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What Lies Inside a Dead Coral: Diversity of Reef-Associated Cryptic Crustacean (Crabs: Anomura and Brachyura) from Different Habitat Characteristics in Tidung Islands, Indonesia

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Abstract

Recent studies have been widely carried out on the important role and ecological function of coral reefs. However, little attention has been given to small and cryptic crustaceans organisms living within different microhabitat in dead corals. This study aimed to reveal the diversity of crustaceans that inhabit dead corals in Tidung Islands, Indonesia. A total of 134 individuals from 41 species in 13 families were recorded within eight dead corals taken from two different sites. Furthermore, the species identified from Tidung Kecil were significantly different and more diverse than Tidung Besar. It was suggested that differences in anthropogenic pressure between Tidung Besar and Kecil might have an important role in the spread of crab crustaceans' organisms. Xanthidae from infraorder Brachyura were observed to be the most dominant family, while Galatheidae and Porcellanidae from infraorder Anomura spread almost equally in both sites. Additionally, *Psaumis cavipes* and *Chlorodiella nigra* were species with the largest contribution of crab crustaceans' communities in the death of coral's ecosystem in the Tidung Islands. This result indicated that dead corals might play a key role in supporting and providing a habitat for crustacean cryptic.

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1. Introduction

A coral reef is an ecosystem that has important ecological functions in supporting the life of marine organisms. However, they are mostly affected by highly anthropogenic activities that directly influence the ecosystems and reef-associated marine organisms (Enochs, 2012; Damar *et al*., 2019; Rahman *et al*., 2020). Aside from these activities, another factor that also directly affects the environment is tourism. Though this industry has rapidly driven economic growth, it still causes various problems in the context of sustainable development, such as marine waste. Recent studies have shown that the volume of waste generated by tourism activities is twice the local waste production (Manomaivibool, 2015), thus this condition potentially affect the coral reef ecosystem in disease outbreaks (Lamb *et al*., 2014). Consequently, the coral reefs were carefully studied in Seribu Islands in order to gain baseline data about their health status. It was found that 46.15%, 30.76%, and 23.07% were mainly categorized in poor, good, and moderate conditions (Hadi *et al*., 2018). This indicates that almost half of the coral reefs in Seribu islands, Jakarta was in crisis condition.

Aside having suffered from tourism activities, due to anthropogenic pressure and other environmental factors, the coral reef ecosystems became degraded and promoted macro-algae domination (Allgeier *et al*., 2020). A dead coral is defined as skeletons that were devoid of live coral tissue, yet still attached to the reef matrix. Furthermore, abundant algae and other encrusting organisms such as ascidians and sponges usually colonized the structure of the coral head (Kramer *et al*., 2017). Dead coral colonies have also been identified as a microhabitat for some invertebrate organisms including crustaceans (Kramer *et al*., 2014; Hazeri *et al*., 2019).

Crustacean is known as one of many cryptic invertebrates associated with coral reef ecosystem. They play an important role in the food chain and are also known as a liaison between primary producers and subsequent consumers, and in turn, one of the most important sources of nutrition and energy for fishes (Head *et al*., 2018; Niketa *et al*., 2020). This fauna utilizes coral reefs as a micro-habitat that provides shelter or foraging (Depczynski and Bellwood, 2004; Enochs, 2012). Furthermore, these small and cryptic organisms such as sessile, encrusting, and mobile species which find niches in reef spaces contribute greatly to coral reef biodiversity. Many of these organisms have obligate associations with both live and dead corals (Head *et al*., 2015). They form a mutualism symbiotic relationship with them by providing mucus that is associated with detritus which is a food for crustaceans (Stella *et al*., 2011). The coral reefs are also utilized as a shelter for these organisms from predators. Therefore, they often indirectly benefit from the presence of crustaceans, including Anomura and Brachyura which are the most abundant and diverse species inhabiting the coastal areas down to the deep sea (Hendrickx, 1996; Komai and Tsuchida, 2014).

Studies on the diversity of crustaceans in coral reefs ecosystem and dead corals have been widely carried out in Southern America (Magellan), Brazil, Indian Ocean (Chagos), and Australia (Vinuesa *et al*., 2008; Almeida *et al*., 2010; Santos *et al*., 2012; Kramer *et al*., 2017). Although a good number of studies focused on sub-trophic and Mediterranean areas, Indonesia which has thousands of islands do not obtain significant attention. Therefore, this study aims to investigate and compare the diversity of the crustacean community on different habitat characteristics in Tidung Islands, Jakarta. This study only focused on the infraorder level of crustaceans, namely Anomura and Brachyura due to the fact that these two infraorders were the dominant organisms found in coastal areas down to the deep sea, especially in dead corals.

