

**DETERMINING THE ABUNDANCE, DENSITY, POPULATION
STRUCTURE, AND FEEDING PREFERENCE OF *DRUPELLA*
SNAILS ON KOH TAO, THAILAND**

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entitled
**DETERMINING THE ABUNDANCE, DENSITY, POPULATION
STRUCTURE, AND FEEDING PREFERENCE OF *DRUPELLA*
SNAILS ON KOH TAO, THAILAND**

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THAILAND

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ABSTRACT

Coral reefs around the world are threatened with a wide range and anthropogenic and natural stresses, and over-predation by corallivores is one of them. On Koh Tao, Thailand, *Drupella* snails were observed in two locations: Chalok Ban Kao and Ta Cha. The aim of our study was to look at 1) whether or not *Drupella* were still feeding on *Fungiid* corals, 2) *Drupella* aggregation abundance, 3) feeding preferences, and 4) severity of infestation at the two sites. We found that *Drupella* were still preying on *Fungiid* corals, a shift in diet which started after the 2010 bleaching event. Our surveys suggest that *Drupella* aggregations appear to be localised in one area or depth, and are few and far between in other areas. *Drupella* were mostly found on hard corals, with 3 genera of coral being infected: *Fungia*, *Acropora*, and *Pocillopora*. *Acropora* and *Pocillopora* are long known as preferred preys while preying on *Fungia* was not commonly observed. Lastly the surveys suggest that the density of *Drupella* in Chalok and Ta Cha are 1.175 and 1.167 m⁻² respectively, which is not classified as an outbreak. However, larger scale studies are required to adequately determine the severity of *Drupella* infestations because the ‘outbreak’ may be at an unsurveyed location.

KEYWORDS: *DRUPELLA* / DENSITY / CORAL REEF / CORALLIVORE /
AGGREGATION

36 PAGES

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CHAPTER I

INTRODUCTION AND RATIONALE

1.1 Introduction

The importance of coral reefs cannot be questioned. They provide habitat for marine organisms, as well as food, coastal protection, income, and livelihoods for coastal populations. The services provided by coral reefs are estimated to be worth as much as USD 30 billion annually (Cesar et al, 2003). The *Scleractinian* hard corals are considered the backbones of the reef ecosystem. The coral polyps live in a mutual symbiosis with the photosynthetic zooxanthellae algae, and this simple relationship is fundamental in making this ecosystem possible (Cesar, 2002). The *Scleractinian* hard corals are the reef-builders of the coral reef. Without them there will be no reef that supports one of the most bio-diverse ecosystems on the planet (Knowlton, Nancy et al. 2010), and therefore no natural support system to sustain coastal human livelihoods. A greater understanding of coral reef ecology and the subsequent preservation and conservation efforts of this fragile ecosystem are therefore crucial in order to sustain the ways of life that depend on a healthy reef.

Coral reefs are sensitive to many factors which directly or indirectly affect their health (Graham et al. 2006). The factors are either anthropogenic, for example: eutrophication (Fabricius, 2011), pollution (Todd et al. 2010), debris (Gregory, 2009), unregulated tourism (Krieger, 2012), damaging fishing/boat practices (Wilkinson, 2000); or they are natural, including storms and tsunamis (Witt et al. 2011), changes in the physical environment (temperature or oxygen levels), which could lead to events like coral bleaching, increased susceptibility to diseases (Miller et al. 2009), and over-predation of corals (Birkeland, 1982). These problems, whether natural or anthropogenic, do not exist in isolation, but are dynamic and interrelated. One problem is enough to kick start a series of negative consequences for the reef. For example,

eutrophication enriches nutrients around coral reefs, increases water turbidity allowing less light to shine through and be utilized by corals, as well as smothering corals with sedimentation. This in turn will lead to decreases in coral health and diversity, and macro-algae can rapidly take over the stressed coral reef ecosystem (Fabricius, 2011).

When thinking of outbreaks of corallivores (organisms that eat corals), the famous crown-of-thorns starfish (*Acanthaster planci*) springs to mind. Outbreaks since the 1960s in the Indo-Pacific region have been documented (Endean & Chesher, 1973; Keyal et al. 2012), and the damage left behind is a fundamentally destroyed reef ecosystem due to the amount of corals being consumed. In Japan, an infestation of *Acanthaster planci* was observed in Iriomote Island. They noticed three things after the infestation: 1) there were no coral-polyp feeders in the dead/rubble reefs, most likely because there is no food; 2) Resident species declined in dead reefs, probably because of a reduction in structural complexity in dead reefs; and 3) Both resident and visitor fishes declined in dead/rubble reefs (Sano et al. 1987). Outbreaks of corallivores can have a devastating impact on the reef ecosystem, and a greater understanding of corallivores and their outbreaks are crucial in order to mitigate these threats.

This project is concerned with a recent outbreak of *Drupella* snails, another corallivore. In large aggregations, they are capable of wiping clean large areas of coral cover on the reef, which may take years to recover (Turner, 1994; Cumming, 2009). Published literatures so far have pointed to rapid population increases in the Indo-Pacific (Turner, 1994; McClanahan, 1997; Shafir, 2008). Little is known regarding the ecology of *Drupella* and less is known regarding the effective management of such corallivores.

1.2 Objectives

This study is conducted as a follow up to observations made by Hoeksema et al. (2013) in which *Drupella* snails were seen feeding on *Fungiid* corals after the bleaching event in 2010. As *Drupella* usually aggregate on *Acroporiid* corals this study aims to determine:

1. whether *Drupella* snails are still aggregating on *Fungiid* corals
2. the abundance of *Drupella* aggregations
3. the preferred substrate type
4. the severity of the infestation

The study will be carried out in the field using quadrat and aggregation surveys.

