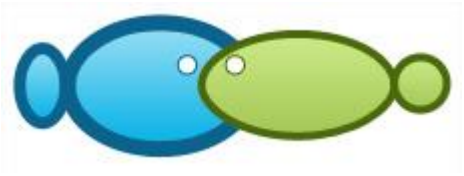

Morphological characters of the giant mottled eel (*Anguilla marmorata*) from the waters of Sulawesi, Indonesia

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Abstract. The present study aimed to determine the morphological characters of the giant mottled eel (*Anguilla marmorata*) from the waters of Sulawesi. The evaluation of six morphological characters, namely the body height at front pectoral fin (BHPF), body height at front dorsal fin (BHDF), body height at front anus (BHA), dorsal fin height (DFH), anal fin height (AFH) and caudal fin height (CFH), was conducted in 130 individuals of giant mottled eel originating from the Sioyong, Sausu, Tambu, and Buol Rivers in Central Sulawesi; Pondidaha River in South East Sulawesi, and Likupang River in North Sulawesi. An analysis of discriminating morphological characters was conducted using the discriminant analysis (DA) and the kinship evaluation was conducted based on the agglomerative hierarchical clustering (AHC). The analysis results revealed that the BHPF, BHDF, BHA, CFH, and DFH characters contributed to differences in the morphological characters between the populations. The six populations analyzed formed three groups. In general, there were differences in the morphological characters of *A. marmorata* from the waters of Sulawesi.
Key Words: habitat characteristics, distinguishing characters, fin, body height, Sulawesi.

Introduction. Indonesia is recognized to have at least nine species/subspecies of the giant mottled eel (Sugeha & Suharti 2008) from approximately seventeen species in the world (Tesch 1977), which include *Anguilla bicolor bicolor*, *A. nebulosa nebulosa*, *A. bicolor pacifica*, *A interiorisis*, *A. borneensis*, *A. celebensis*, *A. marmorata*, *A. obseura* and *A. megastoma.* The distribution is from along the coast of Sumatra, the southern coast of Java, Bali, West Nusa Tenggara, East Nusa Tenggara, along the western coast of Kalimantan, the waters of Sulawesi, Maluku to the waters of Papua (Fahmi 2015). The giant mottled eel (*Anguilla marmorata*) is one of the species distributed in the waters of Sulawesi as its natural habitat.

The characteristics of the habitat in the waters of Sulawesi support the presence of *A. marmorata*. Fish adapt to the environment and their morphological characteristics vary for different habitats, with changes in the body shape, color and fins (Matthews 1998). Analysis of morphological characters in *A. marmorata* is needed as basic information about morphological variation and kinship. Morphological characters in *A. marmorata* which are commonly evaluated include the total length, head length, pre-dorsal head length, pre-anal length, pre-dorsal length, and anodorsal. In addition to these characters, morphological evaluation has also been conducted on the vomarine teeth, body color, anodorsal length rations, and vertebral counts (Edge 1939) and on the eyes (Atta 2013).

Numerous studies pertaining to morphological characters in *A. marmorata* have been conducted, including those by Hewavitharane et al (2017), Kadir et al (2017), Hwang et al (2015), Sugeha & Genisa (2015), and Lin et al (2005). Studies regarding the morphology of *A. marmorata* in the waters of Sulawesi have also been conducted by Hartanto et al (2015) in the Likupang River and by Ndobe (2010) in the Palu River. However, studies that comparatively evaluated morphological characters in several rivers

of Sulawesi using methods that are related to the measurement of the height of certain body parts have never been reported.

Therefore, morphological information of *A. marmorata* found in the waters of Central Sulawesi (Sioyong River, Sausu River, Tambu, and Buol River), South East Sulawesi (Pondidaha River), and North Sulawesi (Likupang River) by evaluating characters that are related to the fins and body height is needed.

Material and Method

Sample collection. A collection of 130 *A. marmorata* samples was conducted in the waters of Sulawesi: 26 samples from the Sioyong River, 22 samples from the Sausu River, 21 samples from the Tambu River and 11 samples from the Buol River in Central Sulawesi; 24 samples from the Pondidaha River in South East Sulawesi, and 26 samples from the Likupang River in North Sulawesi. The *A. marmorata* sample collection was conducted using wooden fish traps (bubu). The collected samples of *A. marmorata* were placed in styrofoam containers that had been previously prepared in order to be analyzed in the laboratory.

