Assessing the Role of Dead Fungiidae Corals as Refugia for Cryptic Biodiversity

by

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Abstract:

With the rise in coral mortality, dead coral habitats are becoming an ever-increasing part of the coral reef ecosystem. There is little research on the cryptofauna of these organisms in comparison to epibenthic and nektonic communities associated with coral reefs. Within the Indo-Pacific Ocean dead mushroom corals (Scleractinia: Fungiidae) provide a unique habitat within rubble for cryptofaunal communities. The contribution of these dead Fungiidae corals, to this community and the wider reef, is yet to be investigated. The aim of this study was to analyse the role of dead Fungiidae corals (DFCs) as refugia for cryptofauna, and to analyse the impact of DFCs to the wider reef community of Koh Tao, Thailand. Echinodermata, Platyhelminthes and Opistobranchia (Mollusca: Heterobranchia) were used as a representation of motile cryptofauna, due to their ecological importance. DFCs were overturned, and rubble habitats were analysed as a baseline comparison to the abundance and diversity of life within dead coral habitats. The data collected from this study was compared to data collected by the New Heaven Reef Conservation Programme on Koh Tao, who observed indicator species of the reef that were not using dead coral habitats as a place of refuge. This comparison enabled the significance of DFCs on the habitats to be estimated. The results showed that DFCs have a significant role in refugia for cryptofauna, particularly within the group Opistobranchia, as six new species for Koh Tao were observed exclusively under DFCs. To conclude, the role of DFCs and rubble habitats must further be explored to find the true biodiversity within coral reef ecosystems.

Introduction:

Cryptofaunal organisms are those that are considered visually 'cryptic' due to size or camouflage. Cryptofauna inhabiting coral reefs, may be found among the framework structure of the reef (Enochs 2011). Cryptofaunic sessile suspension feeders (i.e. sponges and bryozoans), that alter the flow of plankton through their feeding behaviours, and burrowing organisms, that cause weaknesses in the coral skeletons, contribute to the trophodynamics and bioerosion within coral reef ecosystems (Richter and Wunsch 1999; Enochs and Hockensmith 2008; Enochs 2011). Cryptofaunal organisms also contribute to the maintenance of a high biomass within the reef ecosystem by recycling organic matter, allowing coral reefs to be self-sustaining and nutrient rich in oligotrophic waters (Rasheed et al. 2002). There is little knowledge about the cryptofauna associated with coral reefs, in comparison to the epibenthic and nektonic communities (Enochs and Hockensmith 2008), and even less about cryptofauna living within the dead coral habitats/reef rubble (Takada et al. 2007). With the rise of coral mortality, due to ever-increasing threats (Altieri et al. 2017), these rubble habitats are becoming a growing constituent of the coral reef ecosystem (Glynn 1993; Cesar et al. 2003). Gischler (1997) states that coral rubble is one of the most common hard substrates on a reef habitat. Since space is often the key limiting factor in hard substrate environments, coral rubble should be investigated (Jackson and Buss 1975). Rubble habitats support a large diversity of taxa (Enochs 2011), therefore they are important habitats to investigate further, to gain a greater understanding of the range of species that dwell there, potentially including new discoveries of species.

A unique contribution of rubble habitats, solely within the Indo-Pacific Ocean, yet to be studied, is the role of dead mushroom corals (Scleractinia: Fungiidae). Over 70 % of the 50 known species have a free-living phase during adult life (Gittenberger and Hoeksema 2013; Hoeksema and Bongaerts 2015) and can be monostramous (solitary) or polystramous (multiple mouths) (Hoeksema 1991). Often Fungiidae species will have a convex surface, creating a domed shape (Hoeksema 1991), providing a unique space for refugia of cryptofauna. There have been a few studies regarding the diversity of life associated with Fungiidae corals, both within their tentacular region and underneath

their surface (Hoeksema et al. 2012; Gittenberger and Hoeksema 2013; Heidelberg 2013; Bos and Hoeksema 2015; Montano et al. 2015). However, to date there have not been any post-mortality assessments on these associations.