CHAPTER II

LITERATURE REVIEW

Drupella snails are corallivorous gastropods, which means they feed on corals. They enjoy a cryptic behaviour, often seen gathering in small to large aggregations at the base or the underside of a coral (Schoepf et al. 2010). Adults are 2 cm or longer (Black and Johnson, 1994), and can be seen on a variety of coral genera, while juveniles tend to be restricted to the branching corals for protection (Schoepf et al. 2010). *Drupella* shells appear to be whitish brown with spikes, but will most often be covered with purple crustose coralline algae. The morphological differences in species can be spotted in design of the spikes, and how sharp or rounded they are. *Drupella* snails reproduce internally, and can produce up to 200 eggs per mother. They have a planktotrophic early life stage of about 30 days (Turner, 1992). *Drupella* snails reach sexual maturity at 2.5 to 3.5 years, and can live up to 45 years (Black and Johnson, 1994).

In large and numerous aggregations, *Drupella* are capable of inflicting heavy coral loss in large areas of the reef, as seen in many areas of the Indo-Pacific and beyond. Hong Kong (Turner, 1994), Kenya (McClanahan, 1997), The Great Barrier Reef in Australia (Cumming, 1998; Cumming, 2009), Israel (Shafir, 2008), and Koh Tao, Thailand (Hoeksema et al. 2013) are among a few places where *Drupella* outbreaks and the resulting damages are observed and recorded. The damages caused to the reef by *Drupella* rivals that of the more well-known corallivore, the crown-of-thorns starfish (*Acanthaster planci*). Indeed, Loch (1987) argues that some reef damage attributed to the crown-of-thorns starfish may actually be from *Drupella* snails.

Drupella are extremely resilient in terms of food, and have been noted to switch preys when their preferred diet is unavailable. Their most preferred prey are branching corals, most notably *Acropora*, followed by *Pocillopora*, and *Montipora* (Turner, 1994; Hoeksema et al. 2013), but they will go for other prey species if their

preferred preys are unavailable (Schoepf et al. 2010). In Hong Kong, *Acropora* and *Pocillopora* corals are very rare, and thus *Drupella* are observed preying on *Platygyra* instead (Cumming, 1998; Lam, 2007). *Drupella* were found on *Turbinaria*, *Pavona*, *Millepora*, and *Porites* after branching corals were killed in Gulf of Eilat, in Israel (Shafir, 2008).

Furthermore, *Drupella* seem to happily thrive in coral reefs that are affected by some type of disturbance, with higher coral mortality positively correlated with higher numbers of *Drupella* snails. When Hurricane Allen hit Jamaica, Knowlton (1981) observed that the damage attributed to corals by corallivorous snails was higher than the damages caused by the aforementioned storm. Ayling and Ayling (1992) spotted the increase in *Drupella* numbers after Cyclone Ivor affected Pelorus Island of the Great Barrier Reef. This notion has been further pushed by Forde (1992) that *Drupella* snails can probably sense for stressed or dying corals as a biological stimulus to prey. Kita (2005) synthesized montiporic acids A and C after they observed *Drupella* feeding on *Montipora* corals, and also feeding on agar that had sea water which corals bled. They tested to see if *Drupella* would be attracted to these synthesized acids, and experiments showed that *Drupella* were indeed attracted. This could potentially be an efficient tool for reef conservation if *Drupella* becomes a bigger problem. *Drupella* are also able to withstand huge natural stresses such as the siltation stress in the Gulf of Eilat in 1999-2000. The *Drupella* were observed during the siltation event, and four years later, their numbers were up to an astonishing 200 on each 30-cm diameter coral (Shafir, 2008).

Baird (1999) documented massive *Drupella* aggregations after a major bleaching event in 1998 in the Great Barrier Reef where 70% of *Acroporiid* corals were killed, but most of the *Drupella* were still preying on several *Acropora* spp., and only one *Montipora tuberculosa* was observed to have *Drupella* on it.

On Koh Tao, Thailand, from 2006-2010 data, *Drupella* were observed to feed mostly on branching corals, namely the *Acropora* genus, leading to a decline in table corals (Hoeksema et al. 2013). In 2008-2010, the average density of *Drupellas* on

Acropora and *Pocillopora* was at 0.5-1.0 m⁻², and this led to a 60% coral cover loss at 3-6 meters in depth (Hoeksema et al. 2013).

Prior to 2010, the reef areas of Tacha and Chalok Ban Kao (see Figure 1) were locations with known *Drupella* populations prior to the bleaching event of that year. According to Hoeksema and his researchers (2013), few *Drupella* aggregations were actually observed preying on *Fungiid* corals on Koh Tao. However, surveys after the bleaching event noticed something unusual. A lot of *Acropora* died off due to the bleaching, and *Drupella* snails started to aggregate on *Fungiid* corals. Hoeksema suggests that it was unlikely that *Drupella* targeted these *Fungiid* corals due to the bleaching because they were already recovering from it, and also because the largest number of *Drupella* were on *Ctenactis echinata*, a species with low bleaching susceptibility. The research showed that in Tacha, 15 snails were aggregated on a single *Fungia fungites* coral; and in Chalok Ban Kao, four species were affected, namely: *Fungia fungites*, *Lithophyllon repanda*, *Ctenactis echinata*, and *Pleuractis granulosa*.