Sample measurements. The *A. marmorata* samples morphological characters were measured, including the body height at front pectoral fin (BHPF), body height at front dorsal fin (BHDF), body height at front anus (BHA), dorsal fin height (DFH), anal fin height (AFH), and caudal fin height (CFH) (Figure 1). These were observed and equated with the characteristics from the eel identification books (Tabeta et al 1976; Tesch et al 2003; Silfvergrip 2009) with modifications. Morphological measurements were taken using a ruler (0.1 cm accuracy).

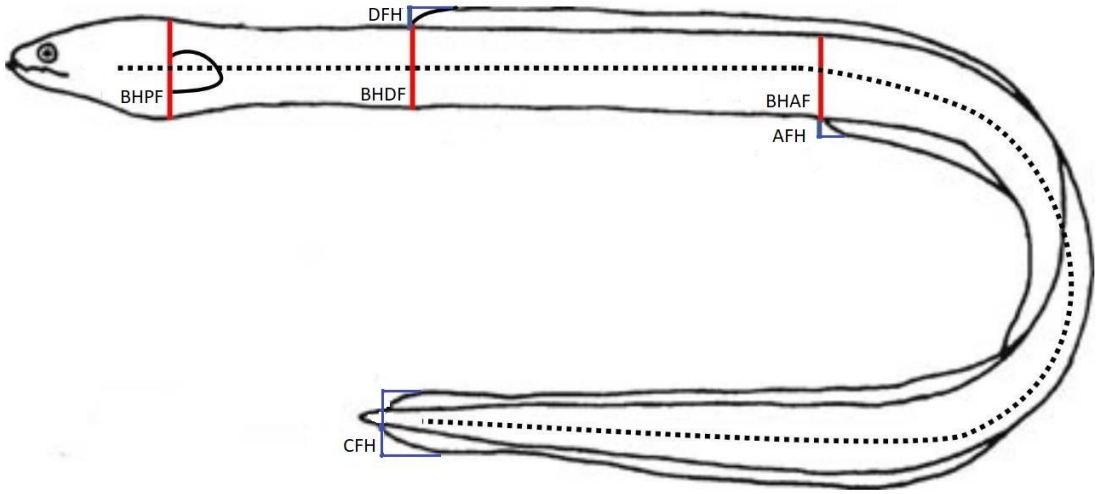

Figure 1. The *Anguilla marmorata* morphology (original).

Data analysis. The morphological data were analyzed using the Excel 2007 and SPSS 16 software programs; evaluation of discriminating characters was conducted based on the discriminant analysis (DA) and kinship evaluation based on agglomerative hierarchical clustering (AHC). Avoiding the effects of different size and ages differences, characteristic values were standardized based on the equation $M_s=M_o(L_s/L_o)^b$ as formulated by Konan et al (2010). M_s was standardized individual characteristics, M_o=the length of measured character, L_s=standard average length, L_o=standard length of individual, b=slope of the regression of $\log_{10}M_o$ on $\log_{10}L_o$ as formulated by Konan et al (2010), Lleonart et al (2000), and Ferrito et al (2007).

Results

Discriminating character. The analysis results revealed a cumulated variance of

89.41% of the morphological characters as population discriminants, for the first two discriminant functions, F1 and F2, namely 70.92% and 18.49% (Table 1). This information suggests that the function of the first discriminant has a discriminating ability of 70.92%, which was higher than the function of the second discriminant which had a discriminating ability of 18.49%.

Table 1

The eigenvalue of morphological characters in *Anguilla marmorata* of the populations comprised in the present study

Value	*Function*				
	F1	*F2*	*F3*	*F4*	*F5*
Eigenvalue	3.4412	0.8973	0.3587	0.1391	0.0160
Discrimination (%)	70.9191	18.4926	7.3932	2.8658	0.3293
Cumulative (%)	70.9191	89.4117	96.8049	99.6707	100.000

The F notation in Table 2 is F-value calculated from the sample. DF1 is the degree of freedom of group (6 populations - 1) and DF2 is the degree of freedom of observation (130 samples - 6 populations). The six morphological characters observed demonstrated different variances and contributed as discriminators in the *A. marmorata* population ($P<0.05$) (Table 2).

Table 2

The value of the unidimensional test of equality of the means of the classes of the morphological characters in *Anguilla marmorata* in the populations comprised in the present study

Characters	*Lambda*	*F*	*DF1*	*DF2*	*p-value*
BHPF	0.2934	59.7262	5	124	<0.0001
BHDF	0.2799	63.7880	5	124	<0.0001
BHA	0.3201	52.6696	5	124	<0.0001
DFH	0.4271	33.2650	5	124	<0.0001
AFH	0.5518	20.1432	5	124	<0.0001
CFH	0.4054	36.3761	5	124	<0.0001

The character that had a more important contribution as a discriminant was DFH in F1, whereas in F2 the contribution of the BHDF character was greater than the others (Table 3).

