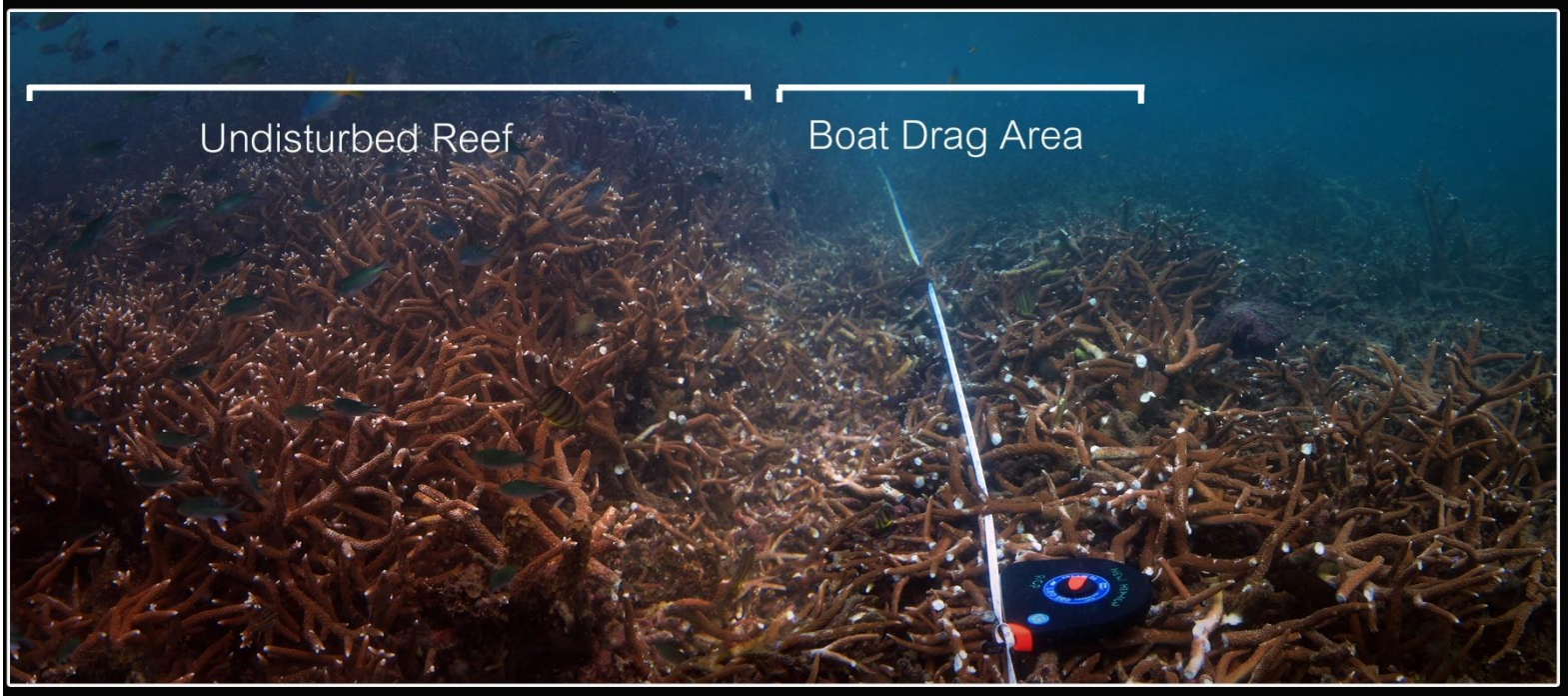
Incident Report and Restoration Overview:
Boat Grounding, Chalok Ban Kao Reef
January 27th, 2015



Technical Report

Incident Report and Restoration Overview Boat Grounding: Chalok Ban Kao Reef January 27th, 2015

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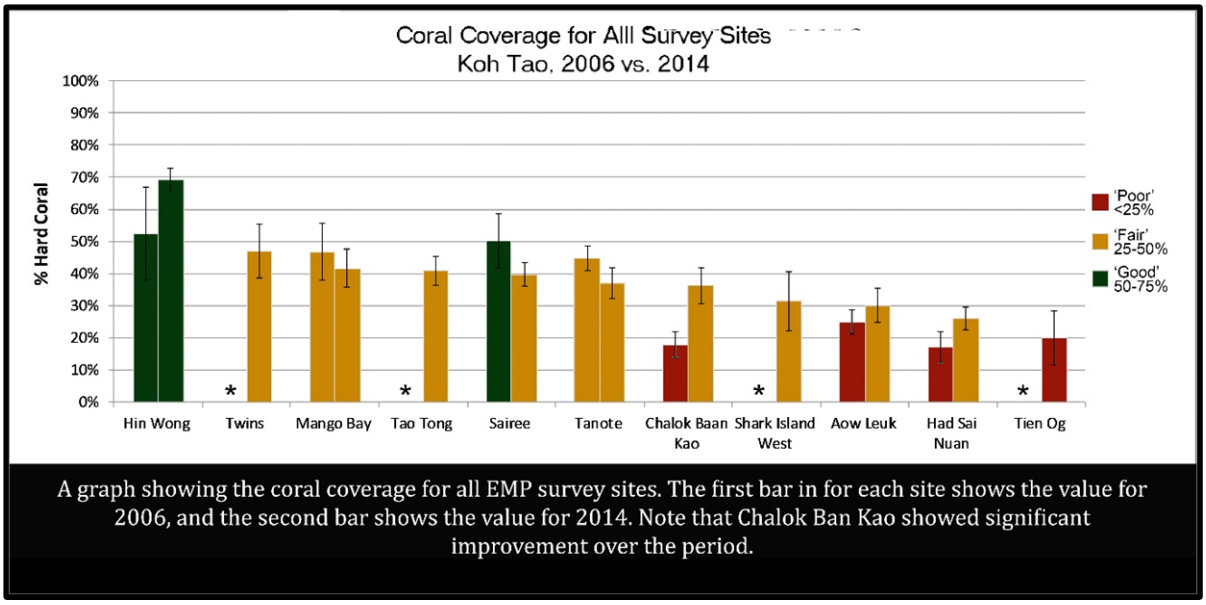
Overview

