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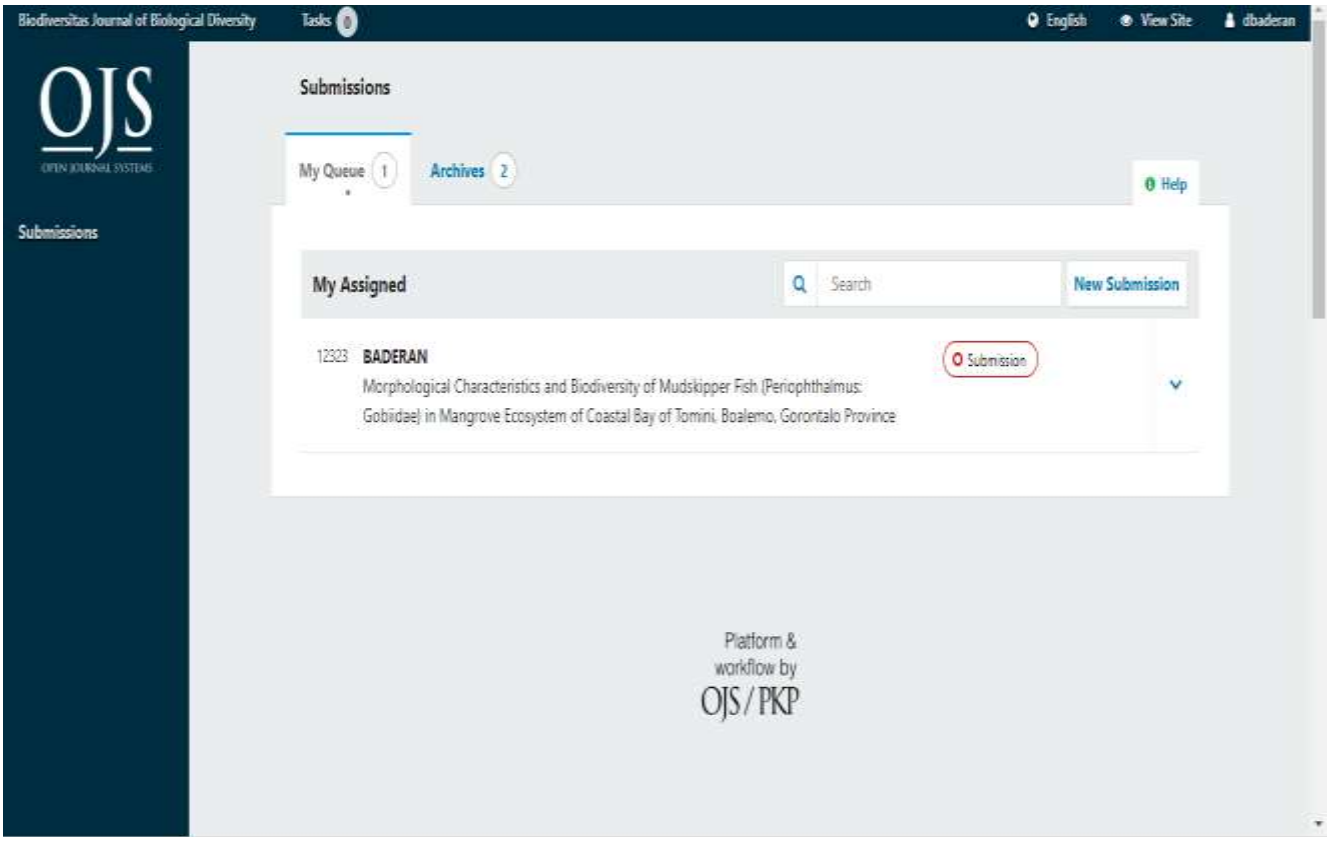

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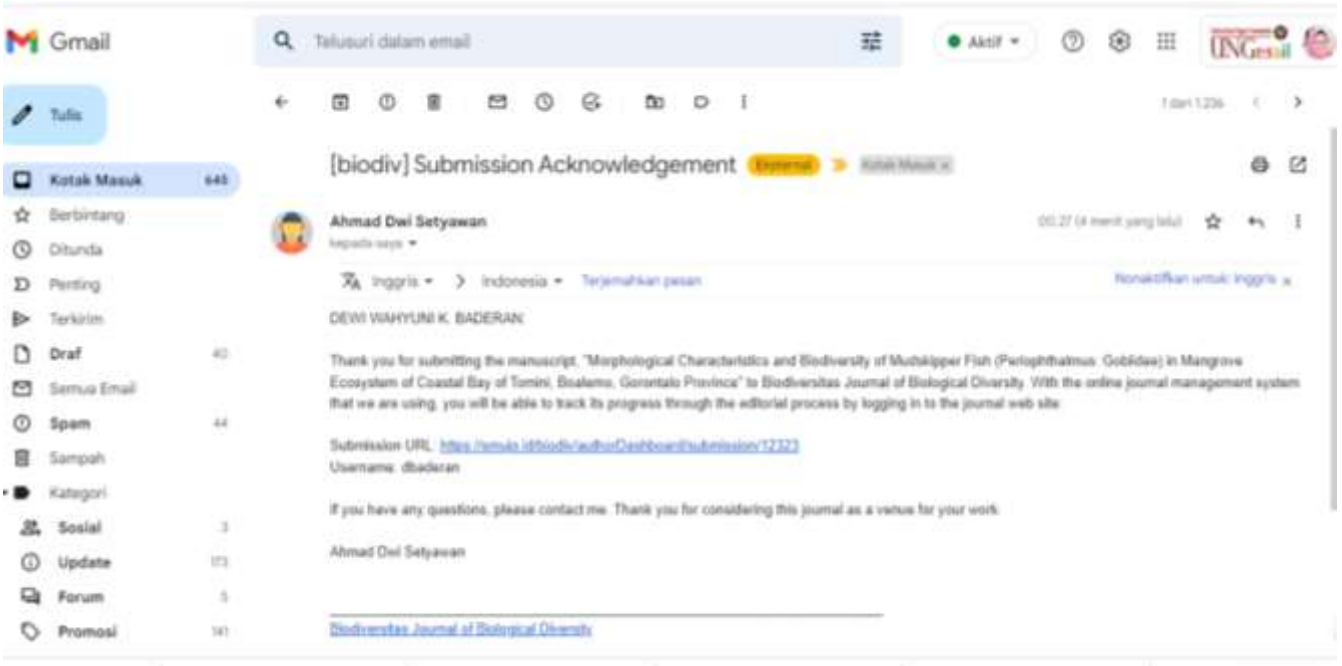

COVERING LETTER

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 (Peripophthalmus: Goobiidae) 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 endemicity.

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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).

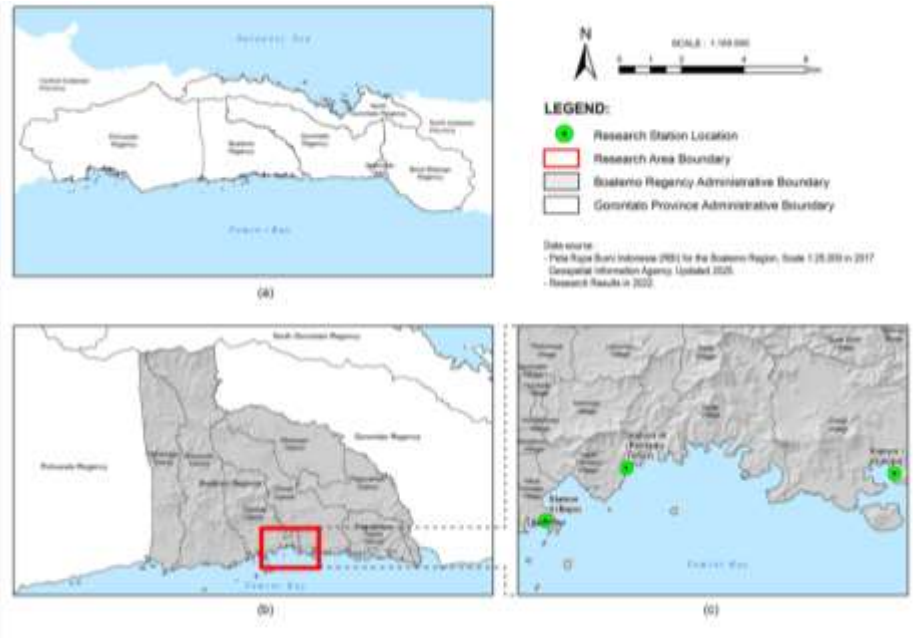

Figure 1. Location of the coastal bay of Tomini, Boalemo, Gorontalo Province indicating the sampling sites of Periophthalmus: Station I (N 00º30.640 E 122º26.982), Station II (N 00º29.818 E 122º20.931), and Station III (N 00º30.736 E 122º22.336)

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). $H' = -\sum_{i=1}^{S} \mathrm{pi}\, ln\, \mathrm{pi}$ where $\mathrm{pi} = \frac{\mathrm{ni}}{\mathrm{N}}$. H′ represents the Shannon-Wiener Diversity index, S for

total species, Ni 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-Wienner is: H′ > 3: High species diversity, 1 ≤ H′ ≤ 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 Pielow 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: $D = \sum \frac{(ni\ (ni-1))}{(N\ (N-1))}$. 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	
Actinopterygii					
Gobiidae	*Periophthalmus argentilineatus*	–	–	√(83)	83
	Periophthalmus kalolo	√(67)	–	–	67
	Periophthalmus malaccensis	√(89)	√(98)	–	187
	Periophthalmus minitus	–	√(75)	–	75
	Periophthalmus variabilis	–	√(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	*P. minutus*	*P. malaccensis*	*P. variabilis*	*P. argentilineatus*	*P. kalolo*
Dermal cup	-	-	-	-	-
One row of teeth on maxilla	+	+	+	+	+
Pelvic frenum	-	+	+	-	+
Pelvic fin wholy 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	*P. minutus*	*P. malaccensis*	*P. variabilis*	*P. argentilineatus*	*P. kalolo*
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	
P. minutus	16	0	1	12	0	11	0	13	0	6	0	13	60
P. malaccensis	11	0	1	12	0	11	0	11	0	6	0	14	58
P. variabilis	14	0	1	12	0	12	0	13	0	6	0	16	52
P. argentilineatus	13	0	1	12	0	12	0	12	0	6	0	16	70
P. kalolo	11	0	1	12	0	11	0	11	0	6	0	14	62

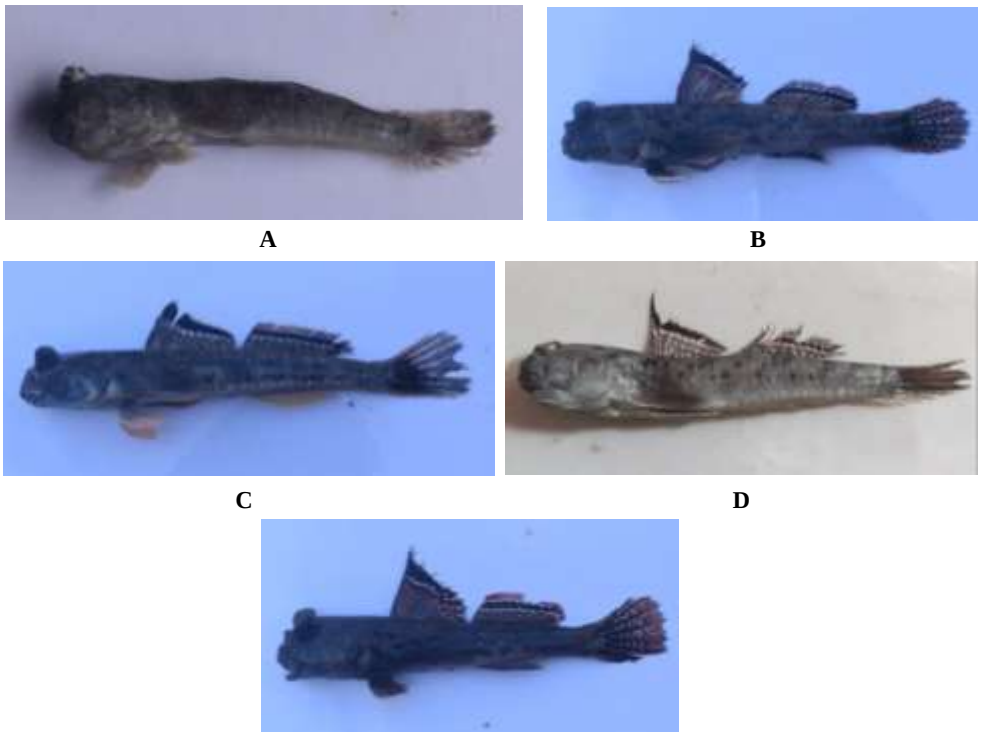

Figure 2. Mudskipper fish in the coastal mangrove ecosystem of Tomini Bay, Boalemo, Gorontalo Province. A. *Periophthalmus minutus*, B. *Periophthalmus malaccensis*, C. *Periophthalmus variabilis*, D. *Periophthalmus argentilineatus*, E. *Periophthalmus kalolo*

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).