CHAPTER III

MATERIALS AND METHODS

3.1 Materials and Personnel:

- Volunteer data collectors; SCUBA diving gears
- Two 1x1m quadrats, divided into 25 squares of 20x20cm per square.
- Pencils; Underwater slates; Reels

3.2 Methods:

3.2.1 Study Sites

Koh Tao is an island located in Surat Thani province, in the Gulf of Thailand, and is one of the most popular dive destinations in the world. It is a small island at only 21 km², yet attracts over 300,000 visitors annually ([Scott, 2009](#)). The economy of the island relies almost entirely on the flourishing diving and tourism industry.

What makes Koh Tao so popular is the abundance of coral reefs around the island. Although not the most pristine, the dive sites are beautiful, and there is a high diversity of marine life around the island. However, due to the constant pressures applied to the reefs from recreational activities such as direct physical damages from inexperienced divers and snorkelers, wastewater runoffs causing algal growths, debris, and sedimentation from land smothering corals, the integrity of the reefs are threatened daily ([Weterings, 2011](#); [Terlouw, 2012](#)).

The surveys will be carried out at two sites: Chalok Ban Kao Bay and Ta Cha on Koh Tao, Thailand (see Figure 3.1).



Figure 3.1. Map of Koh Tao marking *Drupella* sampling sites at 1) Chalok Ban Kao, and 2) Ta Cha in the south of the island.

Chalok Ban Kao Bay is a shallow and family-friendly bay in the south of Koh Tao due to its lagoon that extends outwards to as far as 350 meters ([Terlouw, 2012](#)). The reef in Chalok is largely dominated by beautiful fields of branching and mushroom corals. Data from 2006-2010 indicate that Chalok has a 20.7% hard coral cover. After the bleaching event in 2010, the corals in Chalok went from 100% healthy to nearly 0% healthy in the period between April to June 2010 and problems of sedimentation arrived soon after ([Scott et al. 2010](#)).

There are regular *Drupella* collection efforts in Chalok Ban Kao. The efforts are made by the New Heaven Reef Conservation Program, a member of the Save Koh Tao community group that coordinates conservation efforts with dive schools around the island. NHRCP has estimated to have collected over 60,000 *Drupella* snails over 2 years in Chalok Ban Kao ([New Heaven Dive School website, 2013](#)).

Ta Cha is a lovely dive site at the south of Koh Tao. Ta Cha is annexed to Shark Bay, a famous snorkeling spot to see black-tip reef sharks (*Carcharhinus melanopterus*). The Ta Cha reef is scattered with large boulders that form large parts of the structure of the reef. The entire bay was affected by the mass bleaching in 1998 and still has not fully recovered (Scott personal communication). There are currently no *Drupella* snail collection efforts in Ta Cha.

The survey was done approximately 12.00 pm day time at both sites.

3.2.2 Aggregation Survey

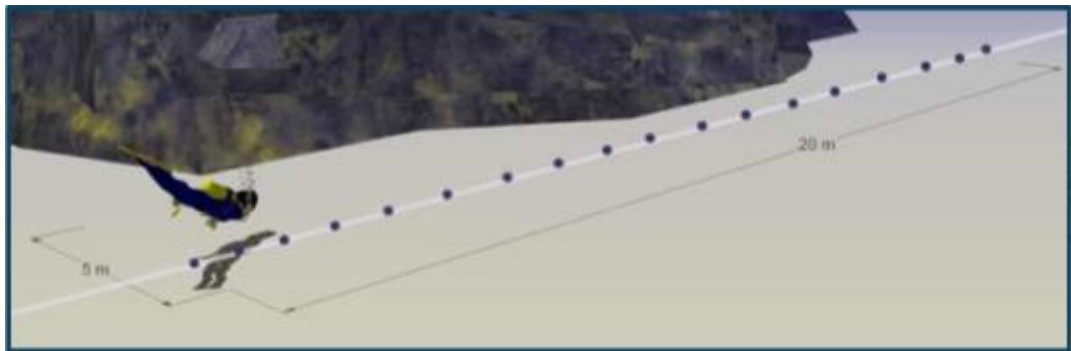


Figure 3.2. A representation of the belt transect survey. The full length is 50m and not 20m as shown in the picture (image courtesy of Chad Scott, 2012).

Drupella aggregations (>5 snails on one coral colony) were noted in 5m wide belt transects using the 50m line transect line at 2m, 4m, 6m, and 8m depths. At each location where a *Drupella* aggregation was found along the 50m transect, the following information was collected:

- i. The numbers of *Drupella* adults, juveniles, and recruits
- ii. The location (distance) of the aggregation along the transect
- iii. Genera of the coral affected
- iv. Growth form of the coral affected
- v. Dimensions of the coral and
- vi. Approximate area/percentage of coral consumed by *Drupella*

The different growth forms include: branching, tabulate, digitate, encrusting, corymbose, massive, submassive, foliose, and mushroom (See Appendix A). Measuring the dimensions of the coral allows us to calculate the surface area of the coral using $A = \pi r^2$ to find the area recently killed by *Drupella*.

The aggregation survey aims to indicate distance between *Drupella* aggregations, and thus provide an indication of the perceived severity of the infestation.

3.2.3 Quadrat Survey

1. A 50m transect line will be deployed at random, representative positions on the reef at 2m, 4m, 6m, and 8m depths.
2. At each 5m mark, a 1m² quadrat will be placed on a side (stick with left or right throughout all surveys) and the dominant substrate type of each 20x20cm square divided in the 1m² quadrat will be noted. The substrate types will be noted as sand (SD), rubble (RB), hard-coral (HC), soft-coral (SC), trash (T), rock (RC), nutrient indicator algae (NIA), or others (OTH) (see Appendix B). The number of *Drupella* snails in each quadrat will also be recorded as adults (>2 cm), juveniles (1-2 cm), and recruits (<1 cm) (Black and Johnson, 1994).

