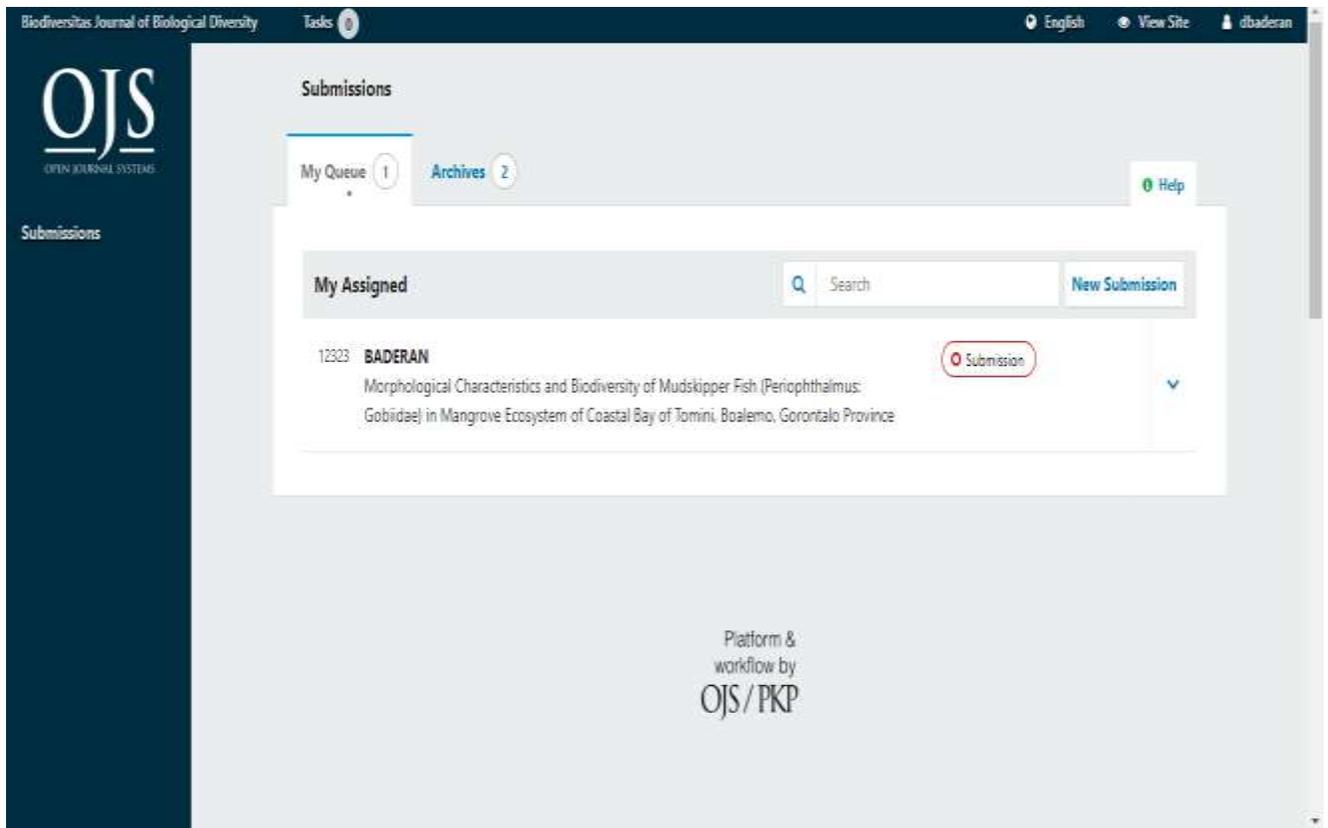
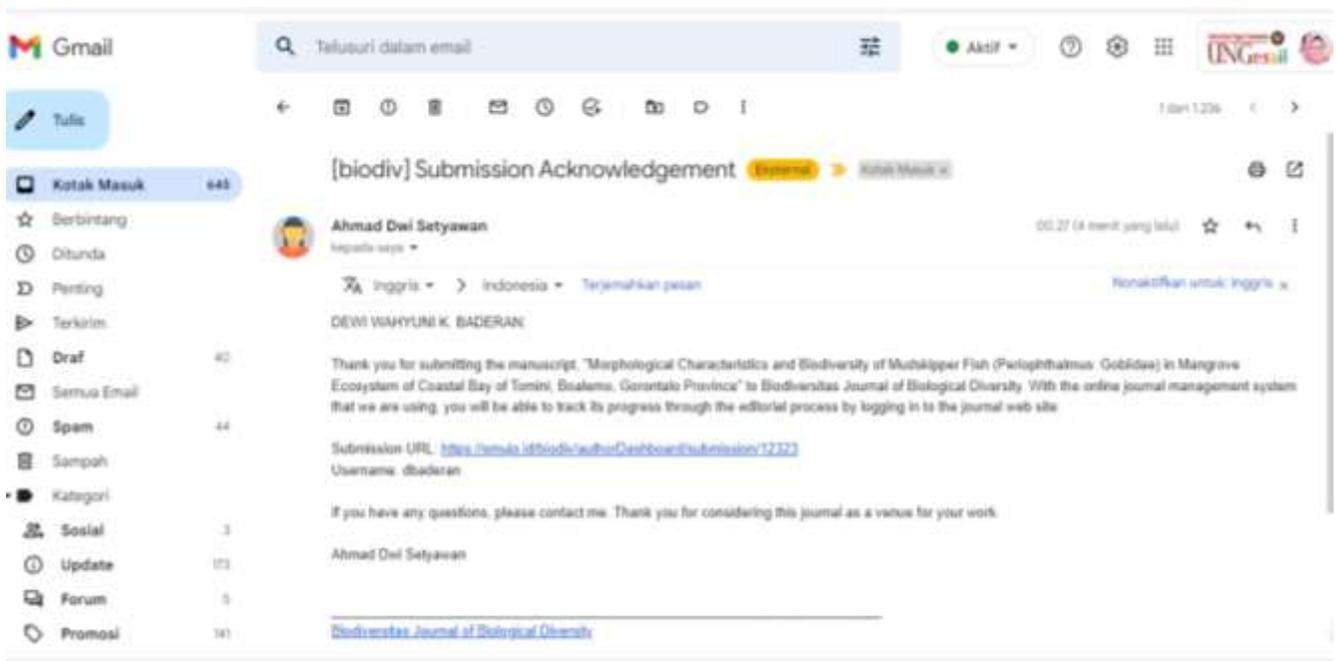


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Kamis, 22 September 2022



## COVERING LETTER

Dear **Editor-in-Chief**,

I herewith enclosed a research article,

**Title:**

**Morphological Characteristics and Biodiversity of Mudskipper Fish (*Periophthalmus: Gobiidae*) in Mangrove Ecosystem of Coastal Bay of Tomini, Boalemo, Gorontalo Province**

**Author(s) name:**

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**Novelty:**

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Revealing the morphological characteristics and biodiversity of Gelodok Fish (*Periophthalmus: Gobiidae*) in the Coastal Mangrove Ecosystem of Tomini Bay, Boalemo, Gorontalo Province, which is the largest bay in Indonesia and holds unique flora and fauna biodiversity with a very high level of endemism.

**Statements:**

This manuscript has not been published and is not under consideration for publication to any other journal or any other type of publication (including web hosting) either by me or any of my co-authors. Author(s) has been read and agree to the Ethical Guidelines.

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**Place and date:**

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**Sincerely yours,**

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Dewi Wahyuni K.Baderan

# Morphological Characteristics and Biodiversity of Mudskipper Fish (Periophthalmus: Gobiidae) in Mangrove Ecosystem of Coastal Bay of Tomini, Boalemo, Gorontalo Province

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Manuscript received: ..... (Date of abstract/manuscript submission). Revision accepted: .....

**Abstract.** The southern sea area of Gorontalo Province is part of Tomini bay, the biggest bay in Indonesia. There lies unique flora and fauna with high endemicity. Mangrove forest located in the coastal bay of Tomini Boalemo is one of the habitats for flora and fauna, a place for spawning, nurturing, and food hunting for fish. The mudskipper is a fish that lives in the mangrove area. This study aims to reveal the morphological characteristics and biodiversity of mudskipper (Periophthalmus: Gobiidae) in the ecosystem of Tomini Boalemo coastal bay of Gorontalo Province. This study employed a quantitative descriptive that also implemented purposive sampling as the sampling method in three ecosystem stations of Tomini Boalemo coastal bay (Dulupi, Bajo, and East Pentadu mangrove). The mudskippers were collected when the water was manually receding by using a fish net. The sample which had been collected were then identified based on 22 morphological, 24 morphometric, and 7 meristic characteristics. The identification results were then compared with the identification key. The species of mudskippers found were then analyzed to figure out the species biodiversity (diversity, evenness, species richness, and dominance indexes). The research result revealed 5 species from Periophthalmus Genus which are *Periophthalmus argentilineatus*, *Periophthalmus kalolo*, *Periophthalmus malaccensis*, *Periophthalmus minutus*, *Periophthalmus variabilis*, with total individuals 561. The score of  $H' = 1.09$  showed that the diversity of mudskipper fish was categorized as medium. The evenness index was 0.99 obtained from 3 observation stations while the lowest dominance index was on station II with a score of 0.34 and the score of (R1) in each station was respectively (0.19); (0.36); and (0.2). The result of this study was used as a database for the sustainable management of Tomini Bay in order to tackle the threats of species extinction through aquatic life protection and preservation to arrange the natural balance and support the availability of the coastal resource for future generations.

**Keywords:** biodiversity, morphology, Periophthalmus, Tomini Bay

## INTRODUCTION

Tomini Bay is the largest bay in Indonesia and is located in the coral triangle initiative. One of the parts of the bay which has rich biodiversity is the mangrove ecosystem which plays an important role in improving coastal sea productivity, spawning area, and nutrient supply needed by various species of fish (Mahesh & Saravanakumar, 2015). In addition, Sellang (2020) stated that the mangrove ecosystem is one of the most important and productive environments for the species of fish, in a tropical area, and sub-tropical estuary which can improve the fertility and productivity of the coastal area. Mudskipper fish (Perciformes: Gobiidae) is one of the faunas that live in the mangrove ecosystem, as mentioned by Latuconsina (2016); Sunarni & Maturbongs (2016) as the loyal resident of the mangrove ecosystem. One of the Genera that belongs to the Family that is widely distributed in that ecosystem is Periophthalmus (WoRMS, 2018; Fishbase, 2018; Clayton, 1993). This Genus occupies primary (organisms that obtain energy from producers) and secondary positions (organisms that obtain energy from primary consumers) in the food chain despite their very small size (Polgar & Lim, 2011) inhabiting muddy habitats, sandy beaches, and mangrove areas (Takita et al., 2011). Mudskipper daily behavior is closely related to tidal rhythm (Ravi, 2013; Muhtadi et al., 2016) where they climb mangrove roots, walk on mudflats, and dig burrows in mud (Bhatt et al., 2009; Al-Behbehani & Ebrahim, 2010; Polgar & Lim, 2011).

The mudskipper fish has various species yet they have numerous similarities in terms of morphology (Gosal et al., 2013). One of its unique characteristics is spending 90% of its life a day living on land, climbing, and perching on the roots of the mangrove or wood, as well as being able to crawl up on the land. Its pectoral fin on its muscular base can

be buckled so that it functions like arms that can be used to crawl and jump above the mud (Murniati & Hasan, 2016; Elviana & Sunarni, 2018). The potential of mudskipper fish as the filter feeder that consumes the organic particles of living creatures suspended in water, has the ability to absorb Lead (Pb) and has a role as a bio-indicator of environmental pollution. The mudskipper can be used by people to fulfill their food needs (Bidawi et al., 2017). *Boleophthalmus boddarti*, one of the mudskipper fish species, has 0.48% fat and 48.26% protein (Sunarni, 2013). A good morphological look of mudskipper fish can be used as an ornamental fish in some Asian countries such as China, Japan, and Korea, even in some parts of Indonesia such as Karawang and Cilacap, mudskipper fish is for sale as dry and smoked fish.

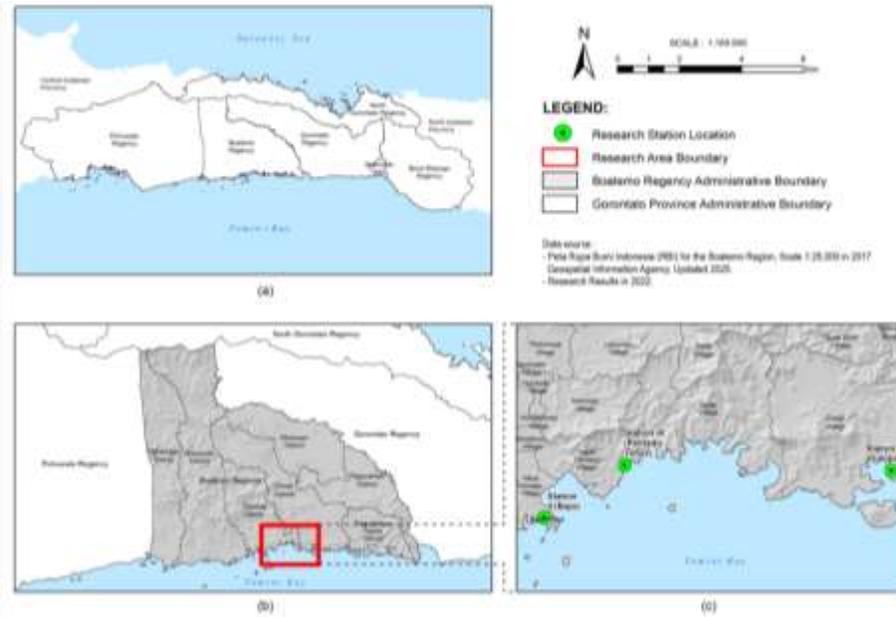
One of the areas in Sulawesi Island which is directly bordered by Tomini Bay is Boalemo Regency. Boalemo in general has a typical characteristic of a coastal area with relatively high resources particularly in the area of mangrove forest and fishery sources, one of which is the mudskipper fish. The existence of this fish in the mangrove ecosystem in the Coastal Bay of Tomini Bualemo is pretty abundant although it is disregarded as a man of the fishers and people in Boalemo are not aware of the potential of the nutrition consisted in the mudskipper fish. As consequence, the existence of the mudskipper fish in the Mangrove Coast Tomini Bay is threatened to be extinct along with the decrease of its population along with the speed of mangrove forest degradation. The main cause of the degradation is the land conversion in mangrove forests to become fish and shrimp ponds. In 1988, the area of mangrove forest in Tomini Bay was noted as big as 17.672 hectares while in 2010, it was degraded to 16.105 hectares, and in 2020, it is predicted to have the remaining area as big as 10.321 hectares (Paino, 2020).

The species of mudskipper which were identified until today are around 41 species in 10 genera (Murdy, 1989; Jaafar & Larson, 2008; Polgar et al., 2013; Umami, 2022). General information related to mudskipper fish has been available yet its species which are found in the Tomini Bay have not been found even the people in the coastal Bay of Tomini Bualemo stated that the mudskipper fish is a kind of poisonous fish. People have not yet known the potential use of the mudskipper fish optimally in terms of ecology, economy, and health so this research is urgent to conduct. This research aims to analyze the morphological characters and biodiversity of mudskipper fish as the reliable resident of the mangrove area in Tomini Bay. The findings of this research can be used as support for formulating policies that aim to minimize the mangrove degradation in the coastal bay of Tomini.

## **MATERIALS AND METHODS**

### **Study area**

This study was carried out in a mangrove ecosystem in the coastal bay of Tomini, Boalemo, Gorontalo Province. It included three observation stations i.e. station I (Dulupi Village), station II (Bajo Village), and station III (East Penatdu Village). This study had been conducted for 5 months from May to September 2022. This study employed a descriptive quantitative method by implementing a purposive sampling method in three stations of the mangrove ecosystem in the coastal bay of Tomini, Boalemo. Data collected were primary and secondary data. The primary data were collected by identifying all species of the mudskipper fish and some of its morphological, morphometrical, and meristical characteristics as well as its biodiversity (diversity, evenness, and species richness indexes) (Figure 1).



**Figure 1.** Location of the coastal bay of Tomini, Boalemo, Gorontalo Province indicating the sampling sites of *Periophthalmus*: Station I (N 00°30.640 E 122°26.982), Station II (N 00°29.818 E 122°20.931), and Station III (N 00°30.736 E 122°22.336)

## Tools and Materials

The tools used were a fish tango, a 3x3 meters fish net, cool box, ziplock, stationery, digital camera, ruler, millimeter block paper, gloves, jar, GPS, thermometer, pH meter, and an Ohaus digital scale with an accuracy of 0.01 g. The materials used were mudskipper fish, 10% formalin, 70% alcohol, tracing paper, ice, sewing thread, and distilled water.

## Procedures

The sampling procedures are as follows: (i) Specimen collection using a 3x3 meters net and hand-collecting in the 3 locations of the mangrove ecosystem of the coastal area of Tomini bay. (ii) Measurement of physical-chemical factors temperature, substrate, water pH, and substrate pH of the environment was done in every location. (iii) The specimen was put in a jar, labeled, and then transferred to the laboratory for identification purposes. (iv) Specimen documentation was carried out utilizing a Nikon DX VR camera with an AF-S NIKKON 18-55 mm lens and a Macro Pro Tama Digital PRO 0.45X HD WIDE LENS SDW-045 52 mm. (v) Furthermore, the mudskipper fish samples were observed and measured for morphological, morphometric and meristic characterization in the Biology Laboratory, Faculty of Mathematics and Natural Sciences, and in the Agricultural Laboratory, Faculty of Agriculture, Universitas Negeri Gorontalo. This observation and measurement step was referred to Aydalina (2016), Larson & Murdy (2001), Gonzalez-Martinez et al. (2020), Kaur et al. (2019), and (Kottelat et al., 1993). Species identification was carried out by referring to Jaafar et al. (2016), Larson & Murdy (2001), and Murdy (1989). Specimen fixation used 70% alcohol and 10% formalin.

## Data analysis

Morphometric and meristics data were analyzed using the Excel program and morphological observations were analyzed descriptively.

Data on the diversity of mudskipper species were analyzed using the Diversity Index ( $H'$ ) (Shannon & Wiener, 1963; Fachrul, 2012).  $H' = -\sum_{i=1}^S p_i \ln p_i$  where  $p_i = \frac{n_i}{N}$ .  $H'$  represents the Shannon-Wiener Diversity index, S for

total species,  $N_i$  for total individuals in a species,  $\ln$  for the natural algorithm, and  $N$  for total individuals found. The value of  $H'$  determines the level of species diversity in an area, where the definition of the value of species diversity according to Shannon-Wiener is:  $H' > 3$ : High species diversity,  $1 \leq H' \leq 3$ : Medium species diversity,  $H' < 1$ : Low species diversity.

Data of species evenness ( $K$ ) were analyzed using the species evenness index which referred to the Pielou Evenness Indices formula (Ludwig & Reynolds, 1988):  $E = H'/\ln S$ .  $E$  represents Evenness Index and  $H'$  represents Shannon-Wiener Diversity Index. Margalef formula was used as Species Richness Index (Magurran, 1988):  $R_1 = \frac{(S-1)}{(\ln N)}$  which  $R_1$  represents Richness Index,  $S$  for Numbers of Species found, and  $N$  for Total Numbers of Individuals.

Dominance data were analyzed using the Simpson formula:  $D = \sum \frac{(n_i(n_i-1))}{(N(N-1))}$ . The results of the dominance index were grouped into  $0 < D < 0.5$  which there are no species that dominate other species or a community structure is stable, and  $0.5 < D < 1$  which means there are species that dominate other species or a community structure is not stable because of ecological pressures (Odum, 1993).

## RESULTS AND DISCUSSION

### Result

#### *Mudskipper Fish at the Research Site*

The results in Table 1 show that the species of mudskipper fish which were found comprising one Gobiidae Family of the Actinopterygii Class: *Periophthalmus argentilineatus*, *Periophthalmus kalolo*, *Periophthalmus malaccensis*, *Periophthalmus minutus*, and *Periophthalmus variabilis*. The total number of mudskipper fish found in the coastal mangrove area of Tomini Bay, Boalemo, as many as 561 individuals were spread across station I-Dulupi village (156 individuals), station II-Bajo village (254 individuals) and station III-East Pentadu village (151 individuals). The classification of mudskipper fish in the coastal mangrove ecosystem of Tomini bay, Boalemo, Gorontalo Province, is presented in Table 1.

**Table 1.** The classification of mudskipper fish in the coastal mangrove ecosystem of Tomini bay, Boalemo, Gorontalo Province

Class, Family	Species	Station			Total Number of Individuals
		I Dulupi	II Bajo	III East Pentadu	
<b>Actinopterygii</b>					
Gobiidae	<i>Periophthalmus argentilineatus</i>	-	-	√(83)	83
	<i>Periophthalmus kalolo</i>	√(67)	-	-	67
	<i>Periophthalmus malaccensis</i>	√(89)	√(98)	-	187
	<i>Periophthalmus minutus</i>	-	√(75)	-	75
	<i>Periophthalmus variabilis</i>	-	√(81)	√(68)	149
	Total				561

Description: (√) found; (-) Not found; and the number in brackets represents the number of individuals observed.

Source: Primary Data, 2022

### *The Morphological Characters of Mudskipper Fish*

**Table 2.** Comparison of Morphological Characters of Mudskipper Fish in the coastal mangrove ecosystem of Tomini Bay, Boalemo, Gorontalo Province

Characters	<i>P. minutus</i>	<i>P. malaccensis</i>	<i>P. variabilis</i>	<i>P. argentilineatus</i>	<i>P. kalolo</i>
Dermal cup	-	-	-	-	-
One row of teeth on maxilla	+	+	+	+	+
Pelvic frenum	-	+	+	-	+
Pelvic fin wholly fused	-	-	-	-	-
Pelvic fin partly fused	-	+	+	-	+
Pelvic fin not fused	+	-	-	+	-
High D1	-	-	-	-	-
Medium D1	+	+	+	+	+
Low D1	-	-	-	-	-
Slightly rounded D1 margins	-	+	-	-	-
Rounded D1 margin	-	-	+	-	+
Straight D1 margin	+	-	-	+	-
White D1 margin	-	-	+	-	+
Single inframarginal brown strip on D1	-	+	+	-	-
Single inframarginal black strip on D1	-	-	-	-	+
Single mesial brown strip on D1	+	-	-	+	-
White spot on proximal on D1	+	+	-	+	+
Reddish orange spot on D1	-	-	+	-	-
Elongated first spine on D1	-	+	+	-	-
Fading strip Mesial on D2	+	+	-	+	+
D1 and D2 connected by a membrane	-	-	-	-	-
Reddish orange pelvic and caudal fins	-	-	+	-	-

### *The Morphometric Characters of Mudskipper Fish*

**Table 3.** Comparison of Morphometric Characters of Mudskipper Fish in the coastal mangrove ecosystem of Tomini Bay, Boalemo, Gorontalo Province

Characters	<i>P. minutus</i>	<i>P. malaccensis</i>	<i>P. variabilis</i>	<i>P. argentilineatus</i>	<i>P. kalolo</i>
Eye diameter	0.051	0.029	0.035	0.061	0.037
Post-orbital length	0.060	0.060	0.060	0.076	0.068
Head length	0.152	0.160	0.137	0.118	0.136
Snout length	0.273	0.274	0.264	0.247	0.256
Pre-dorsal length	0.506	0.070	0.054	0.091	0.055
Pre-ventral length	0.337	0.383	0.368	0.384	0.346
Pre-anal length	0.279	0.313	0.307	0.256	0.299
D1 base length	0.649	0.629	0.632	0.583	0.630
D1 longest spine height	0.214	0.178	0.192	0.163	0.172
D2 base length	0.195	0.237	0.196	0.164	0.233
D2 posterior distance length : caudal pedunculus	0.216	0.174	0.216	0.201	0.211
Head height	0.172	0.163	0.164	0.175	0.143
Front body height	0.157	0.159	0.162	0.187	0.142
Pectoral fin's longest radius length	0.184	0.194	0.194	0.204	0.182
Middle body height	0.206	0.179	0.173	0.164	0.145
Pelvic fin base length	0.170	0.207	0.173	0.184	0.169
Pelvic fins' longest radius length	0.047	0.041	0.063	0.120	0.033
Caudal pedunculus height	0.101	0.116	0.088	0.102	0.103
Anal fin length	0.160	0.165	0.162	0.162	0.142

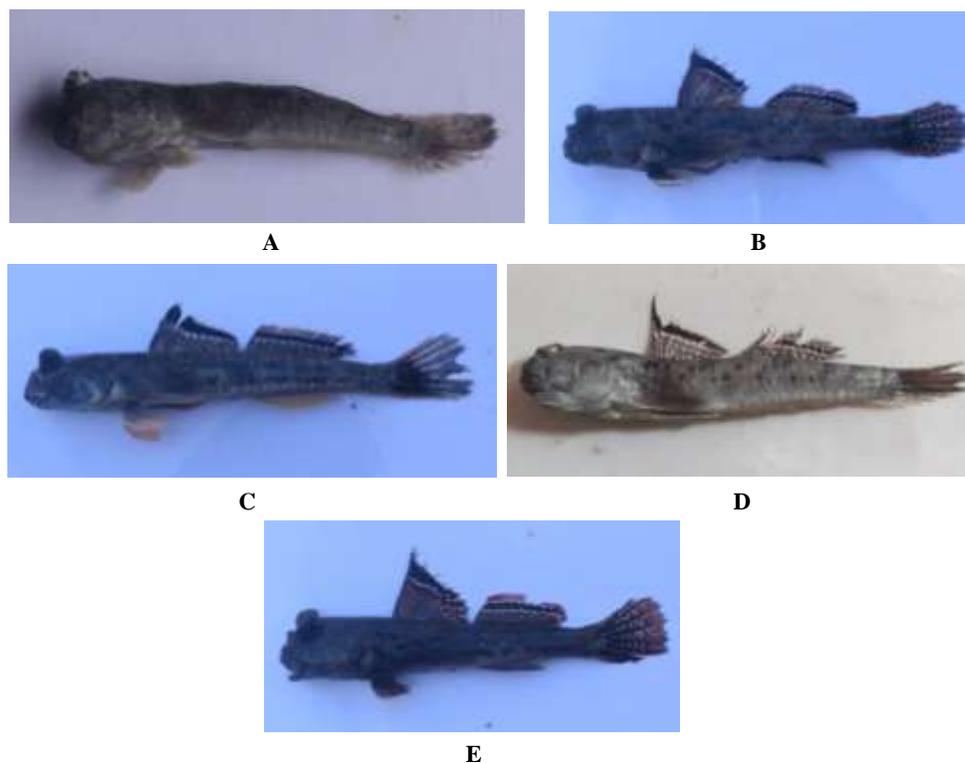
Anal fin's longest radius length	0.201	0.188	0.223	0.165	0.155
Tail stem height	0.081	0.059	0.056	0.127	0.074
Caudal fin height	0.081	0.097	0.099	0.101	0.082
Caudal fin length	0.144	0.162	0.115	0.145	0.152
Eye diameter	0.213	0.234	0.208	0.219	0.167

### Meristic Characters of Mudskipper Fish

Meristic characteristics comparison of mudskipper fish which were found in the coastal mangrove ecosystem of Tomini Bay, Boalemo, Gorontalo Province along with the species' classification are presented in Table 4 and Figure 2.

**Table 4.** Comparison of Meristic Characters of Mudskipper Fish in the coastal mangrove ecosystem of Tomini Bay, Boalemo, Gorontalo Province

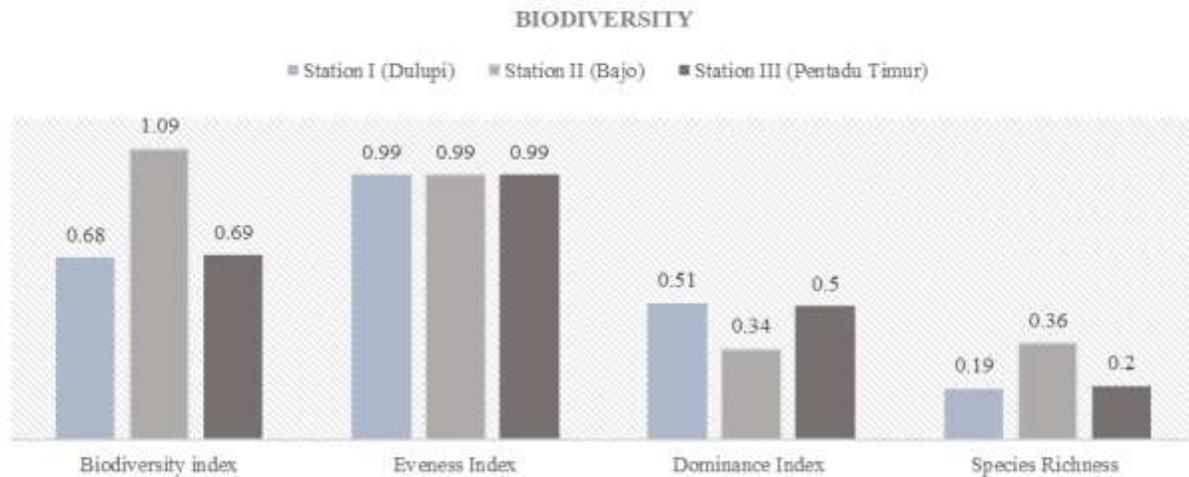
OTU	Number of Spines and Rays												LS
	D1		D2		A		P		V		C		
	S	R	S	R	S	R	S	R	S	R	S	R	
<i>P. minutus</i>	16	0	1	12	0	11	0	13	0	6	0	13	60
<i>P. malaccensis</i>	11	0	1	12	0	11	0	11	0	6	0	14	58
<i>P. variabilis</i>	14	0	1	12	0	12	0	13	0	6	0	16	52
<i>P. argentilineatus</i>	13	0	1	12	0	12	0	12	0	6	0	16	70
<i>P. kalolo</i>	11	0	1	12	0	11	0	11	0	6	0	14	62



**Figure 2.** Mudskipper fish in the coastal mangrove ecosystem of Tomini Bay, Boalemo, Gorontalo Province. A. *Periophthalmus minutus*, B. *Periophthalmus malaccensis*, C. *Periophthalmus variabilis*, D. *Periophthalmus argentilineatus*, E. *Periophthalmus kalolo*

### Biodiversity of Mudskipper Fish Species

The gathered data of mudskipper fish at three locations showed moderate diversity with a value of  $H' = 1.09$ . The Evenness index is 0.99 for 3 observation stations. The lowest dominance value is at station II with a value of 0.34 (Figure 3).



**Figure 3.** Biodiversity (Biodiversity index, Evenness Index, Dominance Index and Species Richness of mudskipper fish in the research site

### Environment Parameters

The results range of the temperature measurement at the three research locations were around 28 -30°C at station I, 29-30°C at station II and 28 -30°C at station III. The value of the acidity degree (pH) of water was in the range of 7.1-8 and the substrate (pH) in the range of 6.8-8.

