Spatio-temporal Distribution and Abundance of Crown-of-Thorns Starfish (*Acanthaster planci* L.) in Three Marine Protected Areas (MPAs) around the Island Garden City of Samal, Philippines

Raquel B. Agustin and Cleto L. Nañola Jr.*

Department of Biological Sciences and Environmental Studies, College of Science and Mathematics, University of the Philippines Mindanao, Mintal, Tugbok District, Davao City 8022, Philippines. *Corresponding author. Email: tingnanola@yahoo.com. Telephone: +63 82 293 0302.

Received 25 July 2012; **Revised** 13 May 2013; **Accepted** 31 May 2013

Abstract

The spatial and temporal distribution of crown-of-thorns starfish or COTS (*Acanthaster planci* L.) was investigated in three marine protected areas (MPAs) around the Island Garden City of Samal (IGaCoS), Philippines, from December 2008 to December 2009. Methods include photo quadrat for the live coral cover and belt transect for the density of COTS and its predators. There was a significant difference in the spatial distribution of COTS among MPAs. Sanipaan Marine Park (SMP) had the highest COTS density while Coral Garden and Aundanao MPAs had the least. Variability of COTS density was attributed to percent coral cover and human intervention (i.e., COTS clean-up drive). At temporal scale, only data from SMP fitted for the analysis. There was no significant difference observed during the sampling periods conducted in April, August, and November 2009. The results suggest longer time of monitoring to cover the life span of COTS, taking into consideration the probable causes for infestation, whether anthropogenic (i.e., harvesting leading to mass spawning) or natural. In conclusion, the spatial distribution of COTS depends on the abundance of their preferred food while the temporal distribution is probably influenced by environmental conditions over time.

Keywords: *Acanthaster planci*; spatio-temporal distribution; Davao Gulf; marine protected areas

Abbreviations:

ANOVA – analysis of variance
COTS – crown-of-thorns starfish
MPAs – marine protected areas
SMP – Sanipaan Marine Park
IGaCoS – Island Garden City of Samal

Introduction

Coral reefs are home to a diverse group of aquatic organisms and are among the most productive tropical marine habitats (Nybakken, 1997; Westmacott et al., 2000). The highest diversity of corals and reef fishes are found at the coral triangle (Carpenter and Springer, 2005; Veron et al., 2009), which include the political boundaries of the Philippines, Malaysia, Indonesia, Papua New Guinea, Timor L'este, and Solomon Islands. The coral triangle, however, is one of the most threatened ecosystems due to anthropogenic and natural causes (Alcala and Russ, 2002; Arceo et al., 2001; Burke et al., 2011; Gardner et al., 2005; McManus et al. 1997; Nañola et al., 2011). Among the natural threats to the coral reef is the episodic attack of crown-of-thorns starfish (COTS), *Acanthaster planci* L., which preys on hard or stony corals (Chester, 1969; Pratchett, 2007).

An indicator of COTS outbreak is when the density of COTS reaches 1 individual per 250 m^2 or more than 30 individuals per hectare (Harriott et al., 2003). COTS infestation had been reported to cause a rapid rate of coral death, with total destruction occurring within just a few months (Fraser et al., 2000). Recovery of reefs damaged by COTS may take several decades (Maltry, 2003; Nybakken, 1997) and can be aggravated by other causes such as overfishing and reduction of herbivore biomass (Adam et al., 2011).

The exact cause of COTS outbreaks is still unknown, but it has been hypothesized that these are natural phenomena (Harriott et al., 2003). Moreover, the natural fluctuations of temperature, salinity, and nutrient levels have been documented as possible contributors to outbreaks (Birkeland, 1982; Fraser et al., 2000). Another theory suggests that outbreaks are caused by human activities that reduce the natural predators of COTS in an ecosystem. Some of the known predators of COTS are the giant triton snail (*Charonia tritonis*), shrimp (*Hymenocera picta*), worm (*Pherecardia striata*), starry pufferfish (*Arothron hispidus*), several species of reef fishes (*Balistoides viridescens*, *Pseudobalistes flavimarginatus*, *Cheilinus undulatus*) (Glynn, 1982; Maltry, 2003), and the polyp (*Psuedocorynactis* sp.) (Bos et al., 2008).

Reproductive biology of COTS has been reported to be triggered by temperature variations. In Indonesia, the sex organs of COTS would begin to develop in August when the water temperature is high (Fraser et al., 2000), and breeding was observed in the Great Barrier Reef from December to April when temperature drops at around 28 °C (Lucas, 1973; Harriott et al., 2003).

In the Davao Gulf found in the Southern Philippines, COTS outbreaks had been well documented (Mallo, 2007). Because of the infestation, concerned groups have conducted manual harvesting of COTS (Mallo, 2007). However, there is an absence of information regarding their actual abundance and spatial distribution. Thus, this study aimed to determine the spatio-temporal distribution and abundance of *A. planci* in three spatially distributed marine protected areas (MPAs) around the Island Garden City of Samal (IGaCoS).

