Occurrence distribution of coral-dwelling shrimp among the coral growth forms of the Tidung Islands, Jakarta, Indonesia

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Abstract. Coral reefs are widely known as essential ecosystems that hold various marine organisms, including various crypto-organisms. Cryptofauna, which live among the interstices of coral reefs, significantly escalates the coral reef biodiversity. The complexity of the reef-building corals' niche could shape the shrimp community structure. This research aims to examine the shrimp diversity and to analyze the shrimp communities on different coral growth structures in Tidung Island, Seribu Islands. The dead coral heads were collected using the timed swim method and the cryptofauna was collected by shattering the dead coral heads. Each species of cryptofauna was photographed and identified. The shrimp community structure was calculated using the multivariate statistic. A total of 165 obligate coral-dwelling shrimps specimens of 30 species belonging to seven families were found. During this study, most of the organisms discovered were from the Alpheidae and Hippolytidae families, who contributed to the relative abundance with up to 34.55 and 30.91%, respectively. The multivariate analysis using non-Metric Dimensional Scaling (nMDS) highlighted three clustering habitat locations between the study sites and the coral growth forms, based on the shrimp abundance. *Alpheus pasificus* predominantly contributed to the community of the arborescent coral type (in the Tidung Besar coastal zone) and to the corymbose coral type (in the Tidung Kecil coastal zone). Local environmental conditions, such as the food resources, predation threat and coral presence (hosting an associate fauna) are presumed to be important factors affecting the coral-dwelling shrimps.
Key Words: dead coral, niche availability, shrimps, Tidung Islands.

Introduction. Coral reefs are essential marine ecosystems providing many functions and services through their biodiversity (Halpern et al 2008; Hoegh-Guldberg et al 2007; Micheli et al 2014; Small et al 1998). These ecosystems contribute to the protection of the coastline, providing feeding and nursery grounds for a variety of invertebrates. Most of the coral reef ecosystems were based on hermatypic corals, which can calcify and form various types of growth forms, through mutualistic symbiosis with dinoflagellates (*Symbiodinium* sp.) (Dustan et al 2013; Graham & Nash 2013). These growth forms of coral are widely known as coral lifeforms and consist of two different types of growth. The first type of growth is characterized by axial and radial corallites of the genus Acropora (Veron 2000), while the second type of growth is characterized only by radial corallites of thenon-Acropora genus (Veron 2000). The first type of coral growth forms comprised arborescent, bottle-brush, caepitose, caepito-corymbose, digitate, arborescent-table, digitate, arborescent-table and corymbose (Suharsono 2008), forming the three-dimensional structure of coral reefs and providing various niches (Graham & Nash 2013). The majority of these coral growth forms are composed of a high biodiversity of invertebrate taxa, including the cryptofauna communities. Specifically, this complex structure could provide habitat protection and enhance the cryptofauna biodiversity within ecosystems (Bertness & Bruno 2001; Plaisance et al 2009).

Reef structures are the most supporting habitat for cryptofauna, such as crustaceans on Indo Pacific Coral reefs. Among these crustaceans, the shrimp groups were predominant in the coral reefs, reaching around 20% of the total cryptofauna communities (Plaisance et al 2011; Stella et al 2011). Crabs were the second group of a high diversity in the coral reefs' cryptofauna community (Hamid & Wardiatno 2018; Zairion et al 2018). These two family groups are the most common living cryptofauna perceived on dead coral structures (Kramer et al 2014). The associations of cryptofauna and coral are either obligate or facultative (Edgar & Shaw 1995; Keable 1995; Kramer et al 2013; Pratchett 2001; van Tienderen & van der Meij 2016). Most of the cryptofauna species living on dead coral rubbles have obligate, highly productive and opportunistic characters (Takada et al 2016; van Tienderen & van der Meij 2016). These organisms commonly had a high diversity in the habitats determined by the living and dead corals (Enochs & Manzello 2012; Kramer et al 2014; Malik et al 2018; Plaisance et al 2009; Stier & Leray 2014).

Generally, cryptofauna's colonization process of the dead coral and coral rubble takes less than a few weeks. As an illustration, crustaceans only need two weeks to colonize such new habitats (Enochs et al 2011; Takada et al 2007; Valles et al 2006). This cryptofauna presence on corals may correspond to the various environmental factors (Madduppa et al 2019; Piercy et al 2014). However, precisely assessing how environmental factors are correlated to the cryptofauna abundance rates still remains a subject of investigation.