Although it has been established by Enochs (2011) that a greater biomass of cryptofauna is associated more with live coral than dead coral, there is an equal representation of Phyla associated with dead corals. This is due to the available space for successional colonization of sponges, calcareous alga, cyanobacteria etc. (Choi 1984, Enochs and Hockensmith 2008) which provide a wider variety of food for non-symbiotic taxa than in live coral habitats. High biomasses of cryptofauna are found within reef rubble, since the complex structures of the rubble provide refuge from predators and habitat disturbance (Choi 1984; Hereu et al. 2005; Takada et al. 2007; Enochs 2011). During this study, the extent to which dead Fungiidae corals (DFCs) provide refuge for cryptofaunal life is investigated, as it is clear that not all taxonomic groups rely solely on these habitat structures as refuge from predation. Many groups display capable defence mechanisms against predators. For example, the long spines of sea urchins are an effective deterrent from predators (Tenger and Levin 1983; Moitoza and Phillips 1979). Other species rely on chemical defences, such as many of the Platyhelminthes flatworms and Opistobranch sea slugs, which contain aposematic species. This is when their vibrant colourations or patterns warn fish or other predators, such as the moon wrasse, *Thalassoma lunare*, of the toxins they carry and therefore deter predation through the learning of predators to avoid certain patterns (Ang and Newman 1998; Ritson-Williams and Paul 2007).

To analyse the role of DFCs in refuge for cryptofauna and the contributions of DFCs to the wider reef communities, the Phyla Echinodermata and Platyhelminthes, and the infraclass Opistobranchia (Mollusca: Heterobranchia) were used as representatives of the motile cryptofaunic community, since each of these taxonomic groups may be of great value to the ecology of coral reefs and have a dynamic influence on the rubble habitats. Echinodermata are made up of five classes: Asteroidea, Echinoidea, Crinoidea, Ophiuroidea and Holothuroidea; each having their own ecological function within the coral reef ecosystem. For example, the class Echinoidea are typically omnivorous grazers; by removing algae and other encrusting species, such as coral from rock surfaces, they make space for new species to colonize (Birkeland 1988). Providing this disturbance at an intermediate level, this can help promote diversity in coral reef ecosystems (Burkepile and Hay 2008). Opistobranchia also aid intermediate disturbance by feeding on algae, sponges and cyanobacteria (Faulkner and Ghiselin 1983; Cruz-Rivera and Paul 2002), all of which have been found to outcompete/overgrow corals if not predated/grazed upon regularly (Jackson and Buss 1975; Aerts 2000; Jompa and McCook 2002). Some Opistobranchia obtain bioactive compounds that have been used in the pharmaceutical industry (Charupant et al. 2007; Molinski et al. 2008; Lane et al. 2011; He et al. 2014; Malve 2016). In addition to this, Opistobranchia have been used as indicators of changing oceanic climates, which can help scientists with reef monitoring (Goddard and Pearse 2011). As well as this, their diversity and colour, particularly prominent in the clade Nudibranchia, are of great attraction to tourists (Mehrotra and Scott 2015). Finally, Platyhelminthes have been found to predate on commercially important species of oysters, mussels, giant clams etc. (Galleni et al. 1980; Newman et al. 1993; O'Connor and Newman 2001). Some species, have also been found to feed on a variety of *Acropora* corals (Nosratpour 2008)*.

As well as analysing the diversity of Echinodermata, Platyhelminthes and Opistobranchia within dead coral habitats, the data from the current study was compared with data from the Ecological Monitoring Programme (EMP) transects conducted by the New Heaven Reef Conservation Programme (NHRCP) in Koh Tao. This was to give a baseline study to compare the abundance and diversity of species within the current study and to give an indication of the impact of DFCs on the

wider reef community, by analysing the diversity of invertebrates and fish that did not use substrate as refugia.

Method

This study was conducted using SCUBA at four different reef sites (Chalok bay 10.067915˚N 99.826727˚E, Tien Og 10.065823˚N 99.832239˚E, Tao Tong 10.069373˚N 99.816027˚E, and Sai Nuan 10.074198˚N 99.816464˚E) on the south of the Island of Koh Tao, Thailand (see figure one). Chalok Bay is a sandy bay composed of dense coral reefs ranging from depths of 0.5 m – 15 m. Tien Og has been comprised mainly of dead coral since the 1998 global bleaching event (R Mehrotra, pers. comm.). Tao Tong is a short stretch of coast defined by a high abundance of Fungiidae corals throughout all parts of the thin fringing reef, with a steeper benthic gradient and a reef extending to 10 m. Sai Nuan is a small bay characterised by a relatively extensive 'reef-edge' community, where solitary corals and colonies make up a greater spatial cover than at other sites, with the edge extending down to 13 m. All dives were 60-90 minutes, dependent on air consumption. Three dives were taken at Chalok and Tien Og, two at Tao Tong and one at Sai Nuan. A variety of sites were sampled to explore a diversity of habitats and to avoid pseudoreplication of samples.

Figure 1: Map of Koh Tao, Thailand. Bottom corner, Koh Tao marked with red marker with the south of mainland Thailand to the left.