Materials and Methods

Study Areas

The study was conducted from December 2008 to December 2009 in three MPAs around IGaCoS. The study sites are the Aundanao MPA near the eastern coast of the main island, the Coral Garden MPA near Talikod Island, and the Tambo MPA or the Sanipaan Marine Park near the northern coast of the main island (Figure 1). Among the MPAs, only Coral Garden MPA is situated far from any river outlet and is a very popular recreational dive site. On the other hand, the two MPAs are reached by agricultural wastes coming from major rivers that drain north of the gulf. Details of the management schemes in these sites have been described by Mellomeda-Quesada et al. (2010).

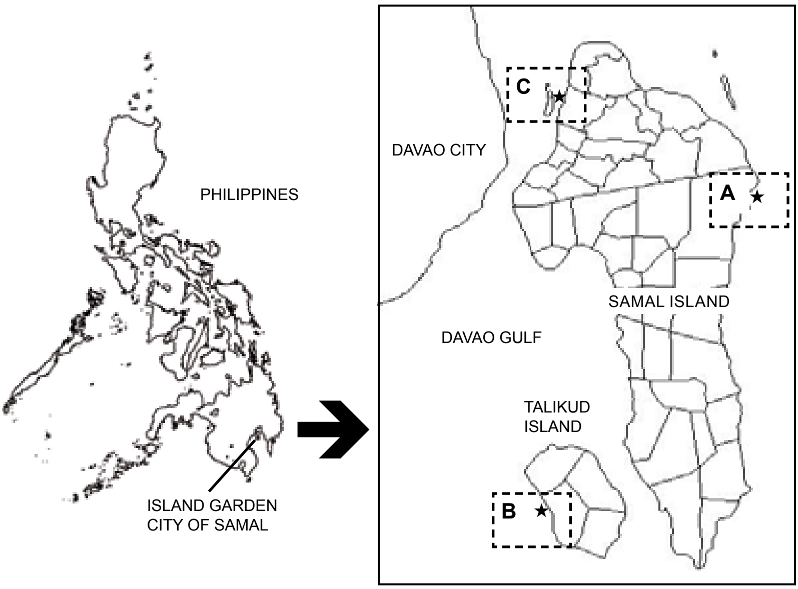

Figure 1. Map showing the location of the Island Garden City of Samal (IGaCoS), Philippines, and the three marine protected areas (MPAs) in the Davao Gulf: (A) Aundanao MPA, (B) Coral Garden MPA, and (C) Tambo MPA (Sanipaan Marine Park)

Data Collection

In Aundanao MPA, sampling periods were conducted one year apart, December 2008 and December 2009. While in Coral Garden MPA and SMP, three sampling periods were conducted: in April (weak easterlies), in August (southwest monsoon), and in November (northeast monsoon). All data were taken in 2009. The basic unit of sampling is a 50-m transect.

Photo Quadrat for Benthic Classification

Benthic assessment was conducted using the photo transect method (English et al., 1997). A 50-m transect was laid at desired depth (~5 m) contour. A series of nearly overlapping photos were taken along the transect using digital cameras (i.e., Sony Cybershot DSC-T70 and Olympus Stylus 760) with underwater housing. In the laboratory, the photos were pieced together and enhanced using Adobe Photoshop CS2. The pictures were then uploaded in the Coral Point Count with Excel extensions (Kohler and Gill, 2006). A border offset was specified depending on the depth when the photograph was taken. In this study, 9 stratified points (3 points per row) were overlaid on the images, and the benthic life form was classified in each point using the life form categories (Table 1). Other components of the benthic classification, such as abiotic factors (e.g., sand, silt, rock, and rubble), algae, and other faunas were also recorded to enhance site description.

After all the photos were scored, total hard coral and soft coral cover per transect were computed using the formula:

$$\%\text{ cover of each category} = \frac{\text{Total count of each category}}{\text{Sum of all counts}} \times 100$$

Table 1. Simplified benthic life form classification

Code	Description
HC	Hard coral
SC	Soft coral
SP	Sponges
A	All types of algae (macro, turf, *Halimeda*) including algae assemblages
SI/S	Silt and sand
R	Rubble
RCK	Rock
OT	Other fauna (e.g., echinoderms, *Spirobranchus*, and gorgonians)
DC/DCA	Dead coral and dead coral with algae

Source: Modified from English et al. (1997)

Belt Transect for the Observation of COTS

The transect used for the photo transect was also utilized to determine the density of COTS. A 5-m belt width (2.5 m on each side of the transect) was used for the observation of COTS density (Hill and Wilkinson, 2004). All COTS found inside the 50 × 5 dimension were counted and recorded accordingly.

Within the same belt transect and same width of observation, COTS predators were also visually counted. These include the common predators such as the giant triton snail (*C. tritonis*) and different species of reef fishes (i.e., *A. hispidus*, *B. viridescens*, *P. flavimarginatus*).

Data analyses

COTS density through time and among the different sites were analyzed using one-way analysis of variance (ANOVA) and Tukey's post hoc test using Minitab ver. 16.

Results and Discussion

A total of 138 COTS individuals were observed for the entire duration of the study. The number of transects, date, and coordinates surveyed for each MPA is presented in Table 2. All of the reported values of COTS density in the three MPAs fell within the level of an outbreak (Table 3).