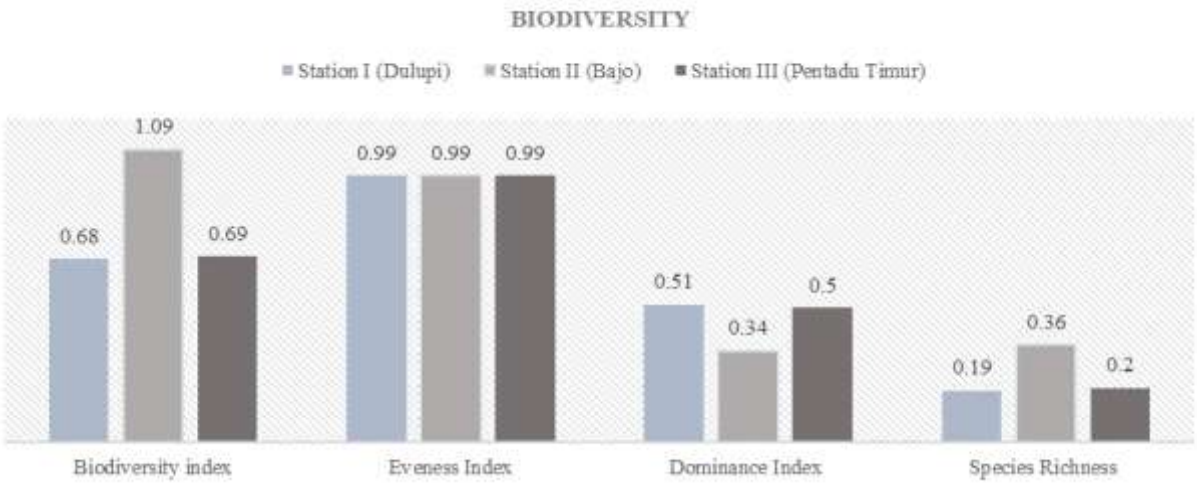

Figure 3. Biodiversity (Biodiversity index, Eveness Index, Dominance Index and Species Richness of mudskipper fish in the research site

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 (^{0}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), Periopthalmus 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_1 XVI, D_2 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_1 XI, D_2 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_1 XI, D_2 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 argentilineatus*
   D_1 XIII, D_2 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_1 XI, D_2 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℃, the measurement results of environmental parameters showed that the average temperature range was 28-30℃. 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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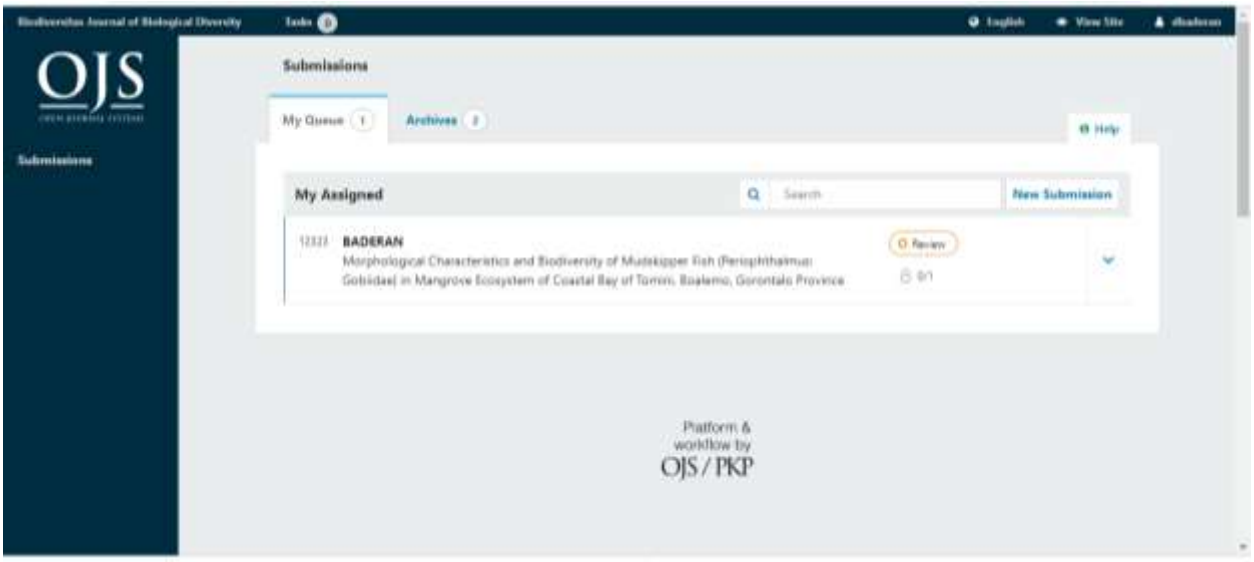

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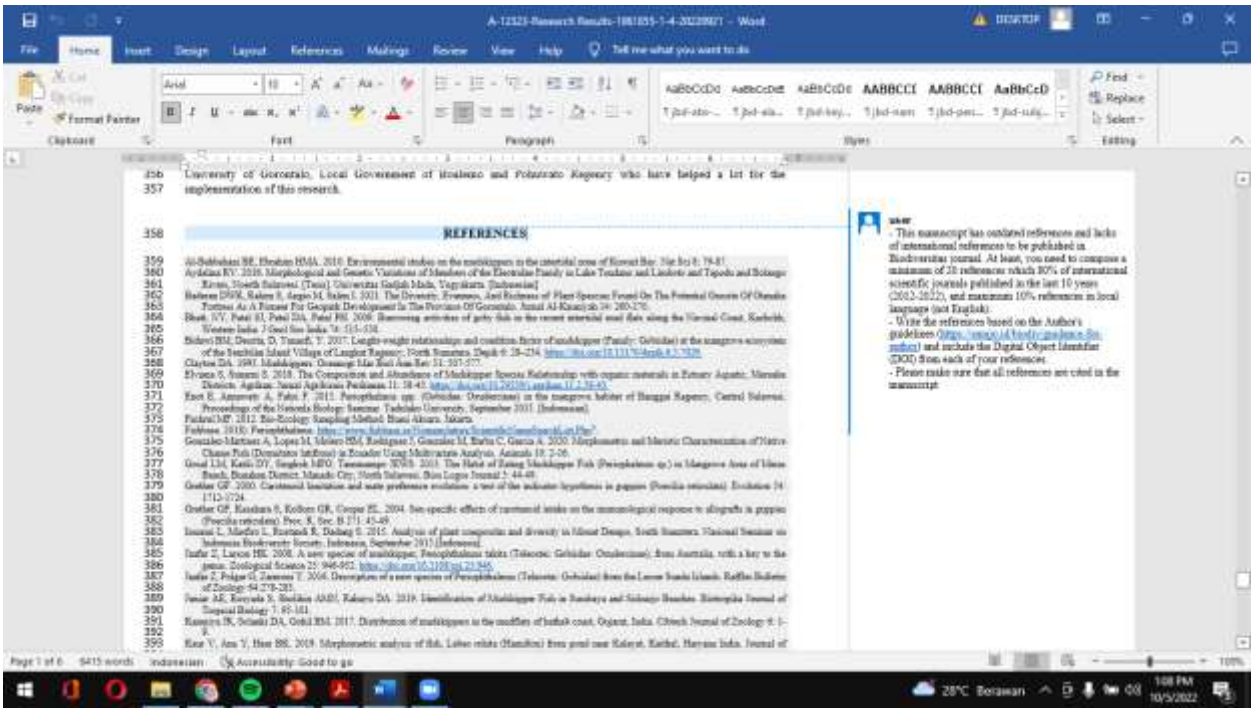

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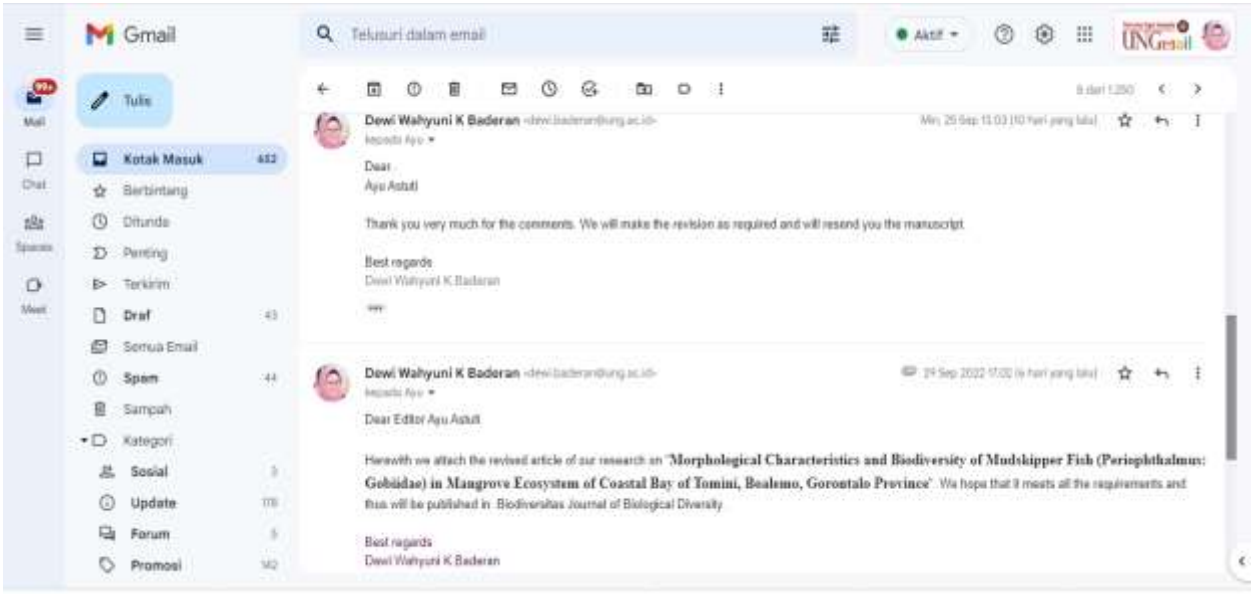

