Journal of Ecosystem Sciences and Eco-Governance (JESEG)
www.jeseg.carsu.edu.ph

Vol. 4, No. 1 | June 2022
PRINT ISSN 2704 4394 | ONLINE ISSN 2782 8522
DOI: https://doi.org/10.54610/jeseg/4.1.2022.003

Crown-of-Thorns starfish (COTS) outbreak in Sogod Bay, Southern Leyte, Philippines

Gladys Ludevese-Pascual[1,], Jerome Jack O. Napala[1], Ryan P. Tomol[1], Lara Jessa L. Oyong[1], Jovie Marie P. Alfante[2] and John Philip Lou M. Lumain[2]*

[1]Bioresource Production Technology Center (BioProTeC), Southern Leyte State University-Bontoc, San Ramon Bontoc Southern Leyte, Philippines.

[2]College of Veterinary Medicine, Visayas State University, Visca, Baybay City, Leyte, Philippines

*Corresponding Author
*Email:glpascual@yahoo.com
Received: March 29, 2022
Revised: June 16, 2022
Accepted: June 28, 2022
Available Online: June 29, 2022

Cite this article: Pascual, G.L., Napala, J.J.O., Tomol, R.P., Oyong, L.J.L., Alfante, J.M.P., & Lumain, J.P.L.M. (2022). Crown-of-Thorns starfish (COTS) outbreak in Sogod Bay, Southern Leyte, Philippines, *Journal of Ecosystem Science and Eco-Governance*, **4**(1):24-30.

A B S T R A C T

Sogod Bay is known for its high diversity and abundance of hard coral. However, this resource is under threat due to the coral predator, crown-of-thorns starfish (COTS) *Acanthaster* spp. The findings of 2021 COTS outbreaks in reefs belonging to territorial waters of Liloan, Libagon, San Francisco, Malitbog, and Padre Burgos, Southern Leyte, are reported here. The lowest COTS count was recorded for Padre Burgos while highest in Malitbog with 13 and 20 COTS 100 m^{-2}, respectively, exceeding the outbreak threshold of 0.25 COTS 100 m^{-2}. COTS collected from Malitbog, although highest in number, weighed lightest (251 ± 128g) while heaviest in San Francisco (621 ± 250g). The majority of COTS collected were in the juvenile stage with sizes ranging from 6-15 cm, corresponding to COTS age of 1-2 years. Regarding COTS sexes, the proportion of female COTS was higher relative to male COTS in Padre Burgos and Malitbog while lower in Libagon, Liloan, and San Francisco. A trend in the low total count of COTS regenerating arm was observed, indicative of the absence of COTS predator. Overall, the findings of this study imply that the COTS outbreak in Sogod Bay is a recurring phenomenon. Thus management efforts should be directed into areas with the over-the-outbreak threshold of COTS. The large quantities of COTS observed in Sogod Bay, Southern Leyte would further necessitate an improved management strategy, to reduce the detrimental impact of COTS outbreaks in the reef ecosystem. Periodic monitoring of COTS along Sogod Bay is recommended to reveal the extent of damage and potential clean-up efforts. Conduct of trainings to include Information, Education, and Communication (IEC) campaign to municipalities categorized under active outbreak status is also recommended. Finally, studies are warranted to look into COTS population replenishment, and outbreak drivers.

Keywords: *Coral reef, corallivore, aggregation, disc diameter, arms*

1 Introduction

Outbreaks of the corallivorous crown-of-thorns starfish (COTS, *Acanthaster* spp.) present one of the major large-scale acute disturbances that have caused persistent and widespread loss of coral cover across Indo-Pacific coral reefs (Kroon et al., 2021). Known to be one of the largest and most efficient predators of scleractinian corals (Birkeland 1989), coral-feeding adults (20-35 cm diameter) are reported to have the highest predation rates (150 to 250 cm^2 day^{-1}) and demonstrate prey preference for branching and table corals but could also prey upon most coral species (Kayal et al. 2012; Pratchett et al. 2017). A reef system with approximately 40-50% live coral cover may be

