The dietary preferences, depth range and size of the Crown of Thorns Starfish (*Acanthaster* spp.) on the coral reefs of Koh Tao, Thailand

By

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Cover image:(NHRCP, 2015)

Preface

This paper is written in light of my 3rd year project based internship of Integrated Coastal Zone management major marine biology at the Van Hall Larenstein University of applied science.
My internship took place at the New Heaven Reef Conservation Program on the island of Koh Tao, Thailand.
During my internship I performed a study on the corallivorous Crown of Thorns starfish, which is threatening the coral reefs of Koh Tao due to high density 'outbreaks'. Understanding the biology of this threat is vital for developing effective conservation strategies to protect the vulnerable reefs on which the islands environment, community and economy rely.

Very special thanks to Chad Scott, program director of the New Heaven Reef Conservation program, for supervising and helping me make this possible.
Thanks to Devrim Zahir.
Thanks to the New Heaven Reef Conservation team; Ploy, Pau, Rahul and Spencer.
Thanks to my supervisor at Van Hall Larenstein;
Peter Hofman.

Abstract

Acanthaster is a specialized coral-feeder and feeds nearly solely, 90-95%, on sleractinia (reef building corals), preferably *Acroporidae* and *Pocilloporidae* families. The *Acanthaster* is common in small numbers on reefs; in these abundances the starfish do not threaten the overall reef health. However when densities increase, large-scale coral predation can cause wide spread coral mortality and destroy the living habitat provided to reef fishes and invertebrates.

These large increases of *Acanthaster* densities are referred to as 'outbreaks'. This increase is likely caused by anthropogenic influences such as; overfishing of predators and nutrient runoff causing phytoplankton blooms, which provide abundant food sources for *Acanthaster* larvae. The threat of the *Acanthaster* outbreaks may have significant implications for the island of Koh Tao compounding other environmental threats.

Acanthaster poses a great biological threat to the coral reefs on which the islands environment and economy rely. Understanding the biology of this population is important in creating effective management techniques for controlling *Acanthaster* population outbreaks on Koh Tao. In this study the dietary preferences, size and depth of *Acanthaster* on Koh Tao were researched.

On Koh Tao the preferred prey genera for Acanthaster is *Fungia,* which was found to be the prey of 17% of *Acanthaster* found during this study. After *Fungia, Pavona* was found as most preferred with 15%, *Porites* 14%, *Acropora & Favia* 9% and *Favites* 8%.

Acanthaster individuals located during the study ranged in size from 12 cm in diameter to 52 cm in diameter. The average size was found to be 35 cm in diameter. The life stage of individuals over 35 cm in diameter is categorized as senile adults, aged 5 years and over.

The majority of *Acanthaster* was found in the size classes 29-36 cm (41%) and 37-44 cm (33%). This means the majority of *Acanthaster* found can be classed in either the life stage; coral feeding adults or senile adults.

The average depth of *Acanthaster* on Koh Tao was found at 9.8 meters deep. The majority of *Acanthaster* was found in the depth classes 6-9 meters (32%) and 9-12 meters (29%) deep. The minimum depth *Acanthaster* was found on was 2.1 meters and the maximum depth was 18.5 meters deep.

This study has produced several interesting results, which have revealed new insights and understanding of the *Acanthaster* population on Koh Tao, Thailand. The dietary preferences of *Acanthaster* on Koh Tao differ significantly from preferences found worldwide. With this insight, areas vulnerable to predatory damage during outbreaks can be pin pointed. It has also opened new questions on what factors specifically affect dietary preferences on Koh Tao.

Together, the results of the dietary preferences, depth and size distribution can help towards the development of better conservation and population control techniques. These techniques are vital in limiting damage caused by human induced *Acanthaster* outbreaks.

Content

Scope, Koh Tao
The island of Koh Tao, Thailand, is located in the western Gulf of Thailand. The land surface area measures approximately 21km2. (Romeo, 2014)

N10’03.985” E099’50.488

Koh Tao

(Google Earth, 2015)

1. Introduction

Acanthaster

The echinoderm asteroid Crown of Thorns starfish (*Acanthaster spp),* referred to, as *Acanthaster* throughout this study, is common throughout the Indo-pacific. (Vercelloni et al 2012) The body of *Acanthaster* consist of a large central disk with 7 to 23 arms covered on the aboral side of the body with venomous defensive spines that may grow up to 5cm in length. (Madl, 2002)

Acanthaster is a specialized coral-feeder and feeds nearly solely, 90-95%, on sleractinia (reef building corals) and preferably the *Acroporidae* and *Pocilloporidae* families. (Bos et al. 2012)

Acanthaster outbreaks.

Acanthaster is common in small numbers on reefs; in these abundances the starfish do not threaten the reef (Bos et al 2012). The functional role of the organism in the ecosystem is to create space where other organisms can settle within the reef structures, which is beneficial to biodiversity. *Acanthaster* preys on faster growing corals giving way for succession of slower growing coral genera. (Porter, 1972) However when densities increase, large-scale coral predation can cause wide spread coral mortality and therefore habitat destruction.

These large increases of *Acanthaster* densities are referred to as 'outbreaks'. (Bos et al 2012)

Although outbreak densities are defined by figures such as >1500p/km^2 on the Great Barrier Reef, the definition of an outbreak is relative to the location and the resource availability on the location. Outbreaks can be divided in three stages: 'build up', 'outbreak' and 'epidemic'. A 'build up' is known as an increase of *Acanthaster* at which densities will not necessarily exceed local resource availability, when densities do exceed this point on a single reef we may speak of an 'outbreak'. 'Epidemics' occur when reef connectivity allows 'outbreaks' to spread amongst other reefs (Hock et al. 2014)

The reason behind *Acanthaster* outbreaks has been studied well, however there is great discussion between scientists about what the root causes of outbreaks are. Research has pointed out that increased population densities are a natural phenomenon that has been occurring relatively frequently for at least 2000 years, but the frequency and severity has been increasing over the past century (Uthicke et al. 2015, Moran et al. 1985).

This increase is likely caused by anthropogenic influences such as; overfishing of predators and nutrient runoff causing phytoplankton blooms, which provide abundant food sources for *Acanthaster* larvae.

Brodie et al (2004) has shown that a doubling of the amount of phytoplankton results in a 10-fold survival rate for *Acanthaster* larvae (Brodie et al. 2004).

The impact of *Acanthaster* outbreaks can be catastrophic for reefs. A single adult starfish can consume approximately 10 m^2 of coral per year (Miller et al. 2015) resulting in outbreaks that have lead to 90% decline in live coral coverage (Grossman, 2014).

The Great Barrier Reef (GBR) has been heavily impacted by *Acanthaster* outbreaks since the early 1960's (Miller et al. 2015). In 2012 the coral coverage on the GBR was half of that when long-term surveys began in 1985. The greater proportion of this decline (42%) (Roche et al. 2015) has been allocated to *Acanthaster* predation, outweighing the effects of threats such as coral disease, bleaching and cyclone damage altogether (Miller et al. 2015).

Fecundity
A major element of *Acanthaster* outbreaks lies in the fecundity of the starfish. *Acanthaster* is separate in sexes and generally occurs in equal male female sex ratios. Males and females must be in close proximity and spawn at the same time to effectively reproduce. Spawning occurs in water temperatures above 27 degrees centigrade. Spawning is commonly observed in the late afternoon with exceptions to mornings and at night. There are contradicting observations on spawning frequency and in which months spawning occurs. (Pratchett et al 2014) In the northern hemisphere on reefs in Japan and the Red Sea observations of spawning generally occur in the summer months (June to August) late afternoon or evenings. In the southern hemisphere on reefs in Australia spawning observations have occurred between December and February, also in the late afternoon or evenings. (Pratchett et al 2014)
Spawning on Koh Tao was observed in mid September 2014, this was the first record of natural spawning in the proximity of the South China Sea (Scott et al. 2014).
Acanthaster has enormous reproductive potential. Female starfish can produce up to 65 million eggs in a season. The amount of eggs released during spawning is related to the starfish size. Individuals measuring less than 30 cm in diameter produce 0.5-2.5 million eggs in a year whilst starfish exceeding 40 cm can produce 46-65 million eggs per year (Pratchett et al. 2014).
With increased larval and juvenile survival due to the anthropogenic influences named, *Acanthaster* has huge potential of recruitment leading to outbreaks and even epidemics (Pratchett et al. 2014).

The outbreaks of *Acanthaster* pose the most significant biological threat in the west-Indo pacific. (Pratchett, 2001) Besides the *Acanthaster* threat, Koh Tao's reefs face a similar biological pressure caused by outbreaks of the corallivorous *Drupella* snails. (Hoeksema et al. 2012)

Environmental and socio-economic threat
The threat of *Acanthaster* outbreaks may have significant implications for the island of Koh Tao reaching further then simply an environmental threat. The following section briefly describes the environmental and socio-economic aspects to this problem.
Coral reefs are considered one of the most threatened ecosystems in the world due to direct and indirect anthropogenic influences.
Coral reef structures that take thousands of years to build provide complex refuges in which organisms can hide from predators. When the corals die, the abundance of reef fish will decline rapidly as larvae and juveniles depend on the reef to settle. (Grossman, 2014) The destruction of a reef can have cascading effects throughout the reef ecosystem, leading to ecological shifts such as benthic algae taking over and resulting in an overall decline in biodiversity (Vercelloni et al. 2012). Besides the ecological importance of the coral reefs, certain economies rely on the tourism generated by these ecosystems.
The island of Koh Tao is a prime example of an economy fuelled by the presence of its coral reefs.

Tourism created by this natural resource supports over 1800 Thai residents on the island, 300-400 expat SCUBA professionals (Wongthong & Harvey, 2014) and 5000 temporary migrant workers mostly from the low-income country of Myanmar

(Churugsa et al. 2010). 94 % is directly involved in the SCUBA diving and snorkelling industry (Wongthong & Harvey, 2014). This industry includes accommodation, restaurants, dive operators and other tourist facilities. These figures suggest a great dependence on healthy reef systems to maintain tourism and thus sustain the local island economy and its livelihoods.