The trends for the benthic cover among the MPAs were as follows: Coral Garden MPA had the highest percentage of hard coral cover dominated by *Porites* sp. while Aundanao MPA had the lowest percentage cover of hard corals. However, in terms of soft coral cover, Aundanao MPA had the highest percentage cover. The three MPAs had similar percentage covers of sponge, algae, silt/sand, and other fauna. Rubble percentage cover was lowest in Coral Garden MPA while the rock percentage cover was highest in Aundanao MPA. Lastly, for the dead coral category, SMP had the highest percentage cover among the three MPAs (Figure 2).

Spatial Distribution

Pooled data sets showed significant difference among the MPAs examined ($F[2,46] = 5.09$, $p = 0.010$). Moreover, Tukey's post hoc test showed that Coral Garden MPA (M = 1.62, 95% CI [0,3.39]) had significantly lower COTS density than SMP (M = 6.15, 95% CI [3.75,8.56]). However, there is no significant difference between the Coral Garden and Aundanao MPAs (M = 1.5, 95% CI [0,4.0]).

The low COTS density in Aundanao MPA may be attributed to the low percentage of hard coral cover, which is the preferred food of COTS (Celliers and Schleyer, 2006). In the absence of hard corals, COTS were observed to

Table 2. Coordinates of the sites sampled in three marine protected areas (MPAs) around the Island Garden City of Samal, Philippines

Sampling month	Transect	Depth (feet)	Coordinates (longitude, latitude)
		Aundanao MPA	
December 2008 and 2009	1	12 to 15	7°05'25.26" N, 125°47'9.92" E
	2	12 to 15	7°05'14.60" N, 125°46'59.05" E
	3	12 to 15	7°05'8.12" N, 125°47'0.10" E
	4	12 to 15	7°05'25.26" N, 125°47'13.38" E
	5	12 to 15	7°05'30.80" N, 125°47'15.43" E
	6	4 to 6	7°05'50.32" N, 125°47'29.15" E
		Coral Garden MPA	
April, August, and November 2009	1	12 to 15	6°56'33.75" N, 125°40'13.57" E
	2	12 to 15	6°56'12.87" N, 125°40'27.49" E
	3	12 to 15	6°55'50.24" N, 125°40'41.41" E
	4	12 to 15	6°55'31.10" N, 125°40'51.85" E
	5	12 to 15	6°55'20.66" N, 125°40'58.81" E
	6	12 to 15	6°56'51.15" N, 125°40'1.39" E
Additional sites in August 2009	7	12 to 15	6°55'36.70" N, 125°40'46.49" E
	8	12 to 15	6°55'58.01" N, 125°40'34.39" E
	9	12 to 15	6°56'40.70" N, 125°40'7.18" E
	10	12 to 15	6°55'36.7" N, 125°40'46.5" E
	11	12 to 15	6°55'58.0" N, 125°40'34.4" E
		Tambo MPA / Sanipaan Marine Park	
April, August, and November 2009 (except sites 4 and 5, which were sampled only in November 2009)	1	12 to 15	7°10'4.91" N, 125°40'57.90" E
	2	12 to 15	7°09'58.72" N, 125°40'58.91" E
	3	12 to 15	7°10'13.85" N, 125°40'51.97" E
	4	12 to 15	7°09'53.50" N, 125°41'0.92" E
	5	12 to 15	7°10'11.60" N, 125°40'54.80" E

Table 3. Average density (individual/250 m^2) of crown-of-thorns starfish (COTS) in every sampling month for the three marine protected areas (MPAs) around the Island Garden City of Samal, Philippines

Month	Aundanao MPA	Coral Garden MPA	Sanipaan Marine Park
December 2008	2.00 ± 2.53	no data	no data
April 2009	no data	1.00 ± 1.26	8.20 ± 3.35
August 2009	no data	2.45 ± 7.16	2.20 ± 1.48
November 2009	no data	1.17 ± 1.47	9.33 ± 8.33
December 2009	1.00 ± 0.63	no data	no data
Total average	1.5	1.74	6.15

