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A comprehensive description of the exoskeleton of six Lobster species (Genus *Panulirus*) in Aceh Province, Indonesia

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ABSTRACT

Lobster (*Panulirus* spp.) is a leading commodity on a local and export scale in Aceh Province, Indonesia, where the population has experienced a significant decline in recent years. This study describes the exoskeleton morphology of six lobster species distributed in Aceh Province, Indonesia. The research was carried out in 2022 stages covering sample preparation, sample shooting, and morphological analysis. The results of the study showed that there were six lobster species in Aceh including *Panulirus penicillatus*, *P. homarus*, *P. longispes*, *P. ornatus*, *P. versicolor*, and *P. polyphagus*. The anatomy of the lobster exoskeleton of six species of *P. penicillatus*, *P. homarus*, *P. longispes*, *P. ornatus*, *P. versicolor* and *P. polyphagus* has marked differences, where each part of the cephalothorax (cervical sulcus, sternum, epistome, maxillaped, pereopod), Abdominal (segment, pleura, pleopod) and caudal (telson, uropod, and protopod) have different shapes. In addition, differences were also found in the color and presence of spines on the dorsal body.

1. Introduction

Lobster is a high economic commodity from Aceh Province (Wahju and Riyanto, 2017). This commodity can be a strategic solution for the economic development of fishermen (Irfannur et al., 2017). Currently, more than 20 lobster species have been identified in the world (Lipcius and Eggleston, 2013), some of which are distributed in the waters of Aceh, including *Panulirus homarus*, *P. longispes*, *P. ornatus*, *P. penicillatus*, *P. polyphagus*, and *P. versicolor* (Damora et al., 2021).

Lobster is a resource that can be recovered (renewable resources) but increased fishing without any restrictions causes population decline (Priyambodo et al., 2020). The high intensity of lobster catching on the south west coast of Aceh is feared to threaten the sustainability of lobster resources in Aceh Province. Damora et al. (2021) also revealed that overfishing has been occurring in the Aceh Province since 2008. Therefore, information regarding the inventory of lobster species is important as a conservation effort so that future management of this

lobster can be designed. One of the conservation efforts that needs to be done is species identification based on exoskeleton analysis. Lobster management in Indonesia has been regulated by the Minister of Marine Affairs and Fisheries Regulation Number 12 of 2020 (PERMEN, 2020) According to the Cockcroft et al. (2011), currently lobster is declared to be still in the low risk category, but it is predicted that in the next few years it will increase to be threatened with extinction if management is not carried out now.

Several studies that have been reported include studies of lobster morphology (Simpson, 1985; Meeren and Uksnoy, 2000), lobster histopathology exposed to heavy metals (Maharajan et al., 2012), reproductive system histology (Pillai et al., 2014), digestive system (Welden et al., 2015), genetic structure (Irisari et al., 2018). Meanwhile, studies regarding the identification of lobsters based on exoskeletons are still very limited, causing this research to be feasible to be developed. The exoskeleton is a morphological character key for identifying lobster species (Raabe et al., 2007; Davies et al., 2014) and its implications for

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mechanical behavior (Cheng et al., 2008). In addition, identification of lobsters based on exoskeleton characters is easier and cheaper than other analyses. Exoskeleton analysis is also one of the lobster conservation efforts by identifying intra-interspecies characters for future management plans.

2. Materials and methods

2.1. Site and time of research

The research was conducted in 2022 with research stages covering preparation, photography, and morphological analysis. Sampling was carried out in the coastal area of Aceh Jaya Regency, Aceh Province, Indonesia (Fig. 1). Lobster morphology preparation and analysis was completed at the Integrated Aquaculture Laboratory, Almuslim University, Indonesia.

2.2. Sample preparation

The lobster used in this study was obtained from the direct catch of fishermen in Lhok Ringai, Aceh Jaya Regency, Aceh Province, Indonesia. The sampling distance is about 2–4 miles from the coast. Ten samples per lobsters species were obtained, with the weights around 500 g and lengths ranging from 18 to 25 cm.

Collected samples were kept alive by sprinkling individuals with water, wet sand and sawdust. The goal is to keep the lobster in low metabolic activity (fainting). Before the lobster samples were put into the box, each lobster sample was wrapped in paper (two layers of flip chart paper per lobster sample and flip chart paper size 65 × 100 cm)

and tightly closed with a total of 10 lobsters per box and then the samples were sent to the laboratory for further analysis (lobster samples were photographed first, then identified by exoskeleton).

2.3. Sample photography

Lobster photos were taken in each dorsal, ventral, lateral, medial, anterior and posterior using a Canon EOS 200D digital camera. Photographs of samples were taken in an upright position, with a green background, and using a measuring instrument (ruler with an accuracy of 0.05cm) as the size of sample. Image editing is done using Adobe Photoshop CS 6 software (Table 1).

2.4. Exoskeleton determination

The results of image editing are illustrated scientifically using manual methods, where each lobster species is drawn in detail using a pencil covering all specific exoskeleton characters (Akmal et al. 2022). The illustration starts with the whole figure of lobster body, the dorsal and ventral cephalothorax, the dorsal and ventral abdominal somites, the dorsal and ventral caudal sections, the pereopod, pleopod and maxilliped sections. Determination of anatomical nomenclature using references to studies that have been reported, namely Goy (2010), Löw et al. (2016), and Hettiarachchi et al. (2022).

2.5. Data analysis

The data are presented in the tables and scientific illustrations. Data analysis was conducted descriptively by comparing the specific

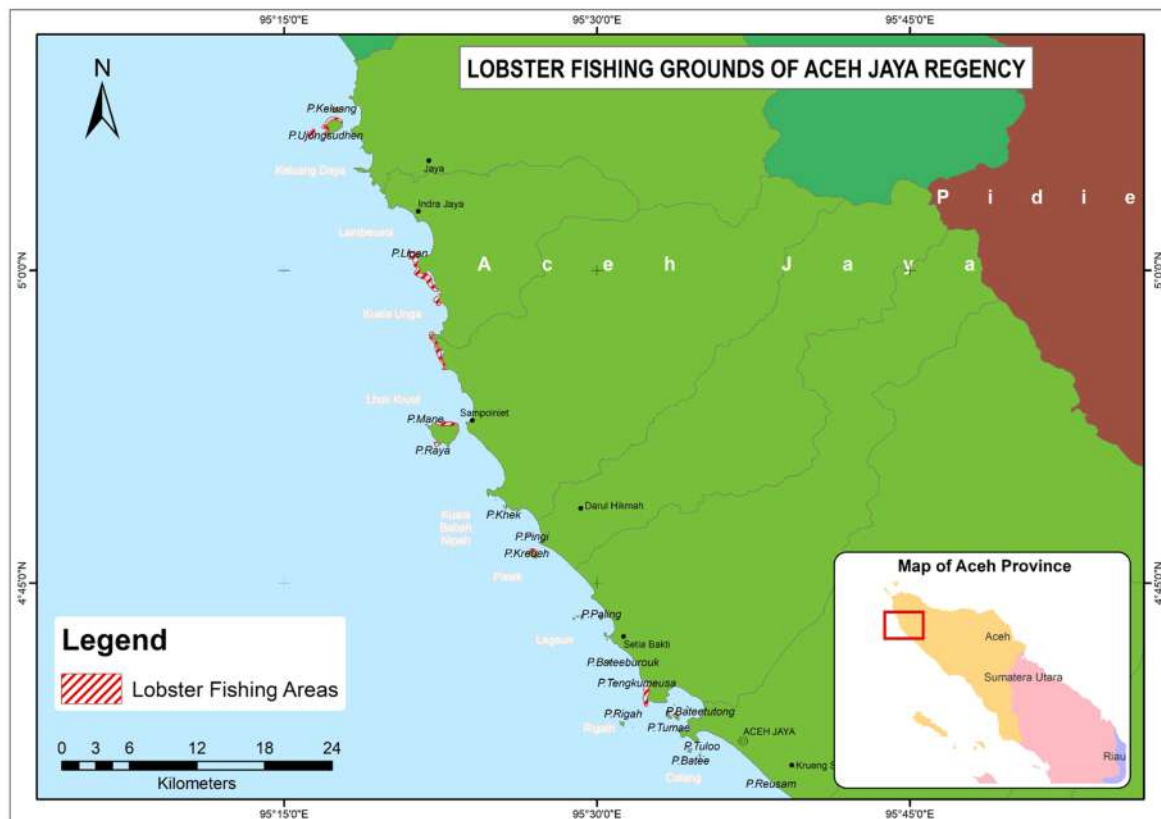


Fig. 1. Map of lobster fishing areas in Aceh Jaya Regency, Aceh Province, Indonesia.

Table 1
Comparison of the exoskeleton structure of six *Panulirus* species in Aceh Province, Indonesia.

No	Region	Structure	<i>P. penicillatus</i>	<i>P. homarus</i>	<i>P. ornatus</i>	<i>P. polyphagus</i>	<i>P. versicolor</i>	<i>P. longispes</i>
1	Cephalothorax	Form	✓ Width and length in the thorax	✓ Long and slender in the thorax	✓ Length and width in the thorax	✓ Long and slender in the thorax	✓ Width and length in the thorax	✓ Long and slender in the thorax
			✓ There are more small bumps around the thorax	✓ There are a few small bumps on the thorax	✓ There are a few small bumps on the thorax	✓ The little bumps are barely visible	✓ There are no small bulges on the thorax	✓ There are many small bumps on the thorax
		Spines	✓ There are more spines but blunt and irregularly located	✓ There are few spines but sharp and irregularly located	✓ There are many spines but blunt and slightly irregular	✓ There are few spines but sharp and parallel	✓ There are some sharp spines	✓ There are more spines but sharp and slightly irregular
			✓ The front spines are not well developed	✓ The front spines are not well developed	✓ The front spines are developing well	✓ The front spines are developing well	✓ The front spines are developing well	✓ The front spines are developing well
			✓ The front spines are 4 sharp and parallel spines	✓ The front spines are 3 spines, there are 1 small blunt spine and 2 large sharp spines	✓ The front spines have 2 small blunt and 2 large sharp spines	✓ The front spines are 2 large sharp spines	✓ The front spines have 2 small and 2 large sharp spines	✓ The front spines are 2 large and sharp spines
		Cepha dorsal	✓ Has a complete sulcus in the thorax	✓ Does not have a sulcus in the thorax	✓ Does not have a sulcus in the thorax	✓ Has a complete sulcus to the thorax	✓ Has a complete sulcus to the thorax	✓ Has a complete sulcus to the thorax
			✓ Spina on pointed carapace	✓ Spina on sharp carapace	✓ Spina on pointed carapace	✓ Spina on sharp carapace	✓ Spina on pointed carapace	✓ Spina on sharp carapace
		Cepha ventral	✓ There are 6 legs and there is no protrusion at the end of the sixth leg	✓ There are 6 legs and there is no protrusion at the end of the sixth leg	✓ There are 6 legs and there is no protrusion at the end of the sixth leg	✓ There are 6 legs and there is no protrusion at the end of the sixth leg	✓ There are 6 legs and there is a protrusion at the end of the sixth leg	✓ There are 6 legs and there is a protrusion at the end of the sixth leg
			✓ There are no curves in the middle of the body	✓ In the middle of the body there is an indentation	✓ In the middle of the body there is an indentation	✓ There are no curves in the middle of the body	✓ There are no curves in the middle of the body	✓ In the middle of the body there is an indentation
			✓ There are 3 blunt spines and 3 sharp spines on the underside of the antenna	✓ There are 3 sharp spines on the underside of the antenna	✓ There are 3 sharp spines on the underside of the antenna	✓ There are 3 sharp spines on the underside of the antenna	✓ There are 3 sharp spines on the underside of the antenna	✓ There are 3 sharp spines and 6 blunt spines on the underside of the antenna
			✓ Pleopod sheet wide and long	✓ Pleopod sheet wide	✓ Pleopod sheet wide and long	✓ Pleopod sheet long and pointed	✓ Pleopod sheet long and pointed	✓ Pleopod sheet wide and long
			✓ The lateral side is pointed and slender	✓ The lateral side is pointed and slender	✓ Wide and pointed lateral side	✓ Wide and pointed lateral side	✓ Wide and pointed lateral side	✓ The lateral side is pointed and slender
2	Abdomen	✓ Telson spines are rough and parallel	✓ Telson spines are smooth and parallel	✓ Telson spines are rough and blunt	✓ Fine telson spines	✓ Telson spines are rough and parallel	✓ Telson spines are rough and parallel	
3	Caudal							

characters between the collected lobster species.

3. Results

3.1. Morphology of lobster

Lobsters have an exoskeleton which is a hard layer and is equipped with spines. Each lobster species has specific characteristics such as differences in colors. In addition, the development of large and small spines starts from the head to the tail, but on the head the spines are more dominant. Morphologically, lobsters are divided into three major regions consisting of the cephalothorax, abdomen and caudal regions. The cephalothorax region is the anterior part of the combined head and chest that is wrapped in a slightly cylindrical carapace, swells and fuses with the thorax. Abdomen region is part of the body in the form of segments consisting of 6 segments. Segments 1–3 are called tergums, while segments 4–6 are called pleurons. The caudal region is the tail formed by the urupod and telson.

