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Morphological differentiation among estuarine catfishes of the family Ariidae of the Matang mangrove ecosystem, Perak, Malaysia

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ABSTRACT Morphometric and meristic analysis indicates that the six species of the ariid catfishes of the genera *Arius* recorded from Sungai Selinsing of the Matang mangroves can be distinguished on the basis of their pre-dorsal length, inter-orbital width, number of gill rakers and head length. *Arius sangor* has the longest pre-dorsal length and the widest inter-orbital width while *Arius truncatus* has the lowest number of gill rakers. *Arius maculatus* is separated from all other ariids of the area in having the highest number of gill rakers while *A. caelatus* is a species with the longest dorsal spine. Discriminant analysis employed has shed valuable insights on these morphological differentiations.

ABSTRAK Analisis morphometrik and meristik menunjukkan ke enam-enam spesies belukang daripada genus *Arius* yang direkodkan di paya bakau Matang boleh dibezakan berdasarkan panjang pre-dorsal, kelebaran inter-orbital, jumlah sisir insang dan panjang kepala. *Arius sagor* memiliki pre-dorsal yang terpanjang dan inter-orbital terlebar sementara *A. truncatus* mempunyai jumlah sisir insang yang paling sedikit. *Arius maculatus* dibezakan daripada semua belukang di kawasan ini dengan memiliki jumlah sisir insang paling banyak sementara *A. caelatus* adalah spesies belukang yang mempunyai spina dorsal terpanjang. Analisis discriminan yang digunakan berjaya memberikan gambaran yang mendalam mengenai perbezaan morfologi spesies *Arius* yang dikaji.

(morphometric, meristic, ariid catfishes, discriminant analysis)

INTRODUCTION

Fish species are generally distinguished by their external morphology. Such is also the case with the estuarine catfish family Ariidae where morphological characters such as the bony head shield and the shape of the tooth patch on the roof of the mouth (palantines) are used [1, 2, 3, 4, 5, 6, 7, 8]. Lately, a few studies that incorporate a combination of morphometrics, meristics and morphological characters for taxa differentiation within the Ariidae have been carried out [9, 10, 11, 12, 13]. Kailola [13] differentiated 34 species of the Australo-Papuan ariids based on osteology, morphology, meristic and morphometric characters. Tilak [14] used characteristics of the osteocranium and the Weberian apparatus in characterising the family as well as the genus and species within the Ariidae.

This paper describes morphological differentiation of the various ariid catfishes found in the Matang mangroves, Perak. The discriminant analysis, based on morphometric and meristic characters, was used to differentiate the species.

MATERIALS AND METHODS

Fifty specimens of each ariid species were taken for morphometric and meristic measurements. Six morphometric characters measured were pre-dorsal length, head length, snout length, inter-orbital width, dorsal spine length and anal spine length as suggested by Kailola [13]. The two meristic counts were numbers of gill raker on the first gill arch and anal-fin ray. Morphometric measurements were recorded to the nearest 0.1 mm with a pair of calipers.

The eight variables were used in the discriminant analysis to defferentiate the six ariid species. To eliminate the influence of body size differences, all morphometric measurements were corrected for covariance in length and adjusted to the mean standard length [15, 16]. The discriminant analysis uses a linear combination of the discriminating variables ($X_{1 \ldots p}$) in the form of $Z = a_1X_1 + a_2X_2 + \ldots\ldots + a_pX_p$. The coefficients a_1, $a_2 \ldots a_p$ were chosen so as to maximize the F ratio for a one way analysis of variance. The Mahalanobis distance [17] was used to determine distance between the ariid species in relation to the discriminant variables measured [18].

Discriminant analysis was performed using the stepwise discriminant function analysis (SDFA) on the corrected morphometric measurements and meristic counts of the six *Arius* species. Scatter plots were then made on the best discriminant functions. The discriminant analysis was run on a PC using the statistical software Statistica version 5.0 [19].

RESULTS AND DISCUSSION

Table 1 shows means of morphometric measurements adjusted for standard length of the ariids of Matang mangrove. *Arius sagor* has the longest head, pectoral spine, pre-dorsal, snout and inter-orbital lengths, and it is clearly differentiated from all other ariid species based on these characters. Members of the ariid fishes have 17 to 24 anal-fin rays (Table 2). However, the number of the rays is overlapped among the species and it is not a good character for species differentiation. *Arius truncatus* is different from other species in having the least number of gill rakers, ranging from eight to eleven, while *A. maculatus* is distinguishable from all other ariids by possessing 18 to 22 gill rakers (Table 3). All of these characters have been widely used in previous studies on ariid catfish elsewhere [2, 3, 7, 12].