At each site, two 100 m transects were randomly laid out though the reef; one transect was shallow (2-4 m) and the other was deep (4-8 m). This was to avoid pseudoreplication, ensuring the same depth would not be surveyed if the site had already been visited. At a range of 5 m on either side of the transect line, large (>20 cm diameter) and small (≤20 cm diameter) DFCs were overturned by hand. A 20x20 cm quadrat was used to define a single replicate of rubble, since this was an intermediate size value with reference to the size of DFCs. The first layer of rubble within the quadrat was over turned to find any organisms hiding within the rubble habitat. Organisms in Echinodermata, Opistobranchia or Platyhelminthes were noted down if found underneath or attached to the underside of the DFC or a piece of rubble.

When an organism within Echinodermata, Platyhelminthes or Opistobranchia were observed, a photo was taken using an Olympus Tough TG830, this was to confirm identification of the species at the surface; the species was noted along with the substrate it was found under. Unfortunately, the tallies for species found and number of corals/quadrats analysed are not linked. Therefore, the replicates used in data analysis were the individual dives. Chi-square tests were conducted by hand to determine if there was a significant association between the abundance of each taxonomic groups and the substrates they were found under. PRIMER 7 was used to calculate the Margalef's diversity index values. These values were used in all other tests concerning diversity. PRIMER 7 was also used to conduct ANOSIM tests to determine the similarity of the diversity of each taxonomic group under large and small DFCs and the diversity of each taxonomic group under DFCs and rubble. Kruskal-Wallis tests were conducted using SPSS 24 to determine if there was a significant difference between: the median abundance of each taxonomic group under DFCs (large and small combined) and the median abundance and diversity of each taxonomic group within rubble habitats and under DFCs. Post hoc Mann-Whitney U tests were conducted when any Kruskal-Wallis test showed a significant difference. Since no Platyhelminthes were found in the rubble, statistical comparisons were not possible of this taxonomic group to Echinodermata and Opistobranchia.

During the analysis of this study, the fish, invertebrate and substrate EMP data collected by NHRCP from 2009-2017 were analysed (see Scott 2013, 2014 for full methodology of the EMP transects). With regards to the fish and invertebrate EMP surveys the diversity of each site was compared using a Kruskal Wallis test and post hoc Mann-Whitney U tests, if Kruskal Wallis comparisons were found to be significant ($p < 0.05$). These comparisons gave an indication as to which sites supported greater diversity of organisms overall. This was then compared against the percentage of rubble and DFCs at each site (calculated using the substrate surveys) to see if the percentage of DFCs and/or rubble had an influence on the diversity of fauna not using these habitats as refuge. The abundance of Echinodermata, Platyhelminthes and Opistobranchia observed in the NHRCP invertebrate transects were also analysed, using a Kruskal-Wallis test, to provide a baseline comparison of abundances to the current study. Furthermore, these abundances were compared to the abundances observed in the current study by testing for a significant difference, using a Kruskal-Wallis test, to see if DFCs played a role in the refuge for these taxonomic groups.

Results:

In total 559 DFCs were over-turned and examined (296 small, 263 large) and 270 rubble quadrats were observed. Twelve species (124 individuals) of Echinoderms, five species (seven individuals) of Platyhelminthes and 17 species (47 individuals) of Opistobranchia were recorded during this study. The total abundance of each taxonomic group under all substrate types can be found in figure 2.
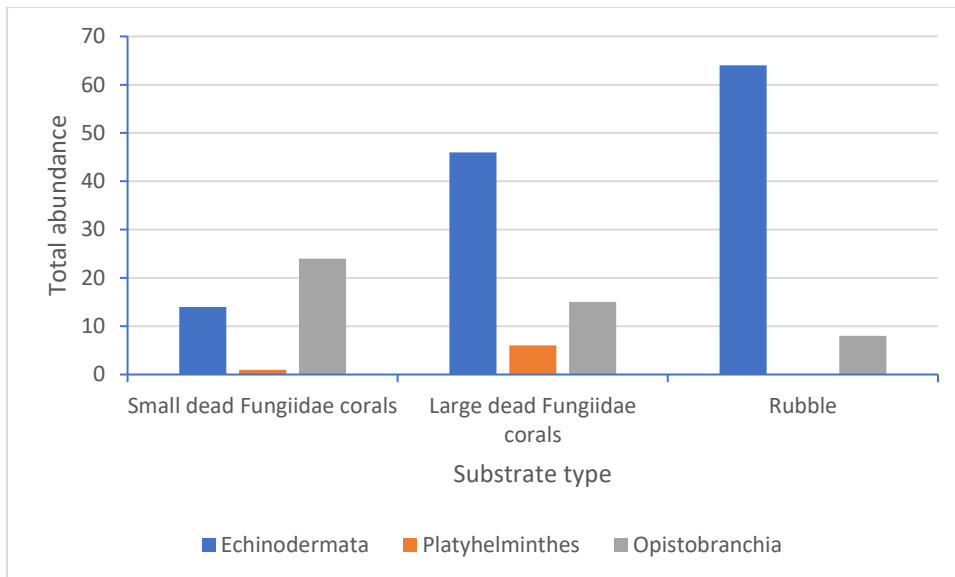
Figure 2: The abundance of Echinodermata, Platyhelminthes, Opistobranchia on large (>20 cm) and small (≤20 cm) dead Fungiidae corals and rubble habitats across Chalok, Tien Og, Tao Tong and Sai Nuan, Koh Tao, Thailand.