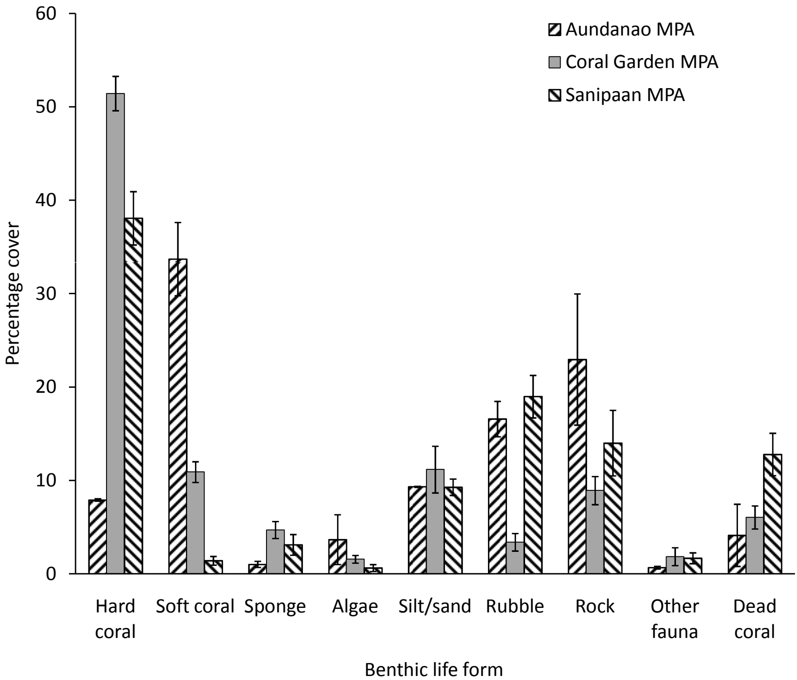

Figure 2. Average percentage cover of each benthic life form in the three marine protected areas (MPAs) around the Island Garden City of Samal, Philippines (Note: Vertical lines represent standard error bars.)

attack soft corals (Moran, 1986). However, despite the high percentage cover of soft corals in Aundanao MPA, there was no trace of soft coral attack by COTS.

In contrast, Coral Garden MPA had the highest percentage of hard coral cover among the three MPAs (Figures 2 and 3). Despite this, the MPA had a very low COTS density though still fell within the outbreak category (Harriott et al., 2003) (Table 3). Being a popular recreational dive site, this MPA was subjected to COTS harvesting by resorts personnel and other concerned divers of the area to protect the coral reef. This might be the reason for the low density of COTS in the area. In 2003, the local government unit, in cooperation with some organizations and the local community, conducted a COTS clean-up project, which resulted in the collection of more than 1500 individuals along the 4-km stretch of the MPA (Estremera, 2003). In 2007, separate clean-up drives were also conducted in some areas around the island, including Coral Garden MPA, and an estimated 3000 individuals were collected (Gevera, 2007; Palacio, 2007).

On the other hand, the SMP, which is not a popular recreational dive site and was not included in the clean-up drives conducted in 2003 and 2007 (Estremera, 2003; Gevera, 2007; Palacio, 2007) had the highest COTS

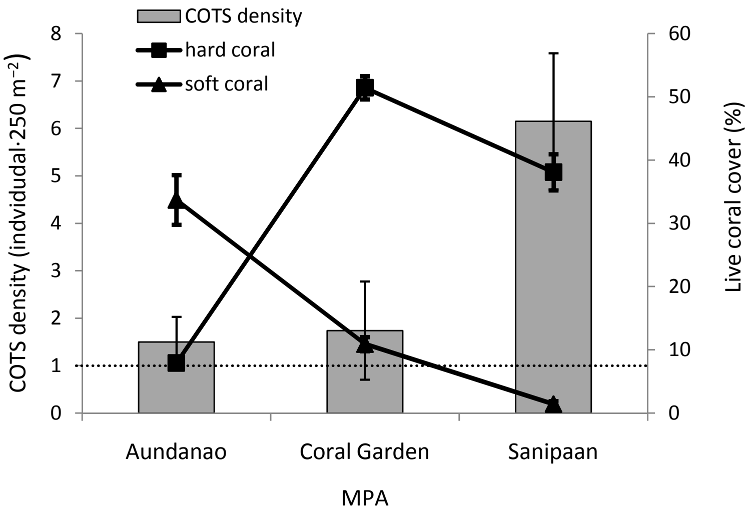

Figure 3. Spatial distribution of average adult crown-of-thorns starfish (COTS) density (bar graph, primary *y* axis) and live coral cover percentage (line graph, secondary *y* axis) in the three marine protected areas (MPAs) (Note: Vertical bars represent the standard error, and the broken line represents the minimum level of an outbreak.)

density, having more than 6 individuals per 250 m^2 (Table 3). This value is very alarming, being six times more than the minimum value to consider an outbreak, which is 1 individual per 250 m^2 (Harriot et al., 2003). The absence of human intervention (i.e., manual harvesting) plus having the second highest percentage of hard coral cover (Figure 2) could have been the reasons for the high density of COTS in the area. For these reasons, the area depicts the natural COTS density distribution for the reefs along the eastern coast of Samal Island.

Temporal Distribution

Only Aundanao MPA was not able to follow the three-month sampling period designed for the study. This was because during the initial survey of the MPA on December 2008, it was observed that the area had a low hard coral percentage composition (8.04%) and, instead, was dominated by soft corals (37.63%), which are the least food preference of COTS (Figure 2). Since a low COTS density was already expected because of the low hard coral cover, the three-month sampling frequency was no longer done. Instead, a follow-up survey was conducted on December 2009 to check if there were any significant changes after a year. As expected, there were no changes observed ($F[1,11] = 0.88$, $p = 0.370$) (Figure 4).

In Coral Garden MPA, no significant difference in the density of COTS ($F[2,23] = 0.19$, $p = 0.828$) was observed among the three sampling months (Figure 5). From the literature, it was expected that there would be a high COTS population for the period December to April (Harriott et al., 2003). However, this was not the case with Coral Garden MPA.

For SMP, similar results were observed. There was no significant difference across time ($F[2,12] = 3.37$, $p = 0.076$) though the density of COTS for the August sampling was a bit lower ($M = 2.2$) compared with April ($M = 8.2$) and November ($M = 9.33$) samplings (Table 3, Figure 6).