**Tabel 5.** Physics and chemical parameters of the research site waters

Environment Parameters	Coastal Mangrove Area of Tomini Bay, Boalemo		
	Station I Dulupi	Station II Bajo	Station I Dulupi
Temperature (°C)	28-30	29-30	28-30
Substrat	Mud	Mud rocks	Mud
Water pH	7.1-8	7.3-8	7.1-8
Subtrat pH	7.5-8	6.8-7	7.5-8

### Discussion

There are five mudskipper fish species that can be found in the coastal mangrove ecosystem of Tomini Bay, Boalemo, Gorontalo Province which all of the species are part of Genus *Periophthalmus*. It shows that even though mudskipper fish spreads all over Indo-Pacific (Springer, 1982), *Periophthalmus* tends to stay in mangrove ecosystems. Thus, the result of this study is in line with previous studies which were conducted in the coastal ecosystems around Indo-Pacific such as Maluku (Rumahlatu et al., 2020); Taniwel et al., 2020), South Papua (Sunarni & Maturbongs, 2016; Umami, 2022), East Java (Juniar et al., 2019), Central Sulawesi (Enot et al., 2015), North Sumatera (Muhtadi et al., 2016), Malacca Strait and Malay Peninsula (Polgar et al., 2014). All species found by researchers have high similarity in morphological features because they are part of the same genus (Table 2).

- a. *Periophthalmus minutus*  
D<sub>1</sub> XVI, D<sub>2</sub> I,12; A 11; P 13; V 6; C 13  
Eyes without dermal cup; one row of teeth on the maxilla; pelvic fin without frenum; moderate D1 height with straight margins, single brown strip mesial with numerous proximal white spots, without spinal elongation; D2 with dusky brown stripe mesially; D1 and D2 are not connected by a membrane; lateral scales 60; head length 0.273% SL; pelvic fin basal length 0.047% SL; anal fin basal length 0.201% SL; D1 basal length 0.214% SL; D2 basal length 0.216% SL; caudal peduncle height 0.081% SL (Figure 2, Table 3, Table 4).
- b. *Periophthalmus malaccensis*  
D<sub>1</sub> XI, D<sub>2</sub> I,12; A 11; P 11; V 6; C 14  
Eyes without dermal cup; one row of teeth on the maxilla; the pelvic is clear and prominent; moderate D1 height with slightly rounded margins, a single inframarginal brown strip with numerous proximal white spots, first spine elongated; D2 with faded brown stripe mesial; D1 and D2 are not connected by a membrane; lateral scales 58; head length 0.274% SL; pelvic fin basal length 0.027% SL; anal fin basal length 0.188% SL; D1 basal length 0.178% SL; D2 basal length 0.174% SL; caudal peduncle height 0.097% SL (Figure 2, Table 3, Table 4). *Periophthalmus malaccensis* also has bright blue spots on the chin and operculum, it also has prominent transverse folds on the snout (Polgar, 2016).
- c. *Periophthalmus variabilis*  
D<sub>1</sub> XI, D<sub>2</sub> I,12; A 11; P 11; V 6; C 14  
Eyes without dermal cup; one row of teeth on the maxilla; the pelvic frenum is clear and prominent; the pelvic is orange at least at the margins; moderate D1 height with rounded margins, a single inframarginal brown strip with many proximal white spots, first spine elongated, white margin; D2 with single inframarginal orange stripe and black single stripe mesial, with reddish-orange spots at the base; the anal fins are orange at least at the margins; D1 and D2 are not connected by a membrane; lateral scales 52; head length 0.264% SL; pelvic fin basal length 0.027% SL; anal fin basal length 0.063% SL; D1 basal length 0.192% SL; D2 basal length 0.216% SL; caudal peduncle height 0.099% SL (Figure 2, Table 3, Table 4). When alive, the branchiostegal membrane of the fish shows pigmentation (Setiawan et al., 2019).
- d. *Periophthalmus argentineatus*  
D<sub>1</sub> XIII, D<sub>2</sub> I,12; A 12; P 12; V 6; C 16  
Eyes without dermal cup; one row of teeth on the maxilla; pelvic without frenum; moderate D1 height with straight margins, single brown strip mesial with numerous proximal white spots, without spinal elongation; D2 with dusky brown stripe mesial; D1 and D2 are not connected by a membrane; lateral scales 70; head length 0.247% SL; pelvic fin basal length 0.12% SL; anal fin basal length 0.165% SL; D1 basal length 0.163% SL; D2 basal length 0.201% SL; caudal peduncle height 0.101% SL (Figure 2, Table 3, Table 4).
- e. *Periophthalmus kalolo*  
D<sub>1</sub> XI, D<sub>2</sub> I,12; A 11; P 11; V 6; C 14  
Eyes without dermal cup; one row of teeth on the maxilla; vestigial pelvic frenum; pelvic fins fused about half of the pelvic fins; moderate D1 height with rounded margins, single black stripe inframarginal with proximal white spots, without spinal elongation; D2 with inframarginal faded strip; D1 and D2 are not connected by a membrane; lateral scales 62; head length 0.256% SL; pelvic fin basal length 0.033% SL; anal fin basal length 0.155% SL; D1 basal length 0.172% SL; D2 basal length 0.211% SL; caudal peduncle height % SL (Figure 2, Table 3, Table 4).

Morphological adaptations of mudskipper fish cause variations in morphometric and meristic measurements (Nugroho et al., 2016). Gangan et al. (2016) added that meristic characters such as scales before and after the pectoral filaments, pectoral fins, dorsal fins, abdominal fins and anal fins are characters that can distinguish species in the genus. In addition, other factors that influence differences in fish morphology are food availability, environmental conditions and the stage of fish maturity. Another character with a high probability of variation is coloration. Fish coloration is influenced by many factors including genetic, environmental, dietary, and physiological factors (Nusslein-Volhard & Singh, 2017). Due to the instability of the correlation character, this character is mostly neglected when identifying fish species.

The difference in species diversity between the three stations is influenced by environmental conditions. The high and low species diversity is influenced by many factors and one of the factors is environmental quality. Khouw (2009) further explained that species diversity is used to measure the stability of a community which is the ability of a community to keep itself stable despite disturbances to its components. Maturbongs et al. (2018) argued that the area or mud substrate is a habitat for various nekton, which indicates the area has abundant food sources. The existence of habitat variations (substrate), such as physical conditions and the surrounding environment affects the diversity of fish species. The diversity index at the research site was 1.09, this indicated that a high level of diversity of mudskipper fish in the Coastal Bay of Tomini, Bualemo, was included in the moderate criteria. In addition, it also showed that water productivity was quite balanced.

The comparison of the Evenness index of mudskipper fish in the research locations had the same Evenness index value of 0.99. This value indicated that the Evenness in the three locations was stable. The Evenness index shows the degree of Evenness of individual abundance between each species. If each species has the same number of individuals, then the community has a maximum Evenness value. On the other hand, if the Evenness value is small, then the community has dominant, sub-dominant, and dominated species, eventually, the community has a minimum Evenness. The Evenness value had a range between 0-1, if the index value obtained was close to one, it means that the distribution is more even (Ismaini et al., 2015; Baderan et al., 2021). Figure 3 presents the index of Evenness of the mudskipper (*Periophthalmus*) species in the Coastal Bay of Tomini, Bualemo, which was included in a stable community. Thus, the population between species of the genus *Periophthalmus* on the Coastal Bay of Tomini, Bualemo, was fairly even, so that disturbances did not easily occur and were able to return to their initial conditions.

Species richness in the research locations was low with the Specific Richness Index (R1) at each station as follows 0.19 (Station I Dulupi), 0.36 (Station II Bajo); 0.2 (Station III East Pentadu). Species richness refers to the number of species in a community. The number of species in the field determines the size of the richness index. The Margalef richness index divides the number of species by the natural logarithm function meaning that the increase in the number of species is inversely proportional to the increase in the number of individuals. Generally, a community/ecosystem with an abundant number of species will have a small number of individuals in each of these species.

The dominance of species in water often occurs due to several things including competition for natural food by certain species accompanied by changes in environmental quality and also an imbalance between predators and prey which are resulted in competition between species. Maturbongs et al. (2018) explained that dominance occurs because of the result of the competition process for evicting one individual against another. Okyere (2018) stated that at low tide the estuary area is dominated by brackish fish species, one of which is from the Gobiidae family. This statement is true because mudskipper fish is more active during low tide conditions both on the coast and at an estuary, on the other hand, mudskipper fish will hide in their nests at high tide to avoid predators. The dominance index of mudskipper fish was 0.51 which indicated that the level of species dominance in these waters was moderate, thus there were no dominant species in these waters.

Environmental factors that are very supportive and the absence of predators made several species of mudskipper fish thrive and spread across the area. In line with research conducted by Mahadevan & Ravi (2015) which stated that the right water temperature range for mudskipper fish was between 23.5-35.5°C, the measurement results of environmental parameters showed that the average temperature range was 28-30°C. Furthermore, Bidawi et al. (2017) explained that mudskipper species had tolerance to wide changes in temperature and salinity indicating that water temperature is one of the environmental factors that affect the spread and diversity of mudskipper species.

The pH content of the substrate ranged from 6.8 to 8. It means that the water conditions for the life of mudskipper fish were in the neutral range. The difference in soil pH at the research sites was caused by the contribution of leaf, root, and stem litter that fell to the ground and decomposed to form soil organic matter (Nurlailita & Kusmana, 2015). The pH of the substrate greatly affects the resistance of organisms that live at the bottom of the waters, both infauna and epifauna. This occurred due to the influence of tidal or brackish water during the formation of this land and subsequent tidal processes (Nurlailita & Kusmana, 2015). Furthermore, Kanejiya et al. (2017) explained that the distribution of mudskipper fish was significantly influenced by environmental factors such as pH, temperature, and salinity. Regarding to the presence of mudskipper fish with substrate conditions in the mangrove area at the three stations, (Kanejiya et al., 2017) added that substrate differences play an important role in the distribution of mudskipper fish.

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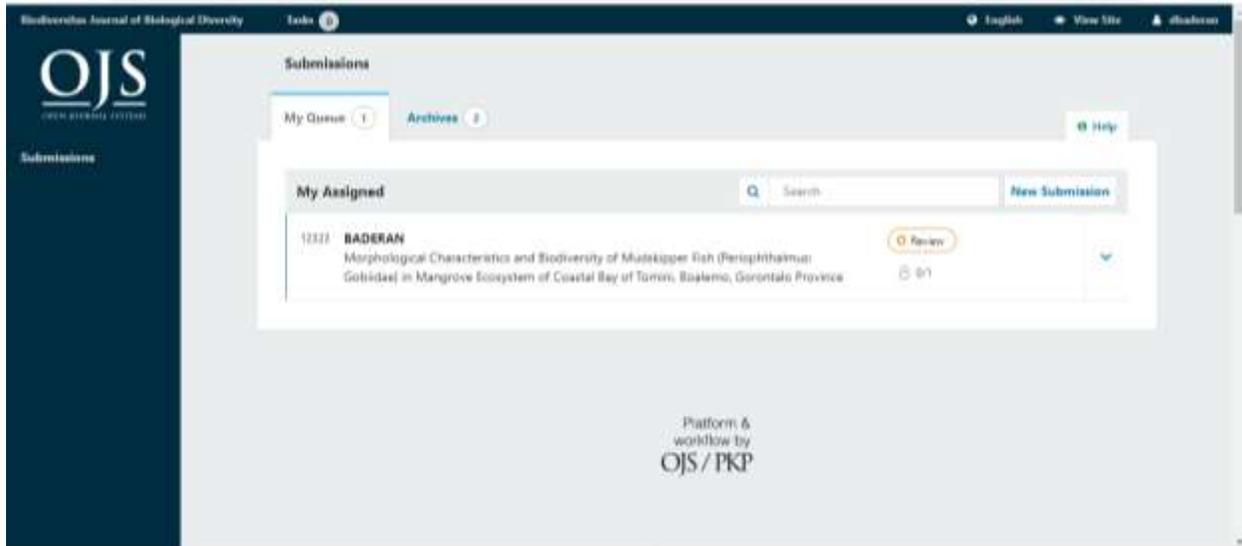
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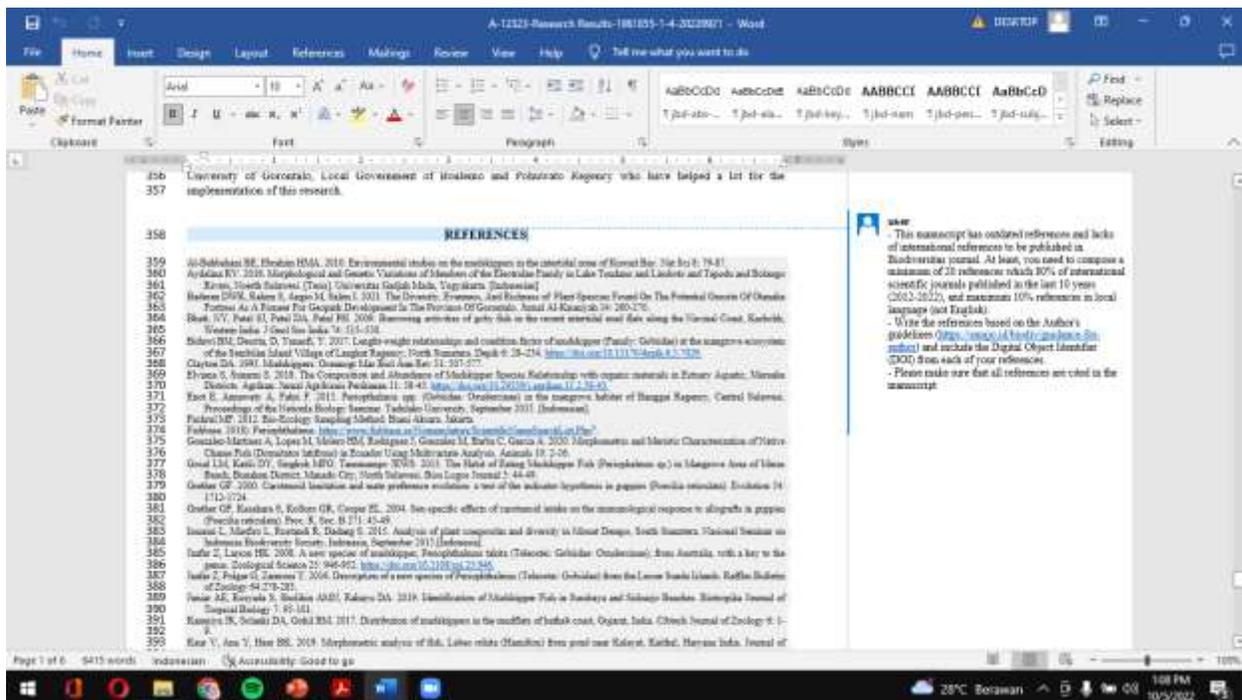
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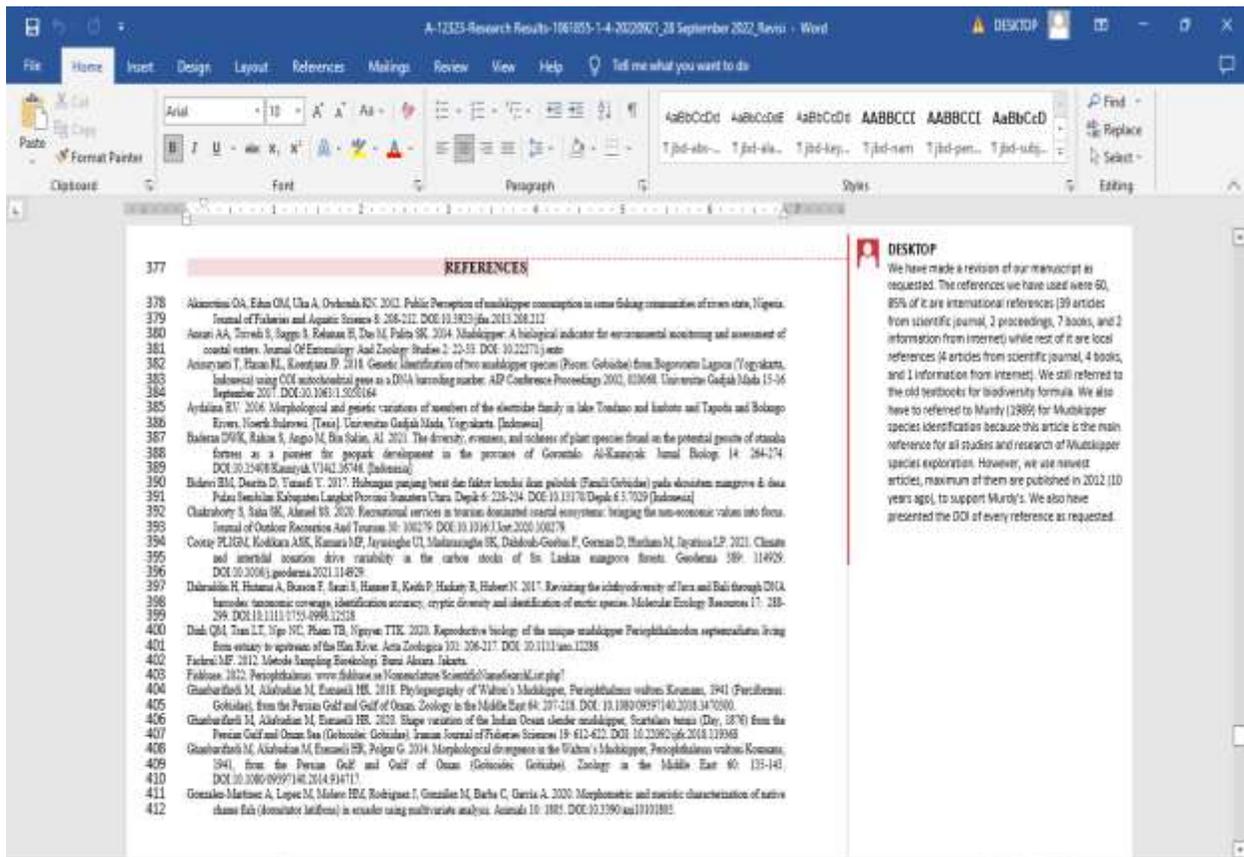
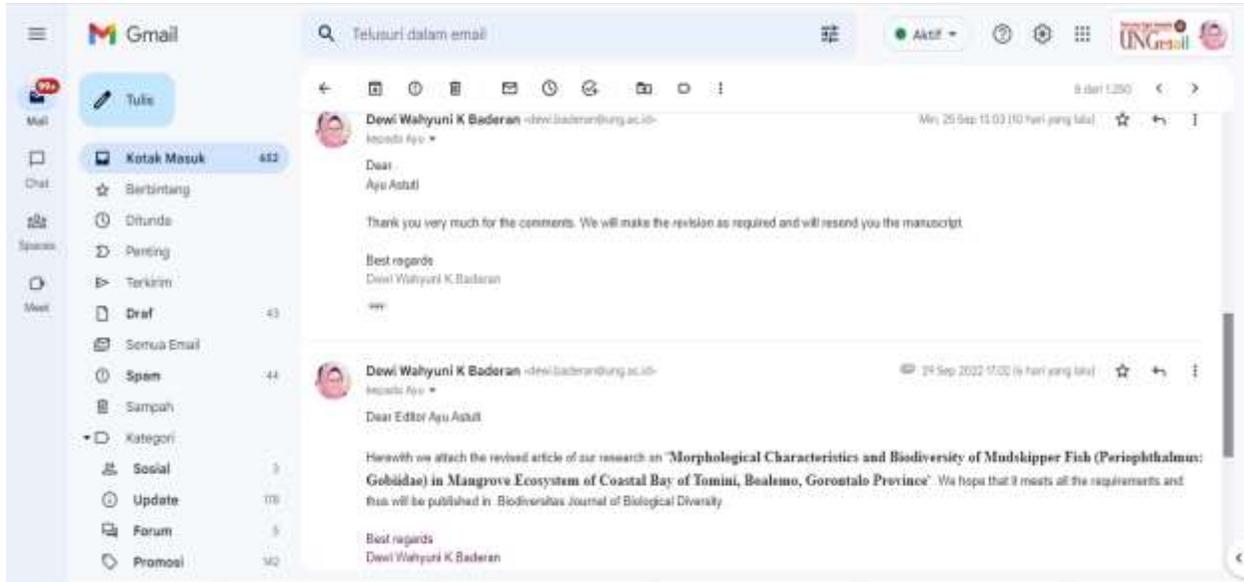
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Dear Ayu Katali & SADRAN

Dear Ayu Katali Thank you very much for the comments. We will make the revision as required and will reward you for the manuscript. Best regards

21 Sep 2022 11:02



1 **Morphological characteristics and biodiversity of mudskipper fish**  
2 **(*Periophthalmus: Gobiidae*) in mangrove ecosystem of coastal Bay of**  
3 **Tomini, Gorontalo Province, Indonesia**

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11 **Abstract.** The southern sea area of Gorontalo Province is part of Tomini bay, the biggest bay in Indonesia. There lies unique flora and  
12 fauna with high endemicity. Mangrove forest located in the coastal bay of Tomini Boalemo is one of the habitats for flora and fauna, a  
13 place for spawning, nurturing, and food hunting for fish. The mudskipper is a fish that lives in the mangrove area. This study aims to  
14 reveal the morphological characteristics and biodiversity of mudskipper (*Periophthalmus: Gobiidae*) in the ecosystem of Tomini Boalemo  
15 coastal bay of Gorontalo Province. This study employed a quantitative descriptive that also implemented purposive sampling as the  
16 sampling method in three ecosystem stations of Tomini Boalemo coastal bay (Dulupi, Bajo, and East Pentadu mangrove). The mudskippers  
17 were collected when the water was manually receding by using a fish net. The sample which had been collected were then identified based  
18 on 22 morphological, 24 morphometric, and 7 meristic characteristics. The identification results were then compared with the identification  
19 key. The species of mudskippers found were then analyzed to figure out the species biodiversity (diversity, evenness, species richness,  
20 and dominance indexes). The research result revealed 5 species from *Periophthalmus* Genus which are *Periophthalmus argenteincausatus*,  
21 *Periophthalmus kalela*, *Periophthalmus malaccensis*, *Periophthalmus minutus*, *Periophthalmus variabilis*, with total individuals 561. The  
22 score of  $H' = 1.09$  showed that the diversity of mudskipper fish was categorized as medium. The evenness index was 0.99 obtained from 3  
23 observation stations, while the lowest dominance index was on station II with a score of 0.34 and the score of  $R_i$  in each station was  
24 respectively (0.19); (0.36); and (0.2). The result of this study was used as a database for the sustainable management of Tomini Bay in  
25 order to tackle the threats of species extinction through aquatic life protection and preservation to arrange the natural balance and support  
26 the availability of the coastal resource for future generations.

27 **Keywords:** biodiversity, morphology, *Periophthalmus*, Tomini Bay

28 **INTRODUCTION**

29 Tomini Bay is the largest bay in Indonesia and is located in the coral triangle initiative. One of the parts of the bay which  
30 has rich biodiversity is the mangrove ecosystem which plays an important role in improving coastal sea productivity,  
31 spawning area, nutrient supply needed by various species of fish (Nguyen and Parnel 2017; Lapolo et al. 2019), and potential  
32 of biodiversity (Cooray et al. 2021). In addition, Sellang (2020) stated that the mangrove ecosystem is one of the most  
33 important and productive environments for the species of fish, in a tropical area, and sub-tropical estuary which can improve  
34 the fertility and productivity of the coastal area. Mudskipper fish (Perciformes: Gobiidae) is one of the faunas that live in  
35 the mangrove ecosystem, as mentioned by Latuconsina (2016) and Rha'ifa et al. (2021) as the loyal resident of the mangrove  
36 ecosystem. One of the Genera that belongs to the Family that is widely distributed in that ecosystem is *Periophthalmus*  
37 (WoRMS 2018; Fishbase 2022). This Genus occupies primary (organisms that obtain energy from producers) and secondary  
38 positions (organisms that obtain energy from primary consumers) in the food chain despite their very small size (Polgar et  
39 al. 2017) inhabiting muddy habitats, sandy beaches, and mangrove areas (Mahadevan and Ravi 2015). Mudskipper daily  
40 behavior is closely related to tidal rhythm (Ravi, 2013) where they climb mangrove roots, walk on mudflats, and dig burrows  
41 in mud (Ansari et al. 2014; Hui et al. 2019; Hidayat et al. 2022).

42 The mudskipper fish has various species yet they have numerous similarities in terms of morphology (Ridho et al. 2019).  
43 One of its unique characteristics is spending 90% of its life a day living on land, climbing, and perching on the roots of the  
44 mangrove or wood, as well as being able to crawl up on the land. Its pectoral fin on its muscular base can be buckled so that  
45 it functions like arms that can be used to crawl, jump above the mud, and attached to rocks and open roots (Huang 2013;  
46 Wicaksono et al. 2016). The potential of mudskipper fish as the filter feeder that consumes the organic particles of living  
47 creatures suspended in water, has the ability to absorb Lead (Pb) and has a role as a bio-indicator of environmental pollution.  
48 The mudskipper can be used by people to fulfill their food needs because it has a high value of nutrition (Akinrotimi et al.  
49 2012; Bidawi et al. 2017). *Boleophthalmus boddarti*, one of the mudskipper fish species, has a high value of fat in the liver  
50 (554.45±4.49 mg/g), protein (3.5±0.35 mg/100mg), and 1.5 ± 0.47mg/100mg protein in the muscle (Kanejiya et al. 2017).  
51 A good morphological look of mudskipper fish can be used as an ornamental fish in some Asian countries such as China,

52 Japan, and Korea, even in some parts of Indonesia such as Karawang and Cilacap, mudskipper fish is for sale as dry and  
53 smoked fish. Besides, mudskipper as the native residents of mangrove habitat creates a natural view that is awaited by the  
54 tourists (Chakraborty et al. 2020).

55 One of the areas in Sulawesi Island which is directly bordered by Tomini Bay is Boalemo Regency. Boalemo in general  
56 has a typical characteristic of a coastal area with relatively high resources particularly in the area of mangrove forest and  
57 fishery sources, one of which is the mudskipper fish. The existence of this fish in the mangrove ecosystem in the Coastal  
58 Bay of Tomini Boalemo is pretty abundant although it is disregarded as a man of the fishers and people in Boalemo are not  
59 aware of the potential of the nutrition consisted in the mudskipper fish. As consequence, the existence of the mudskipper  
60 fish in the Mangrove Coast Tomini Bay is threatened to be extinct along with the decrease of its population along with the  
61 speed of mangrove forest degradation. The main cause of the degradation is the land conversion in mangrove forests to  
62 become fish and shrimp ponds. This is affirmed by Hai et al. (2020), mangrove is an important component of the coastal  
63 ecosystem which is severely and globally threatened by various causing factors. In 1988, the area of mangrove forest in  
64 Tomini Bay was noted as big as 17.672 hectares while in 2010, it was degraded to 16.105 hectares, and in 2020, it is predicted  
65 to have the remaining area as big as 10.321 hectares (Paino 2020).

66 The species of mudskipper which were identified until today are around 43 species in 10 genera (Polgar et al. 2013; Rupp  
67 2021). General information related to mudskipper fish has been available yet its species which are found in the Tomini Bay  
68 have not been found even the people in the coastal Bay of Tomini Boalemo stated that the mudskipper fish is a kind of  
69 poisonous fish. People have not yet known the potential use of the mudskipper fish optimally in terms of ecology, economy,  
70 and health so this research is urgent to conduct. This research aims to analyze the morphological characters and biodiversity  
71 of mudskipper fish as the reliable resident of the mangrove area in Tomini Bay. The findings of this research can be used as  
72 support for formulating policies that aim to minimize the mangrove degradation in the coastal bay of Tomini.

## 73 MATERIALS AND METHODS

### 74 Study area

75 This study was carried out in a mangrove ecosystem in the coastal bay of Tomini, Boalemo, Gorontalo Province. It  
76 included three observation stations i.e. station I (Duhupi Village), station II (Bajo Village), and station III (East Penatchu  
77 Village). This study had been conducted for 5 months from May to September 2022. This study employed a descriptive  
78 quantitative method by implementing a purposive sampling method in three stations of the mangrove ecosystem in the  
79 coastal bay of Tomini, Boalemo. Data collected were primary and secondary data. The primary data were collected by  
80 identifying all species of the mudskipper fish and some of its morphological, morphometrical, and meristical characteristics  
81 as well as its biodiversity (diversity, evenness, and species richness indexes) (Figure 1).



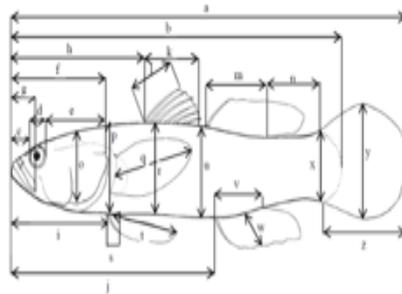
83  
84 **Figure 1.** Location of the coastal bay of Tomini, Boalemo, Gorontalo Province indicating the sampling sites of *Periophthalmus*.  
85 Station I (N 00°30.640 E 122°26.982), Station II (N00°29.818 E 122°20.931), and Station III (N 00°30.736 E 122°22.336)

86 **Tools and Materials**

87 The tools used were a fish tango, a 3x3 meters fish net, cool box, ziplock, stationery, digital camera, ruler, millimeter  
88 block paper, gloves, jar, GPS, thermometer, pH meter, and an Ohaus digital scale with an accuracy of 0.01 g. The materials  
89 used were mudskipper fish, 10% formalin, 70% alcohol, tracing paper, ice, sewing thread, and distilled water.

90 **Procedures**

91 The sampling procedures are as follows: (i) Specimen collection using a 3x3 meters net and hand-collecting in 3  
92 locations of the mangrove ecosystem of the coastal area of Tomini bay. (ii) Measurement of physical-chemical factor  
93 temperature, substrate, water pH, and substrate pH of the environment was done in every location. (iii) The specimen was  
94 put in a jar, labeled, and then transferred to the laboratory for identification purposes. (iv) Specimen documentation was  
95 carried out utilizing a Nikon DX VR camera with an AF-S NIKKON 18-55 mm lens and a Macro Pro Tama Digital PRO  
96 0.45X HD WIDE LENS SDW-045 52 mm. (v) The mudskipper fish samples were observed and measured for morphological,  
97 morphometric and meristic characterization in the Biology Laboratory, Faculty of Mathematics and Natural Sciences, and  
98 in the Agricultural Laboratory, Faculty of Agriculture, Universitas Negeri Gorontalo. This observation and measurement  
99 step was referred to (Larson and Murdy 2001; Polgar et al. 2013; Maryam et al. 2015; Aydalina 2016; Ghanbarifardi et al.  
100 2018; Kaur et al. 2019; Mahadevan et al. 2019; and Gonzalez-Martinez et al. 2020). Species identification was carried out  
101 by referring to (Murdy 1989; Larson and Murdy 2001; Jaafar et al. 2016). Specimen fixation used 70% alcohol and 10%  
102 formalin.



109 **Figure 2.** Skema karakterisasi morfometrik mudskipper: (a) total length, (b) standard length, (c) Pre-orbital length, (d) eye diameter, (e)  
110 panjang daerah post-orbital, (f) panjang kepala, (g) panjang mulut, (h) panjang daerah pre-dorsal, (i) panjang daerah pre-ventral, (j)  
111 panjang pangkal sirip dorsal pertama, (k) panjang pangkal sirip dorsal kedua, (l) tinggi jari-jari terpanjang sirip dorsal pertama, (m) panjang pangkal  
112 sirip dorsal kedua, (n) panjang jarak antara bagian posterior sirip dorsal kedua dengan batang ekor, (o) tinggi kepala, (p) tinggi tubuh  
113 bagian depan, (q) panjang jari-jari terpanjang sirip pectoral, (r) tinggi tubuh bagian tengah, (s) panjang pangkal sirip pelvik, (t) panjang  
114 jari-jari terpanjang sirip pelvik, (u) tinggi pangkal ekor, (v) panjang pangkal sirip anal, (w) panjang jari-jari terpanjang sirip anal, (x) tinggi  
115 batang ekor, (y) tinggi sirip ekor, (z) panjang sirip ekor (Larson & Murdy, 2001, dimodifikasi oleh penulis).