When considering the differences between the taxonomic groups studied, there was no significant difference (Kruskal-Wallis $p > 0.05$) between the median abundance of Echinodermata and Opistobranchia under DFCs (large and small combined). There was, however, a significantly higher abundance (Kruskal Wallis, $K = 13.51$, $df = 2$, $p < 0.05$) of Echinodermata (median = 0 ± 19 range) compared to Platyhelminthes (median = 0 ± 3 range) (Mann-Whitney U, $U = 4.5$, $n_{1,2} = 108, 45$, $p = 0.001$), as well as a significantly higher abundance of Opistobranchia (median = 0 ± 5 range) compared to Platyhelminthes (median = 0 ± 3 range) (Mann-Whitney U, $U = 8.5$, $n_{1,2} = 153, 45$, $p = 0.004$). Whilst there was variation in the abundance of these taxonomic groups, there was found to be no significant difference ($p > 0.05$) between the diversity of species under the DFCs observed. When analysing the median abundances of Echinodermata, Platyhelminthes and Opistobranchia in the NHRCP invertebrate EMP surveys, there was a significant difference between all taxonomic groups (Kruskal-Wallis, $K = 178.29$, $df = 2$, $p < 0.05$). Subsequent Mann-Whitney U tests were conducted, and found that there were significantly more (Mann-Whitney U, $p < 0.05$) Echinodermata (Median = 0 ± 400 range) than Platyhelminthes (Median = 0 ± 2 range) and Opistobranchia (Median = 0 ± 11 range). There was also significantly more (Mann-Whitney U, $p < 0.05$) Opistobranchia than Platyhelminthes. When these abundances were compared to current study there was no significant difference in the abundance of Echinodermata (Kruskal-Wallis, $p > 0.05$). However, there were significantly more Platyhelminthes ($K = 55.95$, $df = 1$, $p < 0.05$) and Opistobranchia ($K = 11.780$, $df = 1$, $p < 0.05$) found under DFCs in the current study compared to the NHRCP invertebrate EMP surveys. Median and range and mean values for the abundance of each taxa for the NHRCP data and the current study can be found in table 1.

Table 1: The median, range and mean abundances of Echinodermata, Platyhelminthes and Opistobranchia found by the New Heaven Reef Conservation Programme (NHRCP) and the current study across Chalok, Tien Og, Tao Tong and Sai Nuan, Koh Tao, Thailand. The mean abundance is presented since the replicates for the current study and NHRCP were different.

	Median		Range		Mean	
	NHRCP	Current Study	NHRCP	Current study	NHRCP	Current Study
Echinodermata	0	0	± 400	± 30	10.58	1.29
Platyhelminthes	0	0	± 2	± 3	0.033	0.58
Opistobranchia	0	0	± 11	± 9	0.416	0.8

Association in the abundance and similarities in the diversity of each taxonomic group were studied with relation to the size of the DFC (large or small). There was a significant association between Echinodermata abundance and large Fungiidae corals (Chi-Square = 14.8274, df = 11, $p < 0.05$); this was also true for Platyhelminthes (Chi-square = 5.354, df = 4, $p < 0.05$). There was, however, no significant association in the abundance of Opistobranchia with regards to DFC size (Chi-square, $p > 0.05$). The Margalef's diversity index values for Echinodermata, Platyhelminthes and Opistobranchia under large and small DFCs can be found in table 2. With regards to the diversity, Echinodermata found under large and small DFCs were significantly similar (ANOSIM R = 0.192, p = 3.6 %); however, this was not the case for Platyhelminthes and Opistobranchia (ANOSIM p > 5%).

