9.40	18.60	12.81 ± 0.57	7.67	17.28	11.87 ± 0.59	6.88	19.80	12.40 ± 0.75
SNL	3.10	7.20	4.86 ± 0.26	3.14	7.96	4.47 ± 0.27	3.10	7.80	5.05 ± 0.23
PDL	24.48	41.40	33.21 ± 0.91	23.66	43.80	32.18 ± 1.01	21.60	44.90	32.87 ± 1.36
FDFL	5.50	15.90	9.14 ± 0.59	4.58	15.72	8.60 ± 0.52	4.60	14.94	9.49 ± 0.59
SDFL	28.20	50.30	38.57 ± 1.13	23.80	58.80	37.82 ± 1.92	26.10	57.60	38.49 ± 1.82
PFL1	14.10	29.10	18.67 ± 0.68	9.40	23.26	15.68 ± 0.74	10.02	29.80	18.02 ± 1.10
PFL2	9.60	19.10	13.44 ± 0.52	7.92	18.80	13.20 ± 0.54	7.50	21.18	14.00 ± 0.77
CFL	12.36	20.82	16.28 ± 0.52	11.60	23.48	16.32 ± 0.70	11.46	24.90	16.73 ± 0.67
CPL	6.20	15.80	11.43 ± 0.45	5.40	16.38	9.03 ± 2.55	3.14	15.30	9.13 ± 0.73
AFL	26.40	45.72	35.06 ± 1.01	21.24	50.20	32.86 ± 7.21	23.32	49.62	35.10 ± 1.68

Notes: TL = total length; SL = standard length; BD = body depth; ED = eye diameter; HD = head depth; HL = head length; HW = head width; SNL = snout length; PDL = predorsal length; FDFL = first dorsal fin length; SDFL = second dorsal fin length; PFL1 = pectoral fin length; PFL2 = pelvic fin length; CFL = caudal fin length; CPL = caudal peduncle fin length; and AFL = anal fin ray length.

Even though similar species were studied, different proportions of TL and SL were recorded as fish growth might be affected by several factors (Onsoy *et al.* 2011), including growth phase, food availability and quality, size range, health and general fish condition, as well as the preservation techniques and sampling procedure, namely sample size and length range.

The morphometric study on *B. boddarti* has also been conducted by Murdy (1989) on samples from India, Thailand, Malaysia and Indonesia. However, revisiting the current morphological condition of this species seems crucial to depict the fish health condition in its habitat along with its physiological and biological conditions (Mehmood *et al.* 2021).

The meristic count was used to show any traits that can be counted (Kumari *et al.* 2020), exhibiting the range of lateral line scales (LLS) of 56 - 146 with mean of 109.50 ± 5.82 (Table 3). Meanwhile, *Boleopthalmus pectinirostris* a closely related fish species to *B. boddarti,* was recorded with 84 - 123 scales count (Murdy 1989). The meristic count of samples obtained from three sampling sites was almost similar to the findings on the studied *B. boddarti* from five populations in Pulau Pinang, Kuala Selangor, Banting, Negeri Sembilan and Melaka (Daud *et al.* 2005).

Table 3 Meristic characteristics of *B. boddarti* in three selected mangrove areas

MEC	Matang (N=24)			Pendas (N=24)			Pekan (N=24)		
	Range		Mean ± SE	Range		Mean ± SE	Range		Mean ± SE
	Min	Max		Min	Max		Min	Max	
ADF	5.00	5.00	5.00 ± 0.00	4.00	6.00	5.00 ± 0.06	5.00	5.00	5.00 ± 0.00
PDF	17.00	27.00	23.71 ± 0.41	19.00	27.00	24.29 ± 0.38	19.00	25.00	22.92 ± 0.31
AF	17.00	26.00	22.71 ± 0.40	19.00	29.00	24.50 ± 0.54	20.00	27.00	22.58 ± 0.29
NOS	8.00	12.00	10.75 ± 0.21	6.00	8.00	7.13 ± 0.80	8.00	15.00	10.38 ± 0.32
LLS	90.00	132.00	109.96 ± 2.34	60.00	101.00	74.38 ± 2.05	56.00	146.00	109.50 ± 5.82

Notes: ADF = interior dorsal fin ray count; PDF = posterior dorsal fin ray count; AF = anal fin ray count; NOS = number of stripes; and LLS = lateral line scales count.