The quadrat survey aims to investigate *Drupella* densities, the number of adults, juveniles, and recruits per square meter, as well as information on preferred substrates at different depths.

CHAPTER IV

RESULTS

4.1 Chalok Aggregation Survey Results

The largest number of aggregations is 9 aggregations, at 4m depth. The nine aggregations had a combined number of 250 *Drupella* among them. The second largest is 3 aggregations, at 2m depth. A single aggregation was found at 6m depth, and lastly none at 8m depth. It is also interesting to note that all the *Drupella* spotted were adults.

Sampling depth (m)		Life stage			Avg distance between aggregations (m)	# of Agg
		Adult	Juvenile	Recruit		
2	Total <i>Drupella</i>	21	0	0	0.5	3
	Avg# per agg	7	0	0		
	Total (%)	100	0	0		
	Min	6	0	0		
	Max	9	0	0		
4	Total <i>Drupella</i>	250	0	0	5.222	9
	Avg# per agg	25	0	0		
	Total (%)	100	0	0		
	Min	17	0	0		
	Max	38	0	0		
6	Total <i>Drupella</i>	17	0	0	n/a	1
	Avg# per agg	17	0	0		
	Total (%)	100	0	0		
	Min	17	0	0		
	Max	17	0	0		
8	Total <i>Drupella</i>	0	0	0	n/a	0
	Avg# per agg	0	0	0		
	Total (%)	0	0	0		
	Min	0	0	0		
	Max	0	0	0		

Table 4.1. Summary table of *Drupella* aggregations in terms of adults, juveniles, and recruits in Chalok at 2m, 4m, 6m, and 8m.

4.1.1 Chalok Aggregation 2m

At Chalok 2m, three *Drupella* aggregations were found close to each other at 8, 8, and 9 meters along the transect line. All three aggregations were on *Acropora* branching corals. They were medium-sized corals with maximum diameters at 25, 30 and 30 cm. The estimated percentage of coral recently killed was low, at 10-15%. All the *Drupella* counted were adults.

Location on transect (m)	Distance (m)	Life Stage			Genus	GF	%RK	Max D (cm ²)	Approx Area (cm ²)	Area RK (cm ²)
		Adult	Juvenile	Recruit						
9		6	0	0	Acropora	B	10	25	491	49
8	1	6	0	0	Acropora	B	10	30	707	71
8	0	9	0	0	Acropora	B	15	30	707	106

Table 4.2. Table showing *Drupella* aggregations found along Chalok transect, at 2m depth.

Genus Affected: *Acropora* 100%

Growth Forms Affected: Branching 100%

4.1.2 Chalok Aggregation 4m

At Chalok 4m, nine *Drupella* aggregations were observed along the 50m transect line. Their locations were quite evenly distributed along the transect line (see Table 7.3). The calculated average distance between aggregations is 5.2m. Eight out of the 9 aggregations were observed on mushroom corals, with one being a tabulate *Acropora* coral. This confirms that *Drupella* snails are still aggregating on *Fungioid* corals after the bleaching. The total number of *Drupella* on this transect line is large, at 250 adults. That is an average of 28 adults per aggregation. What is interesting here is the size range of infested corals. The largest mushroom coral targeted was 35cm in diameter, and the smallest mushroom coral targeted was 6cm in diameter. Ironically, the smallest mushroom coral (6cm) had 34 adult *Drupella* snails preying on it, the second largest aggregation in this transect.

Location on transect (m)	Distance (m)	Life Stage			Genus	GF	%RK	Max D (cm ²)	Approx Area (cm ²)	Area RK (cm ²)
		Adult	Juvenile	Recruit						
47		28	0	0	Fungia	R	30	13	133	40
40	7	24	0	0	Fungia	R	65	18	254	165
32	8	17	0	0	Fungia	R	15	12	113	17
26.5	5.5	24	0	0	Fungia	R	40	19	283	113
24	2.5	31	0	0	Fungia	R	35	20	314	110
21	3	34	0	0	Fungia	R	35	6	28	10
20	1	20	0	0	Fungia	R	20	20	314	63
13	7	34	0	0	Fungia	R	70	35	962	673
8	5	38	0	0	Acropora	T	65	30	707	459

Table 4.3. Table showing *Drupella* aggregations found along Chalok transect, at 4m depth.

Genus Affected: Acropora 11.1%, Fungia 88.9%

Growth Forms Affected: Tabulate 11.1%, Mushroom 88.9%



Figure 4.1. *Drupella* snails feeding on a *Fungia* coral in Chalok Ban Kao (image by: Chad Scott).

4.1.3 Chalok Aggregation 6m

Only one aggregation was found on the 50m transect line at 6m depth. There were 17 adults on a single 35cm diameter *Acropora* branching coral. It is estimated that 15% of it was recently killed by *Drupella* snails.

Location on transect (m)	Distance (m)	Life Stage			Genus	GF	%RK	Max D (cm ²)	Approx Area (cm ²)	Area RK (cm ²)
		Adult	Juvenile	Recruit						
47.1		17	0	0	Acropora	B	15	35	962	144

Table 4.4. Table showing *Drupella* aggregations found along Chalok transect, at 6m depth.

Genus Affected: Acropora 100%

Growth Forms Affected: Branching 100%

4.1.4 Chalok Aggregation 8m

No *Drupella* aggregations were found at 8m depth on the transect line that was laid. There were hardly any hard corals, which may explain the absence of *Drupella* snails.