In Indonesia, shrimps significantly contribute to the diversity in most of the coastal reefs. Some research has been conducted to understand the biodiversity of fauna associated with corals (Malik et al 2018; Mascaró et al 2012; Oigman-pszczol & Creed 2006). It is fundamental to identify the precedent community of invertebrates on their structural hosts, because it could give information about how coral growth forms influence the shrimp community's composition. Baseline studies are essential to understand the distribution of the diversity and the richness of this fauna in the Indonesian reefs. Furthermore, cryptofauna are interesting groups as they are easy to collect on the reef structure, especially on dead corals. Corymbose and arborescent types are among the most accessible dead stony coral structures found in Tidung Islands. These two kinds of growth forms have different reef-building patterns, with potentially different cavities availability. Corymbose coral has primary branches that are closely compact and their short branches grow vertically at the centre of the colony, while arborescent corals form thickets with straight tapered branches and subbranches with obtuse angles (Veron 2000). A study on the organisms' presence within the different ecological niches offered by the dead corals could provide informations about the diversity in the coral reefs. This paper aimed to investigate the shrimps' ecological niche offered by the different branching growth forms of dead corals in Tidung Islands, Seribu Islands.

Material and Method

Description of the study sites. This research was located in Tidung Islands, Seribu Islands, Jakarta (Figure 1). The Tidung Islands are surrounded by coral reefs and consists of two main islands: Tidung Besar and Tidung Kecil. Tidung Besar Island is more prominent in size and more exposed to anthropogenic disturbances (e.g., tourism, anchoring and organic waste) (Beeden et al 2014; D'Angelo & Wiedenmann 2014; Gil et al 2015). Tidung Besar Island was accessible for tourist activities, while Tidung Kecil Island has been put under protection, due to its conservation areas. Three and four sites were selected in Tidung Besar and Tidung Kecil, respectively.

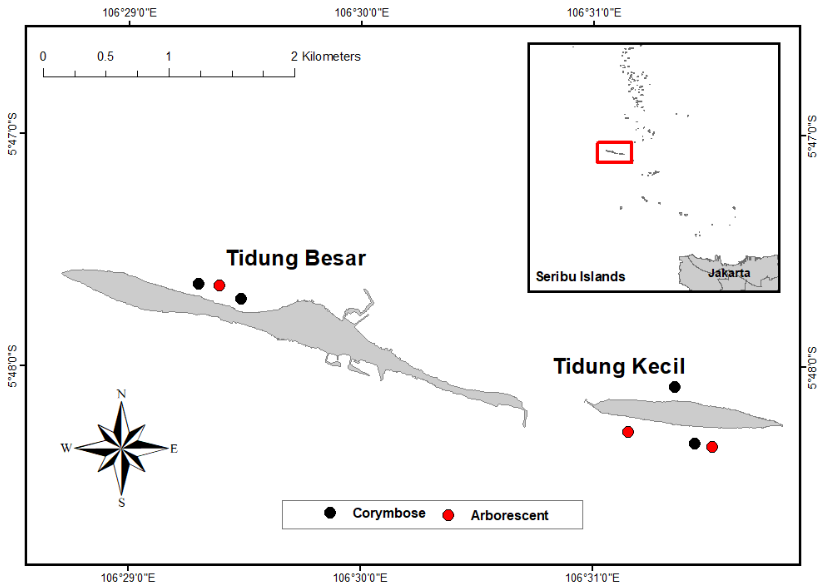

Figure 1. Map of the study sites in the Tidung Islands, Seribu Islands.

Sampling design. Dead coral samples were collected using the timed swim method. Divers recorded two different genera of dead coral colonies around the observation sites. Then, the corals of *Acropora* or *Pocillopora* genus were selected on the basis of their respective growth forms. Samples were collected at depths between 3 and 5 m, representing 3 to 4 corals in each island on the outer reef, from branching dead coral colonies distinguished into arborescent and corymbose (Wen et al 2013). Dead coral colonies were characterized by the absence of polyps and turf algae, or crustose coralline algae covering the surface of the coral skeleton (Head et al 2015).