According to Lindsey (1988), the changes in water temperature or radiation during the fish's early development sometimes cause a meristic variation. Upon observation, the body shade of *B. boddarti* samples collection was found as having the darkest brown shade in Matang Perak population followed by the population in Pekan Pahang and light brown shade in Pendas Johor population.

Different body coloration exhibited in samples from different localities might be correlated with the egg hatching event, as when larvae dispersed into the water and swam to settle down, they will soon develop their coloration by matching their body coloration with the surroundings (Swenson *et al.* 2001). On the other hand, variation in skin color is also a result of natural selection events with high environmental variation in contrast between objects (e.g., plant materials, rocks, soil) and acts as an important advantage against predation (Pinto *et al.* 2020).

Features of *B. boddarti* External and Internal Organs

Several pronounced external features of *B. boddarti* is presented in Figure 5, including dorsal fin, caudal fin, pectoral fin, pelvic fin, and anal fin. The first dorsal fin has a long spine projected from the fin margin. A similar feature was present in other species from *Boleophthalmus* genera, namely *Boleophthalmus poti, Boleophthalmus birdsongi* and *Boleopthalmus caeruleomaculatus* (Dinh *et al.* 2015; Nugroho 2016).

Other prominent traits expressed by *B. boddarti* are the goggle-eyes projected from above of its head. Apart from that, *B. boddarti* also has unique black stripes and blue spots on its body and fins, which are the most distinctive features of *B. boddarti* (Djumanto *et al.* 2012). *B. boddarti* has a complete has a stomach, loops of intestine, liver, swim bladder, heart, kidney duct, gonads, and gills. The gonad is located at the end of the abdominal cavity. The ducts of the kidney, anus and gonad are channelled to the urogenital opening (Fig. 6) (Dinh *et al.* 2015).

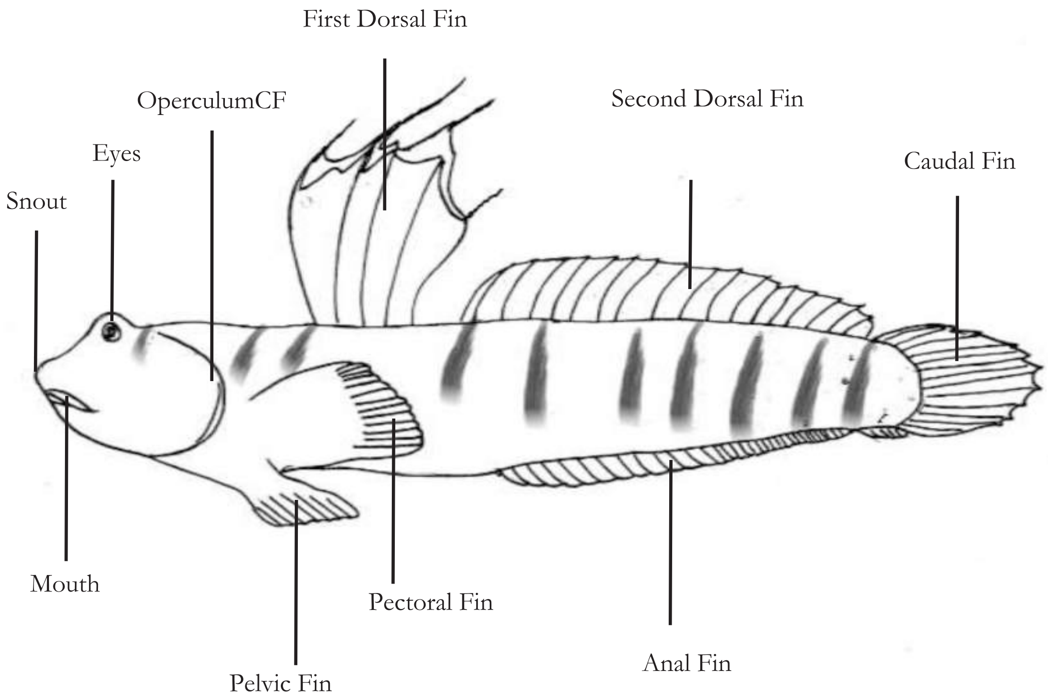

Figure 5 The drawing of external features of *B. boddarti*
Source: Polgar *et al.* (2013).