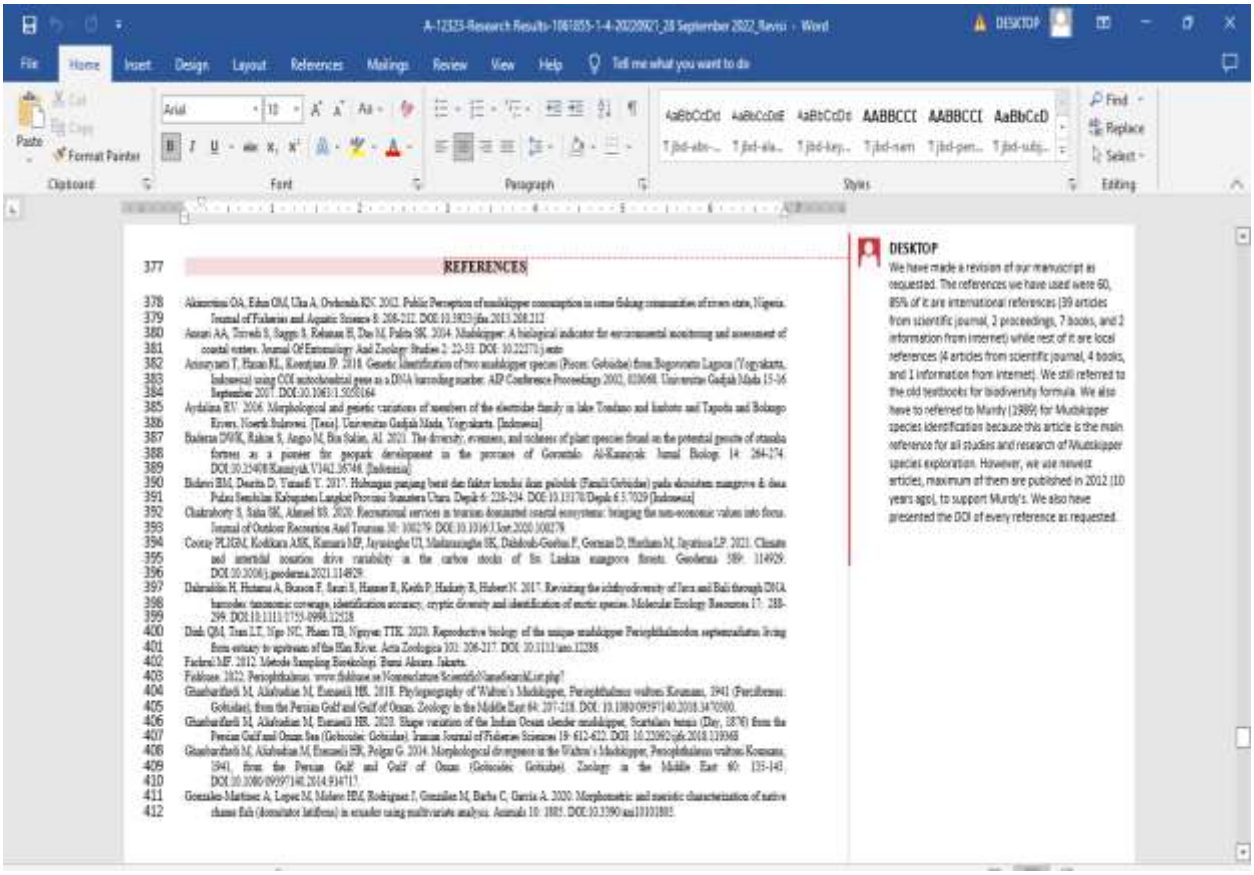

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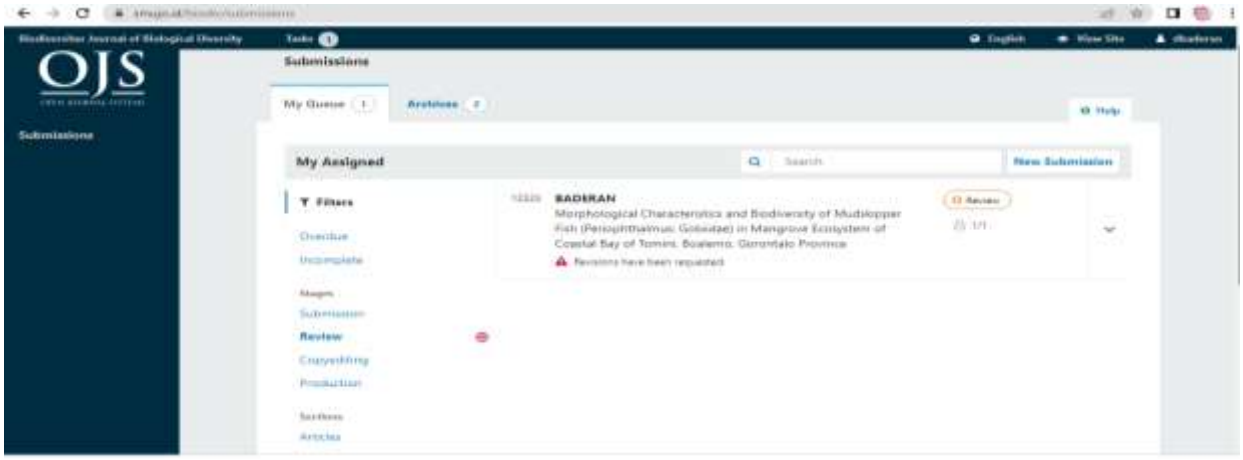

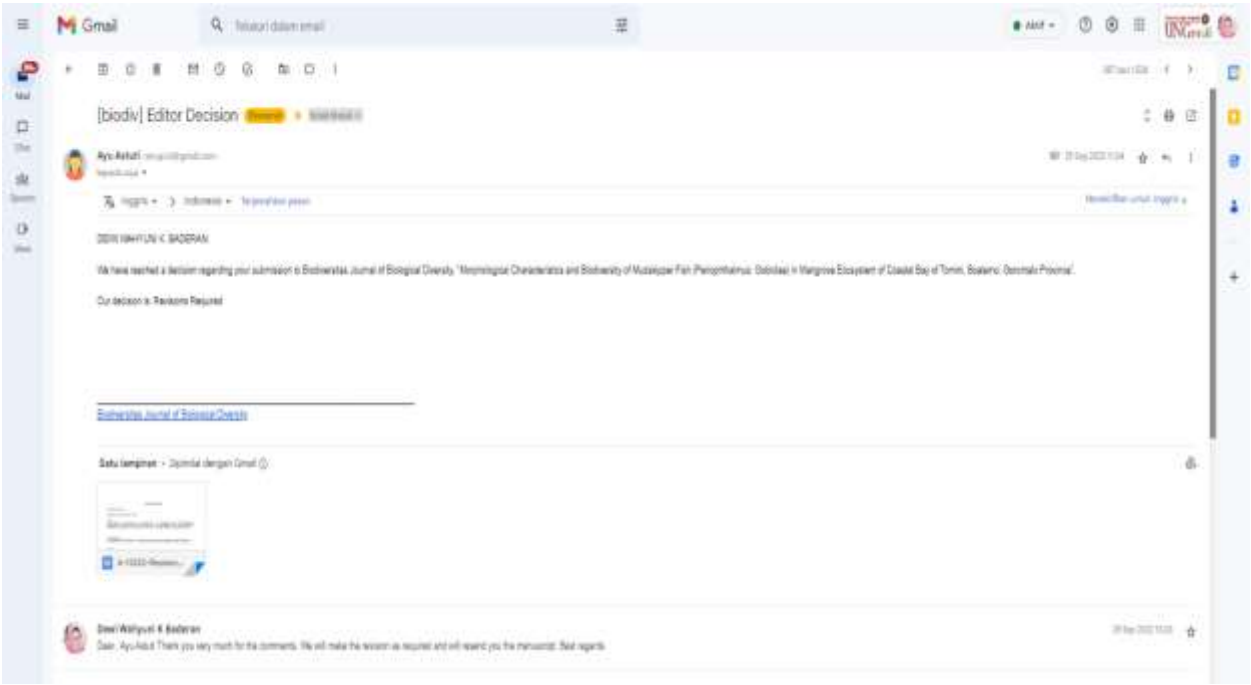

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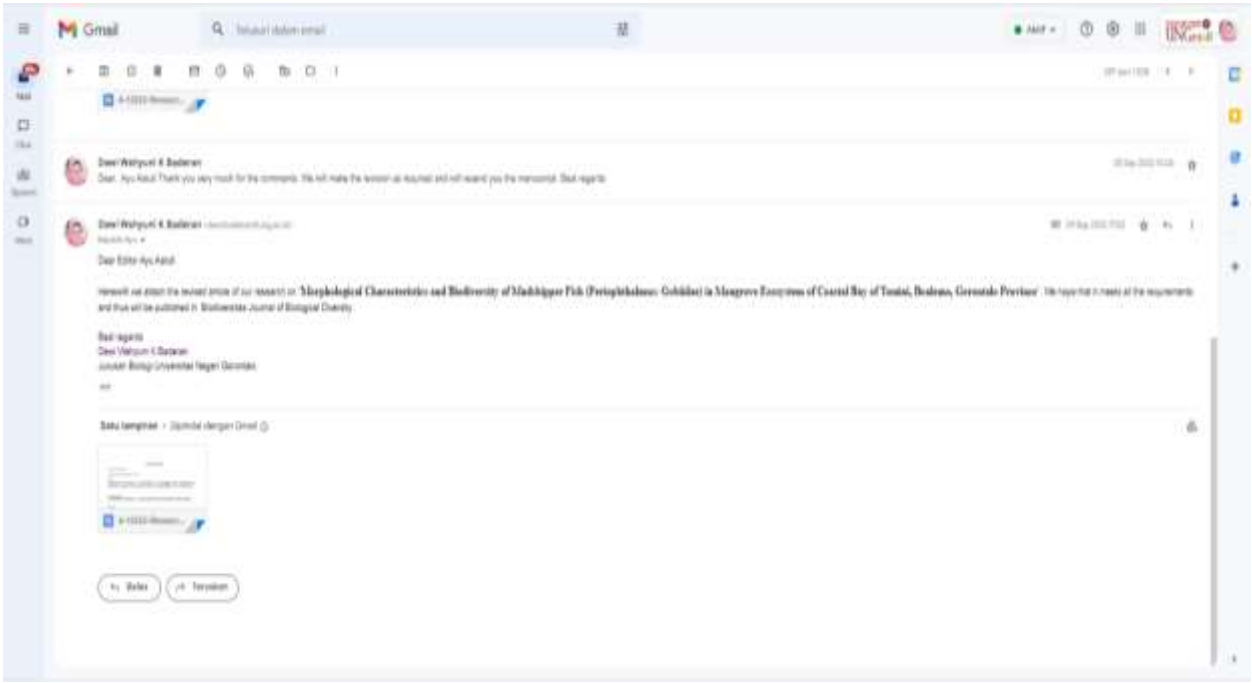

Morphological characteristics and biodiversity of mudskipper fish (Periophthalmus: Gobiidae) in mangrove ecosystem of coastal Bay of Tomini, Gorontalo Province, Indonesia

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 R_i 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, nutrient supply needed by various species of fish (Nguyen and Parnel 2017; Lapolo et al. 2019), 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 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) and Rha'ifa et al. (2021) 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 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). Mudskipper 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 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, jump above the mud, and attached 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, 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 because it has a high value of nutrition (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±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). 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. Besides, mudskipper as the native residents of mangrove habitat creates a natural view that is awaited by the tourists (Chakraborty et al. 2020).

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. This is affirmed by Hai et al. (2020), mangrove is an important component of the coastal ecosystem which is severely and globally threatened by various causing factors. 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 43 species in 10 genera (Polgar et al. 2013; Rupp 2021). 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 Penatclu 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 (N00°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 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) 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) 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 (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; 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.

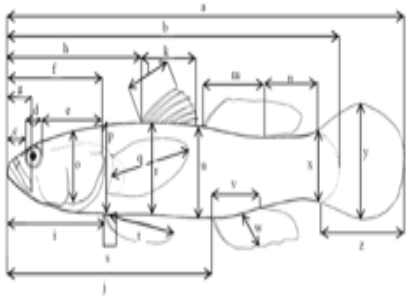

Figure 2. Skema karakterisasi morfometrik mudskipper: (a) total length, (b) standard length, (c) Pre-orbital length, (d) eye diameter, (e) panjang daerah post-orbital, (f) panjang kepala, (g) panjang mulut, (h) panjang daerah pre-dorsal, (i) panjang daerah pre-ventral, (j) panjang daerah pre-anal, (k)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

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). $H' = -\sum_{i=1}^{S} pi\, ln\, pi$ where $pi = \frac{ni}{N}$. H' represents the Shannon-Wiener Diversity index, S for total species, Ni 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 Pielow Evenness Indices formula (Ludwig and 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: $D = \sum \frac{(ni\,(ni-1))}{(N\,(N-1))}$. The results of the dominance index were grouped into $0 < D < 0.5$ in 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 1971; Krebs 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 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	
Actinopterygii					
Gobiidae	*Periophthalmus argentilineatus*	–	–	√(83)	83
	Periophthalmus kalolo	√(67)	–	–	67
	Periophthalmus malaccensis	√(89)	√(98)	–	187
	Periophthalmus minitus	–	√(75)	–	75
	Periophthalmus variabilis	–	√(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	*P. minutus*	*P. malaccensis*	*P. variabilis*	*P. argentilineatus*	*P. kalolo*
Dermal cup	-	-	-	-	-
One row of teeth on maxilla	+	+	+	+	+
Pelvic frenum	-	+	+	-	+
Pelvic fin wholy 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	-	-	+	-	-

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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 1st to 6th characters has been shown in the Figure 3. The rest of the 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	-	-	+	-	-

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	*P. minutus*	*P. malaccensis*	*P. variabilis*	*P. argentilineatus*	*P. kalolo*
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 peduncolus	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	0.059	0.056	0.127	0.074
Caudal peduncolus 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

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	
P. minutus	16	0	1	12	0	11	0	13	0	6	0	13	60
P. malaccensis	11	0	1	12	0	11	0	11	0	6	0	14	58
P. variabilis	14	0	1	12	0	12	0	13	0	6	0	16	52
P. argentilineatus	13	0	1	12	0	12	0	12	0	6	0	16	70
P. kalolo	11	0	1	12	0	11	0	11	0	6	0	14	62

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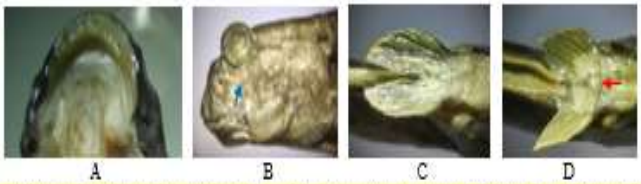
It would be better if it was accompanied by a picture of the characters.