Sample collection. The volume of the dead coral sample was calculated by measuring the water transfer. The dead corals were then checked and mindfully broken up utilizing a beetle and chisel (Hernaman & Munday 2005). Sample sorting (sieving) was carried out using a 500-micron benthos-sieve to collect the cryptofauna. Also, any remaining hidden cryptofauna in the broken dead coral was inspected and removed one by one. All samples were preserved with clove oil and ethanol (90%) for further identification. Each cryptofauna sample was photographed using a DSLR camera and identified using a microscope, to the family level. Among all of the cryptofauna obtained, the crustacean family was the main focus of this study, being the most abundant family.

Data analysis. Data obtained from the on-site sampling were then analyzed by calculating the abundance and family richness, in order to assess the general condition of shirmps on each dead coral (Odum 1996; Arifin et al 2020):

$$N = \frac{n_i}{A}$$

$$S = \frac{S_i}{A}$$

Where:
N – reef fish abundance;
n_i - total number of shrimps at the *i*-th of observation location;
S – species richness;
S_i - total number of shrimp species at the *i*-th of observation location;
A – observation area.

The Shannon-Wiener Diversity Index (H') was calculated for each island and coral growth type for assessing the diversity of shrimps inside every dead coral sample (Odum 1996; Dhahiyat et al 2003; Arifin et al 2020):

$$H' = \sum_{i=1}^{S} [p_i \ ln \, p_i]$$

Where:
H' – Shannon-Wiener Diversity Index;
p_i - (n_i/n); n_i - total number of shrimp individuals of type-i;
n - total number of shrimp individuals of all types.
Primer v.7 was used to conduct a multivariate analysis on the cryptofauna assemblage composition, by considering spatial variations (islands) and coral branching type changes (Clarke & Gorley 2015; Kruskal 1964). Non-metric multidimensional scaling (nMDS), using a Bray-Curtis similarity index for calculating the cryptofauna abundance with a quadratic root transformation, was used to visualize the shrimps community grouping, based on the coral growth forms and on the influence of the different sites.

$$S_{17} = 100\left(1 - \frac{\sum_i |y_{i1} - y_{i2}|}{\sum_i y_{i1} + \sum_i y_{i2}}\right) \equiv 100 \frac{\sum_i min\{y_{i1}, y_{i2}\}}{(\sum_i y_{i1} + \sum_i y_{i2})/2}$$

Where:
S_{17} - Bray-Curtis similarity index;
y_{i1} or y_{i2} - the count (or biomass, percent cover, etc) of the *i*-th species from sample one or two.
Similarity percentages (SIMPER) was conducted to examine the cryptic assemblages that contributed with 80% to the cryptofauna, among the coral growth forms and the sites. The SIMPER analysis (contribution of each species to the dissimilarity between each two groups, calculated from the Bray-Curtiss dissimilarity matrix) was built on the basis of the Analysis of Similarities (ANOSIM) (Clarke & Gorley 2015):

$$R = \frac{r_B - r_W}{M/2}$$

Where:
R - the test statistic; its values range from -1 to 1; when positive, similarity within sites is higher; when negative, similarity between sites is higher; zero represents no difference in the similarities between sites and within sites;
$\bar{r}_B$ - average of rank similarities of samples/replicates from different sites;
$\bar{r}_W$ - average of rang similarities of samples/replicates within sites;
M - $n(n-1)/2$; n - number of samples.

Results

Coral-dwelling shrimps composition. A total of 165 shrimp specimens (30 species belonging to seven families) were collected from dead coral heads in Tidung Kecil Island. Tidung Kecil (22 species and 45 individual L^{-1}) had a higher species richness and abundance than Tidung Besar (18 species and 42 individual L^{-1}). The abundance for the different coral growth forms was not significantly different, but the species richness for the corymbose corals (24 species) was higher than for the arborescent corals (18 species). Regarding the species richness and abundance at the study sites and for the investigated coral growth forms, the Alpheidae family (15 species with 28 individual L^{-1}) and Hippolytidae family (8 species with 25 individual L^{-1}) were found to be the most representative (Figure 2). The diversity index of the shrimp communities reached high values (>0.5) all study sites, being considered in a stable condition.