2. Material and Methods

2.1 Sampling Design

Dead coral colonies were collected during expeditions in January 2019 from two locations in Tidung Islands. Tidung Besar was known to have more anthropogenic pressure, while Tidung Kecil had less pressure (Cindewiyani and Herdiansyah, 2019; Adrianto *et al*., 2021) (Figure 1). This category was distinguished by differences in the population and activities on both islands. Furthermore, Tidung Besar had a higher anthropogenic pressure from tourism activities and population (Sumandiarsa *et al*., 2021) when compared to Tidung Kecil. It has also been allocated to be a settlement island, while Tidung Kecil has been reserved for conservation purposes (Hayati *et al*., 2020).

Four dead coral colonies were taken from each sampling location at a depth of 1 to 6 m. The life forms of four dead coral colonies in Tidung Besar consisted of one Coral Branching (CB) and three Acropora Tabulate (ACT). Furthermore, four other samples were obtained from Tidung Kecil comprising of Acropora

Digitate (ACD), Coral Submassive (CSM), and two Acropora Tabulate (ACT). The determination of dead coral colonies was characterized by the presence of fertile algae that predominantly cover the dead corals (Plaisance *et al*., 2009; Kramer *et al*., 2017).

The collection of dead coral was based on previous studies which focused on reef-associated cryptic organisms (Plaisance *et al*., 2009; 2011; Pertiwi *et al*., 2018). The volume of the samples was measured by putting each of them into a bucket (20 L) filled with seawater. Therefore, the volume of spilled water was assumed to be the dead coral's volume. The average volume in both sites were 3.478 ± 1.057 L for Tidung Besar and 2.610 ± 0.608 L for Tidung Kecil.

2.2 Collecting and Sorting Cryptic Crustacean (Crabs)

After each volume was obtained, samples of dead corals were placed into a bucket (20 L) filled with seawater and an aerator was used to prevent the species from escaping or dying (Plaisance *et al*., 2011). Furthermore, each sample of dead corals was gently broken into small pieces (± 5 cm) using a hammer. All crustaceans (crabs) encountered were taken gently using tweezers, and the remaining dead coral fragments were quickly placed back into the bucket to repeat the sorting process and examined closely. The water was filtered three times (mesh size 70-80 µm) to ensure all the crustaceans were counted during the sorting process.

All collected Anomura and Brachyura organisms were immersed in small cups containing clove oil for ±1 minute to minimize the movement of the biota during documentation. Furthermore, the documentation for specimen with size range of 3 to 7 cm was carried out using clean petri dish and was observed and captured using DSLR camera with macro lens, while those less than 2 cm was documented under binocular microscope. All samples were stored into a 10 ml bottle which contained 96% ethanol and labeled according to the location and sample number. This procedure was repeated and applied to the remaining dead corals taken at the observation site. All collected Anomura and Brachyura species was identified based on their morphology to the lowest possible taxon using identification book titled Crustacea: Guide of the world (Debelius, 2000).

2.3 Data Analysis

The differences in density between Anomura and Brachyura species from crab groups on dead corals in Tidung Besar and Kecil were analyzed using the Mann-Whitney test (Stella *et al*., 2010). This test was used to examine the differences between the two sample groups that were not interrelated. It could also be interpreted as an analysis of two different sample subjects (Mann and Whitney, 1947).

The community indices in this study consisted of three components, namely Shannon-Wiener index (H'), Evenness index (E), and Simpson index (C) (Shannon and Weaver, 1949; Heip, 1974). The Shannon-Wiener index (H') was used to analyze how many different species of crab groups were found in a community. Furthermore, the Evenness index (E) was used to analyze the similarity or flatness of species from the group of crabs found in a community. The Simpson index (C) was also used to analyze the species of crab groups which were commonly found in a community.

Non-Metric Multidimensional Scaling (nMDS) was used to analyze the distribution patterns of the Anomura and Brachyura species on dead corals. It was also applied to represent the original position of the data, in this case samples of dead corals, in a multidimensional space as accurately as possible using a reduction in the number of dimensions. This was performed in order to easily plot and visualize the samples. The nMDS was analyzed using Primer 7.

Similarity Percentage (SIMPER) was used to examine which species was accounted for differences and generate a ranking of its contribution in the crustacean group, Anomura and Brachyura (Gibert and Escarguel, 2019). We used PAST 4.0 to analyzed SIMPER.

3. Results and Discussion

3.1 Species Richness and Density

A total of 134 individuals were recorded and collected from eight dead corals colony and 41 species in 13 families were divided into two infraorders, namely Anomura and Brachyura. A total of 32 species were found in Tidung Besar with a density of 3.23 ind/L which was recorded in 4 dead corals colonies, while 33 was found in Tidung Kecil with a density of 8.53 ind/L (Table 1). Furthermore, the difference in the sampling location was strongly related to the composition at the infraorder level. About 37 species from Anomura were also found in both locations. Family Porcellanidae had the most abundant (8 species) followed by Galatheidae (4 species). Meanwhile a total of 97 species from Brachyura was extracted from 11 families. The highest