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



A B C D

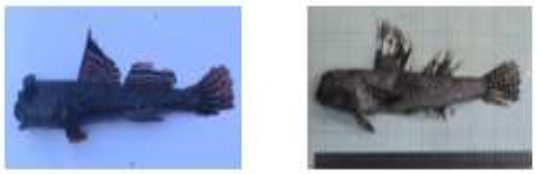
Figure 3. Karakteristik morfologis ikan Mudskipper fish diarea pesisir ekosistem mangrove Teluk Tomini, Boalemo, Provinsi Gorontalo: A. Satu baris gigi pada maxilla; B. Dermal-Cup; C. Sirip pelvik tidak menyatu; D. Sirip pelvik menyatu. Frenum ditunjukkan oleh arah panah berwarna merah.

A (1) A (2)

B (1) B (2)

C (1) C (2)

D (1) D (2)



E (1) E (2)

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

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

It has been revised as suggested.

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 observation stations. The lowest dominance value was at station II with a value of 0.34 (Figure 5).

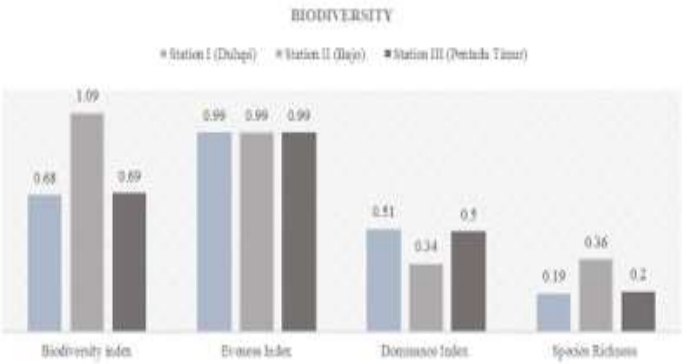


Figure 5. Biodiversity (Biodiversity index, Eveness Index, Dominance Index and Species Richness of mudskipper fish in the research site

Environment Parameters

The results range of the temperature measurement at 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. Kondisi ekologis Stasiun I (Dulupi) kawasan mangrove berdasarkan penampakkan visual masih baik-padat, memiliki tekstur habitat tanah berpasir dan berlumpur dengan ditumbuhi tumbuhan mangrove. Stasiun II (Bajo) kawasan mangrove telah dialihfungsikan menjadi pemukiman, tanpa memperhatikan nilai penting dari tumbuhan mangrove. Berdasarkan penampakkan visual kondisi mangrove memiliki tekstur tanah berpasih dan berlumpur, banyak sampah-sampah yang berserakan dan banyak mangrove anakan yang mati dan rusak. Stasiun III (East Pentadu) berdasarkan penampakkan visual kondisi mangrove memilki tekstur tanah berlumpur dan tanah berlumpur bebatan. Kondisi mangrove masih baik dan regenerasi perteumbuhan anakan mangrove pada area tersebut tumbuh cepat dan banyak.

Tabel 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
Substrat	Mud	Mud rocks	Mud
Water pH	7.1-8	7.3-8	7.3-8
Subtrat pH	7.5-8	6.8-7	6.8-7.5

Discussion

There were five species mudskipper fish that 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 even though mudskipper fish spread in all over the tropical and subtropical habitat, except in the western tropical Atlantic and eastern tropical Pacific (Springer 1982; Jaafar and Murdy 2017). Periopthalmus tends to stay in mangrove ecosystems. Hal ini disebabkan oleh karena mangrove menyediakan banyak detritus, kepiting kecil, ikan kecil, udang, dan arthropoda yang merupakan makanan Periophthamus (Rha'ifa et al. 2021). Thus, the result of this study was in line with previous studies which were conducted in the coastal ecosystems around Indo-Pacific (Pormansyah et al. 2019), such as Maluku (Rumahlatu

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It is important to describe the ecological conditions of each sampling station.

Sudah ditambahkan

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

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

a. *Periophthalmus minutus*
D_1 XVI, D_2 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_1 XI, D_2 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_1 XI, D_2 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 argentilineatus*
D_1 XIII, D_2 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 sirip anal 18-26 (Jaafar & Murdy (2017).

e. *Periophthalmus kalolo*
D_1 XI, D_2 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 argentilineatus* yakni hanya 18-22 (Jaafar & Murdy (2017).

Morphological adaptations of mudskipper fish created variations in morphometric and meristic measurements (Nugroho et al. 2016; Dinh 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.

as number of dorsal spines, the presence of finger-like projections in the maxillodentary ligament in the lip of the lower jaw and the epaxialis muscle attaching anteriorly of the frontal and epioccipital junction can 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 character with a high probability of variation is coloration. Fish coloration is influenced by many factors including genetic, environmental, dietary, and physiological factors (Nüsslein-Volhard and 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 was influenced by many factors 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 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 (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 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 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 fell to the ground and decomposed to form soil organic matter (Tajbakhsh et al. 2018). 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. Furthermore, Kanejiya et al. (2017) explained that the distribution of mudskipper fish was significantly influenced by environmental factors such as pH, temperature, salinity, and the other ecological conditions (Ghanbarifardi et al. 2014). Regarding to the presence of mudskipper fish with substrate conditions in the mangrove area at the three stations, added that substrate differences play an important role in the distribution of mudskipper fish.

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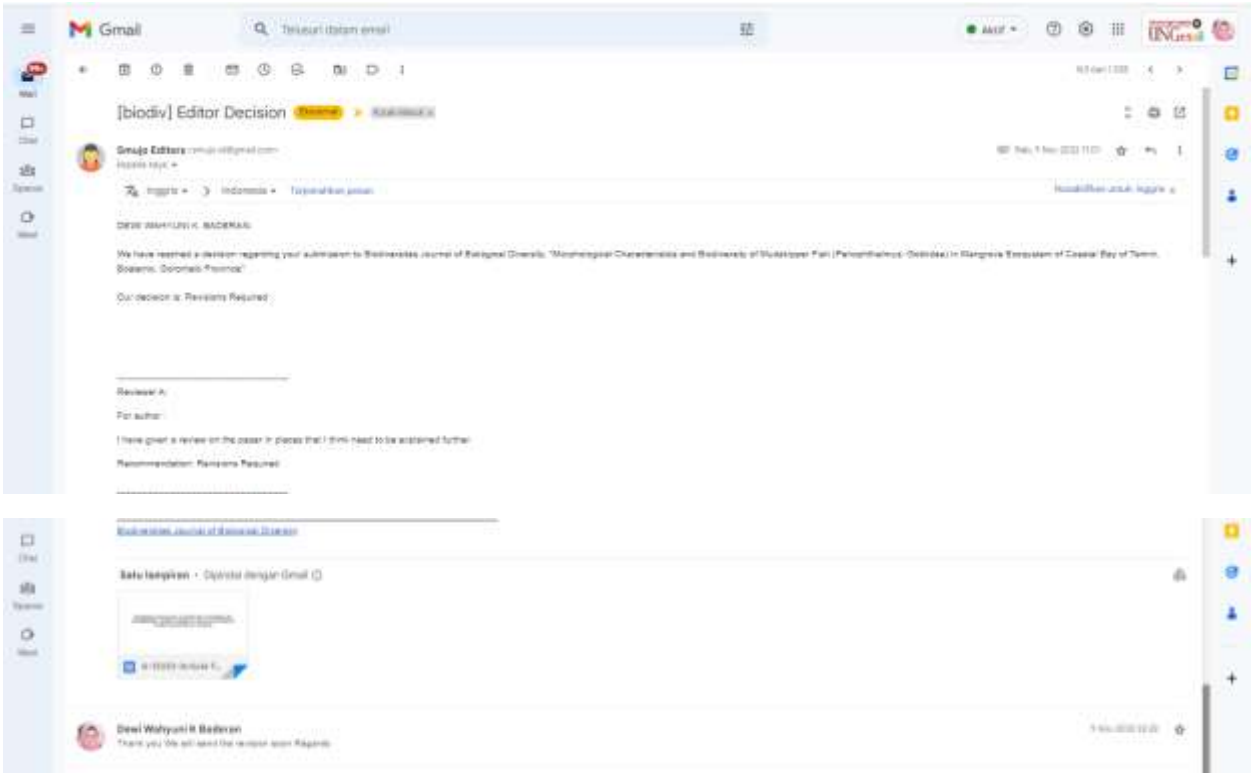
REVISI KE-3

Rabu, 9 November 2022



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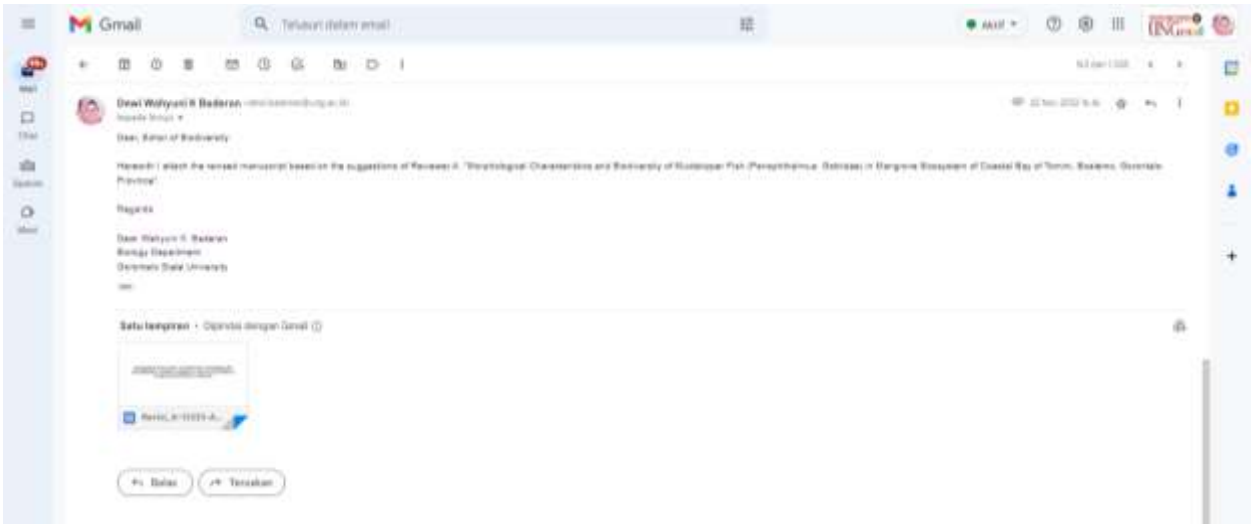
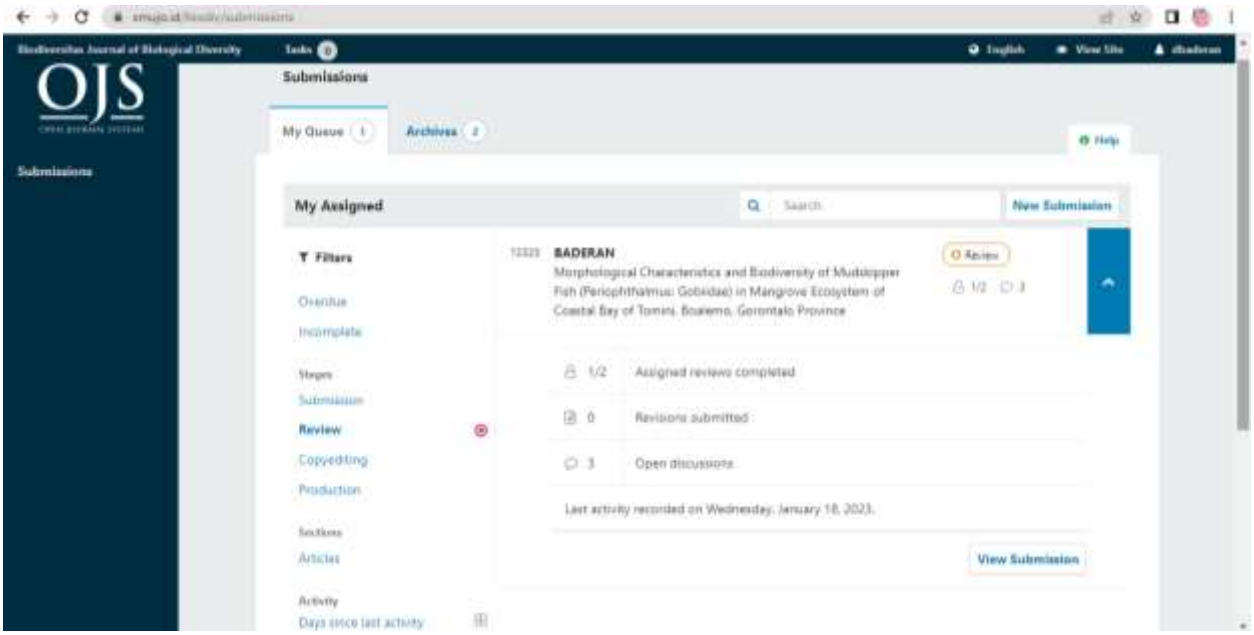