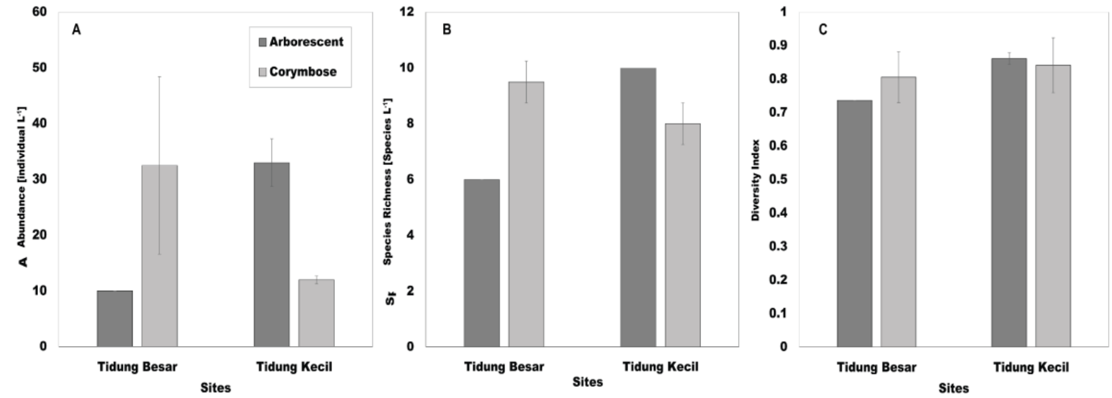

Figure 2. Taxa composition of shrimps (a) at the study sites, (b) for the coral growth forms and (c) in terms of diversity index.

Distribution and pattern coral-dwelling shrimps. The coral dwelling shrimps distribution showed that several species were found for different combinations of study sites with coral growth forms (Table 1, Figure 3). According to the results, there are several shrimps whose species level could not be determined because of the samples damage (presumed to belong to the *Alpheus* sp., *Gonodactylus* sp., *Heptacarpus* sp., *Lysmata* sp., *Saron* sp., *Paramesodopsis* sp. and *Metapenaeopsis* sp.). Thus, for the following analysis, those organisms were identified at the genus level.

Table 1

Occurrence and distribution of shrimps at coral growth forms and study sites

Family	*Taxa*	*Coral growth forms*		*Study sites*	
		Arborescent	*Corymbose*	*Tidung Besar*	*Tidung Kecil*
Alpheidae	*Alpheopsis* sp.	+	+	+	-
	Alpheopsis trispinosus	-	+	+	-
	Alpheopsis yaldwyni	+	-	+	-
	Alpheus leviusculus	+	-	-	+
	Alpheus lottini	-	+	-	+
	Alpheus malleodigitus	+	+	+	+
	Alpheus parvirostris	+	+	+	+
	Alpheus pasificus	+	+	+	+
	Alpheus soror	-	+	+	-
	Alpheus sp.	+	+	-	+
	Alpheus sp2.	-	+	+	+
	Alpheus sp3.	-	+	-	+
	Alpheus sp4.	-	+	-	+
	Alpheus sp5.	-	+	+	-
	Synalpheus charon	+	+	-	+
Corallanidae	*Argathona macronema*	+	+	+	+
Gonodactylidae	*Gonodactylus affinis*	+	+	+	+
	Gonodactylus sp.	-	+	+	+
Hippolytidae	*Heptacarpus kincaidi*	+	+	+	+
	Heptacarpus sp.	+	+	+	+
	Heptacarpus sp2.	+	-	-	+
	Heptacarpus tridens	+	-	-	+
	Lysmata sp.	-	+	+	-
	Saron marmoratus	-	+	-	+
	Saron sp.	-	+	+	-
	Saron sp2.	-	+	+	-
Mysidae	*Paramesodopsis* sp.	+	-	-	+
Palaemonidae	*Periclimenes lucasi*	+	+	+	+
	Periclimenes magnificus	+	+	-	+
Penaeidae	*Metapenaeopsis* sp.	+	-	-	+

+: present; -: absent.

