

The first dedicated
Carpe Diem &
Coral Reef CPR
crown of thorns starfish
removal in the Maldives

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Georgia Coward
Anderson Mayfield
Andrew Bruckner



Executive Summary

Carpe Diem Maldives Pvt. Ltd. in partnership with **Coral Reef CPR** completed a week-long crown of thorns starfish removal effort involving seventeen recreational divers from nine countries. Over a one week period the Carpe Diem safari vessel collected a total of 900 COTS from 15 reefs on North Malé and South Malé Atolls. In most cases the reefs had a low density of starfish, although larger outbreaks were recorded at several reefs, notably Black Coral Reef, Veli G'andu, stage reef and Hudeli Bodi Giri. The team was able to remove all of the starfish seen on twelve of the reefs, while three reefs with larger outbreaks require additional return clean-up efforts to fully eradicate starfish from the aforementioned reefs.

Clean-up efforts undertaken during this period are much more challenging than previous efforts, partially due to poor visibility and rough seas, and more importantly because the starfish are no longer aggregated in restricted areas. During the onset of the outbreaks in 2013-2015, affected reefs had very high coral cover and the starfish typically formed a front consisting of hundreds to thousands of animals. Once the starfish consumed most of the coral, they spread out in search of food, and are now widely dispersed through outer reef environments. In most cases the starfish were not actively feeding, as there is very little surviving coral due to large losses sustained during the 2016 bleaching event. As a result, most starfish were found feeding on less preferred species such as *Porites lobata*, *Porites rus*, faviid corals, and free-living fungiids. However, in locations where more *Acropora* survived, they were congregating on the remaining corals, severely decimating those colonies that are more tolerant to higher sea water temperatures and are the key to rapid recovery of Maldivian reefs.

This effort demonstrated that crown of thorns starfish removal can be undertaken at a very low cost in a safe and effective manner relying on assistance from recreational divers alongside trained marine biologists and dive masters.



Carpe Diem Safari Vessel was used to mobilize the dive team to collection sites

Aknowledgements

The trip would not have been such a success without the incredible team aboard the Carpe Diem. The enthusiasm, skill and friendliness of all the dive masters made this trip run with ease and at the highest safety standard, and most importantly made the trip fun for everyone! Coral Reef CPR would like to personally thank Carpe Diem's Managing Director, Agnes van Linden, for all of her hard work in organizing the trip and her ambition to conduct this trip. The Carpe Diem dive leaders, dive masters and instructors, including Inthi, Hussein, Athau, Raif, Chakku, Zinah, Farish and Abdullah were instrumental in making this a safe and successful mission. Thanks to everyone in the Maldives who assisted the team in finding locations that currently had crown of thorns starfish outbreaks. Finally, this trip would not have been possible (or as fun) without the recreational divers that joined the liveaboard. It was wonderful to have 17 divers opt to dive with a difference, and join us on this removal week.



Participants of the first Carpe Diem Pvt. Ltd. and Coral Reef CPR dedicated crown-of-thorns starfish (COTS) clean-up mission

Introduction

Crown of thorns starfish (COTS)

The crown of thorns starfish (COTS; *Acanthaster planci*) is an echinoderm in the family *Acanthasteridae*. They are closely related to sea urchins, and are normal inhabitants of coral reefs in the Indo-Pacific Ocean and Red Sea. These large starfish can have up to 22 arms and adults can attain a size of 80cm. COTS have a central disc and mouth located on the underside of their body with rows of tube feet with suckers covering their arms. Their aboral surface (top) is covered with 3-5 cm long, venomous spines.

These starfish are the most voracious coral predator found on shallow water tropical coral reefs. They have destroyed entire reef systems during severe outbreaks. A single COTS will eat one coral every day and can consume all of the corals within a 6-10 square meter area within one year. Under 'normal' circumstances, COTS occur at low densities on a reef, and when uncommon, they serve a key role, increasing coral diversity by preventing common fast-growing corals from taking over. Unfortunately, COTS outbreaks appear to be increasing in frequency and distribution and appear to be less selective, consuming both their preferred species of corals – the fast growing branching and plating corals - as well as the longer-lived, slow growing massive corals that form the framework of reefs. Fluctuations in COTS abundance may also be related to their life-history characteristics, such as their high fecundity, short generation times, highly-defended spine-covered body, remarkable ability to regenerate detached arms, ability to go for prolonged periods without feeding, and tendency to aggregate.