Table 1. Biodiversity metric for each individual of cryptic crustacean (crab) observed in Tidung Besar and Tidung Kecil

Order / Family	Species	Tidung Besar (ind)	Tidung Kecil (ind)
Anomura		13	24
Galatheidae		5	14
	Galathea pilosa	-	2
	Galathea sp1	-	7
	Galathea sp2	1	5
	Galathea sp3	4	-
Porcellanidae		8	10
	Periclemenes sp1	1	-
	Petrolisthes armatus	-	2
	Petrolisthes galathinus	1	1
	Petrolisthes sp1	-	1
	Petrolisthes tomentosus	-	5
	Polyonyx gibbesii	4	1
	Polyonyx sp1	1	-
	Polyonyx sp2	1	-
Brachyura		32	65
Aethridae		-	1
	Aethra scruposa	-	1
Domeciidae		2	1
	Domecia sp1	1	1
	Domecia sp2	1	-
Dromiidae		1	2
	Dromia sp1	-	2
	Dromia sp2	1	-
Epialtidae		3	9
	Hoplophrys oatesii	1	1
	Hoplophrys sp1	1	-
	Oxypleurodon bipartitum	1	-
	Tiarinia cornigera	-	5
	Tiarinia sp1	-	3
Euryplacidae		1	-
	Psopheticoides sp1	1	-
Grapsidae		1	-
	Geograpsus sp1	1	-
Homolidae		1	-
	Latreillopsis sp1	1	-
Parthenopidae		1	-
	Daldorfia horrida	1	-
Portunidae		1	1
	Thalamita prymna	-	1
	Thalamita crenata	1	-
Trapeziidae		1	1
	Trapezia cymodoce	1	-
	Trapezia digitalis	-	1
Xanthidae		20	50
	Chlorodiella nigra	7	20
	Chlorodius cytherea	-	1
	Cyclodius obscurus	3	7
	Cyclodius ungulatus	-	1
	Danielea noelensis	-	1
	Danielea sp1	1	-
	Etisus laevimanus	-	14
	Etisus sp2	3	-
	Etisus sp3	-	4
	Etisus sp4	1	-
	Psaumis cavipes	5	2
TOTAL		45	89

Table 2. Mann – Whitney test result demonstrating the effect of site on species richness and density on Anomura and Brachyura in Tidung Islands. (* indicates significant ρ value)

Crabs Group	Mean species richness		Mean density	
	Variance (U)	ρ value	Variance (U)	ρ value
Anomura	53.038	0.0051*	59.365	0.008*
Brachyura	58.288	0.078	59.365	0.015*

Table 3. Biodiversity indices in Tidung Islands for Anomura and Brachyura between two sites

Infraorder	Index	Tidung Besar	Tidung Kecil
Anomura	Shannon-Wiener Index (H')	0.125	0.201
	Evenness Index (E)	0.18	0.168
	Simpson Index (C)	0.008	0.013
Brachyura	Shannon-Wiener Index (H')	0.326	0.47
	Evenness Index (E)	0.187	0.268
	Simpson Index (C)	0.027	0.078

diversity was recorded from family Xanthidae, followed by Epialtidae comprising of 11 and 5 species, and the rest was no more than two individuals.

A significant difference in species richness was found on Anomura using the Mann-Whitney test, while on Brachyura there was no significant difference (Table 2). Most of the crustacean recorded belong to Brachyura and most of them were categorized as family Xanthidae, which comprises of 12 species in Tidung Besar and 14 in Tidung Kecil. However, only two families belonged to Anomura were found in each site, namely Galatheidae and Porcellanidae.

The richness of Anomuran species was two times higher in Tidung Kecil than Tidung Besar (Figure 2). The number of species density varied greatly and Tidung Kecil had approximately two times higher density than Tidung Besar (Figure 3). Furthermore, the Mann–Whitney test revealed a significant difference for Anomura and Brachyura in mean density (Table 2).

3.2 Community Structure of Crustacean Crab Group

The Shannon – Wiener diversity index (H') in Tidung Besar and Tidung Kecil for Anomura and Brachyura was categorized as being low. Furthermore, same result was also found on the Evenness Index (E) for both species. The Simpson Index (C) values among Tidung Besar and Tidung Kecil was closed to 0 and categorized as low for both Anomura and Brachyura (Table 3).

The ordination based on nMDS test revealed that the composition of crab crustaceans' cryptic assemblages was non-differed at 40% similarity level (green dashed line). However, at the 20% level (green plotted line), all dead corals showed a clear difference between the two sites (Figure 4). The 2D stress value of nMDS (0.072) indicated that the ordination was a good representation of the underlying dissimilarity value. At the 20.90% similarity level, *Psaumis cavipes* (Figure 5) had the largest contribution with about 44.6% in determining the relationship of the cryptic species composition from crab groups in Tidung Besar and Kecil (Table 4). This was followed by *Polyonyx* sp. (17.94%), *Chlorodiella nigra* (15.87%) and *Ceradocus serratus* (10.79%). Meanwhile, cryptic species from other crab groups tended to have a very small percentage contribution in Tidung Besar and Tidung Kecil. The similarity percentage of 27.30 % indicated that *Chlorodiella nigra* (Figure 5) had the largest percentage contribution of 52.9% in determining the relationship between the species of cryptic biota from crab animal groups on both islands (Table 4). This was followed by *Cyclodius obscurus* which had a contribution percentage of 22.37%, meanwhile other species had less than 10% values.