Results of discriminant analysis indicate that the selected characters are useful in distinguishing the six species of the genus *Arius* recorded from the Matang mangrove ecosystem. These characters have also been used with some degree of success in differentiating the species for specimens caught particularly in the western central Atlantic [4, 5] and eastern central Atlantic [6]. A similar finding was also observed by Kailola [13] in her study of the ariid fishes of the northern New Guinea.

The SDFA indicates that all the morphometric and meristic characters were included in the analysis, and their rankings, in the order they entered the analysis, is given in Table 4. The SDFA produces five discriminant functions, indicated as root 1, 2, 3, 4, and 5, with the first two functions explaining 88% of the total variation (Table 5). The means of the canonical variables (Table 6) show that the discriminant function 1 separates *Arius sagor* from the rest of the arrids, while discriminant function 2 separates *A. truncates*, discriminant function 3 separates *A. maculates* and discriminant function 4 separates *A. caelatus* from the rest of the ariids. Discriminant function 5 separates *A. utik* and *A. venosus* from the rest (Table 6). The factor structure matrix (Table 7) indicates that the variables pre-dorsal length and inter-orbital width contributed most to the first discriminat function while number of gill rakers and pre-dorsal length contributed most to the second discriminant function. Number of gill rakers contributed most to the third discriminant function while dorsal spine length contributed most to the 4th and head length to the 5th discriminat functions (Table 7).

The scatter plots of the discriminat function scores for all cases for root 1 and root 2 show that the *Arius* spp. can be separated based on pre-dorsal length, inter-orbital width and number of gill rakers on the first gill arch. *Arius sagor* and *A. truncatus* are clearly separated from the rest of the *Arius* species which are clustered into two groups; the first, comprising *A. caelatus* and *A. maculatus*, while the second consisting *A. venosus* and *A. utik* (Figure 1).

Although *A. maculatus* and *A. caelatus* were clustered together in the analysis of root 1 versus root 2 (Figure 1), they were separated when plotted under root 3 versus root 4 (Figure 2). The former has higher gill raker counts on its first gill arch (Table 3), while the latter has a long and robust dorsal spine (Table 1) and less gill raker counts on its first gill arch (Table 3). *Arius venosus* and *A. utik* are separated from other *Arius* spp. by having shorter pre-dorsal length and narrower inter-orbital width (Table 1) and it is shown when plotted under root 1 versus root 5 (Figure 3).

The Mahalanobis distance shows that *A. sagor* and *A. truncatus* are very different from each other as well as from the rest of the *Arius* spp. *Arius caelatus, A. maculatus, A. venosus* and *A. utik* are somewhat similar (Table 8 and Figure 3). Among the latter four species, *A. venosus* and *A. utik* are similar to each other, and also that they are more similar to *A. caelatus* than to *A. maculatus*. Misidentifications would most probably occur between *A. venosus* and *A. utik*. Overall, the discriminant model classified 100% of all cases of *Arius* spp. correctly (Table 9).

Table 1. Means of morphometric measurements of the six species of ariids of the Matang mangroves adjusted for standard length used in discriminant analysis. Fifty specimens were used for each species. Asterisk (*) indicates a highly significant difference ($p<0.01$).

Morphometric measurement	*Arius caelatus*	*Arius maculatus*	Arius *sagor*	*Arius truncatus*	*Arius utik*	*Arius venosus*	F Ratio
Dorsal spine length	41.70 ± 2.14	37.85 ± 1.47	39.34 ± 1.61	40.12 ± 2.00	27.06 ± 2.25	31.53 ± 1.84	433*
Head length	43.24 ± 2.12	46.64 ± 2.00	59.16 ± 1.84	51.36 ± 1.33	40.56 ± 1.33	39.11 ± 1.10	1078*
Inter-orbital width	15.62 ± 0.84	14.01 ± 1.01	23.64 ± 0.99	11.03 ± 0.61	12.20 ± 0.48	12.06 ± 0.51	1894*
Pectoral spine length	33.32 ± 1.82	34.71 ± 1.21	45.68 ± 1.68	30.45 ± 2.20	24.71 ± 0.98	28.51 ± 1.29	984*
Pre-dorsal length	57.37 ± 1.84	63.67 ± 2.08	80.96 ± 1.92	71.58 ± 1.67	52.34 ± 1.2	53.71 ± 1.14	2341*
Snout length	15.04 ± 0.82	16.87 ± 0.60	19.08 ± 0.76	14.93 ± 0.53	13.35 ± 0.39	13.44 ± 0.43	617*

Table 2. Frequency distribution of anal-fin ray counts in *Arius* of the Matang mangroves. Fifty pecimens were used for each species.