An aggregation of COTS destroying table corals (*Acropora*) on North Malé Atoll in 2015

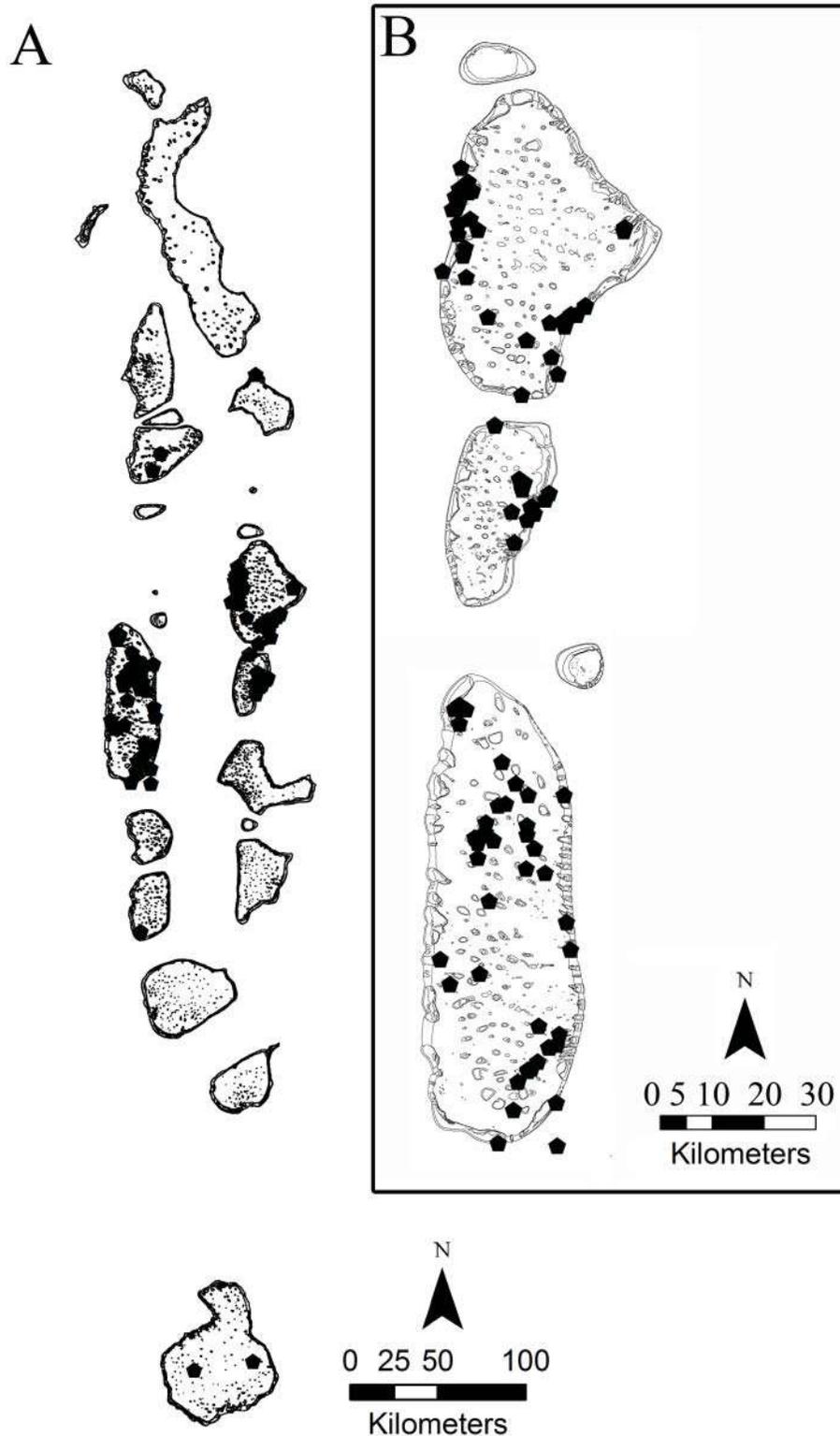


The aboral surface showing the spines



The oral surface and its everted stomach

The current outbreak in the Maldives emerged in 2013 on the western side of North Male Atoll, and has spread throughout the atoll and to Ari Atoll and South Male Atoll, with localized outbreaks in eight other atolls. The starfish have devastated entire reefs, and they continue to spread, re-emerging after the 2016 coral bleaching event. More information on COTS outbreaks in the Maldives can be found in our 'Crown of Thorns Technical Manual', available at coralreefcp.org