3.3 Discussion

3.3.1 Biodiversity of crustacean cryptic and habitat characteristic

This study represents the first attempts to provide a baseline of reef-associated crustacean cryptic (crabs group) community in Tidung Island. About 134 individuals was found and recorded from 13 families of crab group on the Island. The community indices showed that all the category revealed low level of diversity, similarity, and dominancy. Differences in the characteristics of location based on the density of species between Tidung Besar and Tidung Kecil indicates that habitat conditions and abiotic factors may influence the spread of these organisms (Giraldes *et al*., 2017). Tidung Besar which had more anthropogenic pressure yielded low species richness and density. Furthermore, Tidung Kecil which represent less pressure in anthropogenic showed higher species richness and density. The most common types of species recorded in this study was found in Tidung Kecil, because most of the dead corals were found in fragments. Most of them often transformed into coral rubble over time. Therefore, these two microhabitats might have similar structure and attributes for both of the abundance and biomass of crustacean (Kramer *et al*., 2014). In Tidung Besar, both live and dead corals and cryptic crustaceans have more options of determining where they live and also hide from predator species (Behringer and Hart, 2017; Brooker *et al*., 2018). Recent studies have also shown that the morphology of corals influences the patterns of richness and abundance of associated crustaceans (Klompmaker *et al*., 2013).

Xanthidae was the dominant family found in both location in Tidung Islands followed by Porcellanidae and Galatheidae. Studies about decapods diversity were conducted in several locations in Indonesia and it was discovered that this family is the most abundant species found in many branching corals (Pertiwi *et al*., 2014; Anggraeni *et al*., 2015; Al Malik *et al*., 2018; Kholilah *et al*., 2018; Pertiwi *et al*., 2018). Xanthidae and Galatheidae were commonly found in shallow tidal, spread along rocky, cobble, and sandy substrate (Naderloo and Türkay, 2012). It was also found that Porcellanidae is the third highest abundant family after Xanthidae and Galathediae and has the highest number of specimens found in dead corals (Enochs and Manzello, 2012; Santos et al., 2012), especially on Pari Island (Madduppa *et al*., 2019). Furthermore,

Table 4. Similarity percentage (SIMPER) on cryptic crab group in Tidung Besar and Tidung Kecil (based on average similarity 20.90% and 27.30%)

Species per Group	Average Density	Average Similarity	% Contribution	% Cumulative
Tidung Besar				
Average similarity: 20.90%				
Psaumis cavipes	0.58	9.32	44.6	44.6
Polyonyx gibbesii.	0.54	3.75	17.94	62.55
Chlorodiella nigra	0.51	3.32	15.87	78.41
Ceradocus serratus	0.46	2.26	10.79	89.21
Tidung Kecil				
Average similarity: 27.30 %				
Chlorodiella nigra	1.55	14.44	52.9	52.9
Cyclodius obscurus	1.01	6.11	22.37	75.27
Tiarinia sp.	0.5	2.71	9.93	85.2