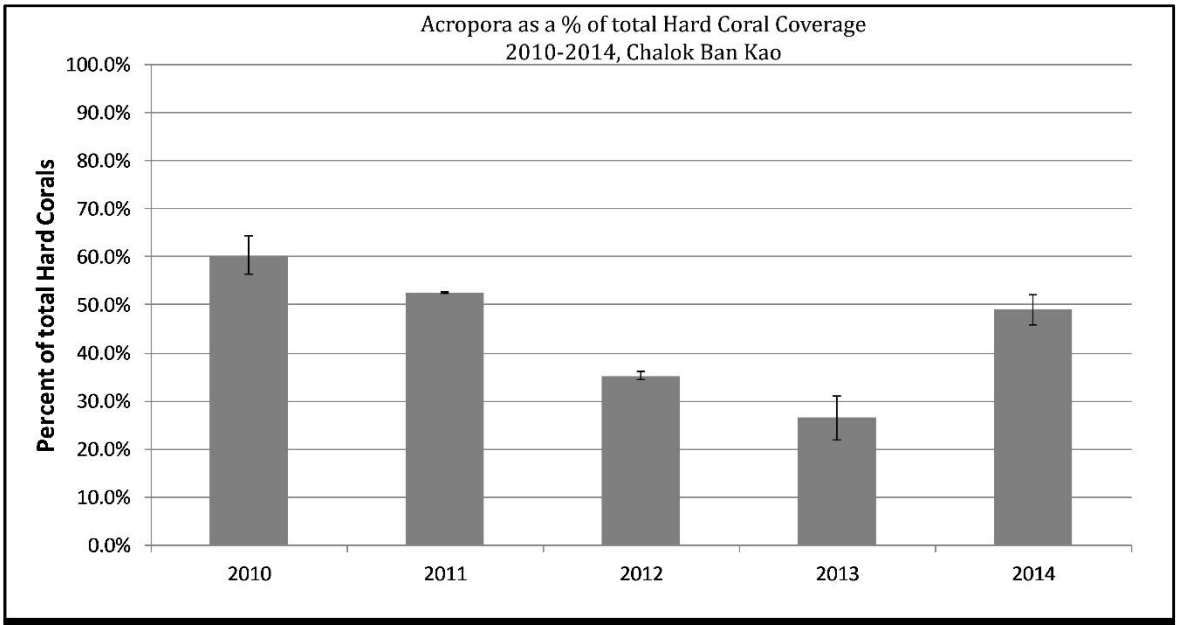
Chalok Ban Kao is a reef located in a secluded bay on the Southern end of the island of Koh Tao, Thailand. The bay consists of a shallow reef (1-5 m) which is primarily dominated by branching *Acropora* corals. The reef crest and slope (5.1-8 meters) is primarily dominated by mushroom corals, followed by the deeper reef which is primarily sand with scattered massive *Diploastrea* corals. The Bay is an important economic site for tourism activities, including snorkeling and diving, as well as the most ecologically rich bay on the southern end of the island. Chalok Baan Kao has been affected by several mass disturbance events and chronic stressors over the last 3 decades, beginning with typhoon Gay in 1989, which caused a large amount of structural damage to the area (Vongvisessomja 2009). The coral structure of the bay was further impacted by Typhoon Linda in 1997 (Vongvisessomja 2009, Phongsuwan et al. 2013). The following year, the bay was hard hit by the bleaching event of 1998, greatly reducing coral cover, especially for more vulnerable Acroporid and Pocillioporid species (Yeemin 2006, Phongsuwan et al. 2013). The reefs were left little time to recover, as mass bleaching occurred again in 2010 (Phongsuwan et al. 2013) causing around 60% mortality in the shallow reef (<6m depth) of the bay (Scott et al. 2017). However, our data shows that overall, the amount of coral in the bay increased between the years of 2006 and 2014, as the reefs recovered from Typhoon Gay and the 1998 bleaching event, as shown below.