119 **Data analysis**

120 Morphometric and meristics data were analyzed using the Microsoft Excel program and morphological observations were  
121 analyzed descriptively.  
122 Data on the diversity of mudskipper species were analyzed using the Diversity Index ( $H'$ ) (Shannon and Wiener 1963;  
123 Fachrul 2012).  $H' = -\sum_{i=1}^S p_i \ln p_i$  where  $p_i = \frac{n_i}{N}$ ,  $H'$  represents the Shannon-Wiener Diversity index, S for total species,  
124  $N$  for total individuals in a species,  $\ln$  for the natural logarithm, and  $N$  for total individuals found. The value of  $H'$  determines  
125 the level of species diversity in an area, where the definition of the value of species diversity according to Shannon-Wiener  
126 is:  $H' > 3$ : High species diversity,  $1 \leq H' \leq 3$ : Medium species diversity,  $H' < 1$ : Low species diversity.  
127 Data of species evenness ( $K$ ) were analyzed using the species evenness index which referred to the Pielou Evenness  
128 Indices formula (Ludwig and Reynolds 1988):  $E = H' / \ln S$ .  $E$  represents Evenness Index and  $H'$  represents Shannon-Wiener  
129 Diversity Index. Margalef formula was used as Species Richness Index (Magurran 1988):  $R_1 = \frac{(S-1)}{(\ln(N))}$  which  $R_1$  represents  
130 Richness Index, S for Numbers of Species found, and N for Total Numbers of Individuals. Dominance data were analyzed

131 using the Simpson formula:  $D = \frac{n(n-1)}{\sum (n_i(n_i-1))}$ . The results of the dominance index were grouped into  $0 < D < 0.5$  in which  
 132 there are no species that dominate other species or a community structure is stable, and  $0.5 < D < 1$  which means there are  
 133 species that dominate other species or a community structure is not stable because of ecological pressures (Odum 1971;  
 134 Krebs 2014).

## 135 RESULTS AND DISCUSSION

### 136 Result

#### 137 *Mudskipper Fish at the Research Site*

138 The results in Table 1 show that the species of mudskipper fish which were found comprised one Gobiidae Family of the  
 139 Actinopterygii Class: *Periophthalmus argentilineatus*, *Periophthalmus kalolo*, *Periophthalmus malaccensis*,  
 140 *Periophthalmus minutus*, and *Periophthalmus variabilis*. The total number of mudskipper fish found in the coastal mangrove  
 141 area of Tomini Bay, Boalemo, as many as 561 individuals were spread across station I-Dulupi village (156 individuals),  
 142 station II-Bajo village (254 individuals) and station III-East Pentadu village (151 individuals). The classification of  
 143 mudskipper fish in the coastal mangrove ecosystem of Tomini bay, Boalemo, Gorontalo Province, is presented in Table 1.  
 144

145 **Table 1.** The classification of mudskipper fish in the coastal mangrove ecosystem of Tomini bay, Boalemo, Gorontalo Province  
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Class, Family	Species	Station			Total Number of Individuals
		I Dulupi	II Bajo	III East Pentadu	
Actinopterygii					
Gobiidae	<i>Periophthalmus argentilineatus</i>	-	-	√(83)	83
	<i>Periophthalmus kalolo</i>	√(67)	-	-	67
	<i>Periophthalmus malaccensis</i>	√(89)	√(98)	-	187
	<i>Periophthalmus minutus</i>	-	√(75)	-	75
	<i>Periophthalmus variabilis</i>	-	√(81)	√(68)	149
	Total				561

147 Description: (√) found; (-) Not found; and the number in brackets represents the number of individuals observed.

148 Source: Primary Data, 2022

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#### 151 *The Morphological Characters of Mudskipper Fish*

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153 **Table 2.** Comparison of Morphological Characters of Mudskipper Fish in the coastal mangrove ecosystem of Tomini Bay, Boalemo,  
 154 Gorontalo Province

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Characters	<i>P. minutus</i>	<i>P. malaccensis</i>	<i>P. variabilis</i>	<i>P. argentilineatus</i>	<i>P. kalolo</i>
Dermal cup	-	-	-	-	-
One row of teeth on maxilla	+	+	+	+	+
Pelvic frenum	-	+	+	-	+
Pelvic fin wholly fused	-	-	-	-	-
Pelvic fin partly fused	-	+	+	-	+
Pelvic fin not fused	+	-	-	+	-
High D1	-	-	-	-	-
Medium D1	+	+	+	+	+
Low D1	-	-	-	-	-
Slightly rounded D1 margin	-	+	-	-	-
Rounded D1 margin	-	-	+	-	+
Straight D1 margin	+	-	-	+	-
White D1 margin	-	-	+	-	+
Single infamarginal brown strip on D1	-	+	+	-	-
Single infamarginal black strip on D1	-	-	-	-	+
Single mesial brown strip on D1	+	-	-	+	-
White spot on proximal on D1	+	+	-	+	+
Reddish orange spot on D1	-	-	+	-	-



#### Microsoft Office User

It would be better if it was accompanied by a picture of the characters.

It has been revised as suggested. The 1<sup>st</sup> to 6<sup>th</sup> characters has been shown in the Figure 3. The rest of it can be seen on Figure 4.

Elongated first spine on D1	-	+	+	-	-
Fading strip Mesial on D2	+	+	-	+	+
D1 and D2 connected by a membrane	-	-	-	-	-
Reddish orange pelvic and caudal fins	-	-	+	-	-

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### The Morphometric Characters of Mudskipper Fish

**Table 3.** Comparison of Morphometric Characters of Mudskipper Fish in the coastal mangrove ecosystem of Tomini Bay, Boalemo, Gorontalo Province

Characters	<i>P. minutus</i>	<i>P. malaccensis</i>	<i>P. variabilis</i>	<i>P. argenteincaus</i>	<i>P. kalolo</i>
Pre-orbital length	0.051	0.029	0.035	0.061	0.037
Eye diameter	0.060	0.060	0.060	0.076	0.068
Head length	0.152	0.160	0.137	0.118	0.136
Snout length	0.273	0.274	0.264	0.247	0.256
Post-orbital length	0.506	0.070	0.054	0.091	0.055
Pre-dorsal length	0.337	0.383	0.368	0.384	0.346
Pre-ventral length	0.279	0.313	0.307	0.256	0.299
Pre-anal length	0.649	0.629	0.632	0.583	0.630
D1 base length	0.214	0.178	0.192	0.163	0.172
D1 longest spine length	0.195	0.237	0.196	0.164	0.233
D2 base length	0.216	0.174	0.216	0.201	0.211
Posterior distance length : caudal pedunculus	0.172	0.163	0.164	0.175	0.143
Head height	0.157	0.159	0.162	0.187	0.142
Front body height	0.184	0.194	0.194	0.204	0.182
Pectoral fin's longest ray length	0.206	0.179	0.173	0.164	0.145
Middle body height	0.170	0.207	0.173	0.184	0.169
Pelvic fin base length	0.047	0.041	0.063	0.120	0.033
Pelvic fins' longest radius length	0.101	0.116	0.088	0.102	0.103
Caudal base height	0.160	0.165	0.162	0.162	0.142
Anal fin length	0.201	0.188	0.223	0.165	0.155
Anal fin's longest radius length	0.081	0.099	0.096	0.127	0.074
Caudal pedunculus height	0.081	0.097	0.099	0.101	0.082
Caudal fin height	0.144	0.162	0.115	0.145	0.152
Caudal fin length	0.213	0.234	0.208	0.219	0.167

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### Meristic Characters of Mudskipper Fish

The comparison of meristic characteristics of mudskipper fish which were found in the coastal mangrove ecosystem of Tomini Bay, Boalemo, Gorontalo Province along with the species' classification are presented in Table 4 and Figure 2.

**Table 4.** Comparison of Meristic Characters of Mudskipper Fish in the coastal mangrove ecosystem of Tomini Bay, Boalemo, Gorontalo Province

OTU	Number of Spines and Rays												LS
	D1		D2		A		P		V		C		
	S	R	S	R	S	R	S	R	S	R	S	R	
<i>P. minutus</i>	16	0	1	12	0	11	0	13	0	6	0	13	60
<i>P. malaccensis</i>	11	0	1	12	0	11	0	11	0	6	0	14	58
<i>P. variabilis</i>	14	0	1	12	0	12	0	13	0	6	0	16	52
<i>P. argenteincaus</i>	13	0	1	12	0	12	0	12	0	6	0	16	70
<i>P. kalolo</i>	11	0	1	12	0	11	0	11	0	6	0	14	62

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It would be better if it was accompanied by a picture of the characters.

It has been revised as suggested. The characters can be seen in Figure 2.

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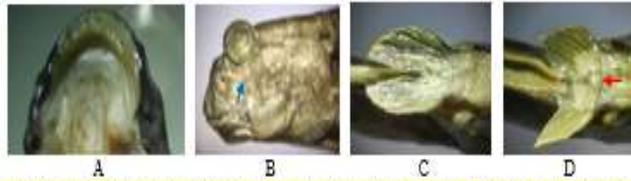


Figure 3. Karakteristik morfologis ikan Mudskipper fish diarea pesisir ekosistem mangrove Teluk Tomini, Boalemo, Provinsi Gorontalo. A. Satu baris gigi pada maxilla; B. Dermal-Cup; C. Sirip pelvik tidak menyatu; D. Sirip pelvik menyatu. Frenum ditunjukkan oleh arah panah berwarna merah.

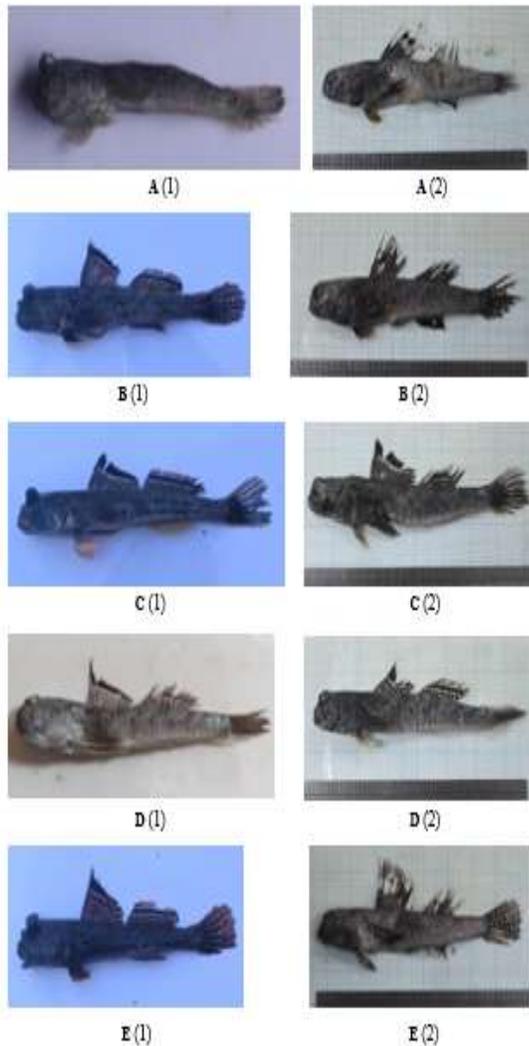
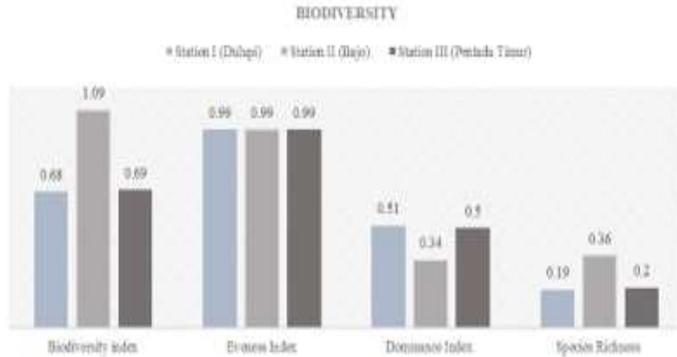


Figure 4. Mudskipper fish in the coastal mangrove ecosystem of Tomini Bay, Boalemo, Gorontalo Province. A. *Periophthalmus minuhar*; B. *P. malaccensis*; C. *P. variabilis*; D. *P. argenteolineatus*; E. *P. katiale* Gambar 2 adalah foto specimen yang dipreservasi di suhu 20°C selama 1 bulan.

MO Microsoft Office User  
 The fish pictures should use a scale to know the actual size.

It has been revised as suggested.

245 The gathered data of mudskipper fish at three locations showed moderate diversity with a value of  $H' = 1.09$ . The  
 246 Evenness index was 0.99 based on 3 observation stations. The lowest dominance value was at station II with a value of 0.34  
 247 (Figure 5).



254 Figure 5. Biodiversity (Biodiversity index, Evenness Index, Dominance Index and Species Richness) of mudskipper fish in the research site

271 **Environment Parameters**

272 The results range of the temperature measurement at three research locations were around 28 -30°C at station I, 29-30°C  
 273 at station II and 28 -30°C at station III. The value of the acidity degree (pH) of water was in the range of 7.1-8 and the  
 274 substrate (pH) in the range of 6.8-8. Kondisi ekologis Stasiun I (Duhupi) kawasan mangrove berdasarkan penampakan  
 275 visual masih baik-padat, memiliki tekstur habitat tanah berpasir dan ber lumpur dengan ditumbuhi tumbuhan mangrove.  
 276 Stasiun II (Bajo) kawasan mangrove telah dialihfungsikan menjadi pemukiman, tanpa memperhatikan nilai penting dari  
 277 tumbuhan mangrove. Berdasarkan penampakan visual kondisi mangrove memiliki tekstur tanah berpasir dan ber lumpur,  
 278 banyak sampah-sampah yang berserakan dan banyak mangrove anakan yang mati dan rusak. Stasiun III (East Pentada)  
 279 berdasarkan penampakan visual kondisi mangrove memiliki tekstur tanah ber lumpur dan tanah ber lumpur bebatan. Kondisi  
 280 mangrove masih baik dan regenerasi pertumbuhan anakan mangrove pada area tersebut tumbuh cepat dan banyak.  
 281

282 **Tabel 5.** Physics and chemical parameters of the waters study area

Environment Parameters	Coastal Mangrove Area of Tomini Bay, Boalemo		
	Station I Duhupi	Station II Bajo	Station III East Pentada
Temperature (°C)	28-30	29-30	28-30
Substrat	Mud	Mud rocks	Mud
Water pH	7.1-8	7.3-8	7.3-8
Substrat pH	7.5-8	6.8-7	6.8-7.5

284 **Discussion**

285 There were five species mudskipper fish that could be found in the coastal mangrove ecosystem of Tomini Bay,  
 286 Boalemo, Gorontalo Province in which all of the species were part of Genus Periophthalmus. It implied that even though  
 287 mudskipper fish spread in all over the tropical and subtropical habitat, except in the western tropical Atlantic and eastern  
 288 tropical Pacific (Springer 1982; Jaafar and Murdy 2017). Periophthalmus tends to stay in mangrove ecosystems. Hal ini  
 289 disebabkan oleh karena mangrove menyediakan banyak detritus, kepiting kecil, ikan kecil, udang, dan arthropoda yang  
 290 merupakan makanan Periophthalmus (Rha'ifa et al. 2021). Thus, the result of this study was in line with previous studies  
 291 which were conducted in the coastal ecosystems around Indo-Pacific (Pormansyah et al. 2019), such as Maluku (Rumahlatu

**Microsoft Office User**  
 It is important to describe the ecological conditions of each sampling station.

Sudah ditambahkan

**Microsoft Office User**  
 It may be necessary to discuss why these mudskipper like or have more populations in that habitat (mangrove ecosystem) than another ecosystem.

292 et al. 2020; Taniwel et al. 2020), South Sumatera (Ridho et al. 2019), West Nusa Tenggara (Rha'ifa et al. 2021), Yogyakarta  
293 (Arisuryanti et al. 2018), North Sulawesi (Polgar et al. 2017), Java and Bali (Dahrudin et al. 2017), Malacca Strait and  
294 Malay Peninsula (Polgar et al. 2014). All species found by researchers possessed high similarity in morphological features  
295 because they are part of the same Genus (Table 2).

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a. *Periophthalmus muriei*

D, XVI, D, I, 12; A 11; P 13; V 6; C 13

Eyes without dermal cup; one row of teeth on the maxilla; pelvic fin without frenum; moderate D1 height with straight margins, single brown strip mesial with numerous proximal white spots, without spinal elongation; D2 with dusky brown stripe mesially; D1 and D2 are not connected by a membrane; lateral scales 60; head length 0.273% SL; pelvic fin basal length 0.047% SL; anal fin basal length 0.201% SL; D1 basal length 0.214% SL; D2 basal length 0.216% SL; caudal peduncle height 0.081% SL (Figure 2, Table 3, Table 4). **Di beberapa keadaan, frenum bisa terlihat melalui magnification (Jaafar & Murdy (2017).**

b. *Periophthalmus malaccensis*

D, XI, D, I, 12; A 11; P 11; V 6; C 14

Eyes without dermal cup; one row of teeth on the maxilla; the pelvic is clear and prominent; moderate D1 height with slightly rounded margins, a single inframarginal brown strip with numerous proximal white spots, first spine elongated; D2 with faded brown stripe mesial; D1 and D2 are not connected by a membrane; lateral scales 58; head length 0.274% SL; pelvic fin basal length 0.027% SL; anal fin basal length 0.188% SL; D1 basal length 0.178% SL; D2 basal length 0.174% SL; caudal peduncle height 0.097% SL (Figure 2, Table 3, Table 4). *Periophthalmus malaccensis* also has bright blue spots on the chin and operculum, it also has prominent transverse folds on the snout (Polgar 2016).

c. *Periophthalmus variabilis*

D, XI, D, I, 12; A 11; P 11; V 6; C 14

Eyes without dermal cup; one row of teeth on the maxilla; the pelvic frenum is clear and prominent; the pelvic is orange at least at the margins; moderate D1 height with rounded margins, a single inframarginal brown strip with many proximal white spots, first spine elongated, white margin; D2 with single inframarginal orange stripe and black single stripe mesial, with reddish-orange spots at the base; the anal fins are orange at least at the margins; D1 and D2 are not connected by a membrane; lateral scales 52; head length 0.264% SL; pelvic fin basal length 0.027% SL; anal fin basal length 0.063% SL; D1 basal length 0.192% SL; D2 basal length 0.216% SL; caudal peduncle height 0.099% SL (Figure 2, Table 3, Table 4). When alive, the branchiostegal membrane of the fish shows pigmentation (Setiawan et al. 2019).

d. *Periophthalmus argenteincaus*

D, XIII, D, I, 12; A 12; P 12; V 6; C 16

Eyes without dermal cup; one row of teeth on the maxilla; pelvic without frenum; moderate D1 height with straight margins, single brown strip mesial with numerous proximal white spots, without spinal elongation; D2 with dusky brown stripe mesial; D1 and D2 are not connected by a membrane; lateral scales 70; head length 0.247% SL; pelvic fin basal length 0.12% SL; anal fin basal length 0.165% SL; D1 basal length 0.163% SL; D2 basal length 0.201% SL; caudal peduncle height 0.101% SL (Figure 2, Table 3, Table 4). **Jumlah sisik transversal dari basal D2 ventroposteriorly ke basal strip anal 18-26 (Jaafar & Murdy (2017).**

e. *Periophthalmus kaioia*

D, XI, D, I, 12; A 11; P 11; V 6; C 14

Eyes without dermal cup; one row of teeth on the maxilla; vestigial pelvic frenum; pelvic fins fused about half of the pelvic fins; moderate D1 height with rounded margins, single black stripe inframarginal with proximal white spots, without spinal elongation; D2 with inframarginal faded strip; D1 and D2 are not connected by a membrane; lateral scales 62; head length 0.256% SL; pelvic fin basal length 0.033% SL; anal fin basal length 0.155% SL; D1 basal length 0.172% SL; D2 basal length 0.211% SL; caudal peduncle height % SL (Figure 2, Table 3, Table 4). **Jumlah sisik transversal dari basal D2 ventroposteriorly ke basal sirip anal lebih sedikit daripada *Periophthalmus argenteincaus* yakni hanya 18-22 (Jaafar & Murdy (2017).**

Morphological adaptations of mudskipper fish created variations in morphometric and meristic measurements (Nugroho et al. 2016; Dimh et al. 2020; Ghanbarifardi et al. 2020). Jaafar & Murdy (2017) added that morphological characters such

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Descriptions of each species need to include appropriate references.

It has been revised as suggested

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Descriptions of each species need to include appropriate references.

It has been revised as suggested

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Descriptions of each species need to include appropriate references.

It has been revised as suggested

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It is necessary to make a table regarding the variations in morphometric analysis.

The variations were already been shown in Table 2 and 3.

348 as number of dorsal spines, the presence of finger-like projections in the maxillo-dentary ligament in the lip of the lower jaw  
349 and the epaxialis muscle attaching anteriorly of the frontal and epioccipital junction can distinguish genera in the family.  
350 Meristic characters such as the scales before and after the pectoral filaments, pectoral fins, dorsal fins, abdominal fins, and  
351 anal fins are characters that can distinguish species in the genus. In addition, other factors that influence differences in fish  
352 morphology are food availability, environmental conditions, and the stage of fish maturity. Another character with a high  
353 probability of variation is coloration. Fish coloration is influenced by many factors including genetic, environmental, dietary,  
354 and physiological factors (Nüsslein-Volhard and Singh 2017). Due to the instability of the correlation character, this  
355 character is mostly neglected when identifying fish species.

356 The difference in species diversity between the three stations is influenced by environmental conditions. The high and  
357 low species diversity was influenced by many factors and one of the factors is environmental quality. Krebs (2014) further  
358 explained that species diversity is used to measure the stability of a community which is the ability of a community to keep  
359 itself stable despite disturbances to its components. Maturbongs et al. (2018) argued that the area or mud substrate is a habitat  
360 for various nekton, which indicates the area has abundant food sources. The existence of habitat variations (substrate), such  
361 as physical conditions and the surrounding environment affects the diversity of fish species. The diversity index at the  
362 research site was 1.09, this indicated that a high level of diversity of mudskipper fish in the Coastal Bay of Tomini, Bualemo,  
363 was included in the moderate criteria. In addition, it also showed that water productivity was quite balanced.

364 The comparison of the Evenness index of mudskipper fish in the research locations had the same Evenness index value  
365 of 0.99. This value indicated that the Evenness in the three locations was stable. The Evenness index shows the degree of  
366 Evenness of individual abundance between each species. If each species has the same number of individuals, then the  
367 community has a maximum Evenness value. On the other hand, if the Evenness value is small, then the community has  
368 dominant, sub-dominant, and dominated species, eventually, the community has a minimum Evenness. The Evenness value  
369 had a range between 0-1, if the index value obtained was close to one, it means that the distribution is more even (Ludwig  
370 and Reynolds 1988; Baderan et al. 2021). Figure 3 presents the index of Evenness of the mudskipper (*Periophthalmus*)  
371 species in the Coastal Bay of Tomini, Bualemo, which was included in a stable community. Thus, the population between  
372 species of the genus *Periophthalmus* on the Coastal Bay of Tomini, Bualemo, was fairly even, so that disturbances did not  
373 easily occur and were able to return to their initial conditions.

374 Species richness in the research locations was low with the Specific Richness Index (R1) at each station as follows 0.19  
375 (Station I Dulupi), 0.36 (Station II Bajo), 0.2 (Station III East Pentadu). Species richness refers to the number of species in  
376 a community. The number of species in the field determines the size of the richness index. The Margalef richness index  
377 divides the number of species by the natural logarithm function meaning that the increase in the number of species is  
378 inversely proportional to the increase in the number of individuals. Generally, a community/ecosystem with an abundant  
379 number of species will have a small number of individuals in each of these species.

380 The dominance of species in water often occurs due to several things including competition for natural food by certain  
381 species accompanied by changes in environmental quality and also an imbalance between predators and prey which are  
382 resulted in competition between species. Maturbongs et al. (2018) explained that dominance occurs because of the result of  
383 the competition process for evicting one individual against another. Okyere (2018) stated that at low tide the estuary area is  
384 dominated by brackish fish species, one of which is from the Gobiidae family. This statement is true because mudskipper  
385 fish is more active during low tide conditions both on the coast and at an estuary, on the other hand, mudskipper fish will  
386 hide in their nests at high tide to avoid predators. The dominance index of mudskipper fish was 0.51 which indicated that  
387 the level of species dominance in these waters was moderate, thus there were no dominant species in these waters.

388 Environmental factors that are very supportive and the absence of predators made several species of mudskipper fish  
389 thrive and spread across the area. In line with research conducted by Mahadevan and Ravi (2015) which stated that the right  
390 water temperature range for mudskipper fish was between 23.5-35.5°C, the measurement results of environmental  
391 parameters showed that the average temperature range was 28-30°C. Furthermore, Bidawi et al. (2017) explained that  
392 mudskipper species had tolerance to wide changes in temperature and salinity indicating that water temperature is one of the  
393 environmental factors that affect the spread and diversity of mudskipper species.

394 The pH content of the substrate ranged from 6.8 to 8. It means that the water conditions for the life of mudskipper  
395 fish were in the neutral range. The difference in soil pH at the research sites was caused by the contribution of leaf, root, and  
396 stem litter that fell to the ground and decomposed to form soil organic matter (Tajbakhsh et al. 2018). The pH of the substrate  
397 greatly affects the resistance of organisms that live at the bottom of the waters, both infauna and epifauna. This occurred due  
398 to the influence of tidal or brackish water during the formation of this land and subsequent tidal processes. Furthermore,  
399 Kanejiya et al. (2017) explained that the distribution of mudskipper fish was significantly influenced by environmental  
400 factors such as pH, temperature, salinity, and the other ecological conditions (Ghambarifardi et al. 2014). Regarding to the  
401 presence of mudskipper fish with substrate conditions in the mangrove area at the three stations, added that substrate  
402 differences play an important role in the distribution of mudskipper fish.

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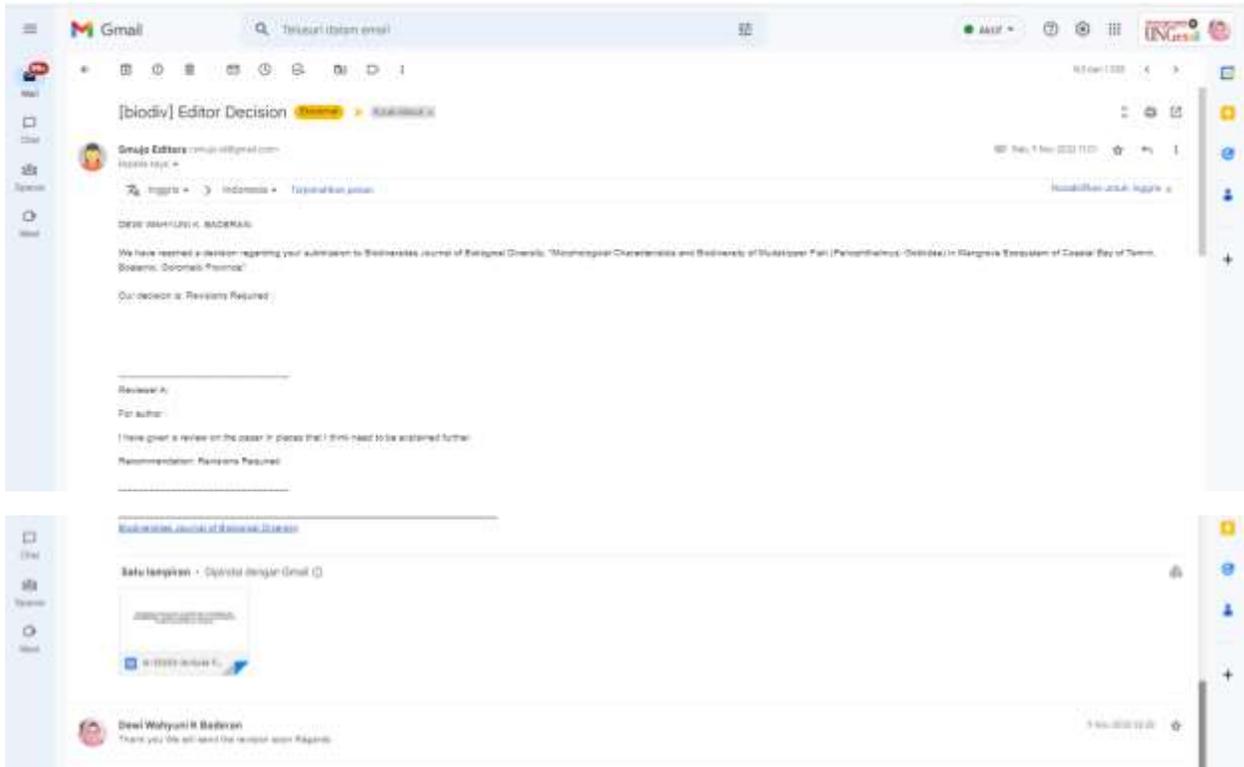
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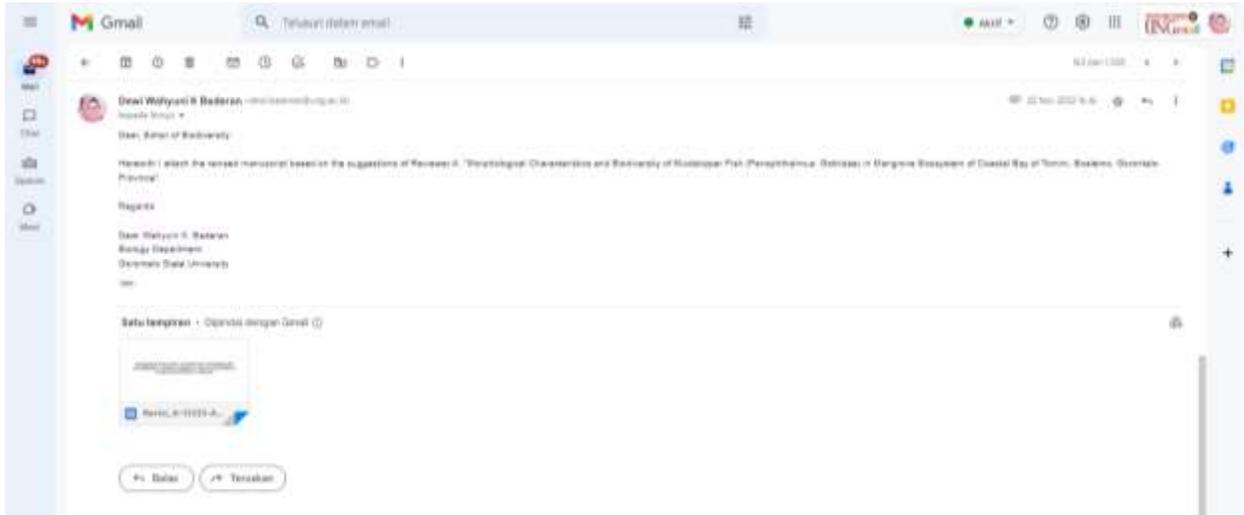
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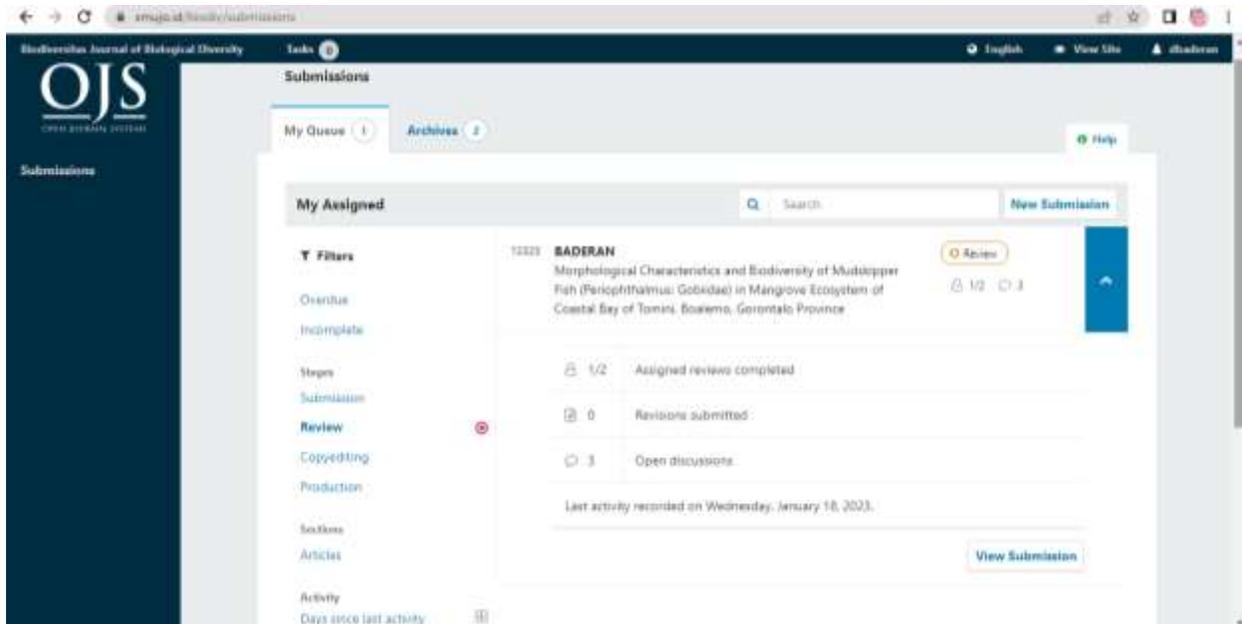
## REVISI KE-3