4.2 Chalok Quadrat Survey Results

The highest density of *Drupella* was 2.2 adults and 0.1 juveniles, at 2m. That is followed by 1.1 adults and 0.3 juveniles, at 6m. Third highest was 0.9 adults and 0.1 juveniles, at 4m. Lastly, no *Drupella* snails were found in the Chalok quadrat survey at 8m.

Sampling		Life stage		
depth (m)		Adult	Juvenile	Recruit
2	Total	22	1	0
	Avg m ⁻²	2.2	0.1	0
	% of total	95.7	4.3	0
4	Total	9	1	0
	Avg m ⁻²	0.9	0.1	0
	% of total	90	10	0
6	Total	11	3	0
	Avg m ⁻²	1.1	0.3	0
	% of total	78.6	21.4	0
8	Total	0	0	0
	Avg m ⁻²	0	0	0
	% of total	0	0	0

Table 4.5. Summary table of quadrat survey on *Drupella* density, and number of adults, juveniles, and recruits in Chalok at 2m, 4m, 6m, and 8m.

4.2.1 Chalok Quadrat 2m:

Due to some unexpected circumstances (one of our volunteer divers ran out of air), we could not collect the data for the substrate types on the quadrat survey at 2m. However, we did manage to get the number of *Drupella* snails at this depth. It had the highest density of *Drupella*, at 2.2 adults and 0.1 juveniles per m², out of the four depths surveyed in Chalok.

Location on transect (m)	Life Stage			Substrate Types (%)								
	Adult	Juvenile	Recruit	HC	SC	DC	RC	RB	SD	T	NIA	OTH
0	0	0	0	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
5	4	0	0	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
10	9	0	0	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
15	0	0	0	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
20	1	1	0	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
25	7	0	0	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
30	0	0	0	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
35	1	0	0	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
40	0	0	0	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
45	0	0	0	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a

Table 4.6. This table outlines the Chalok 2m quadrat results.

4.2.2 Chalok Quadrat 4m:

There were 10 *Drupella* snails found in total within the quadrats, with 9 adults and 1 juvenile. The substrates were predominantly hard coral and rubble.

Location on transect (m)	Life Stage			Substrate Types (%)								
	Adult	Juvenile	Recruit	HC	SC	DC	RC	RB	SD	T	NIA	OTH
0	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	52	0	0	0	48	0	0	0	0
10	0	0	0	32	0	0	8	60	0	0	0	0
15	0	0	0	32	0	0	28	20	0	0	0	20
20	3	0	0	48	0	0	0	52	0	0	0	0
25	0	1	0	40	0	0	0	60	0	0	0	0
30	6	0	0	60	0	0	0	40	0	0	0	0
35	0	0	0	28	0	0	0	72	0	0	0	0
40	0	0	0	16	0	0	8	72	0	0	0	4
45	0	0	0	32	0	0	8	60	0	0	0	0

Table 4.7. This table outlines the Chalok 4m quadrat results. Numbers of *Drupella* snails founds and the substrate types in the quadrat are shown.

4.2.3 Chalok Quadrat 6m:

The quadrat with the most number of *Drupella* is at location 5m, with 100% of the substrates identified as hard corals. A single juvenile *Drupella* was spotted at 35m, and the substrate was entirely rubble.

Location on transect (m)	Life Stage			Substrate Types (%)								
	Adult	Juvenile	Recruit	HC	SC	DC	RC	RB	SD	T	NIA	OTH
0	0	0	0	4	0	0	4	76	16	0	0	0
5	6	2	0	100	0	0	0	0	0	0	0	0
10	4	0	0	52	0	0	0	48	0	0	0	0
15	1	0	0	84	0	0	4	12	0	0	0	0
20	0	0	0	56	0	0	0	44	0	0	0	0
25	0	0	0	64	0	0	0	36	0	0	0	0
30	0	0	0	12	0	0	0	88	0	0	0	0
35	0	1	0	0	0	0	0	100	0	0	0	0
40	0	0	0	72	0	0	0	28	0	0	0	0
45	0	0	0	32	0	0	0	68	0	0	0	0

Table 4.8. This table outlines the Chalok 6m quadrat results.

4.2.4 Chalok Quadrat 8m

Very few hard corals were found during this quadrat survey. The substrate types were predominantly rubble or sand across the transect line, and no *Drupella* snails were found at 8m.

Location on transect (m)	Life Stage			Substrate Types (%)								
	Adult	Juvenile	Recruit	HC	SC	DC	RC	RB	SD	T	NIA	OTH
0	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	12	0	0	0	44	44	0	0	0
10	0	0	0	0	0	0	0	52	48	0	0	0
15	0	0	0	0	0	0	0	40	60	0	0	0
20	0	0	0	8	0	0	0	52	40	0	0	0
25	0	0	0	20	0	0	36	24	20	0	0	0
30	0	0	0	0	0	0	0	8	92	0	0	0
35	0	0	0	0	0	0	0	40	52	0	0	8
40	0	0	0	0	0	0	0	40	40	0	0	20
45	0	0	0	4	0	0	8	68	20	0	0	0

Table 4.9. This table outlines the Chalok 8m quadrat results.

4.3 Ta Cha Aggregation Survey Results

Due to a lack of manpower we could not execute the 8m survey in Ta Cha, and therefore we have no data regarding *Drupella* aggregations at 8m. Table 7.10 shows the results of the Ta Cha aggregation survey. No *Drupella* aggregations (and hardly any individuals) were found during 2m and 4m surveys. In our 6m survey however, we found 14 aggregations, with 104 adults, 10 juveniles, and 8 recruits in total. The average distance between aggregations is 2.62m apart.