Morphological characteristics and biodiversity of mudskipper fish (Periophthalmus: Gobiidae) in mangrove ecosystem of coastal Bay of Tomini, Gorontalo Province, Indonesia

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 R_c 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, nutrient supply needed by various species of fish (Nguyen and Parnel 2017; Lapolo et al. 2019), 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 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) and Rha'ifa et al. (2021) 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 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). Mudskipper 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 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, jump above the mud, and attached 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, 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 because it has a high value of nutrition (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±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). 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. Besides, mudskipper as the native residents of mangrove habitat creates a natural view that is awaited by the tourists (Chakraborty et al. 2020).

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. This is affirmed by Hai et al. (2020), mangrove is an important component of the coastal ecosystem which is severely and globally threatened by various causing factors. 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 43 species in 10 genera (Polgar et al. 2013; Rupp 2021). 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 (Duhupi 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 (N00°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 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) 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) 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 (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; 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.

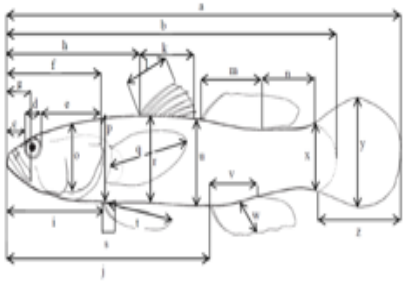


Figure 2. Morphometric characterization scheme of the mudskipper: (a) total length, (b) standard length, (c) Pre-orbital length, (d) eye diameter, (e) post-orbital length, (f) post-orbital length, (g) mouth length, (h) pre-dorsal length, (i) pro ventral length, (j) pre-anal length, (k) first dorsal fin 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 spin, (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).

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). $H' = -\sum_{i=1}^{n} pi\, ln\, pi$ where $pi = \frac{ni}{N}$. H' represents the Shannon-Wiener Diversity index, S for total species, Ni 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-Wienner 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 Pielow Evenness Indices formula (Ludwig and 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: $D = \sum \frac{(ni\,(ni-1))}{(N\,(N-1))}$. The results of the dominance index were grouped into $0 < D < 0.5$ in 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 1971; Krebs 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 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	
Actinopterygii					
Gobiidae	*Periophthalmus argentilineatus*	–	–	√(83)	83
	Periophthalmus kalolo	√(67)	–	–	67
	Periophthalmus malaccensis	√(89)	√(98)	–	187
	Periophthalmus minitus	–	√(75)	–	75
	Periophthalmus variabilis	–	√(81)	√(68)	149
Total					561

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

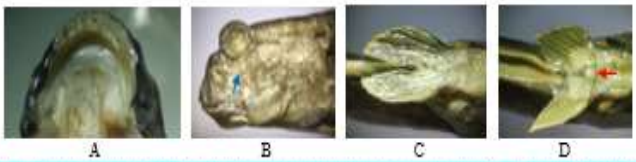
The Morphological Characters of Mudskipper Fish

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

Characters	*P. minutus*	*P. malaccensis*	*P. variabilis*	*P. argentilineatus*	*P. kalolo*
Dermal cup	-	-	-	-	-
One row of teeth on maxilla	+	+	+	+	+
Pelvic frenum	-	+	+	-	+
Pelvic fin wholy 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	-	-	+	-	-

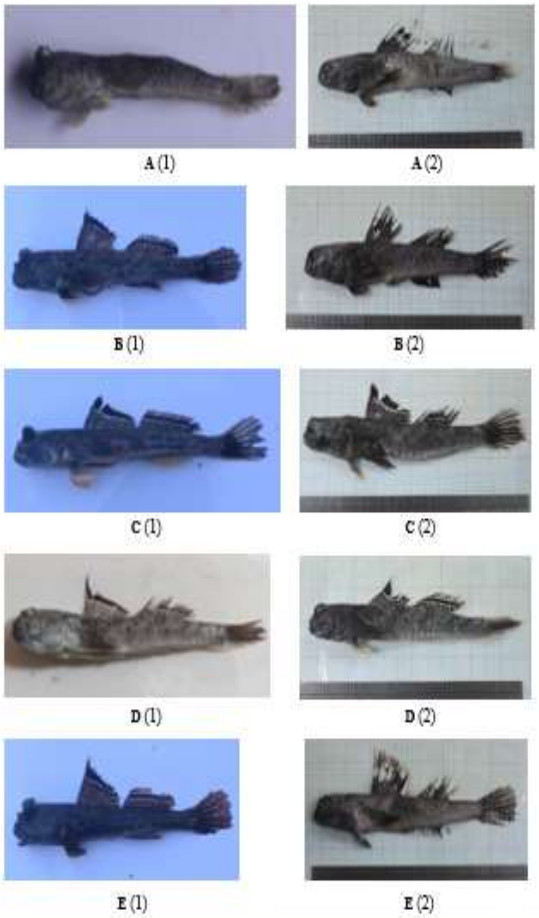
MO **Microsoft Office User**
It would be better if it was accompanied by a picture of the characters.

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



A B C D

Figure 3. The characteristics of mudskipper fish in the coastal area of 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 (1) A (2)

B (1) B (2)

C (1) C (2)

D (1) D (2)

E (1) E (2)

Figure 4. Mudskipper fish in the coastal mangrove ecosystem of Tomini Bay, Boalemo, Gorontalo Province. A. *Periophthalmus minutus*; B. *P. malaccensis*; C. *P. variabilis*; D. *P. argentilineatus*; E. *P. kalolo*. 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	-	-	+	-	-

155
156
157 ***The Morphometric Characters of Mudskipper Fish***
158
159 **Table 3.** Comparison of Morphometric Characters of Mudskipper Fish in the coastal mangrove ecosystem of Tomini Bay, Boalemo,
160 Gorontalo Province
161

Characters	*P. minutus*	*P. malaccensis*	*P. variabilis*	*P. argentilineatus*	*P. kalolo*
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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164 ***Meristic Characters of Mudskipper Fish***
165
166 The comparison of meristic characteristics of mudskipper fish which were found in the coastal mangrove ecosystem of
167 Tomini Bay, Boalemo, Gorontalo Province along with the species' classification are presented in Table 4 and Figure 2.
168
169 **Table 4.** Comparison of Meristic Characters of Mudskipper Fish in the coastal mangrove ecosystem of Tomini Bay, Boalemo, Gorontalo
170 Province
171

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	
P. minutus	16	0	1	12	0	11	0	13	0	6	0	13	60
P. malaccensis	11	0	1	12	0	11	0	11	0	6	0	14	58
P. variabilis	14	0	1	12	0	12	0	13	0	6	0	16	52
P. argentilineatus	13	0	1	12	0	12	0	12	0	6	0	16	70
P. kalolo	11	0	1	12	0	11	0	11	0	6	0	14	62

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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 characters can be seen in Figure 2.

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 observation stations. The lowest dominance value was at station II with a value of 0.34 (Figure 5).

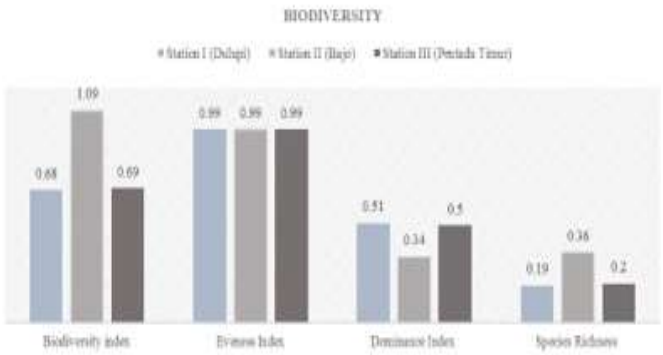

Figure 5. Biodiversity (Biodiversity index, Eveness Index, Dominance Index and Species Richness of mudskipper fish in the research site

Environment Parameters

The results range of the temperature measurement at 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. The ecological condition of Station I (Duhupi) of mangrove area based on its visual look 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 vital values of mangrove plants. Based on its visual look, the ground texture of the mangrove forest there is sandy and muddy. Many garbages were scattered and many mangrove saplings were died and broken. In station III (East Pentadu), according to its visual appearance, the ground texture of the mangrove was mudy. The mangrove condition was still considered good and the regeneration of the growing sappling in the area is considered quick and plenty.

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

Discussion

There were five species mudskipper fish that 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 even though mudskipper fish spread in all over the tropical and subtropical habitat, except in the western tropical Atlantic and eastern tropical Pacific (Springer 1982; Jaafar and Murdy 2017). Periopthalmus tends to stay in mangrove ecosystems. This is due to the existence of many detritus, small crabs, small fish, shrimps, and arthropods in mangrove which are food for Periophthamus (Rha'ifa et al. 2021). Thus, the result of this study was in line with previous studies which were conducted in the coastal ecosystems around Indo-Pacific (Pormansyah et al. 2019), such as Maluku (Rumahlatu et al. 2020; Tanjwel 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.

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

a. *Periophthalmus minutus*
D_I XVI, D_2 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 a magnification (Jaafar & Murdy (2017).

b. *Periophthalmus malaccensis*
D_I XI, D_2 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_I XI, D_2 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 argentilineatus*
D_I XIII, D_2 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). The total of transverse scale from ventroposterior D2 basal to the basal of anal fin is 18-26 (Jaafar & Murdy (2017).

e. *Periophthalmus kalolo*
D_I XI, D_2 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 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 of transverse scale from ventroposterior D2 basal to the basal of anal fin is fewer than *Periophthalmus argentilineatus* that is only 18-22 (Jaafar & Murdy (2017).

Morphological adaptations of mudskipper fish created variations in morphometric and meristic measurements (Nugroho et al. 2016; Dinh et al. 2020; Ghanbarifardi et al. 2020). Jaafar & Murdy (2017) added that morphological characters such 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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Descriptions of each species need to include appropriate references.

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Descriptions of each species need to include appropriate references.

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.

and the epaxialis muscle attaching anteriorly of the frontal and epioccipital junction can 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 character with a high probability of variation is coloration. Fish coloration is influenced by many factors including genetic, environmental, dietary, and physiological factors (Nüsslein-Volhard and 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 was influenced by many factors 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 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 (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 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 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 fell to the ground and decomposed to form soil organic matter (Tajbakhsh et al. 2018). 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. Furthermore, Kanejiya et al. (2017) explained that the distribution of mudskipper fish was significantly influenced by environmental factors such as pH, temperature, salinity, and the other ecological conditions (Ghanbarifardi et al. 2014). Regarding to the presence of mudskipper fish with substrate conditions in the mangrove area at the three stations, added that substrate differences play an important role in the distribution of mudskipper fish.

