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CHARACTERIZATION OF SIX LOBSTER SPECIES OF THE GENUS *PANULIRUS* (DECAPODA, PALINURIDAE) FROM ACEH WATERS, INDONESIA BASED ON MORPHOMETRIC ANALYSIS

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Characterization of Six Lobster Species of the genus *Panulirus* (Decapoda, Palinuridae) from Aceh Waters, Indonesia Based on Morphometric Analysis. Irfannur, I., Saputra, S., Muliari, M., Akmal, Y. & Batubara, A. S. — Aceh Province is a potential area for the exploitation of *Panulirus*, with six species of *Panulirus* inhabiting coastal areas and coral ecosystems in Aceh Province including *P. homarus, P. longipes, P. ornatus, P. penicillatus, P. polyphagus*, and *P. versicolor*. This study aims to characterise six species of *Panulirus* originating from Aceh as management and conservation efforts in the future. This research was conducted from 2022–2023 at Simeulue Island (*P. homarus*, *P. longipes*, *P. penicillatus*, and *P. versicolor*) and Aceh Jaya Regency (*P. ornatus* and *P. polyphagus*), Aceh Province, Indonesia. The collected samples were then transported to the Aquaculture Integrated Laboratory, Almuslim University, Indonesia for further analysis. The collected lobsters were of mature size (body weight and total length reaching 500 g and 18–25 cm) with a total of 10 individuals per species. A total of 58 morphometric characters were measured, of which total length (TL) was used as the coefficient of data transformation, so only 57 characters were subjected to statistical tests. Statistical analysis of the measured morphometric characters was performed using univariate ANOVA (analysis of variance) and multivariate DFA (discriminant function analysis) methods using SPSS Ver. 22. Univariate and multivariate morphometric

analysis allowed the classification of six *Panulirus* species based on their specific characters. A total of 51 out of 57 morphometric characters were significantly different ($P < 0.05$), while only the six characters were not significantly different. *P. ornatus* is the species with the highest species distance compared to the other five *Panulirus* species based on DFA analysis (scatter plot). Morphometric analysis to differentiate the six *Panulirus* species provides more comprehensive information on key morphological identification characters.

Key words: characters, significantly, comprehensive, univariate and multivariate.

Introduction

The genus *Panulirus* is a trading commodity that has high economic value in the world. There are 21 taxa that have been identified in this genus (Ptacek et al., 2001), where all of the taxa of this genus are threatened category (IUCN, 2023). This is because fishing activities are out of control (overfishing), while conservation efforts are still very limited. Not only mature size, the exploitation of puerulus-size *Panulirus* is increasingly being carried out in Indonesia for cultivation and export needs (Priyambodo et al., 2020). Therefore, monitoring of the *Panulirus* species must be routinely carried out to determine the ideal handler in the future.

The distribution of *Panulirus* covers the Indo-Pacific (Pollock, 1992), where Indonesia is the natural habitat of several *Panulirus* species. There are 8 species of lobsters scattered in Indonesian waters, namely *Panulirus femoristriga*, *P. homarus*, *P. longipes*, *P. ornatus*, *P. penicillatus*, *P. polyphagus*, *P. stimpsoni*, and *P. versicolor* (Wahyudin et al., 2016; Setyanto et al., 2019; Handayani et al., 2019; Madduppa et al., 2022). Apart from fulfilling the export market, *Panulirus* is also in great demand in the local market even though the price is relatively high. This triggers more intensive fishing activities for this group of species (Lastria et al., 2023).

The distribution of *Panulirus* in Indonesia includes the island of Bali (Asvin et al., 2019), Java (Milton et al., 2014; Aisyah & Triharyuni, 2017; Rina et al., 2022), Kalimantan (Amin et al., 2022), Maluku (Ongkers et al., 2014; Wahyudin et al., 2016), Nusa Tenggara (Priyambodo et al., 2020), Sulawesi (Musbir et al., 2018; Nur, 2018), Sumatra (Akmal et al., 2023), and Papua (Wahyudin et al., 2017; Situmorang et al., 2021). On the island of Sumatra, six species of *Panulirus* inhabit coastal areas and coral ecosystems in Aceh Province (Akmal et al., 2023). The six species include *P. homarus, P. longipes, P. ornatus, P. penicillatus, P. polyphagus*, and *P. versicolor* (fig. 1). Aceh Province is a potential area for the utilization of *Panulirus*, and it is hoped that the exploitation of this species can be carried out in a sustainable manner so that it can improve the community's economy.

Research that has been conducted related to the *Panulirus* species in Indonesia includes genetics and diversity (Haryono & Ambariyanto, 2018; Andriyono et al., 2019; Permana et al., 2019), distribution and dynamics (Milton et al., 2014; Wahyudin et al., 2017; Damora et al., 2019; Tomi, 2019; Priyambodo et al., 2020), reproduction (Ongkers et al., 2014; Musbir et al., 2018), feeding habit (Amin et al., 2022), parasite infection (Nur, 2018), fishing method (Priyambodo et al., 2017; Rina et al., 2022), mariculture (Syafrizal et al., 2018; Amali & Sari, 2020), and morphology (Muzammil & Kurniadi, 2021; Situmorang et al., 2021). The research on the morphology of *Panulirus* is still limited, such as morphometric, meristic, and exoskeletons which are analyzed descriptively (Ahmed et al., 2022; Hettiarachchi et al., 2022; Akmal et al., 2023), while the analysis is based on morphometric characters in depth (quantitative statistics) has never been done. Therefore this research has a high urgency in relation to future *Panulirus* conservation plans.

Material and Methods

Time and site

This research was conducted from 2022–2023. Sampling was carried out on Simeulue Island (*P. homarus*, *P. longipes*, *P. penicillatus*, and *P. versicolor*) and Aceh Jaya Regency (*P. ornatus* and *P. polyphagus*), Aceh Province, Indonesia (fig. 2). The collected samples were then transported to the Aquaculture Integrated Laboratory, Almuslim University, Indonesia for further analysis.