Sampling depth (m)		Life stage			Avg distance between aggregations (m)	# of Agg
		Adult	Juvenile	Recruit		
2	Total <i>Drupella</i>	0	0	0	0	0
	Avg# per agg	0	0	0		
	Total (%)	0	0	0		
	Min	0	0	0		
	Max	0	0	0		
4	Total <i>Drupella</i>	0	0	0	0	0
	Avg# per agg	0	0	0		
	Total (%)	0	0	0		
	Min	0	0	0		
	Max	0	0	0		
6	Total <i>Drupella</i>	104	10	8	2.62	14
	Avg# per agg	7.42857	0.71429	0.57143		
	Total (%)	85.2	8.2	6.6		
	Min	15	8	8		
	Max	17	0	0		

Table 4.10. Summary table of *Drupella* aggregations in terms of adults, juveniles, and recruits in Ta Cha at 2m, 4m, and 6m.

4.3.1 Ta Cha Aggregation 2m:

No *Drupella* aggregations were found in the Ta Cha 2m survey.

4.3.2 Ta Cha Aggregation 4m:

No *Drupella* aggregations were found in the Ta Cha 2m survey.

4.3.3 Ta Cha Aggregation 6m:

A total of 14 aggregations were found at this depth. A single aggregation was found on a 30cm *Pocillopora* coral, while the other 13 were all aggregated on *Acropora* branching corals. All the adults were on the *Acropora* branching corals; there was one aggregation of 5 juveniles on a 20cm *Acropora* branching coral, and 3 juveniles and 8 recruits on the *Pocillopora* coral. It is probable that no *Drupella* aggregations were found at the 2m and 4m depth because many of them were found here at 6m.

Location on transect (m)	Distance (m)	Life Stage			Genus	GF	%RK	Max D (cm ²)	Approx Area (cm ²)	Area RK (cm ²)
		Adult	Juvenile	Recruit						
46.5		9	0	0	ACR	B	5	30	707	35
45.1	1.4	10	0	0	ACR	B	15	60	2826	424
43.5	1.6	8	0	0	ACR	B	15	50	1963	294
40.8	2.7	15	0	0	ACR	B	15	55	2375	356
40.8	0	11	0	0	ACR	B	40	30	707	283
40.6	0.2	8	0	0	ACR	B	30	60	2826	848
40.6	0	9	0	0	ACR	B	40	30	707	283
39.1	1.5	7	0	0	ACR	B	10	30	707	71
38.6	0.5	7	0	0	ACR	B	30	40	1256	377
34.3	4.3	8	2	0	ACR	B	40	55	2375	950
31.5	2.8	0	5	0	ACR	B	50	20	314	157
29.1	2.4	5	0	0	ACR	B	30	30	707	212
18.3	10.8	7	0	0	ACR	B	20	30	707	141
9.8	8.5	0	3	8	POCIL	C	40	30	707	283

Table 4.11. *Drupella* aggregations at the Ta Cha 6m survey.

4.4 Ta Cha Quadrat Survey Results:

No *Drupella* snails were found at 2m and 4m, but 32 adults and 3 juveniles were found in total at 6m, with a total *Drupella* density of 3.5/m².

Sampling depth (m)		Life stage		
		Adult	Juvenile	Recruit
2	Total	0	0	0
	Avg m ⁻²	0	0	0
	% of total	0	0	0
4	Total	0	0	0
	Avg m ⁻²	0	0	0
	% of total	0	0	0
6	Total	32	3	0
	Avg m ⁻²	3.2	0.3	0
	% of total	91.4	8.6	0

Table 4.12. Summary table of quadrat survey on *Drupella* density, and number of adults, juveniles, and recruits in Ta Cha at 2m, 4m, and 6m.

4.4.1 Ta Cha Quadrat 2m:

No *Drupella* snails were found during the Tacha 2m quadrat survey. There was 0% hard coral cover in some quadrat locations, and the substrate type was determined as largely rubble for the length of the transect line. There were four locations with 40-76% hard coral cover but had no *Drupella*.

Location on transect (m)	Life Stage			Substrate Types (%)								
	Adult	Juvenile	Recruit	HC	SC	DC	RC	RB	SD	T	NIA	OTH
0	0	0	0	76	0	0	8	0	16	0	0	0
5	0	0	0	48	0	0	0	52	0	0	0	0
10	0	0	0	0	0	0	40	60	0	0	0	0
15	0	0	0	8	0	0	0	92	0	0	0	0
20	0	0	0	16	0	0	0	84	0	0	0	0
25	0	0	0	0	0	0	16	32	52	0	0	0
30	0	0	0	0	0	0	8	24	68	0	0	0
35	0	0	0	40	0	0	16	44	0	0	0	0
40	0	0	0	52	0	0	28	0	20	0	0	0
45	0	0	0	0	0	0	0	0	0	0	100	0

Table 4.13. This table outlines the Ta Cha 2m quadrat results.

4.4.2 Ta Cha Quadrat 4m:

No *Drupella* snails were found during the Ta Cha 4m quadrat survey. There were hardly any hard corals to be found at 4m and was mostly rubble or sand.

Location on transect (m)	Life Stage			HC	SC	DC	Substrate Types (%)			T	NIA	OTH
	Adult	Juvenile	Recruit				RC	RB	SD			
0	0	0	0	24	0	0	0	76	0	0	0	0
5	0	0	0	0	0	12	0	88	0	0	0	0
10	0	0	0	8	0	0	0	92	0	0	0	0
15	0	0	0	28	0	0	0	72	0	0	0	0
20	0	0	0	0	0	0	0	0	100	0	0	0
25	0	0	0	0	0	0	0	0	100	0	0	0
30	0	0	0	12	0	0	0	0	88	0	0	0
35	0	0	0	0	0	0	0	0	100	0	0	0
40	0	0	0	0	0	0	0	0	100	0	0	0
45	0	0	0	0	0	0	0	56	44	0	0	0

Table 4.14. This table outlines the Ta Cha 4m quadrat results.