Cumulative threat

Besides the threat of *Acanthaster* outbreaks, the coral reefs of Koh Tao also face several anthropogenic threats. In 2010 Koh Tao witnessed a mass-bleaching event due to high water temperatures associated with global warming. 2010 saw 95% of corals bleach resulting in 78% mortality in the Chalok Baan Kao bay south of the island. (Hoeksema et al. 2012) Global warming is an indirect threat to reefs worldwide; tourism however poses a direct threat to the island of Koh Tao:

The number of tourists between 1993 and 2002 increased with an amount of 346% a large share of this is due to foreign tourism, which saw an increase of nearly 500% in the this period. (Churugsa et al. 2010) 2013 saw record figures of 1000 tourist on some days. This accounts for the 130 to 150 thousand annual visits. (Szuster & Dietrich, 2014) By 2024 annual visits are expected to reach 250.000. (Szuster & Dietrich, 2014) As the island has an area of approximately 21km2 (Romeo, 2014) these ever rising tourism numbers accompanied by the land development of facilities catering to the demand are affecting the natural resources including the coral reefs on which the economy relies.

Anthropogenic nutrient input caused by deforestation, sewage and other terrestrial runoff is posing a threat to the reefs. High nutrient levels have been linked to algae blooms smothering the reef and encouragement of coral mortality. (Romeo, 2014)

The anthropogenic threats discussed are relevant to this study as it shows *Acanthaster* outbreak problem is part of a cumulative threat faced by the coral reefs of Koh Tao and the local economy dependent on this resource. The cumulative pressures may enhance the severity of threats. For example; a reef faced with a bleaching event on top of an *Acanthaster* outbreak will face greater mortality.

Study

Research into the local *Acanthaster* population of Koh Tao plays an important role in the effective management of population outbreaks, which may threaten reef ecosystems and add to the cumulative threat. In this study the depth distribution, size and dietary preferences of *Acanthaster* found on reefs around the island of Koh Tao has been researched and analysed.

Feeding behaviour

As the threat to the reefs posed by *Acanthaster* is through predation, the feeding behaviour of the starfish is an important factor to understand. The *Acanthaster* population of Koh Tao has not been studied in this way to date. Research in feeding behaviour is fundamental in understanding the influence on reefs around Koh Tao.

Acanthaster has a flexible body, making it possible for the starfish to feed on different shapes and sizes of coral. *Acanthaster uses* a wax esterase, which breaks down the energy reserves of the prey coral (De'ath & Moran, 1998).

The *Acanthaster* has feeding preferences that are found to differ between populations worldwide. The starfish tends to feed more on certain types of corals than others depending on location. On reefs around Hawaii 80-90% of predation was on *Montipora* coral. In Panama, this same preferred prey comprises only 7% of the coral coverage and

the most common species, *Pocillopora,* was avoided. *Acanthaster* in the Red Sea contrarily prefers the *Pocillopora* genus. (De'ath & Moran, 1998)
In a 1990 field study by Keesing on the Great Barrier Reef *Acanthaster* preyed primarily on *Acropora, Seriatopora* and *Stylophora*. Non-preferred species were found to be *Porites, Favites, Goniastrea, Cyphastrea.* In the same study, laboratory experiments showed *Acanthaster* to highly prefer the *Acropora* corals and only consume *Porites* when other genera were depleted. (Keesing, 1990)
De'ath & Moran (1998) found that after *Acropora, Fungia* was the most preferred prey species of coral on field studies on the Great Barrier Reef. This was noted as a surprising find as previous studies found *Fungia* to be a least favoured genus. (De'ath & Moran, 1998)

Non-preferred prey is subject to increasing levels of predation in areas where preferred prey is depleted.
Prey preference is found to be affected by several attributes; these are the surface area complexity, biomass, nutritional value and abundance. The efficiency of certain prey types is the most important factor to prey selection. (Keesing, 1990)
Another theory on feeding preferences, which fits prey efficiency, involves defensive attacks by coral symbionts on preying *Acanthaster.* This theory was tested by Pratchett (2001) using aquarium feeding trials. Pratchett found that symbionts living on coral (e.g. *Trapezia spp.* crabs) affect the preference of *Acanthaster* in prey species. This phenomenon may explain why *Acant*haster in Panama avoided *Pocillopora* corals even though it was most abundant and favoured in other areas (De'ath & Moran, 1998).
However, in the presence of the symbionts, the corals are not immune to attack and are readily preyed upon when coral prey is limited. (Pratchett, 2001)
Prey preferences may also be related to "ingestive conditioning" where the *Acanthaster* is conditioned to a usually non-preferred prey. When this conditioning is observed the starfish will accept this non-preferred prey over available 'preferred' prey such as *Acropora.*
(Keesing, 1990)

Size
The size of individuals of the *Acanthaster* population on Koh Tao is an important factor to understand outbreaks as the number of eggs released during spawning is related to the size of the starfish (Pratchett et al. 2014). On Lizard Island, in the northern Great Barrier Reef, individuals were found to range between 11-62 cm. Keesing (1990) found individuals on wheeler reef (Great Barrier Reef) to have markedly different sizes between January and June. The peak sizes in January were found to be 17cm and 47cm with an average of 37.4cm. These figures changed to peaks of 22cm and 42cm with an average of 28.6cm in June. Laboratory rearing of *Acanthaster* found a growth from 17cm to 24cm in a three-month period. Keesing (1990)
Size of *Acanthaster* is categorized in different life stages. Coral feeding juveniles between the ages of 0,5-2 years measure 1-20 cm. Coral feeding adults between the ages of 2-5 years measure 20-35 cm. Senile adults of over 35 cm are aged 5+ years. (Pratchett et al. 2014)
Individuals smaller than 30 cm have a cryptic nature, often coming out to feed nocturnally. For small juveniles this is explained by reducing daytime predation. It is however surprising larger individuals measuring 15+ cm still behave in this cryptic manner as they have substantial defensive spines. (De'ath & Moran, 1998)

Depth

The depth at which *Acanthaster* is found is an important factor in predicting outbreaks and focussing population control efforts.

Research conducted on a reef in the Philippines found 60% of *Acanthaster* to be distributed at a depth of 4-5m, where maximum depth of *Acanthaster* was observed at 18m, (Bos et al 2012)

Size distribution of *Acanthaster* has been found to be depth dependant. In the central Great Barrier Reef *Acanthaster* size has been shown to directly increase with depth. (Keesing, 1990)

Goal

Acanthaster poses a great biological threat to the coral reefs on which the islands environment and community rely. Understanding the biology of this population is important in creating effective management techniques for controlling *Acanthaster* population outbreaks on Koh Tao. In this study the dietary preferences, size and depth of *Acanthaster* on Koh Tao are researched.

Fig. 1.1 (NHRCP, 2015)

Fig. 1.2(NHRCP,2015)

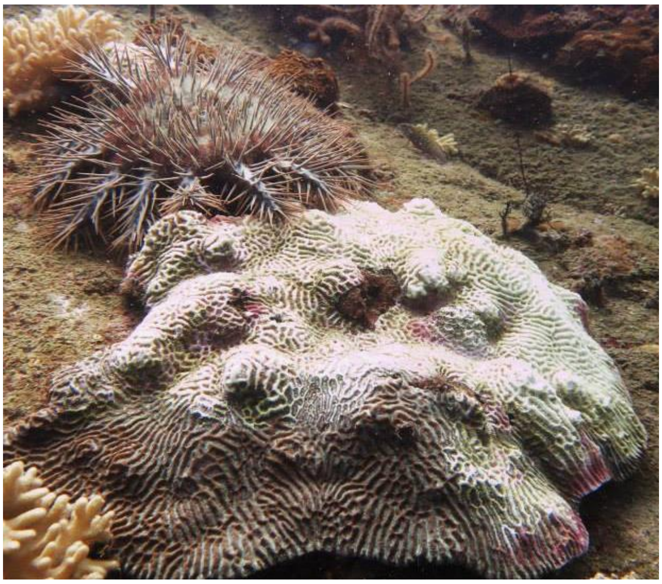


Fig. 1.3(NHRCP, 2015)

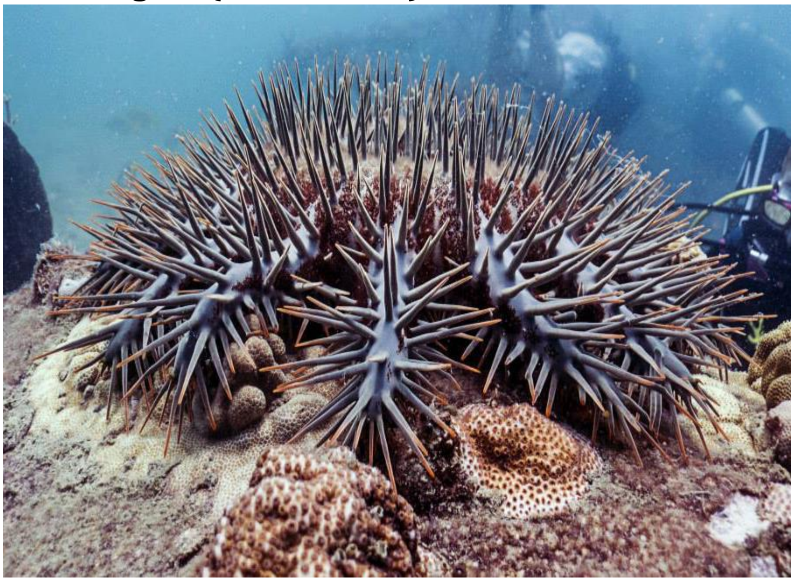


Fig 1.4(NHRCP, 2015)

Fig 1.1 shows the cryptic nature of *Acanthaster hiding* under a coral colony.
Fig 1.2 shows *Acanthaster* feeding on *Acropora* corals.
Fig 1.3 shows feeding scars (white exposed skeleton) left on a coral colony after predation by *Acanthaster.*
Fig 1.4 shows *Acanthaster* feeding on *Porites* coral.

All photographs taken by NHRCP on Koh Tao, Thailand.

2. Research questions

1. What is the diet of *Acanthaster* on the reefs of Koh Tao comprised of?

2. What is the effect on *Acanthaster* abundance in relation to preferred prey coral coverage on reefs of Koh Tao?

3. How is feeding behaviour, described in 'feeding' and 'not-feeding', represented on the reefs of Koh Tao.

4. What size range is *Acanthaster* found in on the reefs of Koh Tao?

5. What size class of *Acanthaster* is most abundant on the reefs of Koh Tao?

6. What is the relation between depth and size of *Acanthaster* on the reefs of Koh Tao?

7. What is the depth range of *Acanthaster* on the reefs of Koh Tao?

3. Hypothesis

Feeding

1. The diet of *Acanthaster* is comprised mostly of corals in the genus *Acropora* and *Pocillopora* as preferred prey.

2. *Acanthaster* is more abundant in areas where preferred prey has a high percentage of coral coverage.

3. *Acanthaster* is commonly found feeding, because non-feeding individuals will hide due to the cryptic nature of *Acanthaster*.

Size

4. Size of *Acanthaster* will range between 11 and 62 centimetres in diameter, as juveniles are cryptic by day, SCUBA encounters of individuals < 20 cm will be uncommon.