Locations of reported outbreaks throughout the Maldives between 2013-2016

Removing crown of thorns

The need to remove outbreaks

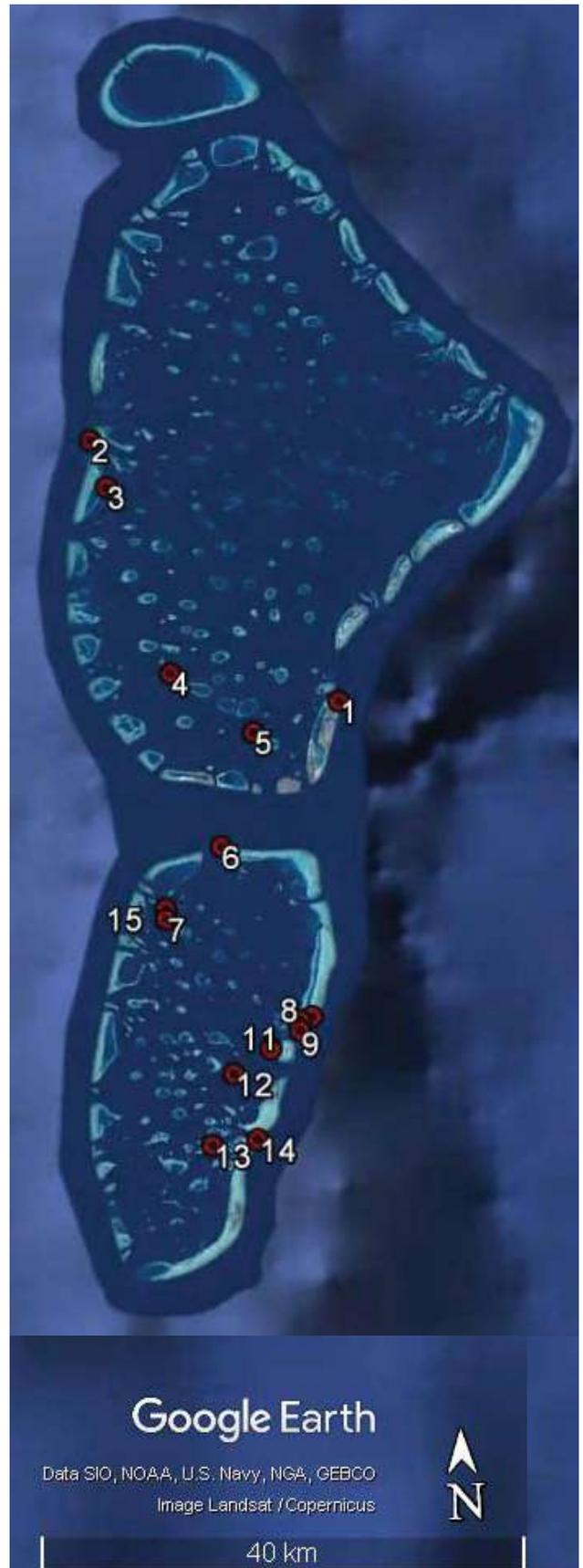
It is critical that COTS are removed from Maldivian reefs both further destruction of the corals that survived the 2016 bleaching event, and to reduce the potential for successful reproduction and future outbreaks. Reproduction occurs annually through broadcast spawning, where the starfish release eggs and sperm into the water column synchronously. Under 'normal' conditions, the majority of resulting larvae typically die due to food limitations or become prey for planktivorous fishes. However, if there are unnaturally high levels of nutrients that trigger plankton blooms, the increased food availability for COTS larvae may allow many more to survive and settle onto the reef. One animal at full size can produce more than 60 million eggs each year, and survival is greater when there are more COTS in close proximity.