The temporal results simply indicate that there is no distinct seasonality of COTS along the eastern coast of Samal Island within a year. Temporal variation may possibly occur over several years or within its life cycle that span 8 years (Fraser et al., 2000). In Davao Gulf, very high densities of COTS observed in the years 2003 and 2007 (Estremera, 2003; Gevera, 2007; Palacio, 2007) could be the temporal cycle of COTS infestation that occurs every four years. This coincides with the sexual maturity of COTS occurring within two to three years (Fraser et al. 2000). Using historical information, the next infestation is projected to occur in 2011. However, there was no major report of COTS outbreak occurring within that year. It is worth noting though that in 2010, Davao Gulf was affected by the El Niño phenomenon, although not as much as areas in the West Philippine Sea. Increased oceanic temperatures could have caused the decline in the percentage of coral cover, which became a deterrent to the increase of COTS. Moran (1997) reported that the first

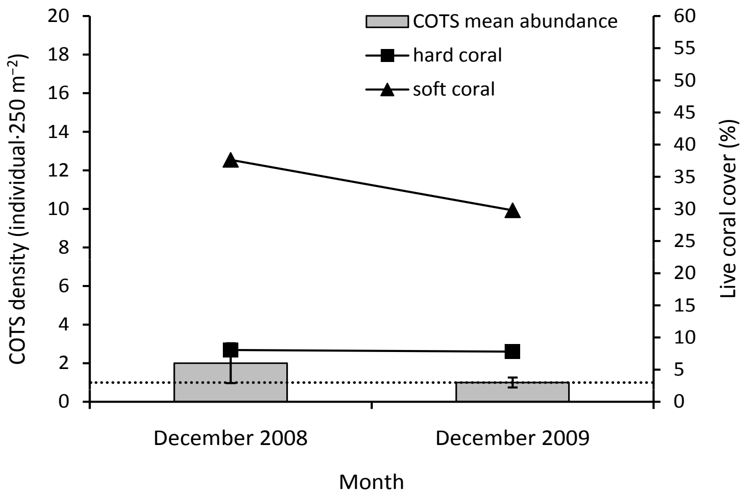

Figure 4. Temporal distribution of average adult crown-of-thorns starfish (COTS) density (bar graph, primary *y* axis) and live coral cover percentage (line graph, secondary *y* axis) in Aundanao Marine Protected Area (Note: Vertical bars represent error bars, and the broken line represents the minimum level of an outbreak.)

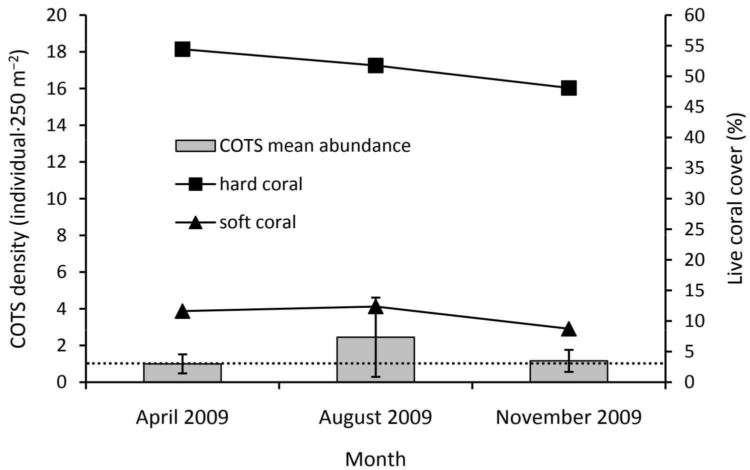

Figure 5. Temporal distribution of average adult crown-of-thorns starfish (COTS) density (bar graph, primary *y* axis) and live coral cover percentage (line graph, secondary *y* axis) in Aundanao Marine Protected Area (Note: Vertical bars represent error bars, and the broken line represents the minimum level of an outbreak.)

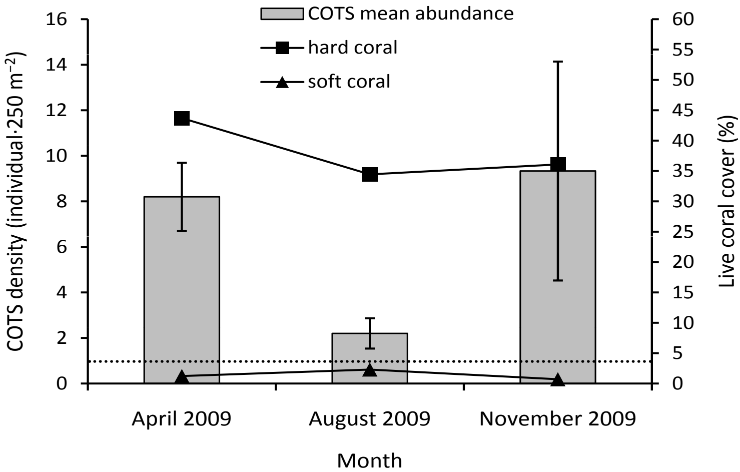

Figure 6. Temporal distribution of average adult crown-of-thorns starfish (COTS) density (bar graph, primary *y* axis) and live coral cover percentage (line graph, secondary *y* axis) in Sanipaan Marine Park (Note: Vertical bars represent error bars, and the broken line represents the minimum level of an outbreak.)

stage of an outbreak is marked by high coral cover. Moreover, in Coral Garden MPA, high percentage of coral cover in 2009 was contributed mainly by *Porites*. COTS, however, mainly prefer table *Acropora* (Moran, 1986). Selective consumption by COTS could explain why coral cover remained high during the 2009 sampling despite the outbreak that occurred in 2007 (Gevera, 2007; Palacio, 2007).