Table 2: Margalef's diversity index (d) for large (>20 cm) and small (≤20 cm) Fungiidae corals found at Chalok, Tien Og, Tao Tong and Sai Nuan, Koh Tao, Thailand. N/A indicates no species were found and therefore a Margalef's diversity index cannot be calculated.

	d - large	d - small
Echinodermata	0.61	0
Platyhelminthes	0.16	N/A
Opistobranchia	0.26	0.86

When comparing the abundance of Echinodermata, Platyhelminthes and Opistobranchia, found under large and small DFCs and rubble habitats, a significant difference was found (Kruskal-Wallis test: Echinodermata, K = 8.21, df = 2, $p < 0.05$; Platyhelminthes, K = 6.47, df = 2, $p < 0.05$; Opistobranchia, K = 6.178, df = 2, $p < 0.05$). Subsequent Mann-Whitney U tests showed significantly higher abundance of Echinodermata within the rubble (median = 0 ± 26 range) compared to small (median = 0 ± 9) DFCs (Mann-Whitney U, U = 11, $n_{1,2}$ = 108 p = 0.008) but, there was no significant difference between the abundance of Echinodermata found within the rubble and large DFCs (Mann-Whitney U, p > 0.05). There was found to be a significantly higher abundance of Opistobranchia under DFCs (median = 0 ± 5 range) than within the rubble (median = 0 ± 2 range) (Mann-Whitney U, U = 14, $n_{1,2}$ = 153, p = 0.016), but, with regard to Platyhelminthes found under DFCs, compare to within rubble habitats, there was no significant difference in the abundance.

When considering the diversity of rubble and DFC habitats, there was significant similarity of Opistobranchia between reef rubble (d = 0.36) and DFCs (d = 1.22) (R = 0.276, p = 0.6 %). However, the diversity of Echinodermata found under reef rubble (d = 0.63) and DFCs (d = 0.86) were neither significantly similar or different (ANOSIM, Kruskal Wallis p > 0.05). Since no Platyhelminthes were found in the rubble, statistical comparisons were not possible of this taxonomic group to Echinodermata and Opistobranchia.

In order to evaluate the effects of rubble and DFCs on the diversity of indicator species of fish and invertebrates not using dead coral habitats as refuge; the Margalef's diversity index value of indicator species of fish, percentage of rubble and percentage of DFCs, found through the NHRCP EMP surveys, for each site was compared. The data for this comparison can be found in table 3 and the significance in differences of diversity can be found in table 4. Tien Og was found to have the highest percentage of rubble and second highest percentage of DFC and had a significantly higher diversity of invertebrates, compared to the other three sights, and significantly lower diversity of fish. By contrast, Sai Nuan, had the lowest percentage of both rubble and DFCs and had the highest diversity of fish.

Table 3: The Margalef's diversity index (d) of invertebrates and fish and the percentage of rubble and dead Fungiidae corals at Chalok, Tien Og, Tao Tong and Sai Nuan, Koh Tao, Thailand. Raw data obtained from Ecological Monitoring Programme transect surveys (2009-2017) collected by the New Heaven Reef Conservation Programme. The number in brackets indicates the highest diversity/percentage. One being the highest, four being the lowest.

	Invertebrate Margalef's Diversity index (d)	Fish Margalef's Diversity index (d)	Percentage of Rubble (%)	Percentage of dead Fungiidae corals (%)
Chal ok	0.42 (4)	1.16 (3)	31.89 (3)	0.038 (3)
Tien Og	1.21 (1)	1.16 (4)	39.26 (1)	0.26 (2)
Tao Tong	0.62 (3)	1.2 (2)	36.76 (2)	0.51 (1)
Sai Nuan	0.81 (2)	1.23 (1)	28.4 (4)	0.03 (4)

Table 4: Kruskal Wallis and subsequent Mann-Whitney U tests were conducted to determine the significance in difference in fish and invertebrate diversity (d) between Chalok, Tien Og, Tao Tong and Sai Nuan (Koh Tao, Thailand). Raw data was Data obtained from Ecological Monitoring Programme transect surveys (2009-2017) collected by the New Heaven Reef Conservation Programme. The Mann-Whitney U values displayed in bold are significant.

	d	K	df	p	Mann-Witney U
Fish Diversity	1.19	30.97	3	< 0.05	**Chalok, Tien Og p < 0.05;** Chalok, Tao Tong p > 0.05; Chalok, Sai Nuan p > 0.05; **Tien Og, Tao Tong p < 0.05;** **Tien Og, Sai Nuan p < 0.05;** Tao Tong, Sai Nuan p > 0.05
Invertebrate diversity	0.69	125.96	3	< 0.05	**Chalok, Tien Og p < 0.05;** **Chalok, Tao Tong p < 0.05** **Chalok, Sai Nuan p < 0.05;** **Tien Og, Tao Tong p < 0.05;** **Tien Og, Sai Nuan p < 0.05;** **Tao Tong, Sai Nuan p < 0.05**

Discussion:

The results from this study indicate that there was no significant difference found between the median diversity of Echinodermata, Platyhelminthes and Opistobranchia found under DFCs, illustrating that DFCs do not provide homes tailored to any one of these taxa specifically. However, there was seen to be a variation in the diversity and abundance within Echinodermata, Platyhelminthes and Opistobranchia found under DFCs and rubble habitats.