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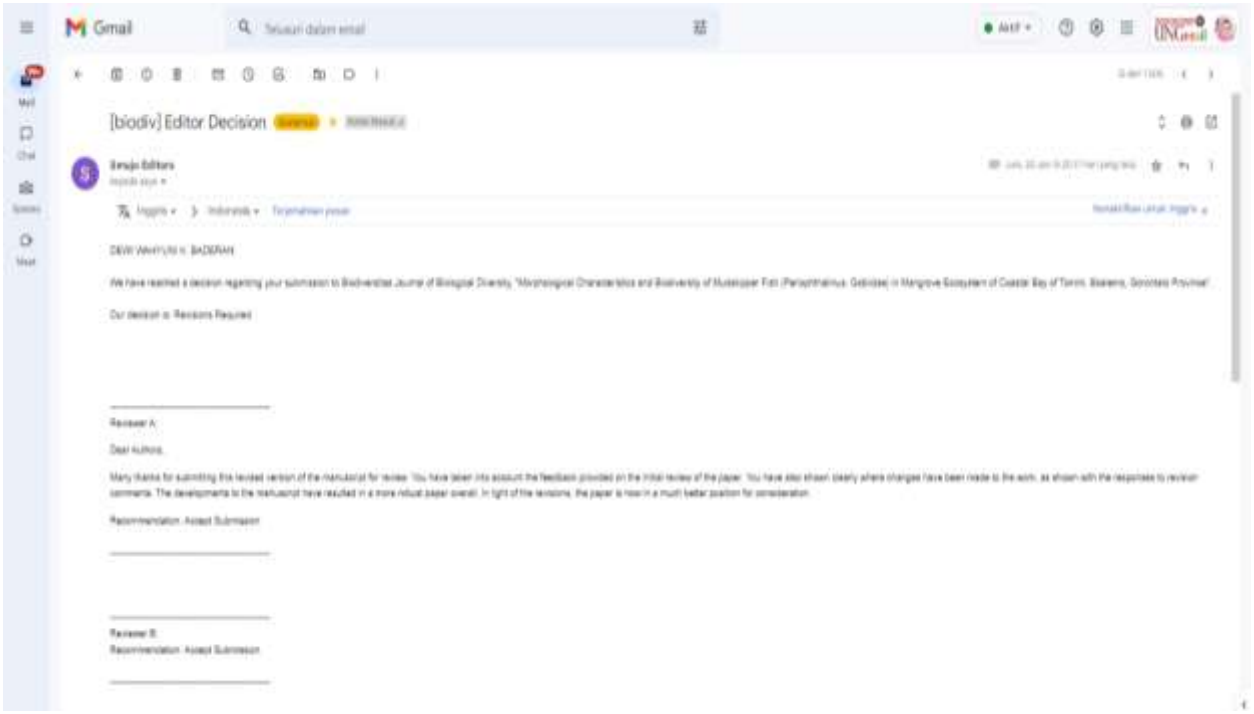
REVISI KE-4

Jumat, 20 Januari 2023



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, 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 (Dulugi, Bajo, and East Pentadu mangrove). The mudskippers were collected ~~when the water was manually receding~~ manually 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 ~~7~~ seven meristic characteristics. The identification results were then compared with the identification key. The ~~species of mudskippers found were then analyzed to figure out~~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 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 R_1 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~~ 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 (Cooray et al. 2021). In addition, Sellang (2020) stated that the mangrove ecosystem is one of the most important and productive environments for ~~the species of fish~~fish species, in a tropical area, and sub-tropical ~~estuary~~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 Latuconsina (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 (Mahadevan 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 a day living on land, climbing, and perching on the roots of the mangrove or wood, a~~s well as~~nd being able to crawl up on the land (Makharimah et al. 2016). Its pectoral fin on its muscular base can be buckled ~~so that it functions~~to function like an arms ~~that can be~~ used to crawl, jump above the mud, and attach~~ed~~ 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, ~~has the ability to~~can absorb Lead (Pb) and has a role as a bio-indicator of environmental pollution (Akinrotimi et al. 2012). ~~The mudskipper can be used by~~

Reviewer November 28, 2022
Italcise the genus name

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

Reply Resolve

Reviewer Results
Dewi K Baderan 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

peoplePeople can use the mudskipper to fulfill their food needs because it has a high valueof nutritionnutritional 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±4.49 mg/g), protein (3.5±0.35 mg/100mg), and 1.5 ± 0.47mg/100 mg protein in the muscle (Kanejiya et al. 2017). Mudskipper fish also have economic value in several countries in Asia. In China, Japan and Korea, for instanceFor instance, mudskipper with beautiful morphological characters can be used as ornamental fish in China, Japan, and Korea, Mudskipper with beautiful morphological characters can be used as ornamental fish, while i. They are generally sold as preserved products in Indonesian Indonesia they are generally sold as preserved products, such as dried and smoked fish (Faridah-Hanum et al. 2014). Besides, mudskipper, as the native residents of mangrove habitat creates a natural view that is, creates a natural view awaited by the tourists (Chakraborty et al. 2020).

One of the areas in Sulawesi Island directly borders which is directly bordered by Tomini BayTomini Bay is Boalemo Regency. Boalemo generally has a typical characteristic of a coastal area with relatively high resources, 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. Therefore, the existence of this fish in the mangrove ecosystem in the Coastal Bay of Tomini Bualemo is pretty abundant. However, although it is disregarded as fishermen and people in Boalemo are not unaware of the potential of the nutrition consisted in the mudskipper fish. ConseAs consequentlyee, 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 alignsong 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. Thatis 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 area of mangrove forestmangrove 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 (Paino 2020).

The species of mudskipper which weremudskipper species identified until today are around 43 species in 10 genera (Polgar et al. 2013; Rupp 2021). General information related to mudskipper fish has been available yet its species which are found in the Tomini Bayabout mudskipper fish has been available, yet its species in Tomini Bay have not been found e. Even the people in the coastal Bay of Tomini Bualemo stated that the mudskipper fish is a kind of poisonous fishpoisonous. 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 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), station II (Bajo Village), and station III (East Penatdu Village). The three sampling locations were chosen because they have healthy mangrove forests. This study had beenwas conducted for 5 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. Data 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 meristical characteristics, as well as its biodiversity (diversity, evenness, and species richness indexes) (Figure 1).

Reviewer
In what way? High calorific content?

It is explained in the next sentence

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

Regina
Revised as suggested

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

Revised as suggested

Reviewer
See points on number formatting.

Revised as suggested

Reviewer
How were sample locations selected?

Revised as suggested

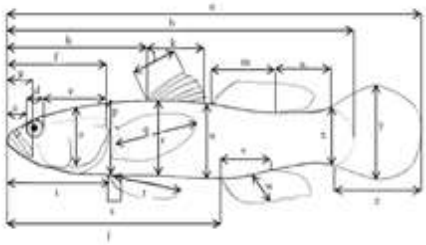
Figure 1. Location of the coastal bay of Tomini, Boalemo, Gorontalo Province indicating the sampling sites of Periophthalmus: Station I (N 00°30.640 E 122°26.982), Station II (N00°29.818 E 122°20.931), and Station III (N 00°30.736 E 122°22.336)

Tools and Materials

The tools used were a scoop net, a 5x5 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 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 ~~in~~ 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; 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.



Regina
Revised as suggested

Reviewer
Please state the depth and time that these observations were conducted

Revised as suggested

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) pro 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 spin, (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).

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). $H' = -\sum_{i=1}^{S} pi\, ln\, pi$ where $pi = \frac{ni}{N}$. H' represents the Shannon-Wiener Diversity index, S for total species, Ni 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-Wienner 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~~The species-evenness index analyzed species evenness (K) data ~~which~~ referred to the Pielow Evenness Indices formula (Ludwig and Reynolds 1988);. E = H'/ln S. Where E represents Evenness Index, and ~~H'~~ H' represents Shannon-Wiener Diversity Index. Margalef formula was used 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 Species found, and N for the Total Numbers of Individuals. Dominance data were analyzed using the Simpson formula: $D = \sum \frac{(ni\,(ni-1))}{(N\,(N-1))}$ ~~which D represents Dominance Index, ni for Number of Individuals that belo~~D represents the Dominance Index, ni for Number of Individuals belonging to species *i*, and N Total Numbers of Individuals. The results of the dominance index were grouped into $0 < D < 0.5$, in which ~~there are no species that dominate other species or a community structure is stabl~~no species dominate other species or a stable community structure. While, ~~and~~ index $0.5 < D < 1$, ~~which means there are species that dominate other species or a community structure is not~~ meaning some species dominate other species or a community structure is unstable because of ecological pressures (Odum 1971; Krebs 2014).

Reviewer
Explain the formula more clearly here

Revised as suggested

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 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~~, Tomini Bay, Boalemo's coastal mangrove area, is as many as 561 individuals, ~~were S~~spreading 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	
Actinopterygii					
Gobiidae	*Periophthalmus argentilineatus*	–	–	83	83
	Periophthalmus kalolo	67	–	–	67
	Periophthalmus malaccensis	89	98	–	187
	Periophthalmus minitus	–	75	–	75
	Periophthalmus variabilis	–	81	68	149

Regina
Revised as suggested

Markup Area

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	*P. minutus*	*P. malaccensis*	*P. variabilis*	*P. argentilineatus*	*P. kalolo*
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	-	-	+	-	-

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	*P. minutus*	*P. malaccensis*	*P. variabilis*	*P. argentilineatus*	*P. kalolo*
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 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' 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

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 comparation. This data shown average values of each species.

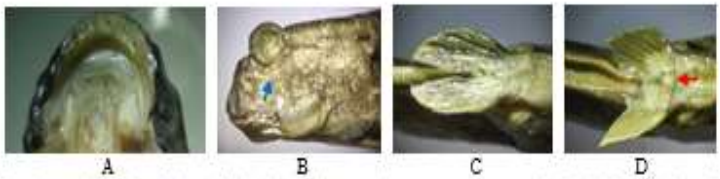
Anal ~~fin's~~ fin's longest ray length	0.081	0.059	0.056	0.127	0.074
Caudal peduncuhus height	0.081	0.097	0.099	0.101	0.082
Caudal fin height	0.144	0.162	0.115	0.145	0.152
Caudal fin length	0.213	0.234	0.208	0.219	0.167

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	
P. minutus	10	0	1	12	0	11	0	13	0	6	0	13	60
P. malaccensis	11	0	1	12	0	11	0	11	0	6	0	14	58
P. variabilis	14	0	1	12	0	12	0	13	0	6	0	16	52
P. argentilineatus	13	0	1	12	0	12	0	12	0	6	0	16	70
P. kaloio	11	0	1	12	0	11	0	11	0	6	0	14	62



A B C D

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

A (1) A (2)

B (1) B (2)

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 comparation. This data shown average values of each species.

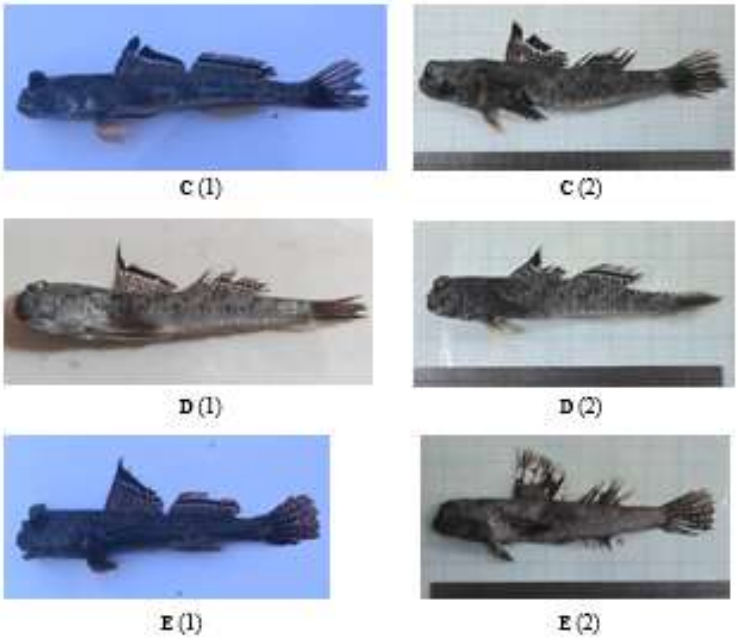


Figure 4. Mudskipper fish in the coastal mangrove ecosystem of Tomini Bay, Boalemo, Gorontalo Province. A. ***Periophthalmus minutus***; B. ***P. malaccensis***; C. ***P. variabilis***; D. ***P. argentilineatus***; E. ***P. kalolo***. Figure 2 is a photo of a specimen ~~which~~ that had been preserved under a -50°C temperature for ~~1~~ one 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).