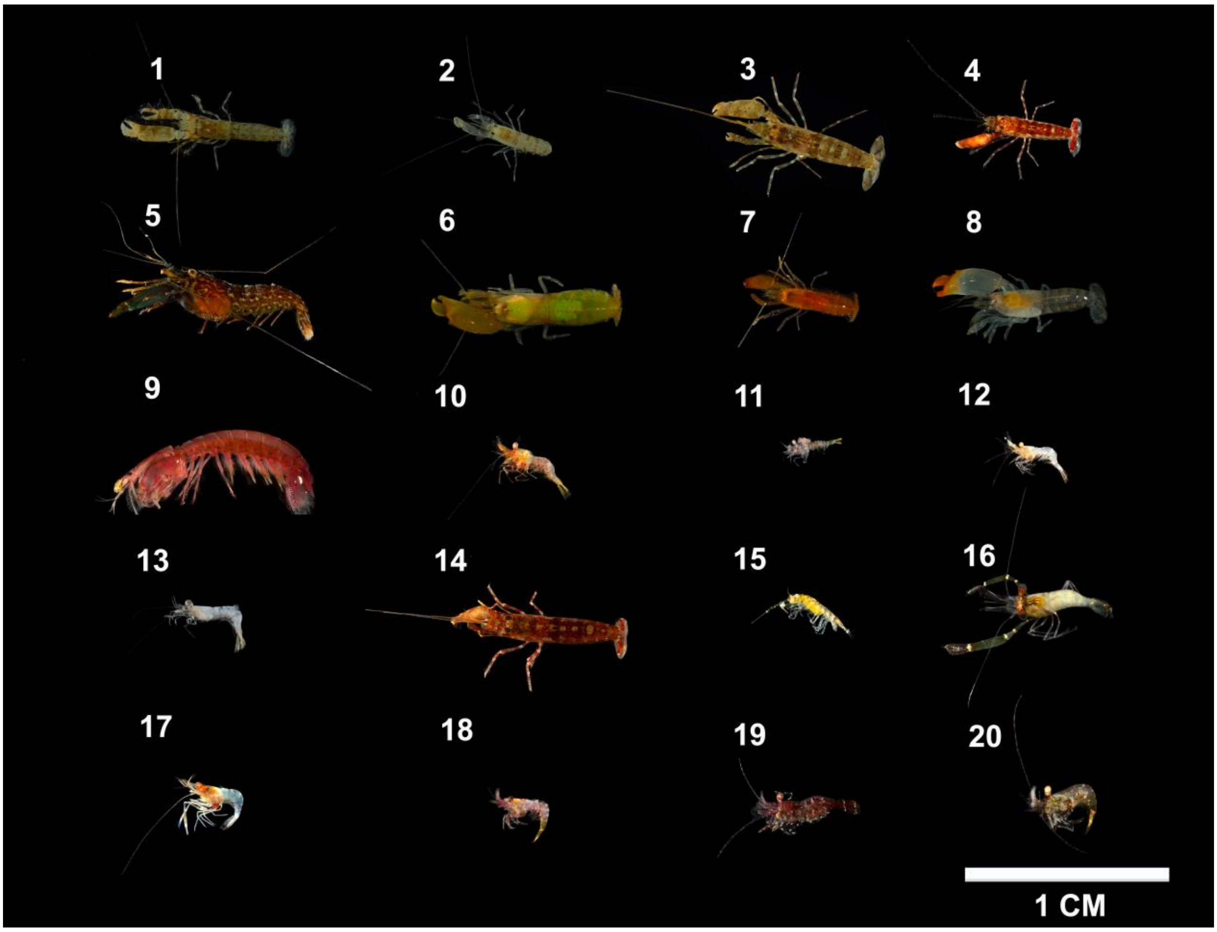

Figure 3. The coral-dwelling shrimps discovered in Tidung Islands environment: (1) *Alpheopsis trispinosus*, (2) *Alpheus leviusculus*, (3) *Alpheus malleodigitus*, (4) *Alpheus pasificus*, (5) *Alpheus soror*, (6,7,8) *Alpheus* sp., (9) *Gonodactylus affinis*, (10) *Heptacarpus kincaidi*, (11,12) *Heptacarpus* sp., (13) *Heptacarpus tridens*, (14) *Lysmata* sp., (15) *Paramesodopsis* sp., (16) *Periclimenes lucasi*, (17) *Periclimenes magnificus*, (18) *Saron marmoratus*, (19,20) *Saron* sp.