3.1.1. Cephalothorax

The cepha area consists of the antennae, antennae, cornea, rostrum,

ophthalmic artery, protocephalon, oris, maxilliped, epistome, and mandible. Antennules have a stem shape that is not elongated, at each base of the anterior part of the rostrum branching into two parts resembling a vertical V. Antennae have a round rod shape with a long tapered tip that exceeds the length of the antennae, and has sharp, jagged spines on the posterior antenna. Antennule functions as a tool for touch, taste and smell. In addition, the antenna is also used as a protective device to detect food or objects from a distance, while the antennae function as chemical and mechanical sensors, namely air, temperature, moisture content, vibration, and detect objects at close range. Cornea is a compound eye that is stalked and is located diventral lateral to the rostrum process. Cornea serves to distinguish between dark and light, observe movement, and determine the position of food.

Rostrum is the leading part of the cepha which has a sharp tip and serves as a tool to attack the enemy. The rostrum consists of the rostrum process and the rostrum spine. Rostrum spine is a sharp-tipped spine and is located anteriorly. Rostrum process has a curved and sharp shape at the top of the eye. Rostrum process serves as a tool for the body's defense in a state of danger. The ophthalmic artery is a branch that supplies blood to the eye. The ophthalmic artery has the function of carrying blood away from the eye and branching into smaller vessels

that open into a network of spaces, as well as a series of sinuses that drain blood back to the heart. The protocephalon is the stalk and the place where the blood vessels unite in the eye. The protocephalon functions as a sensory device as well as to detect food.

Maxilliped is a form of small walking legs that have fine hairs on each part of the foot. Maxilliped has a function as a tool to filter food and bring food to the mouth. The mandible is formed from a pair of segmental appendages that correspond to the pedipalps of Chelicerata. The mandible functions as a sense, regulating the movement of water around the gills. The epistome is the underside of the head formed by a broad plate below the base of the antenna. The epistome has a function to protect the muscles attached to the epistome wall. The oris is a cavity where food and water enter which is located on the ventral part of the cepha surrounded by the mandible and maxilliped.

The dorsal thorax region consists of the cervical sulcus, branchiostegite, while the ventral thorax consists of the sternum, and pereopod. Pereiopods have 5 pairs of walking legs which have fine hairs on the ends of the feet, and in female pereiopods on the fifth leg there is a small capitulum while the male pereiopod does not have a capitulum. Pereiopods are 5 pairs of lobster walking legs to move around. The cervical sulcus is a line that forms an indentation on the dorsal of the lobster's head. Sulcus cervicalis has a different form of curve in each species. The sternum is located on the ventral surface of five pairs of foot bearing segments consisting of left and right, the first to fifth foot bearing segments and has a different indentation shape in each species. The sternum serves as a place of attachment for the pereopod and protects the organs below the sternum. Branchiostegite is the side of the lobster head that serves to protect the gills. Branchiostegite has an elongated shape located lateral to the lobster head.

3.1.2. Abdominal

The abdominal region consists of the pleopods, pleura and abdominal somites. Pleopod is a locomotion tool in the form of 4 pairs of swimming legs, which have different ends such as length, width, and point. Pleopods function to swim with a push backwards, as a counterweight to swimming when at the bottom of the water, the female pleopod has a biramous and long bear where the eggs are and are cemented. The pleura is an open branch space on each body between the carapace edge and the base of the pereopod that points upward. The pleura has a wide, pointed, slender lateral side and serves as a liaison between the thorax and the abdominal somites. Abdomen somites is part of the lobster body which consists of 6 segments and the abdomen somites serves to assist the movement of the lobster.

3.1.3. Caudal

The caudal region consists of the anus, uropod, protopod, and telson. The anus has a round shape that is wide and flat, splitting into two parts on the lower surface of the telson, the anus is an organ of reproduction and digestion. Uropods are the leaf appendages of the last caudal segment. Uropod has an oval shape and at the end of its base there are fine spines, and serves as a swimming tool for balance. Telson has the same shape as the uropod but the telson is located in the middle of the tail, has a strong propulsion function for swimming. The protopod is the anterior dorsal part which is the basis of the telson and uropod parts associated with the sixth somites. Uropod and telson is the tail that is connected to form a fan and serves as a means of controlling the direction back and forth when swimming.

3.2. Lobster exoskeleton anatomy comparison

In the dorsal cephalothorax region (carapace) of *P. penicillatus* has a greenish-brown color, and the ventral part is yellowish green (Fig. 2A). Yellow spots also appear on *P. penicillatus* and *P. homarus* ventrally. The dorsal part of the cephalothorax of *P. homarus* has a blue-green color and on the ventral side it is yellowish (Fig. 2B). In the cephalothorax region of *P. longispes* on the dorsal side it has a dark brown to reddish color, while on the ventral side it is light brown and there are white spots (Fig. 2C).

On the dorsal cephalothorax of *P. ornatus* has a blue color mixed with a little black, and on the ventral part it is white mixed with orange color and there are orange spots (Fig. 2D). *P. versicolor* in the dorsal cephalothorax region has a black color which is more dominant than turquoise, while in the ventral section it has white color and there are black spots (Fig. 2E). The dorsal cephalothorax of *P. pholypagus* has a light brown color and the ventral side is orange (Fig. 2F) (Figs. 3–8).

On the dorsal cephalothorax of *P. penicillatus* has spines that grow irregularly and has two large spines of rostrum spine that develop anteriorly. The anteriodorsal rostrum has four sharp spines, consisting of two medium spines and two small spines, while in the anterior part of the epistome there are three medium-sized blunt spines (Fig. 9A). The spines of the dorsal cephalothorax of *P. homarus* grow irregularly and have two large spines (rostrum spine) that develop anteriorly. In addition, the anteriodorsal rostrum has three sharp spines, while the anterior epistome has three blunt spines (Fig. 10A).

In the dorsal cephalothorax of *P. longispes* has spines that grow parallel and neatly arranged, there are two large spines that develop anteriorly, while the anteriodorsal section has four sharp spines, namely two small spines and two large spines. In addition, in the anterior part of

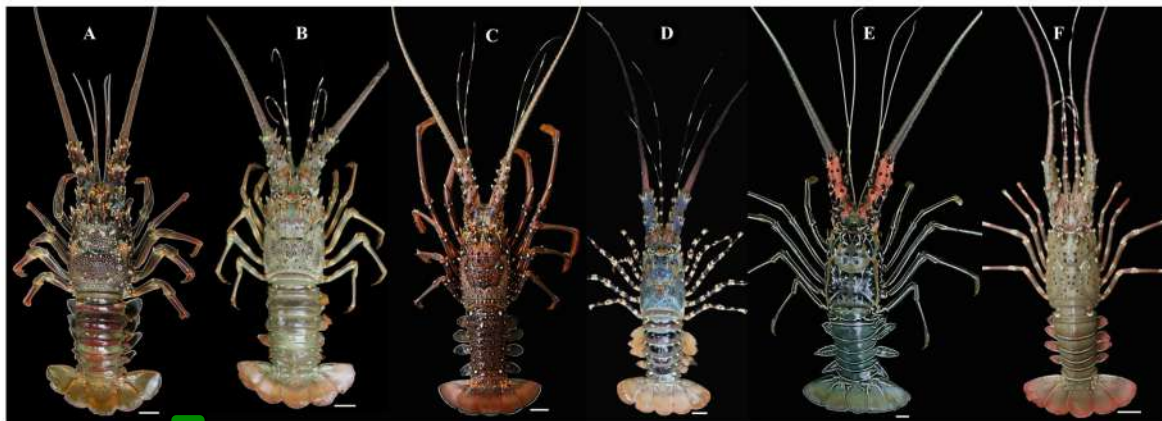


Fig. 2. Genus *Panulirus*. (A) *Panulirus penicillatus*, (B) *Panulirus homarus*, (C) *Panulirus longispes*, (D) *Panulirus ornatus*, (E) *Panulirus versicolor*, (F) *Panulirus pholypagus*. Bar scale: 2 cm.

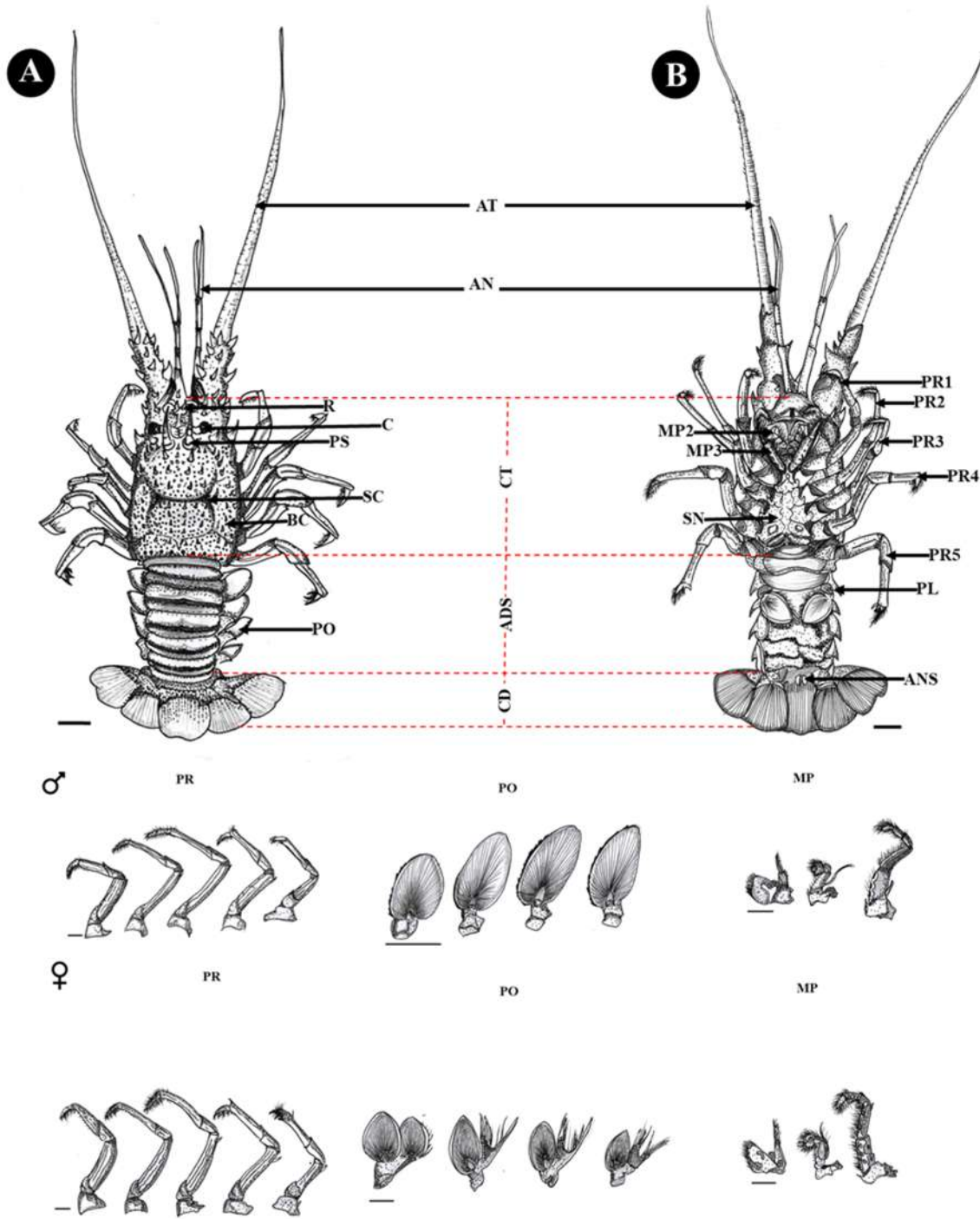


Fig. 3. The morphology of *Panulirus penicillatus* appears dorsal (A) and ventral (B). Where AN: antennule, AT: antennae, PR: pereopod, SC: sulcus cervical, BC: branchiostegite, PO: pleopod, PL: pleura, C: cornea, PC: processus rostrum, MP: maxilliped, SN: sternum, ANS: anus, ADS: abdomen somites, CT: cephalothorax, CD: caudal. Bar scale: 2 cm for Fig. A dan B; Bar scale: 1 cm for figure ♂ and ♀.