Carpe Diem and Coral Reef CPR COTS removal trip

From May 13 to 20, 2017 seventeen recreational divers from nine different countries joined the first dedicated COTS removal trip. Over the week, 15 different reefs were dived throughout North and South Malé Atolls (right). These ranged from sand banks, outer reefs, channels, deep pinnacles and giri formations.

Table 1. Reefs surveyed for COTS in May, 2017

ID	Reef Name	Latitude	Longitude
1	Back Faru	4.237778	73.55283
2	Bodu Hithi Thila	4.453528	73.36292
3	Giri	4.414861	73.37486
4	Black Coral Reef	4.264583	73.42178
5	Feydhoo Wall	4.215861	73.48531
6	Vaadoo Caves	4.128028	73.45772
7	Veli G'andu	4.074278	73.41367
8	Miyaru Faru	3.993972	73.51428
9	Gulhi Faru	3.986583	73.51389
10	Stage	3.996583	73.52339
11	Kuda Giri	3.973639	73.49106
12	Big Sand Bank	3.956028	73.46236
13	Vilivaruru Giri	3.903556	73.44442
14	Kandooma Thilla	3.906667	73.47894
15	Hudeli Bodi Giri	4.08225	73.41364





A diver holding a crown of thorns starfish with a PVC pipe

We conducted manual removal of the starfish, as this has the fewest negative consequences to the reef and involves the lowest cost. We used a hollow PVC tube, approximately 60 cm long and 0.5 inch diameter, with one end cut at a 45 degree angle. Our divers worked in small teams, each with a dive master. Starfish were collected and carefully placed into large mesh bags with an aluminum or stainless steel handle.

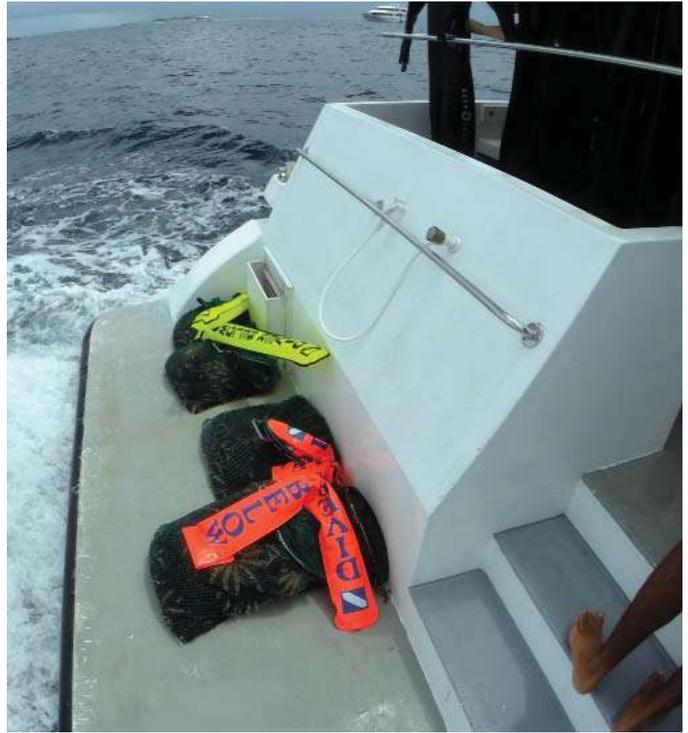


A diver transporting a bag of crown of thorns starfish

Lift bags were attached to the handle to increase swimming efficiency as the bags fill up, and once they were full, the bags were inflated and sent to the surface. This method minimizes the risk of injuries associated with divers transporting the bags on the surface, especially when there is swell and/or currents. COTS were only removed on snorkel at one site (Hudeli Bodi Giri).

Once the COTS were on board the diving *dhoni*, they were counted and placed in large plastic tubs with lids. The starfish were buried on islands every night. Coral Reef CPR scientists also sampled a subset of each reef's starfish for genetic analysis.

