Biodiversity of lobster larvae (Panulirus spp.) from the Indonesian Eastern Indian Ocean

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Abstract. Lobster fisheries play an important role in the development of Indonesian fisheries management. The tropical lobster genus Panulirus has high species diversity in the Indonesian Eastern Indian Ocean. The Indonesian government has designated lobster fisheries as one of the types of fisheries requiring special attention in 11 of the Fisheries Management Areas in the Republic of Indonesia (FMARI). Each management area has specific ecological characteristics and may have unique lobster species richness. Studies on the temporal and spatial distribution of lobster species during all life phases are necessary to determine the connectivity of lobster populations. This study aimed to identify the species of lobster larvae of the genus Panulirus in FMARI 573. Samples were collected from several locations, including Pacitan, Trenggalek, Tulungagung, Banyuwangi, and Lombok, in July-August 2018. Data were analysed descriptively through species identification based on morphological traits. Identification of the samples was carried out at the sampling site and in the laboratory. The study found six species of lobster larvae: Panulirus ornatus (local name udang mutiara), P. homarus (udang pasir), P. penicillatus (udang batu), P. versicolor (udang bambu), P. longipes (udang batik) and P. polyphagus (udang Pakistan). These species were unevenly distributed at the study sites. Further research is needed to analyse the distribution and connectivity of lobster populations by analysing species composition during different life phases (larva/puerulus, juvenile, adult) at different spatial and temporal scales.

1. Introduction
The Java South Sea Biogeographical Region is included among 232 eco-regions in the classification proposed in the global system for coastal areas and exposure known as the Marine Eco-regions of the World (MEOW). The South Java region is included in the Central Indo-Pacific marine realm and Java transitional provinces [1] The transition areas of Java include the South Java Sea, South Nusa Tenggara Sea, Sawu Sea, and West of Timor Sea. The length of the South Java sea coast is around 1,500.12 km, stretching from the Ujung Kulan Peninsula (Pandeglang, Banten Province) in the west to Blambangan Peninsula (Banyuwangi, East Java Province) in the east. Lobster fisheries in South Java are dominated by small-scale fisheries. These are generally classified as multi-gear and multi-species fisheries, because lobster fishermen also catch other species such as pomfret, cob and octopus with fishing gear that differs from one target species to another.

Although dominated by small-scale fisheries, the contribution of these activities to national fisheries production is very large. Even though the national production volume of lobster is minimal, the value (in rupiah) is very high, rating second-highest when compared to other fisheries
commodities. This is because lobster is an exported fishery product. Lobsters from the *Palinuridae* family inhabit all tropical and sub-tropical marine waters where lobster becomes very ecologically and economically important.

Most fish species and coastal decapods have pelagic and diffuse larval phases culminating in settlement in suitable coastal habitats. Recent studies have shown that larvae actively search for these suitable habitats using swimming and censorship capabilities [2]. The lobster's lifecycle includes the transition from the planktonic (phyllosoma) larval phase, metamorphosing into the nektonic post-larvae (puerulus) phase, characterized by a move towards the coast to settle in shallow coastal waters. Following this, the puerulus will moult to become small lobsters that are benthic and settled [3].

The lobster larval phase is relatively lengthy (up to almost 18 months in some species) and usually includes 7-13 phyllosoma phases which all differ from each other and are characterized by one or more cocoon (instars) periods [4]. The initial phyllosoma growth stage immediately following hatching from the egg has very limited swimming ability. This results in larvae being widely spread to offshore waters by waves, so that by the end of the phyllosoma phase, most palinurid species are found in oceanic waters outside continental borders, up to approximately 1500 km from the coast [5–7].

The location and trigger of metamorphosis from the final phyllosoma phase to the puerulus phase is uncertain because of difficulties in obtaining evidence via observation or experimentation. This means that the mechanism by which they move towards the coast into shallow water once the phyllosoma have metamorphosed into puerulus is also unclear. However, it is likely that it involves a combination of the ability to swim actively towards the coast and the use of natural processes on the beach or passive processes such as surface currents caused by wind [8].

On one hand, the actual evidence for active movement towards the coast is very weak because the evidence is obtained from the measurement of very low levels of swimming power and tiny amounts of energy released [9]. On the other hand, evidence for passive movement towards the beach is derived from the correlation between the time at which a puerulus settles and natural phenomena such as coastal wind, rain and current patterns [10–12].

The distribution of puerulus in some offshore surveys indicates that their movement is towards the coast rather than randomly spread. This indicates that the puerulus phase and the final phase of the phyllosoma are able to move towards the shore or shallow waters from offshore waters more than 50 km away, representing the period during which the settlement process takes place. This period is very influential on the stock of local lobster populations, which indirectly affects the local lobster catch [13].

From the explanation above, it can be concluded that lobster fisheries are very important for the Indonesian economy. However, lobster fisheries management measures to protect and preserve lobster resources are relatively neglected. The purpose of this activity, therefore, is to develop formulations to protect ecosystems and conserve lobster resources. The first thing that needs to be done is to study the pattern of spread of lobster larvae in each species spatially and temporally.