The species found at all sites and coral growth forms were *Alpheus malleodigitus*, *Alpheus parvirostris*, *Alpheus pasificus*, *Gonodactylus affinis*, *Heptacarpus kincaidi*, *Heptacarpus* sp., and *Periclimenes lucasi* (Table 1, Figure 3). Several species of coral dwelling shrimps, including *Alpheopsis yaldwyni*, *Alpheus leviusculus*, *Heptacarpus* sp1., *Heptacarpus tridens*, *Paramesodopsis* sp., and *Metapenaeopsis* sp. (Table 1, Figure 3) were found only on arborescent coral growth forms. As well as coral growth, individual shrimps only found in Tidung Besar, such as *Alpheopsis* sp., *Alpheopsis trispinosus*, *Alpheopsis yaldwyni*, *Alpheus soror*, *Alpheus* sp5., *Lysmata* sp., *Saron* sp., and *Saron* sp2. (Figure 3). There are two organisms from Mysidae and Penaeidae families that rarely occurred during this study.

The visualization of nMDS highlights the clustering pattern between study sites and coral growth forms (Figure 4). The Bray-Curtis dissimilarity index showed low similarity values (30%) during this study. There are significant differences in the organisms' abundance between Tidung Besar and Tidung Kecil Island. The SIMPER analysis represents the species contribution to the similarity within groups (Table 2) and the primary vectors (linear discriminants), which determined the disjunction on the nMDS plot (Figure 4). The *A. pasificus* generally contributed to the arborescent coral type and at Tidung Besar Island, while *Alpheus* sp. contributed to the corymbose coral type and at Tidung Kecil Island. Therefore, the nMDS grouping is driven mostly by the most abundant shrimps' on each group.

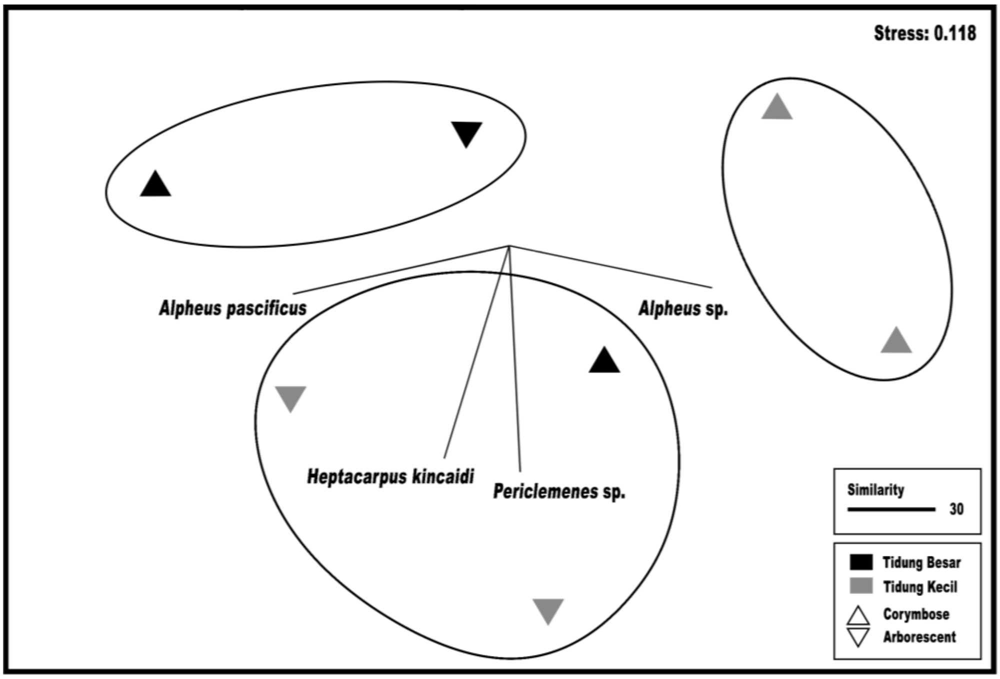

Figure 4. Non-metric multidimensional scaling based on coral dwelling shrimps abundance at all study sites. Vectors represent the identified species at the habitat locations.