5. Size classes will show predominantly adult *Acanthaster,* as juveniles are more cryptic in nature.

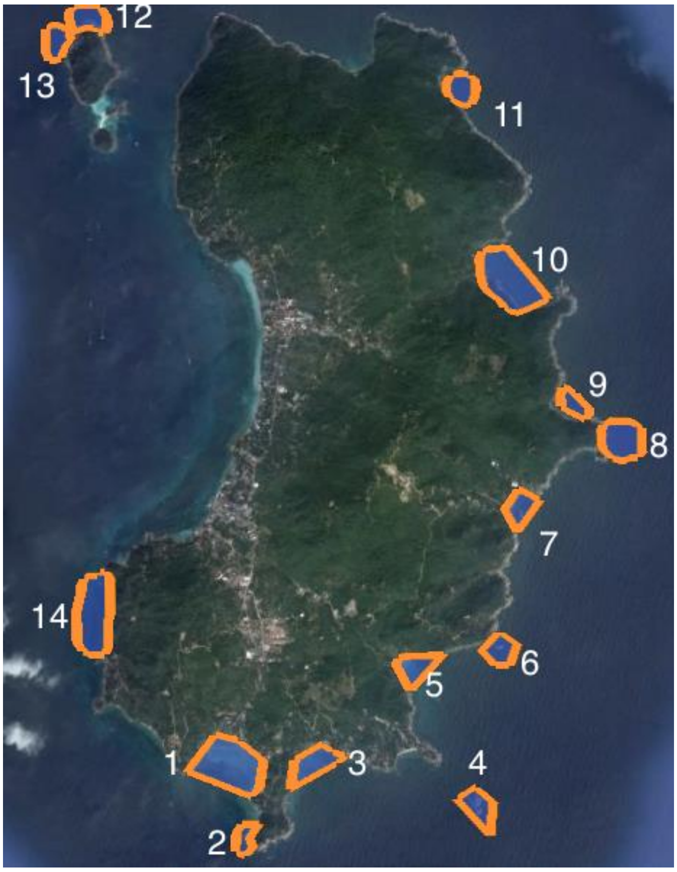
6. Size of *Acanthaster* is directly correlated to depth.

Depth

7. *Acanthaster* is found at a depth ranging from 4-18 meters.

4. Material and methods.

Survey area
Data was collected on 14 sites around the island of Koh Tao between January 2014 and March 2015.



Site
1. Chalok Ban Kao
2. Budha Rock
3. Taa Chaa
4. Shark Island
5. Aow Leuk
6. King Kong Rock
7. Tanote
8. Lam Tien
9. Aow Mao
10. Hin Wong
11. Lighthouse
12. Green Rock
13. Red Rock
14. Sai Nuan

Table. 4.1 name survey area

←Fig. 4.1 survey areas (Google Earth, 2015)

Data collection

Size of *Acanthaster* was measured using the maximum diameter of the starfish. A measuring tape in centimetres was used to measure the distances between the furthest tips of the arm on the aboral side of the body between the spines.

- Depth was measured using a diving computer levelled on the depth of the central disk of the starfish.

- Behaviour was assessed as feeding and non-feeding. If an individual was spotted on a coral it was marked as feeding, and the coral genera was noted. On other substrates such as rock and sediment the individual was marked as non-feeding.

- Prey coral genus was noted as the genus of coral the starfish was found on during the survey.

- Abundance is measured in average number of collected individuals per site.

"Collection" survey

"Collection data" was gathered during *Acanthaster* collections performed by the New Heaven Reef Conservation Program. The collections are a means of managing the population outbreaks of *Acanthaster* on Koh Tao. Using a free-swimming survey (SCUBA), data on *Acanthaster* was taken before collection.
Collection data was taken between January 2014 and April 2015. Collections took place in the afternoon.

Observation survey

Observation data was collected in the same way as the collection data. During free-swimming (SCUBA) surveys data was collected on "observed" *Acanthaster* starfish. During observation surveys no starfish were collected.

Observation data was collected between September 2014 and Febuary 2015 during the afternoon.

The collection data and observations data were used together in data analysis with the exception of abundance analysis where only the collection data was used.

Existing comparative data: Koh Tao Ecological Monitoring Program (EMP)

The EMP transect is a research method used on Koh Tao to monitor coral reef health and biodiversity over time on fixed transect lines at 13 survey sites. Every site consists of two transect lines, a 'deep line' (6-10m depth) and a 'shallow line' (2-5m depth). Transect lines are made up of four 5x20m sections along a 100m transect line with 5m intervals between each section.
Three types of survey are conducted along the EMP, these are all performed using the roving diver technique:

1. *Invertebrate survey*
2. *Fish survey*
3. *Substrate survey*

(Scott, 2014)

Data from the substrate surveys was used to calculate percentage of coral coverage per genera. This data was used to compare *Acanthaster* abundance, measured in average observations per site, with coverage of prey coral genera.
As the data on each survey site is recorded along a deep and a shallow transect line the coral coverage figures for both lines were compared separately.

Materials

Full SCUBA equipment:

- BCD
- Fins
- Regulator
- Mask
- Tank
- Weights
- Surface marker buoy + reel (for safe ascent)

Survey equipment:

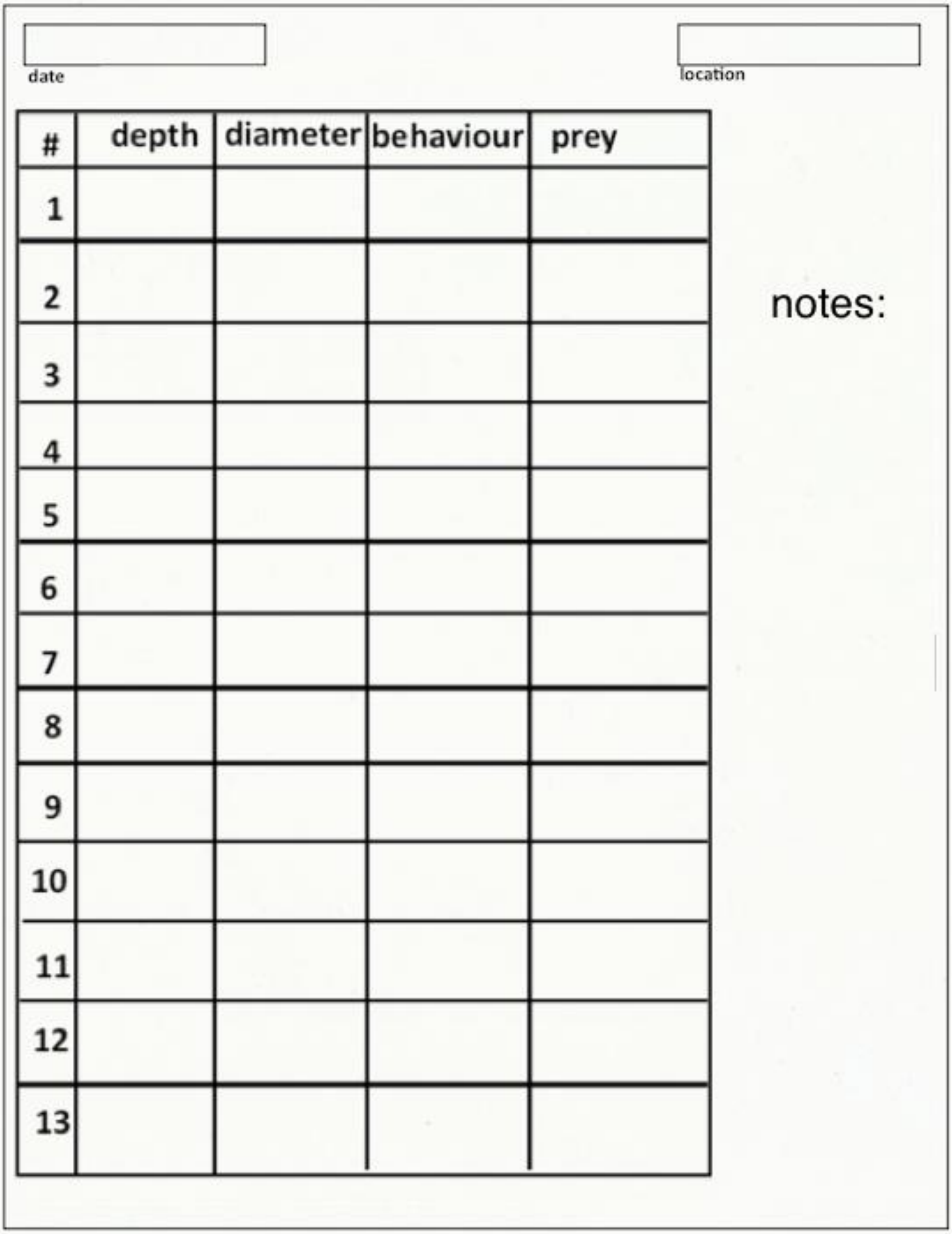
- Qualified SCUBA divers
- Slate with survey sheet (see appendix)
- Dive computer or depth gauge.
- Compass
- Measuring tape (cm)

Transport:

- Boat equipped for SCUBA diving activities

Data analysis.