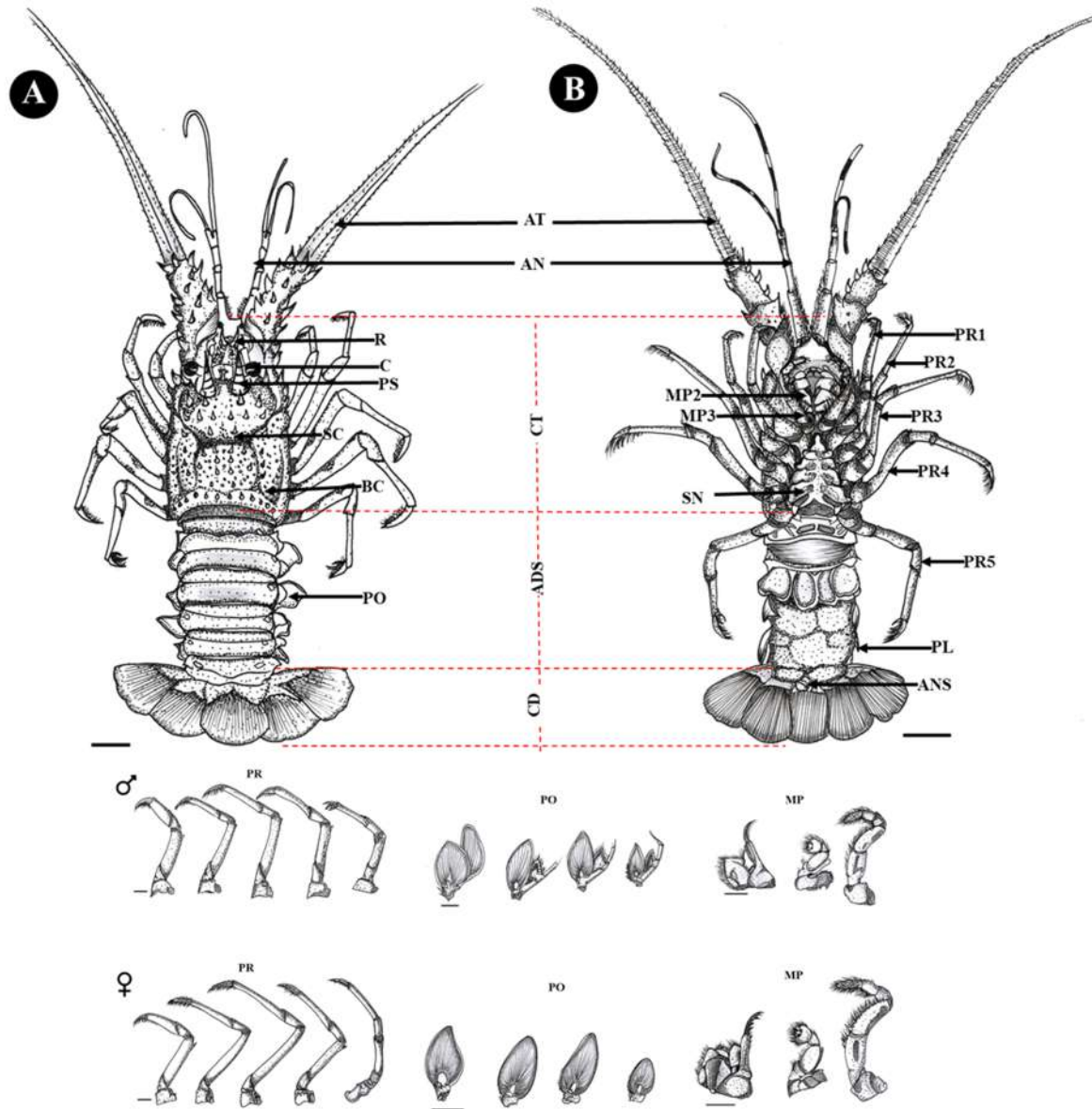


Fig. 4. The morphology of *Panulirus homarus* appears dorsal (A) and ventral (B). Where AN: antennule, AT: antennae, PR: pereopod, SC: sulcus cervical, BC: branchiostegite, PO: pleopod, PL: pleura, C: cornea, PC: processus rostrum, MP: maxilliped, SN: sternum, ANS: anus, ADS: abdomen somites, CT: cephalothorax, CD: caudal. Bar scale: 2 cm for Fig. A and B; Bar scale: 1 cm for figure ♂ and ♀.

the epistome there are nine, namely three large and sharp spines and six small blunt spines (Fig. 11A). In the dorsal region of the cephalothorax of *P. ornatus* has spines that develop regularly, and in the anteriodorsal section there are four spines, namely two blunt spines and two sharp spines. The spina rostrum has two large spines developing anteriorly, while the anterior epistome has three small and blunt spines (Fig. 12A).

Spines on the dorsal cephalothorax of *P. versicolor* which have spines on the cepha and spina rostrum have two large spines that develop anteriorly. On the anteriodorsal side there are two blunt spines and two sharp spines. Anterior to the epistome are three large, sharp spines (Fig. 13A). On the dorsal cephalothorax of *P. pholypagus* has spines that

grow parallel and neatly arranged. The rostrum spine has two large spines and develops anteriorly. The anteriodorsal section has two large and sharp spines, while the anterior epistome has two sharp, large and small spines (Fig. 14A).

On the dorsal side of the *P. penicillatus* abdomen has six segments that are reddish green (Fig. 2A), while on the ventral side of the abdomen there are four pairs of pleopod sheets that are wide and long (Fig. 15A) and have a dark green color (Fig. 2A). Meanwhile, on the lateral side of the abdomen there are white spots surrounding the pleura which are wide and pointed (Figs. 2A and 15B). In the dorsal abdominal region of *P. homarus* has six greenish-brown segments (Fig. 2B), while in the

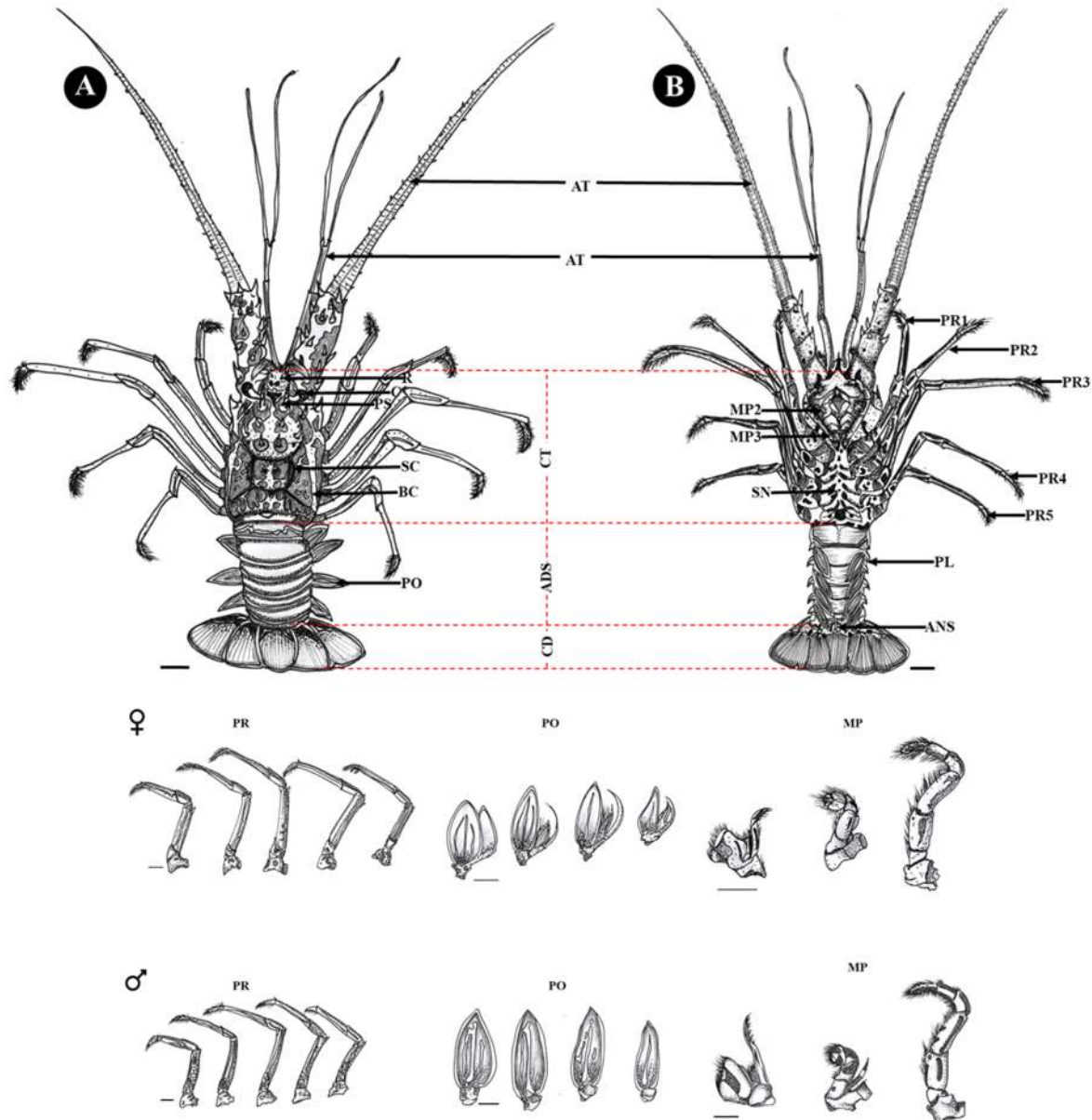


Fig. 5. The morphology of *Panulirus versicolor* appears dorsal (A) and ventral (B). Where AN: antennule, AT: antennae, PR: pereopod, SC: sulcus cervical, BC: branchiostegite, PO: pleopod, PL: pleura, C: cornea, PC: processus rostrum, MP: maxilliped, SN: sternum, ANS: anus, ADS: abdomen somites, CT: cephalothorax, CD: caudal. Bar scale: 2 cm for Fig. A dan B; Bar scale: 1 cm for figure ♂ and ♀.

ventral abdomen there are four pairs of pleopod sheets that are wide (Fig. 16A) and have an orange color on each sheet (Fig. 2B). On the lateral side of the abdomen there are white spots surrounding the pleura which are slender and pointed (Figs. 2B and 16B). *P. ornatus* has six dorsal abdominal segments which are blue-black in color (Fig. 2D). On the ventral abdomen there are four pairs of pleopod sheets that are long and wide (Fig. 17A) and each sheet has an orange color (Fig. 2D). On the lateral side of the abdomen there is a pleura that is broad and pointed (Fig. 17B) and has white spots surrounding it (Fig. 2D).

On the dorsal of *P. longispes* abdomen region has six segments that are dark reddish brown (Fig. 2C) and on the ventral abdomen there are four

pairs of pleopod sheets that are long and wide (Fig. 18A) and reddish brown on each sheet (Fig. 2C). On the lateral side of the abdomen there are white and red spots surrounding the pleura which are slender and tapered (Figs. 2C and 18B). On the dorsal abdomen of *P. versicolor* has six segments that are light green mixed with black and white (Fig. 2E) and on the ventral abdomen it has four pairs of pleopod sheets that are long and slender (Fig. 19A) and have black and white on the abdomen (Fig. 2E). On the lateral side of the abdomen is the pleura, which is broad and pointed (Fig. 19B), and has white lines surrounding it (Fig. 2E).

On the dorsal of *P. pholypagus* abdomen region has six segments that are light brown mixed with dark brown (Fig. 2F) while on the ventral

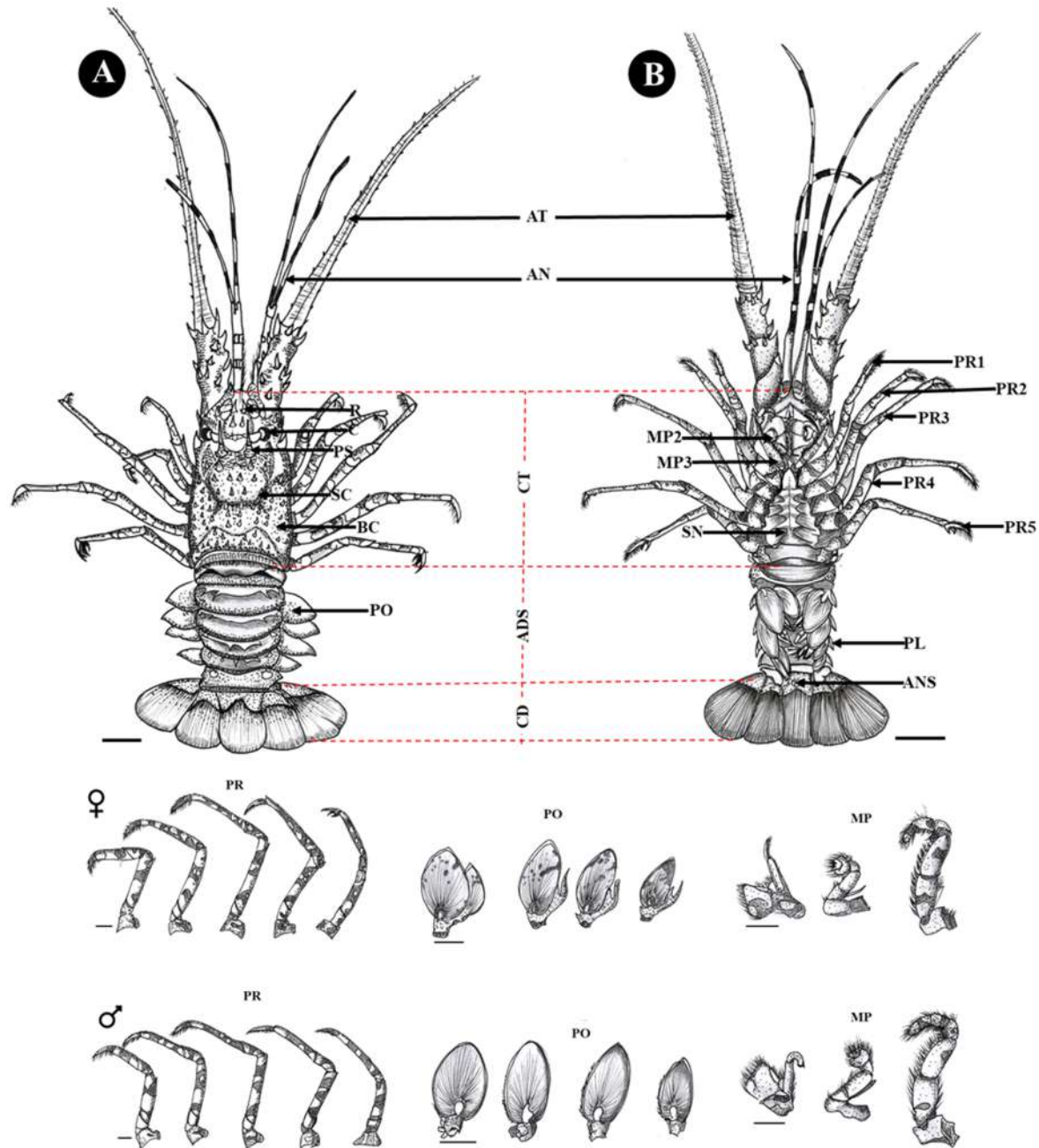


Fig. 6. The morphology of *Panulirus ornatus* appears dorsal (A) and ventral (B). Where AN: antennule, AT: antennae, PR: pereopod, SC: sulcus cervical, BC: branchiostegite, PO: pleopod, PL: pleura, C: cornea, PC: processus rostrum, MP: maxilliped, SN: sternum, ANS: anus, ADS: abdomen somites, CT: cephalothorax, CD: caudal. Bar scale: 2 cm for Fig. A dan B; Bar scale: 1 cm for figure ♂ and ♀.

abdomen there are 4 pairs of pleopod sheets that are wide and slender (Fig. 20A) and pink on each sheet (Fig. 2F). Meanwhile, on the lateral side of the abdomen there is a pleura that is wide and pointed (Fig. 20B) and has white spots around it (Fig. 2F).