able to support 20-30 COTS per hectare (Harriott et al., 2003). However, during an outbreak (≥ 30 adult COTS hectare^{-1}; Dixon 1996), the coral consumption of COTS exceeds coral growth (Grand et al., 2014). These coral-feeding adults are characterized by high predation rates, alongside large aggregations, and outbreaks often result in the collapse of an entire colony leading to devastating ecological impacts on reef systems on both short and long-term timescale (Elston and Dallison, 2019). COTS outbreaks have been occurring across Philippine archipelago, including the Eastern Visayas (Inopacan, Leyte and Southern Leyte), Central Visayas (Bohol); Mindoro (Apo Reef and Puerto Galera), Sulu Sea (Tubbataha reef) and Davao Del Norte (Samal Island) as mentioned by De Dios et al. (2014). While various methods have been employed in controlling outbreaks of COTS worldwide, i.e., manual extraction and burying of COTS ashore, injection with either formalin, copper sulphate, ammonium hydroxide, sodium bisulphate (dry acid), or acetic acid, and underwater fencing to avoid movements, most of these control measures are either detrimental to coral reefs, expensive to implement or time-consuming (De Dios and Sotto, 2015).

Sogod Bay (10° 12' N, 125° 12' E), a large bay in the southern part of Leyte, Philippines, is characterized by a rich diversity of marine habitats, including mangrove forests, narrow fringing coral reefs, and seagrass beds (Calumpong et al., 1994). Bordered by 11 municipalities: Padre Burgos, Malitbog, Tomas Oppus, Bontoc, Sogod, Libagon, Liloan, San Francisco, Pintuyan, and San Ricardo with islands of Limasawa also forming part of the bay. Sogod Bay has become a popular tourist destination and a tourist favorite diving site. It has been mentioned by Taylor et al. (2004) that Sogod Bay remains to have some of the least disturbed coral reef habitats in the Philippines. To date, a total of 257 species of hard corals were identified with *Favia* spp. as the most abundant coral species in Sogod Bay (Dallison and Tyley, 2021). Hence, it has become an important fishing ground as the area is rich in tuna, flying fish, herrings, anchovies, shellfish, lobsters, and Spanish mackerel.

However, the rich coral reef ecosystem in Sogod Bay appeared to be susceptible to various threats, including COTS that are often abundant in shallow waters (< 12 m depth, Taylor et al., 2004). The first report of a massive COTS infestation in reefs off Malitbog, Tomas Oppus, and Limasawa was in 2002 (De Dios et al., 2014) and again in Limasawa in 2004 (van Bochove et al., 2011). COTS outbreaks were reported in 2012 and 2014 (De Dios et al., 2014) and, recently, in 2019 (Elston and Dallison, 2019). Considering that no COTS outbreaks in Sogod Bay were reported in succeeding years, this paper aims to give a follow-up report on the COTS outbreaks in Sogod Bay; and to determine the life stages (e.g., early juvenile, juvenile, subadult, and adults) and proportions of female to male COTS along with other basic morphometric parameters in various collection sites in 5 municipalities in Sogod Bay, Southern Leyte, Philippines. Findings from this study are essential as to improved management efforts to reduce the detrimental impact of COTS outbreaks in the reef ecosystem in Sogod Bay.

2 Materials and Methods

Study Sites

Based on logistics, historical, and COTS sighting reports from coastal communities in Sogod Bay, five main sites were selected: Padre Burgos, Malitbog, Libagon, Liloan, and San Francisco (Figure 1). These sites are characterized by a mix of coral life forms, ranging from branching to foliose and massive (De Dios et al., 2014). Permission from the local government units (LGUs) and from the provincial government was secured before conducting the field survey. Upon visual inspection and cursory assessment, the main collection site within each municipality was determined based on the highest COTS aggregation.

Sampling

COTS population was assessed from July 26, 2021, to August 9, 2021. Two stages were employed based on the works of Miller et al. (2009). Firstly, a manta tow survey to provide a general description of the coral reef ecosystem and to gauge broad changes in abundance and distribution of COTS within the reef. Based upon findings of the Manta tow, the second stage involving a SCUBA search was employed (Figure 2a). This collection is to provide quantitative measures of the abundance of COTS. This stage is also advantageous as it allows detection of juvenile COTS, which are cryptic and could not be observed during manta tow. Using sticks, COTS were carefully collected and immediately placed in rice/flour bags/plastic crates and brought

to the boat or shore for further examination and measurement following the protocols described by Gianguzza et al. (2015). Extra care was taken during the collection process as stress may induce COTS to spawn (Fraser et al. 2000). After measurement, COTS were eradicated by burying in the sand in areas not reached by tides (Figure 2b).

Measured parameters

After manual extraction, the count of COTS in each collection site was recorded. Criteria for determining types of COTS outbreaks are based on Englehardt (1997). COTS age was approximated according to Miller et al. (2019) (Table 1).