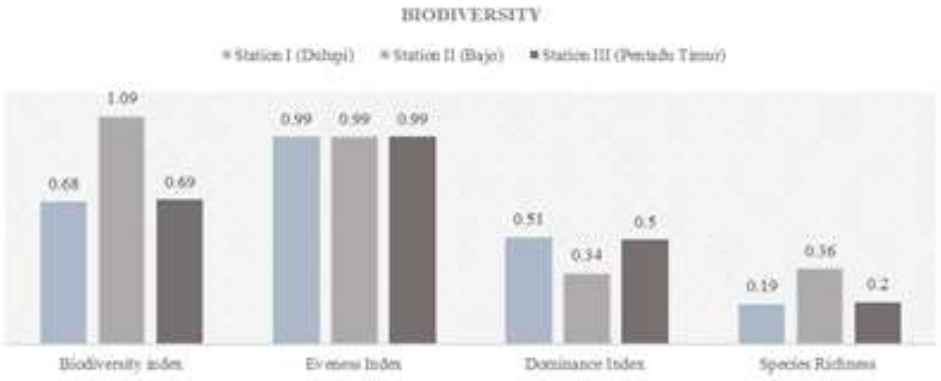


Figure 5. Biodiversity (Biodiversity index, Evenness Index, Dominance Index, and Species Richness of mudskipper fish in the research site

Environment Parameters

The results range of the temperature measurement at three research locations ~~were~~ was 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~~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. ~~The ecological condition of Station I (Duhupi) of mangrove area based on its visual look~~Based on its visual look, the ecological condition of Station I (Duhupi) of the mangrove area was still considered good-solid, posse~~s~~sing 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 ~~vital~~ strong values of mangrove plants. Based on its visual look, the ground texture of the mangrove forest ~~there~~ is sandy and muddy. Large rubbish ~~were~~ was scattered, and many mangrove saplings ~~were died and~~died and were broken. In station III (East Pentadu), according to its visual appearance, the ground texture of the mangrove was muddy. ~~The~~ However, the mangrove condition was still considered good, and the regeneration of the growing ~~sappling~~ saplings in the area ~~is~~ was considered quick and plenty.

~~Tabel~~ 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
~~Subtrat~~ Substrate pH	7.5-8	6.8-7	6.8-7.5

Discussion

~~There were five species mudskipper fish that~~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 ~~even though mudskipper fish spread in~~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). Periopthalmus tends to stay in mangrove ecosystems. That~~is~~ is due to the existence of many detritus, small crabs, small fish, shrimps, and arthropods in mangrove~~s~~ which are food for Periophthamus (~~Rha'ifa~~ Rha'ifa et al. 2021). Thus, the result of this study was in line with previous studies ~~which were~~ conducted in the coastal ecosystems around Indo-Pacific (Pormansyah et al. 2019). ~~,~~ S~~s~~uch as Maluku (Rumahlatu et al. 2020; Taniwel et al. 2020), South Sumatera (Ridho et al. 2019), West Nusa Tenggara (~~Rha'ifa~~ Rha'ifa et al. 2021), Yogyakarta (Arisuryanti et al. 2018), North Sulawesi (Polgar et al. 2017), Java and Bali (Dahruddin et al. 2017), Malacca Strait and Malay Peninsula (Polgar et al. 2014). ~~All species found by researcher~~Researchers found all species possessed high similarity in morphological features because they are part of the same Genus (Table 2).

a. *Periophthalmus minutus*
D_I XVI, D_{II} 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 a magnification (Jaafar & Murdy (2017).

b. *Periophthalmus malaccensis*
D_I XI, D_{II} 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~~ First spine elongated; D2 with faded brown stripe mesial; ~~D1 and D2 are not connected by a membrane~~ 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* ~~also~~ has bright blue spots on the chin and operculum, it also has prominent transverse folds on the snout (Polgar 2016).

Reviewer
Large amounts of rubbish

Revised as suggested

Reviewer
Muddy

Revised as suggested

Reviewer
italicize here

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

c. *Periophthalmus variabilis*
D_1 XI, D_2 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 a single inframarginal brown strip with many proximal white spots, first The first spine elongated, white margin; D2 with single inframarginal orange stripe and black single stripe mesial. R, with reddish-orange spots at the base; the anal fins are orange, at least at the margins; AD1 and D2 are not connected by a membrane 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).

d. *Periophthalmus argentilineatus*
D_1 XIII, D_2 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). The total of transverse scale from ventroposterior D2 basal to the basal of the anal fin is 18-26 (Jaafar & Murdy (2017).

e. *Periophthalmus kalolo*
D_1 XI, D_2 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 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 of transverse scale from ventroposterior D2 basal to the basal of anal fin is fewer than *Periophthalmus argentilineatus* thattransverse scale from ventroposterior D2 basal to the basal of anal fin is fewer than Periophthalmus argentilineatus, which is only 18-22 (Jaafar & Murdy (2017).

Morphological adaptations of mudskipper fish created variations in morphometric and meristic measurements (Nugroho et al. 2016; Dinh et al. 2020; Ghanbarifardi et al. 2020). Jaafar & 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 epaxialis muscle attaching anteriorly of the frontal and epioccipital junction can could distinguish genera in the familyFamily. 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 genusGenus. 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 many factors including 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.

The difference in species diversity between the three stations is influenced by environmental condiEnvironmental conditions influence the difference in species diversity between the three stations. The high and low species diversity was influenced by many factorsMany 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 level of 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 evenness in the three locations was stable. The Evenness index shows the degree of Evenness evenness of individual abundance between each species. If each species has the same number of individuals, then the community has a maximum Evenness valueThe 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, it means that the distribution is more even (Ludwig and Reynolds 1988; Baderan et al. 2021). Figure 3 presents the index of Evenness 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 ofpundant 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 resultedn 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 conducted 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 fell to the ground and decomposed to form soil organic matter (Tajbakhsh et al. 2018). The pH of the substrate PH greatly affects the resistance of organisms that live at the bottom of the waters, both infauna and epifauna. Thatis occurred due to the influence of tidal or brackish water during the formation of this land and subsequent tidal processes. Furthermore, Kanejiya et al. (2017) explained that the distribution of mudskipper fish was significantly influenced by environmental factors such as pH, temperature, salinity, and the other ecological conditions (Ghanbarifardi et al. 2014). Regarding Therefore, regarding to the presence of mudskipper fish with substrate conditions in the mangrove area at the three stations, added thathe 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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Reviewer
italicize here

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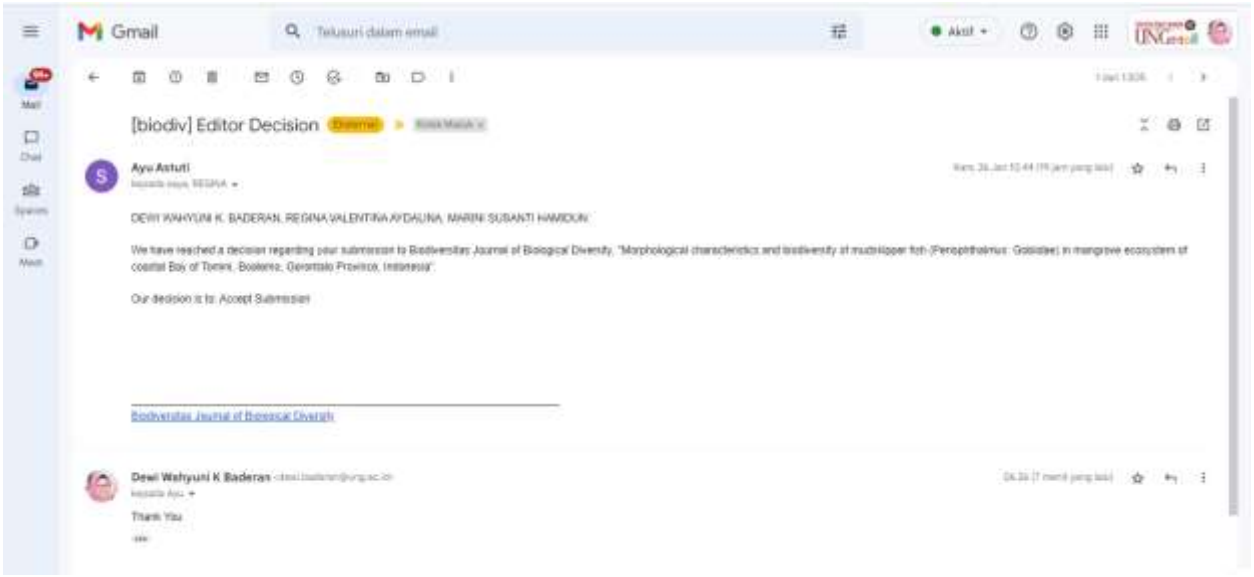

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Morphological characteristics and biodiversity of mudskipper fish (*Periophthalmus*: Gobiidae) in mangrove ecosystem of coastal Bay of Tomini, Gorontalo Province, Indonesia

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[2]Wallacea Research Centre For Biodiversity Conservation and Climate Change, Universitas Negeri Gorontalo, Jl. Sandoral Sudirman No.06 Kota Gorontao. Tel: (0435)821123, Fax: (0435)821752.

Manuscript received: xxx 2023. Revision accepted: xxx January 2023.

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: xxxx.* 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 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 R_1 in each station was respectively (0.19); (0.36); and (0.2). 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, 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; Luquin et al. 2019), 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 Lateconnisa (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 (Mahadevan 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 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 (Makharomah et al. 2016). Its pectoral fin on its muscular base can be buckled to function like on 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±4.49 mg/g), protein (3.5±0.35 mg/100mg), and 1.5 ± 0.47mg/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 (Prasno 2020).

The mudskipper species identified until today are around 43 species in 10 genera (Polgar et al. 2013; Rapp 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), station II (Bajo Village), and station III (East Penahki 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 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 indicating the sampling sites of Periophthalmus: 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)

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 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; 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.

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). $H' = -\sum_{i=1}^{S} pi \ln pi$ where $pi = \frac{ni}{N}$. H' represents the Shannon-Wiener Diversity index, S for total species, Ni 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 ≤ H' ≤ 3: Medium species diversity, H' < 1: Low species diversity.

The species-evenness index analyzed species evenness (K) data referred to the Pielow 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: $D = \sum \frac{(ni\,(ni-1))}{(N\,(N-1))}$. 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 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; Keebs 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 argentilineatus*, *Periophthalmus kalolo*, *Periophthalmus malaccensis*, *Periophthalmus minutus*, and *Periophthalmus variabilis*. The total number of mudskipper fish found in Tomini Bay, Boalemo's coastal mangrove area, is as many as 561 individuals. Spreading across station I-Dulupi village (156 individuals), station II-Baju 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.

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 sandy and muddy textures of ground habitat with mangroves growing on it. In Station II (Baju), 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.

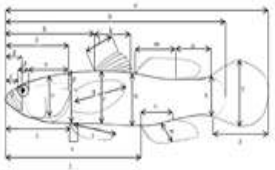


Figure 2. Morphometric characterization scheme of the mudskipper. (a) total length, (b) standard length, (c) Pre-orbital length, (d) eye diameter, (e) post-orbital length, (f) post-orbital length, (g) mouth length, (h) pre-dorsal length, (i) pre ventral length, (j) pre-anal length, (k) first dorsal fin 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 spin, (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, Boalemo, Gorontalo Province

Class, Family	Species	Station			Total Number of Individuals
		I Dulupi	II Baju	III East Pentadu	
Actinopterygii					
Gobiidae	*Periophthalmus argentilineatus*	–	–	83	83
	Periophthalmus kalolo	67	–	–	67
	Periophthalmus malaccensis	89	98	–	187
	Periophthalmus minutus	–	75	–	75
	Periophthalmus variabilis	–	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, Boalemo, Gorontalo Province

Characters	*P. minutus*	*P. malaccensis*	*P. variabilis*	*P. argentilineatus*	*P. kalolo*
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	-	-	+	-	-

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

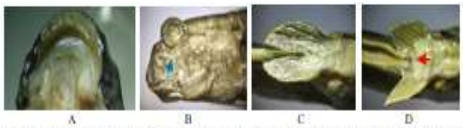
Characters	*P. minutus*	*P. malaccensis*	*P. variabilis*	*P. argentilineatus*	*P. kalolo*
Pre-orbital length	0.051	0.029	0.035	0.061	0.037
Eye diameter	0.060	0.060	0.060	0.076	0.068
Head length	0.152	0.160	0.137	0.118	0.136
Snout length	0.273	0.274	0.264	0.247	0.256
Post-orbital length	0.506	0.070	0.054	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

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.