In the dorsal of *P. penicillatus* caudal region has five fin sheets (Fig. 15A) consisting of uropods and telsons with reddish-green

coloration on each sheet (Fig. 2A) accompanied by the anteriodorsal part there are small parallel and sharp spines. The posterior part of the uropod has a broadened shape while the posterior telson is not dilated (Fig. 15A). *P. homarus* in the dorsal caudal section contained five fin sheets (Fig. 16A), consisting of a uropod and telson with orange color on each sheet (Fig. 2B) accompanied by a few blunt smooth spines on the

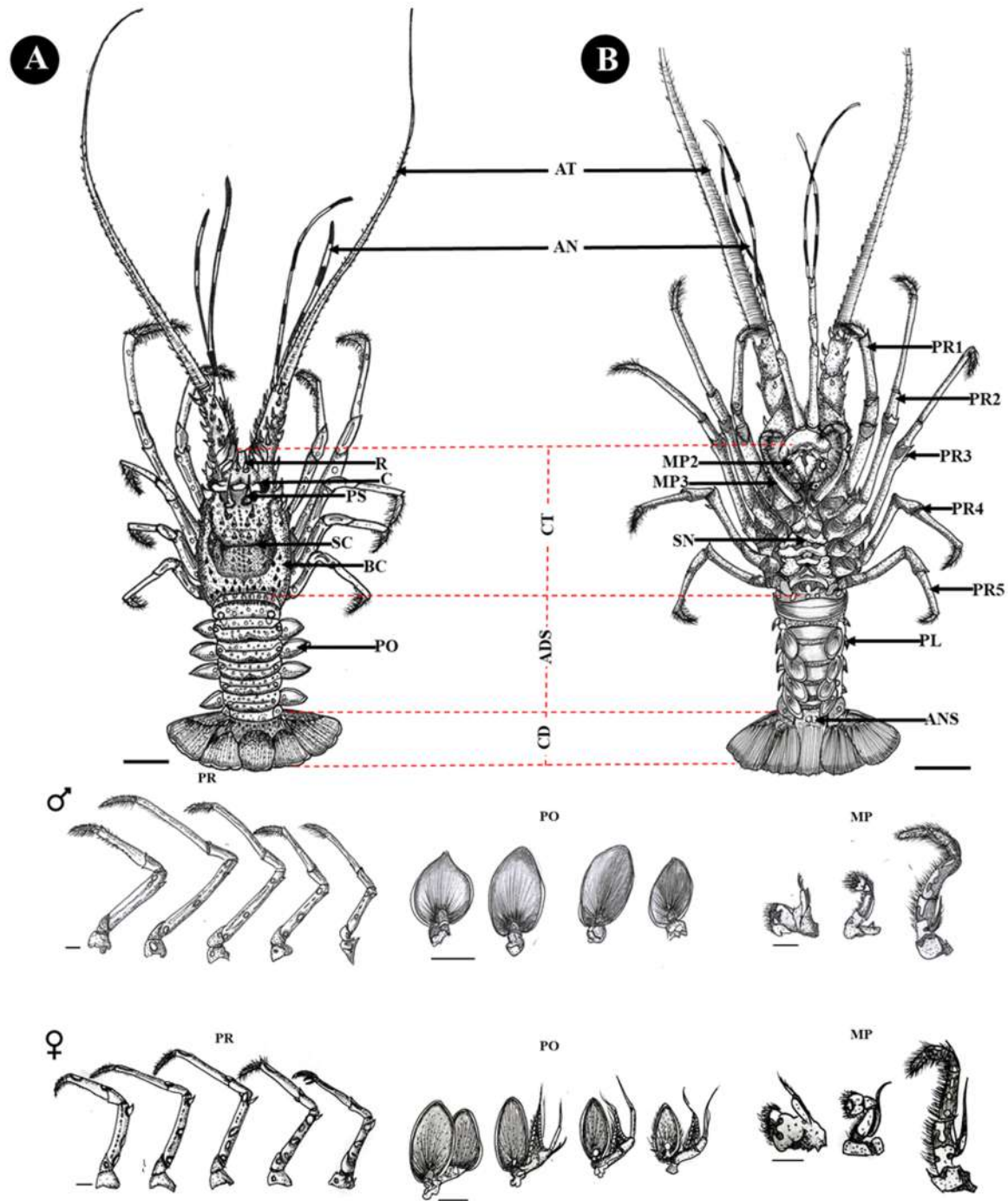


Fig. 7. The morphology of *Panulirus longispes* appears dorsal (A) and ventral (B). Where AN: antennule, AT: antennae, PR: pereopod, SC: sulcus cervical, BC: branchiostegite, PO: pleopod, PL: pleura, C: cornea, PC: processus rostrum, MP: maxilliped, SN: sternum, ANS: anus, ADS: abdomen somites, CT: cephalothorax, CD: caudal. Bar scale: 2 cm for Fig. A dan B; Bar scale: 1 cm for figure ♂ and ♀.

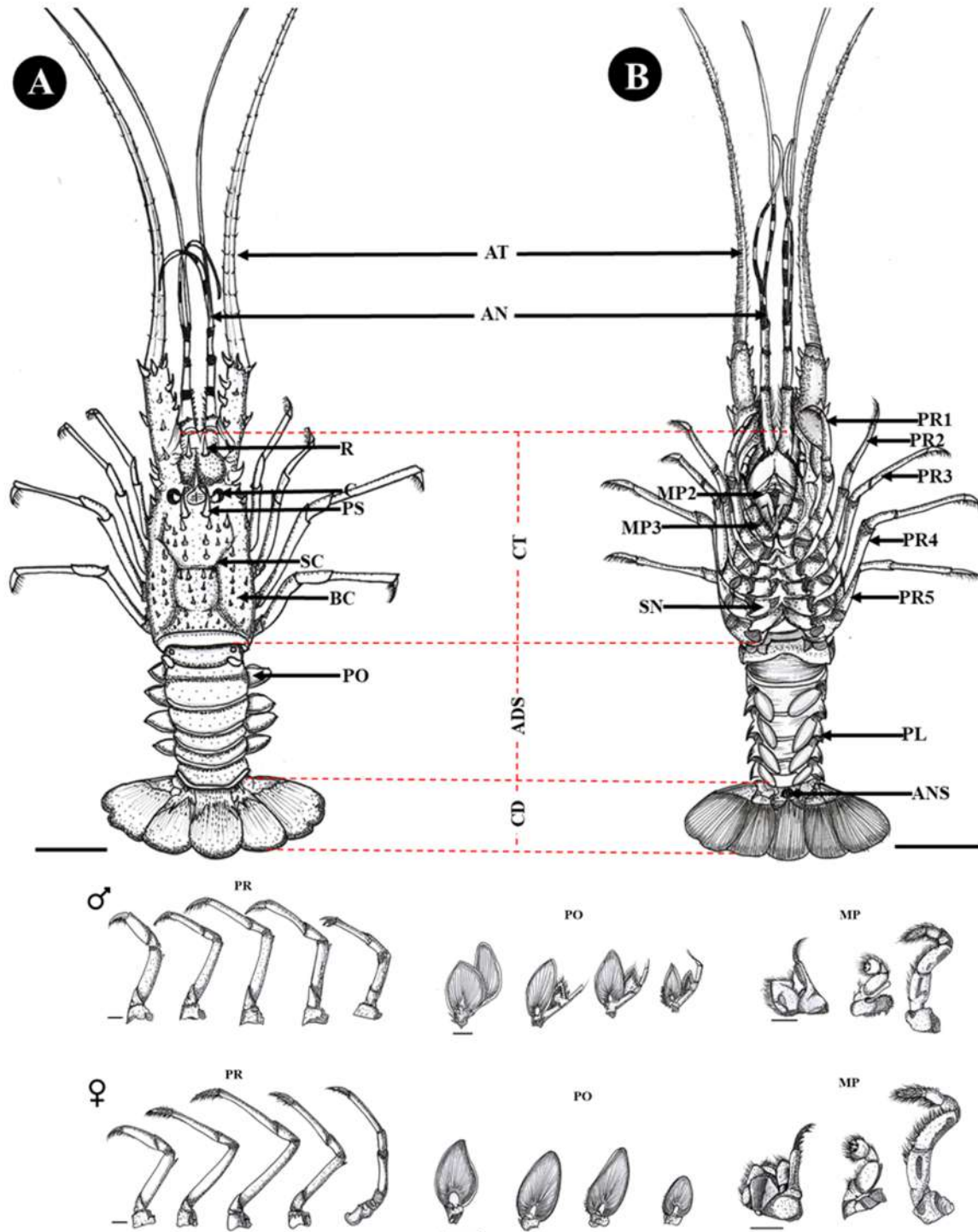


Fig. 8. The morphology of *Panulirus pholypagus* appears dorsal (A) and ventral (B). Where AN: antennule, AT: antennae, PR: pereopod, SC: sulcus cervical, BC: branchiostegite, PO: pleopod, PL: pleura, C: cornea, PC: processus rostrum, MP: maxilliped, SN: sternum, ANS: anus, ADS: abdomen somites, CT: cephalothorax, CD: caudal. Bar scale: 2 cm for Fig. A dan B; Bar scale: 1 cm for figure ♂ and ♀.

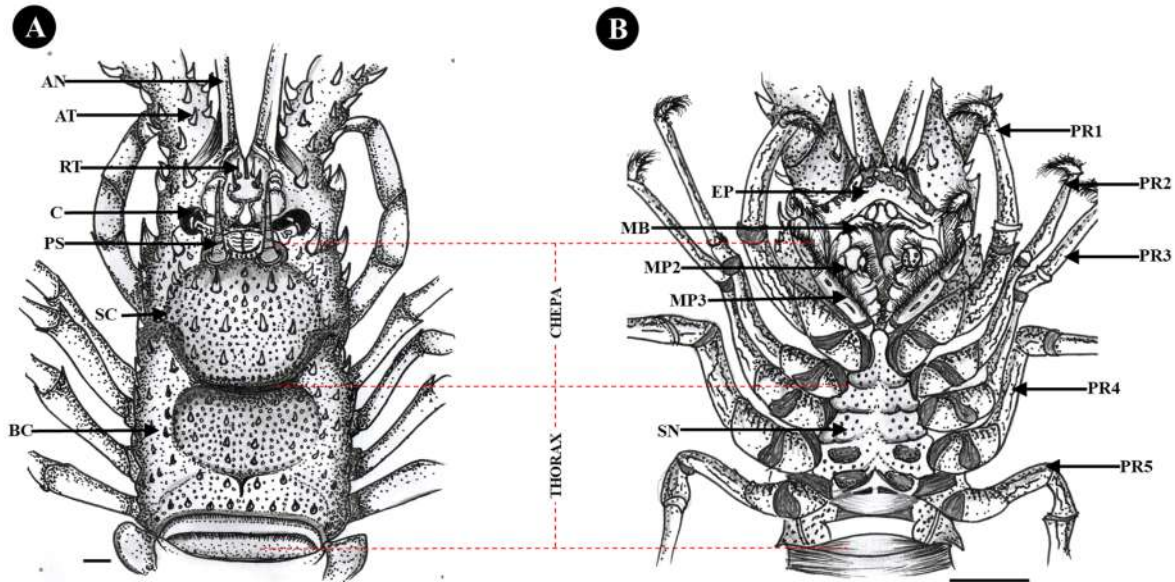


Fig. 9. The cephalothorax morphology of *Panulirus penicillatus* appears dorsal (A) and ventral (B). Where AN: antennule, AT: antennae, PR: pereopods, RT: rostrum, C: cornea, PC: prosesus rostrum, SC: sulcus cervicalis, BC: branchiostegite, SN: sternum, MP: maxilliped, MB: mandible, EP: epistome. Bar scale: 2 cm.