Rabu, 9 November 2022



Revisi Ke-3 Di kirimkan kembali lewat OJS pada Tanggal 22 November 2022 dan dikirimkan Bukti lewat Email





1 **Morphological characteristics and biodiversity of mudskipper fish**  
 2 **(Periophthalmus: Gobiidae) in mangrove ecosystem of coastal Bay of**  
 3 **Tomini, Gorontalo Province, Indonesia**

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11 **Abstract.** The southern sea area of Gorontalo Province is part of Tomini bay, the biggest bay in Indonesia. There lies unique flora and  
 12 fauna with high endemicity. Mangrove forest located in the coastal bay of Tomini Boalemo is one of the habitats for flora and fauna, a  
 13 place for spawning, nurturing, and food hunting for fish. The mudskipper is a fish that lives in the mangrove area. This study aims to  
 14 reveal the morphological characteristics and biodiversity of mudskipper (*Periophthalmus: Gobiidae*) in the ecosystem of Tomini Boalemo  
 15 coastal bay of Gorontalo Province. This study employed a quantitative descriptive that also implemented purposive sampling as the  
 16 sampling method in three ecosystem stations of Tomini Boalemo coastal bay (Dulupi, Bajco, and East Pentadu mangrove). The mudskippers  
 17 were collected when the water was manually receding by using a fish net. The sample which had been collected were then identified based  
 18 on 22 morphological, 24 morphometric, and 7 meristic characteristics. The identification results were then compared with the identification  
 19 key. The species of mudskippers found were then analyzed to figure out the species biodiversity (diversity, evenness, species richness,  
 20 and dominance indexes). The research result revealed 5 species from *Periophthalmus* Genus which are *Periophthalmus argentilineatus*,  
 21 *Periophthalmus kafele*, *Periophthalmus malaccensis*, *Periophthalmus minutus*, *Periophthalmus variabilis*, with total individuals 561. The  
 22 score of  $H'$  = 1.09 showed that the diversity of mudskipper fish was categorized as medium. The evenness index was 0.99 obtained from 3  
 23 observation stations, while the lowest dominance index was on station II with a score of 0.34 and the score of  $R_2$  in each station was  
 24 respectively (0.19); (0.36); and (0.2). The result of this study was used as a database for the sustainable management of Tomini Bay in  
 25 order to tackle the threats of species extinction through aquatic life protection and preservation to arrange the natural balance and support  
 26 the availability of the coastal resource for future generations.

27 **Keywords:** biodiversity, morphology, *Periophthalmus*, Tomini Bay

28 **INTRODUCTION**

29 Tomini Bay is the largest bay in Indonesia and is located in the coral triangle initiative. One of the parts of the bay which  
 30 has rich biodiversity is the mangrove ecosystem which plays an important role in improving coastal sea productivity,  
 31 spawning area, nutrient supply needed by various species of fish (Nguyen and Parael 2017; Lapolo et al. 2019), and potential  
 32 of biodiversity (Cooray et al. 2021). In addition, Seilang (2020) stated that the mangrove ecosystem is one of the most  
 33 important and productive environments for the species of fish, in a tropical area, and sub-tropical estuary which can improve  
 34 the fertility and productivity of the coastal area. Mudskipper fish (Perciformes: Gobiidae) is one of the faunas that live in  
 35 the mangrove ecosystem, as mentioned by Laruconsina (2016) and Rha'ifa et al. (2021) as the loyal resident of the mangrove  
 36 ecosystem. One of the Genera that belongs to the Family that is widely distributed in that ecosystem is *Periophthalmus*  
 37 (WoRMS 2019; Fishbase 2022). This Genus occupies primary (organisms that obtain energy from producers) and secondary  
 38 positions (organisms that obtain energy from primary consumers) in the food chain despite their very small size (Polger et  
 39 al. 2017) inhabiting muddy habitats, sandy beaches, and mangrove areas (Mahadevan and Ravi 2015). Mudskipper daily  
 40 behavior is closely related to tidal rhythm (Ravi, 2013) where they climb mangrove roots, walk on mudflats, and dig burrows  
 41 in mud (Ansari et al. 2014; Hui et al. 2019; Hidayat et al. 2022).  
 42 The mudskipper fish has various species yet they have numerous similarities in terms of morphology (Ridho et al. 2019).  
 43 One of its unique characteristics is spending 90% of its life a day living on land, climbing, and perching on the roots of the  
 44 mangrove or wood, as well as being able to crawl up on the land. Its pectoral fin on its muscular base can be buckled so that  
 45 it functions like arms that can be used to crawl, jump above the mud, and attached to rocks and open roots (Huang 2013;  
 46 Wicaksono et al. 2016). The potential of mudskipper fish as the filter feeder that consumes the organic particles of living  
 47 creatures suspended in water, has the ability to absorb Lead (Pb) and has a role as a bio-indicator of environmental pollution.  
 48 The mudskipper can be used by people to fulfill their food needs because it has a high value of nutrition (Akinrotimi et al.  
 49 2012; Bidawati et al. 2017). *Boleophthalmus boddarti*, one of the mudskipper fish species, has a high value of fat in the liver  
 50 (554.45±4.49 mg/g), protein (3.5±0.35 mg/100mg), and 1.5 ± 0.47mg/100mg protein in the muscle (Kanejiya et al. 2017).  
 51 A good morphological look of mudskipper fish can be used as an ornamental fish in some Asian countries such as China,

52 Japan, and Korea, even in some parts of Indonesia such as Karawang and Cilacap, mudskipper fish is for sale as dry and  
53 smoked fish. Besides, mudskipper as the native residents of mangrove habitat creates a natural view that is awaited by the  
54 tourists (Chakraborty et al. 2020).

55 One of the areas in Sulawesi Island which is directly bordered by Tomini Bay is Boalemo Regency. Boalemo in general  
56 has a typical characteristic of a coastal area with relatively high resources particularly in the area of mangrove forest and  
57 fishery sources, one of which is the mudskipper fish. The existence of this fish in the mangrove ecosystem in the Coastal  
58 Bay of Tomini Boalemo is pretty abundant although it is disregarded as a man of the fishers and people in Boalemo are not  
59 aware of the potential of the nutrition consisted in the mudskipper fish. As consequence, the existence of the mudskipper  
60 fish in the Mangrove Coast Tomini Bay is threatened to be extinct along with the decrease of its population along with the  
61 speed of mangrove forest degradation. The main cause of the degradation is the land conversion in mangrove forests to  
62 become fish and shrimp ponds. This is affirmed by Hai et al. (2020), mangrove is an important component of the coastal  
63 ecosystem which is severely and globally threatened by various causing factors. In 1988, the area of mangrove forest in  
64 Tomini Bay was noted as big as 17.672 hectares while in 2010, it was degraded to 16.105 hectares, and in 2020, it is predicted  
65 to have the remaining area as big as 10.321 hectares (Paimo 2020).

66 The species of mudskipper which were identified until today are around 43 species in 10 genera (Polgar et al. 2013; Rupp  
67 2021). General information related to mudskipper fish has been available yet its species which are found in the Tomini Bay  
68 have not been found even the people in the coastal Bay of Tomini Boalemo stated that the mudskipper fish is a kind of  
69 poisonous fish. People have not yet known the potential use of the mudskipper fish optimally in terms of ecology, economy,  
70 and health so this research is urgent to conduct. This research aims to analyze the morphological characters and biodiversity  
71 of mudskipper fish as the reliable resident of the mangrove area in Tomini Bay. The findings of this research can be used as  
72 support for formulating policies that aims to minimize the mangrove degradation in the coastal bay of Tomini.

## 73 MATERIALS AND METHODS

### 74 Study area

75 This study was carried out in a mangrove ecosystem in the coastal bay of Tomini, Boalemo, Gorontalo Province. It  
76 included three observation stations i.e. station I (Dulupi Village), station II (Bajo Village), and station III (East Penatdu  
77 Village). This study had been conducted for 5 months from May to September 2022. This study employed a descriptive  
78 quantitative method by implementing a purposive sampling method in three stations of the mangrove ecosystem in the  
79 coastal bay of Tomini, Boalemo. Data collected were primary and secondary data. The primary data were collected by  
80 identifying all species of the mudskipper fish and some of its morphological, morphometrical, and meristical characteristics  
81 as well as its biodiversity (diversity, evenness, and species richness indexes) (Figure 1).



83

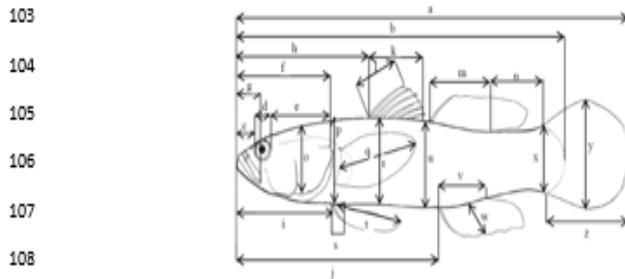
84 **Figure 1.** Location of the coastal bay of Tomini, Boalemo, Gorontalo Province indicating the sampling sites of *Periophthalmus*:  
85 Station I (N 00°30.640 E 122°26.982), Station II (N00°29.818 E 122°20.931), and Station III (N 00°30.736 E 122°22.336)

86 **Tools and Materials**

87 The tools used were a fish tango, a 3x3 meters fish net, cool box, ziplock, stationary, digital camera, ruler, millimeter  
88 block paper, gloves, jar, GPS, thermometer, pH meter, and an Ohaus digital scale with an accuracy of 0.01 g. The materials  
89 used were mudskipper fish, 10% formalin, 70% alcohol, tracing paper, ice, sewing thread, and distilled water.

90 **Procedures**

91 The sampling procedures are as follows: (i) Specimen collection using a 3x3 meters net and hand-collecting in 3  
92 locations of the mangrove ecosystem of the coastal area of Tomini bay. (ii) Measurement of physical-chemical factor  
93 temperature, substrate, water pH, and substrate pH of the environment was done in every location. (iii) The specimen was  
94 put in a jar, labeled, and then transferred to the laboratory for identification purposes. (iv) Specimen documentation was  
95 carried out utilizing a Nikon DX VR camera with an AF-S NIKKON 18-55 mm lens and a Macro Pro Tama Digital PRO  
96 0.45XHD WIDE LENS SDW-045 52 mm. (v) The mudskipper fish samples were observed and measured for morphological,  
97 morphometric and meristic characterization in the Biology Laboratory, Faculty of Mathematics and Natural Sciences, and  
98 in the Agricultural Laboratory, Faculty of Agriculture, Universitas Negeri Gorontalo. This observation and measurement  
99 step was referred to (Larson and Murdy 2001; Polgar et al. 2013; Maryam et al. 2015; Aydalina 2016; Ghanbarifardi et al.  
100 2018; Kanur et al. 2019; Mahadevan et al. 2019; and Gonzalez-Martinez et al. 2020). Species identification was carried out  
101 by referring to (Murdy 1989; Larson and Murdy 2001; Jaafar et al. 2016). Specimen fixation used 70% alcohol and 10%  
102 formalin.



109 **Figure 2.** Morphometric characterization scheme of the mudskipper: (a) total length, (b) standard length, (c) Pre-orbital length, (d) eye  
110 diameter, (e) post-orbital length, (f) post-orbital length, (g) mouth length, (h) pre-dorsal length, (i) pre-ventral length, (j) pre-anal length,  
111 (k) first dorsal fin base length, (l) height of the longest first spiny dorsal fin, (m) second dorsal fin base length, (n) length of caudal  
112 peduncle, (o) head height, (p) front body height, (q) length of the longest spiny pectoral fin, (r) middle body height, (s) middle body height,  
113 (t) length of the longest spiny pelvic spin, (u) caudal fin height, (v) anal fin base length, (w) length of the longest spiny anal fin, (x) Caudal  
114 peduncle depth, (y) caudal fin height, (z) caudal fin length (Larson & Murdy, 2001; modified by authors).

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117

118 **Data analysis**

119 Morphometric and meristics data were analyzed using the *Microsoft Excel* program and morphological observations were  
120 analyzed descriptively.

121 Data on the diversity of mudskipper species were analyzed using the Diversity Index ( $H'$ ) (Shannon and Wiener 1963;  
122 Fachrul 2012).  $H' = -\sum_{i=1}^S p_i \ln p_i$  where  $p_i = \frac{n_i}{N}$ .  $H'$  represents the Shannon-Wiener Diversity index,  $S$  for total species,  
123  $N_i$  for total individuals in a species,  $\ln$  for the natural logarithm, and  $N$  for total individuals found. The value of  $H'$  determines  
124 the level of species diversity in an area, where the definition of the value of species diversity according to Shannon-Wiener  
125 is:  $H' > 3$ : High species diversity,  $1 \leq H' \leq 3$ : Medium species diversity,  $H' < 1$ : Low species diversity.

126 Data of species evenness ( $K$ ) were analyzed using the species evenness index which referred to the Pielou Evenness  
127 Indices formula (Ludwig and Reynolds 1988):  $E = H'/\ln S$ .  $E$  represents Evenness Index and  $H'$  represents Shannon-Wiener  
128 Diversity Index. Margalef formula was used as Species Richness Index (Magurran 1988):  $R_1 = \frac{(S-1)}{(\ln(N))}$ , which  $R_1$  represents  
129 Richness Index,  $S$  for Numbers of Species found, and  $N$  for Total Numbers of Individuals. Dominance data were analyzed

130 using the Simpson formula:  $D = \sum \frac{(n_i)(n_i-1)}{(N)(N-1)}$ . The results of the dominance index were grouped into  $0 < D < 0.5$  in which  
 131 there are no species that dominate other species or a community structure is stable, and  $0.5 < D < 1$  which means there are  
 132 species that dominate other species or a community structure is not stable because of ecological pressures (Odum 1971;  
 133 Krebs 2014).

## 134 RESULTS AND DISCUSSION

### 135 Result

#### 136 *Mudskipper Fish at the Research Site*

137 The results in Table 1 show that the species of mudskipper fish which were found comprised one Gobiidae Family of the  
 138 Actinopterygii Class: *Periophthalmus argentilineatus*, *Periophthalmus kalolo*, *Periophthalmus malaccensis*,  
 139 *Periophthalmus minutus*, and *Periophthalmus variabilis*. The total number of mudskipper fish found in the coastal mangrove  
 140 area of Tomini Bay, Boalemo, as many as 561 individuals were spread across station I-Dulupi village (156 individuals),  
 141 station II-Bajo village (254 individuals) and station III-East Pentadu village (151 individuals). The classification of  
 142 mudskipper fish in the coastal mangrove ecosystem of Tomini bay, Boalemo, Gorontalo Province, is presented in Table 1.  
 143

144 **Table 1.** The classification of mudskipper fish in the coastal mangrove ecosystem of Tomini bay, Boalemo, Gorontalo Province  
 145

Class, Family	Species	Station			Total Number of Individuals
		I Dulupi	II Bajo	III East Pentadu	
<b>Actinopterygii</b>					
Gobiidae	<i>Periophthalmus argentilineatus</i>	-	-	√(83)	83
	<i>Periophthalmus kalolo</i>	√(67)	-	-	67
	<i>Periophthalmus malaccensis</i>	√(89)	√(98)	-	187
	<i>Periophthalmus minutus</i>	-	√(75)	-	75
	<i>Periophthalmus variabilis</i>	-	√(81)	√(68)	149
	Total				561

146 Description: (√) found; (-) Not found; and the number in brackets represents the number of individuals observed.

147 Source: Primary Data, 2022

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#### 150 *The Morphological Characters of Mudskipper Fish*

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152 **Table 2.** Comparison of Morphological Characters of Mudskipper Fish in the coastal mangrove ecosystem of Tomini Bay, Boalemo,  
 153 Gorontalo Province

154

Characters	<i>P. minutus</i>	<i>P. malaccensis</i>	<i>P. variabilis</i>	<i>P. argentilineatus</i>	<i>P. kalolo</i>
Dermal cup	-	-	-	-	-
One row of teeth on maxilla	+	+	+	+	+
Pelvic frenum	-	+	+	-	+
Pelvic fin wholly fused	-	-	-	-	-
Pelvic fin partly fused	-	+	+	-	+
Pelvic fin not fused	+	-	-	+	-
High D1	-	-	-	-	-
Medium D1	+	+	+	+	+
Low D1	-	-	-	-	-
Slightly rounded D1 margins	-	+	-	-	-
Rounded D1 margin	-	-	+	-	+
Straight D1 margin	+	-	-	+	-
White D1 margin	-	-	+	-	+
Single inframarginal brown strip on D1	-	+	+	-	-
Single inframarginal black strip on D1	-	-	-	-	+
Single brown strip mesially on D1	+	-	-	+	-
White spot on proximal on D1	+	+	-	+	+
Reddish orange spot on D1	-	-	+	-	-

MO Microsoft Office User

It would be better if it was accompanied by a picture of the characters.

It has been revised as suggested. The 1<sup>st</sup> to 6<sup>th</sup> characters has been shown in the Figure 3. The rest of the it can be seen on Figure 4.

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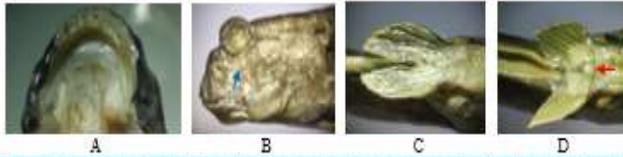


Figure 3. The characteristics of mullet fish in the coastal area of mangrove ecosystem in Tomini Bay, Boalemo, Gorontalo Province. A. One-row teeth on maxilla. B. Dorsal-Cup. C. Pelvic fin without frenum. D. Pelvic fin without frenum. The frenum was shown by a red arrow.

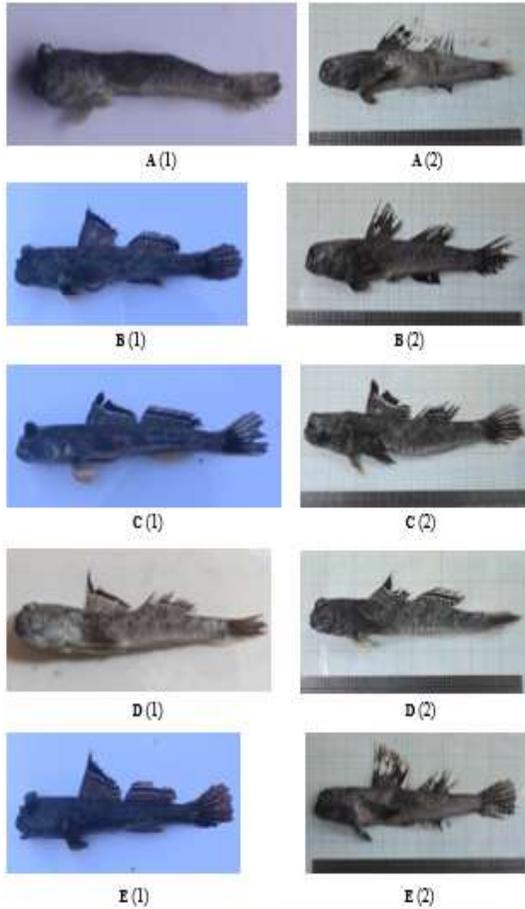


Figure 4. Mullet fish in the coastal mangrove ecosystem of Tomini Bay, Boalemo, Gorontalo Province. A. *Forcipgobius minutus*, B. *P. malaccensis*, C. *P. variabilis*, D. *P. argenteus*, E. *P. kaloid*. Figure 2 is a photo of a specimen which had been preserved under a -50°C temperature for 1 month.

**Microsoft Office User**  
 The fish pictures should use a scale to know the actual size.  
 It has been revised as suggested.

Elongated first spine on D1	-	+	+	-	-
Dusky strip mesially on D2	+	+	-	+	+
D1 and D2 connected by a membrane	-	-	-	-	-
Reddish orange pelvic and caudal fins	-	-	+	-	-

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### The Morphometric Characters of Mudskipper Fish

**Table 3.** Comparison of Morphometric Characters of Mudskipper Fish in the coastal mangrove ecosystem of Tomini Bay, Boalemo, Gorontalo Province

Characters	<i>P. minutus</i>	<i>P. malaccensis</i>	<i>P. variabilis</i>	<i>P. argenteilvatus</i>	<i>P. kalolo</i>
Pre-orbital length	0.051	0.029	0.035	0.061	0.037
Eye diameter	0.060	0.060	0.060	0.076	0.068
Head length	0.152	0.160	0.137	0.118	0.136
Snout length	0.273	0.274	0.264	0.247	0.256
Post-orbital length	0.506	0.070	0.054	0.091	0.055
Pre-dorsal length	0.337	0.383	0.368	0.384	0.346
Pre-ventral length	0.279	0.313	0.307	0.256	0.299
Pre-anal length	0.649	0.629	0.632	0.583	0.630
D1 base length	0.214	0.178	0.192	0.163	0.172
D1 longest spine length	0.195	0.237	0.196	0.164	0.233
D2 base length	0.216	0.174	0.216	0.201	0.211
Length of caudal pedunculus	0.172	0.163	0.164	0.175	0.143
Head height	0.157	0.159	0.162	0.187	0.142
Front body height	0.184	0.194	0.194	0.204	0.182
Pectoral fin's longest ray length	0.206	0.179	0.173	0.164	0.145
Middle body height	0.170	0.207	0.173	0.184	0.169
Pelvic fin base length	0.047	0.041	0.063	0.120	0.033
Pelvic fins' longest ray length	0.101	0.116	0.088	0.102	0.103
Caudal base height	0.160	0.165	0.162	0.162	0.142
Anal fin length	0.201	0.188	0.223	0.165	0.155
Anal fin's longest ray length	0.081	0.059	0.056	0.127	0.074
Caudal pedunculus height	0.081	0.097	0.099	0.101	0.082
Caudal fin height	0.144	0.162	0.115	0.145	0.152
Caudal fin length	0.213	0.234	0.208	0.219	0.167

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### Meristic Characters of Mudskipper Fish

The comparison of meristic characteristics of mudskipper fish which were found in the coastal mangrove ecosystem of Tomini Bay, Boalemo, Gorontalo Province along with the species' classification are presented in Table 4 and Figure 2.

**Table 4.** Comparison of Meristic Characters of Mudskipper Fish in the coastal mangrove ecosystem of Tomini Bay, Boalemo, Gorontalo Province

OTU	Number of Spines and Rays												LS
	D1		D2		A		P		V		C		
	S	R	S	R	S	R	S	R	S	R	S	R	
<i>P. minutus</i>	16	0	1	12	0	11	0	13	0	6	0	13	60
<i>P. malaccensis</i>	11	0	1	12	0	11	0	11	0	6	0	14	58
<i>P. variabilis</i>	14	0	1	12	0	12	0	13	0	6	0	16	52
<i>P. argenteilvatus</i>	13	0	1	12	0	12	0	12	0	6	0	16	70
<i>P. kalolo</i>	11	0	1	12	0	11	0	11	0	6	0	14	62

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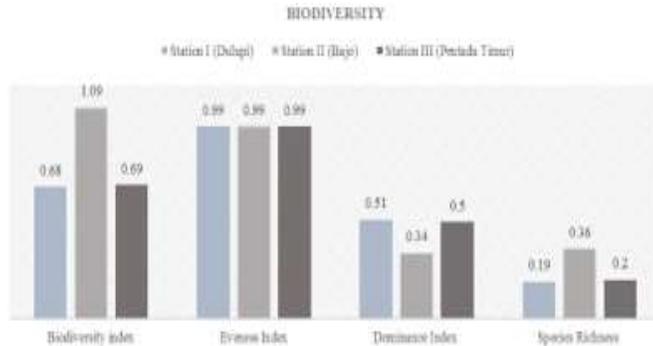
#### Microsoft Office User

It would be better if it was accompanied by a picture of the characters.

It has been revised as suggested. The characters can be seen in Figure 2.

244 The gathered data of mudskipper fish at three locations showed moderate diversity with a value of  $H' = 1.09$ . The  
 245 Evenness index was 0.99 based on 3 observation stations. The lowest dominance value was at station II with a value of 0.34  
 246 (Figure 5).

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266 Figure 5. Biodiversity (Biodiversity index, Evenness Index, Dominance Index and Species Richness of mudskipper fish in the research site

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270 **Environment Parameters**

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272 The results range of the temperature measurement at three research locations were around 28 -30°C at station I, 29-30°C  
 273 at station II and 28 -30°C at station III. The value of the acidity degree (pH) of water was in the range of 7.1-8 and the  
 274 substrate (pH) in the range of 6.8-8. The ecological condition of Station I (Duhupi) of mangrove area based on its visual look  
 275 was still considered good-solid, possessing sandy and muddy textures of ground habitat with mangroves growing on it. In  
 276 Station II (Bajo), the mangrove area had been shift-transferred to a settlement area without considering the vital values of  
 277 mangrove plants. Based on its visual look, the ground texture of the mangrove forest there is sandy and muddy. Many  
 278 garbages were scattered and many mangrove saplings were died and broken. In station III (East Pentadu), according to its  
 279 visual appearance, the ground texture of the mangrove was muddy. The mangrove condition was still considered good and  
 280 the regeneration of the growing sappling in the area is considered quick and plenty.

281

Tabel 5. Physics and chemical parameters of the waters study area

Environment Parameters:	Coastal Mangrove Area of Tomini Bay, Boalemo		
	Station I Duhupi	Station II Bajo	Station III East Pentadu
Temperature (°C)	28-30	29-30	28-30
Substrate	Sand and mud	Sand and mud	Mud
Water pH	7.1-8	7.3-8	7.3-8
Subtrat pH	7.5-8	6.8-7	6.8-7.5

282

283 **Discussion**

284 There were five species mudskipper fish that could be found in the coastal mangrove ecosystem of Tomini Bay,  
 285 Boalemo, Gorontalo Province in which all of the species were part of Genus Periopthalmus. It implied that even though  
 286 mudskipper fish spread in all over the tropical and subtropical habitat, except in the western tropical Atlantic and eastern  
 287 tropical Pacific (Springer 1982; Jaafar and Murdy 2017). Periopthalmus tends to stay in mangrove ecosystems. This is due  
 288 to the existence of many detritus, small crabs, small fish, shrimps, and arthropods in mangrove which are food for  
 289 Periopthalmus (Rha'ifa et al. 2021). Thus, the result of this study was in line with previous studies which were conducted  
 290 in the coastal ecosystems around Indo-Pacific (Pormansyah et al. 2019), such as Maluku (Rumahlatu et al. 2020; Tanirvel et

**Microsoft Office User**  
 It is important to describe the ecological conditions of each sampling station.

Already been added.

**Microsoft Office User**  
 It may be necessary to discuss why these mudskipper like or have more populations in that habitat (mangrove ecosystem) than another ecosystem.

Already been added.

291 al. 2020), South Sumatera (Ridho et al. 2019), West Nusa Tenggara (Rha'ifa et al. 2021), Yogyakarta (Arisuryanti et al.  
292 2018), North Sulawesi (Polgar et al. 2017), Java and Bali (Dahrudin et al. 2017), Malacca Strait and Malay Peninsula  
293 (Polgar et al. 2014). All species found by researchers possessed high similarity in morphological features because they are  
294 part of the same Genus (Table 2).

296  
297 a. *Periophthalmus murudus*

298 D, XVI, D, I, 12; A 11; P 13; V 6; C 13

299 Eyes without dermal cup; one row of teeth on the maxilla; pelvic fin without frenum; moderate D1 height with straight  
300 margins, single brown strip mesial with numerous proximal white spots, without spinal elongation; D2 with dusky  
301 brown stripe mesially; D1 and D2 are not connected by a membrane; lateral scales 60; head length 0.273% SL; pelvic  
302 fin basal length 0.047% SL; anal fin basal length 0.201% SL; D1 basal length 0.214% SL; D2 basal length 0.216% SL;  
303 caudal peduncle height 0.081% SL (Figure 2, Table 3, Table 4). **In some conditions, the frenum can be seen through a  
304 magnification (Jaafar & Murdy (2017)).**

305  
306 b. *Periophthalmus malaccensis*

307 D, XI, D, I, 12; A 11; P 11; V 6; C 14

308 Eyes without dermal cup; one row of teeth on the maxilla; the pelvic is clear and prominent; moderate D1 height with  
309 slightly rounded margins, a single inframarginal brown strip with numerous proximal white spots, first spine elongated;  
310 D2 with faded brown stripe mesial; D1 and D2 are not connected by a membrane; lateral scales 58; head length 0.274%  
311 SL; pelvic fin basal length 0.027% SL; anal fin basal length 0.188% SL; D1 basal length 0.178% SL; D2 basal length  
312 0.174% SL; caudal peduncle height 0.097% SL (Figure 2, Table 3, Table 4). *Periophthalmus malaccensis* also has  
313 bright blue spots on the chin and operculum, it also has prominent transverse folds on the snout (Polgar 2016).