A consistent finding was that there were significantly fewer Platyhelminthes than Echinodermata or Opistobranchia (see figure 2). This was also found in the NHRCP EMP invertebrate survey (see figure 3). When comparing the data from the current study to the data collected from the NHRCP survey (see figure 4), however, there were significantly more Platyhelminthes under DFCs. This implies that DFCs are a more suitable habitat for Platyhelminthes than the live reef. Since a number of Platyhelminthes species are known to feed on *Acropora* tissue and other invertebrates such as mussels (Galleni et al. 1980; Glynn 2013; Hume et al. 2014), it is unlikely that these organisms are using DFCs as a feeding ground. Therefore, it could be that Platyhelminthes use DFCs as a point of refuge from predation. Although some species of Platyhelminthes have been described as aposematic and able to mimic aposematic species (Ang and Newman 1988; Newman et al. 1994), no specific research has been done on the role of aposematism and the species found in this study. Therefore, it might be that these species do not possess aposematic colouration or other secondary metabolites that could deter predators, and therefore refuge is found to be the best method of protection against predation. Further research needs to be conducted on the aposematic properties of the species found here to confirm this. To support this theory further, it would be useful to conduct night dives to see if more Platyhelminthes take refuge under DFCs, since aposematic colouration not useful at night.
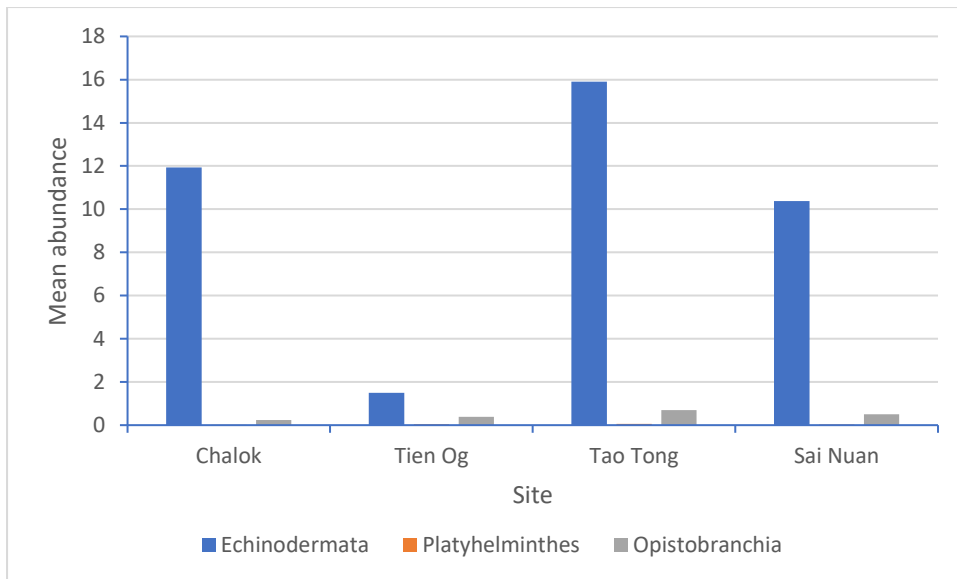
Figure 3: the mean abundance of Echinodermata, Platyhelminthes and Opistobranchia at Chalok, Tien Og, Tao Tong and Sai Nuan, Koh Tao, Thailand. Data taken from New Heaven Reef Conservation Programme Ecological Monitoring Programme transects of invertebrates.
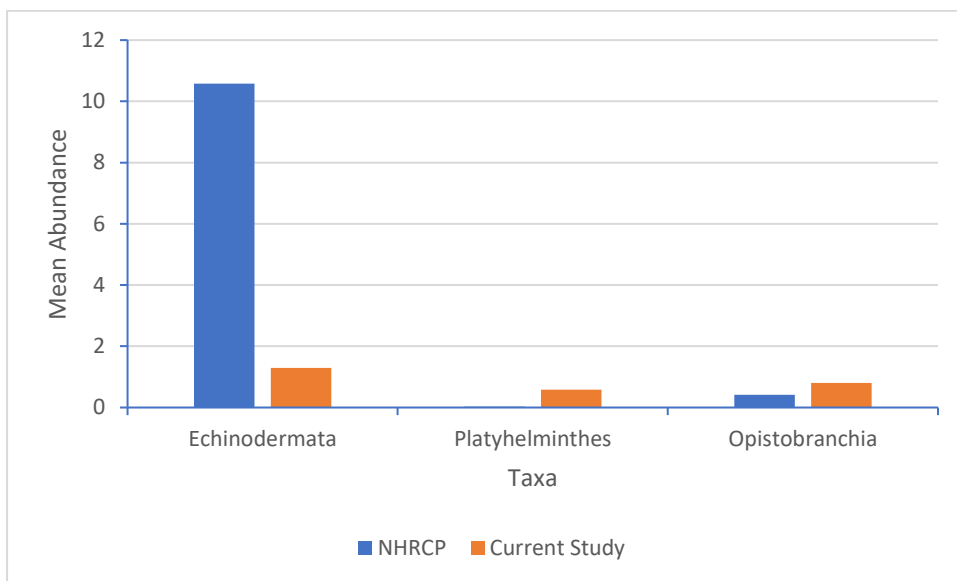