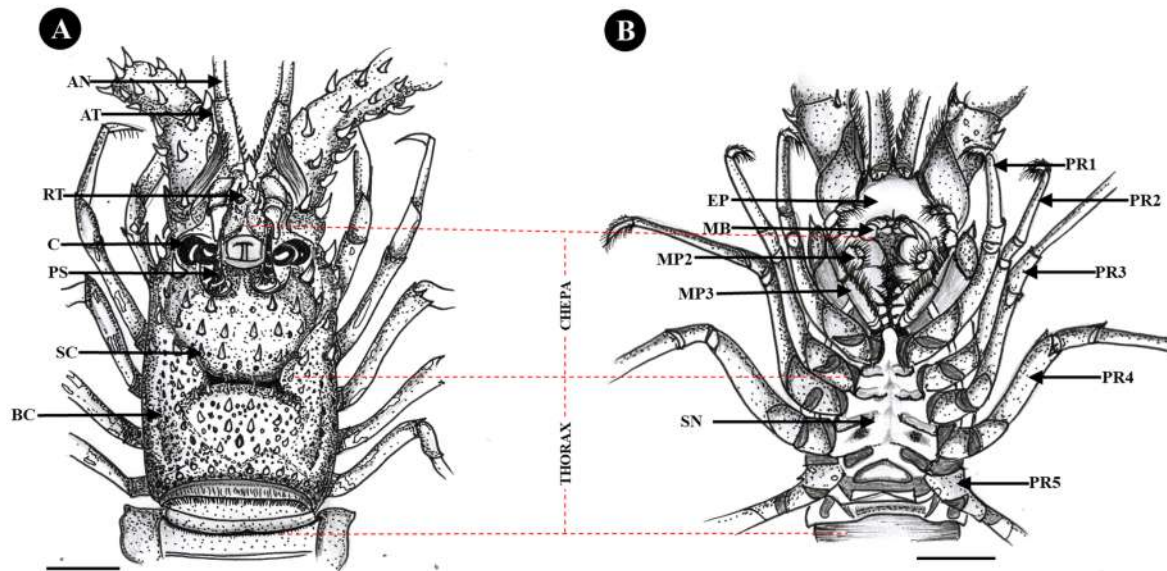


Fig. 10. The cephalothorax morphology of *Panulirus homarus* appears dorsal (A) and ventral (B). Where AN: antennule, AT: antennae, PR: pereopods, RT: rostrum, C: cornea, PC: prosesus rostrum, SC: sulcus cervicalis, BC: branchiostegite, SN: sternum, MP: maxilliped, MB: mandible, EP: epistome. Bar scale: 2 cm.

anteriodorsal side. The posterior part of the uropod has a wide triangular shape while the posterior telson has a wide round shape (Fig. 16A). On the dorsal caudal part of *P. ornatus* there are five fan-shaped sheets (Fig. 17A) which have an orange color (Fig. 2D), and on the anteriodorsal there are sharp parallel fine spines on the uropod and telson. Posteriorly the uropod and telson have a broadened shape (Fig. 17A).

The dorsal of *P. longispes* caudal region has five fan-shaped sheets (Fig. 18A) with reddish brown color (Fig. 2C), and on the anteriodorsal region there are sharp parallel fine spines on the uropod and telson

sections. The posterior region of the uropod has a broadened shape while the posterior telson is not dilated (Fig. 18A). On the dorsal of *P. versicolor* caudal region has a light green color (Fig. 2E) of five fin sheets, and on the anteriodorsal it has a few blunt fine spines. The posterior part of the uropod has a broadened shape while the posterior telson is not dilated (Fig. 19A). *P. polypagus* caudal dorsally has five fin sheets (Fig. 20A) which have a pink color (Fig. 2F) and on the anteriodorsal there are few sharp fine spines. Posteriorly the uropod and telson have a broadened shape (Fig. 20A).

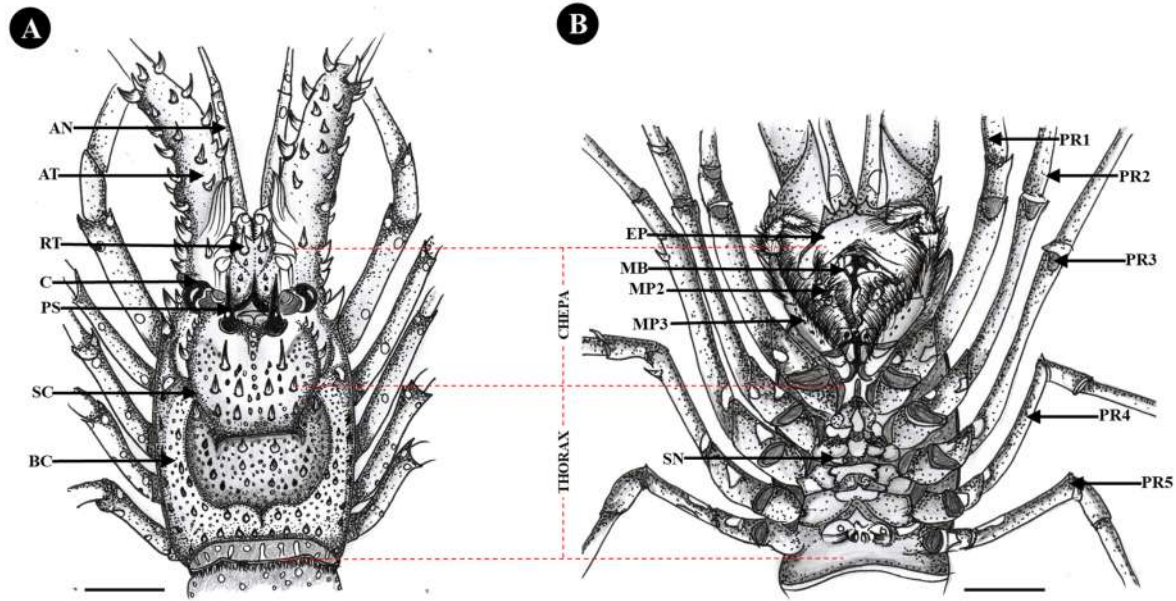


Fig. 11. The cephalothorax morphology of *Panulirus longispes* appears dorsal (A) and ventral (B). Where AN: antennule, AT: antennae, PR: pereopods, RT: rostrum, C: cornea, PC: prosesus rostrum, SC: sulcus cervicalis, BC: branchiostegite, SN: sternum, MP: maxilliped, MB: mandible, EP: epistome. Bar scale: 2 cm.

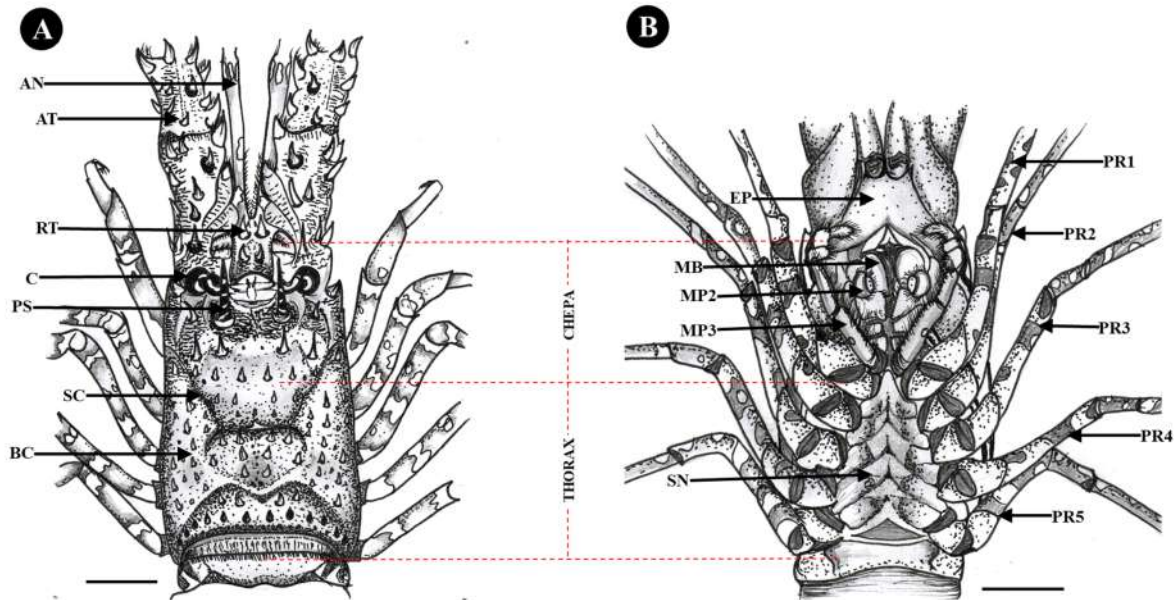


Fig. 12. The cephalothorax morphology of *Panulirus ornatus* appears dorsal (A) and ventral (B). Where AN: antennule, AT: antennae, PR: pereopods, RT: rostrum, C: cornea, PC: prosesus rostrum, SC: sulcus cervicalis, BC: branchiostegite, SN: sternum, MP: maxilliped, MB: mandible, EP: epistome. Bar scale: 2 cm.

In the dorsal cephalothorax region of *P. penicillatus*, there is a cervical sulcus which is wide, long and clearly shaped and reaches the thoracic region. In addition, there are many small and blunt spines (Fig. 9A). The dorsal cephalothorax of *P. Homarus* is long and slender, and has an indistinct cervical sulcus, and there are small blunt projections (Fig. 10A). In the dorsal cephalothorax of *P. longispes* has a clear cervical sulcus that reaches the thoracic region, and is long, slender and has

smaller blunt projections (Fig. 11A).

In the dorsal of *P. ornatus* cephalothorax region has a clear cervical sulcus shape and wide, long, and a few small blunt projections (Fig. 12A). In the dorsal cephalothorax region of *P. versicolor* has a wide, long size and there is a cervical sulcus shape that is not clearly visible. There are only a few small blunt projections in the cepha (Fig. 13A). *P. pholypagus* in the dorsal cephalothorax region is long, slender and has

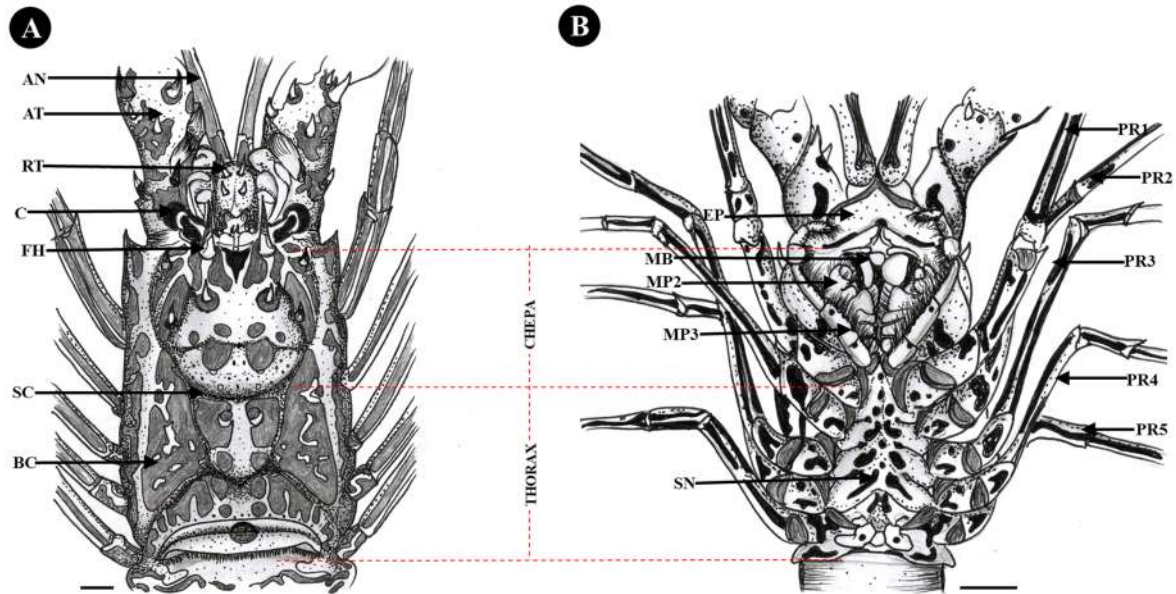


Fig. 13. The cephalothorax morphology of *Panulirus versicolor* appears dorsal (A) and ventral (B). Where AN: antennule, AT: antennae, PR: pereiopods, RT: rostrum, C: cornea, PC: prosesus rostrum, SC: sulcus cervicalis, BC: branchiostegite, SN: sternum, MP: maxilliped, MB: mandible, EP: epistome. Bar scale: 2 cm.

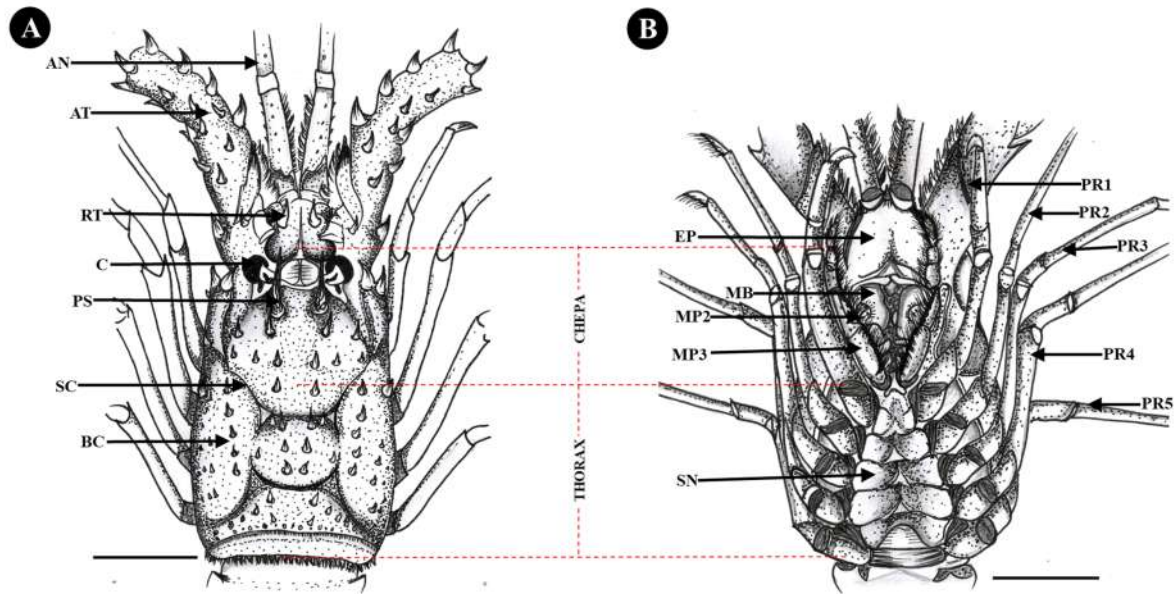


Fig. 14. The cephalothorax morphology of *Panulirus polyphagus* appears dorsal (A) and ventral (B). Where AN: antennule, AT: antennae, PR: pereiopods, RT: rostrum, C: cornea, PC: prosesus rostrum, SC: sulcus cervicalis, BC: branchiostegite, SN: sternum, MP: maxilliped, MB: mandible, EP: epistome. Bar scale: 2 cm.

a clear cervical sulcus shape and reaches up to the thoracic region. There are many small blunt projections (Fig. 14A).