2. **Research Methods**

2.1. **Time and Research Location**
The data were collected mainly from the South Coast of Java Island (part of East Java province which includes Pacitan, Trenggalek, and Banyuwangi), with an additional location in the waters of Central Lombok (West Nusa Tenggara). Data collection activities were carried out in July-August 2018.

2.2. **Data Collection Method**
Data collected were lobster larvae from fishermen. Each larval species was sampled and identified directly at the sampling location.
2.3. Data Analysis
Following collection, the sample was calculated using the number per individual per species in each location. Representative documentation of species was carried out on location and repeated during detailed sample identification in the laboratory.

3. Results and Discussion
Based on the morphological and anatomical observations of lobster larvae at the research station, six species of lobster larvae were found. These were (local names in brackets): *Panulirus ornatus* (*udang mutiara*), *P. homarus* (*udang pasir*), *P. penicillatus* (*udang batu*), *P. versicolor* (*udang bamboo*), *P. longipes* (*udang batik*) and *P. polyphagus* (*udang Pakistan*) with uneven distribution in each study location (Table 1).

| No | Latin, international and local name | Photograph | Location                  |
|----|-------------------------------------|------------|---------------------------|
| 1  | *Panulirus ornatus* Ornate spiny lobster *Udang Mutiara/kentangan/cemara* | ![Photograph](image1) | Pacitan, Trenggalek, Banyuwangi, Lombok |
| 2  | *P. homarus* Green sand lobster, scalloped spiny lobster *Udang pasir/pantung/bireng* | ![Photograph](image2) | Pacitan, Trenggalek, Banyuwangi, Lombok |
| 3  | *P. versicolor* Green lobster *Udang bambu/metalik/kendal* | ![Photograph](image3) | Pacitan, Banyuwangi, Lombok |

Table 1. Species of lobster larvae found at study sites.
The larval life of lobsters is spent mostly in the open ocean where most of the larvae are widely distributed [4]. This particular issue on the dispersal and distribution of lobster larvae has been a major concern for research studies into the life history of lobsters in several countries and regions, including Australia, Brazil, Japan, Mexico, New Zealand, Norway, the Caribbean and Florida in the United States. The recruitment of lobster larvae depends on the successful return of sufficient phyllosoma to the coastal waters. There is a correlation between the levels of settlement of the puerulus stage of lobster and subsequent recruitment to the fishery. This process is linked with oceanographic processes that are operating towards the end of the oceanic migration of the larval and puerulus stages [14,15].

The presence of six species of adult tropical Indo-West Pacific spiny lobsters within the catch of South Java lobster fishers during the study supports the findings of previous studies conducted in various parts of Indonesia. These species have been the major catch of the fishers from locations along the coastal areas of Indonesia’s eastern Indian Ocean, stretching from the eastern part of East Nusa Tenggara to the western region of Aceh [16–20]. In addition, information from unpublished sources indicate that these six lobsters were found in some of the districts along the coast of South Java, including: Jember, East Java; Pacitan, East Java; Gunung Kidul, Yogyakarta; Kebumen, Central Java; Cilacap, Central Java; and Pangandaran, West Java. Adult lobsters are sedentary, as they do not migrate after settling and perform their feeding and social behaviour in area spanning less than 1 km.
outside of their home range. Thus their behaviour indicates a high level of site fidelity [21]. More than that, the South Java waters are considered to have a high plankton biomass and a high concentration of suspended matter, due to the main upwelling area in the region being situated along the coasts of Java and Sumbawa [22,23]. Consequently, this area has an abundance of resources, including various sedentary species and lobsters in particular.

In terms of oceanographic processes (i.e. the association of physical and biological processes) in the region, there are several regional current systems entering the South Java waters, serving as potential sources of lobster larvae. The regional current systems serving as larval transport sources come from the South China Sea [24], the Bay of Bengal in the West Indian Ocean [25], ocean circulation on Australia’s Northern Shelf [26], the Banda and Arafura Seas current [27], and the North and South Pacific Region [28]. Other physical processes have been shown to create upwelling that enriches the region, namely the eddy-resolving ocean circulation in the Asian-Australian region and seasonal heat budget in the mixed layer of the south eastern tropical Indian Ocean [29,30]. These interconnected oceanographic processes have created an area serving as a habitat for spiny lobsters. Looking at the pathways of the Indonesian Through Flow (ITF) within the Indian Ocean [31], it is likely that the larvae may also be distributed to East African Seas, Arabian Seas, Andaman Seas and the Bay of Bengal through several current systems in the Indian Ocean. These systems include the South Equatorial Current (SEC), Agulhas Current, South Java Current and Leeuwin Current. This provides the background for the possibility of future studies into whether the South Java region is a source or sinks area for these six extant spiny lobster species.

4. Conclusion
Six species of lobster larvae were found at the study site. These six species are: *Panulirus ornatus*, *P. homarus*, *P. penicillatus*, *P. versicolor*, *P. longipes* and *P. polyphagus*. Observations on the distribution of these six lobster species from the Indian Ocean to the eastern part of Indonesian waters showed that they are not evenly distributed at each study location. Further research is needed to examine the distribution and connectivity of lobster populations by analyzing the variation in species distribution and lobster community species composition during different life phases (larva/puerulus, juvenile, adult) at different temporal and spatial scales.

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