Others have mentioned that environmental factors play a role in the COTS population (Nybakken, 1997; Harriott et al., 2003) such that the rate of precipitation can be used as proxy for increase in nutrient inputs from river runoffs to project patterns of massive spawning (Birkeland, 1982). Theoretically, events that occurred years ago can be reconstructed or back-calculated through historical rainfall data. To test this premise, the observed outbreak in May 2003 (Estremera, 2003) and May–June 2007 (Gevera, 2007; Palacio, 2007) must coincide with a significant amount of rainfall two to three years prior when COTS reached sexual maturity (Fraser et al. 2000). Historical rainfall data indicated high average monthly rainfall two to three years before the outbreak in 2003 (Figure 7). In 2000, the average monthly rainfall in the months of June, July, and August were 7.20 mm, 7.37 mm, and 8.75 mm, respectively. In the same months for 2001, the values were 6.67 mm, 6.84 mm, and 9.51 mm, respectively. Whereas, for the 2007 outbreak, it was only two years before the outbreak (in 2005) that rainfall was high

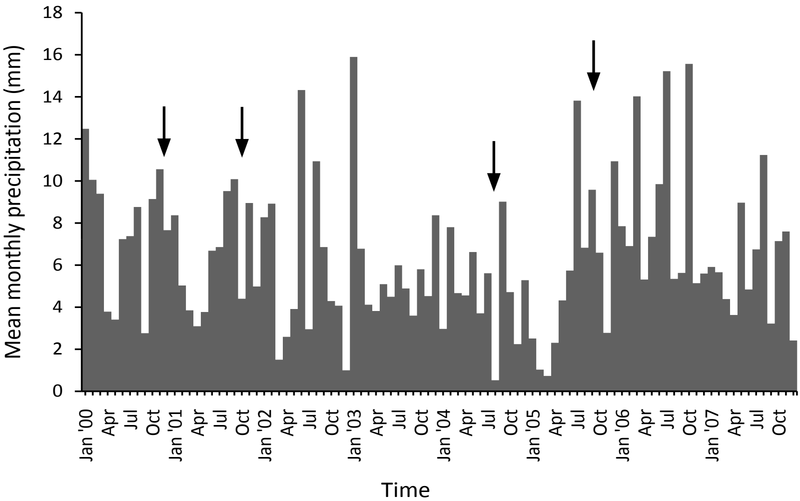

Figure 7. Average monthly rainfall data (mm) from January 2000 to December 2007 (Note: Arrows point to the average monthly rainfall for the months of June, July, and August) (Source: Data from NCDC [2012])

during the months of June (5.72 mm), July (13.81 mm), and August (6.82 mm). Three years before the outbreak (in 2004), the amount of rainfall on the same months were only 3.71 mm, 5.60 mm, and 0.52 mm, respectively (Figure 7). This may suggests that there is a possible relationship between survival of larvae in relation to nutrient increase via river runoff, but further test is needed to validate this hypothesis.

Another angle that needs to be investigated is the possibility that the harvesting of COTS by divers during the clean-up program in 2003 as a response to the COTS outbreak caused the subsequent 2007 outbreak. It is known that mature COTS release their eggs when subjected to stress (Fraser et al., 2000). During collection, which ran for approximately an hour, COTS were placed inside sacks and remained submerged in water. This could possibly have triggered mass spawning before the COTS were brought out of the water.

COTS Predators

The abundance of its predators was also studied to determine how they affect the COTS distribution spatially. In the three MPAs, only two fish families of COTS predators were observed. These were the triggerfishes (Family Balistidae) and pufferfishes (Family Tetraodontidae). Though present, the two fish families had very low densities in the three MPAs (Figure 8). The low

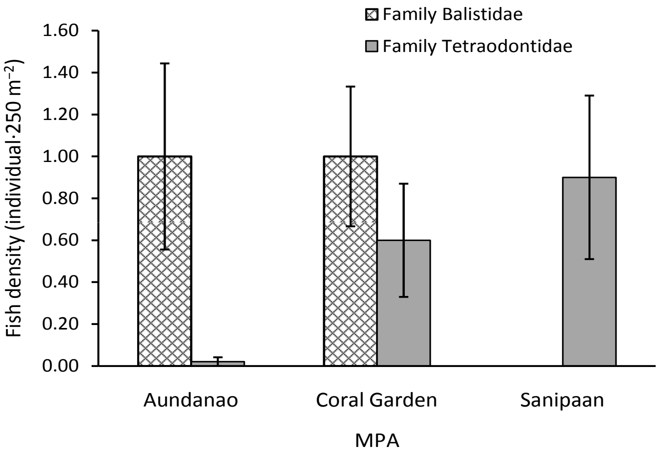

Figure 8. Average fish crown-of-thorns starfish (COTS) predator of the families Balistidae and Tetraodontidae in the three marine protected areas (MPAs) around the Island Garden City of Samal, Philippines (Note: Vertical bars represent the standard error.)