Several bags of starfish on the aft deck of the Carpe Diem



Carpe Diem dive masters are emptying collection bags

Two buckets containing nearly 125 starfish removed from one reef



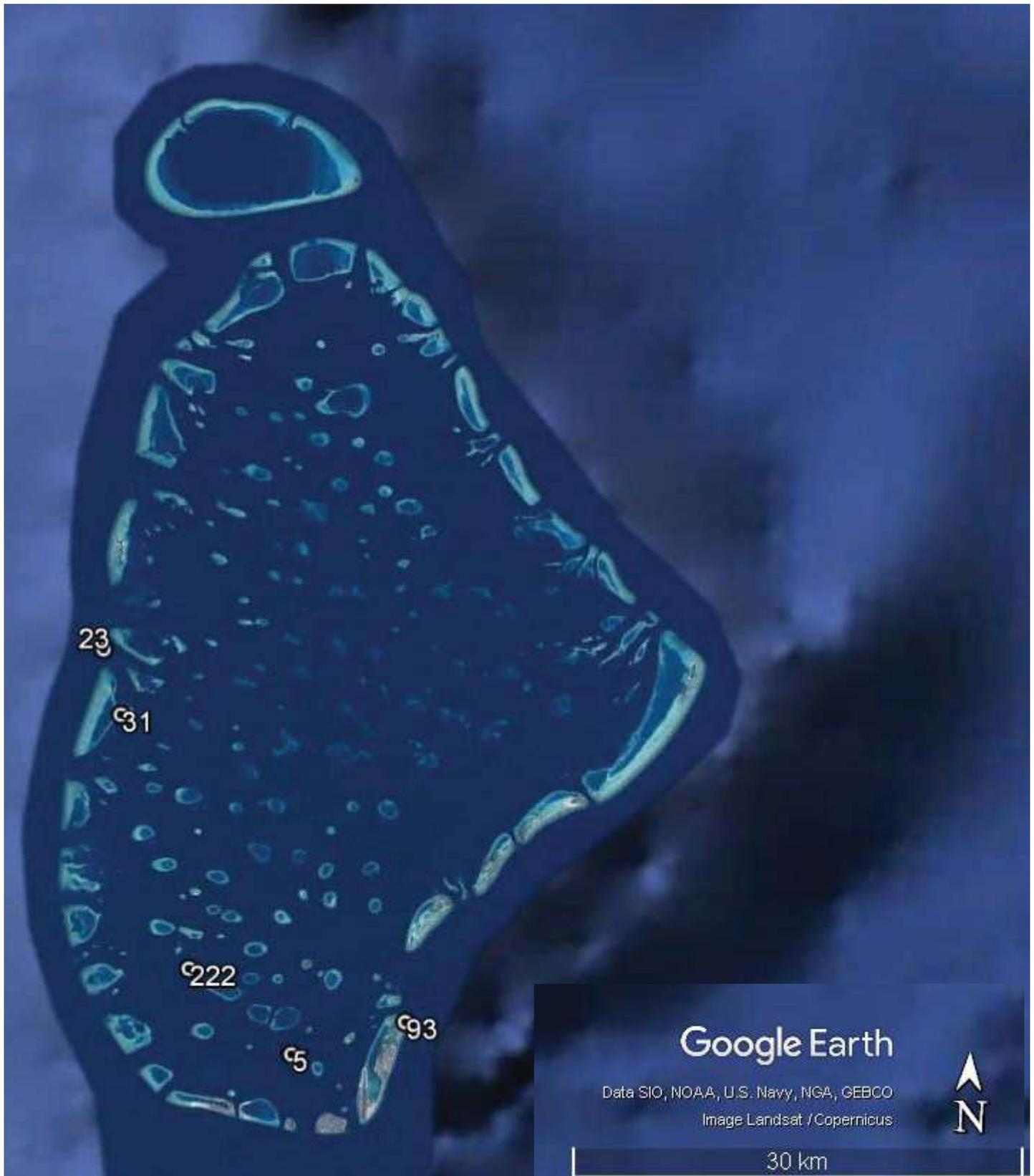
ID	Reef Name	Number of COTS removed
1	Back Faru	93
2	Bodu Hithi Thila	23
3	Giri	31
4	Black Coral Reef	222
5	Feydhoo Wall	5
6	Vaadoo Caves	4
7	Veli G'andu	227
8	Miyaru Faru	0
9	Gulhi Faru	0
10	Stage	106
11	Kuda Giri	0
12	Big Sand Bank	60
13	Vilivaru Giri	1
14	Kandooma Thilla	0
15	Hudeli Bodi Giri	128
Total		900