During age approximation, COTS were positioned on its aboral side (spines facing down), allowing its arms to settle flat. The longest ventral diameter was measured with a measuring tape to estimate COTS age.

The COTS were weighed to the nearest 0.01 g with an electronic precision balance (A & D Apollo GF-2002A Precision Balance, 2, 200g capacity). The number of whole and undamaged arms, including short, regenerating arms, was manually counted. The procedures of Caballes and Pratchett (2014) were employed to determine the sexes. An incision was made along one of the COTS arms, and approximately a quarter teaspoon of gonads was removed. Male gonads are light yellow to beige, while female gonads are orange to yellow.

Data analysis

Descriptive statistics were used to analyze the data, and values were presented as means ± SD. Graphic presentations of results were carried out with Microsoft Excel 2016.

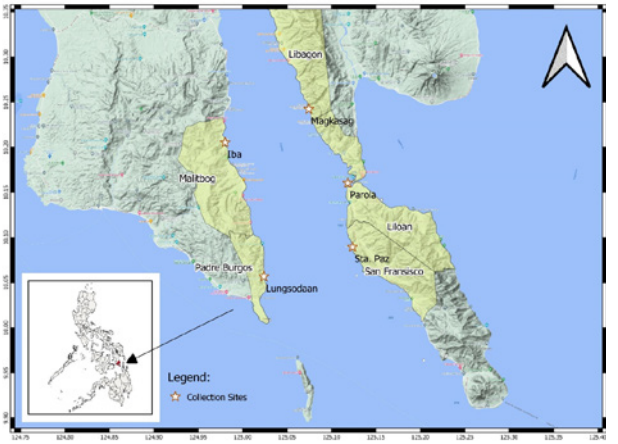

Figure 1. Map showing the various crown-of-thorns starfish (COTS) collection sites (★) in 5 municipalities in Sogod Bay, Southern Leyte, Philippines

Figure 2. SCUBA-assisted manual extraction of crown-of-thorns starfish (COTS) in various collection sites in 5 municipalities in Sogod Bay, Southern Leyte, Philippines (a); burying of COTS after measurement (b)

3 Results and Discussion

Similar to the observation of Taylor et al. (2004) that COTS in Sogod Bay appear in shallow waters (< 12 m depth), all COTS were extracted at an average depth of 10 m. The lowest COTS count was recorded in Padre Burgos while the highest in Malitbog with 40 and 61 COTS, respectively, equivalent to 13 and 20 COTS 100 m^{-2} (Table 2). COTS collected from all sites exceeded the outbreak threshold of 0.25 COTS 100 m^{-2} (Elston and Dallison, 2019). While the primary reason for the COTS outbreak inside Sogod Bay is still unknown, De Dios et al. (2014) hypothesized that larval seeding from outside the bay via tidal current may have resulted in COTS population replenishment. The presence of the corallimorph, *Paracorynactis* sp., believed to help reduce COTS population (De Dios and Sotto 2015), that was found in reef areas in Padre Burgos back in 2014 (De Dios et al. 2014) was not observed in the present study. Removal via overfishing of important COTS predators may also contribute to the uncontrolled COTS population in Sogod Bay.

It can be noted that among the five sites surveyed, Malitbog has the highest total number of COTS collected (20 COTS 100 m^{-2}), and this was higher than the COTS population recorded in 2014 (15 COTS 100 m^{-2}, De Dios and Sotto, 2015) and 2019 (8 COTS 100 m^{-2}, J Dimzon, *personal communication*). This area has been consistently reported with mass COTS infestation since 2002 (Figure 3). Further study is warranted to determine outbreak drivers as the reef ecosystem in Malitbog is reported to be primarily patchy (De Dios et al., 2014).

Most of the COTS collected were in the juvenile category with sizes ranging within the 6-15 cm mean disc diameter, corresponding to COTS age of 1-2 years (Table 3). The relatively smaller COTS sizes observed in the present study as compared to the reported COTS sizes of 13-32 cm by De Dios and Sotto (2015) may indicate that the COTS outbreak recorded in 2021 may be due to a single annual cohort as opposed to multiple cohorts as suggested by De Dios and Sotto (2015). According to Bos et al. (2013), the spawning season of COTS in the Philippines could occur between March-May. Because most of the COTS size in the present study corresponds to the juvenile stage, the removal of juvenile COTS as employed in the present study may be timely as it decreases the chance of larval seeding.