314  
315 c. *Periophthalmus variabilis*

316 D, XI, D, I, 12; A 11; P 11; V 6; C 14

317 Eyes without dermal cup; one row of teeth on the maxilla; the pelvic frenum is clear and prominent; the pelvic is orange  
318 at least at the margins; moderate D1 height with rounded margins, a single inframarginal brown strip with many  
319 proximal white spots, first spine elongated, white margin; D2 with single inframarginal orange stripe and black single  
320 stripe mesial, with reddish-orange spots at the base; the anal fins are orange at least at the margins; D1 and D2 are not  
321 connected by a membrane; lateral scales 52; head length 0.264% SL; pelvic fin basal length 0.027% SL; anal fin basal  
322 length 0.063% SL; D1 basal length 0.192% SL; D2 basal length 0.216% SL; caudal peduncle height 0.099% SL (Figure  
323 2, Table 3, Table 4). When alive, the branchiostegal membrane of the fish shows pigmentation (Setiawan et al. 2019).

324  
325 d. *Periophthalmus argenteolineatus*

326 D, XIII, D, I, 12; A 12; P 12; V 6; C 16

327 Eyes without dermal cup; one row of teeth on the maxilla; pelvic without frenum; moderate D1 height with straight  
328 margins, single brown strip mesial with numerous proximal white spots, without spinal elongation; D2 with dusky  
329 brown stripe mesial; D1 and D2 are not connected by a membrane; lateral scales 70; head length 0.247% SL; pelvic  
330 fin basal length 0.12% SL; anal fin basal length 0.165% SL; D1 basal length 0.163% SL; D2 basal length 0.201% SL;  
331 caudal peduncle height 0.101% SL (Figure 2, Table 3, Table 4). **The total of transverse scale from ventroposterior D2  
332 basal to the basal of anal fin is 18-26 (Jaafar & Murdy (2017)).**

333  
334 e. *Periophthalmus haioio*

335 D, XI, D, I, 12; A 11; P 11; V 6; C 14

336 Eyes without dermal cup; one row of teeth on the maxilla; vestigial pelvic frenum; pelvic fins fused about half of the  
337 pelvic fins; moderate D1 height with rounded margins, single black stripe inframarginal with proximal white spots,  
338 without spinal elongation; D2 with inframarginal dusky strip; D1 and D2 are not connected by a membrane; lateral  
339 scales 62; head length 0.256% SL; pelvic fin basal length 0.033% SL; anal fin basal length 0.155% SL; D1 basal length  
340 0.172% SL; D2 basal length 0.211% SL; caudal peduncle height % SL (Figure 2, Table 3, Table 4). **The total of  
341 transverse scale from ventroposterior D2 basal to the basal of anal fin is fewer than *Periophthalmus argenteolineatus*  
342 that is only 18-22 (Jaafar & Murdy (2017)).**

343  
344 Morphological adaptations of mudskipper fish created **variations in morphometric and meristic measurements (Nugroho  
345 et al. 2016; Dinh et al. 2020; Ghanbarifardi et al. 2020). Jaafar & Murdy (2017) added that morphological characters such  
346 as number of dorsal spines, the presence of finger-like projections in the maxillodentary ligament in the lip of the lower jaw**

MO Microsoft Office User  
Descriptions of each species need to include appropriate references.

It has been revised as suggested

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It has been revised as suggested

MO Microsoft Office User  
It is necessary to make a table regarding the variations in morphometric analysis.

The variations were already been shown in Table 2 and 3.

347 and the epaxialis muscle attaching anteriorly of the frontal and epioccipital junction can distinguish genera in the family.  
348 Meristic characters such as the scales before and after the pectoral filaments, pectoral fins, dorsal fins, abdominal fins, and  
349 anal fins are characters that can distinguish species in the genus. In addition, other factors that influence differences in fish  
350 morphology are food availability, environmental conditions, and the stage of fish maturity. Another character with a high  
351 probability of variation is coloration. Fish coloration is influenced by many factors including genetic, environmental, dietary,  
352 and physiological factors (Nüsslein-Volhard and Singh 2017). Due to the instability of the correlation character, this  
353 character is mostly neglected when identifying fish species.

354 The difference in species diversity between the three stations is influenced by environmental conditions. The high and  
355 low species diversity was influenced by many factors and one of the factors is environmental quality. Krebs (2014) further  
356 explained that species diversity is used to measure the stability of a community which is the ability of a community to keep  
357 itself stable despite disturbances to its components. Maturbongs et al. (2018) argued that the area or mud substrate is a habitat  
358 for various nekton, which indicates the area has abundant food sources. The existence of habitat variations (substrate), such  
359 as physical conditions and the surrounding environment affects the diversity of fish species. The diversity index at the  
360 research site was 1.09, this indicated that a high level of diversity of mudskipper fish in the Coastal Bay of Tomini, Bualemo,  
361 was included in the moderate criteria. In addition, it also showed that water productivity was quite balanced.

362 The comparison of the Evenness index of mudskipper fish in the research locations had the same Evenness index value  
363 of 0.99. This value indicated that the Evenness in the three locations was stable. The Evenness index shows the degree of  
364 Evenness of individual abundance between each species. If each species has the same number of individuals, then the  
365 community has a maximum Evenness value. On the other hand, if the Evenness value is small, then the community has  
366 dominant, sub-dominant, and dominated species, eventually, the community has a minimum Evenness. The Evenness value  
367 had a range between 0-1, if the index value obtained was close to one, it means that the distribution is more even (Ludwig  
368 and Reynolds 1988; Baderan et al. 2021). Figure 3 presents the index of Evenness of the mudskipper (*Periophthalmus*)  
369 species in the Coastal Bay of Tomini, Bualemo, which was included in a stable community. Thus, the population between  
370 species of the genus *Periophthalmus* on the Coastal Bay of Tomini, Bualemo, was fairly even, so that disturbances did not  
371 easily occur and were able to return to their initial conditions.

372 Species richness in the research locations was low with the Specific Richness Index (R1) at each station as follows 0.19  
373 (Station I Dulupi), 0.36 (Station II Bajo); 0.2 (Station III East Pentadu). Species richness refers to the number of species in  
374 a community. The number of species in the field determines the size of the richness index. The Margalef richness index  
375 divides the number of species by the natural logarithm function meaning that the increase in the number of species is  
376 inversely proportional to the increase in the number of individuals. Generally, a community/ecosystem with an abundant  
377 number of species will have a small number of individuals in each of these species.

378 The dominance of species in water often occurs due to several things including competition for natural food by certain  
379 species accompanied by changes in environmental quality and also an imbalance between predators and prey which are  
380 resulted in competition between species. Maturbongs et al. (2018) explained that dominance occurs because of the result of  
381 the competition process for evicting one individual against another. Okyere (2018) stated that at low tide the estuary area is  
382 dominated by brackish fish species, one of which is from the Gobiidae family. This statement is true because mudskipper  
383 fish is more active during low tide conditions both on the coast and at an estuary, on the other hand, mudskipper fish will  
384 hide in their nests at high tide to avoid predators. The dominance index of mudskipper fish was 0.51 which indicated that  
385 the level of species dominance in these waters was moderate, thus there were no dominant species in these waters.

386 Environmental factors that are very supportive and the absence of predators made several species of mudskipper fish  
387 thrive and spread across the area. In line with research conducted by Mahadevan and Ravi (2015) which stated that the right  
388 water temperature range for mudskipper fish was between 23.5-35.5°C, the measurement results of environmental  
389 parameters showed that the average temperature range was 28-30°C. Furthermore, Bidawi et al. (2017) explained that  
390 mudskipper species had tolerance to wide changes in temperature and salinity indicating that water temperature is one of the  
391 environmental factors that affect the spread and diversity of mudskipper species.

392 The pH content of the substrate ranged from 6.8 to 8. It means that the water conditions for the life of mudskipper  
393 fish were in the neutral range. The difference in soil pH at the research sites was caused by the contribution of leaf, root, and  
394 stem litter that fall to the ground and decomposed to form soil organic matter (Tajbakhsh et al. 2018). The pH of the substrate  
395 greatly affects the resistance of organisms that live at the bottom of the waters, both infauna and epifauna. This occurred due  
396 to the influence of tidal or brackish water during the formation of this land and subsequent tidal processes. Furthermore,  
397 Kanajiyra et al. (2017) explained that the distribution of mudskipper fish was significantly influenced by environmental  
398 factors such as pH, temperature, salinity, and the other ecological conditions (Ghanbarifardi et al. 2014). Regarding to the  
399 presence of mudskipper fish with substrate conditions in the mangrove area at the three stations, added that substrate  
400 differences play an important role in the distribution of mudskipper fish.

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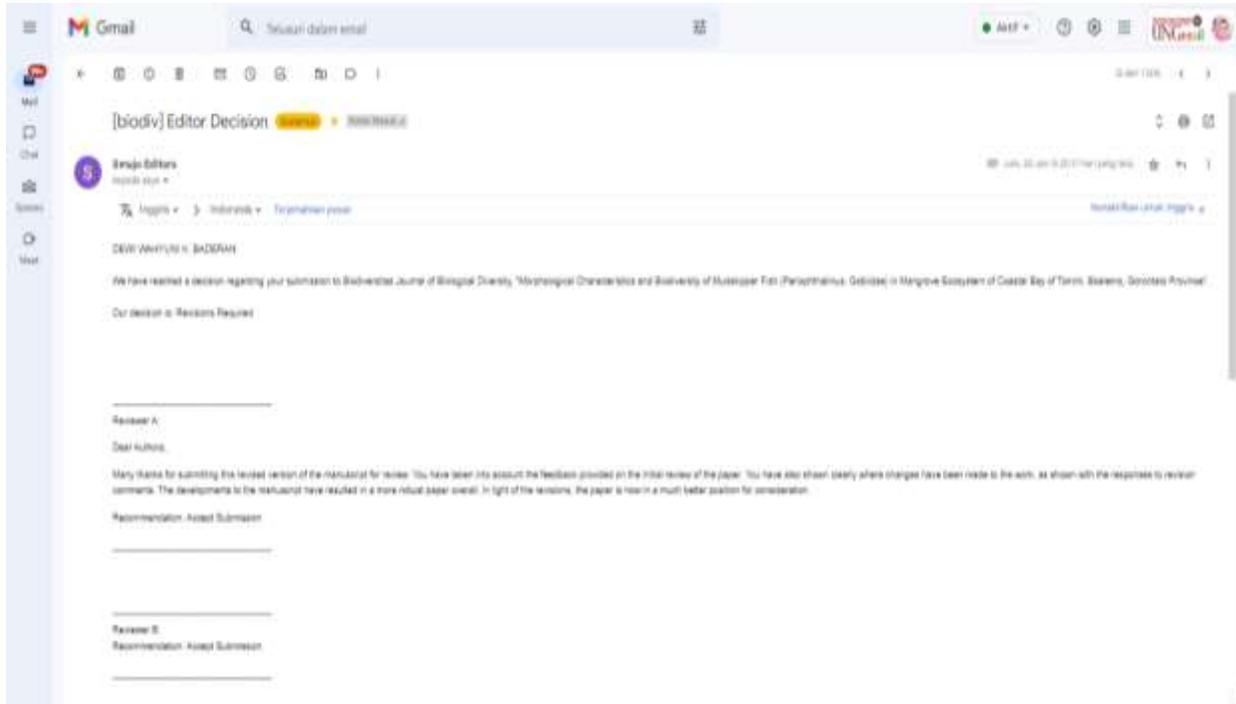
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## REVISI KE-4

Jumat, 20 Januari 2023



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# Morphological characteristics and biodiversity of mudskipper fish (*Periophthalmus* Gobiidae) in mangrove ecosystem of coastal Bay of Tomini, Boalemo, Gorontalo Province, Indonesia

**Abstract.** The southern sea area of Gorontalo Province is part of Tomini bay, the biggest bay in Indonesia. This area has a unique biodiversity, and is Sulawesi endemic. Mangrove-The mangrove forest located in the coastal bay of Tomini Boalemo is one of the habitats for flora and fauna, a place for spawning, nurseries, and food hunting for fish. The mudskipper is a fish that lives in the mangrove area. This study aims to reveal the morphological characteristics and biodiversity of mudskipper (*Periophthalmus*: Gobiidae) in the ecosystem of Tomini Boalemo coastal bay of Gorontalo Province. This study employed a quantitative descriptive that also implemented purposive sampling as the sampling method in three ecosystem stations of Tomini Boalemo coastal bay (Dulaga, Bajo, and East Pentadu mangrove). The mudskippers were collected when the water was normally receding naturally when the water was receding by using a fish net. The sample which had been collected were then identified based on 22 morphological, 24 morphometric, and 25 meristic characteristics. The identification results were then compared with the identification key. The species of mudskippers found were then analyzed to form mudskippers' species were then analyzed to determine the species' biodiversity (diversity, evenness, species richness, and dominance indexes). The research result revealed 5 five species from *Periophthalmus* Genus which are, *Periophthalmus argenteivittatus*, *Periophthalmus kakaia*, *Periophthalmus malaccensis*, *Periophthalmus monnax*, *Periophthalmus variabilis*, with total individuals 561. The score of H<sub>1</sub>-1.09 showed that the diversity of mudskipper fish was categorized as medium. The evenness index was 0.99 obtained from 3 observation stations, while the lowest dominance index was on station II with a score of 0.34 and the score of R<sub>1</sub> in each station was respectively (0.19); (0.36); and (0.2). The result of this study could be used as a database for the sustainable management of Tomini Bay in order to tackle the threats of species extinction through aquatic life protection and preservation to arrange the natural balance and support the availability of the coastal resource for future generations.

**Keywords:** biodiversity, morphology, meristics, *Periophthalmus*, Tomini Bay

## INTRODUCTION

Tomini Bay is the largest bay in Indonesia and is located in the coral triangle initiative. One of the parts of the bay which has rich biodiversity is the mangrove ecosystem which plays an important role in improving coastal sea productivity, spawning area, and nutrient supply needed by various species of fish (Nguyen and Parnel 2017; Lapolo et al. 2019), and potential of biodiversity (Cowray et al. 2021). In addition, Sellang (2020) stated that the mangrove ecosystem is one of the most important and productive environments for the presence of fish species in a-tropical areas and sub-tropical ecosystems, which can improve the fertility and productivity of the coastal area. Mudskipper fish (Perciformes: Gobiidae) is one of the families that live in the mangrove ecosystem, as mentioned by Lantaoconsina (2016) and Rha'ifa-Rha'ifa et al. (2021) as the local resident of the mangrove ecosystem. One of the Genera that belongs to the Family that is Family widely distributed in that ecosystem is *Periophthalmus* (WoRMS 2018; Fishbase 2022). This Genus occupies primary (organisms that obtain energy from producers) and secondary positions (organisms that obtain energy from primary consumers) in the food chain despite their very small size (Polgar et al. 2017), inhabiting muddy habitats, sandy beaches, and mangrove areas (Mahaadevan and Ravi 2015). Mudskippers' daily behavior is closely related to tidal rhythm (Ravi, 2013), where they climb mangrove roots, walk on mudflats, and dig burrows in mud (Ansari et al. 2014; Hui et al. 2019; Hidayat et al. 2022).

The mudskipper fish has various species, yet they have numerous similarities in terms of morphology (Ridho et al. 2019). One of its unique characteristics is spending 90% of its life living on land, climbing, and perching on the roots of the mangrove or wood, as well as being able to crawl up on the land (Mukharomah et al. 2016). Its pectoral fin on its muscular base can be buckled so that it has a suction function like an arm that can be used to crawl, jump above the mud, and attached to rocks and open roots (Huang 2013; Wisaksono et al. 2016). The potential of mudskipper fish as the filter feeder that consumes the organic particles of living creatures suspended in water, has the ability to absorb Lead (Pb) and has a role as a bio-indicator of environmental pollution (Akirotinni et al. 2013). The mudskipper can be used by

Reviewer November 28, 2022  
Italicise the genus name  
The Genus should be written normally (not italicized) based on the Binomial Nomenclature System. It should be italicized if it is written with specific epithet i.e. *Periophthalmus* sp., *Periophthalmus kakaia*, etc.

Reply Resolve

- Reviewer Results
- Dewi K Badaran Revised as suggested
- Reviewer Some of the key words are
- Reviewer why are they loyal? Check
- Reviewer scientific names should be
- Reviewer Please cite here
- Reviewer Please cite here

52 ~~people~~People can use the mudskipper to fulfill their food needs because it has a high ~~value of nutrition~~nutritional value  
 53 (Akinrotimi et al. 2012; Bidawi et al. 2017). *Boleophthalmus boddarti*, one of the mudskipper fish species, has a high  
 54 value of fat in the liver (554.45±4.49 mg/g), protein (3.5±0.35 mg/100mg), and 1.5 ± 0.47mg/100 mg protein in the muscle  
 55 (Kanejiya et al. 2017). Mudskipper fish also have economic value in several countries in Asia. ~~In China, Japan and Korea,~~  
 56 ~~for instance~~For instance, mudskipper with beautiful morphological characters can be used as ornamental fish in China,  
 57 Japan, and Korea. ~~Mudskipper with beautiful morphological characters can be used as ornamental fish, while i.~~ They are  
 58 generally sold as preserved products in Indonesian-Indonesia they are generally sold as preserved products, such as dried  
 59 and smoked fish (Faridah-Hanum et al. 2014). Besides, mudskipper, as the native residents of mangrove habitat ~~creates a~~  
 60 ~~natural view that is,~~ creates a natural view awaited by the tourists (Chakraborty et al. 2020).  
 61 One of the areas in Sulawesi Island ~~directly borders which is directly bordered by Tomini Bay~~Tomini Bay -is Boalemo  
 62 Regency. Boalemo ~~generally has a typical characteristic of a coastal area with relatively high resources, in general has a~~  
 63 ~~typical characteristic of a coastal area with relatively high resources~~ particularly in the area of mangrove forest and fishery  
 64 sources, one of which is the mudskipper fish. ~~Therefore,~~ the existence of this fish in the mangrove ecosystem in the  
 65 Coastal Bay of Tomini Bualemo is pretty abundant. ~~However, although~~ it is disregarded as fishermen and people in  
 66 Boalemo are ~~not un~~aware of the potential of the nutrition consisted in the mudskipper fish. ~~Conse~~As ~~consequence~~the  
 67 existence of the mudskipper fish in the Mangrove Coast Tomini Bay is threatened to be extinct along with the decrease of  
 68 its population. ~~That extinction aligns~~with the speed of mangrove forest degradation. The main cause of the  
 69 degradation is the land conversion in mangrove forests to become fish and shrimp ponds. ~~That is~~ affirmed by Hai et al.  
 70 (2020), ~~that~~ mangrove is an important component of the coastal ecosystem which is severely and globally threatened by  
 71 various causing factors. In 1988, the ~~area of mangrove forest~~mangrove forest area in Tomini Bay was noted as big as  
 72 17,672 hectares, while in 2010, it was degraded to 16,105 hectares, and in 2020, it is predicted to have the remaining area  
 73 as big as 10,321 hectares (Paino 2020).  
 74 The ~~species of mudskipper which were~~mudskipper species identified until today are around 43 species in 10 genera  
 75 (Polgar et al. 2013; Rupp 2021). General information ~~related to mudskipper fish has been available yet its species which~~  
 76 ~~are found in the Tomini Bay~~about mudskipper fish has been available, yet its species in Tomini Bay have not been found  
 77 e. ~~Even~~ the people in the coastal Bay of Tomini Bualemo stated that the mudskipper fish is ~~a kind of poisonous~~  
 78 ~~fish~~poisonous. People have not yet known the potential use of the mudskipper fish optimally in terms of ecology,  
 79 economy, and health, so this research is urgent ~~to conduct~~. This research aims to analyze the morphological characteristics  
 80 and biodiversity of mudskipper fish as the reliable resident of the mangrove area in Tomini Bay. The findings of this  
 81 research can be used as support for formulating policies that aim to minimize the mangrove degradation in the coastal bay  
 82 of Tomini.

## 83 MATERIALS AND METHODS

### 84 Study area

85 This study was carried out in a mangrove ecosystem in the coastal bay of Tomini, Boalemo, Gorontalo Province. It  
 86 included three observation stations, i.e., station I (Dulupi Village), station II (Bajo Village), and station III (East Penatdu  
 87 Village). The three sampling locations were chosen because they have healthy mangrove forests. This study ~~had been~~was  
 88 conducted for ~~5-five~~ months, from May to September ~~2022~~. This study employed a descriptive quantitative method by  
 89 implementing a purposive sampling method in three stations of the mangrove ecosystem in the coastal bay of Tomini,  
 90 Boalemo. ~~Data-~~The data collected were primary and secondary data. The primary data were collected by identifying all  
 91 species of the mudskipper fish and some of its morphological, morphometrical, and meristical characteristics, as well as its  
 92 biodiversity (diversity, evenness, and species richness indexes) (Figure 1).  
 93

R Reviewer  
In what way? High calorific content?

It is explained in the next sentence

R Reviewer  
This sentence doesn't make sense. Can you rephrase?

R Regina  
Revised as suggested

R Reviewer  
Please check formatting of numbers. A full stop in English is used as a decimal point. Do you really mean that the area is only 17 hectares? Or do you mean it is 17,000 hectares?

Revised as suggested

R Reviewer  
See points on number formatting.

Revised as suggested

R Reviewer  
How were sample locations selected?

Revised as suggested

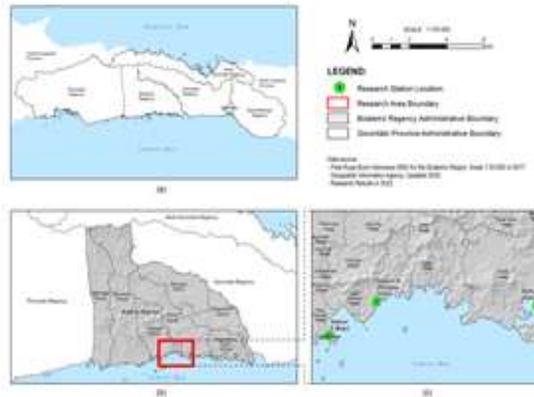


Figure 1. Location of the coastal bay of Tomini, Boalemo, Gorontalo Province indicating the sampling sites of *Pariophthalmis*: Station I (N 00°30.640 E 122°26.982), Station II (N00°29.818 E 122°20.931), and Station III (N 00°30.736 E 122°22.336)

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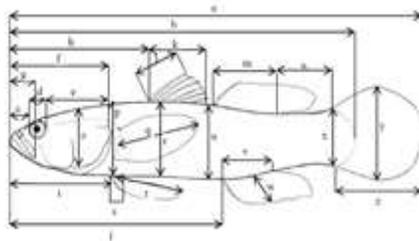
#### Tools and Materials

The tools used were a scoop net, a 3x3 meters fish net, a cool box, a zip lock, stationery, a digital camera, ruler, millimeter block paper, gloves, jar, GPS, thermometer, pH meter, and an Ohaus digital scale with an accuracy of 0.01 g. The materials used were mudskipper fish, 10% formalin, 70% alcohol, tracing paper, ice, sewing thread, and distilled water.

#### Procedures

The sampling procedures are as follows: (i) Specimen collection using a 3x3 meters net and hand-collecting in 3 locations of the mangrove ecosystem of the coastal area of Tomini bay. (ii) Measurement of physical-chemical factor temperature, substrate, water pH, and substrate pH of the environment was done in every location. (iii) Observations and measurements of physical factors are carried out during the day when the sea recedes. (iv) The specimen was put in a jar, labeled, and then transferred to the laboratory for identification purposes. (v) Specimen documentation was carried out utilizing a Nikon DX VR camera with an AF-S NIKKON 18-55 mm lens and a Macro Pro Yama Digital PRO 0.45X HD WIDE LENS SDW-045 52 mm. (vi) The mudskipper fish samples were observed and measured for morphological, morphometric and meristic characterization in the Biology Laboratory, Faculty of Mathematics and Natural Sciences, and the Agricultural Laboratory, Faculty of Agriculture, Universitas Negeri Gorontalo. This observation and measurement step was referred to (Larson and Murdy 2001; Polgar et al. 2013; Maryam et al. 2015; Aydalina 2016; Ghanbanfardi et al. 2018; Kaur et al. 2019; Mahadevan et al. 2019; and Gonzalez-Martinez et al. 2020). Species identification was carried out by referring to (Murdy 1989; Larson and Murdy 2001; Jaafar et al. 2016). Specimen fixation used 70% alcohol and 10% formalin.

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1 Regina  
Revised as suggested

2 Reviewer  
Please state the depths and time that these observations were conducted  
Revised as suggested

122  
123 **Figure 2.** Morphometric characterization scheme of the mudskipper: (a) total length, (b) standard length, (c) Pre-orbital length, (d) eye  
124 diameter, (e) post-orbital length, (f) post-orbital length, (g) mouth length, (h) pre-dorsal length, (i) pro-ventral length, (j) pre-anal length,  
125 (k) first dorsal fin base length, (l) height of the longest first spiny dorsal fin, (m) second dorsal fin base length, (n) length of caudal  
126 peduncle, (o) head height, (p) front body height, (q) length of the longest spiny pectoral fin, (r) middle body height, (s) middle body  
127 height, (t) length of the longest spiny pelvic spine, (u) caudal fin height, (v) anal fin base length, (w) length of the longest spiny anal fin,  
128 (x) Caudal peduncle depth, (y) caudal fin height, (z) caudal fin length (Larson & Murdy, 2001; modified by authors).

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131 **Data analysis**

132 Morphometric and meristics data were analyzed using the *Microsoft Excel* program, and morphological observations  
133 were analyzed descriptively.  
134 Data on the diversity of mudskipper species were analyzed using the Diversity Index ( $H'$ ) (Shannon and Wiener 1963;  
135 Fachrul 2012).  $H' = -\sum_{i=1}^S p_i \ln p_i$  where  $p_i = \frac{n_i}{N}$ .  $H'$  represents the Shannon-Wiener Diversity index,  $S$  for total species,  
136  $N_i$  for total individuals in a species,  $\ln$  for the natural logarithm, and  $N$  for total individuals found. The value of  $H'$   
137 determines the level of species diversity in an area, where the definition of the value of species diversity according to  
138 Shannon-Wiener is:  $H' > 3$ : High species diversity,  $1 \leq H' \leq 3$ : Medium species diversity,  $H' < 1$ : Low species diversity.  
139 ~~Data of species evenness (K) were analyzed using the species evenness index. The species evenness index analyzed~~  
140 ~~species evenness (K) data which referred to the Pielou Evenness Indices formula (Ludwig and Reynolds 1988):~~  $E = H'/\ln S$ .  
141 ~~Where E represents Evenness Index, and  $H'$  represents Shannon-Wiener Diversity Index. Margalef formula was used~~  
142 ~~as Species Richness Index (Magurran 1988):~~  $R_i = \frac{(S-1)}{(\ln(N))}$ , which  $R_i$  represents the Richness Index,  $S$  for the Numbers of  
143 Species found, and  $N$  for the Total Numbers of Individuals. Dominance data were analyzed using the Simpson formula:  
144  $D = \sum \frac{(n_i(n_i-1))}{(N(N-1))}$  which  $D$  represents Dominance Index,  $n_i$  for Number of Individuals that belong to species  $i$ , and  $N$  Total Numbers of Individuals. ~~The~~  
145 ~~results of the~~  
146 ~~dominance index were grouped into~~  $0 < D < 0.5$ , in which ~~there are no species that dominate other species or a community~~  
147 ~~structure is stable; no species dominate other species or a stable community structure. While, and index~~  $0.5 < D < 1$ , ~~which~~  
148 ~~means there are species that dominate other species or a community structure is not meaning some species dominate other~~  
149 ~~species or a community structure is unstable because of ecological pressures (Odum 1971; Krebs 2014).~~

**R Reviewer**  
Explain the formula more clearly here  
Revised as suggested

150 **RESULTS AND DISCUSSION**

151 **Result**

152 *Mudskipper Fish at the Research Site*  
153 The results in Table 1 show that the species of mudskipper fish which were found comprised one Gobiidae Family of  
154 the Actinopterygii Class: *Periophthalmus argentilineatus*, *Periophthalmus kalolo*, *Periophthalmus malaccensis*,  
155 *Periophthalmus minutus*, and *Periophthalmus variabilis*. The total number of mudskipper fish found in ~~the coastal~~  
156 ~~mangrove area of Tomini Bay, Boalemo, Tomini Bay, Boalemo's coastal mangrove area, is~~ as many as 561 individuals,  
157 ~~were~~ ~~spread~~ across station I-Dulupi village (156 individuals), station II-Bajo village (254 individuals), and station III-  
158 East Pentadu village (151 individuals). The classification of mudskipper fish in the coastal mangrove ecosystem of Tomini  
159 bay, Boalemo, Gorontalo Province, is presented in Table 1.

160  
161 **Table 1.** The classification of mudskipper fish in the coastal mangrove ecosystem of Tomini bay, Boalemo, Gorontalo Province  
162

Class, Family	Species	Station			Total Number of Individuals
		I Dulupi	II Bajo	III East Pentadu	
Actinopterygii					
Gobiidae	<i>Periophthalmus argentilineatus</i>	-	-	83	83
	<i>Periophthalmus kalolo</i>	67	-	-	67
	<i>Periophthalmus malaccensis</i>	89	98	-	187
	<i>Periophthalmus minutus</i>	-	75	-	75
	<i>Periophthalmus variabilis</i>	-	81	68	149

**R Regina**  
Revised as suggested

Markup Area

163 Description: (-) found; (·) Not found; and the number in brackets represents the number of individuals observed.  
 164 Source: Primary Data, 2022

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### 167 The Morphological Characters of Mudskipper Fish

168

169 **Table 2.** Comparison of Morphological Characters of Mudskipper Fish in the coastal mangrove ecosystem of Tomini Bay, Boalemo,  
 170 Gorontalo Province

171

Characters	<i>P. minutus</i>	<i>P. malaccensis</i>	<i>P. variabilis</i>	<i>P. argenteolineatus</i>	<i>P. kalolo</i>
Dermal cup	-	-	-	-	-
One row of teeth on the maxilla	+	+	+	+	+
Pelvic frenum	-	+	+	-	+
Pelvic fin wholly fused	-	-	-	-	-
Pelvic fin partly fused	-	+	+	-	+
Pelvic fin is not fused	+	-	-	+	-
High D1	-	-	-	-	-
Medium D1	+	+	+	+	+
Low D1	-	-	-	-	-
Slightly rounded D1 margins	-	+	-	-	-
Rounded D1 margin	-	-	+	-	+
Straight D1 margin	+	-	-	+	-
White D1 margin	-	-	+	-	+
Single inframarginal brown strip on D1	-	+	+	-	-
Single inframarginal black strip on D1	-	-	-	-	+
Single brown strip mesially on D1	+	-	-	+	-
White spot on proximal on D1	+	+	-	+	+
Reddish orange spot on D1	-	-	+	-	-
Elongated first spine on D1	-	+	+	-	-
Dusky strip mesially on D2	+	+	-	+	+
D1 and D2 connected by a membrane	-	-	-	-	-
Reddish orange pelvic and caudal fins	-	-	+	-	-

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173

### 174 The Morphometric Characters of Mudskipper Fish

175

176 **Table 3.** Comparison of Morphometric Characters of Mudskipper Fish in the coastal mangrove ecosystem of Tomini Bay, Boalemo,  
 177 Gorontalo Province

178

Characters	<i>P. minutus</i>	<i>P. malaccensis</i>	<i>P. variabilis</i>	<i>P. argenteolineatus</i>	<i>P. kalolo</i>
Pre-orbital length	0.051	0.029	0.035	0.061	0.037
Eye diameter	0.060	0.060	0.060	0.076	0.068
Head length	0.152	0.160	0.137	0.118	0.136
Snout length	0.273	0.274	0.264	0.247	0.256
Post-orbital length	0.506	0.070	0.054	0.091	0.055
Pre-dorsal length	0.337	0.383	0.368	0.384	0.346
Pre-ventral length	0.279	0.313	0.307	0.256	0.299
Pre-anal length	0.649	0.629	0.632	0.583	0.630
D1 base length	0.214	0.178	0.192	0.163	0.172
D1 longest spine length	0.195	0.237	0.196	0.164	0.233
D2 base length	0.216	0.174	0.216	0.201	0.211
Length of caudal pedunculus	0.172	0.163	0.164	0.175	0.143
Head height	0.157	0.159	0.162	0.187	0.142
Front body height	0.184	0.194	0.194	0.204	0.182
Pectoral fin's longest ray length	0.206	0.179	0.173	0.164	0.145
Middle body height	0.170	0.207	0.173	0.184	0.169
Pelvic fin base length	0.047	0.041	0.063	0.120	0.033
Pelvic fin's longest ray length	0.101	0.116	0.088	0.102	0.103
Caudal base height	0.160	0.165	0.162	0.162	0.142
Anal fin length	0.201	0.188	0.223	0.165	0.155

#### Reviewer

is there any variance in these values between specimens? Be clear here. State whether the values are averages and provide a measure of variance.