Table 2

The species composition of the 4 major groups determined by the coral growth forms and the coral reef sites, using SIMPER (Similarity Percentages – Species Contribution)

Species group^{-1}	*Av. abundance*	*Av. similarity*	*% Contribution*	*% Cumulative*
Coral growth form				
Corymbose, average similarity: 20.49				
Heptacarpus sp.	1.58	4.54	22.15	22.15
Alphaeus malleodigitus	1.10	4.27	20.84	42.99
Gonodactylus affinis	0.75	3.77	18.38	61.36
Alpheus sp.	0.87	3.03	14.81	76.18
Arborescent, average similarity: 27.43				
Alpheus pasificus	1.14	7.52	27.43	27.43
Heptacarpus kincaidi	1.88	5.30	19.30	46.73
Periclimenes lucasi	1.95	4.48	16.32	63.05
Heptacarpus sp.	0.67	2.91	10.60	73.65
Study sites				
Tidung Besar, average similarity: 26.90				
Alpheus malleodigitus	1.61	12.35	45.89	45.89
Alpheus pasificus	0.67	4.45	16.55	62.43
Alpheopsis sp.	1.24	3.70	13.74	76.17
Periclimenes lucasi	1.62	2.14	7.97	84.14
Tidung Kecil, average similarity: 28.98				
Alpheus sp.	1.22	6.84	23.61	23.61
Heptacarpus sp.	0.93	4.44	15.34	38.94
Gonodactylus affinis	0.93	4.19	14.45	53.40
Periclimenes magnificus	1.06	3.40	11.75	65.14

Discussion

Diversity and occurrences. The results showed that the Alpheidae and Hippolytidae shrimp families dominated each study site and coral growth forms. These two families are the most commonly found in Indo-Pacific (Anker 2001; Nye 2013). The high abundance of these two families in dead coral habitats at Tidung Islands is hard to explain, in particular due to the absence of environmental data measurement during this study and to the limited baseline study information on shrimps at the study sites. Environmental conditions could explain the differences of the shrimp communities settlement (van Tienderen & van der Meij 2016) and abundance at the microhabitat locations (Komai et al 2019), most coral-dwelling shrimps having different characteristics between species and families.

According to the visual observation in Tidung Islands, Tidung Besar has a larger coral reefs community and a wider reef crest coverage than Tidung Kecil Island. The higher coverage of the coral area at Tidung Besar provides more space for shrimp to take refuge. However, in terms of anthropogenic pressures, Tidung Besar Island's coral reefs condition was more disturbed, due to more intense tourism and fishing activities. Conversely, Tidung Kecil Island was a conservation area put under the protection of locals, facing less pressure and providing a more appropriate habitat for shrimps. It was hard to determine whether the shrimps persisted since the corals were still alive or if they found shelter only in dead corals. A previous study conducted by Gotelli & Abele (1983) explained how the living coral cover affects the shrimps' migration pattern. A plausible explanation might be the extensive growth of algae on colonies (Figure 5). It seems possible that the corals observed during this research have already been dead for months. Apart from living corals, most of the sessile organisms (foraminifera, bryozoan and algae) growing in dead corals provided food for the shrimps. Thus, the dead coral cover also contributed to the shrimp communities' development. However, further research will need to be conducted in order to determine the occurrence of organisms recruited by coral hosts.