COTS predator density in the MPAs could be a contributing factor to the high density of COTS.

Summary and Conclusion

The spatial distribution of COTS in the MPAs around IGaCoS was a reflection of the density/cover of their preferred food and the harvesting done in 2003 and 2007. SMP, which had high hard coral cover and was not harvested for COTS, had the highest COTS density. Aundanao MPA, which had the poorest coral cover, also had the lowest COTS density. Meanwhile, Coral Garden MPA, despite having the highest hard coral cover among the three MPAs, had low COTS density because the type of coral dominant in the area was not the preferred food of COTS. Moreover, the consecutive COTS collection done in 2003 and 2007 in the area had significantly affected the present density of COTS.

At the temporal scale, only SMP manifested the real distribution of COTS because it was not subjected to human intervention. In this site, there was no significant seasonality of COTS during April, August, and November. The COTS infestation along the east coast of Samal Island, which occurred in 2003 and 2007, followed a four-year cycle. However, the probable reason for the outbreak was hard to identify. Others have suggested that it could have been due to an increase in temperature and precipitation and decrease in salinity. Historical precipitation data was not conclusive. Moreover, the harvesting of COTS in 2003 could have triggered the outbreak in 2007 due to possible mass spawning during the collection process. However, this needs to be investigated further. The low abundance of the natural predators of COTS in the area is another factor that needs to be considered.

In conclusion, the spatial distribution of COTS is highly dependent on the abundance of their preferred food. In areas with high hard coral cover percentage, a high COTS density can also be observed.

Recommendations

COTS, a major predator of corals, present a threat to the reefs of IGaCoS. Hence, regular monitoring of COTS needs to be conducted to control, if not prevent, outbreaks from occurring. The local government of IGaCoS must initiate a clean-up program. However, collection must be done carefully to avoid mass spawning triggered during the collection process. Increasing the awareness of the local communities on the threat of COTS will encourage them to get involved in the effort.

A follow-up study is recommended to arrive at more conclusive results. The site selection must also be expanded to include not only recreational diving areas around IGaCoS.

Acknowledgment

We would like to thank the people who made this study possible: to the different *barangay* captains who are in charge of the three MPAs for permitting us to conduct this study in their respective areas; to the professors of the Department of Biological Sciences and Environmental Studies in UP Mindanao for their comments and suggestions; to Ms. Shasha Suaybaguio, Ms. Macel Plasabas, and Mr. Art Ballesteros for their help in collecting data; to Ms. Mae Paradela and Mr. Michael Bonghanoy for technical support; and lastly, to CHED ZRC XI and the ICECREAM project of DOST-PCAMRD for providing funding support. This manuscript is based on the undergraduate thesis of the main author.

References

Adam, T.C., R.J. Schmitt, S.J. Holbrook, A.J. Brooks, P.J. Edmunds, R.C. Carpenter, and G. Bernardi. 2011. Herbivory, connectivity, and ecosystem resilience: Response of a coral reef to a large-scale perturbation. PLoS ONE 6(8): e23717.

Alcala, A.C., and G.R. Russ. 2002. Status of Philippine coral reef fisheries. Asian Fish. Sci. 15: 177–192.

Arceo, H.O., M.C. Quibilan, P.M. Aliño, G. Lim, and W.Y. Licuanan. 2001. Coral bleaching in Philippine reefs: Coincident evidences with mesoscale thermal anomalies. Bull. Mar. Sci. 69(2): 579–593.

Birkeland, C.E. 1982. Terrestrial runoff as a cause of outbreaks of *Acanthaster planci* (Echinodermata: Asteroidea). Mar. Biol. 69: 175–185.

Bos, A.R., G.S. Gumanao, and F.N. Salac. 2008. A newly discovered predator of the crown-of-thorns starfish. Coral Reefs 27: 581.

Burke, L., K. Reytar, M. Spalding, and A. Perry. 2011. Reefs at risk revisited. World Resources Institute, Washington, DC.

Carpenter, K.E., and V.G. Springer. 2005. The center of the center of marine shore fish biodiversity: The Philippine islands. Environ. Biol. Fishes 72: 467–480.

Celliers, L., and M.H. Schleyer. 2006. Observations on the behaviour and character of an *Acanthaster planci* (L.) aggregation in a high-latitude coral community in South Africa. Western Indian Ocean J. Mar. Sci. 5(1): 105–113.

Chesher, R.H. 1969. Destruction of Pacific corals by the sea star Acanthaster planci. Science 165: 280–283.

English, S.A., C. Wilkinson, and V.J. Baker. 1997. Survey manual for tropical marine resource. ASEAN-Australian Institute of Marine Science Project, Living Coastal Resources, Townsville, Queensland.