Figure 4: the mean abundances of Echinodermata, Platyhelminthes, Opistobranchia found under dead Fungiidae corals in the current study and found along the Ecological Monitoring Programme invertebrate transects from the New Heaven Reef Conservation Programme (NHRCP) from 2009-2017.

Although few Platyhelminthes were observed in the current study, those found were exclusive to underneath large DFCs and not found within the rubble habitat. This highlights that DFCs are a unique form of refuge within the dead coral habitats. Since no Platyhelminthes were found under small DFCs it could be assumed that the size of the individual influences their point of refuge. For example, species found in this study can reach up to 8 cm in length (Bolaños et al. 2016), thus limiting the spaces suitable for them to dwell.

The most abundant group found within Echinodermata, in both studies, was Echinoidea. The majority of organisms within this group are known to be grazers (Birkeland 1988; Mishra 2015), and

since there is limited algal growth found under DFCs, due to a lack of light availability needed for photosynthesis, it could be predicted that there would be a greater abundance of Echinoids in rubble habitats. However, since this is not the case, it could therefore be assumed that food is not the influencing factor in the distribution these organisms, rather it could be that Echinoids are using DFCs as a point of refuge. On the contrary, some species show little sign of needing refuge from DFCs. For example, the data from the NHRCP found *Diedema setosum* to be the most abundant Echinoderm on the open reef. Despite these species being a nocturnal (Shunula and Ndibalema 1986), and therefore being more susceptible to predation during the day (Nelson and Vance 1979), they are found in abundance in broad daylight. This could be due to their long spines that are known to provide effective protection from predation (Tenger and Levin 1983; Moitoza and Phillips 1979). In addition to this, *D. setosum* are often found in aggregations along the reef, providing protection (Pearse and Arch 1969). These aggregations might create particularly safe environments for the urchins in the middle of the aggregation, as predators are unlikely to be able to flip them over and thus access the most vulnerable part of the urchin (Tenger and Levin 1983). Juvenile urchins have also been seen to take refuge under the spine canopy of larger urchins (Tenger and Levin 1983; Moitoza and Phillips 1979), again reducing the need for other forms of refugia such as underneath DFCs. The size of the Echinoid species could have a significant effect as to the degree to which refuge from predation is required (Hereu et al. 2005). To analyse the role of DFCs as refuge for Echinoid species, the size of the organism, as well as their life stage, should be investigated.

The Margalef's index of diversity of Echinodermata (see table 2) was found not to be affected by the size of the DFCs (the diversity of each Echinodermata community were significantly similar). There was also no significant difference or similarity between the diversity of Echinodermata found under DFCs (large and small combined) and rubble. These results imply that both habitats are suitable for a variety of Echinodermata species. As previously discussed this could be due to the food resources provided by rubble habitats and the refuge provided by Fungiidae corals. Since refuge and food are needed by all species, this could explain the evenness in diversity across the habitats. Whilst there were similarities in diversity of species in Echinodermata, across the 3 substrate types, it is worth noting that very few species outside of the class Echinoidea were found in this study. This could indicate that other taxonomic classes, within Echinodermata, do not need to seek refuge under DFCs. For example, in Holothuroidea and Asteroidea display predation deterrence within their early life stages (Iyengar and Harvell 2001). Holothuroidea possess several defence mechanisms against predation, for example: thick body walls, toxic organs, evisceration etc. (Francour 1997).