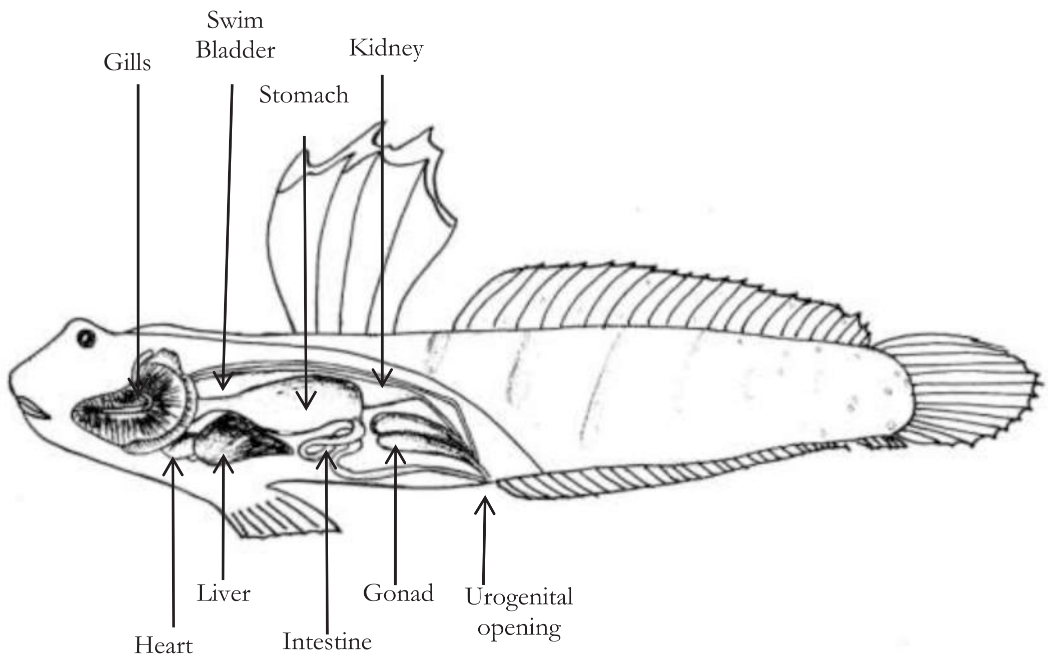

Figure 6 The drawing of the internal organs of *B. boddarti*
Source: Polgar *et al.* (2013).

The Mudskipper Gonads

Both female and male gonads possessed two long projections structures called ovary and testes, respectively. Gonads description of the male and female blue-spotted mudskippers is firstly indicated by the external morphology of genital papilla, which are oval for female and triangle for male (Dinh *et al.* 2015). However, they differ in color and content. Male gonads contain the spermatid fluid, while the female gonads bear the eggs. Both the ovary and testes have four different stages, i.e., immature, maturing or developing state, mature, and spent stages.

Generally, mature male gonads appear in pale pink color compared to the female's which is a bright yellow. The yellow color of the mature ovary is also found in female mudskipper *Periophthalmus barbarus* in Iko Nigeria (Udo *et al.* 2016). However, the study on redbreasted wrasse *Cheilinus fasciatus* has shown that the gonads were so small that caution were needed in determining the stages, while the species has lack of sexual dimorphism (e.g., coloration); therefore, the male and female gonads could not be clearly differentiated (Tresnati *et al.* 2019). Therefore, since the mudskipper did show sexual dimorphism (e.g., coloration) of their gonads, this study focused to understand the mature and immature stages of gonads and the differences of the gonads between genders.

A mature ovary was identified in sample number two indicating a female specimen (Fig 7). The ovary was further extracted from the body and appeared bright yellow (Fig 8). Further observation showed that the ovary was turgid and firm, also interestingly the eggs were able to be seen with the naked eye. Male gonad was identified with a testes having two lobes (Fig 9), which was a swollen structure at the top of the elongated shape.