In terms of COTS sexes, female COTS was higher in number relative to male COTS in Padre Burgos and Malitbog, while this proportion was lower in Libagon, Liloan, and San Francisco (Figure 4). The implications of these findings warrant further study. As Caballes and Pratchett (2014) mentioned, in gonochoric and broadcast spawning species such as COTS, males are more sensitive to spawning cues such as temperature change, reduced salinity, and nutrient enrichment of seawater and phytoplankton. In terms of COTS weight, COTS collected from San Francisco were heaviest (621 ± 250g), while COTS collected from Malitbog, although highest in number (20 COTS 100 m^{-2}), weighed lightest (251 ± 128g). It is unclear whether

Table 1. Crown-of-thorns starfish (COTS) age approximation

Disc diameter (cm)	Age estimate	Category
≤ 5	Less to one (1) year	J (Early Juvenile)
6-15	One (1) to two (2) years	A (Juvenile)
15-25	Two (2) to three (3) years	B (Sub-adult)
> 25	Three (3) plus years	C (Adult)

Table 2. Survey area, depth, counts and status of crown-of-thorns starfish (COTS) in various collection sites in 5 municipalities in Sogod Bay, Southern Leyte, Philippines

Municipalities	Collection site	Survey area (m^2)	Max. depth (m)	Total no. of COTS collected	No. of COTS in 100 m^2	Status
Padre Burgos	Lungsodaan	300	10	40	13	Outbreak
Malitbog	Iba	300	8.5	61	20	Outbreak
Libagon	Magkasag	500	10	61	12	Outbreak
Liloan	Parola	1000	8.5	50	5	Outbreak
San Francisco	Sta. Paz	300	13	43	14	Outbreak

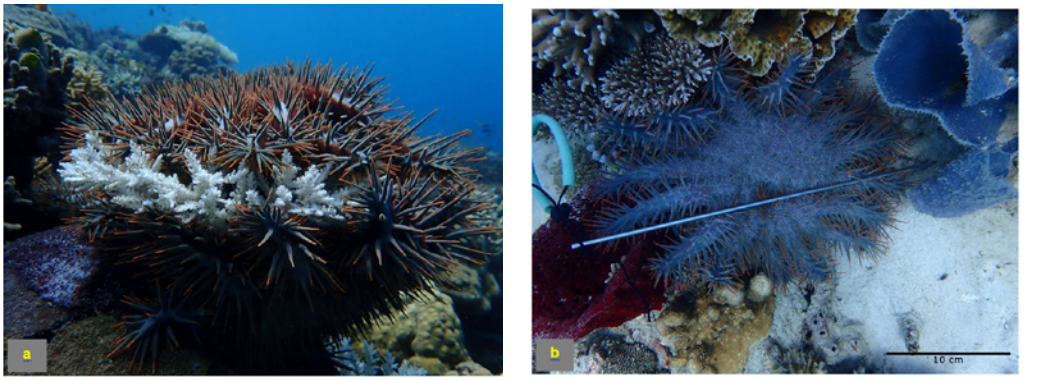

Figure 3. Representative photos (or samples) of the collected crown-of-thorns starfish (COTS) from Brgy. Iba, Malitbog, Southern Leyte, Philippines. Large COTS aggregations can lead to the collapse of an entire coral colony (a). An adult COTS (20-35 cm diameter disc diameter) approximately 3 years plus (b)

Table 3. Counts, disc diameter, age estimate and category of crown-of-thorns starfish (COTS) in various collection sites in 5 municipalities in Sogod Bay, Southern Leyte, Philippines. Values are presented as means ± SD

Municipalities	Total no. of COTS collected	Disc diameter (cm)	Age estimate	Stage
Padre Burgos	40	11.91 ± 4.43	One (1) to two (2) years	Juvenile
Malitbog	61	9.55 ± 2.01	One (1) to two (2) years	Juvenile
Libagon	61	11.50 ± 2.32	One (1) to two (2) years	Juvenile
Liloan	50	11.75 ± 2.16	One (1) to two (2) years	Juvenile
San Francisco	43	13.57 ± 2.64	One (1) to two (2) years	Juvenile