Data was recorded in Microsoft Excel. Excel was used to analyse feeding preferences, by using pie charts and bar charts. Correlations between food availability and *Acanthaster* abundance were also produced using Excel scatterplots.
IBM SPSS was used to analyse the depth and size of crown of thorns using the 'chart builder' function. Histograms and scatterplots were used for depth and size.



date

location

#	depth	diameter	behaviour	prey
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				
11				
12				
13				

notes:

Fig. 4.2 Data collection slate

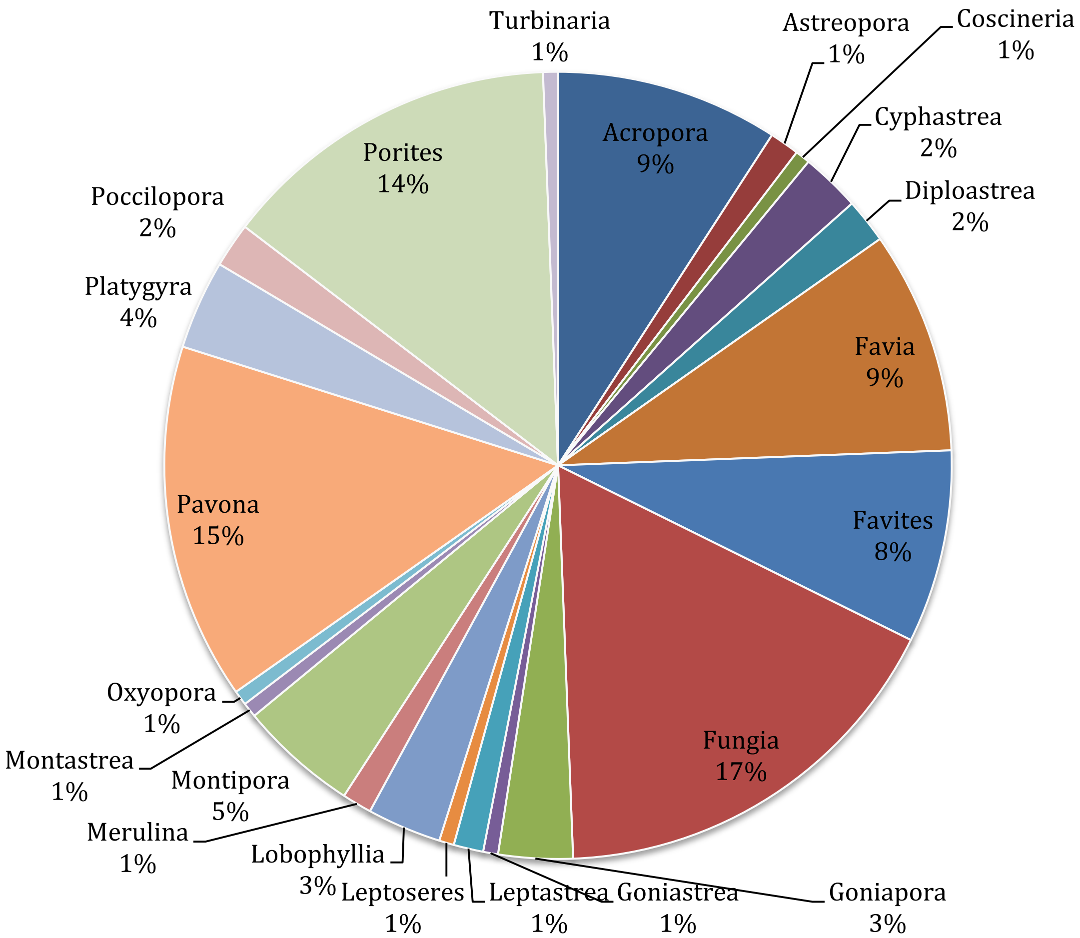
5. Results

Diet of Acanthaster *on Koh Tao*

The chart below (Fig. 5.1) shows the results of the dietary preferences of *Acanthaster* on Koh Tao. *Fungia* is the most preferred genus of coral found during this study. 17% of the surveyed *Acanthaster* (n=248) was found to feed on *Fungia* coral. 15% was found to feed on *Pavona. Porites* represents 14% of the prey coral genera *Acanthaster* was found to feed on. *Acropora* and *Favia* predation was found at 9% of surveyed *Acanthaster. Favites* was found at 8%.

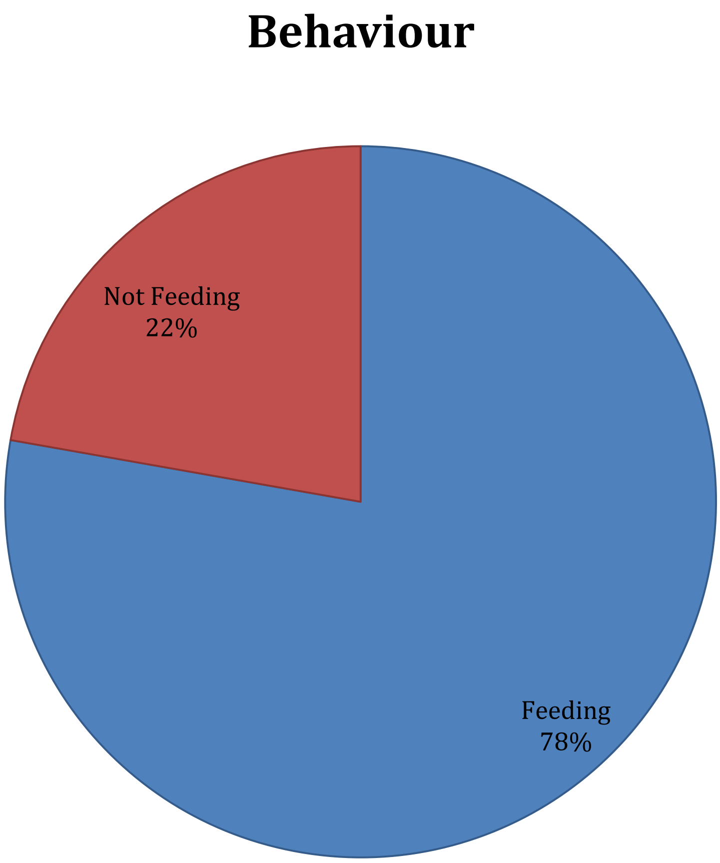
Least found prey coral genera are:
Turbinaria (1%), *Astreopora* (1%), *Coscineria* (1%), *Cyphastrea* (2%), *Diploastrea* (2%), *Goniapora* (3%), *Goniastrea* (1%), *Lobophillia* (3%), *Leptastrea* (1%), *Leptoseres* (1%), *Montipora*(5%), *Merulina* (1%), *Oxyopora* (1%), *Platygyra* (4%) and *Poccilopora* (2%)

Fig. 5.1
PREY CORAL GENERA



Behaviour

Of the surveyed *Acanthaster* (n=248), 78% was found to be feeding and 22% was found not feeding.



Prey availability and Acanthaster *abundance*

In the graphs below the linear regression between abundance of *Acanthaster*, measured in average collections (n=220) per site, and percentage of coral cover of a prey coral genus at site is tested.

The prey coral genera tested are *Acropora, Pocillopra, Fungia* and *Favia.*
Acropora (Fig. 5,2)
The percentage of *Acropora* and *Acanthaster* abundance correlated R^2=0,24 on the deep EMP lines and R^2=0,12 on the shallow EMP lines.

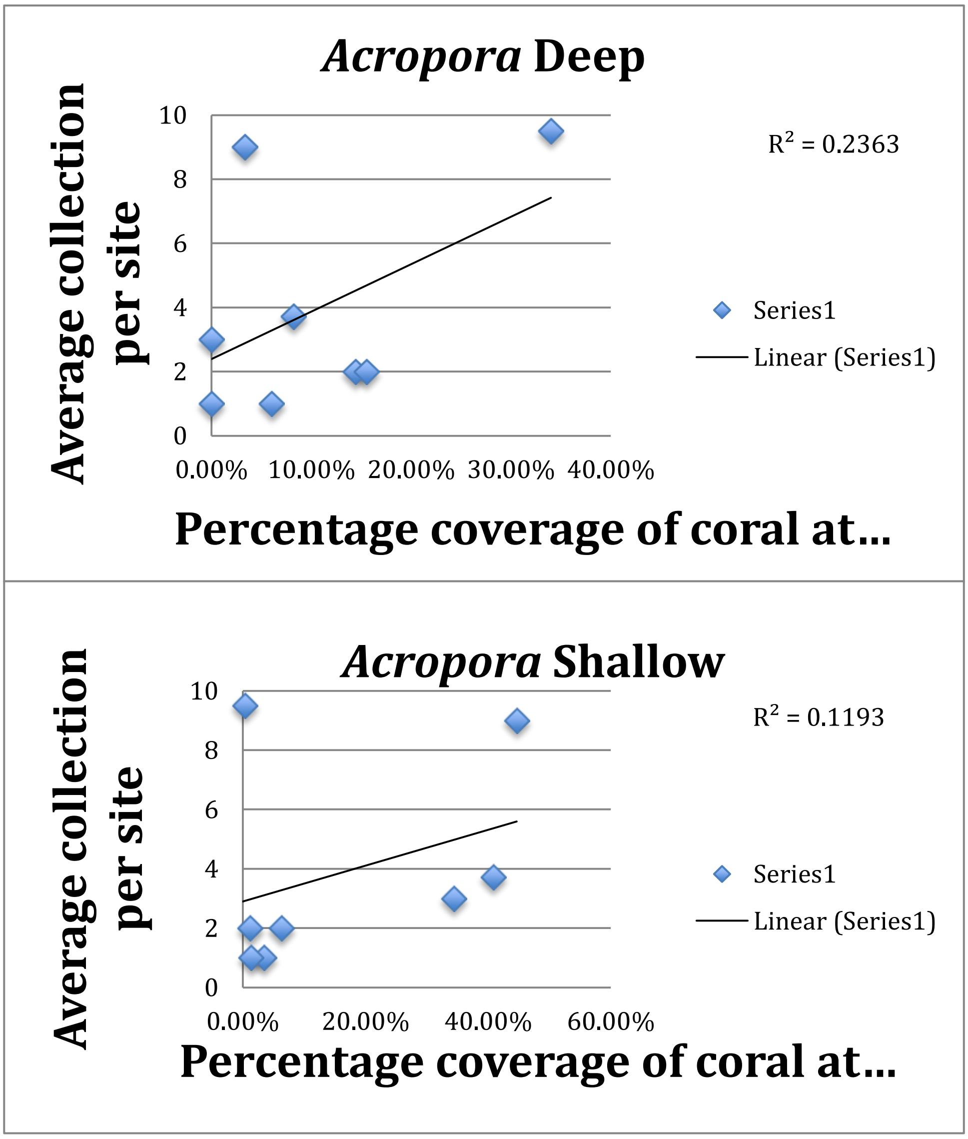


Fig 5.3

Pocillopora (Fig. 5.4)
The percentage of *Pocillopora* and *Acanthaster* abundance correlated R^2=0,31 on the deep EMP lines and R^2=0,19 on the shallow EMP lines.