In the ventral cephalothorax region of *P. penicillatus* has six pereiopods (walking legs) which have many fine hairs on the tips of the feet. At the base of the sixth leg there is no extension towards the median sternum (Fig. 9B). In the ventral cephalothorax of *P. homarus* has six pereiopods with a few fine hairs on each toe and a median extension of the sternum at the base of the sixth leg (Fig. 10B). In the ventral

cephalothorax of *P. longispes* has six pereiopods which have many fine hairs on the tips of the feet. Meanwhile, at the base of the sixth pereiopod there is a medial extension of the sternum (Fig. 11B).

On the ventral cephalothorax of *P. ornatus* has six pereiopods which are overgrown with fine hairs on the tips of the feet and there is no median extension of the sternum at the base of the sixth leg (Fig. 12B). In the ventral cephalothorax of *P. versicolor* has six pereiopods which are overgrown with fine hairs at the ends of the legs. There is an indistinct

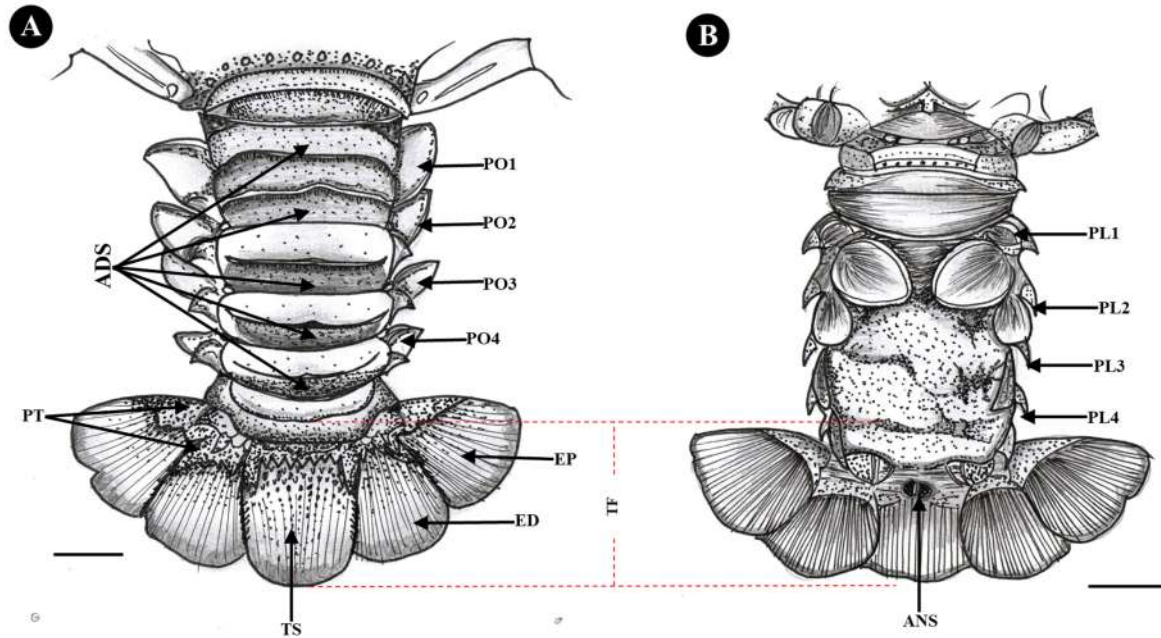


Fig. 15. Abdominal and caudal morphology of *Panulirus penicillatus* appears dorsal (A) and ventral (B). Where PT: protopod, PO: pleopod, PL: pleura, ADS: abdomen somites, TS: telson, ED: endopod, EP: exopod, ANS: anus, TS: tail fan. Bar scale: 2 cm.

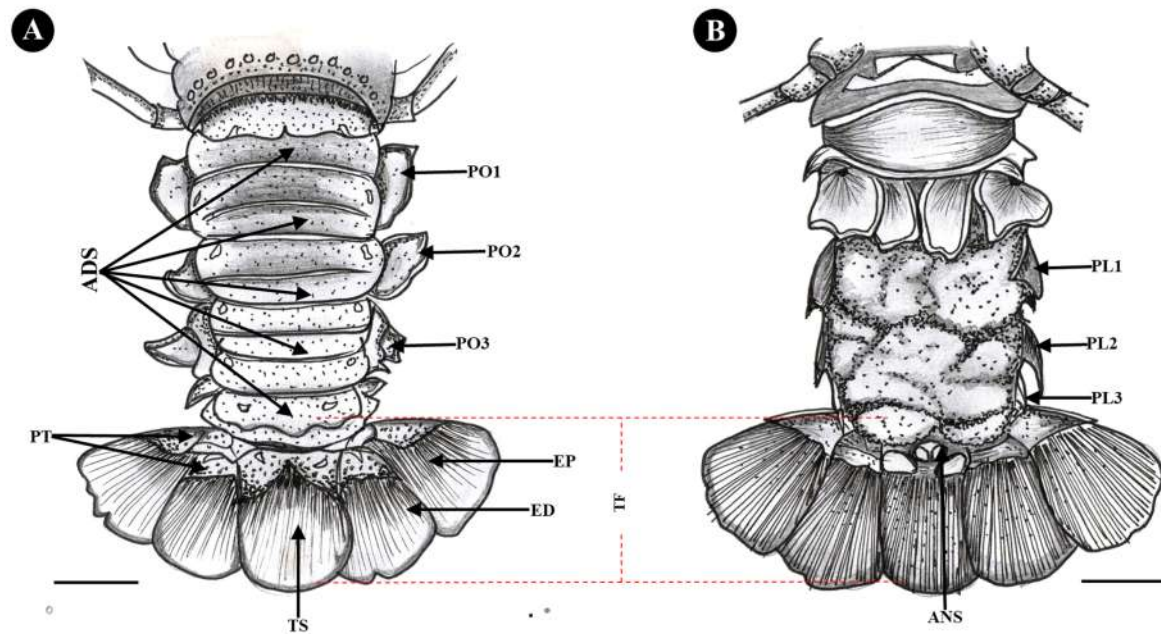


Fig. 16. Abdominal and caudal morphology of *Panulirus homarus* appears dorsal (A) and ventral (B). Where PT: protopod, PO: pleopod, PL: pleura, ADS: abdomen somites, TS: telson, ED: endopod, EP: exopod, ANS: anus, TS: tail fan. Bar scale: 2 cm.

extension towards the median of the sternum at the base of the sixth leg (Fig. 13B). On the ventral cephalothorax of *P. pholypagus* has six pereopods with a few fine hairs at the ends of their feet. Meanwhile, at the base of the sixth pereopod, there is a medial extension of the sternum (Fig. 14B).

In the ventral cephalothorax region of *P. penicillatus*, there is a sternum that has an indistinct indentation (Fig. 9B). In the ventral cephalothorax of *P. homarus* did not have a clear sternal shape (Fig. 10B). In the ventral cephalothorax of *P. longispes*, there is a sternum which has a clear indentation (Fig. 11B). In the ventral cephalothorax region of

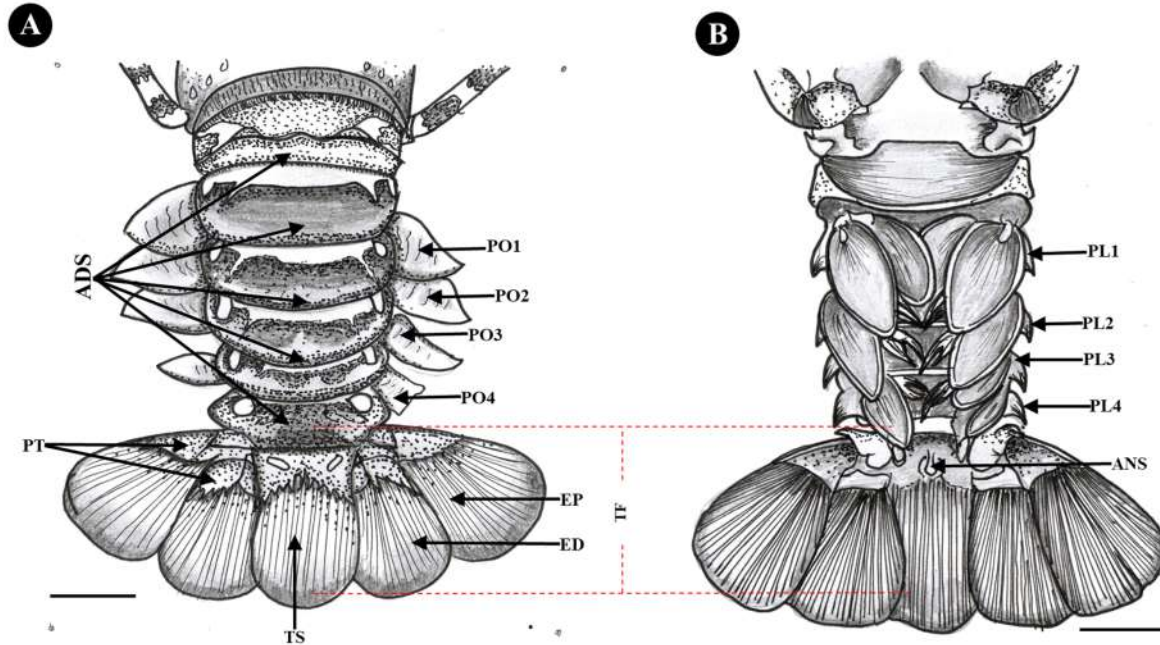


Fig. 17. Abdominal and caudal morphology of *Panulirus ornatus* appears dorsal (A) and ventral (B). Where PT: protopod, PO: pleopod, PL: pleura, ADS: abdomen somites, TS: telson, ED: endopod, EP: exopod, ANS: anus, TS: tail fan. Bar scale: 2 cm.

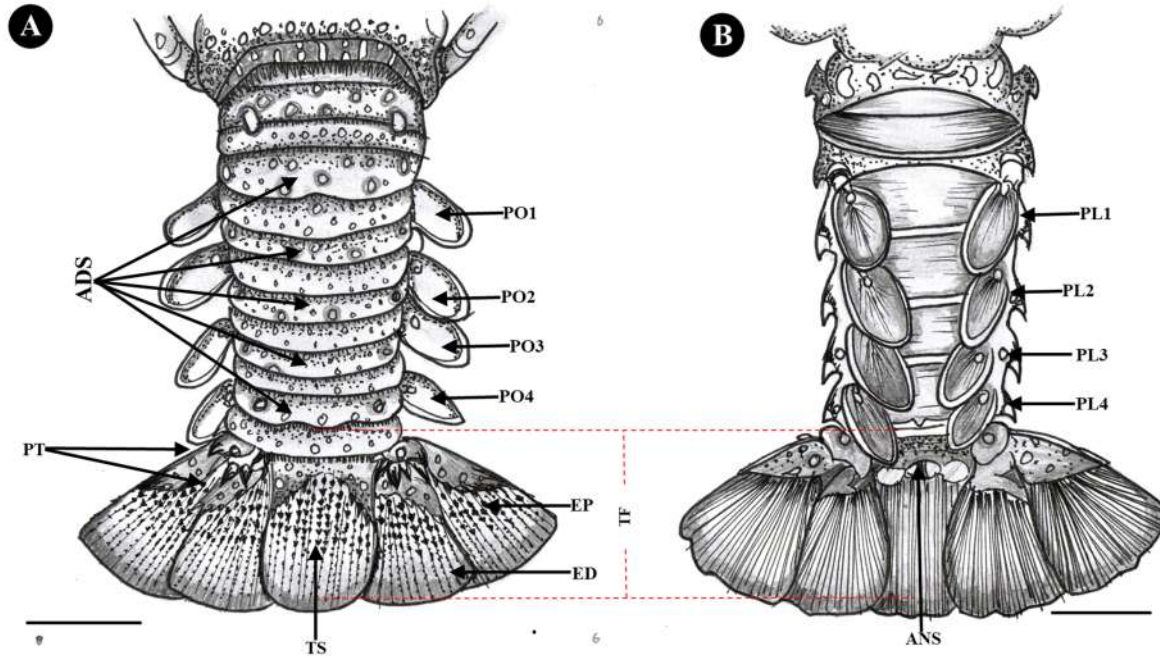


Fig. 18. Abdominal and caudal morphology of *Panulirus longispes* appears dorsal (A) and ventral (B). Where PT: protopod, PO: pleopod, PL: pleura, ADS: abdomen somites, TS: telson, ED: endopod, EP: exopod, ANS: anus, TS: tail fan. Bar scale: 2 cm.