4.4.3 Ta Cha Quadrat 6m:

A total of 32 adults and 3 juveniles were found during the 6m quadrat survey. This is the only depth that we found *Drupella* snails at Ta Cha. The most was 18 adult *Drupella* in one quadrat, followed by 11 adults and a juvenile at locations 40m and 45m respectively. Hard coral cover is generally high, but the majority of the substrate was still rubble.

Location on transect (m)	Life Stage			HC	SC	DC	Substrate Types (%)			T	NIA	OTH
	Adult	Juvenile	Recruit				RC	RB	SD			
0	0	0	0	0	0	0	16	80	4	0	0	0
5	0	0	0	4	0	0	0	88	4	0	0	1
10	0	0	0	4	0	0	4	92	0	0	0	0
15	1	0	0	68	0	0	4	28	0	0	0	0
20	0	0	0	8	0	0	0	92	0	0	0	0
25	0	0	0	56	0	0	0	44	0	0	0	0
30	1	0	0	40	0	0	0	60	0	0	0	0
35	1	2	0	40	0	0	0	60	0	0	0	0
40	18	0	0	76	0	0	0	24	0	0	0	0
45	11	1	0	80	0	0	0	20	0	0	0	0

Table 4.15. This table outlines the 6m quadrat results. At location 5m, one other substrate square was a giant clam.



Figure 4.2. *Drupella* snails feeding on an *Acropora* branching coral. Most of them have purple crustose coralline algae on their shells. The white patches are consumed, and have no coral tissue left.

CHAPTER V

DISCUSSION

5.1 Whether *Drupella* snails are still aggregating on *Fungiid* corals

The Chalok aggregation survey at 4m showed that *Drupella* snails are still aggregating on *Fungiid* corals. Eight aggregations of *Drupella* were found on 8 mushroom corals during the survey. *Drupella* snails on Koh Tao were rarely observed to prey on *Fungiid* corals prior to the 2010 bleaching event (Hoeksema and Moka, 1989; Hoeksema and Koh, 2009; Hoeksema et al. 2013), and the continued presence of *Drupella* on mushroom corals can be due to a variety of reasons. It could be that preferred prey species (*Acropora* or *Pocillopora*) are unavailable and dense mushroom coral gardens satisfy the two needs of safety and a ready food supply, although the areas surveyed were not devoid of preferred prey species of *Drupella*, and the rest of the aggregations found on both sites were mostly on *Acropora*, with a single aggregation found on *Pocillopora* in Ta Cha. Another reason could be that *Drupella* snails, after starting to really prey on mushroom corals after the bleaching, find mushroom corals to be quite appetizing and therefore have adopted a tendency to also look for mushroom corals when feeding in addition to their usually preferred prey species. This could potentially be a gradually developing threat to coral reefs if *Drupella* can indeed pick up a taste for a new coral prey and subsequently add a new prey selection into their menu choice, and there could be extensive damages especially if *Drupella* were to decide prey on a slow-growing coral species such as *Porites*. *Porites astreoides*, for example, can grow only 3.00 – 4.75mm per year (Sterrer, 1992), and if preyed upon by *Drupella* snails they will be quickly wiped out. On the other hand, fast-growing corals like the usual preferred prey *Acropora* can grow quickly and therefore *Drupella* aggregations on *Acropora* will cause fewer damages because of the coral's fast growth rates. *Acropora cerviconis*, *A. prolifera*, and *A. palmata* can grow up to 71, 59-82, and 47-99mm per year respectively (Gladfelter et al. 1978). The

growth rates of the three *Acropora spp.* are at least 10 times faster than that of *P. astreoides*, and would be more resilient against predation from *Drupella*.

5.2 The abundance of *Drupella* aggregations

Drupella probably aggregate for a purpose, although more studies need to be carried out on what exactly happens when they do. *Drupella* aggregations have been seen to disperse (Moyer et al. 1982; Boucher, 1986), which can possibly suggest that there was a purpose for their aggregation before the dispersal. Fellegara (1996) observed large quantities of eggs being laid in a huge aggregation of approximately 3,000 *Drupella rugosa* at Heron Island, and Cumming (2009) suggests that if *Drupella* aggregations are indeed reproductively-themed, then large aggregations of recruits should also be found in future surveys.

In Chalok, there were 3, 9, 1, and 0 aggregations at 2m, 4m, 6m, and 8m respectively. In Ta Cha, there were 0, 0, and 15 aggregations at 2m, 4m, and 6m respectively. In Chalok, 4m is the area with the largest *Drupella* aggregation across the depths surveyed, while in Ta Cha, 15 aggregations (and several random clusters of <5 individuals not counted as aggregations) were found at 6m. It is still unknown whether large aggregations are related to outbreaks or not, but it is plausible that large aggregations would aide in the formation of outbreaks if they contribute to the feeding or increase the population of *Drupella* (Cumming, 2009). The aggregation data collected suggests that *Drupella* populations on Koh Tao may be localised and form large aggregations in one area or depth, and are nowhere to be found, or very few and far between, in other areas of the reef.