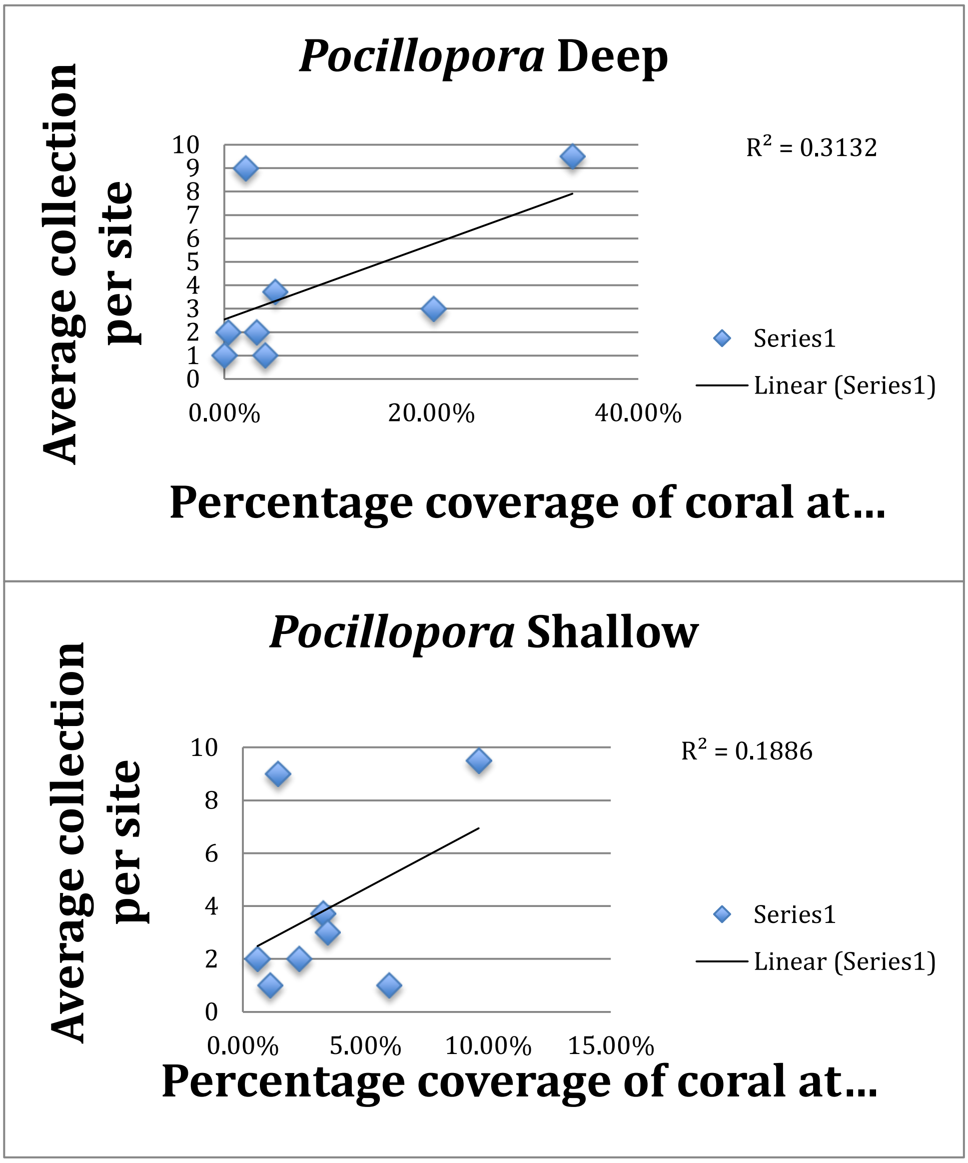


Fig. 5.4

Fungia (Fig. 5.5)
The percentage of *Fungia* and *Acanthaster* abundance negatively correlated R^2=0,04 on the deep EMP lines and R^2=0,11 on the shallow EMP lines.

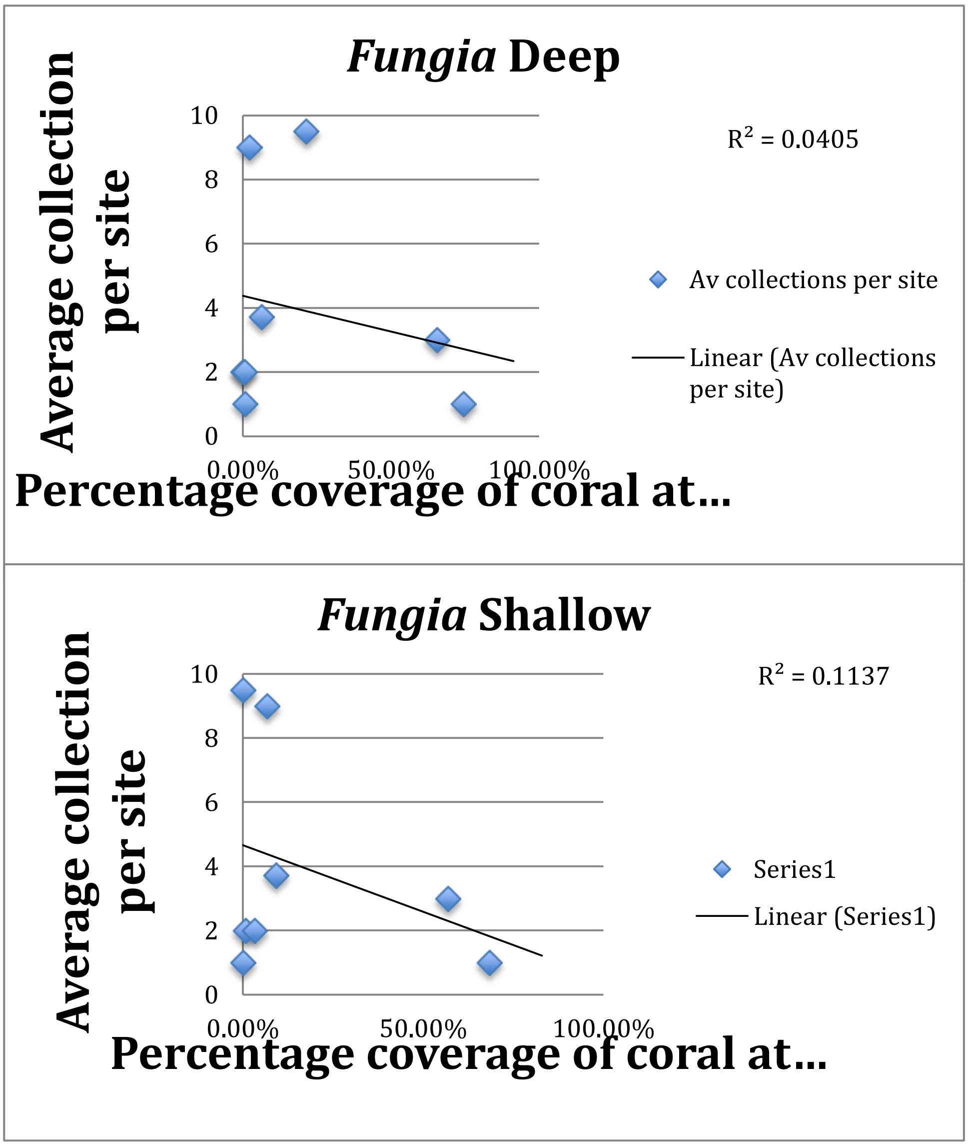


Fig. 5.5

Favia (Fig. 5.6)
The percentage of *Favia* and *Acanthaster* abundance correlated R^2=0,09 on the deep EMP lines and R^2=0,12 on the shallow EMP lines.

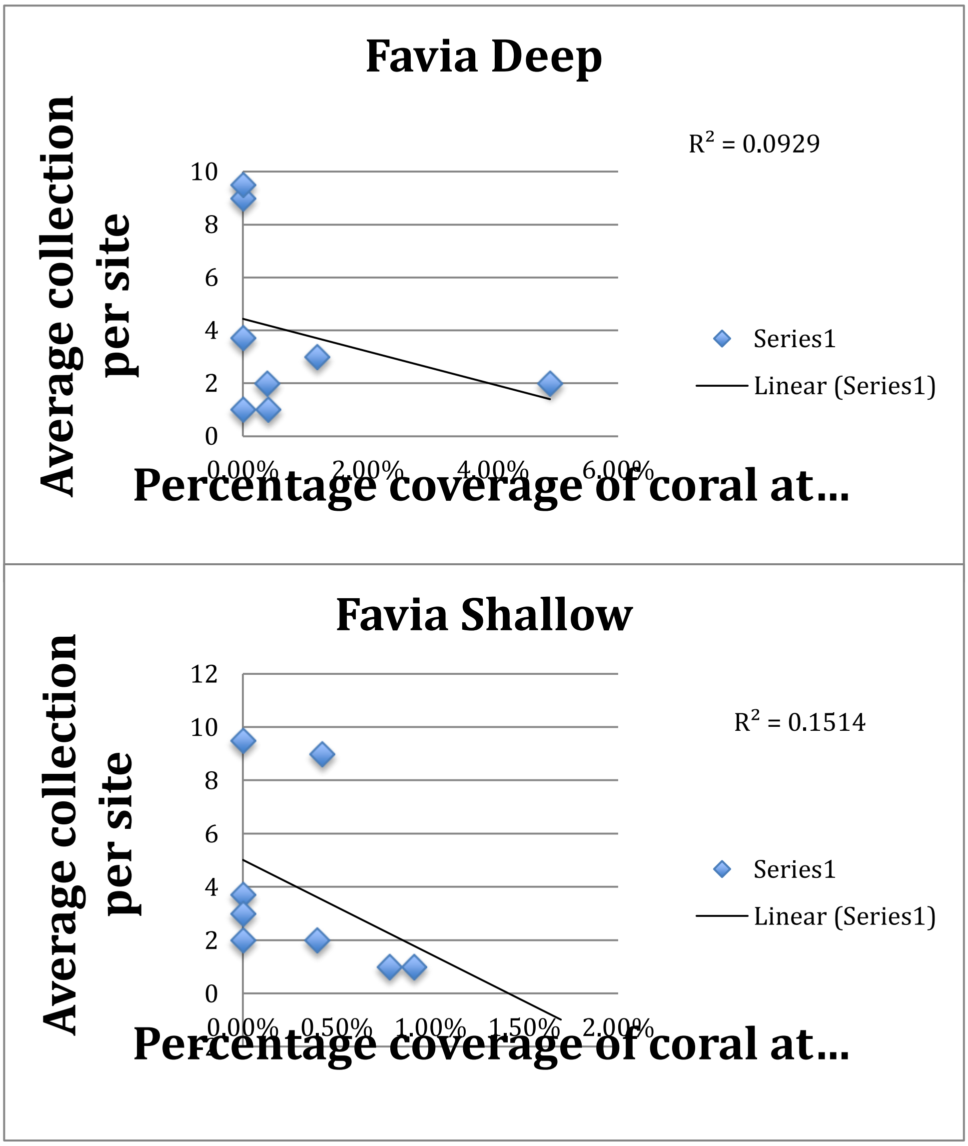


Fig. 5.6

Fig. 5.7 shows the average number of *Acanthaster* collected (n=220) per site this was used to measure abundance.