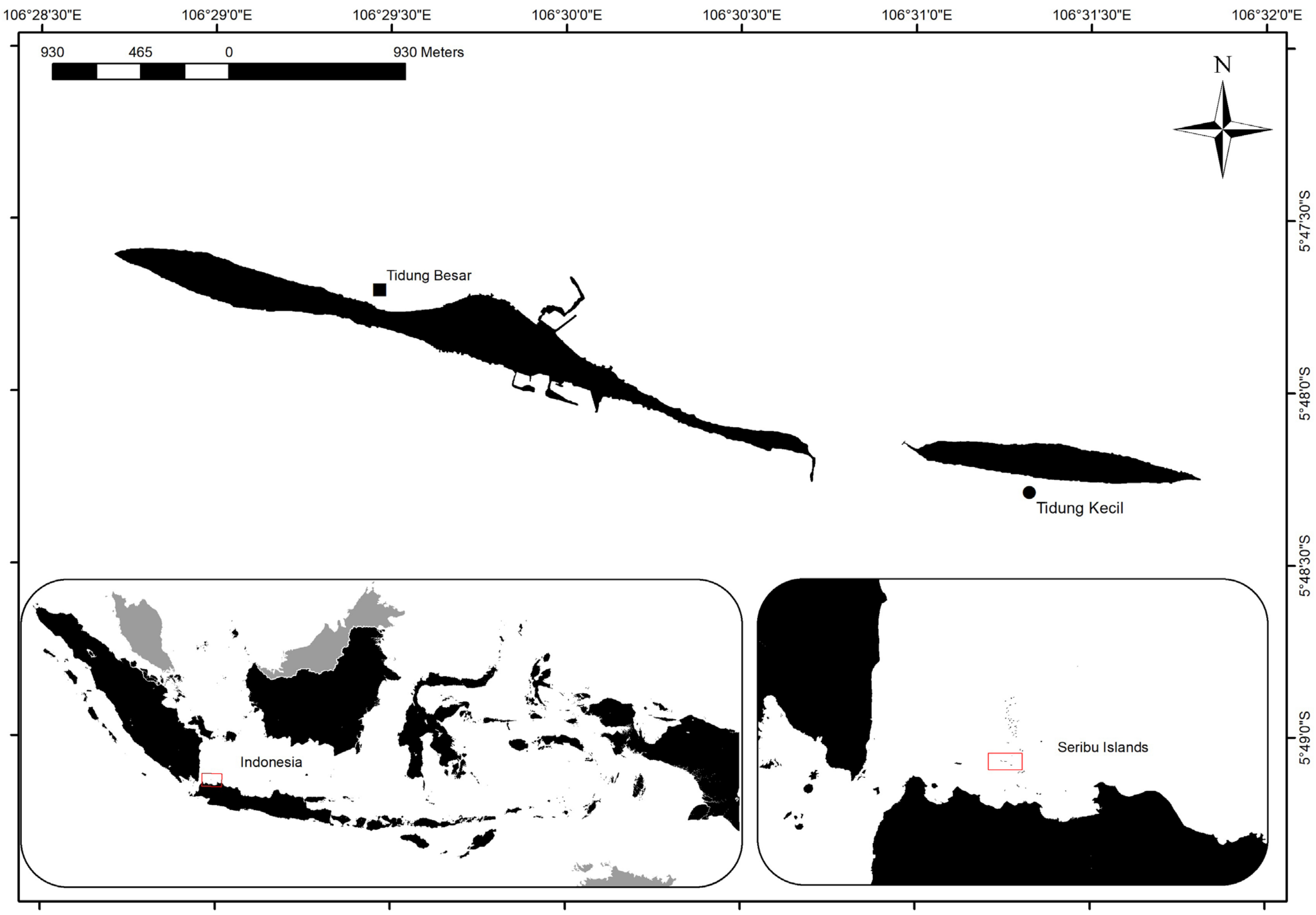

Figure 1. Location map of dead corals collection on Tidung Islands. Four dead corals colonies were collected at each site (Tidung Besar and Tidung Kecil)

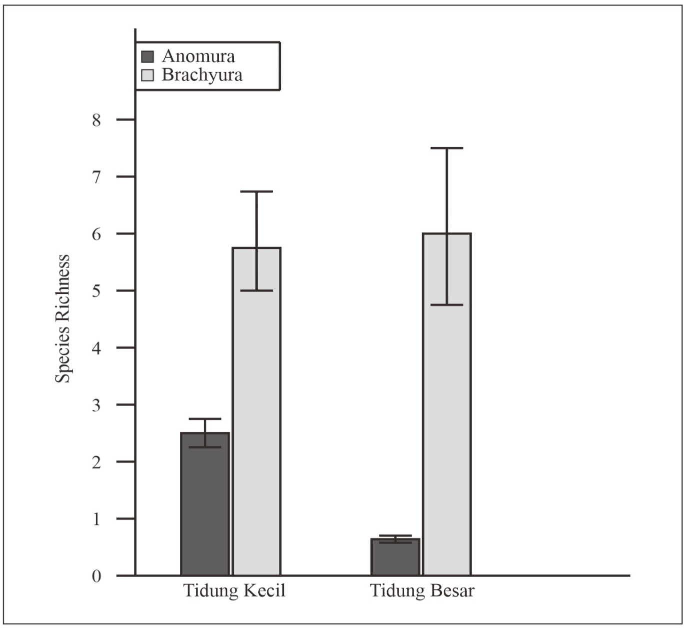

Figure 2. Species richness of Anomura and Brachyura on dead corals between two sites