P. ornatus, there is an indistinct sternal shape (Fig. 12B). In the ventral cephalothorax of *P. versicolor* did not have a clear sternal shape (Fig. 13B). In the ventral cephalothorax region of *P. pholypagus* has a

distinct sternal shape (Fig. 14B).

In the ventral cephalothorax region in the mouth, there are two auxiliary legs called maxillipeds. In the third maxilliped of *P. penicillatus*

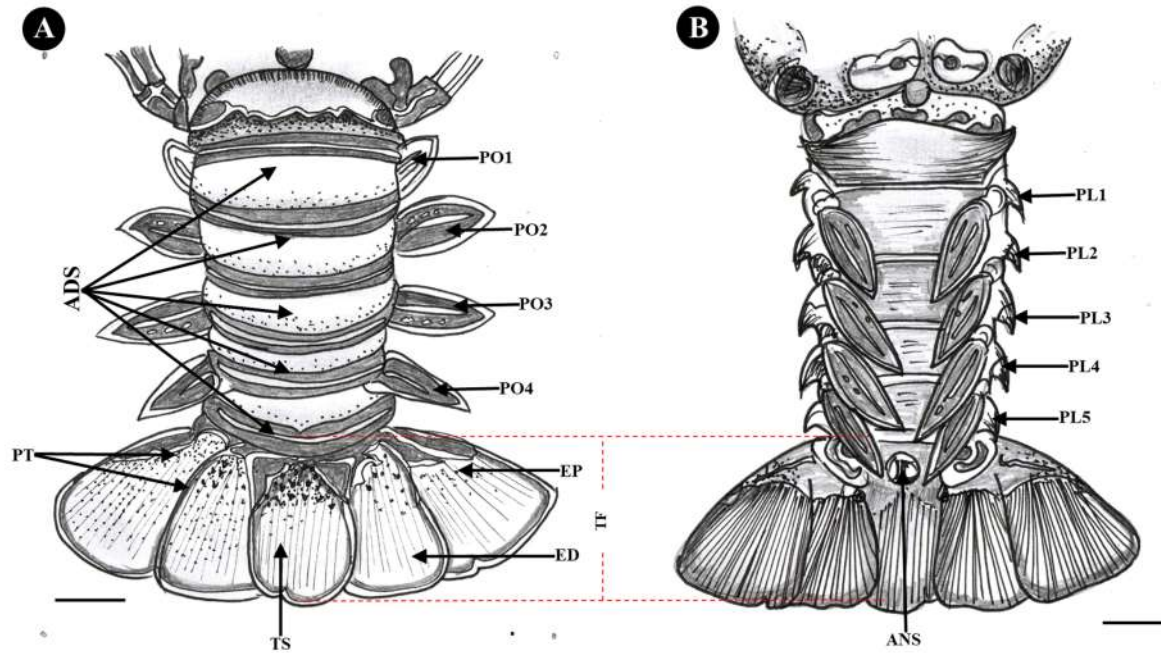


Fig. 19. Abdominal and caudal morphology of *Panulirus versicolor* appears dorsal (A) and ventral (B). Where PT: protopod, PO: pleopod, PL: pleura, ADS: abdomen somites, TS: telson, ED: endopod, EP: exopod, ANS: anus, TS: tail fan. Bar scale: 2 cm.

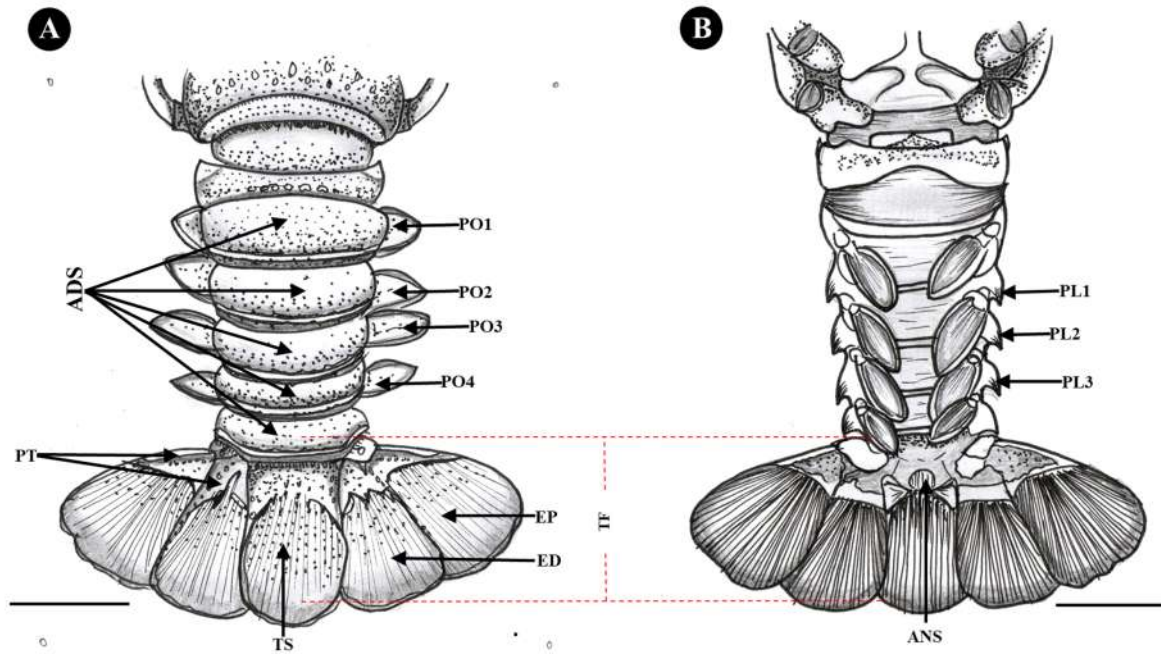


Fig. 20. Abdominal and caudal morphology of *Panulirus polyphagus* appears dorsal (A) and ventral (B). Where PT: protopod, PO: pleopod, PL: pleura, ADS: abdomen somites, TS: telson, ED: endopod, EP: exopod, ANS: anus, TS: tail fan. Bar scale: 2 cm.

had many fine hairs around it (Fig. 21B). In the ventral cephalothorax of *P. homarus*, there is a third maxillaped which has many fine hairs around it (Fig. 22B). In the third dimaxillaped of *P. longispes* has many fine and

dense hairs in the ventral cephalothorax region (Fig. 23B). On the third maxillaped of *P. ornatus*, there are few fine hairs (Fig. 24B). In the third maxillaped of *P. versicolor* had many fine and dense hairs (Fig. 25B). In

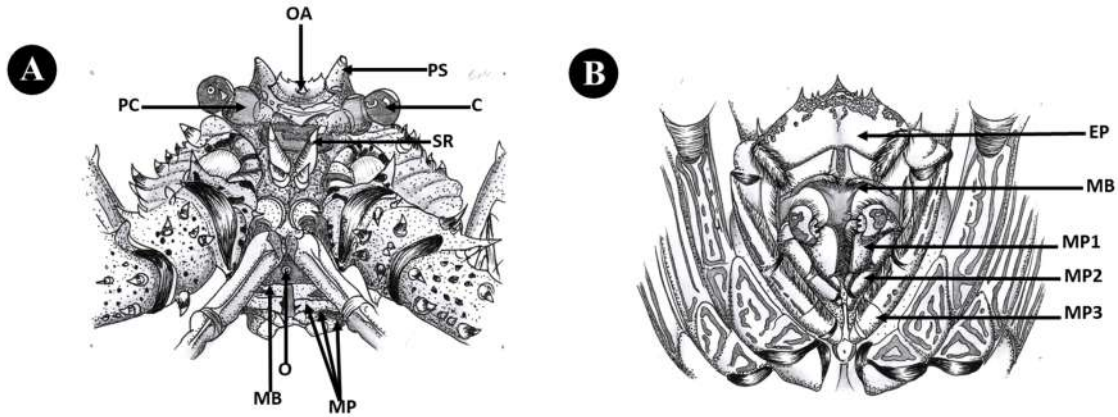


Fig. 21. Morphology of the cephalothorax of *Panulirus penicillatus* appears anterior (A) and ventral (B). Where OA: ophthalmic artery, PC: Protochepalon, PS: Processus rostrum, C: cornea, SR: spina rostrum, O: Oris, MB: mandible, MP: maxillaped, EP: epistome.

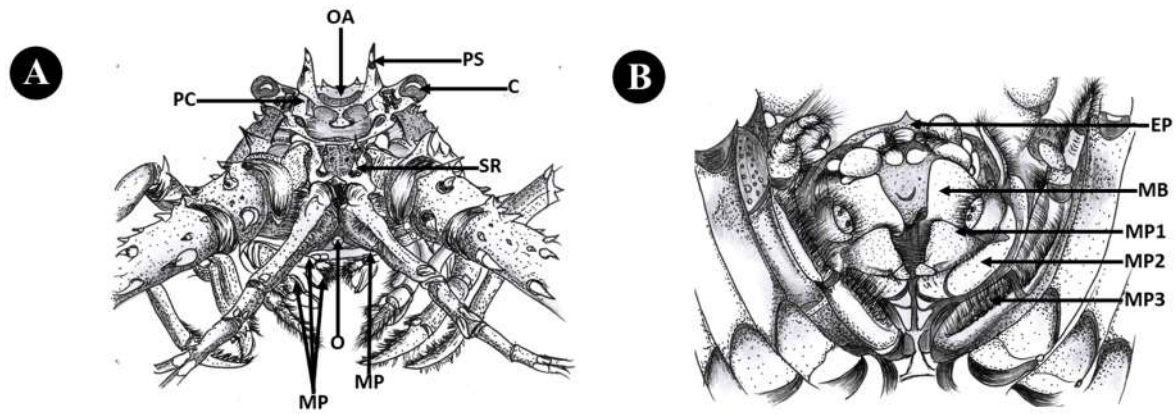


Fig. 22. Morphology of the cephalothorax of *Panulirus homarus* appears anterior (A) and ventral (B). Where OA: ophthalmic artery, PC: Protochepalon, PS: Processus rostrum, C: cornea, SR: spina rostrum, O: Oris, MB: mandible, MP: maxillaped, EP: epistome.

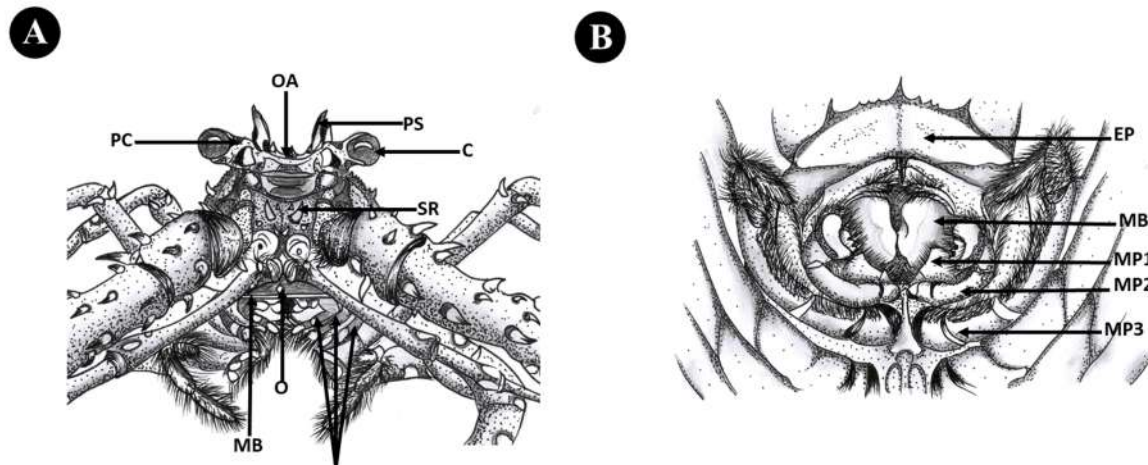


Fig. 23. Morphology of the cephalothorax of *Panulirus longspes* appears anterior (A) and ventral (B). Where OA: ophthalmic artery, PC: Protochepalon, PS: Processus rostrum, C: cornea, SR: spina rostrum, O: Oris, MB: mandible, MP: maxillaped, EP: epistome.

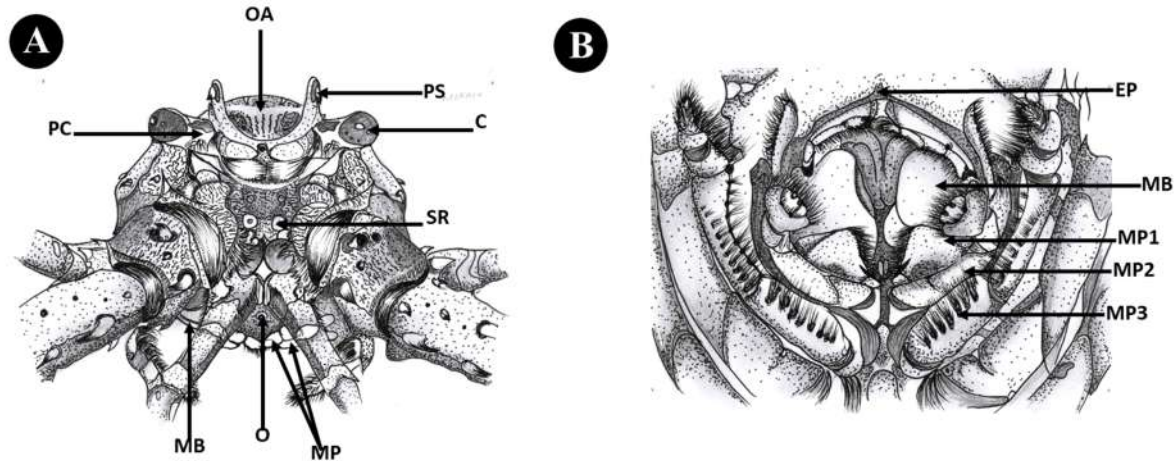


Fig. 24. Morphology of the cephalothorax of *Panulirus ornatus* appears anterior (A) and ventral (B). Where OA: ophthalmic artery, PC: Protochealon, PS: Processus rostrum, C: cornea, SR: spina rostrum, O: Oris, MB: mandible, MP: maxillaped, EP: epistome.