Anal-fin rays	17	18	19	20	21	22	23	24
A. caelatus		4	8	21	17			
A. maculatus			4		17	20	9	
A. sagor	3	21	23	3				
A. truncatus				1	12	21	15	1
A. utik		19	16	14	1			
A. venosus	2	16	25	6	1			

Table 3. Frequency distribution of gill raker counts in *Arius* of the Matang mangroves. Fifty specimens were used for each species.

Gill rakers	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
A. caelatus					1	2	30	14	3						
A. maculatus											5	9	21	13	2
A. sagor						11	13	24	2						
A. truncatus	13	32	3	2											
A. utik							10	20	15	5					
A. venosus							10	20	15	5					

Table 4. Ranking of the variables as they entered in the stepwise discriminant function analysis.

Ranking	Variables
1	Pre-dorsal length
2	Inter-orbital width
3	Gill raker count
4	Dorsal spine length
5	Pectoral spine length
6	Anal-fin ray count
7	Head length
8	Snout length

Table 5. Standardized coefficients for canonical variables of the six ariid species in discriminant analysis.

Discriminant Variables	Root 1	Root 2	Root 3	Root 4	Root 5
Anal-fin ray counts	0.15	-0.09	0.40	0.30	-0.04
Dorsal spine length	-0.08	-0.21	-0.08	0.97	0.08
Gill raker counts	0.05	0.48	0.77	-0.14	0.02
Head length	0.39	-0.27	0.03	-0.04	-1.22
Inter-orbital width	-0.57	0.78	-0.58	0.16	-0.13
Pectoral spine length	-0.44	0.27	0.17	-0.20	0.25
Pre-dorsal length	-0.67	-0.81	0.34	-0.48	0.81
Snout length	-0.11	0.25	0.23	0.42	-0.12
Eigen value	**60.42**	**38.69**	**7.21**	**5.84**	**0.69**
Cummulative Proportion	**0.54**	**0.88**	**0.94**	**0.99**	**1.00**

Table 6. Means of canonical variables of the six ariid species in discriminant analysis.

Groups	Root 1	Root 2	Root 3	Root 4	Root 5
Arius caelatus	0.54	3.61	-1.99	4.56	-0.21
Arius maculatus	0.05	2.88	7.76	1.05	-0.26
Arius sagor	-15.61	1.86	-0.77	-1.58	-0.02
Arius truncatus	1.01	-13.34	-0.05	0.30	-0.03
Arius utik	7.64	3.01	-1.12	-2.57	-1.21
Arius venosus	5.58	2.75	-0.40	-1.23	1.42

Table 7. Factor structure matrix for the six ariid species in discriminant analysis (Pooled-within-groups correlations).

Discriminant Variables	Root 1	Root 2	Root 3	Root 4	Root 5
Anal-fin ray counts	0.03	-0.18	0.29	0.30	-0.31
Dorsal spine length	-0.22	-0.16	0.07	0.83	0.25
Gill raker counts	0.03	0.51	0.73	-0.07	-0.01
Head length	-0.52	-0.27	0.11	-0.15	-0.72
Inter-orbital width	-0.70	0.32	-0.25	-0.05	-0.50
Pectoral spine length	-0.54	0.06	0.13	0.18	0.36
Pre-dorsal length	-0.75	-0.46	0.25	-0.21	-0.27
Snout length	-0.42	0.01	0.31	0.06	-0.38

Table 8. Squared Mahalanobis distances for the six ariid species in discriminant analysis.

Groups	*Arius caelatus*	*Arius maculatus*	*Arius sagor*	*Arius truncatus*	*Arius utik*	*Arius venosus*
Arius caelatus	0.00	110.58	309.89	316.13	105.56	66.27
Arius maculatus	110.58	0.00	333.13	332.67	153.69	107.54
Arius sagor	309.89	333.13	0.00	522.82	556.43	462.29
Arius truncatus	316.13	332.67	522.82	0.00	328.99	290.52
Arius utik	105.56	153.69	556.43	328.99	0.00	13.86
Arius venosus	66.27	107.54	462.29	290.52	13.86	0.00

Table 9. Classification matrix of six ariids species in discriminant analysis.