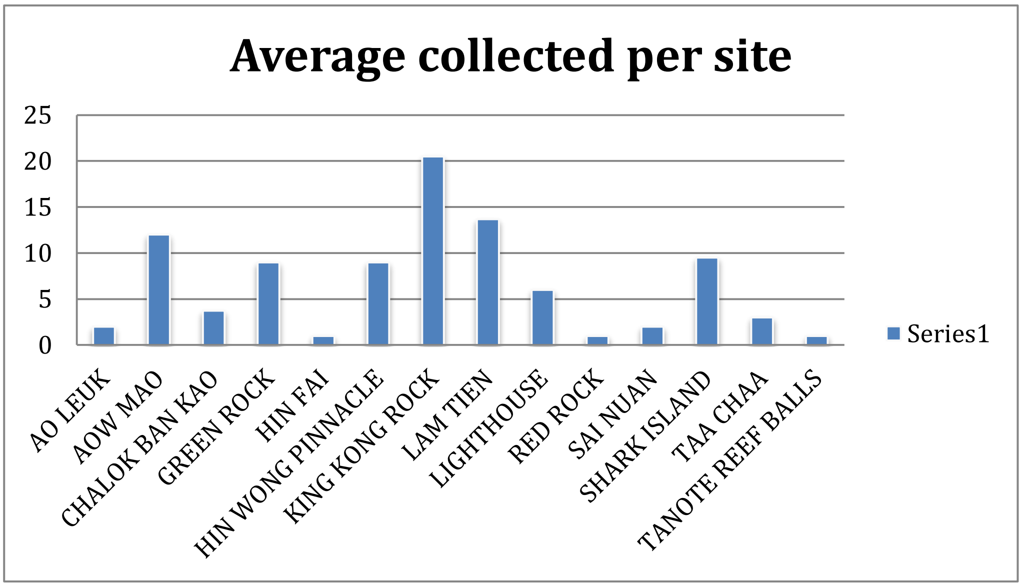


Fig. 5.7

Depth

Fig. 5.8 shows the depth frequency at which *Acanthaster* was found (n=248). The most starfish were found between 6-9 m and 9-12 m deep.

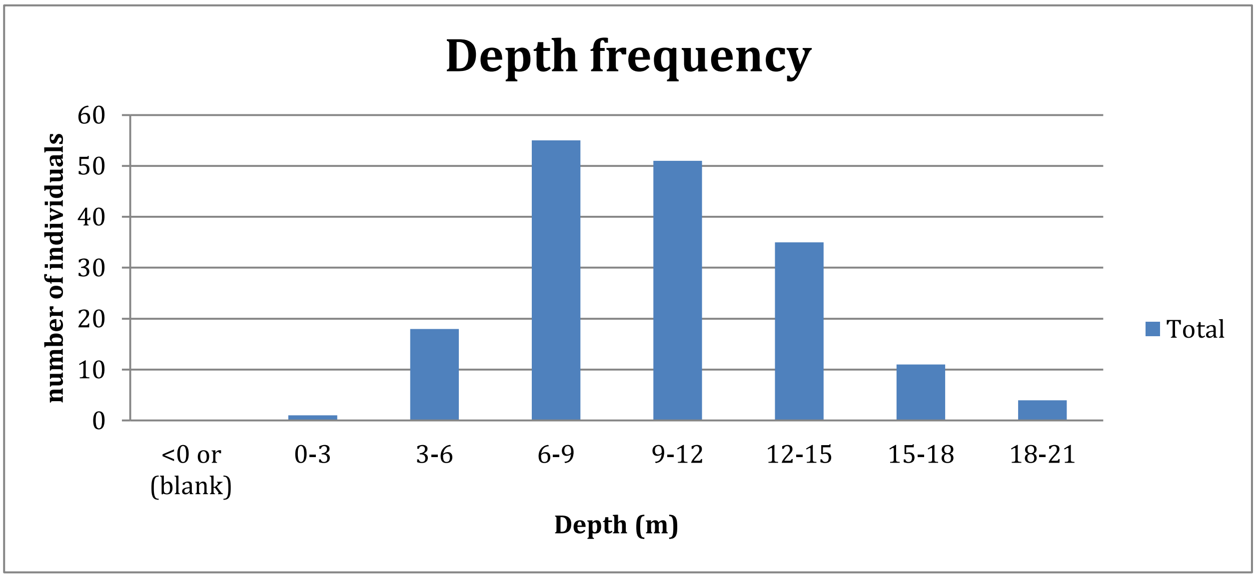


Fig. 5.8

Fig. 5.9 shows the mean depth of *Acanthaster* over a one-year period, no data was collected in November. (n=248)

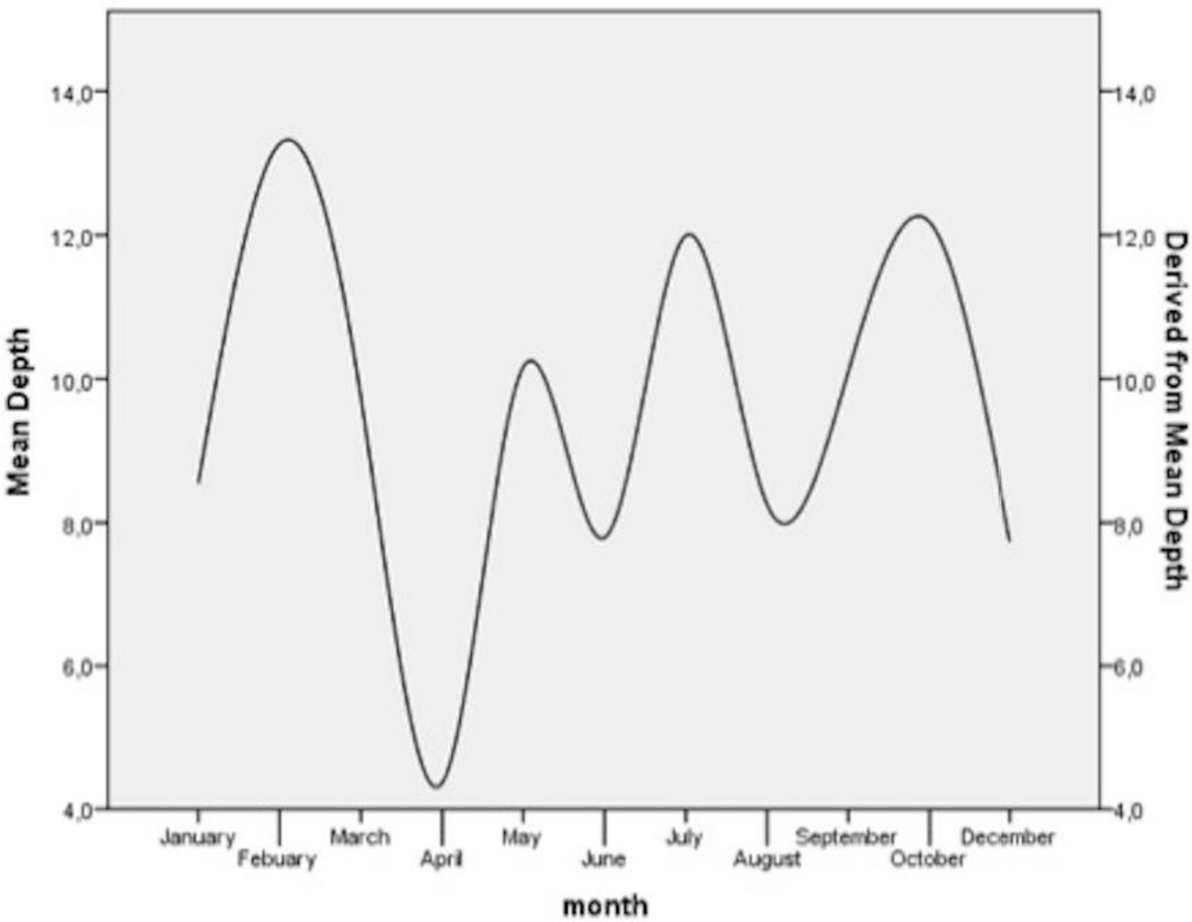


Fig. 5.9

Size

Table 5.1 shows the minimum, maximum and average size of *Acanthaster on* Koh Tao.

Min Size	Max Size	Average Size
12	52	35,0

Table 5.1

Fig. 5.10 shows the average size of *Acanthaster* per site. (n=248)

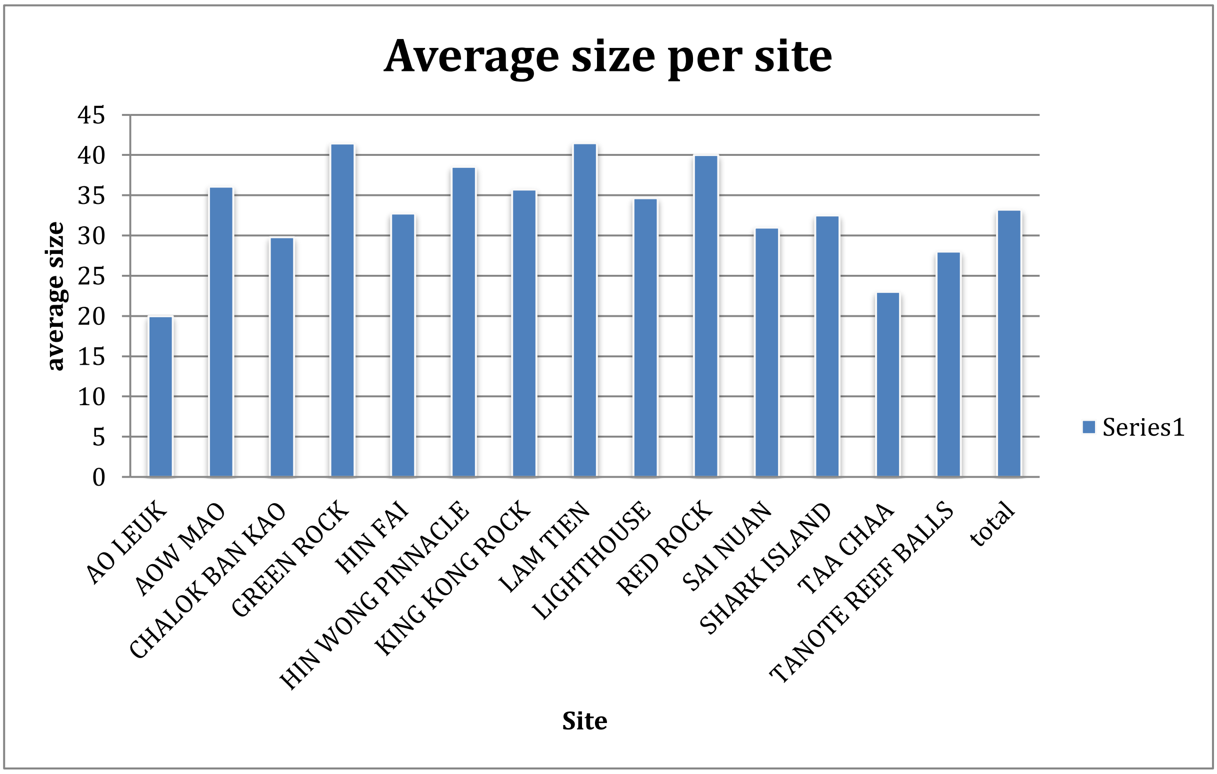


Fig. 5.10

Fig. 5.11 shows the size frequency of *Acanthaster* found (n=248).