Sample preparation

The lobster samples collected came from direct catches using lobster traps and fishermen who catch them in the study area. The collected lobsters were of mature size, had body weight and total length reaching 500 g and 18–25 cm with a total of 10 individuals per species. The samples that have been collected are then covered with sand and moistened wood powder so that the lobsters hibernate to facilitate transportation to the laboratory for morphometric measurements. Before the lobsters were measured morphometrically, the lobsters were first photographed using a Canon EOS 200D digital camera.

P. penicillatus is caught in shallow waters at a depth of 1–4 m in a coral ecosystem that leads to the sea. *P. homarus* is caught in shallow waters, coral reef, and rocky habitat areas. *P. longipes* is found in shallow waters,

coral reef areas, clear water conditions with moderate currents. *P. ornatus* is usually found at depths of 1–10 m, low currents, and coral reef areas. *P. polyphagus* is found at depths > 8 m, clear waters and muddy substrates. *P. versicolor* is found in coral reef areas at depths < 16 m (usually between 4–12 m), clear to turbid water conditions with strong currents.

Morphometric measurements

Morphometric measurements were conducted on 60 lobster samples (10 per species). Morphometric measurements were performed using a digital caliper (error 0.01 mm). The morphometric characters measured total of 58 characters, of which the total length (TL) was used as the coefficient of data transformation, so that

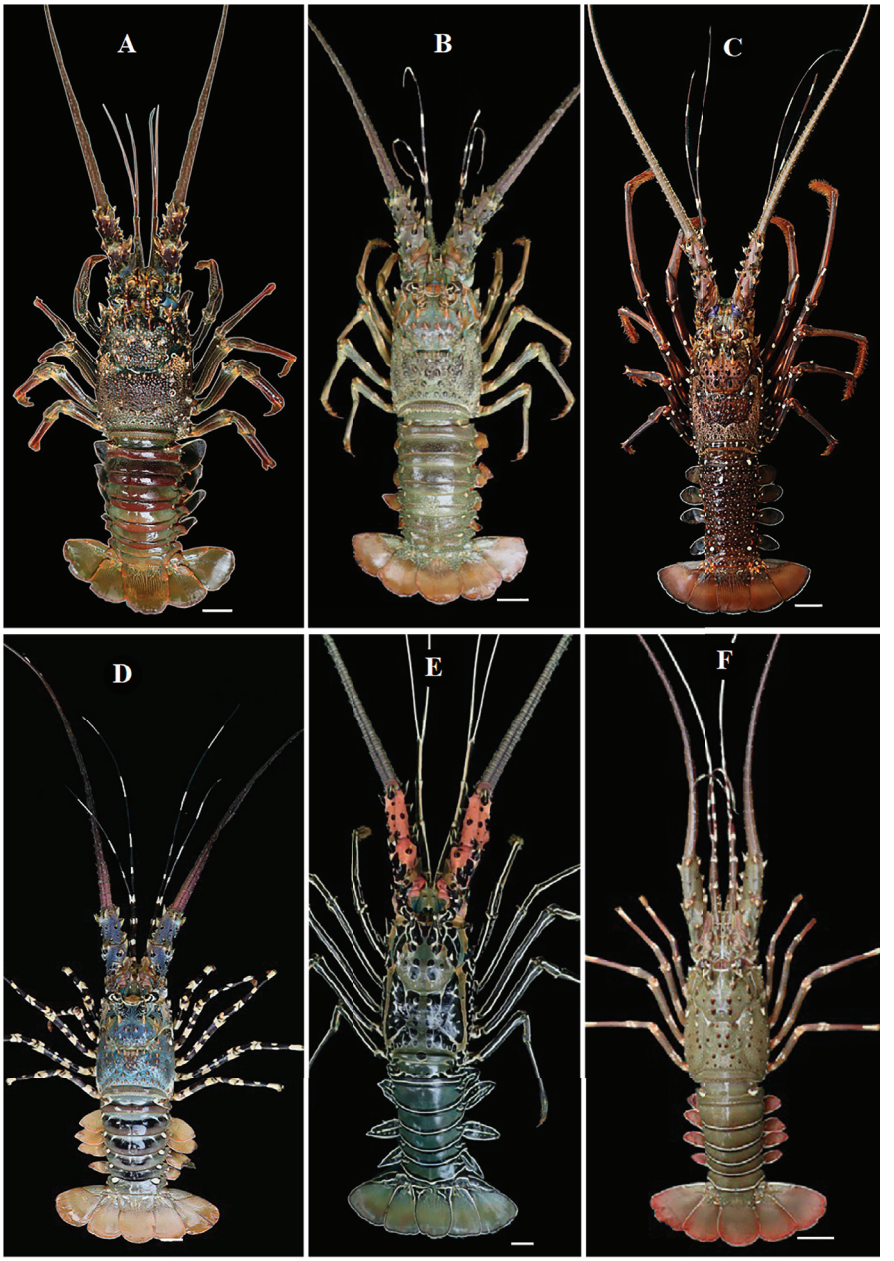

Fig. 1. Sample of the genus *Panulirus*: A — *Panulirus penicillatus* (local name: Lobster Batu), B — *Panulirus homarus* (L. Pasir), C — *Panulirus longipes* (L. Batik), D — *Panulirus ornatus* (L. Mutiara), E — *Panulirus versicolor* (L. Bambu), F —*Panulirus polyphagus* (L. Pakistan). Scale bar 2 cm.