With regards to Opistobranchia, significantly more individuals were found under DFCs in the current study, than on the EMP transect line of the NHRCP studies. As well as this, Opistobranchia were also found to be more abundant under DFCs than within rubble habitats. This could imply that Opistobranchia used DFCs as a form of refuge. A potential explanation for the need of refugia could be the lack of aposematism and/or chemical defence utilised by the species found under DFCs, and since Opistobranchia lack a shell to protect them against predation (Wägele and Klussmann-Kolb 2005) it is possible that refuge taken under DFCs is vital for survival. This is likely the case since aposematism is often an effective defence against predation (Ritson-Williams and Paul 2007) and thus reduces the need for refuge. For example, the *Phyllidia* genus are known to have aposematic colouration (Ritson-Williams and Paul 2007) and are found abundantly on the reefs of Thailand (Chavanich et al. 2013), but in the current study, only one *Phyllidia* juvenile was found under the DFCs. This implies that their aposematic properties reduce their need to seek refuge under DFCs. This in turn suggesting that those without aposematic characteristics would benefit from refuge, such as DFCs.

Seven species of Opistobranchia found in this study were not reported to be found in the 2015 assessment of Opistobranchia on Koh Tao (Mehrotra and Scott 2015), indicating they are new finds in this area. These species new to the island, except *Bornella cf. stellifer,* were found under DFCs only; highlighting the importance of this habitat. In addition to this, *Goniobranchus fidelis,* a sea slug of low density in Thailand (Kasamersiri et al. 2014) was found a total of six times in nine dives, exclusively under DFCs. Since Opistobranchia are known to be an indicator species to ocean climate (Goddard and Pearse 2011), discovering a key habitat in DFCs could aid monitoring of the reef and thus the surrounding ocean climate.

When the considering the diversity of Opistobranchia in the current study, there was significant similarity between DFCs and the rubble habitat. This implies that in order to find maximum diversity of Opistobranchia within dead coral habitats, it is important to explore both rubble and DFCs. Discovering a wide variety of Opistobranchia species could aid development in pharmaceutical produce, as many species contain bioactive compounds (Charupant et al. 2007; Molinski et al. 2008; Lane et al. 2011; He et al. 2014; Malve 2016).

The data provided by NHRCP was also used to analyse the impact of DFCs and rubble on the wider reef community. When considering the variance in species diversity between the sites surveyed at Koh Tao, the EMP transects from NHRCP showed significant difference in the diversity of indicator species of fish and indicator species of invertebrates between Chalok, Tien Og, Tao Tong and Sai Nuan. When comparing the substrate EMP data to that of the fish and invertebrate EMP data, it appears that the substrates along the transect had an influence on the diversity of fish an invertebrates. For example, Tien Og had the highest amount of rubble and the second highest number of DFCs compared to the other three sites. At Tien Og there was the lowest diversity of fish and the highest diversity of invertebrates. On the other hand, Sai Nuan had the lowest amount of reef rubble and DFCs and consequently had the highest diversity of fish and the second highest diversity of invertebrates. There seems to be a clear relationship between an increase in rubble and a decrease in fish between sites. This may be due to the focus of the indicator species – all the species present in the survey are indicators of reef health (Scott 2014), therefore it can be assumed their diversity would decrease with an increase in dead coral. There also appears to be a relationship between DFCs and number of invertebrates. This could be due to the refuge provided by the DFCs, allowing juvenile invertebrates to reach maturity. The current study helps support this as some of the species found under DFCs were juveniles of the indicator invertebrates in this survey e.g. *D. setosum*. However, since so few DFCs were found on the EMP transects, it is not valid to make drastic assumptions without further research. The purpose of comparing this current study to the EMP surveys of NHRCP is to analyse whether the presence of DFCs and rubble have an impact on the diversity of the sites analysed. Since the current study has demonstrated that diversity of life can be found within the rubble, it is worth considering whether any of the species found could be added as indicator species to this survey. With the importance of cryptofauna to the reef community (Enochs and Hockensmith 2008; Enochs 2011) this could be an advantageous piece of information to consider, since these surveys seek to analyse the health of the reefs at each site (Scott 2013).

This is the first study, in light of current literature, to specifically analyse the diversity of cryptofauna under DFCs and the role of DFCs as a place of refugia for cryptofauna. It has also contributed to the limited literature of motile cryptofauna in rubble habitats of coral reefs (Peyrot-Clausade 1980, Klumpp et al. 1988, Takada et al. 2007, Enochs 2011). With the increasing mortality (Altieri et al. 2017) of corals and consequential rise in rubble habitats (Glynn 1993; Cesar et al. 2003) it is important to gauge a clearer understanding of the life found in these places. This study demonstrated that DFCs can provide a unique habitat and place of refuge, concealing species that may not otherwise be noticed; therefore, the analysis of these habitats may lead to a rise in

biodiversity within the reefs. This study has also given insight into the distribution of species, providing a snapshot to the abundance of life that can be found within the seemingly 'dead' areas of reef in Koh Tao. These contributions may help to promote the protection of Koh Tao reefs by government legislation. In conclusion, this study has highlighted the urgent need to continue investigating dead coral habitats, in order to discover the true diversity of coral reefs globally.

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