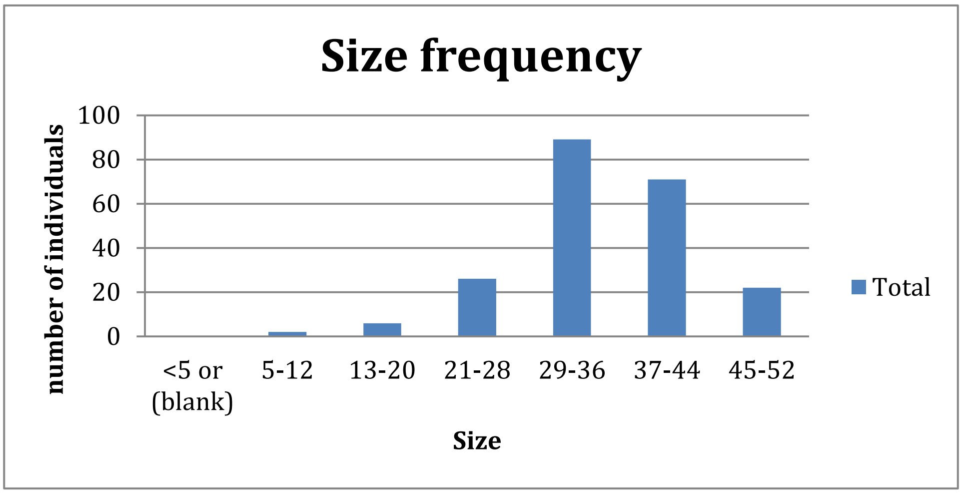


Fig. 5.11

Fig. 5.12 shows the average size of *Acanthaster* over a one-year period. No data was collected for November. (n=248)

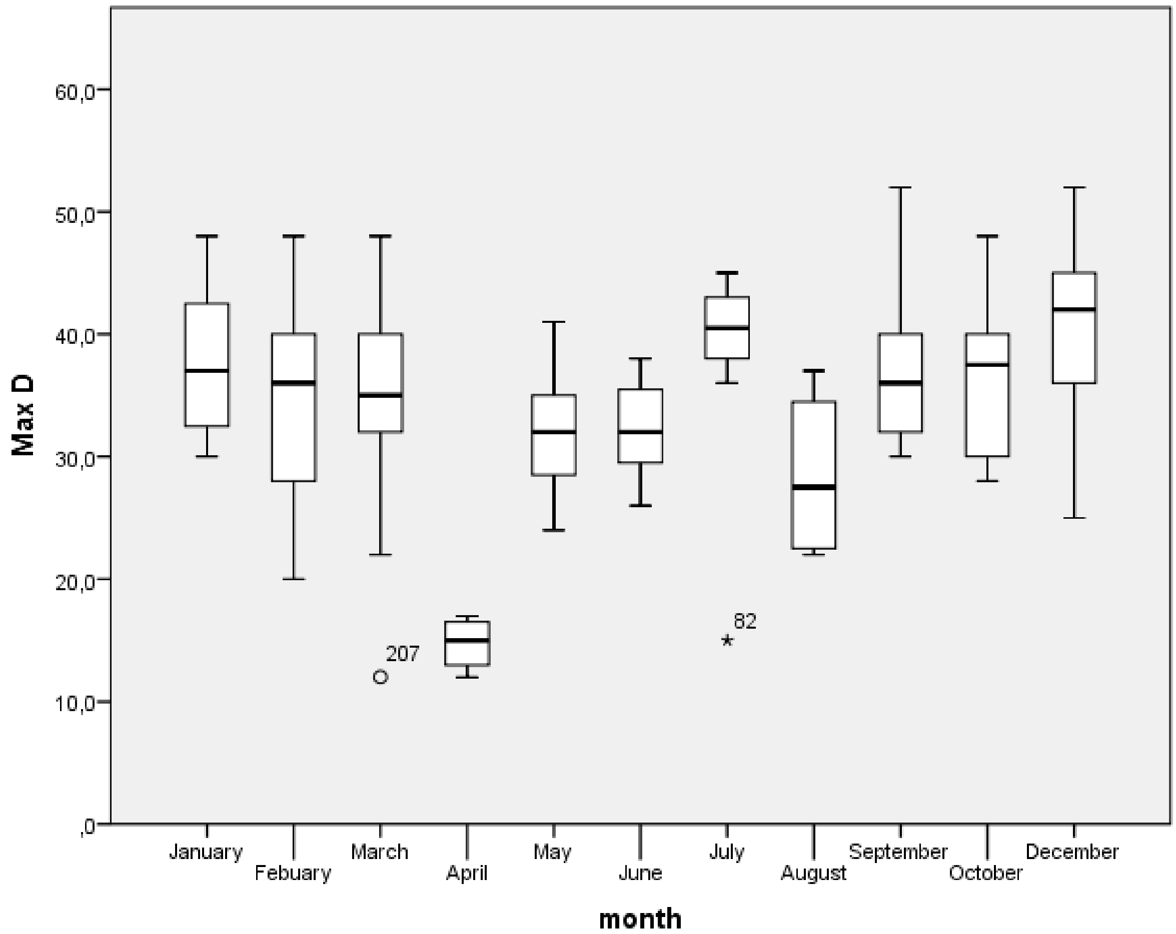


Fig. 5.12

Depth and size

Fig. 5.13 shows a combined graph of average size (green) and average depth (blue) over a one year time period. No data was collected in November. (n=248)

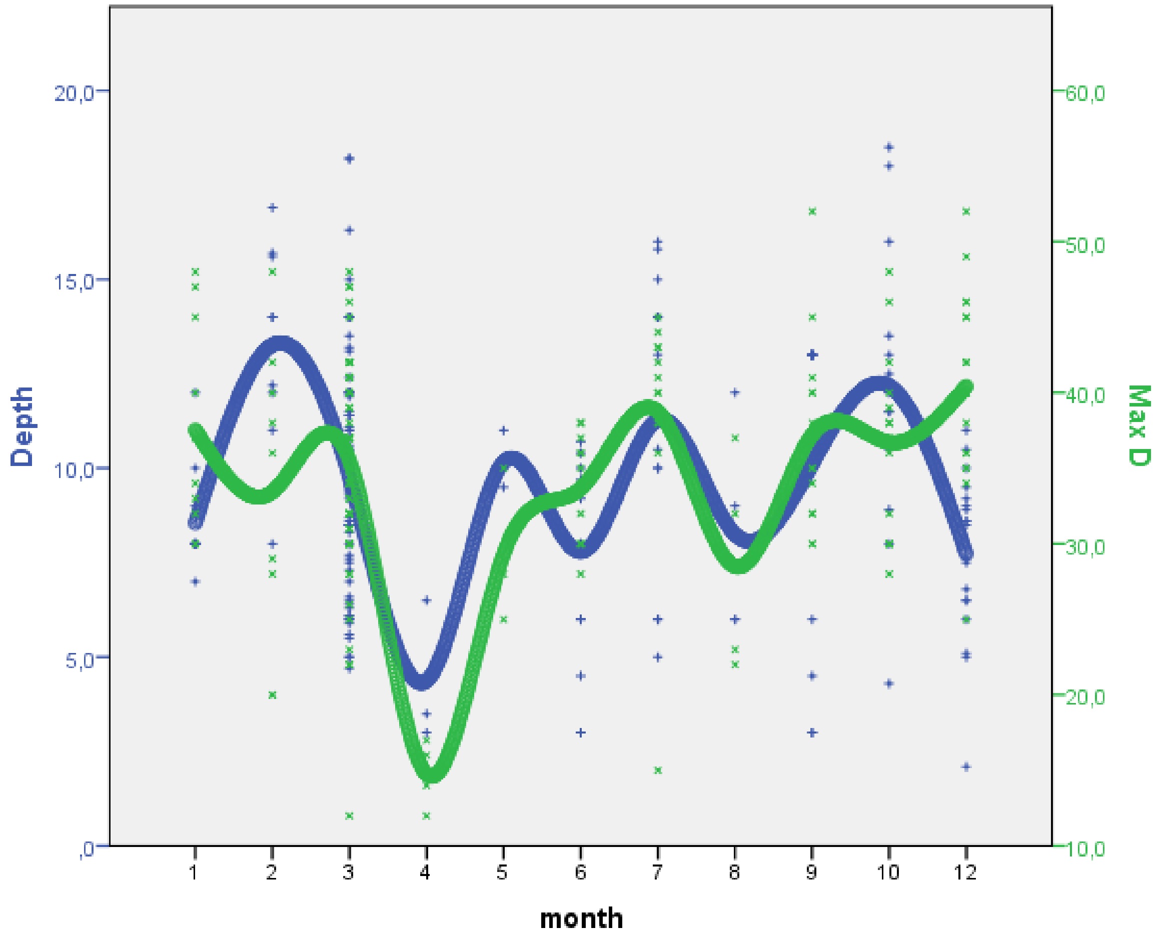


Fig. 5.13

6. Discussion

The goal of this study was to create a greater understanding of *Acanthaster* population on the island of Koh Tao. *Acanthaster* poses a great biological threat to the coral reefs on which the islands environment and community rely. Understanding the biology of this population is important in creating effective management techniques for controlling *Acanthaster* population outbreaks on Koh Tao. In this study the dietary preferences, size and depth of *Acanthaster* on Koh Tao was researched.

Dietary preferences of Acanthaster on Koh Tao

> Question: What is the diet of *Acanthaster* on the reefs of Koh Tao comprised of?
>
> Hypothesis: The diet of *Acanthaster* is comprised mostly of corals in the genus *Acropora* and *Pocillopora* as preferred prey.

Acanthaster on Koh Tao was found to consume a wide range of coral genera (results section Fig. 5.1). However *Acanthaster* showed strong preference for certain genera, which complies with findings of previous studies. Shown by De'ath & Moran (1998) and Keesing (1990) *Acanthaster* population worldwide tend to have different preference in prey coral. These preferences may be caused by a variety of different attributes.
On Koh Tao the most preferred genus of coral is found to be *Fungia,* which was found to be the prey of 17% of *Acanthaster found* during this study. After *Fungia, Pavona* was found as most preferred with 15%, *Porites* 14%, *Acropora & Favia* 9% and *Favites* 8%.