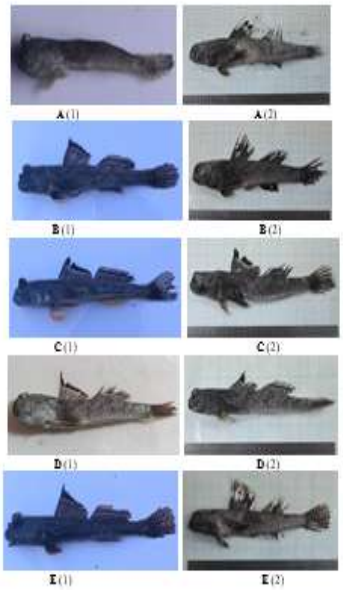
Table 4. Comparison of Meristic Characters of Mudskipper Fish in the coastal mangrove ecosystem of Tomini Bay, Boalemo, Gorontalo Province

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



A B C D

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. A red arrow showed the frenum.



A (1) A (2)
B (1) B (2)
C (1) C (2)
D (1) D (2)
E (1) E (2)

Figure 4. Mudskipper fish in the coastal mangrove ecosystem of Tomini Bay, Boalemo, Gorontalo Province. A. Periophthalmus minutus; B. P. malaccensis; C. P. variabilis; D. P. argentilineatus; E. P. kalolo. Figure 2 is a photo of a specimen that had been preserved under a -50oC temperature for one month.

Biodiversity of Mudskipper Fish Species

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).

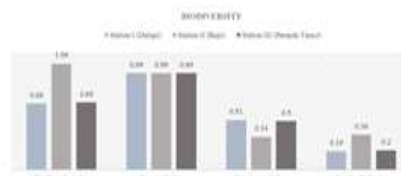


Figure 5. Biodiversity (Biodiversity index, Evenness Index, Dominance Index, and Species Richness of mudskipper fish in the research site

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). Periopthalmus 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 Periophthamus (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 (Pormanoyah et al. 2019). Such as Maluku (Rumahlatu et al. 2020; Tanjwel et al. 2020), South Sumatera (Ridho et al. 2019), West Nusa Tenggara (Rha'ifa et al. 2021), Yogyakarta (Arisuryanti et al. 2018), North Sulawesi (Polgar et al. 2017), Java and Bali (Dahruddin 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_1XVI, D_2I, 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 & Murdy (2017).

Periophthalmus malaccensis

D_1 XI, D_2 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_1 XI, D_2 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).

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 pH	7.5-8	6.8-7	6.8-7.5

Periophthalmus argentilineatus

D_1 XIII, D_2 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). The total transverse scale from ventroposterior D2 basal to the basal of the anal fin is 18-26 (Jaafar & Murdy (2017).

Periophthalmus kalolo

D_1 XI, D_2 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 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 & Murdy (2017).

Morphological adaptations of mudskipper fish created variations in morphometric and meristic measurements (Nugroho et al. 2016; Dinh et al. 2020; Ghanbarifardi et al. 2020). Jaafar & 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 epaxialis 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-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. 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 eventess 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 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 fell to the ground and decomposed to form soil organic matter (Tajhakhoh 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, Kaneyya 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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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 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 R_i in each station was respectively (0.19); (0.36); and (0.2). 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 Latuconsina (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 (Mahadevan 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 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; Bidhwi et al.

2017). *Boleophthalmus boddarti*, one of the mudskipper fish species, has a high 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 (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 (Paino 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°30.640, E 122°26.982), station II (Bajo Village, N 00°29.818, E 122°20.931), and station III (East Penatih Village, N 00°30.736, E 122°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).

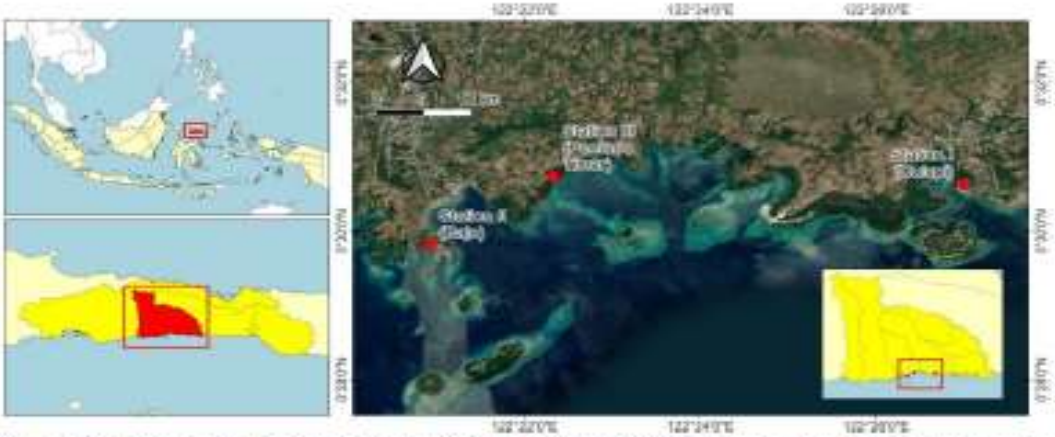

Figure 1. Location of the coastal bay of Tomini, Boalemo, Gorontalo Province, Indonesia, indicating the sampling sites of *Periophthalmus*, i.e.: station I (Dulupi Village), station II (Bajo Village), and station III (East Penatih Village)

Tools and materials

The tools used were a scoop net, a 3x3 sq. 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 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.

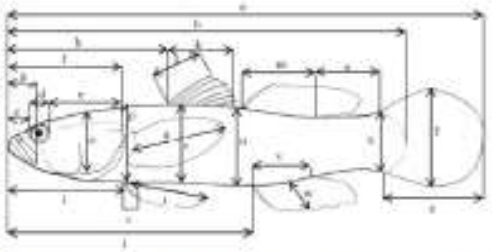

Figure 2. Morphometric characterization scheme of the mudskipper: a. total length; b. standard length; c. Pre-orbital length; d. eye diameter; e. post-orbital length; f. post-orbital length; g. mouth length; h. pre-dorsal length; i. pro ventral length; j. pre-anal length; k. first dorsal fin base length; 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 spin; 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). $H' = -\sum_{i=1}^{S} pi \ln pi$ where $pi = \frac{ni}{N}$. H' represents the Shannon-Wiener Diversity index, S for total species, Ni 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≤ H'≤3: Medium species diversity; H'<1: Low species diversity.

The species-evenness index analyzed species evenness (K) data referred to the Pielow 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): $R_I = \frac{(S-1)}{(\ln (N))}$, which R_I 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: $D = \sum \frac{(ni\,(ni-1))}{(N\,(N-1))}$ 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 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 Dulupi 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	*Periophthalmus argentilineatus*	-	-	83	83
	Periophthalmus kalolo	67	-	-	67
	Periophthalmus malaccensis	89	98	-	187
	Periophthalmus minutus	-	75	-	75
	Periophthalmus variabilis	-	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

Characters	Mudskipper fish				
	P. minutus	*P. malaccensis*	*P. variabilis*	*P. argentilineatus*	*P. kalolo*
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	-	-	+	-	-

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

Characters (cm)	Mudskipper fish				
	P. minutus	*P. malaccensis*	*P. variabilis*	*P. argentilineatus*	*P. kalolo*
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 peduncultu 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 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	
Periophthalmus minutus	16	0	1	12	0	11	0	13	0	6	0	13	60
Periophthalmus malaccensis	11	0	1	12	0	11	0	11	0	6	0	14	58
Periophthalmus variabilis	14	0	1	12	0	12	0	13	0	6	0	16	52
Periophthalmus argentilineatus	13	0	1	12	0	12	0	12	0	6	0	16	70
Periophthalmus kalolo	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 (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 pH	7.5-8	6.8-7	6.8-7.5

Figure 3. The characteristics of mudskipper 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 frenum; D. Pelvic fin without frenum. A red arrow showed the frenum

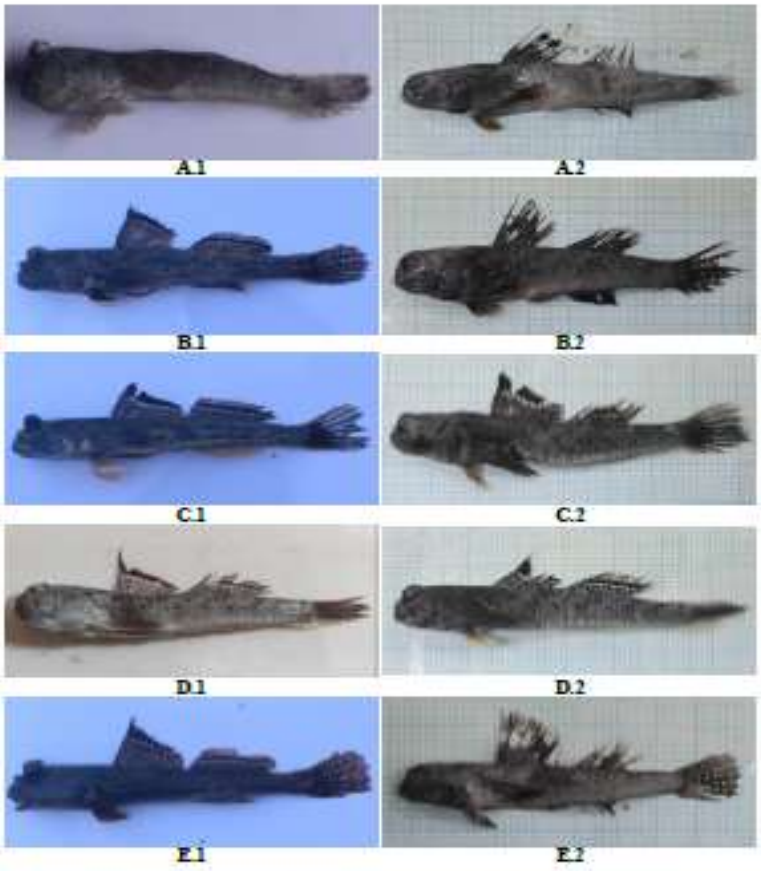

Figure 4. Mudskipper fish in the coastal mangrove ecosystem of Tomini Bay, Boalemo, Gorontalo Province, Indonesia. A. *Periophthalmus minutus*; B. *Periophthalmus malaccensis*; C. *Periophthalmus variabilis*; D. *Periophthalmus argentilineatus*; E. *Periophthalmus kalolo*. These specimens had been preserved under a -50°C temperature for one month

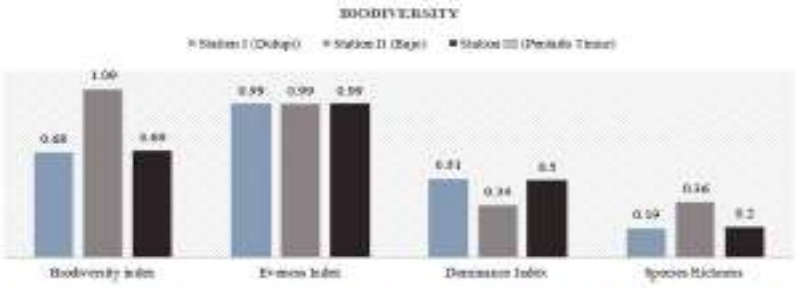

Figure 5. Biodiversity (Biodiversity index, Evenness Index, Dominance Index, and Species Richness of mudskipper fish in the research site of Tomini Bay, Boalemo, Gorontalo Province, Indonesia

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). *Periopthalmus* 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 *Periopthamus* (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 (Pormansyah et al. 2019). Such as Maluku (Rumahlatu et al. 2020; Taniwel et al. 2020), South Sumatera (Ridho et al. 2019), West Nusa Tenggara (Rha'ifa et al. 2021), Yogyakarta (Arisuryanti et al. 2018), North Sulawesi (Polgar et al. 2017), Java and Bali (Dahruddin 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_1 XVI, D_2 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_1 XI, D_2 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_1 XI, D_2 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_1 XIII, D_2 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). 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_1 XI, D_2 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 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; Dinh 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 epaxialis 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-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. 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 (RI) 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 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 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 infauna and epifauna. That occurred due to the influence of tidal or brackish water during the formation of land and subsequent tidal processes. Furthermore, Kanejiya 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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