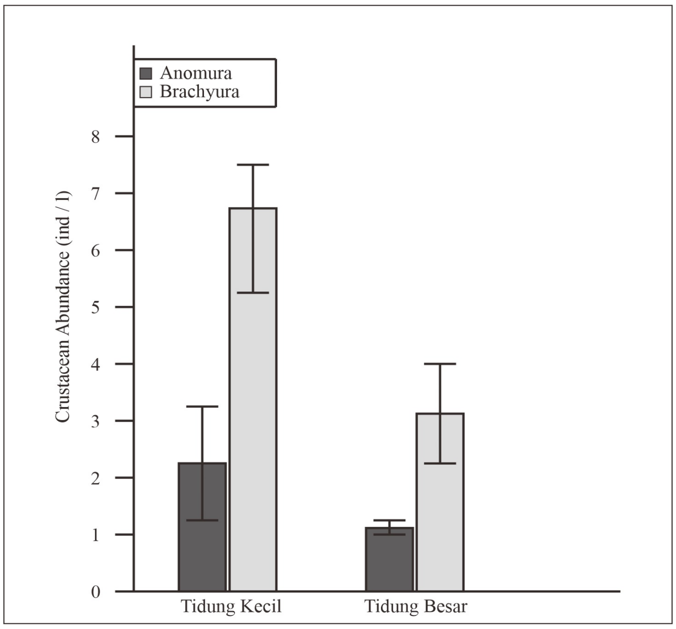

Figure 3. The density (ind/l) of crustacean Anomura and Brachyura on dead corals between two sites

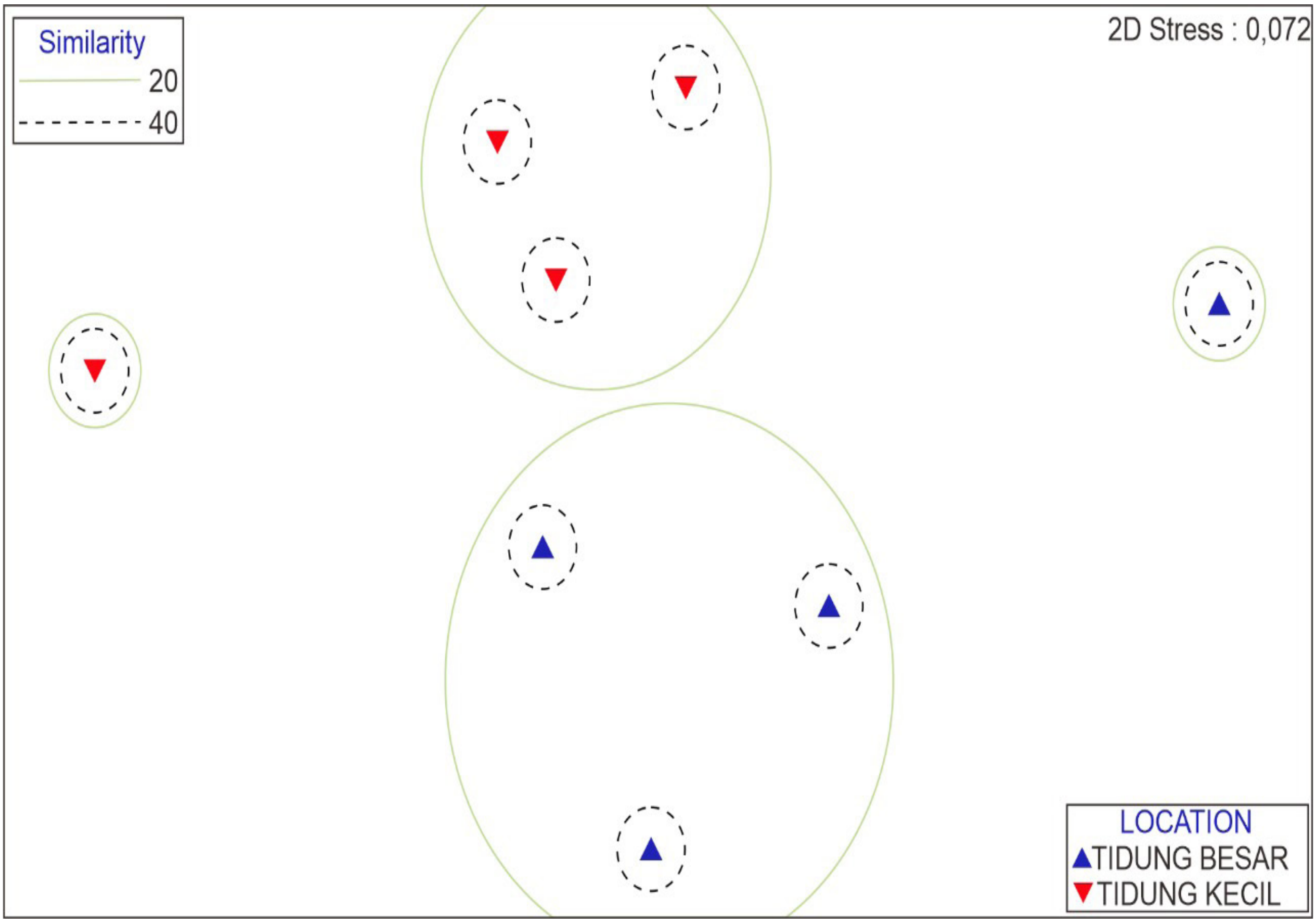

Figure 4. Non-metric multidimensional scaling (nMDS) plot of cryptic crab assemblages using Bray Curtis similarity illustrate the distribution pattern of Anomura and Brachyura between Tidung Besar (blue triangle) and Tidung Kecil (red reverse triangle) on 20% similarity level.