Besides coloration, the mature ovary of *B. boddarti* was found filling out most of the body cavity. This finding was similar to the study on reproduction of the flying fish, *Hirundichthys affinis* (Oliveira *et al.* 2015), where the mature ovary appeared in maximum size and filled almost the fish gut.

The mature testes appeared to be pale pink in color and thicker compared to the immature testes that generally exist in string-like structures. An immature stage of a testis was found almost transparent. The mature testes was whitish to pinkish in color, while the immature testes were almost translucent. The mature testes appeared to be firmer and more swollen bearing the sperms fluid, while the immature was thread-like in structure because the testes were not yet well developed (Fig 10).

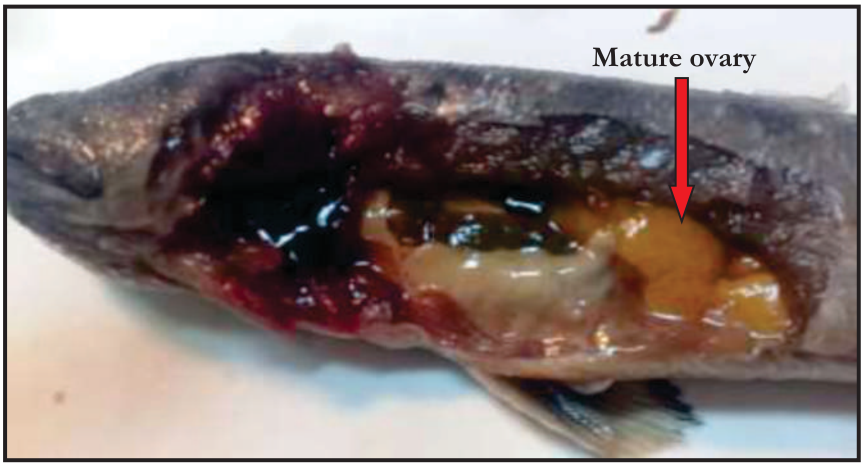

Figure 7 Female ovary of *Boleophthalmus boddarti* filled about a quarter of the fish gut
Note: Sample no. 2 from Matang, Perak.

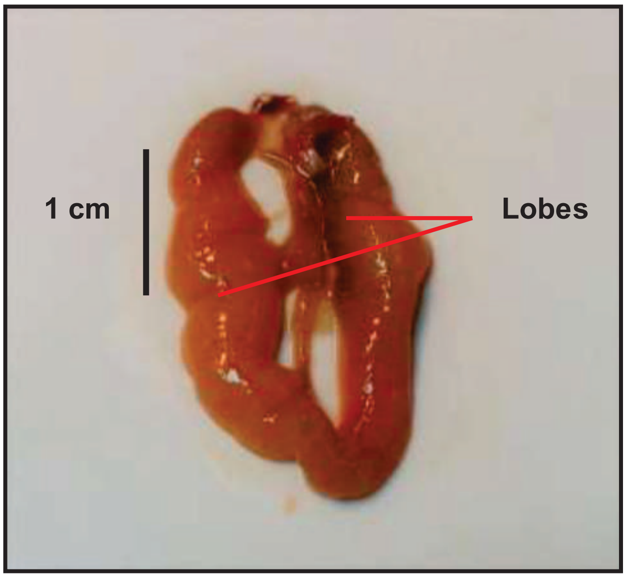

Figure 8 The mature female ovary of *B. boddarti*, sample no. 2 from Matang Perak
Note: Sample no. 2 from Matang, Perak.

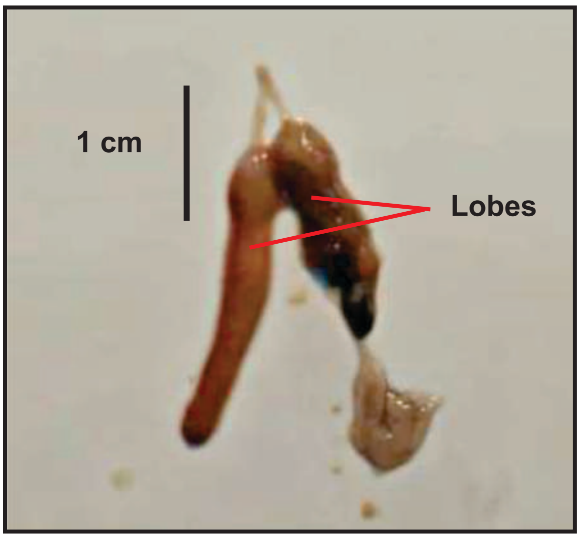

Figure 9 The mature male gonad, testes of *Boleophthalmus boddarti*
Note: Sample no. 2 from Matang Perak.