Table 3

The value of standardized canonical discriminant function coefficients of the morphological characters of *Anguilla marmorata* in the populations comprised in the present study

Characters	*Function*				
	F1	*F2*	*F3*	*F4*	*F5*
BHPF	0.3974	0.2111	-0.4453	-0.9469	-0.8524
BHDF	0.3041	-1.2235	-0.8817	1.2493	0.0924
BHA	0.1174	0.3629	1.3463	-0.7494	0.9967
DFH	0.4756	0.6052	-0.7207	-0.4326	0.2870
AFH	-0.2299	0.1408	0.3161	0.7297	0.3075
CFH	0.3018	0.3071	0.5039	0.3796	-0.6605

The morphological character contributions which had strong roles in classifying the population from strongest to weakest were BHDF, BHPF, BHAF and CFH in F1 and DFH in F2 (Table 4).

Table 4

The correlation matrix structure of the morphological characters of *Anguilla marmorata* in the populations comprised in the present study

Characters	*Function*				
	F1	*F2*	*F3*	*F4*	*F5*
BHDF	.824*	-.510	.029	.146	.179
BHPF	.823*	-.276	.058	-.237	-.158
BHA	.758*	-.299	.416	-.168	.356
CFH	.615*	.310	.384	.388	-.450
DFH	.514	.640*	-.408	.158	.362
AFH	.420	.427	.011	.532*	.303

* Largest absolute correlation between each variable and the discriminant functions.

Similarities. Based on the DA plot (Figure 2), the discriminant 1 function on the X axis strongly separated the *A. marmorata* populations of Buol and Likupang from those of Sausu, Sioyong, and Pondidaha. In addition, the discriminant 2 function on the Y axis separated the *A. marmorata* population of Pondidaha from the populations of Sausu and Sioyong. The discriminant 2 function also separated the *A. marmorata* populations of Buol from that of Likupang. On the other hand, the populations of Sioyong and Sausu were not separated by any of the axis. The population of Tambu tended not to be strongly separated from the other *A. marmorata* populations. The results of the dissimilarity analysis based on morphology (Figure 3) formed 3 population clusters of the *A. marmorata* with a similarity level of >95%. Cluster I consisted of the following populations: Buol and Likupang, cluster II consisted of only the Pondidaha population, and cluster III consisted of Tambu, Sioyong, and Sausu populations.

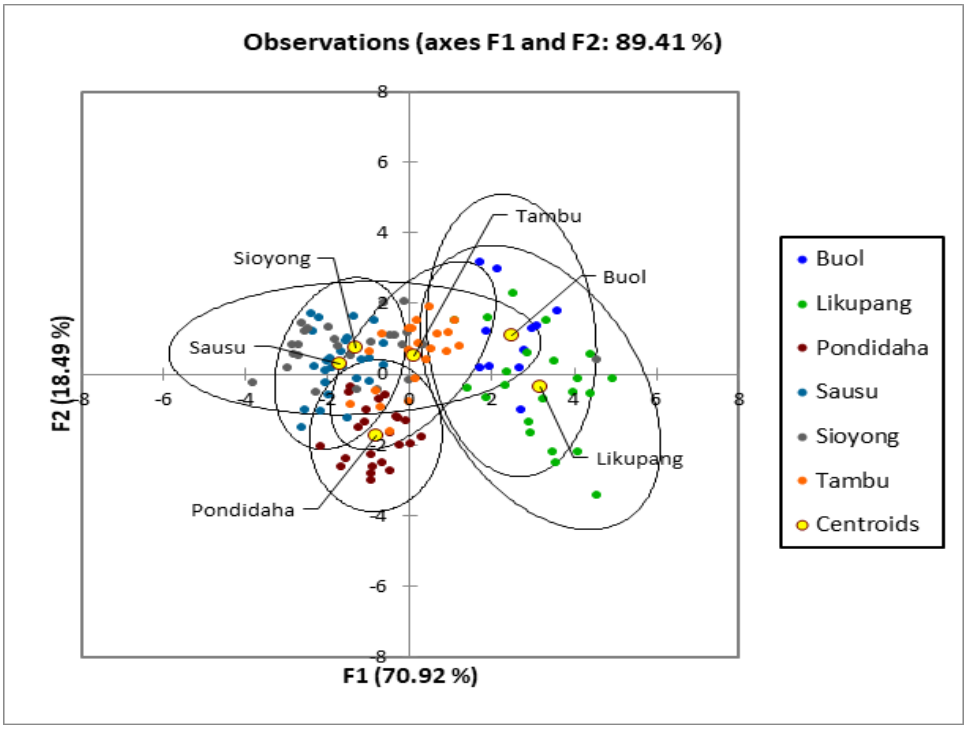

Figure 2. The morphological character scatter plot of the *Anguilla marmorata* populations comprised in the present study based on the discriminant 1 function and discriminant 2 function.