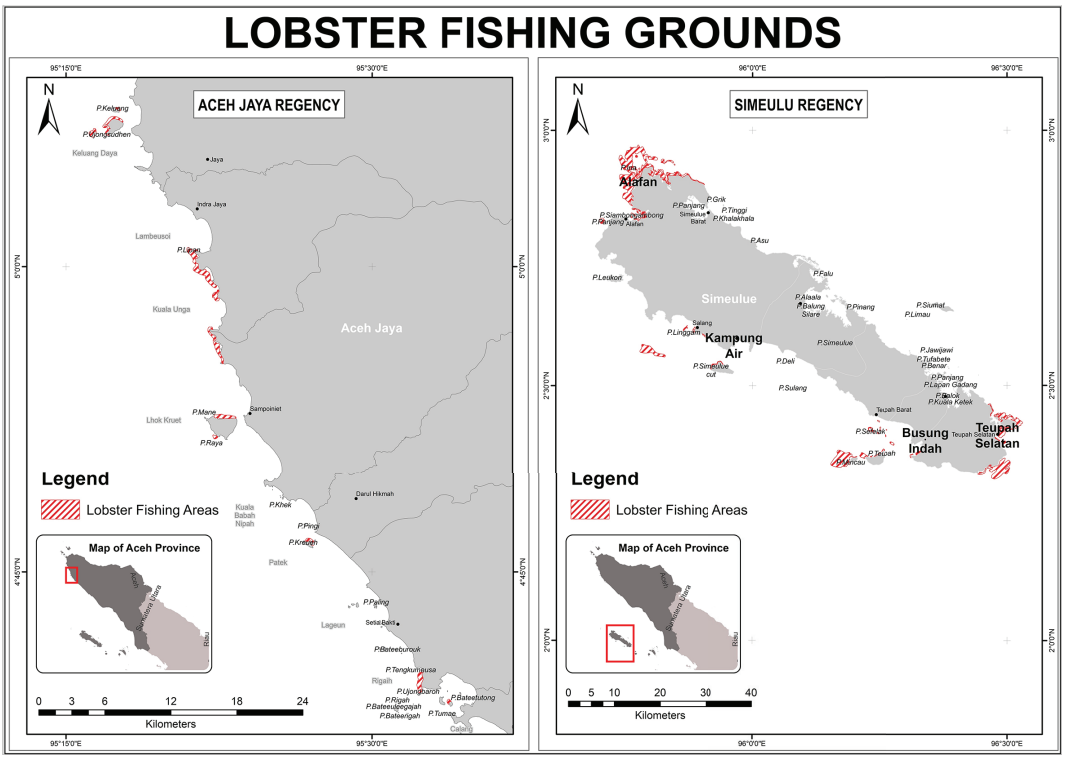

Fig. 2. Map of the research location, where the left is Aceh Jaya Regency and the right is Simeulue Regency (red markers indicate location of the data collection).

only 57 characters were subjected to statistical tests (fig. 3). Morphometric character measurements were modified from the study of Girsang et al. (2014), Szaniawska et al. (2005), and Pardhini et al. (2021). Morphometric measurement data were then transformed using the Batubara et al. (2018) formula:

$$\text{Data trsansformation} = M \times 100 / TL$$

N o t e. M = all measured morphometric characters except TL, TL = total length.

Data analysis

Statistical analysis of the measured morphometric characters was carried out using univariate ANOVA (analysis of variance) and multivariate DFA (discriminant function analysis) methods using SPSS Ver. 22.

Results

Carapace

The results of ANOVA analysis showed that in the anterior cephalothorax, all *Panulirus* species were significantly different ($P < 0.05$), including the characters A1–A6, LA, and RA. The results of ANOVA analysis on the posterior cephalothorax showed that in the six morphometric characters measured, only three characters (B2, B5, and B6) were significantly different ($P < 0.05$), while the other three characters (B1, B3, and B4) were not significantly different ($P > 0.05$) (table 2).

Abdomen and abdominal somites

The results of ANOVA analysis on the abdomen of six *Panulirus* species showed that in the six morphometric characters measured, five characters (C1, C3, C4, C5, and C6) were significantly different ($P < 0.05$), while one other character (C2) was not significantly

Table 1. Lobster morphometric measurements

Body parts	Code	Information
Anterior Cephalothorax	A1	The distance between the widest left point of the carapace to the base of the left eye stalk
	A2	The distance between the right and left of the eye stalks
	A3	The distance between the widest right point of the carapace to the base of the left eye stalk
	A4	The distance between the widest carapace points
	A5	Diagonally point left carapace to right eye
	A6	Diagonally point right carapace to left eye
	RA	Right antenna
	LA	Left antenna
Posterior Cephalothorax	B1	The distance from the posterior point of the carapace to the point on the widest part of the carapace on the left region
	B2	The distance between the widest carapace points
	B3	The distance between the posterior point of the carapace to the point of the widest part of the carapace on the right region
	B4	The distance between the left and right points of the widest carapace posteriorly
	B5	Diagonal from left posterior carapace point to right widest carapace point
	B6	Diagonal from the right posterior carapace point to the left widest carapace point
Abdomen	C1	The distance between the left posterior abdominal point to the left anterior abdominal point
	C2	The distance between the two left and right points of the posterior carapace
	C3	The distance between the posterior point of the right abdomen to the anterior point of the right abdomen
	C4	The distance between the right posterior abdominal point to the left side
	C5	Diagonal from the posterior point of the left abdomen to the anterior point of the right abdomen
	C6	Diagonal from the posterior point of the right abdomen to the anterior point of the left abdomen
Walking Leg (Pereiopod)	E1	The length between the base of the foot to the tip of the first foot
	E2	The length between the base of the foot to the tip of the second foot
	E3	The length between the base of the foot to the tip of the third foot
	E4	The length between the base of the foot to the tip of the fourth foot
	E5	The length between the base of the foot to the tip of the fifth foot
	E1,1	The distance from the ischium point to the merus point of the first foot
	E1,2	The distance between the merus point to the carpus point of the first foot
	E1,3	The distance from the carpus point to the propodus point of the first foot
	E1,4	Distance between propodus point to unguiculate point of the first foot
	E2,1	The distance from the ischium point to the merus point of the second foot
	etc	
Abdominal Somites	R1	Diagonal from the right side point to the left side point of the first abdominal somites
	R2	Diagonal from the right side point to the left side point of the second abdominal somites
	R3	Diagonal from the right side point to the left side point of the third abdominal somites
	R4	Diagonal from the right side point to the left side point of the fourth abdominal somites
	R5	Diagonal from the right side point to the left side point of the fifth abdominal somites
	R6	Diagonal from the right side point to the left side point of the sixth abdominal somites
Caudal (Telson)	D1	The distance between the posterior point of the left telson to the anterior point of the left telson
	D2	The distance between the left and right points of the anterior telson
	D3	The distance between the posterior point of the right telson to the anterior point of the right telson
	D4	The distance between the left and right points of the posterior telson
	D5	Diagonal from the posterior point of the telson on the left to the anterior point of the right telson
	D6	Diagonal from the posterior point of the right telson to the anterior point of the left telson