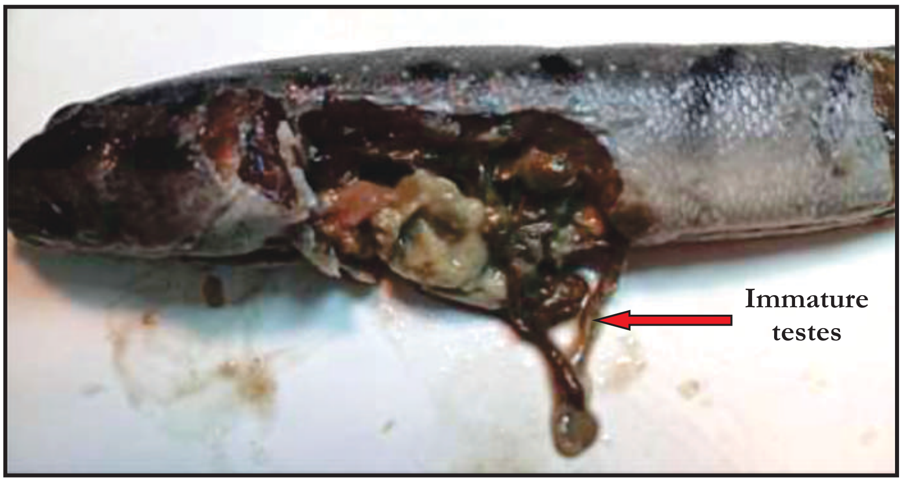

Figure 10 The immature testes of male *Boleophthalmus boddarti* which appear in thinstring-like form
Note: Sample no. 16 from Pekan Pahang.

The presence of fluid in the mature male gonad of *B. boddarti* in pink coloration was found. This result corresponds with the study on the gonad maturity stages of *Prochilodus brevis* where the mature testicles had light pink coloration and the fluid inside the testes was visible under high light intensity (Gurgel *et al.* 2012). However, the different findings of matured testes coloration was documented in the study on gonads morphology and maturity of *Loricariichthys spixii*, where the matured testes were displayed in white coloration and turgid in texture (Duarte *et al.* 2007). Our study concluded that different species might have different matured coloration in their gonads. The immature testes that appeared in string-like form was also found in *Hirundichthys affinis* (Oliveira *et al.* 2015).

Comparisons of Liver Size in the Mature and Immature Ovaries

Mature Ovary

A female *B. boddarti* that bears a mature ovary was found to have a larger liver (Fig 11) than that bears an immature ovary. The liver size of *B. boddarti* was found to increase in proportion following the maturation of the ovary as it was found doubled in size as compared to the liver in the immature ovary. As the ovary becomes mature, it requires a high level of lipid, vitellogenin and other nutrients to nourish the eggs for development (Selman & Wallace 1989).

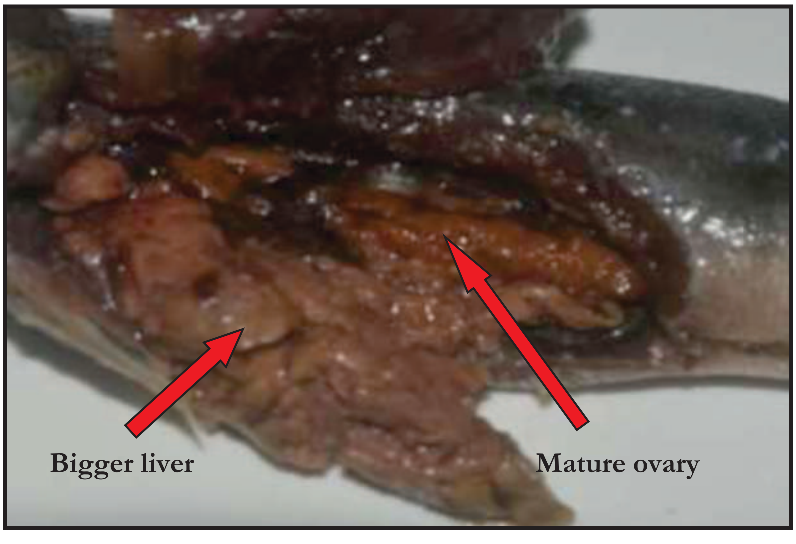

Figure 11 The image of *B. boddarti* liver with the maturing ovary
Note: Sample no. 25 from Pekan Pahang.