Numbers of COTS removed from each reef

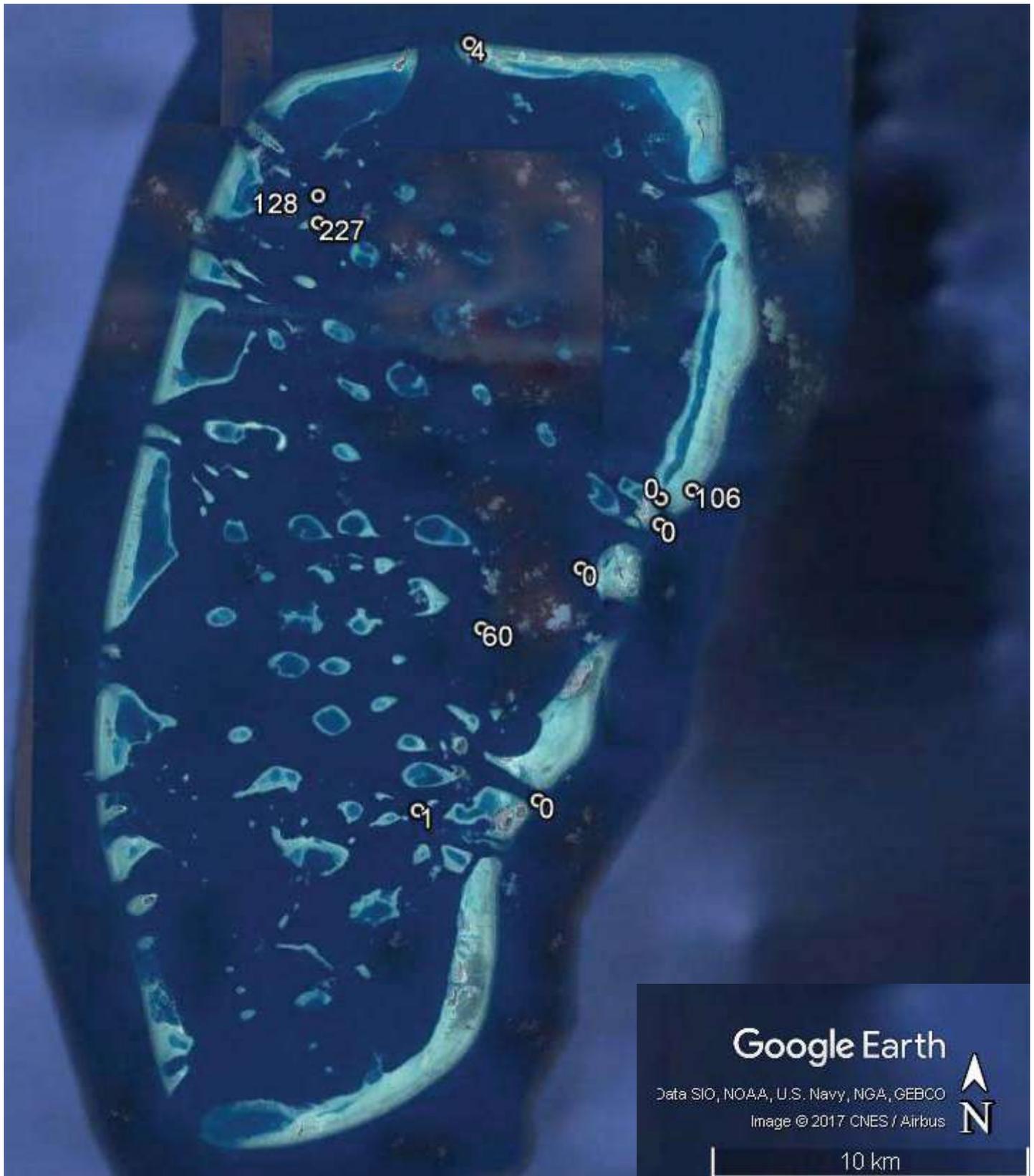


Steps in collecting crown of thorns starfish



Total numbers of COTS removed from reefs on North Malé Atoll.