Estremera, S.A. (18 May) 2003. The battle continues. Sunstar Davao. 24 February 2010. http://www.sunstar.com.ph/static/dav/2003/05/18/feat/the.battle.continues.html.

Fraser, N., B.R. Crawford, and J. Kusen. 2000. Best practices guide for crown-of-thorns cleanups. Proyek Pesisir, Jakarta, Indonesia.

Gardner, T.A., I.M. Cote, J.A. Gill, A. Grant, and A.R. Watkinson. 2005. Hurricanes and Caribbean coral reefs: Impacts, recovery patterns, and role in long-term decline. Ecology 86(1): 174–184.

Gevera, M. (24 May) 2007. DENR XI alarmed on proliferation of "dap-ag." Philippine Information Agency. 24 February 2010. http://www.pia.gov.ph/?m=12&sec=reader&rp=1&fi=p070524.htm&no=2&date=05/24/2007.

Glynn, P.W. 1982. Acanthaster population regulation by a shrimp and a worm, pp. 607–612. In: E.D. Gomez, C.E. Birkeland, R.W. Buddemeier, R.E. Johannes, J.A. Marsh Jr., and R.T. Tsuda (eds.). Proceedings of the 4th International Coral Reef Symposium, vol. 2. Marine Science Center, University of the Philippines, Manila, Philippines.

Harriott, V., L. Goggin, and H. Sweatman. 2003. Crown-of-thorns starfish on the Great Barrier Reef. CRC Reef Research Centre, Queensland, Australia.

Hill, J., and C. Wilkinson. 2004. Methods for ecological monitoring of coral reefs: Version 1. Australian Institute of Marine Science, Townsville, Queensland.

Kohler, K.E., and S.M. Gill. 2006. Coral point count with excel extensions (CPCe): A visual basic program for the determination of coral and substrate coverage using random point count methodology. Comput. Geosci. 32: 1259–1269.

Lucas, J.S. 1973. Reproductive and larval biology of *Acanthaster planci* (L.) in Great Barrier Reef waters. Micronesica 9: 197–203.

Mallo, C.P. (24 May) 2007. Coral-eating starfish imperils Davao Gulf. Sunstar Davao. 30 August 2008. http://www.sunstar.com.ph/static/dav/2007/05/24/news/coral.eating.starfish.imperils.davao.gulf.html.

Maltry, A. 2003. The biology and population fluctuations of *Acanthaster planci* on the Great Barrier Reef. 21 July 2008. http://www.biology.iastate.edu/InternationalTrips/1Australia/Australia%20papers/AcanthasterplanciPops.

McManus, J.W., R.B. Reyes Jr., and C.L. Nañola Jr. 1997. Effects of some destructive fishing methods on coral cover and potential rates of recovery. Environ. Manage. 21(1): 69–78

Mellomeda-Quesada, L., J.D. Montera, M.R. Baird, and C.L. Nañola Jr. 2010. Island Garden City of Samal (IGaCoS). Coral Reef Information Network of the Philippines (PhilReefs). State of the Coasts: Promoting the State of the Coast Reporting. Coral Reef Information Network of the Philippines (Phil Reefs), MPA Support Network, Marine Environment and Resources Foundation Inc., and the Marine Science Institute, University of the Philippines, Diliman, Quezon City.

Moran, P.J. 1986. The *Acanthaster* phenomenon. Oceanogr. Mar. Biol. Annu. Rev. 24: 379–480.

Moran, P.J. 1997. Crown-of-thorns starfish: Questions and answers. Australian Institute of Marine Science, Townsville, Queensland.

Nañola C.L. Jr., P.M. Aliño, and K.E. Carpenter. 2011. Exploitation-related reef fish species richness depletion in the epicenter of marine biodiversity. Environ. Biol. Fishes 90: 405–420.

National Climatic Data Center (NCDC). 2012. Climate data online. 30 July 2012. http://www7.ncdc.noaa.gov/CDO.

National Oceanic and Atmospheric Administration (NOAA). 2009. Ocean explorer. 21 March 2010. http://oceanexplorer.noaa.gov/explorations/03mex/logs/ask/media/belt_transects.html.

Nybakken, J.W. 1997. Marine biology: An ecological approach. 4th ed. Addison-Wesley, Boston, MA.

Palacio, R. (5 June) 2007. DENR raises alarm vs. starfish. Philippine Information Agency. 24 February 2010. http://www.pia.gov.ph/?m=12&fi=p070605.htm&date=06/05/2007.

Pratchett, M.S. 2007. Feeding preferences of *Acanthaster planci* (Echinodermata: Asteroidea) under controlled conditions of food availability. Pacific Sci. 61(1): 113–120.

Veron, J.E.N., L.M. Devantier, E. Turak, A.L. Green, S. Kininmonth, M. Stafford-Smith, and N. Peterson. 2009. Delineating the coral triangle. Galaxea, J. Coral Reef Studies 11: 91–100.

Westmacott, S., K. Teleki, S. Wells, and J. West. 2000. Management of bleached and severely damaged coral reefs. IUCN, Gland, Switzerland, and Cambridge, UK. 6:37.