Immature Ovary

Immature ovary has a small-lobe structure with pinkish pale color (Oliveira *et al.* 2015). Smaller liver size was found in the resting stage of the immature ovary compared to the liver size in the mature ovary of the female *B. boddarti* (Fig 12). Smaller size of the liver may be due to the hepatic content having been used up during the previous maturation process. Liver size of mudskipper fish corresponds with ovary maturity stage due to the liver function in supplying nutrition for eggs development, such as the supply of lipids and vitellogenin. However, there was a contradiction in a study conducted by Riberio *et al.* (2006) which claimed that liver size is bigger during the maturation process and depleted in size during maturation of the ovary.

Length-Weight Relationship

Morphological and gonads observations have helped in describing the sex of *B. boddarti*. Further confirmation on sex determination of *B. boddarti* can be made through length-weight relationship correlation.

Based on the logarithmic equation of females (Fig. 13a), Log W = 3.145 log TL - 5.339, R^2 = 0.959, n = 29 and male (Fig 13b), Log W = 2.198 log TL - 4.874, R^2 = 0.971, n = 43 it can be determined that b value of female and male were 3.145 and 2.198, respectively (Table 1).

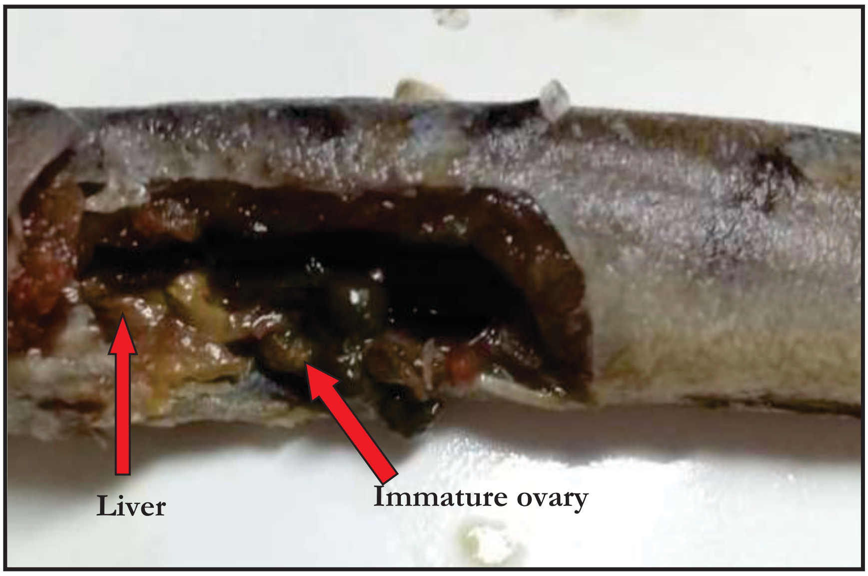

Figure 12 The liver and the immature ovary of the female *Boleophthalmus boddarti*
Note: Fish sample from Pendas.