5.3 The preferred substrate types

In all but one quadrat result, *Drupella* snails were found on quadrats with at least 40% of the substrate types being hard coral. This is in line with established knowledge as *Drupella* mostly inhabit around or under the corals. The only location with a single *Drupella* snail on it without having any hard corals as substrate is at location 35m of Chalok 6m quadrat survey. The substrate type was entirely rubble, indicating that it could be on the move. No *Drupella* snails were found on quadrats that are mostly sand or rubble. *Drupella* snails that were found in quadrats dominated with sand and/or rubble were actually found on hard corals that complete the rest of the substrate makeup of the quadrat. A single quadrat survey had 100% substrate type being nutrient indicator algae, and found no *Drupella* snails in the quadrat.

The different growth forms of corals affected by *Drupella* aggregations are as follows. In Chalok, 4 aggregations were found on branching *Acropora* corals, 1 aggregation on a tabulate (table) *Acropora* coral, and 8 aggregations on *Fungia* corals. In Ta Cha, 13 aggregations were found on branching *Acropora* corals, and a single aggregation on a corymbose *Pocillopora*. All four growth forms can provide a complex habitat and living environment for *Drupella*, which may explain why the aggregations were found in these growth forms. *Acropora* and *Pocillopora* are the preferred prey species (Turner, 1994; Hoeksema et al. 2013), but with the added observation of *Drupella* on mushroom corals it would be interesting to see in future surveys whether mushroom corals would continue being preyed upon.

5.4 The severity of the infestation

According to Cumming (2009), a *Drupella* outbreak consists of ‘any population of elevated density that causes extensive mortality of corals and persists for months and years over large areas of reef’. In addition, Cumming also identified a range of non-outbreak instances at $0-3/m^2$, with the safe end being $0-2/m^2$. Anything >2 deserves mentioning as it is on the high side of what is considered non-outbreaks.

The average number of *Drupella* individuals per m² of Chalok across 4 depths is 1.175/m². The average number of *Drupella* per m² of Ta Cha across 3 depths is 1.167/m². According to the data, it does not appear that either Chalok or Ta Cha is afflicted with a *Drupella* outbreak. If each depth is considered separately, then Chalok 2m and Ta Cha 6m quadrats show a density of 2.3 and 3.5/m² respectively. If judged in isolation Chalok 2m would be considered to be in a threatened status, while Ta Cha 6m would be considered an outbreak. Known *Drupella* outbreaks are related to two species: *Drupella cornus* and *Drupella fragum*. *Drupella rugosa* also aggregate in large aggregations, but tend to do so in ‘normal, low-density’ populations and are not considered as outbreaks of *Drupella* (Cumming, 2009). We have no data regarding the species of the surveyed *Drupella* snails, which would aide in helping us compare the aggregation trends of the different species of *Drupella* snails on Koh Tao with those recorded elsewhere.

It has to be noted that even with 7 surveys across 2 sites at different depths, the sampling size would still be considered small, just because of the sheer size of the sites being surveyed. Therefore any trends or correlations that we can extract from the data can be indicative, but not entirely conclusive of the situation. After the volunteers completed their surveys and were heading back we noticed a vast garden of *Acropora* branching corals infested with at least 10 *Drupella* on every colony as far as the eye can see. The situation looked severe and would be considered an ‘outbreak’. Had the random transect line been laid there the data would have been different, and so would the interpretations of the outcome. *Drupella* surveys call for large sampling sizes across entire sections of the reef, because a portion of the reef is not a representation of the whole reef, and we simply cannot know what is going on unless we survey more areas.

CHAPTER VI

CONCLUSION

Coral reefs are threatened by a number of anthropogenic and natural threats that can fundamentally ruin the reef ecosystems. The threats must be understood, and management policies in response to those threats must be adequate. Over-predation of corals by corallivores such as *Drupella* snails can threaten the reef structure because they directly consume the building blocks of the reef, and therefore reduce the overall reef resilience. This study suggests that *Drupella* populations in Chalok Ban Kao and Ta Cha, Koh Tao are not considered an ‘outbreak’, although the continued observation of *Drupella* preying on *Fungiid* corals in addition to the preferred branching corals suggest that *Drupella* may be able to take up new dietary preferences, and continued monitoring in larger scales are required in order to grasp a clearer picture of the ecological dynamics of this corallivore.

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Appendix:

Appendix A: Coral Growth Forms



Branching coral
(image: www.fau.edu)



Tabulate coral
(image: www.underwaterescapades.com)



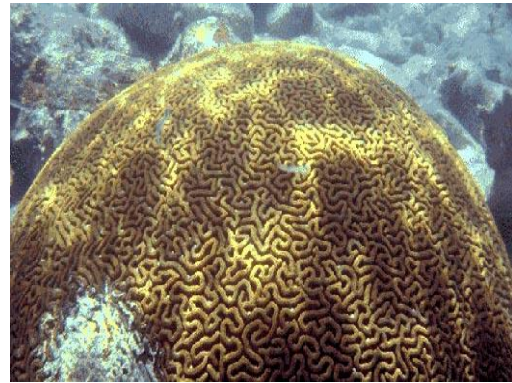
Digitate coral
(image: www.newheavendiveschool.com)



Encrusting coral
(image: www.reefconservation.mu)



Corymbose coral
(image: www.newheavendiveschool.com)



Massive coral
(image: www.ucmp.berkeley.edu)



Submassive coral
(image: www.gaiaguide.info)



Foliose coral
(image: www.omgheart.com)



Mushroom coral
(image: www.deepseaimages.com)

Appendix B: Substrate Types



Sand
(image: www.zesea.com)



Rubble
(image: www.shiftingbaselines.org)



Hard coral
(image: www.vivaboo.com)



Soft coral
(image: www.junglewalk.com)



Trash
(image: news.nationalgeographic.com)



Nutrient indicator algae
(image: www.sail-world.com)



Dead coral
(image: www.oceansrock.org)



Others
(image: animals.nationalgeographic.com)