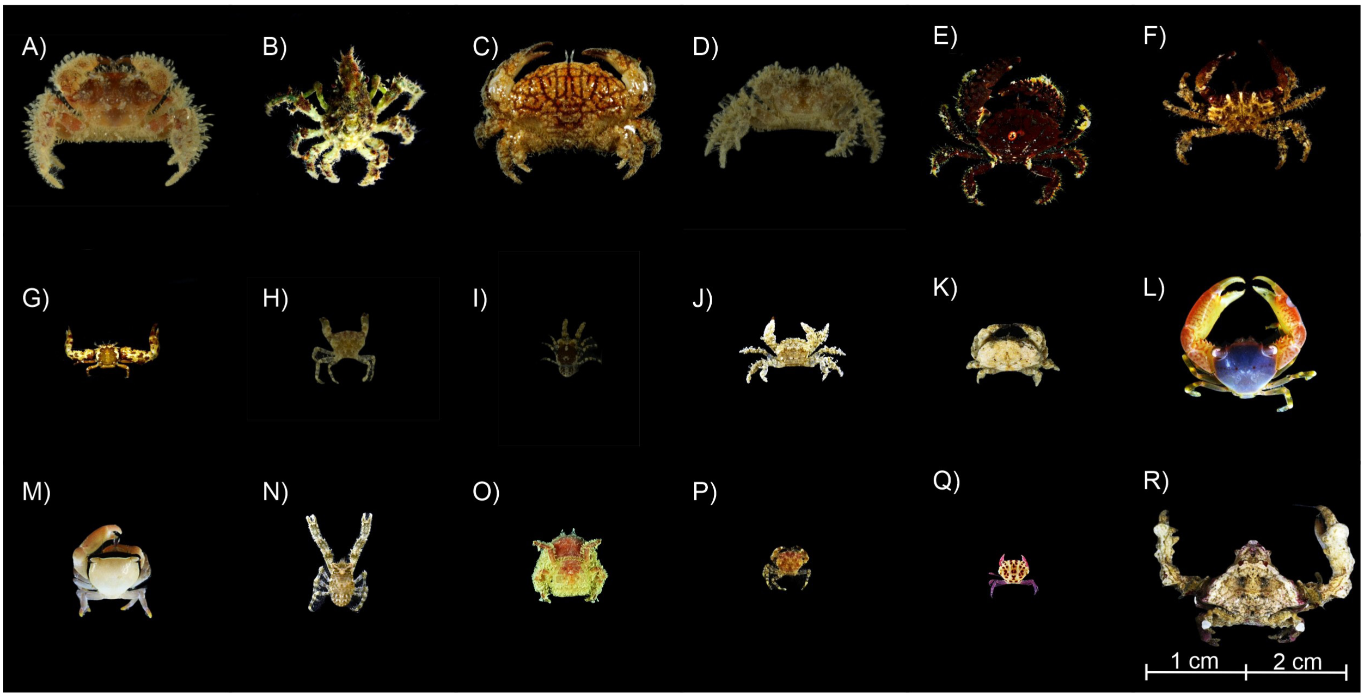

Figure 5. Crustacean (crab group) species discovered in dead coral colonies at Tidung Islands, namely: A) *Thalamita crenata*; B) *Tiarinia* Sp.; C) *Psaumis cavipes*; D) *Chlorodiella cytherea*; E) *Chlorodiella nigra*; F) *Cyclodius obscurus*; G) *Polyonyx* Sp.; H) *Thalamita prymna*; I) *Galathea pilosa*; J) *Etisus* sp1; K) *Etisus* sp2; L) *Trapezia cymodoce*;; M) *Trapezia digitalis*; N) *Galathea* sp1; O) *Dromia* sp1; P) *Psopheticoides* sp1; Q) *Domecia* sp1; R) *Daldorfia horrida*

the family Porcellanidae is commonly found in bottom sandy substrate with coral rubble (Hazeri *et al*., 2019). This demonstrated that Porcellanidae could be easily discovered in many areas compared to other family of Anomura

Chlorodiella nigra is the species with the largest percentage contribution and has a distribution pattern that tends to spread throughout the tropical Indo-Pacific region as well as in the Gulf of Kach, India (Beleem *et al*., 2014) (Figure 5a). Sandy substrate with coral fragments is a suitable habitat criteria for *Chlorodiella nigra* and can be found in shallow waters with a depth of 12 m (Hurley *et al*., 2016). *Psaumis cavipes* (Figure 5c) is also a species that has the largest contribution percentage of 20.90% and a pattern that tends to be evenly distributed throughout the tropical climate region. Furthermore, western Thailand and Phuket are important boundary area between the more oceanic waters of the Indian Ocean and the less saline waters of continental South-East Asia. They are known to have a very good mix of brachyuran fauna, including *Psaumis cavipes* (Ng and Davie, 2002). Indonesia, specifically Tidung Islands also has almost the same water characteristics as Western Thailand and Phuket, hence they are able to survive. The prominent habitat of *Psaumis cavipes* is rocky substrate which tends to support the residence of this species (Ng and Low, 2010).