This is a species characterization data. We don't have a measurement of variance since the focus of this research is not about inter-species comparison. This data shown average values of each species.

Anal <del>fin's</del> longest ray length	0.081	0.059	0.056	0.127	0.074
Caudal pedunculus height	0.081	0.097	0.099	0.101	0.082
Caudal fin height	0.144	0.162	0.115	0.145	0.152
Caudal fin length	0.213	0.234	0.208	0.219	0.167

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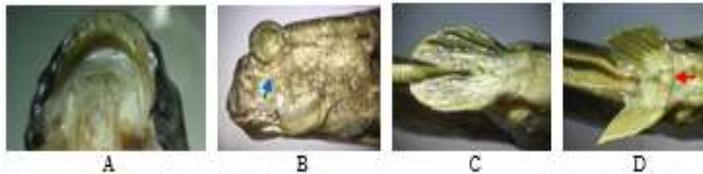
### Meristic Characters of Mudskipper Fish

The comparison of meristic characteristics of mudskipper fish which were found in the coastal mangrove ecosystem of Tomini Bay, Boalemo, Gorontalo Province, along with the species-species' classification, are presented in Table 4 and Figure 2.

**Table 4.** Comparison of Meristic Characters of Mudskipper Fish in the coastal mangrove ecosystem of Tomini Bay, Boalemo, Gorontalo Province

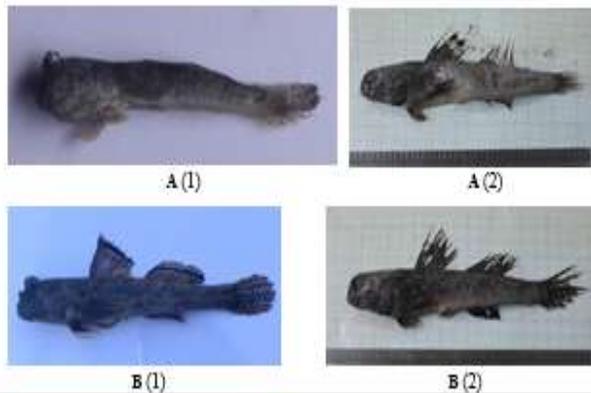
OTU	Number of Spines and Rays												LS
	D1		D2		A		P		V		C		
	S	R	S	R	S	R	S	R	S	R	S	R	
<i>P. minutus</i>	10	0	1	12	0	11	0	13	0	6	0	13	60
<i>P. malaccensis</i>	11	0	1	12	0	11	0	11	0	6	0	14	58
<i>P. variabilis</i>	14	0	1	12	0	12	0	13	0	6	0	16	52
<i>P. argenteolineatus</i>	13	0	1	12	0	12	0	12	0	6	0	16	70
<i>P. kafele</i>	11	0	1	12	0	11	0	11	0	6	0	14	62

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**Figure 3.** The characteristics of mudskipper fish in the coastal area of the mangrove ecosystem in Tomini Bay, Boalemo, Gorontalo Province:

A. one-row teeth on maxilla; B. Dermal-Cup; C. Pelvic fin without frenum; D. Pelvic fin without frenum. The frenum was shown by a red arrow. A red arrow showed the frenum.



**Reviewer**  
Is there any variance in these values between specimens? Be clear here  
  
This is a species characterization data. We don't have a measurement of variance since the focus of this research is not about inter-species comparison. This data shown average values of each species.

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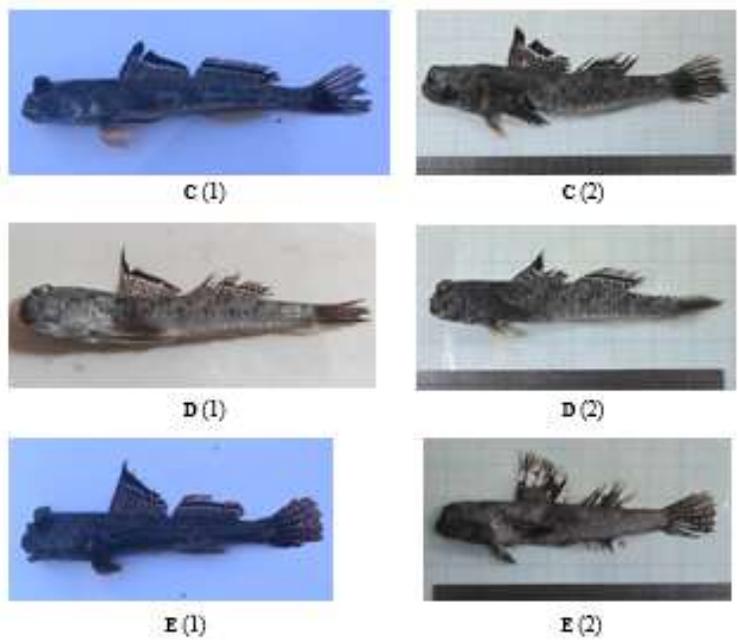


Figure 4. Mudskipper fish in the coastal mangrove ecosystem of Tomini Bay, Bualemo, Gorontalo Province. A. *Pariogthaimus minutus*; B. *P. malaccensis*; C. *P. variabilis*; D. *P. argentilimeatus*; E. *P. kalele*. Figure 2 is a photo of a specimen which had been preserved under a -50°C temperature for 4-month.

**Biodiversity of Mudskipper Fish Species**

The gathered data of mudskipper fish at three locations showed moderate diversity with a value of  $H' = 1.09$ . The Evenness index was 0.99 based on 3-three observation stations. The lowest dominance value was at station II with a value of 0.34 (Figure 5).

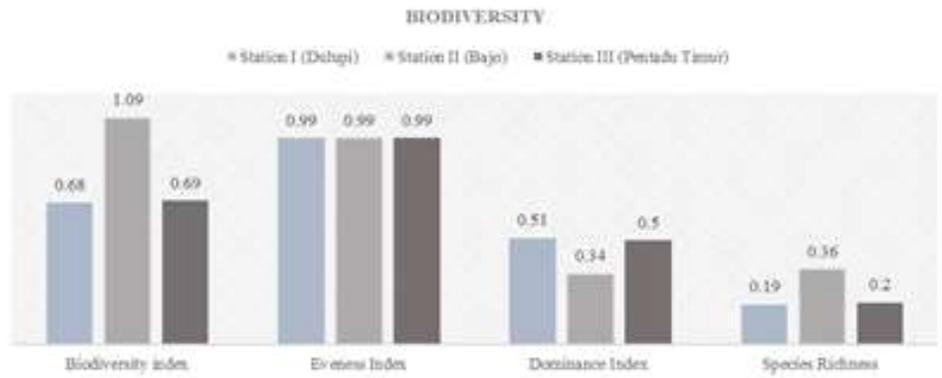


Figure 5. Biodiversity (Biodiversity index, Evenness Index, Dominance Index, and Species Richness of mudskipper fish in the research site

290 **Environment Parameters**

291

292 The results range of the temperature measurement at three research locations ~~were was~~ around 28 -30°C at station I,  
293 29-30°C at station II and 28 -30°C at station III. The value of ~~the acidity degree (pH) of water~~ ~~water's acidity degree (pH)~~  
294 was in the range of 7.1-8, and the substrate (pH) ~~was~~ in the range of 6.8-8. ~~The ecological condition of Station I (Dulupi)~~  
295 ~~of mangrove area based on its visual look~~ ~~Based on its visual look, the ecological condition of Station I (Dulupi) of the~~  
296 ~~mangrove area~~ was still considered good-solid, possessing sandy and muddy textures of ground habitat with mangroves  
297 growing on it. In Station II (Bajo), the mangrove area had been shift-transferred to a settlement area without considering  
298 the ~~vital-strong~~ values of mangrove plants. Based on its visual look, the ground texture of the mangrove forest ~~there is~~  
299 sandy and muddy. Large ~~rubbish~~ ~~was was~~ scattered, and many mangrove saplings ~~were died~~ ~~modified and were~~ broken. In  
300 station III (East Pentadu), according to its visual appearance, the ground texture of the mangrove was ~~muddy~~ ~~The~~  
301 ~~However,~~ the mangrove condition was still considered good, and the regeneration of the growing ~~sappling~~ ~~saplings~~ in the  
302 area ~~is was~~ considered quick and plenty.

303

**Table 5.** Physics and chemical parameters of the waters study area

Environment Parameters	Coastal Mangrove Area of Tomini Bay, Boalemo		
	Station I Dulupi	Station II Bajo	Station III East Pentadu
Temperature (°C)	28-30	29-30	28-30
Substrate	Sand and mud	Sand and mud	Mud
Water pH	7.1-8	7.3-8	7.3-8
Substrate-Substrate pH	7.5-8	6.8-7	6.8-7.5

304

305 **Discussion**

306 ~~There were five species mudskipper fish that~~ ~~Five species of mudskipper fish~~ could be found in the coastal  
307 mangrove ecosystem of Tomini Bay, Boalemo, Gorontalo Province, in which all of the species were part of Genus  
308 *Periophthalmus*. It implied that ~~even though mudskipper fish spread~~ ~~mudskipper fish spread~~ all over the tropical and  
309 subtropical habitat, except in the western tropical Atlantic and eastern tropical Pacific (Springer 1982; Jaafar and Murdy  
310 2017). *Periophthalmus* tends to stay in mangrove ecosystems. ~~This~~ is due to the existence of many detritus, small crabs,  
311 small fish, shrimps, and arthropods in mangroves which are food for *Periophthalmus* (~~Rha'ifa Rha'ifa~~ et al. 2021). Thus, the  
312 result of this study was in line with previous studies ~~which was~~ conducted in the coastal ecosystems around Indo-Pacific  
313 (Pormansyah et al. 2019), ~~Such as~~ Maluku (Rumahlanu et al. 2020; Taniwel et al. 2020), South Sumatera (Ridho et al.  
314 2019), West Nusa Tenggara (~~Rha'ifa Rha'ifa~~ et al. 2021), Yogyakarta (Arisuryanti et al. 2018), North Sulawesi (Polgar et  
315 al. 2017), Java and Bali (Dahruddin et al. 2017), Malacca Strait and Malay Peninsula (Polgar et al. 2014). ~~All species~~  
316 ~~found by researcher~~ ~~Researchers found all species~~ possessed high similarity in morphological features because they are part  
317 of the same Genus (Table 2).

318

319 a. *Periophthalmus minutus*

320 D; XVI, D; I, 12; A 11; P 13; V 6; C 13

321 Eyes without dermal cup; one row of teeth on the maxilla; pelvic fin without frenum; moderate D1 height with  
322 straight margins, single brown strip mesial with numerous proximal white spots, without spinal elongation; D2 with  
323 dusky brown stripe mesially; D1 and D2 are not connected by a membrane; lateral scales 60; head length 0.273% SL;  
324 pelvic fin basal length 0.047% SL; anal fin basal length 0.201% SL; D1 basal length 0.214% SL; D2 basal length  
325 0.216% SL; caudal peduncle height 0.081% SL (Figure 2, Table 3, Table 4). In some conditions, the frenum can be  
326 seen through a ~~magnification~~ (Jaafar & Murdy (2017)).

327

328 b. *Periophthalmus malaccensis*

329 D; XI, D; I, 12; A 11; P 11; V 6; C 14

330 Eyes without dermal cup; one row of teeth on the maxilla; the pelvic is clear and prominent; moderate D1 height with  
331 slightly rounded margins, a single inframarginal brown strip with numerous proximal white spots, ~~first-First~~ spine  
332 elongated; D2 with faded brown stripe mesial; ~~D1 and D2 are not connected by a membrane~~ ~~membrane does not~~  
333 ~~connect D1 and D2~~; lateral scales 58; head length 0.274% SL; pelvic fin basal length 0.027% SL; anal fin basal  
334 length 0.188% SL; D1 basal length 0.178% SL; D2 basal length 0.174% SL; caudal peduncle height 0.097% SL  
335 (Figure 2, Table 3, Table 4). ~~Although~~ *Periophthalmus malaccensis* ~~also~~ has bright blue spots on the chin and  
336 operculum, it also has prominent transverse folds on the snout (Polgar 2016).

337

8 Reviewer  
Large amounts of rubbish  
Revised as suggested

8 Reviewer  
Muddy  
Revised as suggested

8 Reviewer  
italicize here

The Genus should be written normally (not italicized) based on the Binomial Nomenclature System. It would be italicized if it is written with specific epithet i.e. *Periophthalmus* sp., *Periophthalmus kalelo*, etc.

- 338 c. *Periophthalmus variabilis*  
339 D; XI, D; I, 12; A 11; P 11; V 6; C 14  
340 Eyes without dermal cup; one row of teeth on the maxilla; the pelvic frenum is clear and prominent; the pelvic is  
341 orange at least at the margins; moderate D1 height with rounded margins, Aa single inframarginal brown strip with  
342 many proximal white spots, first The first spine elongated, white margin; D2 with single inframarginal orange stripe  
343 and black single stripe mesial R, with reddish-orange spots at the base; the anal fins are orange, at least at the  
344 margins, AD1 and D2 are not connected by a membrane membrane does not connect D1 and D2; lateral scales 52;  
345 head length 0.264% SL; pelvic fin basal length 0.027% SL; anal fin basal length 0.063% SL; D1 basal length 0.192%  
346 SL; D2 basal length 0.216% SL; caudal peduncle height 0.099% SL (Figure 2, Table 3, Table 4). When alive, the  
347 branchiostegal membrane of the fish shows pigmentation (Setiawan et al. 2019).  
348
- 349 d. *Periophthalmus argenteolineatus*  
350 D; XIII, D; I, 12; A 12; P 12; V 6; C 16  
351 Eyes without dermal cup; one row of teeth on the maxilla; pelvic without frenum; moderate D1 height with straight  
352 margins, single brown strip mesial with numerous proximal white spots, without spinal elongation; D2 with dusky  
353 brown stripe mesial; D1 and D2 are not connected by a membrane; lateral scales 70; head length 0.247% SL; pelvic  
354 fin basal length 0.12% SL; anal fin basal length 0.165% SL; D1 basal length 0.163% SL; D2 basal length 0.201% SL;  
355 caudal peduncle height 0.101% SL (Figure 2, Table 3, Table 4). The total of transverse scale from ventroposterior D2  
356 basal to the basal of the anal fin is 18-26 (Jaafar & Murdy (2017)).  
357
- 358 e. *Periophthalmus haiolo*  
359 D; XI, D; I, 12; A 11; P 11; V 6; C 14  
360 Eyes without dermal cup; one row of teeth on the maxilla; vestigial pelvic frenum; pelvic fins fused about half of the  
361 pelvic fins; moderate D1 height with rounded margins, single Single black stripe inframarginal with proximal white  
362 spots, without spinal elongation; D2 with inframarginal dusky strip; D1 and D2 are not connected by a membrane;  
363 lateral scales 62; head length 0.256% SL; pelvic fin basal length 0.033% SL; anal fin basal length 0.155% SL; D1  
364 basal length 0.172% SL; D2 basal length 0.211% SL; caudal peduncle height % SL (Figure 2, Table 3, Table 4). The  
365 total of transverse scale from ventroposterior D2 basal to the basal of anal fin is fewer than Periophthalmus  
366 argenteolineatus that transverse scale from ventroposterior D2 basal to the basal of anal fin is fewer than  
367 Periophthalmus argenteolineatus, which is only 18-22 (Jaafar & Murdy (2017)).  
368

369 Morphological adaptations of mudskipper fish created variations in morphometric and meristic measurements  
370 (Nugroho et al. 2016; Dinh et al. 2020; Ghanbarifardi et al. 2020). Jaafar & Murdy (2017) added that morphological  
371 characteristics such as the number of dorsal spines, the presence of finger-like projections in the maxillo-dentary ligament  
372 in the lip of the lower jaw and the epaxialis muscle attaching anteriorly of the frontal and epioccipital junction can could  
373 distinguish genera in the family Family. Meristic characters such as the scales before and after the pectoral filaments,  
374 pectoral fins, dorsal fins, abdominal fins, and anal fins are characters that can distinguish species in the genus Genus. In  
375 addition, other factors that influence differences in fish morphology are food availability, environmental conditions, and  
376 the stage of fish maturity. Another characteristic with a high probability of variation is coloration. Fish coloration is  
377 influenced by many factors including genetic, environmental, dietary, and physiological factors (Nüsslein-Volhard and  
378 Singh 2017). Due to the instability of the correlation character, this character istic is mostly neglected when identifying fish  
379 species.

380 The difference in species diversity between the three stations is influenced by environmental condi Environmental  
381 conditions influence the difference in species diversity between the three stations. The high and low species diversity was  
382 influenced by many factors Many factors influence the high and low species diversity, and one of the factors is  
383 environmental quality. Krebs (2014) further explained that species diversity is used to measure the stability of a  
384 community which is the ability of a community to keep itself stable despite disturbances to its components. Maturbongs et  
385 al. (2018) argued that the area or mud substrate is a habitat for various nekton, which indicates the area has abundant food  
386 sources. The existence of habitat variations (substrate), such as physical conditions and the surrounding environment,  
387 affects the diversity of fish species. The diversity index at the research site was 1.09, this indicated that a high level of  
388 diversity level of mudskipper fish in the Coastal Bay of Tomini, Bualemo, was included in the moderate criteria. In  
389 addition, it also showed that water productivity was quite balanced.

390 The comparison of the Evenness index of mudskipper fish in the research locations had the same Evenness index value  
391 of 0.99. This value indicated that the Evenness evenness in the three locations was stable. The Evenness index shows the  
392 degree of Evenness evenness of individual abundance between each species. If each species has the same number of  
393 individuals, then the community has a maximum Evenness value The community has a maximum Evenness value if each

394 species has the same number of individuals. On the other hand, if the Evenness value is small, then the community has  
395 dominant, sub-dominant, and dominated species; eventually, the community has a minimum Evenness. The Evenness  
396 value had a range between 0-1; if the index value obtained was close to one, it means that the distribution is more even  
397 (Ludwig and Reynolds 1988; Baderan et al. 2021). Figure 3 presents the index of Evenness-evenness of the mudskipper  
398 (*Periophthalmus*) species in the Coastal Bay of Tomini, Bualemo, which was included in a stable community. Thus, the  
399 population between species of the genus *Periophthalmus* on the Coastal Bay of Tomini, Bualemo, was fairly even, so that  
400 disturbances did not easily occur and were able to return to their initial conditions.

401 Species richness in the research locations was low with the Specific Richness Index (RI) at each station as follows 0.19  
402 (Station I Dulupi), 0.36 (Station II Bajo), 0.2 (Station III East Pentadu). Species richness refers to the number of species  
403 in a community. The number of species in the field determines the size of the richness index. The Margalef richness index  
404 divides the number of species by the natural logarithm function meaning that the increase in the number of species is  
405 inversely proportional to the increase in the number of individuals. Generally, a community/ecosystem with an abundant  
406 number of abundant species will have a small number of individuals in each of these species.

407 The dominance of species in water often occurs due to several things, including competition for natural food by certain  
408 species accompanied by changes in environmental quality and also an imbalance between predators and prey which are  
409 resulted in imbalance between predators and prey, resulting in competition between species. Manurbongs et al. (2018)  
410 explained that dominance occurs because of the result of the competition process for evicting one individual against  
411 another. Okyere (2018) stated that at low tide, the estuary area is dominated by brackish fish species, one of which is from  
412 the Gobiidae family. This statement is true because mudskipper fish is more active during low tide conditions both on the  
413 coast and at an estuary; on the other hand, mudskipper fish will hide in their nests at high tide to avoid predators. The  
414 dominance index of mudskipper fish was 0.51, which indicated that the level of species dominance in these waters was  
415 moderate; thus, there were no dominant species in these waters.

416 Environmental factors that are very supportive and the absence of predators made several species of mudskipper fish  
417 thrive and spread across the area. In line with research conducted by Mahadevan and Ravi (2015), which stated that the  
418 right water temperature range for mudskipper fish was between 23.5-35.5°C, the measurement results of environmental  
419 parameters showed that the average temperature range was 28-30°C. Furthermore, Bidawi et al. (2017) explained that  
420 mudskipper species had tolerance to wide changes in temperature and salinity, indicating that water temperature is one of  
421 the environmental factors that affect the spread and diversity of mudskipper species.

422 The pH content of the substrate ranged from 6.8 to 8. It means that the water conditions for the life of mudskipper  
423 fish were in the neutral range. The difference in soil pH at the research sites was caused by the contribution of leaf, root,  
424 and stem litter that fell to the ground and decomposed to form soil organic matter (Tajbakhsh et al. 2018). The pH of the  
425 substrate PH greatly affects the resistance of organisms that live at the bottom of the waters, both infauna and epifauna.  
426 That is occurred due to the influence of tidal or brackish water during the formation of this land and subsequent tidal  
427 processes. Furthermore, Kanejiya et al. (2017) explained that the distribution of mudskipper fish was significantly  
428 influenced by environmental factors such as pH, temperature, salinity, and the other ecological conditions (Ghanbarifardi  
429 et al. 2014). Regarding Therefore, regarding to the presence of mudskipper fish with substrate conditions in the mangrove  
430 area at the three stations, added that the presence of mudskipper fish with substrate conditions in the mangrove area at the  
431 three stations, substrate differences play an important role in the distribution of mudskipper fish.

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#### 8 Reviewer italicize here

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Italicise the scientific name

Revised as suggested

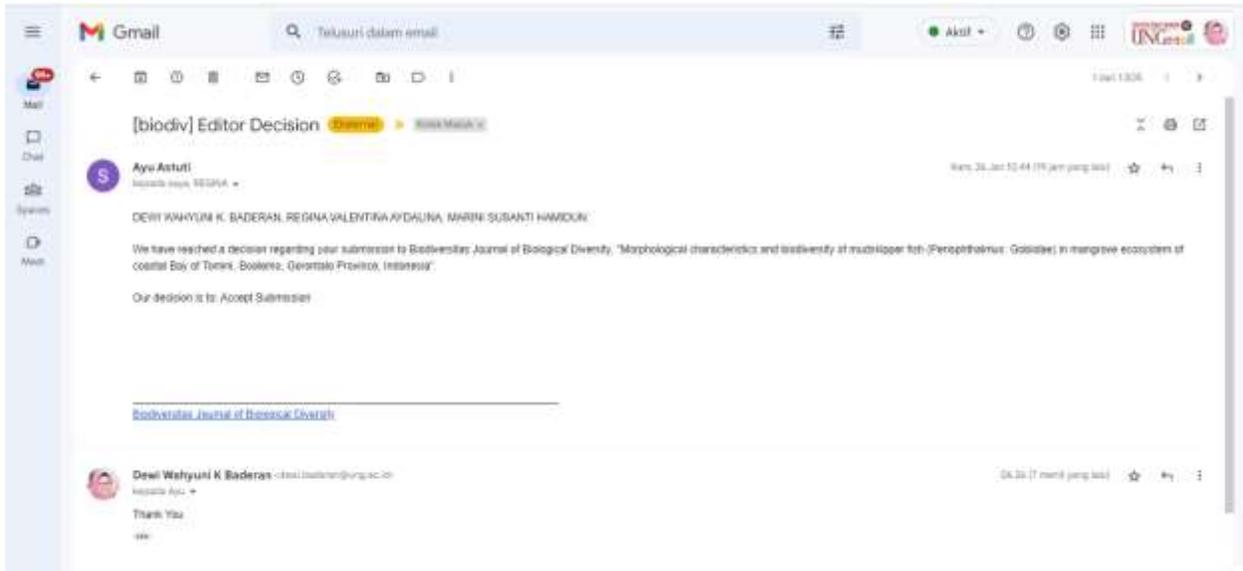
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Revised as suggested

**ACCEPTED**



### Morphological characteristics and biodiversity of mudkipper fish (*Periophthalmus: Gobiidae*) in mangrove ecosystem of coastal Bay of Tomini, Gorontalo Province, Indonesia

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**Abstract.** Baderan DWK, Aydalina RV, Hamidun MS. 2022. Morphological characteristics and biodiversity of mudkipper fish (*Periophthalmus: Gobiidae*) in mangrove ecosystem of coastal Bay of Tomini, Gorontalo Province, Indonesia. *Biodiversitas* 24: xxxix. The southern sea area of Gorontalo Province is part of Tomini Bay, the biggest bay in Indonesia. This area has a unique biodiversity and a Sulawesi endemic. The mangrove forest in the coastal bay of Tomini Boalemo is one of the habitats for flora and fauna, a place for spawning, starting, and food hunting for fish. The mudkipper is a fish that lives in the mangrove area. This study aims to reveal the morphological characteristics and biodiversity of mudkipper (*Periophthalmus: Gobiidae*) in the ecosystem of Tomini Boalemo coastal bay of Gorontalo Province. This study employed a quantitative descriptive that also implemented purposive sampling as the sampling method in three ecosystem stations of Tomini Boalemo coastal bay (Dulapi, Bajo, and East Pansala mangrove). The mudkipper were collected manually when the water was receding until a fish net. The sample which had been collected were then identified based on 22 morphological, 24 morphometric, and seven meristic characteristics. The identification results were then compared with the identification key. The mudkipper species were then analyzed to determine the species' biodiversity (diversity, evenness, species richness, and dominance indices). The research result revealed five species from *Periophthalmus* Genus: *Periophthalmus ornamentalis*, *Periophthalmus laevis*, *Periophthalmus melanurus*, *Periophthalmus melanus*, *Periophthalmus variabilis*, with total individuals 581. The score of  $H'$  = 0.99 showed that the diversity of mudkipper fish was categorized as medium. The evenness index was 0.99 obtained from 3 observation stations, while the lowest dominance index was on station II with a score of 0.34, and the score of  $R_i$  in each station was respectively 0.10, 0.36, and 0.21. The results of this study could be used as a database for the sustainable management of Tomini Bay to tackle the threats of species extinction through aquatic life protection and preservation to arrange the natural balance and support the availability of the coastal resource for future generation.

**Keywords:** biodiversity, morphology, meristic, *Periophthalmus*, Tomini Bay

#### INTRODUCTION

Tomini Bay is the largest bay in Indonesia and is located in the coral triangle initiative. One of the parts of the bay which has rich biodiversity is the mangrove ecosystem which plays an important role in improving coastal sea productivity, spawning area, and nutrient supply needed by various species of fish (Nguyen and Parnel 2017, Lapsala et al. 2019), and potential of biodiversity (Conroy et al. 2021). In addition, Sellang (2008) stated that the mangrove ecosystem is one of the most important and productive environments for fish species in tropical areas and sub-tropical estuaries, which can improve the fertility and productivity of the coastal area. Mudkipper fish (*Periophthalmus: Gobiidae*) is one of the families that live in the mangrove ecosystem, as mentioned by Lataconsua (2016) and Rhaifa et al. (2021) as the local resident of the mangrove ecosystem. One of the Genus that belongs to the Family widely distributed in that ecosystem is *Periophthalmus* (WoRMS 2018; Fishbase 2022). This Genus occupies primary (organisms that obtain energy from producers) and secondary positions (organisms that

obtain energy from primary consumers) in the food chain despite their very small size (Polgar et al. 2017), inhabiting muddy habitats, sandy beaches, and mangrove areas (Mahadevan and Ravi 2015). Mudkipper's daily behavior is closely related to tidal rhythm (Ravi, 2013), where they climb mangrove roots, walk on mudflats, and dig burrows in mud (Ansum et al. 2014; Hai et al. 2019; Hidayat et al. 2022).

The mudkipper fish has various species, yet they have numerous similarities in terms of morphology (Ridha et al. 2019). One of its unique characteristics is spending 90% of its life a day living on land, climbing, and perching on the roots of the mangrove or wood, and being able to crawl up on the land (Mahmoud et al. 2016). Its pectoral fin on its muscular base can be hooked to function like an arm used to crawl, jump above the mud, and attach to rocks and open roots (Huang 2013, Wasiasono et al. 2016). The potential of mudkipper fish as the filter feeder that consumes the organic particles of living creatures suspended in water can absorb Lead (Pb) and has a role as a bio-indicator of environmental pollution (Akmalotami et al. 2012). People can use the mudkipper to fulfill their

food needs because it has a high nutritional value (Akmalotami et al. 2012; Hidayat et al. 2017). *Boleophthalmus boddarti*, one of the mudkipper fish species, has a high value of fat in the liver (554.45±4.49 mg/g), protein (3.51±0.35 mg/100mg), and 1.5 ± 0.47mg/100 mg protein in the muscle (Karejaya et al. 2017). Mudkipper fish also have economic value in several countries in Asia. For instance, mudkipper with beautiful morphological characters can be used as ornamental fish in China, Japan, and Korea. They are generally sold as preserved products in Indonesia, such as dried and smoked fish (Faridah-Hatun et al. 2014). Besides, mudkipper, as the native residents of mangrove habitats, creates a natural view awaited by tourists (Chakrabarti et al. 2020).

One of the areas in Sulawesi Island directly borders Tomini Bay is Boalemo Regency. Boalemo generally has a typical characteristic of a coastal area with relatively high resources, particularly in the mangrove forest and fishery sources, one of which is the mudkipper fish. Therefore, the existence of this fish in the mangrove ecosystem in the Coastal Bay of Tomini Boalemo is pretty abundant. However, it is disregarded as fishermen and people in Boalemo are unaware of the potential of the nutrition contained in the mudkipper fish. Consequently, the existence of the mudkipper fish in the Mangrove Coast Tomini Bay is threatened to be extinct along with the decrease of its population. That extinction aligns with the speed of mangrove forest degradation. The main cause of the degradation is the land conversion in mangrove forests to become fish and shrimp ponds. That is affirmed by Hai et al. (2020), that mangrove is an important component of the coastal ecosystem which is severely and globally threatened by various causing factors. In 1985, the mangrove forest area in Tomini Bay was noted as big as 17,672 hectares, while in 2010, it was degraded to 16,185 hectares, and in 2020, it is predicted to have the remaining area as big as 10,521 hectares (Pinto 2020).