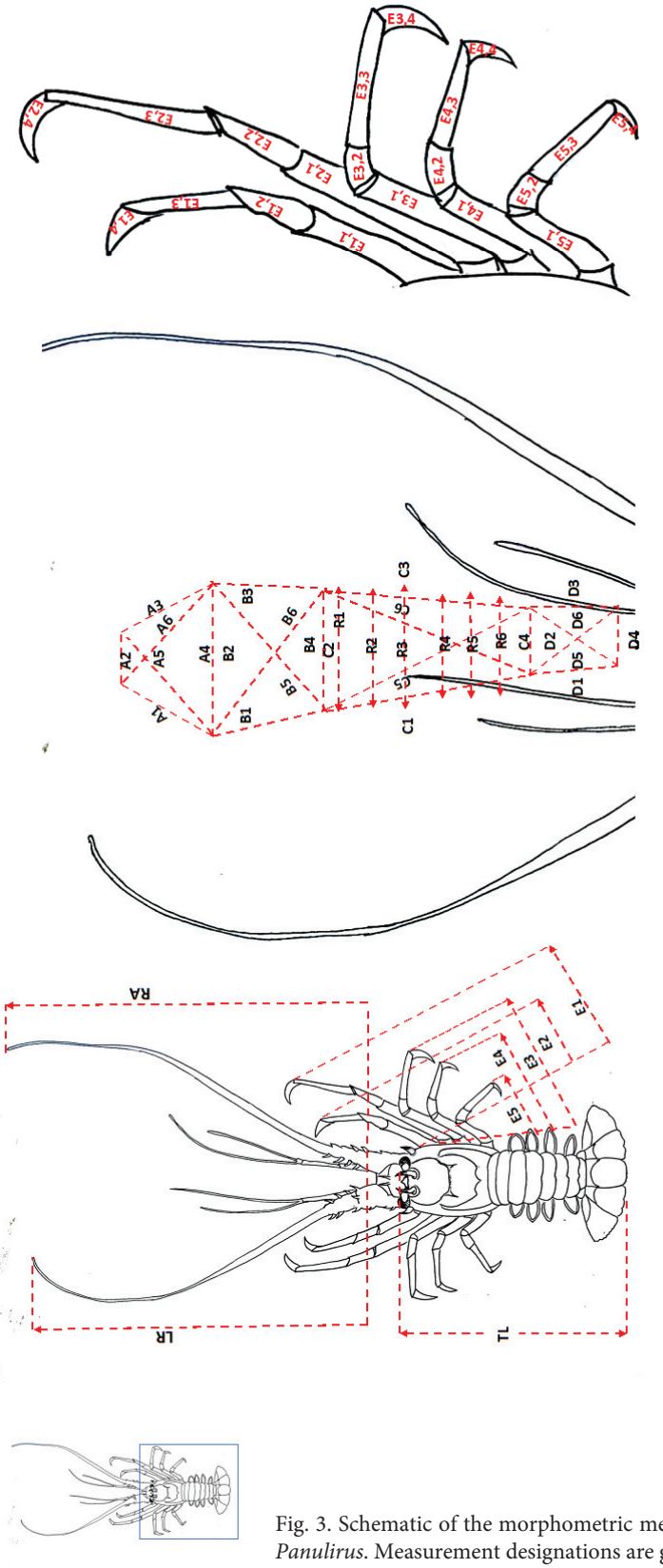

Fig. 3. Schematic of the morphometric measurement of the genus *Panulirus*. Measurement designations are given in table 1.

different (P > 0.05). The results of ANOVA analysis on the abdominal somites of six *Panulirus* species showed that all the measured morphometric characters were significantly different (P < 0.05), including R1–R6 characters (table 2).

Walking leg and telson

The results of ANOVA analysis of the walking legs of six *Panulirus* species showed 24 characters were significantly different (P < 0.05), while only one was not significantly different (P > 0.05). Significantly different of walking legs morphometric characters include E1–E5; E1,1–E1,4; E2,1–E2,4; E3,1–E3,4; E4,1–E4,4; E5,1–E5,3, while only one character that was not significantly different (E5,4). The results of ANOVA analysis on the telson of six *Panulirus* species showed that in the six morphometric characters measured there were 5 characters (D1, D3, D4, D5, and D6) that significantly different (P < 0.05), while one other character (D2) was not significantly different (P > 0.05) (table 2).