Literature states the *Acropora* and *Pocillopora* genera are most commonly found as preferred prey (Bos et al. 2012). However in this study the results show *Pocillopora* to only be represented by 2% of the prey found. Avoidance of *Pocillopora* was found before on reefs in Panama even though it is the most common genus in that area. This find was explained by defensive attacks on *Acanthaster by* coral symbionts such as *Trapezia spp.* crabs and *Alpheus lottina* shrimp. (De'ath & Moran, 1998) Defensive attacks by coral symbionts may also explain why *Pocillopora* is not preferred on Koh Tao, however to conclude this more research must be conducted to the presence and effect of such symbionts on Koh Tao.

Porites was observed as prey in 14% of the *Acanthaster* found, which makes it one of the preferred prey genera. This is interesting to find as it contradicts literature. Laboratory feeding trials showed *Acanthaster to* only consume Porites when other corals were depleted. (Keesing, 1990) in other feeding trials using biochemical extracts from *Acropora* and *Porites*, the Porites extract caused *Acanthaster* to retreat from coral whilst extracts form *Acropora* caused stomach eversion associated with feeding. (De'ath & Moran, 1998)
De'ath & Moran (1998) found *Acanthaster* to least prefer *Porites* on the Great Barrier Reef. Also this may be explained by the presence of coral symbionts, however it was stated that the most likely reason was the low nutritional value of *Porites* over that of *Acropora*, which was most preferred.

Fungia was found to the most preferred prey (17%) during this study. Surprisingly as in most studies *Fungia* is found as a least preferred genus. However Keesing (1990) did find *Fungia* to be most preferred after *Acropora* on the Great Barrier Reef.
Besides the possible role of coral symbionts, the preference for *Fungia* may be explained by a variety of attributes affecting the efficiency of the coral as prey. Non-preferred prey is subject to increasing levels of predation in areas where preferred prey is depleted. (keesing, 1990) The preference found for genera such as *Pavona* and *Porites* may be accounted for by high abundance of these genera over others.
Prey preferences may also be related to "ingestive conditioning" where the *Acanthaster* is conditioned to a usually non-preferred prey. When this conditioning is observed the starfish will accept this non-preferred prey over available 'preferred' prey such as *Acropora.*
(Keesing, 1990) If juvenile starfish are subject to ingestive conditioning due to recruitment on a reef with a high abundance of normally non-preferred coral the *Acanthaster* may feed on these corals in later life stages.

Behaviour

Question: How is feeding behaviour, described in 'feeding' and 'not-feeding', represented on the reefs of Koh Tao?

Hypothesis: *Acanthaster* is commonly found feeding, because non-feeding individuals will hide due to the cryptic nature of *Acanthaster*.

78% of Acanthaster found were observed to be feeding. This is not surprising, as the starfish is known to be cryptic by nature. When not feeding Acanthaster will hide to avoid predation. (De'ath & Moran, 1998)The 22% observed not to be feeding might have been migrating between coral colonies.

Acanthaster abundance and preferred prey coral coverage

Question: What is the effect on *Acanthaster* abundance in relation to preferred prey coral coverage on reefs of Koh Tao?

Hypothesis: *Acanthaster* is more abundant in areas where preferred prey has a high percentage of coral coverage.

Preferred prey genus *Acropora* coverage correlated positively with the abundance of *Acanthaster* (R^2=0,24 deep, R^2=0,12 shallow). This would imply that *Acanthaster* would be more abundant in areas were *Acropora* coverage is higher.

Contradictory to the results of the dietary preference found. *Acanthaster* abundance was found to correlate positively with the coverage of *Pocillopora* (R^2=0,31 deep, R^2=0,19 shallow). This may be explained by the total abundance of *Pocillopora* around Koh Tao being low resulting in less observations of predation of this genus.

Also contradictory to dietary preference results is the negative correlation found between the coverage of *Fungia* and *Acanthaster* abundance.

However these results are less reliable than the results of the dietary preference as the abundance of *Acanthaster* is measured in average number of collected individuals per dive. This is subject to bias as it depends on number of divers collecting, time spent searching etc.

Size of Acanthaster on Koh Tao

> Question: What size range is *Acanthaster* found in on the reefs of Koh Tao?
>
> Hypothesis: Size of *Acanthaster* will range between 11 and 62 centimetres in diameter, as juveniles are cryptic by day, SCUBA encounters of individuals < 20 cm will be uncommon.

The minimum size *Acanthaster* was found at was 12 cm in diameter. Maximum size was found at 52 cm in diameter. The average size was found to be 35 cm in diameter. These figures fit with in the range Pratchett et al (2014) found in the Great Barrier Reef were 11 cm was found as minimum and 62 cm was found as a maximum. Keesing (1990) found an average of 37.5 cm in January on the Great Barrier Reef, which is very comparable to the 35 cm average found on Koh Tao. The life stage of individuals over 35 cm in diameter is categorized as senile adults aged 5 years and over. (Pratchett et al. 2014)

> Question: What size class of *Acanthaster* is most abundant on the reefs of Koh Tao?
>
> Hypothesis: Size classes will show predominantly adult *Acanthaster,* as juveniles are more cryptic in nature.

The majority of *Acanthaster* was found in the size classes 29-36 cm (41%) and 37-44 cm (33%). This means the majority of *Acanthaster* found can be classed in either the life stage; corals feeding adults or senile adults. Less than 10 individuals were found to measure less than 20 cm. This can be explained by the fact that starfish under 20 cm are classed as coral feeding juveniles. (Pratchett et al. 2014) juveniles have been found to be more cryptic, often coming out to feed nocturnally. (De'ath & Moran, 1998) Over time the average size ranged between 30 and 40 cm, however figure 5.12 shows the average size to be around 15 cm in April. This is an interesting variation that cannot be explained. More data must be collected and analysed in April to see if this sharp decline is not due to a low sample size

Relation size and depth

> Hypothesis: What is the relation between depth and size of *Acanthaster* on the reefs of Koh Tao?
>
> Question: Size of *Acanthaster* is directly correlated to depth.

No direct correlation was found between the depth and size of *Acanthaster* on Koh Tao. However in fig. 5.13 size and depth are compared over time. Size seems to fluctuate parallel to the depth over time.

Depth

> Hypothesis: What is the depth range of *Acanthaster* on the reefs of Koh Tao?
> *Question: Acanthaster* is found at a depth ranging from 4-18 meters.

The average depth of *Acanthaster* on Koh Tao was found at 9.8 meters deep. The majority of *Acanthaster* was found in depth the classes 6-9 meters (32%) and 9-12 meters (29%) deep. The minimum depth *Acanthaster* was found on was 2.1 meters and the maximum depth was 18.5 meters deep. Compared to research conducted on the Philippines, where 60% of *Acanthaster* was found at depths between 4 and 5 meters, *Acanthaster* on Koh Tao is found considerably deeper. (Bos et al. 2012

7.Conclusion and recommendations

The goal of this study was to create a greater understanding of the *Acanthaster* population on Koh Tao. The results of this study aim to aid in the development of more effective means of population control to reduce the threat of outbreaks.

This study has produced several interesting results, which have revealed new insights and understanding of the *Acanthaster* population on Koh Tao, Thailand. The dietary preferences of the *Acanthaster* population on Koh Tao differ significantly from other populations worldwide. Many factors local to the area may have an effect on these preferences. The main findings of the dietary preferences found in this study are the great representation of *Fungia* and *Porites* coral genera in the diet of *Acanthaster* and the low amount of *Pocillopora* feeding observations. These finding are found to be interesting as they contradict previous studies where *Fungia* and *Porites* are not found preferred by *Acanthaster. Pocillopora* is commonly found to be a preferred prey species, however *Acanthaster on* Koh Tao seems to avoid this genus of coral. As the threat posed by *Acanthaster* is through predation; knowledge on dietary preferences can help in better understanding where outbreaks may take place.
The factors at play concerning the dietary preferences of *Acanthaster* on Koh Tao may be interesting subjects for future research. For example: Studying the presence of various coral symbionts that may affect prey preference. Or if possible digestive conditioning plays a role in the preference. Feeding trials in an experimental setup using corals and starfish from the reefs of Koh Tao may give us new insights in how these preferences have come to be.

The size frequency of *Acanthaster* found on Koh Tao is also interesting as juveniles are a very rare sight. Observations of mostly large adult starfish are explained by the cryptic nature of juveniles. However understanding where and when recruitment of juveniles takes place can help in preventing population outbreaks by focussing conservation efforts. As juveniles feed nocturnally to reduce the risk of predation, night-time surveys may produce more results concerning juvenile starfish.
The results show *Acanthaster* to have a significantly smaller average size in April, this may indicate the time period of recruitment after spawning. However the sample size of April is too low to be significant. More data on size should be collected during April to prove there is an actual decline in average size that may be linked to a spawning event.

To create a better understanding of outbreaks densities on Koh Tao it is important to monitor the abundance of *Acanthaster* on reefs. The method used to determine abundance in this study (average collected individuals per site) may be subject to bias as the number of surveying divers and area size were not constant. In future monitoring a method should be developed to limit bias. This could be achieved by implementing large quadrants surveyed by a certain amount of divers relative to the size of the area. Comparing this data to variables such as coral coverage, nutrient input and predator/prey presence, could tell us more about population dynamics.
Monitoring the size, depth and feeding of *Acanthaster* should continue because future analysis may reveal patterns over time.

The New Heaven Reef Conservation Program (NHRCP) performs population control on Koh Tao. NHRCP carries out regular collections of *Acanthaster* on reefs where high densities are observed. A team of divers, who scan the reef area for starfish, take data and bring the starfish to the surface. *Acanthasters* are not killed underwater as decomposing tissue will add nutrients to the water. To prevent stress induced spawning care is taken in collecting the individuals. Once on the surface the starfish are dried on the beach and deposed of.
As the reefs of Koh Tao face such a large cumulative Anthropogenic threat. The definition of an outbreak, where densities exceed the local resource availability, is smaller than in less disturbed reefs. Population control should continue on Koh Tao when high densities are observed to protect the reefs. Targeting large individuals should be encouraged as fecundity is related to the size of the starfish. However when densities are low *Acanthaster* should be left to perform their functional role in the ecosystem. Future focus should be on prevention of outbreaks by targeting the known causes of *Acanthaster* outbreaks such as nutrient runoff and overfishing.

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