Groups	Per cent correct	Arius caelatus p = 0.177	Arius maculatus p = 0.099	Arius sagor p = 0.174	Arius truncatus p = 0.174	*Arius utik* p = 0.174	Arius venosus p = 0.199
Arius caelatus	100	50	0	0	0	0	0
Arius maculatus	100	0	50	0	0	0	0
Arius sagor	100	0	0	50	0	0	0
Arius truncatus	100	0	0	0	50	0	0
Arius utik	100	0	0	0	0	50	0
Arius venosus	100	0	0	0	0	0	50
Total	**100**	**50**	**50**	**50**	**50**	**50**	**50**

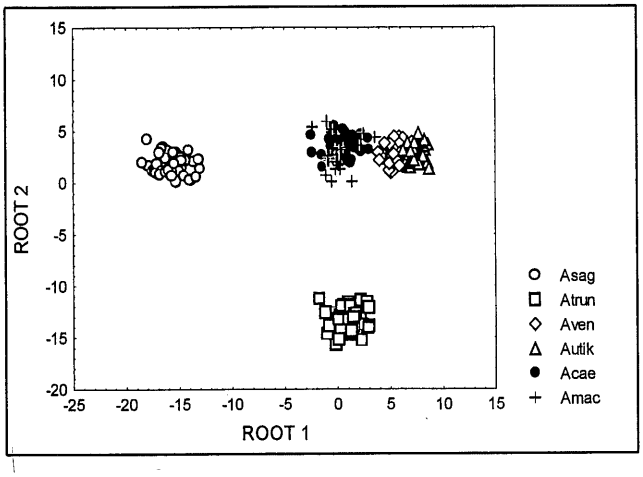

Figure 1. Scatter plots of the discriminant function for root 1 and root 2 of the morphometric and meristic variables of the six ariid species (Acae = *Arius caelatus*; Amac = *Arius maculatus*; Asag = *Arius sagor*; Atrun = *Arius truncatus*; Autk = *Arius utik*; Aven = *Arius venosus*.).

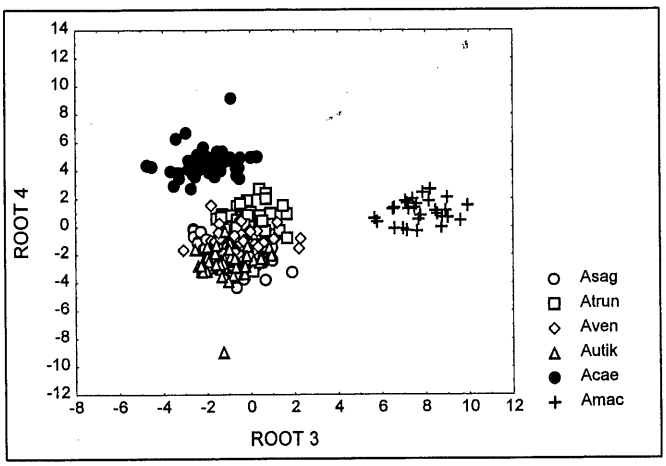

Figure 2. Scatter plots of the discriminant function for root 3 and root 4 of the morphometric and meristic variables of the six ariid species (Acae = *Arius caelatus*; Amac = *Arius maculatus*; Asag = *Arius sagor*; Atrun = *Arius truncatus*; Autk = *Arius utik*; Aven = *Arius venosus*).

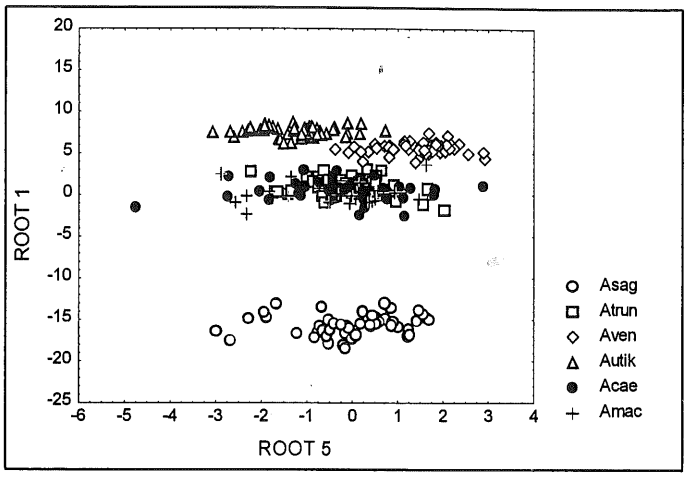

Figure 3. Scatter plots of the discriminant function for root 1 and root 5 of the morphometric and meristic variables of the six ariid species (Acae = *Arius caelatus*; Amac = *Arius maculatus*; Asag = *Arius sagor*; Atrun = *Arius truncatus*; Autk = *Arius utik*; Aven = *Arius venosus*).

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