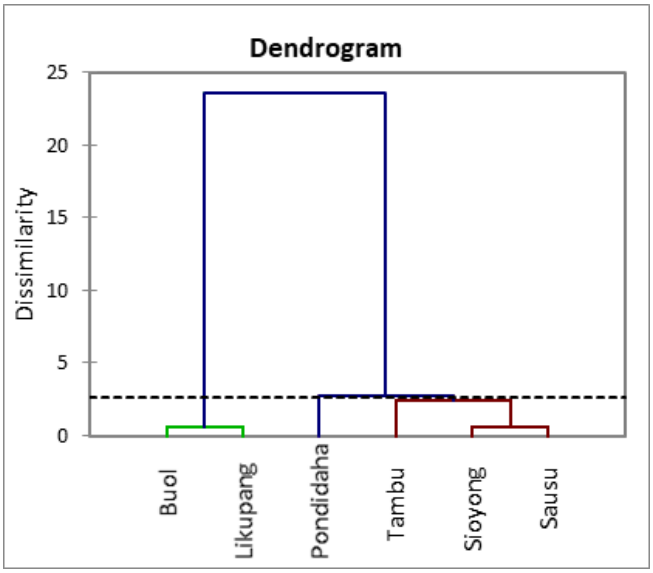

Figure 3. The dissimilarity dendrogram based on the morphology of *Anguilla marmorata* in the populations comprised in the present study.

Discussion. Based on the results of the analyses conducted on six morphological characters of *A. marmorata* from six populations in the waters of Sulawesi, it was revealed that the six populations had different morphological characters. These morphological characters contributed to dissimilarities between the populations. The characters that had a strong role in discriminating the population groups were all the characters evaluated except for the anal fin height (AFH). The body height at front pectoral fin (BHPF), body height at front dorsal fin (BHDF), body height at front anus (BHA), caudal fin height (CFH) discriminated between the Buol, Likupang populations and the Sausu, Sioyong, Pondidaha populations. On the other hand, the dorsal fin height (DFH) character discriminated between the Pondidaha population and the Sausu, Sioyong population. The DFH character also discriminated between the Buol population and the Likupang population. All these discriminating characters are related to fins. The role of the BHDF character as the discriminating morphology in the giant mottled eel from the waters of Sulawesi demonstrated that *A. marmorata* from the waters of Sulawesi had different body height. This character has also been used by Hewavitharane et al (2017) to identify species and morphological differences in glass eel.

The fin characters have been used in classifying the fin types of *A. marmorata* as Edge (1939) who stated that the *A. marmorata* genus consisted of 2 types i.e. ADL (ano dorsal length)/TL (total length), in %, those with long fins and those with short fins. Furthermore, Sugeha & Suharti (2008) and Sugeha (2010) divided the fin types of *A. marmorata* from Indonesia into 3 categories depending on the ADL/TL ratio values: the short-finned ≤6%, the moderate finned between 7–13%, and the long-finned ≥14%.

The results of the dissimilarity analysis formed 3 population clusters of *A. marmorata*. The lowest dissimilarity was found in cluster I, between the Buol population and Likupang population. These two populations were found in different provinces: the Buol population is found in Central Sulawesi while the Likupang population is found in North Sulawesi. Even though the two populations are found in different areas, they have more similar morphological characters, due to the almost identical characteristics of the living environments of the two populations. The highest dissimilarity was found between the cluster I population and the Pondidaha population which was placed in cluster II. The cluster III population consisted of the Tambu, Sioyong, and Sausu populations which originated from Central Sulawesi. The placement of these three populations in the same group could be justified by their origin situated in closely positioned habitats, allowing them to have nearly identical evolutionary conditions.

Conclusions. According to our study, *A. marmorata* originating from the Sulawesi waters had different morphological characters, among which BHPF, BHDF, BHA, CFH, and

DFH were distinguishing characters. The dissimilarities of the morphological trades of the six eel populations determined three clusters, evolving in nearly similar environmental conditions.

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