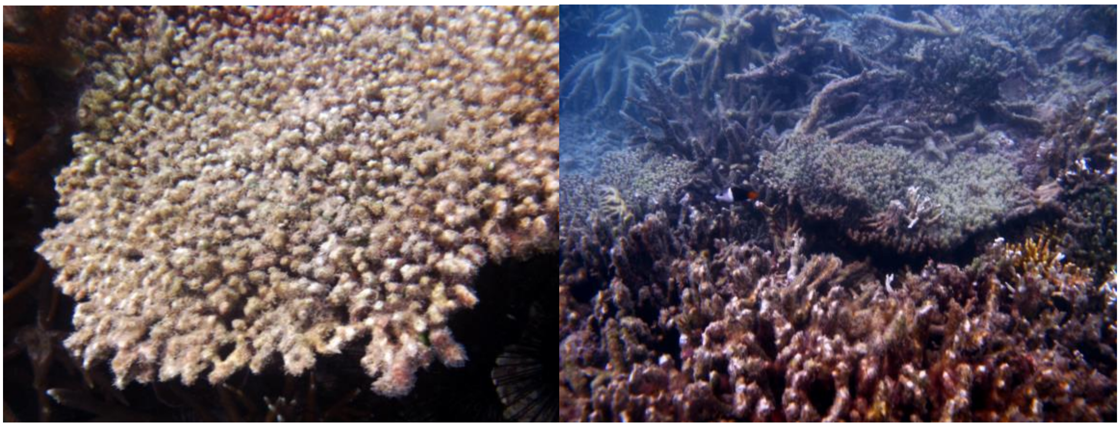

Figure 5. Coral reefs condition at Tidung Island (original).

Coral-dwelling shrimp distribution. Alpheidae, Hippolytidae and Palaemonidae dominated the shrimp distribution in the Tidung Islands. In tropical marine habitats, Alpheidae and Hippolytidae shrimp families are generally found in benthic communities (Baby et al 2015; Mathews & Anker 2009). As Palaemonidae constitutes the most prominent family of coral-dwelling shrimps, a wide spatial distribution is not surprising (Anger 2013). Tidung Islands are considered to be a suitable habitat for these three families, based on the availability of seagrass and mangroves, as well as on the variation of bottom sediment from coarse quartz sands to rough rocky coral (Calado et al 2007; Figueiredo & Anderson 2009; Russ et al 2010).

A. pasificus (Figure 3.5) is one of the shrimp species that contributes considerably to the arborescent coral type and to the Tidung Besar Island's fauna. *Alpheus* sp. (Figure 3.6, Figure 7, Figure 8) is a shrimp genus mostly found on corymbose corals and among the Tidung Kecil Island's fauna. *Alpheus* genus shrimps could create holes in dead coral heads, in order to expand their living niche, leading to the escalation of *Alpheus*'s abundance (Santos et al 2012). Some researchers stated that *Alpheus* genus, which is primarily composed of crustaceans, has an essential contribution to the marine ecosystems, being of a wide variety and abundance, through the Caridean shrimps (Anker et al 2016; Madduppa et al 2019; McKeon et al 2012; Soledade et al 2015). They spread in shallow waters at low and medium depths, especially in the Western Indo-Pacific zone. Those shrimps predominantly live on the surface or in the enlarged natural cavities of the dead coral heads (Santos et al 2012; Xin et al 2012). Several *Alpheidae* shrimp species (*Alpheus lottini*) find shelter in *Pocillopora damicornis* corals, against the seastars predation (Rawlinson & Stella 2012).

Heptacarpus kincaidi (Figure 3.10) has the most considerable abundance, that tends to be evenly spread throughout warm climate seas with waters and benthic conditions similar to the Indonesian seas, including Tidung Islands (Stamatiou & Jensen 2004). Due to their camouflage ability, species of the *Heptacarpus* genus can surviveon various benthic substrates, from rocky shore to sandy beach (Bauer 1981; Pohle et al 2011).

Periclimenes magnificus (Figure 3.17) was one of the most abundant shrimp species of this study. *P. magnificus* is frequently found among the coral reefs, sea anemone, seagrass meadow and gorgonian corals (Azofeifa-solano et al 2014; Bauer & Thiel 2011; Martínez-Mayén & Román-Contreras 2009). *Periclimenes* genus belongs to cleaner shrimps, which live around the coral reef ecosystems, nearby the nekton species (Mascaró et al 2012). Several studies mention that *Periclimenes* life cycle occurs in shallow waters with reef-building coral coverage (Boco & Metillo 2017; Brinkmann & Fransen 2016), analogous to their habitat in the Tidung Islands, in Indonesia.

Conclusions. Overall, the highest abundances and species richness of shrimps were found in Tidung Kecil, among the arborescent branching coral types. *A. pasificus* is one of the shrimp species which most contributed to the assemblages hosted by the arborescent coral type of the Tidung Besar Island and to the corymbose coral type of the Tidung Kecil. The diversity of cryptic assemblages, abundance and family richness among the coral growth forms is not significantly different, which indicates that corymbose and arborescent-table types have a similar density of branches. In the future, studies should extend the research with more types of coral and non-coral objects to observe the different symbiont influence on the shrimp community structure.

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Conflict of interest. The authors declare no conflict of interest.

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