Over the 5.5 diving days, a total of 900 COTS were removed. The highest number of starfish were collected at sand bank reefs, particularly Black Coral Reef, Big Sand Bank and Hudeli Bodi Giri. Starfish were not restricted to specific depths, occurring wherever there was coral. Collection occurred from 0.5m to 30m deep. At every site, except Hudeli Bodi Giri, the COTS were spread out over the reef.



Total numbers of COTS removed from reefs on South Malé Atoll.

This was different from the original outbreaks observed between 2013-2015, when thousands of COTS occurred on single reefs at densities of 5-10 per square meter. One of the main differences is that their preferred food has been greatly diminished and as a result the starfish have spread out in search of living coral. Most of the COTS were not actively feeding when collected, however when feeding, the starfish were generally found on *Acropora*, *Porites*, faviids and fungiids.

Implications of the effort

A single starfish will eat one coral per day, approximately the size of its body, and up to 8 square meters of coral reef per year. The starfish will feed on coral from about 6 months to one year in age until they are 8-10 years old. Based on these estimates, the removal of 900 starfish saved approximately 10,000 square meters of reef from predation.

In addition to the overall reduction in coral loss, removal of starfish from the Maldives reefs at this time is especially important, as there is very little remaining live coral following the catastrophic losses during the 2016 mass bleaching event. Those corals that did survive the bleaching will provide the seed stock to rejuvenate these reefs. In addition these are the corals that resisted the higher temperatures and they may be stronger and better able to cope with future periods of abnormally warm water.

During this mission, COTS were found feeding on many of their less preferred species that normally escape predation, such as *Porites*. These massive boulder corals grow much more slowly than their preferred branching species, and they produce fewer larvae. Their loss can affect the structure of the reef, as these are the corals that form the framework, and recovery could take decades to centuries.

Small colonies of branching *Acropora*, as well as surviving remnants of these species were a primary targets of the starfish, as these are their preferred food items. These corals sustained the highest degree of mortality from bleaching (80-95% loss) and the few survivors are critical for reef recovery.



A starfish that ate >80% of a massive favid coral (*Goniastrea*). Only the base (brown area) is still living.



A large *Porites lobata* being preyed on by a starfish. There are four circular lesions that each represent one day of feeding.

A starfish feeding on the few remaining branches of staghorn coral. These survived the bleaching event and are now succumbing to predation



Education and Outreach

In addition to the COTS removal dives, marine ecology workshops were given each evening to the divers. Topics ranged from coral reef threats, shark biology, fish identification and the ecology of COTS. These were always well attended, and offered a good opportunity to questions and discussions on key topics of marine conservation and ecology.



Summary and future plans

This trip has demonstrated that it is easy and safe to run a crown of thorns starfish removal trip with a team of recreational divers, provided they receive thorough briefings in safe handling and collection practices. Divers are very interested in a new opportunity and to dive with a purpose, and they greatly increase the efficiency of collection. Through the use of a larger team, it is possible to cover multiple depths of the reef, from shallow snorkeling depths to the base of the reef system in a systematic manner.

We are currently planning additional COTS removal trips, and plan to make this a regular trip.

List of participants

Name	Position	Country
Agnes van Linden	Carpe Diem pvt. – Managing Director	Maldives
Andrew Bruckner	Coral Reef CPR Director	USA
Georgia Coward	Coral Reef CPR – Coral Reef Ecologist	UK
Anderson Mayfield	Coral Reef CPR – Coral Reef Ecologist	USA
Karin Anne-Marie Blomfeldt	Diver and medical support	Sweden
Lars Richard Erik Blomfeldt	Diver and medical support	Sweden
Sarah Blomfeldt	Diver and medical support	Sweden
Trevor Woolmore	Diver	UK
Tracey Woolmore	Diver	UK
Naoko Machida	Diver	Japan
Fiona Gordon	Diver	Australia
Ben	Diver	Australia
Robert Thomas	Diver	UK
Anna Negm	Diver	Russia
Anne Wharmby	Diver	UK
Patrik Boesch	Diver	Switzerland
Douwe Theodoor De Graaf	Diver	Netherlands
Hubert Baumann	Diver	Germany
Nils Baumann	Diver	Germany
Naoko Machida	Diver	Japan
Daniel Oskar Frick	Diver	Switzerland