The mudkipper species identified until today are around 43 species in 10 genera (Polgar et al. 2015; Rapp 2021). General information about mudkipper fish has been available, yet the species in Tomini Bay have not been found. Even the people in the coastal Bay of Tomini Boalemo stated that the mudkipper fish is poisonous. People have not yet known the potential use of the mudkipper fish optimally in terms of ecology, economy, and health, so this research is started. This research aims to analyze the morphological characteristics and biodiversity of mudkipper fish as the reliable resident of the mangrove area in Tomini Bay. The findings of this research can be used as support for formulating policies that aim to minimize the mangrove degradation in the coastal bay of Tomini.

#### MATERIALS AND METHODS

##### Study area

This study was carried out in a mangrove ecosystem in the coastal bay of Tomini, Boalemo, Gorontalo Province. It included three observation stations, i.e., station I (Dulapi Village), station II (Bajo Village), and station III (East Pansala Village). The three sampling locations were chosen because they have healthy mangrove forests. This study was conducted for five months, from May to September 2022. This study employed a descriptive quantitative method by implementing a purposive sampling method in three stations of the mangrove ecosystem in the coastal bay of Tomini, Boalemo. The data collected were primary and secondary data. The primary data were collected by identifying all species of the mudkipper fish and some of its morphological, morphometric, and meristic characteristics, as well as its biodiversity (diversity, evenness, and species richness indexes) (Figure 1).



Figure 1. Location of the coastal bay of Tomini, Boalemo, Gorontalo Province indicating the sampling sites of *Periophthalmus*: Station I (N 00°30'40" E 122°26'08"), Station II (N00°29'8" E 122°20'93"), and Station III (N 00°30'35" E 122°22'36")

**Tools and Materials**

The tools used were a scoop net, a 3x3 meters fish net, a cool box, a zip lock, stationary, a digital camera, ruler, millimeter block paper, gloves, jar, GPS, thermometer, pH meter, and an Ohaus digital scale with an accuracy of 0.01 g. The materials used were mudskipper fish, 10% formalin, 70% alcohol, tracing paper, ice, sewing thread, and distilled water.

**Procedures**

The sampling procedures are as follows: (i) Specimen collection using a 3x3 meters net and hand-collecting in 3 locations of the mangrove ecosystems of the coastal area of Tomini bay. (ii) Measurement of physical-chemical factor temperature, substrate, water pH, and substrate pH of the environment was done in every location. (iii) Observations and measurements of physical factors are carried out during the day when the sea recedes. (iv) The specimen was put in a jar, labeled, and then transferred to the laboratory for identification purposes. (v) Specimen documentation was carried out utilizing a Nikon DX VR camera with an AF-S NIKKON 18-55 mm lens and a Macro Pro Tama Digital PRO 0.45X HD WIDE LENS SDW-045 52 mm. (vi) The mudskipper fish samples were observed and measured for morphological, morphometric and meristic characterization in the Biology Laboratory, Faculty of Mathematics and Natural Sciences, and the Agricultural Laboratory, Faculty of Agriculture, Universitas Negeri Gorontalo. This observation and measurement step was referred to (Larson and Mundy 2001, Pojaja et al. 2013, Maryam et al. 2015, Aylalina 2016, Ghazharifani et al. 2018, Kaur et al. 2019, Mahadevan et al. 2019, and Gonzalez-Martinez et al. 2020). Species identification was carried out by referring to (Murdy 1989; Larson and Mundy 2001, Jaafar et al. 2016). Specimen fixation used 70% alcohol and 10% formalin.

**Data analysis**

Morphometric and meristics data were analyzed using the *Microwork Excel* program, and morphological observations were analyzed descriptively.

Data on the diversity of mudskipper species were analyzed using the Diversity Index (H') (Shannon and Wiener 1963; Facheul 2012).  $H' = -\sum_{i=1}^n p_i \ln p_i$  where  $p_i = \frac{n_i}{N}$ . H' represents the Shannon-Wiener Diversity Index, S for total species, Ni for total individuals in a species, N for the natural logarithm, and N for total individuals found. The value of H' determines the level of species diversity in an area, where the definition of the value of species diversity according to Shannon-Wiener is: H' > 3: High species diversity, 1 ≤ H' ≤ 3: Medium species diversity, H' < 1: Low species diversity.

The species-evenness index analyzed species evenness (K) data referred to the Pielou Evenness Indices formula (Ludwig and Reynolds 1988);  $E = H'/\ln S$ . Where E represents Evenness Index, and H' represents Shannon-Wiener Diversity Index. Margalef formula was used as

$$\text{Species Richness Index (Magurran 1988): } R_1 = \frac{(S-1)}{(S/N)^2}$$

where R<sub>1</sub> represents the Richness Index, S for the Number of Species found, and N for the Total Number of Individuals. Dominance data were analyzed using the Simpson formula:  $D = \frac{1}{\sum_{i=1}^S (n_i/N)^2}$ . D represents the

Dominance Index, ni for Number of Individuals belonging to species i, and N Total Number of Individuals. The results of the dominance index were assigned into 0 < D < 0.5, in which no species dominate other species or a stable community structure. While index 0.5 < D < 1, meaning some species dominate other species or a community structure is unstable because of ecological pressures (Odum 1971, Kerho 2014).

**RESULTS AND DISCUSSION**

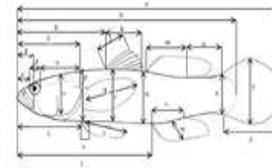
**Result**

**Mudskipper Fish at the Research Site**

The results in Table 1 show that the species of mudskipper fish which were found comprised one Gobiidae Family of the Actinopterygii Class: *Periophthalmus argenteus*, *Periophthalmus kalalo*, *Periophthalmus malaccensis*, *Periophthalmus nemus*, and *Periophthalmus variabilis*. The total number of mudskipper fish found in Tomini Bay, Gorontalo's coastal mangrove area, is as many as 561 individuals. Spreading across station I-Dulupi village (156 individuals), station II-Bajo village (254 individuals), and station III-East Pentadi village (151 individuals). The classification of mudskipper fish in the coastal mangrove ecosystem of Tomini bay, Gorontalo, Gorontalo Province, is presented in Table 1.

**Environment Parameters**

The results range of the temperature measurement at three research locations was around 28 -30°C at station I, 29-30°C at station II and 28 -30°C at station III. The value of water's acidity degree (pH) was in the range of 7.1-8, and the substrate (pH) was in the range of 6.8-8. Based on its visual look, the ecological condition of Station I (Dulupi) of the mangrove area was still considered good-solid, possessing stony and muddy textures of ground habitat with mangroves growing on it. In Station II (Bajo), the mangrove area had been shift-transferred to a settlement area without considering the strong values of mangrove plants. Based on its visual look, the ground texture of the mangrove forest is sandy and muddy. Large rubbish was scattered, and many mangrove saplings died and were broken. In station III (East Pentadi), according to its visual appearance, the ground texture of the mangrove was muddy. However, the mangrove condition was still considered good, and the regeneration of the growing saplings in the area was considered quick and plenty.



**Figure 2.** Morphometric characterization scheme of the mudskipper: (a) total length, (b) standard length, (c) Pre-orbital length, (d) eye diameter, (e) post-orbital length, (f) post-orbital length, (g) mouth length, (h) pre-dorsal length, (i) pre-ventral length, (j) pre-anal length, (k) first dorsal fin base length, (l) height of the longest first dorsal fin, (m) second dorsal fin base length, (n) length of caudal peduncle, (o) head height, (p) front body height, (q) length of the longest spiny pectoral fin, (r) middle body height, (s) middle body height, (t) length of the longest spiny pelvic fin, (u) caudal fin height, (v) anal fin base length, (w) length of the longest spiny anal fin, (x) Caudal peduncle depth, (y) caudal fin height, (z) caudal fin length (Larson & Murdy, 2001; modified by authors).

**Table 1.** The classification of mudskipper fish in the coastal mangrove ecosystem of Tomini bay, Gorontalo Province

Class, Family	Species	Station			Total Number of Individuals
		I Dulupi	II Bajo	III East Pentadi	
<b>Actinopterygii</b>					
Gobiidae	<i>Periophthalmus argenteus</i>	—	—	83	83
	<i>Periophthalmus kalalo</i>	67	—	—	67
	<i>Periophthalmus malaccensis</i>	89	98	—	187
	<i>Periophthalmus nemus</i>	—	75	—	75
	<i>Periophthalmus variabilis</i>	—	81	68	149
Total					561

Description: (+) found, (-) Not found, the number in brackets represents the number of individuals observed. Source: Primary Data, 2022

**The Morphological Characters of Mudskipper Fish**

**Table 2.** Comparison of Morphological Characters of Mudskipper Fish in the coastal mangrove ecosystem of Tomini Bay, Gorontalo Province

Characters	<i>P. nemus</i>	<i>P. malaccensis</i>	<i>P. variabilis</i>	<i>P. argenteus</i>	<i>P. kalalo</i>
Dorsal eye	+	+	+	+	+
One row of teeth on the maxilla	+	+	+	+	+
Pelvic finless	+	+	+	+	+
Pelvic fin wholly fused	-	-	-	-	-
Pelvic fin partly fused	-	+	-	-	+
Pelvic fin is not fused	+	-	-	-	-
High D1	-	+	+	+	+
Medium D1	-	+	+	+	+
Low D1	-	-	-	-	-
Slightly ovalish D1 margin	-	+	+	+	+
Rounded D1 margin	-	+	+	+	+
Straight D1 margin	+	-	-	-	-
White D1 margin	-	+	+	+	+
Single infra-anal brown strip on D1	-	+	+	+	+
Single infra-anal black strip on D1	-	+	+	+	+
Single brown strip mesally on D1	+	+	+	+	+
White spot on postanal on D1	+	+	+	+	+
Reddish orange spot on D1	-	+	+	+	+
Elongated first spine on D1	-	+	+	+	+
Dusky strip mesally on D2	+	+	+	+	+
D1 and D2 connected by a membrane	-	+	+	+	+
Reddish orange patch and caudal fan	-	+	+	+	+

**The Morphometric Characters of Mudkipper Fish**

**Table 3.** Comparison of Morphometric Characters of Mudkipper Fish in the coastal mangrove ecosystem of Tomini Bay, Boalemo, Gorontalo Province

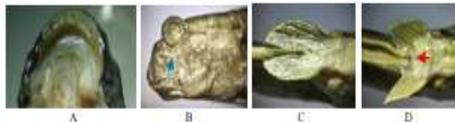
Characters	<i>P. rotundus</i>	<i>P. malaccensis</i>	<i>P. variabilis</i>	<i>P. argenteivittatus</i>	<i>P. kalolo</i>
Pre-orbital length	0.051	0.029	0.035	0.061	0.037
Eye diameter	0.060	0.060	0.060	0.076	0.068
Head length	0.152	0.160	0.137	0.118	0.136
Nostril length	0.271	0.274	0.264	0.247	0.256
Post-orbital length	0.506	0.070	0.054	0.091	0.055
Pre-dorsal length	0.337	0.383	0.368	0.384	0.346
Pre-ventral length	0.270	0.313	0.307	0.256	0.299
Pre-anal length	0.649	0.629	0.632	0.583	0.630
D1 base length	0.214	0.178	0.192	0.163	0.172
D1 longest spine length	0.195	0.237	0.196	0.164	0.233
D2 base length	0.216	0.174	0.216	0.201	0.211
Length of caudal pedunculus	0.172	0.163	0.164	0.175	0.143
Head height	0.157	0.159	0.162	0.187	0.142
Front body height	0.184	0.194	0.194	0.204	0.182
Pectoral fin's longest ray length	0.206	0.170	0.173	0.164	0.145
Middle body height	0.170	0.207	0.173	0.184	0.169
Pelvic fin base length	0.047	0.041	0.063	0.120	0.033
Pelvic fin's longest ray length	0.101	0.116	0.088	0.102	0.103
Caudal base height	0.160	0.165	0.162	0.162	0.142
Anal fin length	0.201	0.188	0.223	0.165	0.155
Anal fin's longest ray length	0.081	0.059	0.056	0.127	0.074
Caudal pedunculus height	0.081	0.097	0.099	0.101	0.082
Caudal fin height	0.144	0.162	0.115	0.145	0.152
Caudal fin length	0.211	0.214	0.208	0.210	0.167

**Meristic Characters of Mudkipper Fish**

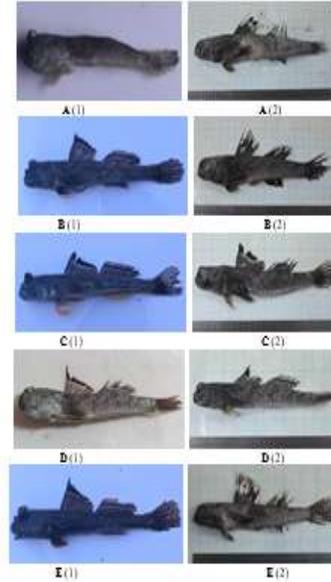
The comparison of meristic characteristics of mudkipper fish which were found in the coastal mangrove ecosystem of Tomini Bay, Boalemo, Gorontalo Province, along with the species' classification, are presented in Table 4 and Figure 2.

**Table 4.** Comparison of Meristic Characters of Mudkipper Fish in the coastal mangrove ecosystem of Tomini Bay, Boalemo, Gorontalo Province

OTU	Number of Spines and Rays												LS
	D1		D2		A		P		V		C		
	S	R	S	R	S	R	S	R	S	R	S	R	
<i>P. rotundus</i>	16	0	1	12	0	11	0	13	0	6	0	13	80
<i>P. malaccensis</i>	11	0	1	12	0	11	0	11	0	6	0	14	58
<i>P. variabilis</i>	14	0	1	12	0	12	0	13	0	6	0	16	52
<i>P. argenteivittatus</i>	13	0	1	12	0	12	0	12	0	6	0	16	70
<i>P. kalolo</i>	11	0	1	12	0	11	0	11	0	6	0	14	62



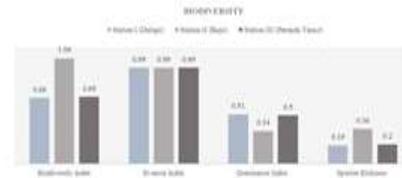
**Figure 3.** The characteristics of mudkipper fish in the coastal area of the mangrove ecosystem in Tomini Bay, Boalemo, Gorontalo Province. A. one-row teeth on maxilla, B. Dental-Cup, C. Pelvic fin without femur, D. Pelvic fin without femur. A red arrow showed the femur.



**Figure 4.** Mudkipper fish in the coastal mangrove ecosystem of Tomini Bay, Boalemo, Gorontalo Province. A. *Periophthalmodon steinitz*, B. *P. malaccensis*, C. *P. variabilis*, D. *P. argenteivittatus*, E. *P. kalolo*. Figure 2 is a photo of a specimen that had been preserved under a -50°C temperature for one month.

**Biodiversity of Mudkipper Fish Species**

The data of mudkipper fish at three locations showed moderate diversity with a value of  $H' = 1.09$ . The Evenness index was 0.99 based on three observation stations. The lowest dominance value was at station II with a value of 0.34 (Figure 5).



**Figure 5.** Biodiversity (Biodiversity) index, Evenness Index, Dominance Index, and Species Richness of mudkipper fish in the research site

### Discussion

Five species of mudkipper fish could be found in the coastal mangrove ecosystem of Tomini Bay, Bualemo, Gorontalo Province, in which all of the species were part of Genus *Periophthalmus*. It implied that mudkipper fish spread all over the tropical and subtropical habitat, except in the western tropical Atlantic and eastern tropical Pacific (Springer 1982; Jaafar and Mundy 2017). *Periophthalmus* tends to stay in mangrove ecosystems. That is due to the existence of many detritus, small crabs, small fish, shrimps, and arthropods in mangroves which are food for *Periophthalmus* (Rha'ifa et al. 2021). Thus, the result of this study was in line with previous studies conducted in the coastal ecosystems around Indo-Pacific (Pomanyah et al. 2019). Such as Malaka (Ramahatu et al. 2020; Taminel et al. 2020), South Sumatera (Ridho et al. 2019), West Nusa Tenggara (Rha'ifa et al. 2021), Yogyakarta (Arisyanti et al. 2018), North Sulawesi (Poljar et al. 2017), Java and Bali (Dahuddin et al. 2017), Malacca Strait and Malay Peninsula (Poljar et al. 2014). Researchers found all species possessed high similarity in morphological features because they are part of the same Genus (Table 2).

#### *Periophthalmus retusus*

D<sub>3</sub> XVI, D<sub>2</sub> I, 12; A 11; P 13; V 6; C 13

Eyes without dermal cap; one row of teeth on the maxilla; pelvic fin without frenum; moderate D1 height with straight margins, single brown strip mesial with numerous proximal white spots, without spinal elongation; D2 with dusky brown stripe mesially; D1 and D2 are not connected by a membrane; lateral scales 60; head length 0.273% SL; pelvic fin basal length 0.047% SL; anal fin basal length 0.201% SL; D1 basal length 0.214% SL; D2 basal length 0.216% SL; caudal peduncle height 0.081% SL (Figure 2, Table 3, Table 4). In some conditions, the

frenum can be seen through magnification (Jaafar & Mundy 2017).

#### *Periophthalmus malaccensis*

D<sub>3</sub> XI, D<sub>2</sub> I, 12; A 11; P 11; V 6; C 14

Eyes without dermal cap; one row of teeth on the maxilla; the pelvic fin is clear and prominent; moderate D1 height with slightly rounded margins, a single inframarginal brown strip with numerous proximal white spots. First spine elongated; D2 with faded brown stripe mesial; a membrane does not connect D1 and D2; lateral scales 58; head length 0.274% SL; pelvic fin basal length 0.027% SL; anal fin basal length 0.188% SL; D1 basal length 0.178% SL; D2 basal length 0.174% SL; caudal peduncle height 0.097% SL (Figure 2, Table 3, Table 4). Although *Periophthalmus malaccensis* has bright blue spots on the chin and operculum, it also has prominent transverse folds on the snout (Poljar 2016).

#### *Periophthalmus variabilis*

D<sub>3</sub> XI, D<sub>2</sub> I, 12; A 11; P 11; V 6; C 14

Eyes without dermal cap; one row of teeth on the maxilla; the pelvic fin is clear and prominent; the pelvic fin is orange at least at the margins; moderate D1 height with rounded margins. A single inframarginal brown strip with many proximal white spots. The first spine elongated, white margin; D2 with single inframarginal orange stripe and black single stripe mesial. Reddish-orange spots at the base; the anal fins are orange, at least at the margins. A membrane does not connect D1 and D2; lateral scales 52; head length 0.264% SL; pelvic fin basal length 0.027% SL; anal fin basal length 0.063% SL; D1 basal length 0.192% SL; D2 basal length 0.216% SL; caudal peduncle height 0.099% SL (Figure 2, Table 3, Table 4). When alive, the branchiostegal membrane of the fish shows pigmentation (Setiawan et al. 2019).

Table 5. Physics and chemical parameters of the water study area

Environment Parameters	Coastal Mangrove Area of Tomini Bay, Bualemo		
	Station I Dulupi	Station II Bajo	Station III East Pentadu
Temperature (°C)	28.30	29.30	28.30
Substrate	Sand and mud	Sand and mud	Mud
Water pH	7.1-8	7.3-8	7.3-8
Salinity (ppt)	7.5-8	6.8-7	6.8-7.5

#### *Periophthalmus argenteolatus*

D<sub>3</sub> XIII, D<sub>2</sub> I, 12; A 12; P 12; V 6; C 16

Eyes without dermal cap; one row of teeth on the maxilla; pelvic without frenum; moderate D1 height with straight margins, single brown strip mesial with numerous proximal white spots, without spinal elongation; D2 with dusky brown stripe mesial; D1 and D2 are not connected by a membrane; lateral scales 70; head length 0.247% SL; pelvic fin basal length 0.12% SL; anal fin basal length 0.165% SL; D1 basal length 0.163% SL; D2 basal length

0.201% SL; caudal peduncle height 0.101% SL (Figure 2, Table 3, Table 4). The total transverse scale from ventroposterior D2 basal to the basal of the anal fin is 18-26 (Jaafar & Mundy 2017).

#### *Periophthalmus kalisio*

D<sub>3</sub> XI, D<sub>2</sub> I, 12; A 11; P 11; V 6; C 14

Eyes without dermal cap; one row of teeth on the maxilla; vestigial pelvic frenum; pelvic fins fused about half of the pelvic fin; moderate D1 height with rounded

margins. Single black stripe inframarginal with proximal white spots, without spinal elongation; D2 with inframarginal dusky stripe; D1 and D2 are not connected by a membrane; lateral scales 62; head length 0.256% SL; pelvic fin basal length 0.033% SL; anal fin basal length 0.155% SL; D1 basal length 0.172% SL; D2 basal length 0.211% SL; caudal peduncle height % SL (Figure 2, Table 3, Table 4). The total transverse scale from ventroposterior D2 basal to the basal of anal fin is fewer than *Periophthalmus argenteolatus*, which is only 18-22 (Jaafar & Mundy 2017).

Morphological adaptations of mudkipper fish created variations in morphometric and meristic measurements (Nugroho et al. 2018; Diah et al. 2020; Ghaubanfandi et al. 2020). Jaafar & Mundy (2017) added that morphological characteristics such as the number of dorsal spines, the presence of finger-like projections in the maxillostomatary ligament in the lip of the lower jaw and the epaxialis muscle attaching anteriorly of the frontal and epoccipital junction could distinguish genera in the Family. Meristic characters such as the scales before and after the pectoral filaments, pectoral fins, dorsal fins, abdominal fins, and anal fins are characters that can distinguish species in the Genus. In addition, other factors that influence differences in fish morphology are food availability, environmental conditions, and the stage of fish maturity. Another characteristic with a high probability of variation is coloration. Fish coloration is influenced by genetic, environmental, dietary, and physiological factors (Nüsslein-Volhard and Singh 2017). Due to the instability of the correlation character, this characteristic is mostly neglected when identifying fish species.

Environmental conditions influence the difference in species diversity between the three stations. Many factors influence the high and low species diversity, and one of the factors is environmental quality. Krebs (2014) further explained that species diversity is used to measure the stability of a community which is the ability of a community to keep itself stable despite disturbances to its components. Matarbongs et al. (2018) argued that the area or mud substrate is a habitat for various nekton, which indicates the area has abundant food sources. The existence of habitat variations (substrate), such as physical conditions and the surrounding environment, affects the diversity of fish species. The diversity index at the research site was 1.09; this indicated that a high diversity level of mudkipper fish in the Coastal Bay of Tomini, Bualemo, was included in the moderate criteria. In addition, it also showed that water productivity was quite balanced.

The comparison of the Evenness index of mudkipper fish in the research locations had the same Evenness index value of 0.99. This value indicated that the evenness in the three locations was stable. The Evenness index shows the degree of evenness of individual abundance between each species. The community has a maximum Evenness value if each species has the same number of individuals. On the other hand, if the Evenness value is small, then the community has dominant, sub-dominant, and dominated species; eventually, the community has a minimum Evenness. The Evenness value had a range between 0-1; if

the index value obtained was close to one, the distribution is more even (Ludwig and Reynolds 1988; Baderan et al. 2021). Figure 3 presents the index of evenness of the mudkipper (*Periophthalmus*) species in the Coastal Bay of Tomini, Bualemo, which was included in a stable community. Thus, the population between species of the genus *Periophthalmus* on the Coastal Bay of Tomini, Bualemo, was fairly even so that disturbances did not easily occur and were able to return to their initial conditions.

Species richness in the research locations was low with the Specific Richness Index (R1) at each station as follows (Station I Dulupi), 0.36 (Station II Bajo), 0.2 (Station III East Pentadu). Species richness refers to the number of species in a community. The number of species in the field determines the size of the richness index. The Margalef richness index divides the number of species by the natural logarithm function meaning that the increase in the number of species is inversely proportional to the increase in the number of individuals. Generally, a community ecosystem with abundant species will have a small number of individuals in each of these species.

The dominance of species in water often occurs due to several things, including competition for natural food by certain species accompanied by changes in environmental quality and an imbalance between predators and prey, resulting in competition between species. Matarbongs et al. (2018) explained that dominance occurs because of the result of the competition process for evicting one individual against another. Okyere (2018) stated that at low tide, the estuary area is dominated by brackish fish species, one of which is from the Gobiidae family. This statement is true because mudkipper fish is more active during low tide conditions both on the coast and at an estuary; on the other hand, mudkipper fish will hide in their nests at high tide to avoid predators. The dominance index of mudkipper fish was 0.51, which indicated that the level of species dominance in these waters was moderate; thus, there were no dominant species in these waters.

Environmental factors that are very supportive and the absence of predators made several species of mudkipper fish thrive and spread across the area. In line with research by Mahadevan and Ravi (2015), which stated that the right water temperature range for mudkipper fish was between 23.5-35.5°C, the measurement results of environmental parameters showed that the average temperature range was 28-30°C. Furthermore, Bidowi et al. (2017) explained that mudkipper species had tolerance to wide changes in temperature and salinity, indicating that water temperature is one of the environmental factors that affect the spread and diversity of mudkipper species.

The pH content of the substrate ranged from 6.8 to 8. It means that the water conditions for the life of mudkipper fish were in the neutral range. The difference in soil pH at the research sites was caused by the contribution of leaf, root, and stem litter that fell to the ground and decomposed to form soil organic matter (Tajbakhsh et al. 2018). The substrate pH greatly affects the resistance of organisms that live at the bottom of the waters, both in fauna and epifauna. That occurred due to the influence of tidal or brackish

water during the formation of land and subsequent tidal processes. Furthermore, Kamejima et al. (2017) explained that the distribution of mudskipper fish was significantly influenced by environmental factors such as pH, temperature, salinity, and other ecological conditions (Ghanbarifardi et al. 2014). Therefore, regarding the presence of mudskipper fish with substrate conditions in the mangrove area at the three stations, substrate differences play an important role in the distribution of mudskipper fish.

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**PUBLISH**

## Morphological characteristics and biodiversity of mudskipper fish (*Periophthalmus*: Gobiidae) in mangrove ecosystem of coastal Bay of Tomini, Boalemo, Gorontalo Province, Indonesia

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**Abstract.** Baderan DWK, Aydalina RV, Hamidun MS. 2023. Morphological characteristics and biodiversity of mudskipper fish (*Periophthalmus*: Gobiidae) in mangrove ecosystem of coastal Bay of Tomini, Gorontalo Province, Indonesia. *Biodiversitas* 24: 498-507. The southern sea area of Gorontalo Province is part of Tomini bay, the biggest bay in Indonesia. This area has a unique biodiversity and is Sulawesi endemic. The mangrove forest in the coastal bay of Tomini Boalemo is one of the habitats for flora and fauna, a place for spawning, nurturing, and food hunting for fish. The mudskipper is a fish that lives in the mangrove area. This study aims to reveal the morphological characteristics and biodiversity of mudskipper (*Periophthalmus*: Gobiidae) in the ecosystem of Tomini Boalemo coastal bay of Gorontalo Province. This study employed a quantitative descriptive that also implemented purposive sampling as the sampling method in three ecosystem stations of Tomini Boalemo coastal bay (Dulupi, Bajo, and East Pentadu mangrove). The mudskippers were collected manually when the water was receding using a fish net. The sample which had been collected were then identified based on 22 morphological, 24 morphometric, and seven meristic characteristics. The identification results were then compared with the identification key. The mudskippers' species were then analyzed to determine the species' biodiversity (diversity, evenness, species richness, and dominance indexes). The research result revealed five species from *Periophthalmus* Genus: *Periophthalmus argentifimatus*, *Periophthalmus kalulu*, *Periophthalmus malaccensis*, *Periophthalmus minutus*, *Periophthalmus variabilis*, with total individuals 561. The score of  $H'$ : 1.09 showed that the diversity of mudskipper fish was categorized as medium. The evenness index was 0.99 obtained from 3 observation stations, while the lowest dominance index was on station II with a score of 0.34, and the score of  $R_i$  in each station was respectively (0.19), (0.36), and (0.3). The results of this study could be used as a database for the sustainable management of Tomini Bay to tackle the threats of species extinction through aquatic life protection and preservation to arrange the natural balance and support the availability of the coastal resource for future generations.

**Keywords:** Biodiversity, meristics, morphology, *Periophthalmus*, Tomini Bay

### INTRODUCTION

Tomini Bay is the largest bay in Indonesia and is located in the coral triangle initiative. One of the parts of the bay which has rich biodiversity is the mangrove ecosystem which plays an important role in improving coastal sea productivity, spawning area, and nutrient supply needed by various species of fish (Nguyen and Parnel 2017; Lapolo et al. 2018), and potential of biodiversity (Cooray et al. 2021). In addition, Sellang (2020) stated that the mangrove ecosystem is one of the most important and productive environments for fish species in tropical areas and sub-tropical estuaries, which can improve the fertility and productivity of the coastal area. Mudskipper fish (Perciformes: Gobiidae) is one of the families that live in the mangrove ecosystem, as mentioned by Lataconsina (2016) and Rha'ifa et al. (2021) as the local resident of the mangrove ecosystem. One of the Genera that belongs to the Family widely distributed in that ecosystem is *Periophthalmus* (WoRMS 2018; Fishbase 2022). This Genus occupies primary (organisms that obtain energy from producers) and secondary positions (organisms that obtain energy from

primary consumers) in the food chain despite their very small size (Polgar et al. 2017), inhabiting muddy habitats, sandy beaches, and mangrove areas (Mahadewa and Rani 2015). Mudskippers' daily behavior is closely related to tidal rhythm (Rani 2013), where they climb mangrove roots, walk on mudflats, and dig burrows in mud (Ansari et al. 2014; Hui et al. 2019; Hidayat et al. 2022).

The mudskipper fish has various species, yet they have numerous similarities in terms of morphology (Ridho et al. 2019). One of its unique characteristics is spending 90% of its life a day living on land, climbing, and perching on the roots of the mangrove or wood, and being able to crawl up on the land (Mukharomah et al. 2016). Its pectoral fin on its muscular base can be buckled to function like an arm used to crawl, jump above the mud, and attach to rocks and open roots (Huang 2013; Wicaksono et al. 2016). The potential of mudskipper fish as the filter feeder that consumes the organic particles of living creatures suspended in water can absorb Lead (Pb) and has a role as a bio-indicator of environmental pollution (Akinrotimi et al. 2012). People can use the mudskipper to fulfill their food needs because it has a high nutritional value (Akinrotimi et al. 2012; Bidawi et al.

2017). *Boleophthalmus boddarti*, one of the mudskipper fish species, has a high value of fat in the liver ( $554.45 \pm 4.49$  mg/g), protein ( $3.5 \pm 0.35$  mg/100mg), and  $1.5 \pm 0.47$  mg/100 mg protein in the muscle (Kanejiya et al. 2017). Mudskipper fish also have economic value in several countries in Asia. For instance, mudskipper with beautiful morphological characters can be used as ornamental fish in China, Japan, and Korea. They are generally sold as preserved products in Indonesia, such as dried and smoked fish (Faridah-Hanum et al. 2014). Besides, mudskipper, as the native residents of mangrove habitats, creates a natural view awaited by tourists (Chakraborty et al. 2020).