Table 2. Univariate analysis (ANOVA) for the six *Panulirus* species in Aceh, Indonesia

Part	Code	*Panulirus homarus*	*Panulirus longipes*	*Panulirus ornatus*	*Panulirus penicillatus*	*Panulirus polyphagus*	*Panulirus versicolor*
1	2	*3*	*4*	*5*	*6*	*7*	*8*
Anterior Cephalothorax	A1	24.35 ± 5.47^{c}	23.79 ± 2.48b^{c}	20.48 ± 1.49^{a}	25.28 ± 2.09^{c}	21.41 ± 1.09^{ab}	23.71 ± 1.18^{bc}
	A2	7.52 ± 1.06^{a}	7.25 ± 1.74^{a}	11.01 ± 1.25^{b}	7.75 ± 0.91^{a}	6.71 ± 0.89^{a}	7.89 ± 1.23^{a}
	A3	24.35 ± 5.47^{c}	23.79 ± 2.48^{bc}	20.48 ± 1.49^{a}	25.28 ± 2.09^{c}	21.41 ± 1.09^{ab}	23.71 ± 1.18^{bc}
	A4	24.61 ± 1.01^{ab}	24.28 ± 1.43^{ab}	23.98 ± 1.80^{ab}	25.86 ± 4.16^{b}	23.53 ± 0.58^{a}	24.85 ± 1.36^{ab}
	A5	27.10 ± 1.87^{b}	27.17 ± 3.06^{b}	24.91 ± 1.17^{a}	29.20 ± 1.49^{c}	25.02 ± 0.87^{a}	28.53 ± 1.52^{bc}
	A6	27.10 ± 1.87^{b}	27.17 ± 3.06^{b}	24.91 ± 1.17^{a}	29.20 ± 1.49^{c}	25.02 ± 0.87^{a}	28.54 ± 1.52^{bc}
	LA	118.15 ± 29.51^{ab}	142.74 ± 20.69^{ab}	213.01 ± 47.09^{c}	97.45 ± 19.65^{a}	227.42 ± 105.31^{c}	163.66 ± 44.61^{b}
	RA	131.01 ± 29.23^{ab}	143.10 ± 26.86^{ab}	216.13 ± 33.86^{c}	100.69 ± 20.60^{a}	202.97 ± 89.31^{c}	157.95 ± 48.19^{b}
Posterior Cephalothorax	B1	18.92 ± 2.03^{a}	19.44±1.68^{a}	18.84 ± 1.97^{a}	19.86 ± 1.79^{a}	20.34 ± 1.36^{a}	20.27 ± 2.05^{a}
	B2	24.61 ± 1.01^{ab}	24.28 ± 1.43^{ab}	23.98 ± 1.80^{ab}	25.86 ± 4.16^{b}	23.53 ± 0.58^{a}	24.85 ± 1.36^{ab}
	B3	18.76 ± 1.76^{a}	19.44 ± 1.68^{a}	18.84 ± 1.97^{a}	19.86 ± 1.79^{a}	20.34 ± 1.36^{a}	20.27 ± 2.05^{a}
	B4	22.10 ± 1.50^{a}	20.61 ± 1.32^{a}	21.05 ± 2.23^{a}	22.19 ± 3.33^{a}	20.25 ± 0.96^{a}	22.06 ± 1.62^{a}
	B5	28.16 ± 3.90^{ab}	28.41 ± 1.55^{ab}	27.82 ± 1.88^{a}	30.22 ± 2.36^{b}	29.34 ± 0.69^{ab}	29.48 ± 1.42^{ab}
	B6	28.16 ± 3.90^{ab}	28.41 ± 1.55^{ab}	27.82 ± 1.88^{a}	30.22 ± 2.36^{b}	29.34 ± 0.69^{ab}	29.48 ± 1.42^{ab}
Abdomen	C1	37.63 ± 3.05^{b}	37.64 ± 3.20^{b}	32.87 ± 6.06^{a}	39.23 ± 2.79^{b}	36.47 ± 1.34^{b}	37.90 ± 2.12^{b}
	C2	22.10 ± 1.50^{a}	20.61 ± 1.32^{a}	21.05 ± 2.23^{a}	22.19 ± 3.33^{a}	20.25 ± 0.96^{a}	22.06 ± 1.62^{a}
	C3	37.64 ± 3.04^{b}	37.64 ± 3.20^{b}	32.87 ± 6.06^{a}	39.23 ± 2.79^{b}	36.47 ± 1.34^{b}	36.62 ± 5.02^{b}
	C4	12.47 ± 0.94^{b}	12.44 ± 2.55^{b}	11.63 ± 0.87^{ab}	13.87 ± 0.47^{c}	11.20 ± 0.51^{a}	12.77 ± 0.65^{b}
	C5	38.85 ± 7.01^{b}	40.60 ± 3.43^{b}	32.36 ± 6.68^{a}	42.36 ± 2.75^{b}	39.22 ± 1.09^{b}	40.75 ± 2.03^{b}
	C6	38.91 ± 7.04^{b}	40.60 ± 3.43^{b}	32.36 ± 6.68^{a}	42.33 ± 2.82^{b}	39.22 ± 1.09^{b}	40.75 ± 2.03^{b}
Abdominal Somites	R1	21.82 ± 1.18^{b}	20.45 ± 0.94^{ab}	21.48 ± 0.74^{ab}	22.47 ± 2.46^{b}	19.16 ± 5.25^{a}	22.11 ± 0.77^{b}
	R2	22.79 ± 2.50^{ab}	21.50 ± 1.67^{ab}	22.76 ± 5.93^{ab}	24.17 ± 1.50^{b}	20.52 ± 0.76^{a}	22.92 ± 1.37^{ab}
	R3	23.00 ± 2.29^{cd}	21.81 ± 1.94^{bc}	20.68 ± 0.99^{ab}	24.07 ± 1.65^{d}	20.11 ± 1.49^{a}	22.34 ± 1.15^{c}
	R4	22.20 ± 2.24^{cd}	20.53 ± 1.68^{ab}	20.08 ± 1.73^{a}	23.41 ± 1.56^{d}	19.54 ± 1.62^{a}	21.77 ± 1.14^{bc}
	R5	21.33 ± 1.97^{cd}	19.86 ± 1.38^{ab}	19.17 ± 1.67^{a}	22.51 ± 1.38^{d}	18.79 ± 1.09^{a}	20.79 ± 1.00^{bc}
	R6	20.15 ± 1.62^{b}	19.09 ± 1.30^{ab}	18.58 ± 1.46^{a}	21.94 ± 1.91^{c}	18.43 ± 0.67^{a}	19.94 ± 0.87^{b}
Caudal (Telson)	D1	16.98 ± 1.65^{bc}	17.54 ± 1.72^{bc}	8.25 ± 1.00^{a}	17.04 ± 1.37^{bc}	16.54 ± 1.02^{b}	17.98 ± 1.17^{c}
	D2	12.47 ± 0.94^{a}	12.45 ± 2.54^{a}	11.63 ± 0.87^{a}	13.87 ± 0.47^{a}	14.20 ± 9.43^{a}	12.77 ± 0.65^{a}
	D3	16.49 ± 2.08^{b}	17.54 ± 1.72^{bc}	8.25 ± 1.00^{a}	17.04 ± 1.37^{bc}	16.54 ± 1.02^{b}	17.98 ± 1.17^{c}
	D4	10.86 ± 1.37^{a}	10.54 ± 1.38^{a}	10.68 ± 1.02^{a}	12.88 ± 1.96^{b}	10.50 ± 0.78^{a}	10.26 ± 1.06^{a}
	D5	20.28 ± 1.26^{bc}	20.53 ± 1.79^{c}	13.27 ± 0.90^{a}	21.17 ± 1.02^{c}	19.40 ± 0.83^{b}	20.65 ± 0.89^{c}
	D6	20.28 ± 1.26^{bc}	20.53 ± 1.79^{c}	13.27 ± 0.90^{a}	21.17 ± 1.02^{c}	19.40 ± 0.83^{b}	20.65 ± 0.89^{c}