3.3.2 Anthropogenic factors on diversity of cryptic crustacean

Differences in characteristics of location on the density and species richness of crabs between Tidung Besar and Tidung Kecil indicates that habitat conditions have an important role in the spread of crab organisms (Nogueira *et al*., 2015). Tidung Besar which represents the site with more anthropogenic pressure addresses low density and species richness. Furthermore, Tidung Kecil which received less anthropogenic pressure such as tourism showed high species richness and density. Complexity of habitat shows more diverse crabs, thus provide a variety of resource benefits which determine species diversity (Tews *et al*., 2004). The results of this study stated that the species richness of crab cryptic in Tidung Kecil was due to the availability of dead corals in this location. The dead corals skeleton was a major factor in the high wealth of cryptic crab species due to a high complexity of skeletal structures which provided various shelter.

Crab biota utilizes dead corals as a refuge from epibenthic and nektonic organisms. In Tidung Besar, the relative absence of anthropogenic interference with coral reef ecosystems was characterized by large number of live corals near cryptic fauna which tended to spread widely. They require isolated habitats to thrive (Enochs, 2012), therefore it is not possible for them to move from one dead coral to another. Human disturbances may alter the ecological role of coral reefs and crustacean crabs by possibility of nutrients additions and marine waste due to anthropogenic activities (Zapata, 2017; Richmond *et al*., 2018).

3.3.3 Ecological implications for the coral reef ecosystem

This study did not only reveal the biodiversity matrices of crustacean cryptic (crabs), but also an insight from ecological implications. The high abundance of small organisms such as crustacean plays an important role in supporting coral reef ecosystems and defining the level of coral degradation (González-Gómez *et al*., 2018). Moreover, an increase in the abundance and presence of the mobile invertebrates may have positive effects on food web productivity by delaying the loss of other reef components such as fish (Rogers *et al*., 2018).

Certain individual decapod (e.g., *Mithrax forceps*) played the role of an environmental stressor and coral obligate symbiont by providing mutualism symbiosis to their host (Stachowicz, 2001). They also indirectly facilitated a diverse epifaunal community of thousand species within the coral's branches (Nogueira *et al*., 2015). Furthermore, another individual crab species (*Cymo melanodactylus*) has been significantly proven to slow progression rates of white syndrome on coral colonies and also mitigate effect of this disease on coral reefs (Pollock *et al*., 2013). Thus, the crabs may be seen as a keystone mutualist in this system. This is important to notice because reef survey protocol only target macro-invertebrates such as sea urchins and *Acanthaster plancii* which play key roles in hard coral reefs (Pearman *et al*., 2016). Also, crustacean assemblages are very substantial in terms of maintaining the balance of trophic structure in coral reefs ecosystem (Bachiller and Irigoien, 2015; McClain-Counts *et al*., 2017) despite acting as important food source for reef fishes (Stella *et al*., 2011; Enochs and Manzello, 2012).

There has been few research on the specific role of Brachyura and Anomura on ecosystems except for the Trapeziidae family. They have played an important role in improving the health of coral colonies (Tsuchiya *et al*., 1992). Furthermore, the largest and powerful species of Trapeziid crabs (Trapezia and Tetralia) and snapping shrimps (Alpheidae) can increase the survival and growth of their host by actively defending corals against corallivore *Acantasther plancii* and clearing sediments (Leray *et al*., 2012; Stier *et al*., 2012). This indicates that the presence of crab cryptic strongly promotes the maintenance of biodiversity on coral reefs in dealing with anthropogenic threats, competition among species, and global climate change factors.

4. Conclusion

This study investigated the first attempt on revealing the diversity of cryptic crustacean (crab) in Tidung Islands. It was shown that Tidung Kecil, purposed as a conservation area, had a significantly higher species abundance than Tidung Besar. This was because Tidung Besar was plotted as a tourism area that suffered high anthropogenic pressure. The contrast of crab crustaceans' assemblages presents a preliminary point of investigation that may substantially reflect different habitat and ecological characteristics in Tidung Islands. Furthermore, since these cryptic organisms are very important in supporting coral reef ecosystems as a whole, future studies are recommended to seasonally access in wider region across Indonesia using molecular approach to obtain higher accuracy in species identification.

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Authors' Contributions

The contribution of each author is as follow, PSPA; collected the data, designed the analysis, verified analytical method, and wrote the paper. PS, MGAP, FM, and WAL; collected the data, designed the analysis, performed the analysis, and wrote the paper. BS and HM; conceived the experiment, conceived the presented idea, designed the analysis, and supervised the project. All authors discussed and contributed to the final manuscript.

Conflict of Interest

All authors declare that was no actual or potential conflict of interest.

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