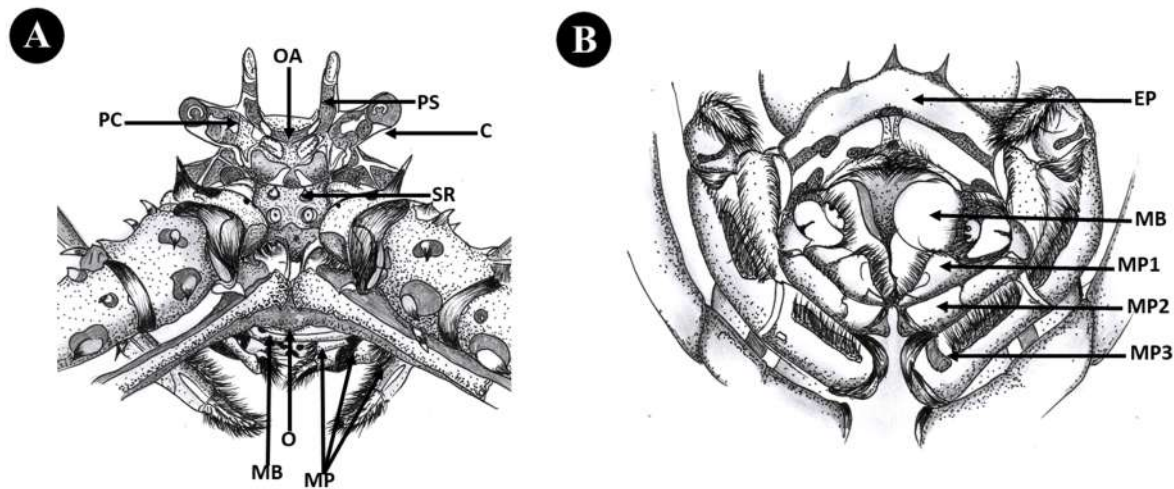


Fig. 25. Morphology of the cephalothorax of *Panulirus versicolor* appears anterior (A) and ventral (B). Where OA: ophthalmic artery, PC: Protochealon, PS: Processus rostrum, C: cornea, SR: spina rostrum, O: Oris, MB: mandible, MP: maxillaped, EP: epistome.

the third maxilliped of *P. pholypagus* has many fine hairs (Fig. 26B).

In the dorsal abdomen region of *P. penicillatus* has clear and tight grooves on each segment (Fig. 15A). On the dorsal abdomen region of *P. homarus* has an indistinct and sparse indentation in the segment (Fig. 16A). On the dorsal abdomen region of *P. longispes* has a well-defined and tight indentation at the segment (Fig. 18A). On the dorsal abdomen region of *P. ornatus*, there is an indistinct and tight indentation at the segment (Fig. 17A). On the dorsal abdomen region of *P. versicolor* has indistinct and sparse indentations in its segments (Fig. 19A). On the dorsal abdomen region of *P. pholypagus* has a well-defined and tight indentation on the segment (Fig. 20A).

The dorsal caudal (tail) region of *P. penicillatus* has a broad, slender protopod with a slightly pronounced thickness of indentation (Fig. 15A). In the dorsal caudal region of *P. homarus* has a protopod shape with a distinct thickness of indentation that is wide and long (Fig. 16A). In the dorsal caudal region of *P. longispes* has a protopod that is long and slender and has a distinct thickness of indentation (Fig. 18A). In the dorsal caudal region of *P. ornatus* has a protopod shape with a clear

thickness and has a width and length (Fig. 17A). The dorsal caudal portion of *P. versicolor* has a long, slender protopod with a distinct thickness of indentation (Fig. 19A). *P. pholypagus* has a protopod that is wide and slender and has a slightly pronounced thickness of indentation (Fig. 20A).

4. Discussion

Morphologically, lobster have a body that is divided into three regions, namely the cephalothorax, abdomen and caudal (Irawan, 2013). The cephalothorax region is the anterior part of the combined head and chest that is wrapped in a slightly cylindrical carapace, swells and merges with the thorax. The abdominal region consists of 6 segments (Tavares, 2014). Segments 1–3 are called tergums, while segments 4–6 are called pleurons. The caudal region is the tail formed by the urupod and telson.

The lobster's cylindrical carapace is fused to the thorax (Quinn, 2023). The lobster's eyes are large enough in the form of compound eyes

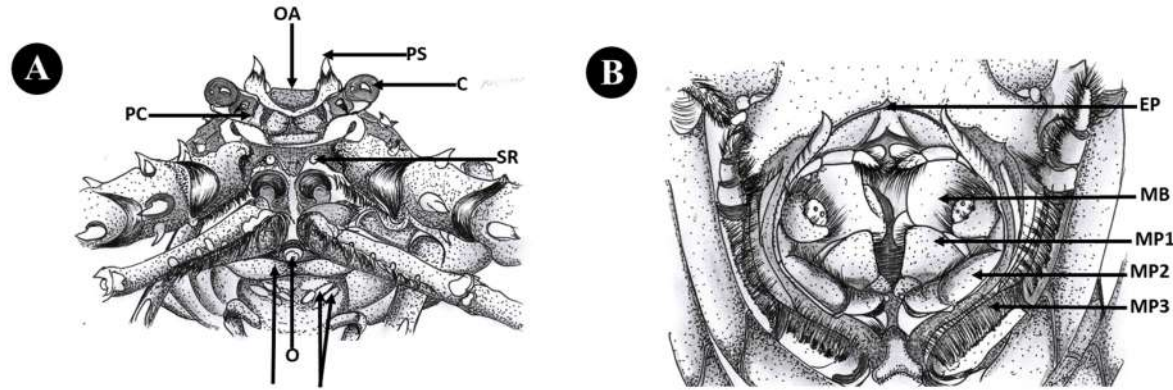


Fig. 26. Morphology of the cephalothorax of *Panulirus polyphagus* appears anterior (A) and ventral (B). Where OA: ophthalmic artery, PC: Protochepalon, PS: Processus rostrum, C: cornea, SR: spina rostrum, O: Oris, MB: mandible, MP: maxilliped, EP: epistome.

accompanied by eye stalks consisting of thousands of ommatidia to spy on the surroundings. The cornea is dark brown, black or white pigmented, or unpigmented and opaque. The epistome consists of a narrow anterior portion between the antennae and a posterior portion usually fully armed with spines on the perimeter of the circular margin to which the labrum is attached. Mandibles are so named due to the fact that their main organs for biting and chewing are a pair of jaws, the mandibles, formed from a pair of segmental appendages that correspond to the pedipalps chelicerata.

In crustaceans, the mandible is preceded by two pairs of antennae (Dahms, 2000). The pleomeric pleura in the anterior is usually not dilated. Male lobsters have strong ventral medial spines. In female lobsters, there are 8 pairs of swimming legs and are used for attachment of eggs. Each leg will interlock around the egg collection (Yeap et al., 2022). When carrying eggs, these legs sometimes move like a fanning motion. This movement can provide the oxygen supply needed for the eggs it carries (Ziegler and Forward, 2007).

The characteristics of spiny lobster are almost the same as freshwater crayfish, the difference is that in the cephalothorax of freshwater crayfish is triangular in shape, wide, and there are spines around the rostrum (Sukmajaya and Suharjo, 2003), while the spiny lobster has a spiny appearance or rostrum that surrounds the entire cephalothorax. There are other specific differences between spiny lobster and freshwater crayfish, where in spiny lobster there are no additional legs and a claw, while in freshwater crayfish they have legs and a claw.

Lobster antennae are on the outside of the peduncular spine and spinose segments. The flagellum antennae are well developed, usually with short plumose setae extending beyond the tip of the telson. Sca-phocerite varies from long and slender to wide and rounded. Usually the lateral margins are serrated and there are one or two longitudinal carinae (Kartika et al., 2022). Some stenopodids also have multiple dorsal and ventral spinules on the sca-phocerite. The epistome is membranous, suboval to triangular anteriorly with median and submedian spines.

The first maxilliped has endopods of 2 or 3 segments (unsegmented in *Macromaxillocaris* and *Globospongicola*), the first two segments with many long plumosa setae, the distal segment when glabrous or with 1–2 plumosaceta (Goy, 2010). The base is large, rounded anteriorly with an outer border supporting a simple solid margin of long setae. The second maxilliped with a very strong 5 segment endopod is reflected medially to the carpo-propoda joint. The dactylus is suboval with a dense margin of short setae along the distodorsal margin. The propodus is wider than the dactylus, densely setose on the dorsal and ventral margins, usually having proximal denticles or solid teeth in Stenopodids and Macro-maxillocarids. Third maxilliped with highly developed, pediform, 5 segment endopod with fused base and coxa. Many long medial setae in

most segments of the exopod are long and slender, with long distal plumose setae.

All pereiopods are uniramous; the first three are chelate; and the third pair is usually the largest, with the second longest pair in *Paraspongicola* and fifth longest in *Macromaxillocaris*. Pereiopods are five pairs of lobster walking legs to move around (Tavares, 2014). There is a small claw in female lobster, while in male lobster there is no claw.

The pleopod of the first pair is uniramous, while the posterior pair is biramous (Irawan, 2013). No one bears an internal attachment. The egg-laying female lobster develops ovigerous setae in pleopods and inspongicolids, the second to fifth pleopods rotated at 90° from their original position. Similar evidence has been found in other crustacean taxa such as *Globospongicola nudibranchus*, *G. spinulatus*, and *Porcellio scaber* (Komai and Saito, 2006; Wolff, 2009).

Uropods do not have diaeresis. The outer edges of exopods are usually serrated and have two elongated ridges. The telson is subtriangular in the Stenopodidae and Macro-maxillocaridae, usually with two rows of longitudinal spines on the back, a lateral spine about midway on each outer margin, and ending in two or three small teeth (Bochini et al., 2020). In the Spongicolidae telson is round or subquadrangular, with two rows of not very pronounced dorsal longitudinal, lateral outer margins and terminal teeth (Saito et al., 2006).

Exoskeleton analysis is related to the measurement of the carapace of lobsters, where this character can be used as an indicator of the size of lobsters worth catching. Lobster at the size of maturity are the ones most valued by the fishery (lobsters have experienced gonad maturity for the first time). Based on previous reports showing *P. homarus* first matured at carapace size reaching 5.75 cm (Kulmiye et al., 2006), *P. longipes* 5.5 cm (Gomez et al., 1994), *P. ornatus* 9.81 cm (Zakaria and Kassim, 1999), *P. penicillatus* 6.66 cm (Chang et al., 2007), and *P. versicolor* 7.8 cm (Frisch, 2007). Determining the size of lobsters worth catching is important as an effort to keep them sustainable. In addition, the Ministry of Maritime Affairs and Fisheries of the Republic of Indonesia has also issued regulations regarding the prohibition of catching lobsters (*Panulirus* spp.) which are laying eggs, weighing < 150 g/lobster and carapace length < 6 cm (PERMEN, 2020). The most important management of lobsters is to determine the size of the catch. Lobsters are categorized as fit to be caught determined by the length of the carapace when the gonads first mature. Therefore, it is necessary to limit the size of catch for each lobster species by fishermen.

Furthermore, lobster management can be carried out by making regulations such as lobster marine protected areas (MPAs). In this area, fishing for lobsters is prohibited, because this area is a habitat for spawning, caring for larvae, and foraging for lobsters. The implementation of MPAs in Norway has had a significant positive impact on lobster populations, including behavior, demographics, density, growth,

and p 18 otypic diversity (Knutsen et al., 2022). MPAs also contribu 21 to an increase in catch-per-unit-effort (CPUE) to 245% and increased the average size of lobsters to 13% in the Norwegian Skagerrak coast (Moland et al., 2013).

5. Conclusions

Exoskeleton analysis successfully identified 6 lobster species based on shape, size and color in the cephalothorax (cervical sulcus, sternum, epistome, maxilliped, pereopod), abdominal (segment, pleura, pleopod), caudal (telson, uropod and protopod) and presence of spines on the dorsal body. The formulation of a lobster management plan in Aceh Province needs to be covered by a regulation so that the lobster population can be controlled. The draft regulation could be in the form of clustering fishing areas, limiting catch size, and prohibiting catching during the spawning season.

CRedit authorship contribution statement

Yusrizal Akmal: Conceptualization, Formal analysis, Investigation, Project administration, Writing – original draft. **Irfannur Irfannur:** Data curation, Formal analysis, Investigation, Methodology, Resources, Writing – review & editing. **Muliari Muliari:** Conceptualization, Investigation, Methodology, Writing – review & editing. **Agung Setia Batubara:** Conceptualization, Investigation, Methodology, Writing – review & editing. **Muchammad Yunus:** Conceptualization, Investigation, Writing – review & editing. **Hani Plumeriastuti:** Conceptualization, Investigation, Writing – review & editing. **Yeni Dhamayanti:** Conceptualization, Investigation, Writing – review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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