1	2	3	4	5	6	7	8
Walking Leg (Pereiopod)	E1	38.77 ± 4.41^{a}	49.97 ± 9.63^{b}	38.98 ± 3.94^{a}	45.66 ± 6.34^{ab}	40.60 ± 10.38^{a}	42.98 ± 4.60^{a}
	E2	45.65 ± 4.46^{a}	62.53 ± 13.90^{c}	45.80 ± 3.40^{a}	54.31 ± 7.12^{b}	45.93 ± 7.36^{a}	52.02 ± 6.85^{ab}
	E3	52.50 ± 5.78^{ab}	61.65 ± 9.68^{c}	50.63 ± 7.02^{a}	59.21 ± 9.54^{bc}	56.98 ± 7.30^{abc}	60.28 ± 7.58^{c}
	E4	45.10 ± 2.74^{a}	52.05 ± 3.96^{bc}	46.26 ± 2.62^{a}	48.51 ± 6.03^{ab}	54.61 ± 2.50^{c}	54.95 ± 6.77^{c}
	E5	37.16 ± 3.53^{a}	43.65 ± 2.85^{bc}	41.20 ± 4.99^{abc}	39.23 ± 3.82^{ab}	45.10 ± 3.44^{c}	42.03 ± 10.16^{abc}
	E1,1	15.78 ± 1.45^{a}	21.14 ± 3.64^{d}	16.93 ± 2.26^{ab}	19.13 ± 2.44^{cd}	16.68 ± 1.13^{ab}	18.35 ± 1.89^{bc}
	E1,2	7.18 ± 0.73^{b}	8.42 ± 2.01^{c}	5.87 ± 0.68^{a}	8.36 ± 1.09^{c}	6.57 ± 0.92^{ab}	7.40 ± 0.66^{bc}
	E1,3	9.08 ± 3.20^{a}	13.52 ± 2.85^{c}	10.29 ± 1.16^{ab}	11.56 ± 1.50^{b}	9.06 ± 1.47^{a}	11.02 ± 1.66^{ab}
	E1,4	6.75 ± 0.63^{bc}	6.85 ± 1.60^{bc}	5.88 ± 0.80^{ab}	7.37 ± 1.15^{c}	5.55 ± 1.00^{a}	6.19 ± 0.73^{ab}
	E2,1	19.64 ± 2.37^{a}	26.16 ± 5.24^{b}	19.68 ± 1.88^{a}	22.78 ± 3.50^{a}	21.41 ± 2.00^{a}	22.77 ± 3.16^{a}
	E2,2	7.48 ± 0.58^{b}	9.05 ± 2.28^{c}	5.98 ± 0.98^{a}	8.85 ± 1.24^{c}	7.06 ± 0.54^{ab}	7.91 ± 0.72^{bc}
	E2,3	12.27 ± 1.25^{a}	18.26 ± 4.21^{c}	14.04 ± 2.49^{ab}	15.34 ± 1.85^{b}	13.27 ± 1.39^{ab}	15.65 ± 2.78^{b}
	E2,4	6.25 ± 0.67^{a}	9.05 ± 2.38^{c}	6.09 ± 0.65^{a}	7.57 ± 1.12^{b}	6.14 ± 0.71^{a}	6.47 ± 1.12^{ab}
	E3,1	21.37 ± 2.21^{ab}	25.64 ± 3.86^{c}	20.32 ± 4.44^{a}	24.31 ± 2.81^{bc}	25.15 ± 3.30^{c}	25.18 ± 3.08^{c}
	E3,2	8.11 ± 0.65^{bc}	8.73 ± 1.61^{c}	6.29 ± 0.88^{a}	8.76 ± 1.03^{c}	7.35 ± 1.30^{b}	8.46 ± 0.65^{c}
	E3,3	15.44 ± 2.11^{a}	17.14 ± 4.09^{ab}	16.34 ± 2.49^{ab}	16.82 ± 1.88^{ab}	17.06 ± 3.18^{ab}	18.67 ± 2.67^{b}
	E3,4	7.58 ± 1.19^{a}	10.13 ± 3.40^{bc}	7.66 ± 0.92^{a}	9.45 ± 1.65^{c}	7.44 ± 1.26^{a}	7.95 ± 1.46^{ab}
	E4,1	16.84 ± 1.41^{a}	19.77 ± 1.66^{cd}	17.28 ± 0.96^{ab}	18.65 ± 2.18^{bc}	21.10 ± 1.73^{d}	20.94 ± 2.47^{d}
	E4,2	8.14 ± 0.55^{b}	8.65 ± 0.82^{bc}	6.22 ± 0.92^{a}	9.47 ± 2.30^{c}	7.99 ± 0.46^{b}	8.85 ± 0.88^{bc}
	E4,3	12.92 ± 1.09^{a}	15.10 ± 1.25^{b}	15.16 ± 1.05^{b}	12.56 ± 1.50^{a}	16.42 ± 0.94^{c}	17.28 ± 2.15^{c}
	E4,4	7.68 ± 0.76^{a}	8.49 ± 0.92^{ab}	7.58 ± 0.97^{a}	7.59 ± 1.40^{a}	9.09 ± 0.49^{b}	8.69 ± 1.06^{b}
	E5,1	11.39 ± 0.97^{a}	15.06 ± 1.54^{c}	13.21 ± 1.70^{b}	12.69 ± 1.10^{ab}	15.39 ± 1.66^{c}	15.27 ± 1.81^{c}
	E5,2	7.59 ± 0.47^{b}	8.33 ± 0.92^{c}	6.32 ± 0.67^{a}	8.53 ± 0.94^{c}	7.88 ± 0.47^{bc}	8.43 ± 0.60^{c}
	E5,3	11.53 ± 0.89^{a}	14.25 ± 0.87^{b}	14.66 ± 1.10^{b}	11.67 ± 1.54^{a}	14.48 ± 0.93^{b}	15.01 ± 2.37^{b}
	E5,4	6.64 ± 1.88^{a}	5.99 ± 1.40^{a}	7.00 ± 2.46^{a}	6.17 ± 1.31^{a}	7.35 ± 1.46^{a}	6.75 ± 1.31^{a}