One of the areas in Sulawesi Island directly borders Tomini Bay is Boalemo Regency. Boalemo generally has a typical characteristic of a coastal area with relatively high resources, particularly in the mangrove forest and fishery sources, one of which is the mudskipper fish. Therefore, the existence of this fish in the mangrove ecosystem in the Coastal Bay of Tomini Boalemo is pretty abundant. However, it is disregarded as fishermen and people in Boalemo are unaware of the potential of the nutrition consisted in the mudskipper fish. Consequently, the existence of the mudskipper fish in the Mangrove Coast Tomini Bay is threatened to be extinct along with the decrease of its population. That extinction aligns with the speed of mangrove forest degradation. The main cause of the degradation is the land conversion in mangrove forests to become fish and shrimp ponds. That is affirmed by Hai et al. (2020), that mangrove is an important component of the coastal ecosystem which is severely and globally threatened by various causing factors. In 1988, the mangrove forest area in Tomini Bay was noted as big as 17,672 hectares, while in 2010, it was degraded to 16,105 hectares, and in 2020, it is predicted to have the remaining area as big as 10,321 hectares (Primo 2020).

The mudskipper species identified until today are around 43 species in 10 genera (Polgar et al. 2013; Rupp 2021). General information about mudskipper fish has been available, yet its species in Tomini Bay have not been found. Even the people in the coastal Bay of Tomini Boalemo stated that the mudskipper fish is poisonous. People have not yet known the potential use of the mudskipper fish optimally in terms of ecology, economy, and health, so this research is urgent. This research aims to analyze the morphological characteristics and biodiversity of mudskipper fish as the reliable resident of the mangrove area in Tomini Bay. The findings of this research can be used as support for formulating policies that aim to minimize the mangrove degradation in the coastal bay of Tomini.

## MATERIALS AND METHODS

### Study area

This study was carried out in a mangrove ecosystem in the coastal bay of Tomini, Boalemo, Gorontalo Province. It included three observation stations, i.e., station I (Dulupi Village, N  $00^{\circ}30.640$ , E  $122^{\circ}26.982$ ), station II (Bajo Village, N  $00^{\circ}29.818$ , E  $122^{\circ}20.931$ ), and station III (East Penanah Village, N  $00^{\circ}30.736$ , E  $122^{\circ}22.336$ ). The three sampling locations were chosen because they have healthy mangrove forests. This study was conducted for five months, from May to September 2022. This study employed a descriptive quantitative method by implementing a purposive sampling method in three stations of the mangrove ecosystem in the coastal bay of Tomini, Boalemo. The data collected were primary and secondary data. The primary data were collected by identifying all species of the mudskipper fish and some of its morphological, morphometrical, and meristic characteristics, as well as its biodiversity (diversity, evenness, and species richness indexes) (Figure 1).

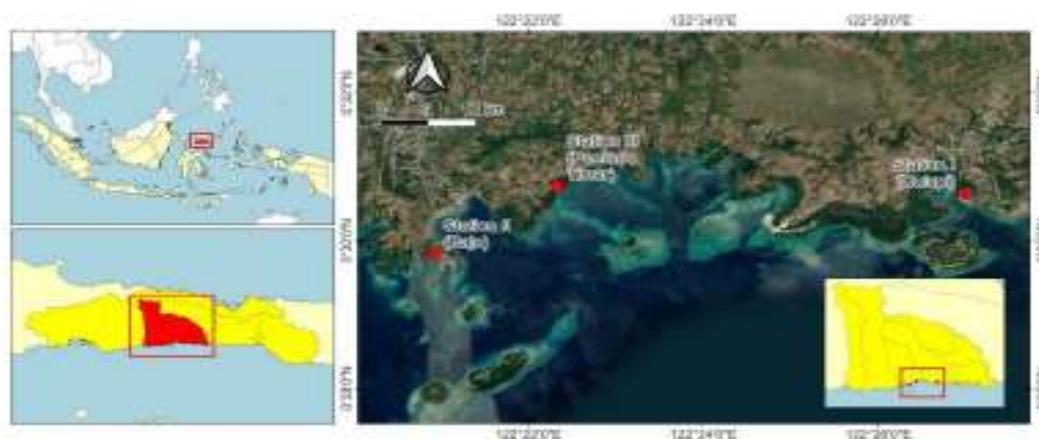


Figure 1. Location of the coastal bay of Tomini, Boalemo, Gorontalo Province, Indonesia, indicating the sampling sites of *Periophthalmus*, i.e.: station I (Dulupi Village), station II (Bajo Village), and station III (East Penanah Village)

### Tools and materials

The tools used were a scoop net, a 3x3 sq. meters fish net, a cool box, a zip lock, stationary, a digital camera, ruler, millimeter block paper, gloves, jar, GPS, thermometer, pH meter, and an Ohaus digital scale with an accuracy of 0.01 g. The materials used were mudskipper fish, 10% formalin, 70% alcohol, tracing paper, ice, sewing thread, and distilled water.

### Procedures

The sampling procedures are as follows: (i) Specimen collection using a 3x3 meters net and hand-collecting in 3 locations of the mangrove ecosystem of the coastal area of Tomini bay; (ii) Measurement of physical-chemical factor temperature, substrate, water pH, and substrate pH of the environment was done in every location; (iii) Observations and measurements of physical factors are carried out during the day when the sea recedes; (iv) The specimen was put in a jar, labeled, and then transferred to the laboratory for identification purposes; (v) Specimen documentation was carried out utilizing a Nikon DX VR camera with an AF-S NIKKON 18-55 mm lens and a Macro Pro Tama Digital PRO 0.45X HD WIDE LENS SDW-045 52 mm; (vi) The mudskipper fish samples were observed and measured for morphological, morphometric and meristic characterization in the Biology Laboratory, Faculty of Mathematics and Natural Sciences, and the Agricultural Laboratory, Faculty of Agriculture, Universitas Negeri Gorontalo. This observation and measurement step was referred to (Larson and Murdy 2001; Polgar et al. 2013; Maryam et al. 2015; Aydalina 2016; Ghanbarifardi et al. 2018; Kaur et al. 2019; Mahadevan et al. 2019; Gonzalez-Martinez et al. 2020). Species identification was carried out by referring to (Murdy 1989; Larson and Murdy 2001; Jaafar et al. 2016) (Figure 2). Specimen fixation used 70% alcohol and 10% formalin.

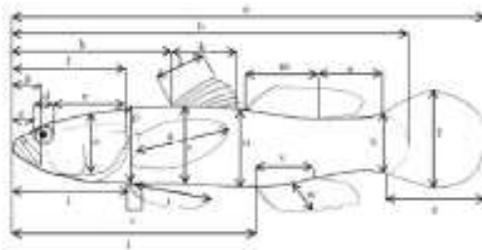


Figure 2. Morphometric characterization scheme of the mudskipper: a. total length; b. standard length; c. Pre-orbital length; d. eye diameter; e. post-orbital length; f. post-orbital length; g. mouth length; h. pre-dorsal length; i. pre-ventral length; j. pre-anal length; k. First dorsal fin base length; l. height of the longest first spiny dorsal fin; m. second dorsal fin base length; n. length of caudal peduncle; o. head height; p. front body height; q. length of the longest spiny pectoral fin; r. middle body height; s. middle body height; t. length of the longest spiny pelvic fin; u. caudal fin height; v. anal fin base length; w. length of the longest spiny anal fin; x. Caudal peduncle depth; y. caudal fin height; z. caudal fin length (Larson and Murdy 2001; modified by authors)

### Data analysis

Morphometric and meristics data were analyzed using the Microsoft Excel program, and morphological observations were analyzed descriptively.

Data on the diversity of mudskipper species were analyzed using the Diversity Index ( $H'$ ) (Shannon and Wiener 1963; Fachrul 2012).  $H' = -\sum_{i=1}^S p_i \ln p_i$  where  $p_i = \frac{N_i}{N}$ .  $H'$  represents the Shannon-Wiener Diversity index, S for total species,  $N_i$  for total individuals in a species, ln for the natural logarithm, and N for total individuals found. The value of  $H'$  determines the level of species diversity in an area, where the definition of the value of species diversity according to Shannon-Wiener is:  $H' > 3$ : High species diversity;  $1 \leq H' \leq 3$ : Medium species diversity;  $H' < 1$ : Low species diversity.

The species-evenness index analyzed species evenness (K) data referred to the Pielou Evenness Indices formula (Ludwig and Reynolds 1988);  $E = H'/\ln S$ . Where, E represents Evenness Index, and  $H'$  represents Shannon-Wiener Diversity Index. Margalef formula was used as Species Richness Index (Magurran 1988):  $R_1 = \frac{(S-1)}{\ln(N)}$ , which  $R_1$  represents the Richness Index, S for the Number of Species found, and N for the Total Number of Individuals. Dominance data were analyzed using the Simpson formula:  $D = \frac{1}{\sum \frac{(n_i(n_i-1))}{(N(N-1))}}$  D represents the Dominance Index,  $n_i$  for Number of Individuals belonging to species  $i$ , and N Total Number of Individuals. The results of the dominance index were grouped into  $0 < D < 0.5$ , in which no species dominate other species or a stable community structure. While index  $0.5 < D < 1$ , meaning some species dominate other species or a community structure is unstable because of ecological pressures (Odum 1971; Krebs 2014).

## RESULTS AND DISCUSSION

### Mudskipper fish at the research site

The species of mudskipper fish which were found comprised one Gobiidae Family of the Actinopterygii Class: *Periophthalmus argentilineatus*, *Periophthalmus kalolo*, *Periophthalmus malaccensis*, *Periophthalmus minutus*, and *Periophthalmus variabilis*. The total number of mudskipper fish found in Tomini Bay coastal mangrove area, is as many as 561 individuals. Spreading across station I at Dukupi village (156 individuals), station II at Bajo village (254 individuals), and station III at East Pentadu village (151 individuals). The classification of mudskipper fish in the coastal mangrove ecosystem of Tomini bay, Boalemo, Gorontalo Province, is presented in Table 1. Morphological appearance of each species can be seen in Figures 3 and 4.

The data of mudskipper fish at three locations showed moderate diversity with a value of  $H'$ : 1.09. The Evenness index was 0.99 based on three observation stations. The lowest dominance value was at station II with a value of 0.34 (Figure 5).

#### The morphological, morphometric and meristic characters of mudskipper fish

Table 2 shows the comparison of morphological characters of mudskipper fish in the coastal mangrove ecosystem of Tomini Bay, Indonesia. Table 3 shows the comparison of morphometric characters of mudskipper fish in the coastal mangrove ecosystem of Tomini Bay, Indonesia. The comparison of meristic characteristics of mudskipper fish which were found in the coastal mangrove ecosystem of Tomini Bay, Indonesia, along with the species' classification, are presented in Table 4 and Figures 3-4.

#### Environment parameters

Table 5 shows the range of temperature measurement at three research locations was around 28-30°C at station I (Dulupi), 29-30°C at station II (Bajo) and 28-30°C at station III (East Pentadu). The value of water's acidity degree (pH)

was in the range of 7.1-8, and the substrate (pH) was in the range of 6.8-8. Based on its visual look, the ecological condition of Station I (Dulupi) of the mangrove area was still considered good-solid, possessing sandy and muddy textures of ground habitat with mangroves growing on it. In Station II (Bajo), the mangrove area had been shift-transferred to a settlement area without considering the strong values of mangrove plants. Based on its visual look, the ground texture of the mangrove forest is sandy and muddy. Large rubbish was scattered, and many mangrove saplings died and were broken. In station III (East Pentadu), according to its visual appearance, the ground texture of the mangrove was muddy. However, the mangrove condition was still considered good, and the regeneration of the growing saplings in the area was considered quick and plenty.

Table 1. The classification of mudskipper fish in the coastal mangrove ecosystem of Tomini bay, Boalemo, Gorontalo Province, Indonesia

Class, Family	Species	Station			Total number of individuals
		I Dulupi	II Bajo	III East Pentadu	
Actinopterygii					
Gobiidae	<i>Periophthalmus argentilineatus</i>	-	-	83	83
	<i>Periophthalmus kalolo</i>	67	-	-	67
	<i>Periophthalmus malaccensis</i>	89	98	-	187
	<i>Periophthalmus minutus</i>	-	75	-	75
	<i>Periophthalmus variabilis</i>	-	81	68	149
Total					561

Note: (✓) found; (-) Not found; the number in brackets represents the number of individuals observed

Table 2. Comparison of morphological characters of mudskipper fish in the coastal mangrove ecosystem of Tomini Bay, Boalemo, Gorontalo Province, Indonesia

Character	Mudskipper fish				
	<i>P. minutus</i>	<i>P. malaccensis</i>	<i>P. variabilis</i>	<i>P. argentilineatus</i>	<i>P. kalolo</i>
Dermal cup	-	-	-	-	-
One row of teeth on the maxilla	+	+	+	+	+
Pelvic frenum	-	+	-	-	+
Pelvic fin wholly fused	-	-	-	-	-
Pelvic fin partly fused	-	+	+	-	+
Pelvic fin is not fused	+	-	-	+	-
High D1	-	-	-	-	-
Medium D1	+	+	+	+	+
Low D1	-	-	-	-	-
Slightly rounded D1 margin	-	+	-	-	-
Rounded D1 margin	-	-	+	-	+
Straight D1 margin	+	-	-	+	-
White D1 margin	-	-	+	-	+
Single inframarginal brown strip on D1	-	+	+	-	-
Single inframarginal black strip on D1	-	-	-	-	+
Single brown strip medially on D1	+	-	-	+	-
White spot on proximal on D1	+	+	-	+	+
Reddish orange spot on D1	-	-	+	-	-
Elongated first spine on D1	-	+	+	-	-
Dusky strip medially on D2	+	+	-	+	+
D1 and D2 connected by a membrane	-	-	-	-	-
Reddish orange pelvic and caudal fins	-	-	+	-	-

Table 3. Comparison of morphometric characters of mudkipper fish in the coastal mangrove ecosystem of Tomini Bay, Boalemo, Gorontalo Province, Indonesia

Characters (cm)	Mudkipper fish				
	<i>P. minutus</i>	<i>P. malaccensis</i>	<i>P. variabilis</i>	<i>P. argentilineatus</i>	<i>P. kalolo</i>
Pre-orbital length	0.051	0.029	0.035	0.061	0.037
Eye diameter	0.060	0.060	0.060	0.076	0.068
Head length	0.152	0.160	0.137	0.118	0.136
Snout length	0.273	0.274	0.264	0.247	0.256
Post-orbital length	0.506	0.070	0.054	0.091	0.055
Pre-dorsal length	0.337	0.383	0.368	0.384	0.346
Pre-ventral length	0.279	0.313	0.307	0.256	0.299
Pre-anal length	0.649	0.629	0.632	0.583	0.630
D1 base length	0.214	0.178	0.192	0.163	0.172
D1 longest spine length	0.195	0.237	0.196	0.164	0.233
D2 base length	0.216	0.174	0.216	0.201	0.211
Length of caudal pedunculus	0.172	0.163	0.164	0.175	0.143
Head height	0.157	0.159	0.162	0.187	0.142
Front body height	0.184	0.194	0.194	0.204	0.182
Pectoral fin's longest ray length	0.206	0.179	0.173	0.164	0.145
Middle body height	0.170	0.207	0.173	0.184	0.169
Pelvic fin base length	0.047	0.041	0.063	0.120	0.033
Pelvic fin's longest ray length	0.101	0.116	0.088	0.102	0.103
Caudal base height	0.160	0.165	0.162	0.162	0.142
Anal fin length	0.201	0.188	0.223	0.165	0.155
Anal fin's longest ray length	0.081	0.059	0.056	0.127	0.074
Caudal pedunculus height	0.081	0.097	0.099	0.101	0.082
Caudal fin height	0.144	0.162	0.115	0.145	0.152
Caudal fin length	0.213	0.234	0.208	0.219	0.167

Table 4. Comparison of meristic characters of mudkipper fish in the coastal mangrove ecosystem of Tomini Bay, Boalemo, Gorontalo Province

OTU	Number of spines and rays												LS
	D1		D2		A		P		V		C		
	S	R	S	R	S	R	S	R	S	R	S	R	
<i>Periophthalmus minutus</i>	16	0	1	12	0	11	0	13	0	6	0	13	60
<i>Periophthalmus malaccensis</i>	11	0	1	12	0	11	0	11	0	6	0	14	58
<i>Periophthalmus variabilis</i>	14	0	1	12	0	12	0	13	0	6	0	16	52
<i>Periophthalmus argentilineatus</i>	13	0	1	12	0	12	0	12	0	6	0	16	70
<i>Periophthalmus kalolo</i>	11	0	1	12	0	11	0	11	0	6	0	14	62

Table 5. Physics and chemical parameters of the waters study area

Environment parameters	Coastal mangrove area of Tomini Bay, Boalemo		
	Station I (Duhupi)	Station II (Bajo)	Station III (East Pentadu)
Temperature (°C)	28-30	29-30	28-30
Substrate	Sand and mud	Sand and mud	Mud
Water pH	7.1-8	7.3-8	7.3-8
Substrate pH	7.5-8	6.8-7	6.8-7.5



Figure 3. The characteristics of mudkipper fish in the coastal area of the mangrove ecosystem in Tomini Bay, Boalemo, Gorontalo Province, Indonesia: A. one-row teeth on maxilla; B. Dermal-Cup; C. Pelvic fin without fraxum; D. Pelvic fin without fraxum. A red arrow showed the fraxum

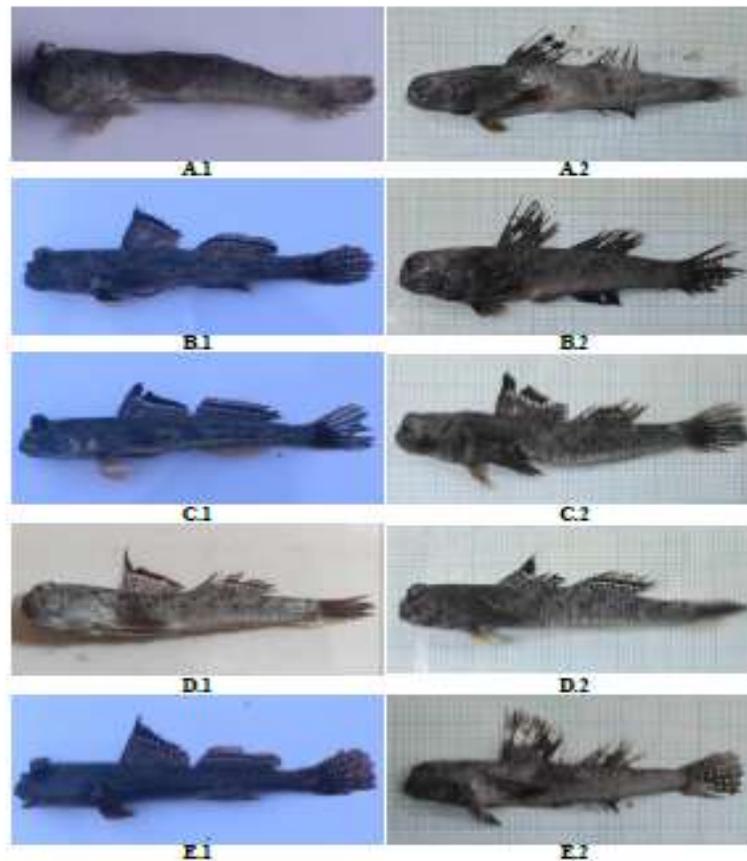


Figure 4. Mudkipper fish in the coastal mangrove ecosystem of Tomini Bay, Boalemo, Gorontalo Province, Indonesia. A. *Perioththalmus sinuatus*; B. *Perioththalmus malaccensis*; C. *Perioththalmus variabilis*; D. *Perioththalmus argenteilincatus*; E. *Perioththalmus kalolo*. These specimens had been preserved under a  $-50^{\circ}\text{C}$  temperature for one month

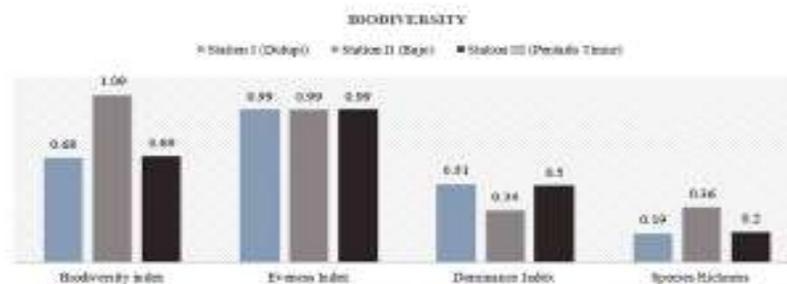


Figure 5. Biodiversity (Biodiversity index, Evenness Index, Dominance Index, and Species Richness) of mudkipper fish in the research site of Tomini Bay, Boalemo, Gorontalo Province, Indonesia

### Discussion

Five species of mudskipper fish could be found in the coastal mangrove ecosystem of Tomini Bay, Boalemo, Gorontalo Province, in which all of the species were part of Genus *Periophthalmus*. It implied that mudskipper fish spread all over the tropical and subtropical habitat, except in the western tropical Atlantic and eastern tropical Pacific (Springer 1982; Jaafar and Murdy 2017). *Periophthalmus* tends to stay in mangrove ecosystems. That is due to the existence of many detritus, small crabs, small fish, shrimps, and arthropods in mangroves which are food for *Periophthalmus* (Rhaifa et al. 2021). Thus, the result of this study was in line with previous studies conducted in the coastal ecosystems around Indo-Pacific (Pormansyah et al. 2019). Such as Maluku (Rumahlatu et al. 2020; Taniwel et al. 2020), South Sumatera (Ridho et al. 2019), West Nusa Tenggara (Rhaifa et al. 2021), Yogyakarta (Ari Suryanti et al. 2018), North Sulawesi (Polgar et al. 2017), Java and Bali (Dahrudin et al. 2017), Malacca Strait and Malay Peninsula (Polgar et al. 2014). Researchers found all species possessed high similarity in morphological features because they are part of the same Genus (Table 2).

#### *Periophthalmus minutus*

D<sub>1</sub> XVI, D<sub>2</sub> I, 12; A 11; P 13; V 6; C 13

Eyes without dermal cup; one row of teeth on the maxilla; pelvic fin without frenum; moderate D1 height with straight margins, single brown strip mesial with numerous proximal white spots, without spinal elongation; D2 with dusky brown stripe mesially; D1 and D2 are not connected by a membrane; lateral scales 60; head length 0.273% SL; pelvic fin basal length 0.047% SL; anal fin basal length 0.201% SL; D1 basal length 0.214% SL; D2 basal length 0.216% SL; caudal peduncle height 0.081% SL (Figure 2, Table 3, Table 4). In some conditions, the frenum can be seen through magnification (Jaafar and Murdy (2017).

#### *Periophthalmus malaccensis*

D<sub>1</sub> XI, D<sub>2</sub> I, 12; A 11; P 11; V 6; C 14

Eyes without dermal cup; one row of teeth on the maxilla; the pelvic is clear and prominent; moderate D1 height with slightly rounded margins, a single inframarginal brown strip with numerous proximal white spots. First spine elongated; D2 with faded brown stripe mesial; a membrane does not connect D1 and D2; lateral scales 58; head length 0.274% SL; pelvic fin basal length 0.027% SL; anal fin basal length 0.188% SL; D1 basal length 0.178% SL; D2 basal length 0.174% SL; caudal peduncle height 0.097% SL (Figure 2, Table 3, Table 4). Although *Periophthalmus malaccensis* has bright blue spots on the chin and operculum, it also has prominent transverse folds on the snout (Polgar 2016).

#### *Periophthalmus variabilis*

D<sub>1</sub> XI, D<sub>2</sub> I, 12; A 11; P 11; V 6; C 14

Eyes without dermal cup; one row of teeth on the maxilla; the pelvic frenum is clear and prominent; the pelvic is orange at least at the margins; moderate D1 height with rounded margins. A single inframarginal brown strip with many proximal white spots. The first spine elongated, white

margin; D2 with single inframarginal orange stripe and black single stripe mesial. Reddish-orange spots at the base; the anal fins are orange, at least at the margins. A membrane does not connect D1 and D2; lateral scales 52; head length 0.264% SL; pelvic fin basal length 0.027% SL; anal fin basal length 0.063% SL; D1 basal length 0.192% SL; D2 basal length 0.216% SL; caudal peduncle height 0.099% SL (Figure 2, Table 3, Table 4). When alive, the branchiostegal membrane of the fish shows pigmentation (Setiawan et al. 2019).

#### *Periophthalmus argentilineatus*

D<sub>1</sub> XIII, D<sub>2</sub> I, 12; A 12; P 12; V 6; C 16

Eyes without dermal cup; one row of teeth on the maxilla; pelvic without frenum; moderate D1 height with straight margins, single brown strip mesial with numerous proximal white spots, without spinal elongation; D2 with dusky brown stripe mesial; D1 and D2 are not connected by a membrane; lateral scales 70; head length 0.247% SL; pelvic fin basal length 0.12% SL; anal fin basal length 0.163% SL; D1 basal length 0.163% SL; D2 basal length 0.201% SL; caudal peduncle height 0.101% SL (Figure 2, Table 3, Table 4). The total transverse scale from ventroposterior D2 basal to the basal of the anal fin is 18-26 (Jaafar and Murdy 2017).

#### *Periophthalmus kalolo*

D<sub>1</sub> XI, D<sub>2</sub> I, 12; A 11; P 11; V 6; C 14

Eyes without dermal cup; one row of teeth on the maxilla; vestigial pelvic frenum; pelvic fins fused about half of the pelvic fin; moderate D1 height with rounded margins. Single black stripe inframarginal with proximal white spots, without spinal elongation; D2 with inframarginal dusky strip; D1 and D2 are not connected by a membrane; lateral scales 62; head length 0.256% SL; pelvic fin basal length 0.033% SL; anal fin basal length 0.155% SL; D1 basal length 0.172% SL; D2 basal length 0.211% SL; caudal peduncle height % SL (Figure 2, Table 3, Table 4). The total transverse scale from ventroposterior D2 basal to the basal of anal fin is fewer than *Periophthalmus argentilineatus*, which is only 18-22 (Jaafar and Murdy 2017).

Morphological adaptations of mudskipper fish created variations in morphometric and meristic measurements (Nugroho et al. 2016; Dimah et al. 2020; Ghanbarifardi et al. 2020). Jaafar and Murdy (2017) added that morphological characteristics such as the number of dorsal spines, the presence of finger-like projections in the maxillodentary ligament in the lip of the lower jaw and the opaxialis muscle attaching anteriorly of the frontal and epioccipital junction could distinguish genera in the Family. Meristic characters such as the scales before and after the pectoral filaments, pectoral fins, dorsal fins, abdominal fins, and anal fins are characters that can distinguish species in the Genus. In addition, other factors that influence differences in fish morphology are food availability, environmental conditions, and the stage of fish maturity. Another characteristic with a high probability of variation is coloration. Fish coloration is influenced by genetic, environmental, dietary, and physiological factors (Nüsslein-Vollhard and Singh 2017). Due to the instability of the correlation character, this

characteristic is mostly neglected when identifying fish species.

Environmental conditions influence the difference in species diversity between the three stations. Many factors influence the high and low species diversity, and one of the factors is environmental quality. Krebs (2014) further explained that species diversity is used to measure the stability of a community which is the ability of a community to keep itself stable despite disturbances to its components. Maturbongs et al. (2018) argued that the area or mud substrate is a habitat for various nekton, which indicates the area has abundant food sources. The existence of habitat variations (substrate), such as physical conditions and the surrounding environment, affects the diversity of fish species. The diversity index at the research site was 1.09; this indicated that a high diversity level of mudskipper fish in the Coastal Bay of Tomini, Bualemo, was included in the moderate criteria. In addition, it also showed that water productivity was quite balanced.

The comparison of the Evenness index of mudskipper fish in the research locations had the same Evenness index value of 0.99. This value indicated that the evenness in the three locations was stable. The Evenness index shows the degree of evenness of individual abundance between each species. The community has a maximum Evenness value if each species has the same number of individuals. On the other hand, if the Evenness value is small, then the community has dominant, sub-dominant, and dominated species; eventually, the community has a minimum Evenness. The Evenness value had a range between 0-1; if the index value obtained was close to one, the distribution is more even (Ludwig and Reynolds 1988; Baderan et al. 2021). Figure 3 presents the index of evenness of the mudskipper (*Periophthalmus*) species in the Coastal Bay of Tomini, Bualemo, which was included in a stable community. Thus, the population between species of the genus *Periophthalmus* on the Coastal Bay of Tomini, Bualemo, was fairly even so that disturbances did not easily occur and were able to return to their initial conditions.

Species richness in the research locations was low with the Specific Richness Index (R1) at each station as follows 0.19 (Station I Dulupi), 0.36 (Station II Bajo), 0.2 (Station III East Penandu). Species richness refers to the number of species in a community. The number of species in the field determines the size of the richness index. The Margalef richness index divides the number of species by the natural logarithm function meaning that the increase in the number of species is inversely proportional to the increase in the number of individuals. Generally, a community/ecosystem with abundant species will have a small number of individuals in each of these species.

The dominance of species in water often occurs due to several things, including competition for natural food by certain species accompanied by changes in environmental quality and an imbalance between predators and prey, resulting in competition between species. Maturbongs et al. (2018) explained that dominance occurs because of the result of the competition process for evicting one individual against another. Okyere (2018) stated that at low tide, the estuary area is dominated by brackish fish species, one of

which is from the Gobiidae family. This statement is true because mudskipper fish is more active during low tide conditions both on the coast and at an estuary; on the other hand, mudskipper fish will hide in their nests at high tide to avoid predators. The dominance index of mudskipper fish was 0.51, which indicated that the level of species dominance in these waters was moderate; thus, there were no dominant species in these waters.

Environmental factors that are very supportive and the absence of predators made several species of mudskipper fish thrive and spread across the area. In line with research by Mahadevan and Ravi (2015), which stated that the right water temperature range for mudskipper fish was between 23.5-35.5°C, the measurement results of environmental parameters showed that the average temperature range was 28-30°C. Furthermore, Bidawi et al. (2017) explained that mudskipper species had tolerance to wide changes in temperature and salinity, indicating that water temperature is one of the environmental factors that affect the spread and diversity of mudskipper species.

The pH content of the substrate ranged from 6.8 to 8. It means that the water conditions for the life of mudskipper fish were in the neutral range. The difference in soil pH at the research sites was caused by the contribution of leaf, root, and stem litter that fall to the ground and decomposed to form soil organic matter (Tajbakhsh et al. 2018). The substrate pH greatly affects the resistance of organisms that live at the bottom of the waters, both infauna and epifauna. That occurred due to the influence of tidal or brackish water during the formation of land and subsequent tidal processes. Furthermore, Kanajiya et al. (2017) explained that the distribution of mudskipper fish was significantly influenced by environmental factors such as pH, temperature, salinity, and other ecological conditions (Ghanbarifardi et al. 2014). Therefore, regarding the presence of mudskipper fish with substrate conditions in the mangrove area at the three stations, substrate differences play an important role in the distribution of mudskipper fish.

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