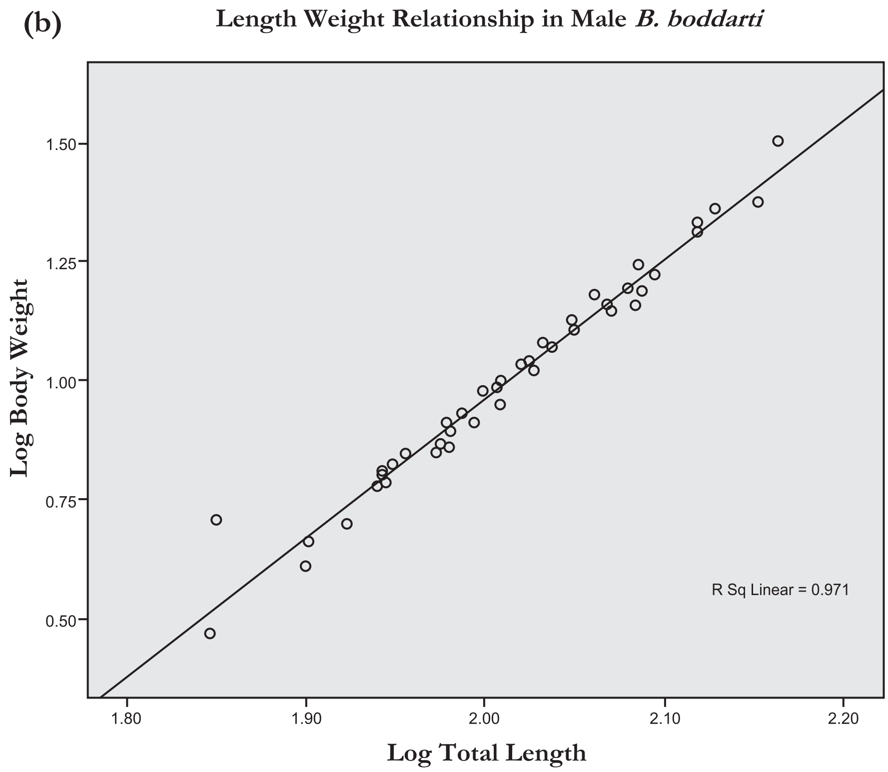

Figure 13 Relationship between logarithmic total length and logarithmic body weight in: (a) female *B. boddarti*. and (b) male *B. boddarti*

Table 1 Determination of regression coefficient (R^2) for female and male *B. boddarti*

Model	R	R^2	Adjusted R^2	Standard error of the estimate
Female	0.979[a]	0.959	0.957	0.04504
Male	0.985[a]	0.971	0.970	0.03937

Notes: a. Predictors: (Constant), Log Body Weight.

Table 2 Equation coefficients of female *B. boddarti*

Female	Unstandardized coefficients		Standardized coefficients			95% Confidence interval for b	
	b-value	Standard error		t	Sig.	Lower bound	Upper bound
(Constant)	-5.339	0.273		-19.530	0.000	-5.902	-4.776
Log body weight	3.145	0.131	0.979	24.069	0.000	2.876	3.414

Note: b = dependent variable, log body weight.

Table 3 Equation coefficients of male *B. boddarti*

Male	Unstandardized coefficients		Standardized coefficients			95% Confidence interval for b	
	b-value	Standard error		t	Sig.	Lower bound	Upper bound
(Constant)	-4.874	0.159		-30.742	0.000	-5.194	-4.553
Log body weight	2.918	0.079	0.985	37.113	0.000	2.759	3.077

Note: b = dependent variable, log body weight.

The b value was the determination of the fish growth pattern, where b = 3. An isometric growth indicates the rate of total length and weight, which were increased at the same rate at b value around 3 and the population depicted an allometric growth (Tables 2 & 3). However, it can differ in value due to different feeding types, genders and maturity of the species.

In our study, both female and male length-weight relationships exhibited a strong positive correlation with correlation coefficient R = 0.979 and 0.985, respectively. The correlation in males was significant at P value = 0.011 level, while the correlation of females was significant at P value = 0.010.

Total length of both male and female *B. boddarti* increased in correlation to their body weight, a similar finding to the mudskipper, *Periophthalmus papilio* (Lawson 2011). However, Dinh *et al.* (2022) added that male and female mudskippers mature at different lengths in reference to mudskipper *Periophthalmus chrysospilos*, in which the males are an egg guarder, the length at first maturity of males is longer than females.

CONCLUSION

Wide variations in some morphological and meristic characteristics of mudskippers were possibly influenced by environmental features that have yet to be determined. Distinct features on mature and immature female gonads of *B. boddarti* help to understand their growth process. At the same time, characteristics of female and male gonads (color, size, contents and textures of the gonads) are documented in our study. The findings from this study is expected to be a baseline for future study on gonads characteristics of mudskippers. The technique applied is proven straightforward and low in cost yet highly informative rather than opting for the high-cost technique of bio-molecular.

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