Note. Different superscripts show significant differences in the respective morphometric characters (average value of morphometric characters±standard deviation). Bold numbers indicate characters that are not significantly different.

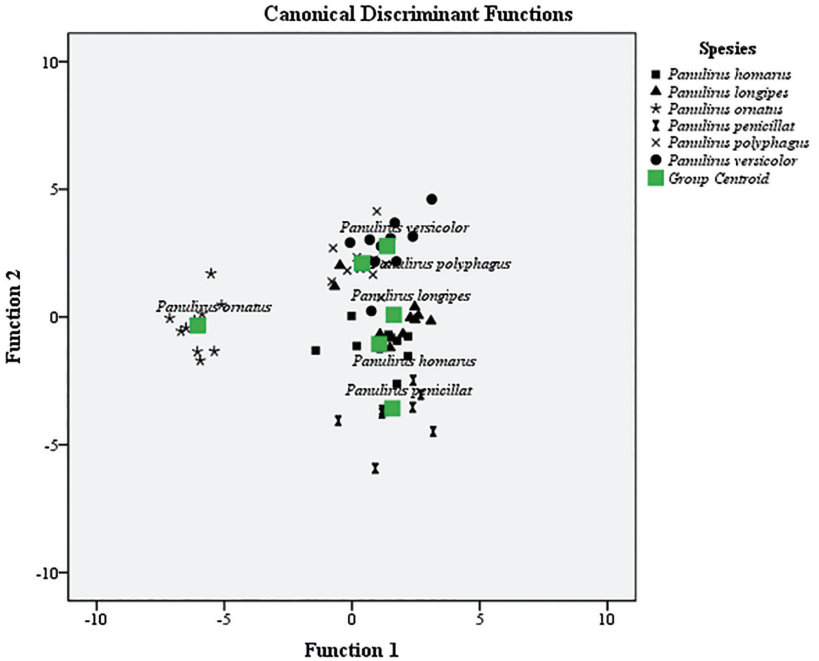

Fig. 4. DFA scatter plot of the six *Panulirus* species in Aceh, Indonesia.

Table 3. Multivariate analysis (Discriminant Function Analysis/DFA) for the six *Panulirus* species in Aceh, Indonesia

	Function				
	1	2	3	4	5
Eigenvalue	8.298	4.847	1.152	0.914	0.285
% of Variance	53.6	31.3	7.4	5.9	1.8
D1	0.904*	0.128	−0.057	0.051	−0.045
D3	0.800*	0.111	−0.074	0.097	0.021
D5	0.587*	0.024	−0.086	0.001	0.101
D6	0.586*	0.024	−0.086	0.001	0.102
R6	0.469*	−0.084	−0.182	0.229	0.208
R3	0.371*	0.033	−0.057	0.084	−0.010
R5	0.344*	0.063	−0.158	0.175	0.119
R4	0.321*	0.040	−0.077	0.045	0.056
C6	0.290*	0.135	−0.043	0.162	0.170
C5	0.290*	0.132	−0.046	0.162	0.169
R1	0.151*	−0.016	−0.018	−0.109	0.134
R2	0.142*	0.010	0.093	−0.102	0.120
D2	0.119*	0.007	0.037	0.058	−0.038
LA	−0.035	0.212*	0.123	0.162	−0.050
RA	−0.077	0.184*	0.165	−0.008	−0.142
E4	0.135	0.304	0.042	−0.192	0.847*
E4,1	0.110	0.244	0.211	−0.146	0.803*
E1,1	0.107	−0.048	0.581	−0.048	0.793*
E2,1	0.157	0.034	0.403	−0.037	0.753*
E4,3	−0.051	0.553	0.098	−0.009	0.173*
E3	0.037	0.131	0.371	−0.079	0.711*
E2	0.157	−0.018	0.441	−0.010	0.694*
E3,3	0.154	0.096	0.271	0.052	0.682*
E3,1	0.061	0.115	0.406	−0.088	0.665*
E2,3	0.089	0.040	0.374	−0.052	0.661*
E5,3	−0.030	0.396	−0.029	−0.202	0.648*
E1,3	0.074	0.133	0.323	−0.085	0.617*
E2,2	0.281	−0.061	0.406	0.146	0.615*
E1	0.014	0.049	0.429	0.011	0.599*
E3,2	0.138	−0.166	0.313	0.022	0.593*
E2,4	0.332	0.013	0.453	0.101	0.586*
E5,1	0.162	0.214	0.044	0.001	0.586*
E4,4	0.160	0.164	0.051	−0.089	0.581*
E1,2	0.257	−0.061	0.466	−0.054	0.581*
A6	0.220	−0.151	0.051	−0.549	0.562*
A5	0.220	−0.151	0.51	0.549	0.562*
E1,4	0.127	0.048	0.271	−0.006	0.554*
E5	0.044	0.244	−0.044	−0.336	0.535*
E4,2	0.297	−0.081	−0.004	0.117	0.521*
D4	0.047	−0.279	−0.166	−0.008	0.492*
B3	−0.102	0.114	0.262	−0.085	0.465*
B1	−0.139	0.107	0.256	−0.100	0.453*
E5,2	0.340	−0.065	0.051	0.104	0.444*
A4	0.039	−0.091	0.187	−0.074	0.441*