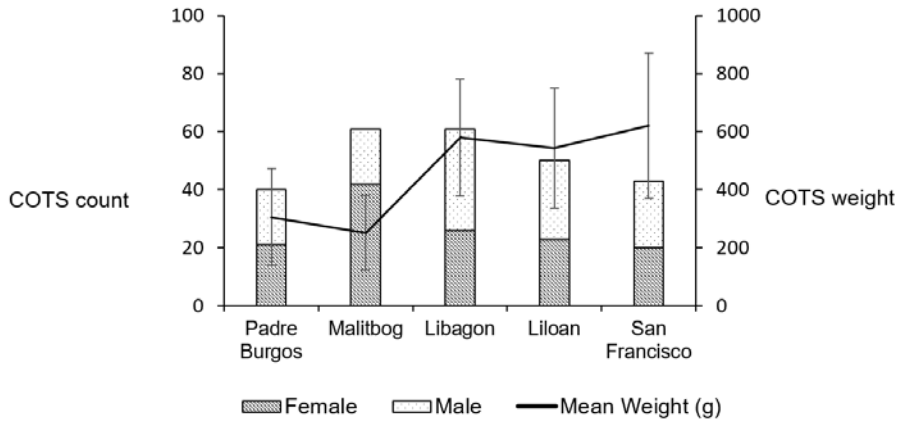

Figure 4. Proportion of female and male crown-of-thorns starfish (COTS) and weight (means ± SD)

the patchy nature of corals in Malitbog (De Dios et al., 2014) may have contributed to the observed lighter weight conditions of the COTS in the area.

Mean COTS arm count ranged from 6-9 (Table 4), which is typical for COTS in the juvenile stage and can reach up to 10-20 arms in the adult stage (Deaker and Byrne, 2022). The trends in the highest mean counts of COTS arms recorded in San Francisco could yield a competitive advantage as each of its arms contains advanced eyes allowing them to integrate a wide field of view of its surroundings (Petie et al., 2016). The trends in the COTS regenerating arm's low total count could indicate the absence of COTS predators. The length

Table 4. Total arm count, regenerating arm count; and length and width of longest and shortest arms of crown-of-thorns starfish (COTS) in various collection sites in 5 municipalities in Sogod Bay, Southern Leyte, Philippines. Values are presented as means ± SD

Sampling Sites	Total no. of COTS collected	Total count of arm	Total count of regenerating arm	Longest arm		Shortest arm	
				Length (cm)	Width (cm)	Length (cm)	Width (cm)
Padre Burgos	40	7.82±2.33	0.55	7.82 ± 2.33	1.85 ± 0.65	4.49 ± 1.29	1.49 ± 0.52
Malitbog	61	6.70±1.33	0.93	6.70 ± 1.33	1.98 ± 0.49	3.77 ± 0.98	1.76 ± 0.35
Libagon	61	8.86±2.05	1.44	8.86 ± 2.05	2.86 ± 1.04	5.26 ± 1.67	2.03 ± 0.60
Liloan	50	8.43±1.71	0.46	8.43 ± 1.71	2.57 ± 0.70	5.57 ± 1.33	2.32 ± 0.58
San Francisco	43	9.00±2.61	0.84	9.00 ± 2.61	2.93 ± 0.82	5.67 ± 1.45	2.45 ± 0.57

and width of the longest and shortest COTS arms are also provided in Table 4.

Overall, the findings of this study imply that the COTS outbreak in Sogod Bay has become a recurring phenomenon. Thus management efforts should be directed into areas with over-the-outbreak threshold of COTS. Findings from this study are essential for improved management efforts to reduce the detrimental impact of COTS outbreaks in the reef ecosystem in Sogod Bay. Further studies to look into COTS population replenishment and outbreak drivers are also essential in developing well-informed decision tools to produce counterproductive management outcomes, as mentioned by Wilmes et al. (2020). Finally, periodic monitoring of COTS along Sogod Bay is recommended to reveal the extent of damage and potential clean-up efforts to reverse impacts on reef ecosystems. Conduct of trainings to include Information, Education, and Communication (IEC) campaign to municipalities categorized under active outbreak status is also recommended.

4 Conclusion and Recommendations

The paper provides updates on the status of COTS outbreaks in Sogod Bay. All survey sites exceeded the outbreak threshold of 0.25 COTS 100 m^{-2}, thus declared under the outbreak category. Since the COTS outbreak in Sogod Bay has been a recurring phenomenon, periodic monitoring of COTS along Sogod Bay is recommended to reveal the extent of damage and potential clean-up efforts. Conduct of trainings to include Information, Education, and Communication (IEC) campaign to municipalities categorized under active outbreak status is also recommended. Further studies on COTS population replenishment and outbreak drivers are also warranted.

5 Acknowledgement

The project received funding support from the Department of Science and Technology-National Research Council of the Philippines (DOST-NRCP) through the Science and Technology Experts' Pool (NSTEP) Research Grant.

Statement of Conflict of Interest

The authors declare no conflict of interest associated with the submission and publication of this manuscript.

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