	1	2	3	4	5
B2	0.039	−0.091	0.187	−0.074	0.441*
B6	0.075	0.123	0.097	0.051	0.365*
B5	0.075	0.123	0.097	0.051	0.365*
A2	0.014	−0.039	0.168	0.057	0.362*
A1	0.321	0.022	−0.008	−0.016	0.332
A3	0.321	0.022	−0.008	−0.016	0.332
E3,4	−0.088	0.223	0.190	−0.153	0.311
E5,4	0.014	0.216	0.181	−0.047	0.310
C4	−0.034	0.039	−0.026	0.150	0.307
B4	0.060	−0.205	−0.014	−0.202	0.302
C2	0.060	−0.205	−0.014	−0.202	0.302
C1	0.226	0.108	0.092	0.155	0.299
C3	0.138	0.071	0.104	0.276	0.295

Note. The star (*) symbol indicates the contribution of the morphometric characters in the respective function.

Discriminant Function Analysis (DFA)

DFA analysis produces 5 functions, where function 1 has an eigenvalue of 8.298 and contributes to 53.6 % of the variance, function 2 has an eigenvalue of 4.847 and contributes to 31.3 % of the variance, function 3 has an eigenvalue of 1.153 and contributes to 7.4 % of variance, while functions 4 and 5 do not contribute significantly because the eigenvalue < 1 (table 3). Based on the scatter plot reconstruction, the six species of *Panulirus* were discriminated into two groups, where group 1 was only *P. ornatus*, while the other 5 species were categorized in group 2 (fig. 4).

Discussion

The results of morphometric analysis on the anterior cephalothorax showed that all characters could be used as identification keys between *Panulirus* species, where the six characters measured were significantly different ($P < 0.05$). Not only the size of the cephalothorax, other studies have revealed that colour, horns and spines also have specific characteristics between *Panulirus* species (Hettiarachchi et al., 2022). Furthermore, not all morphometric characters in the posterior cephalothorax were significantly different (three characters were significantly different from six characters), where these results revealed that the area of these B2, B5, and B6 characters differed between species. The anterior and posterior cephalothorax or also called the carapace of the lobster are morphological characters that are usually used as indicators of species, maturity, catchability, nutritional condition, and body dimensions (Groeneveld & Goosen, 1996; Robertson et al., 2000; Radhakrishnan et al., 2015; Martínez-Calderón et al., 2018). Furthermore, morphological analysis can reveal differences in population, habitat, geographical distribution and sex dimorphism in *Panulirus* species (Sekiguchi, 1991; García-Rodríguez et al., 2004).

On the abdomen and abdominal somites of six *Panulirus* species, it was shown that of the 12 characters measured, only one was not significantly different (C2). These results indicate that there is inter-species distance in the *Panulirus* species, so that 11 significantly different characters can be used as identification keys. Other studies have also revealed that there are differences in the abdominal somites of the *Panulirus* species, namely the

presence of hairs, margins, number, and color (Giraldes et al., 2016; Hettiarachchi et al., 2022). The results of this study validate statistically the characteristics of the abdomen and abdominal somites in the *Panulirus* species, although descriptively this has been revealed in previous studies (Kumar & Daniel, 1975; Kim et al., 2009; Page, 2013; Spanier & Friedmann, 2019; Chesalin et al., 2021).

Telson in six *Panulirus* species showed significant differences in five morphometric characters, and only one character was not significantly different. This result is similar to Hettiarachchi et al. (2022) on four *Panulirus* species (*P. japonicus*, *P. homarus*, *P. longipes*, and *P. stimpsoni*) which revealed that the telsons of each species differed based on margins, shape, color, and the presence of spots. These results were reinforced in this study through statistically tested morphometric measurements, thus clarifying this difference.

Furthermore, based on univariate analysis, it was shown that 24 from 25 total morphometric characters on the walking legs of the six *Panulirus* species were significantly different. These results indicate that the size of each walking leg of the *Panulirus* species has a specific size that can be used as an identification key. Other studies have also carried out analyzes regarding the character of this walking leg, but this research has only been limited to one species, for example the morphometrics of *P. argus* (Anderson et al., 2013; Atherley et al., 2020), *P. polyphagus* (Ikhwanuddin et al., 2014; Waiho et al., 2021), *P. homarus* (Kulmiye et al., 2006; Radhakrishnan et al., 2015), *P. inflatus* (Muñoz-García et al., 2014), *P. interruptus* (Nauen & Shadwick, 1999), *P. guttatus* (Robertson & Butler, 2003), *P. ornatus* (Indarjo et al., 2023). Therefore, the morphometric comparison of the six *Panulirus* species provides more comprehensive information.

Conclusion

Univariate and multivariate morphometric analysis succeeded in classifying six *Panulirus* species based on their specific characteristics. A total of 51 morphometric characters from total 57 were significantly different ($P < 0.05$), while only the six characters were not significantly different. *P. ornatus* is the species with the highest species distance compared to the other five *Panulirus* species based on DFA analysis (scatter plot). Morphometric analysis to distinguish the six *Panulirus* species provides more comprehensive information regarding key morphological identification characters.

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