A graph showing the coral coverage for all EMP survey sites. The first bar in for each site shows the value for 2006, and the second bar shows the value for 2014. Note that Chalok Ban Kao showed significant improvement over the period.

As the reef tourism industry has increased exponentially for the island over the last two decades, the site has also been greatly impacted by chronic threats derived from over-use by divers and snorkelers and development within the bays overlying watershed (Weterings 2011, Szuster and Dietrich 2014, Wongthong & Harvey 2014, Lamb et al. 2014). Studies have shown the bay is subjected to a high input of sewage waste (Romeo 2014), and macro algal levels have greatly increased due to development and the complete destruction of the mangrove forest which used the inhabit the north west coast of the bay. Following the bleaching event of 2010, *Drupella* snail populations abundance increased greatly, reaching outbreak proportions, furthermore feeding preferences have shifted, leading to major structural and functional changes in the coral communities (Hoeksema et al. 2013, Kim 2013, Moerland et al. 2016, Scott et al. 2017a, Scott et al. 2017b). Overall, *Acropora* branching coral populations have suffered more so than the more resilient *Pocillopora* and *Goniastrea* corals in the bay, primarily due to intermittent bleaching events and

chronic predation by *Drupella* snails. However, data indicates that predation rates were highest following the 2010 bleaching (Hoeksema et al 2013) but has since been reduced following the collection of more than 51,000 *Drupella* snails by the New Heaven Reef Conservation Program.



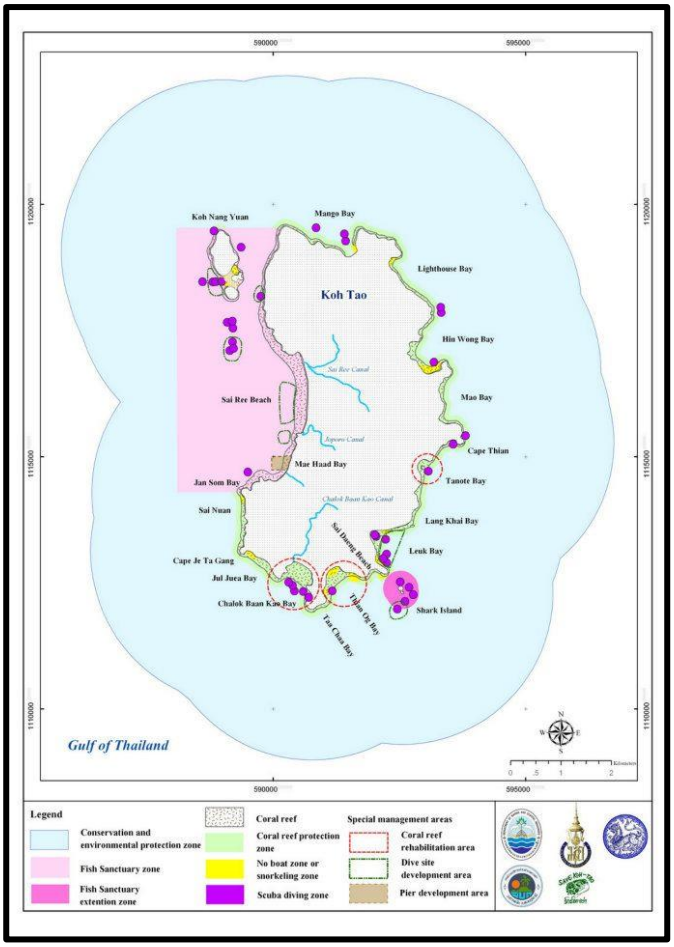
The percentage of Hard Corals which are of the genus Acropora, Chalok Ban Kao, 2010-2014. Showing a drop in percent composition following the 2010 bleaching event, which has been attributed to an outbreak of Drupella Snails (Hoeksema et al 2013).

The bay has historically been used by fishing and diving boats for respite from storms during the North-West monsoons, which has led to considerable anchor damage throughout the area. During some storms, more than 89 boats have been recorded (personally collected data), with only around 14 mooring lines available. This has led to high amounts of structural damage to the deeper reef, indicated by the many turned over *Diploastrea* corals which are more than 1-2 meters in diameter.

Chalok Ban Kao during a storm, showing the number of boats which frequently drop anchors in the bay, as well as some of the historically recorded damage in the area.

Following the mass coral bleaching event of 2010, the Department of Marine and Coastal Resources, Prince of Songkla University (under the guidance of Sakanan Platong), and the local Save

Koh Tao Community Group Implemented the Adopt-a-Reef program, designating 6 sites of the island for coral nursery and rehabilitation work (Platong 2010). Chalok Baan Kao was included in this program, and the New Heaven Reef Conservation Program (NHRCP) was put in charge of its maintenance and ongoing monitoring. As such, coral nurseries and artificial substrates were installed, and weekly monitoring and maintenance was performed by the NHCRP (Scott 2011). This work has continued ever since, using participants and staff of the NHRCP, under the guidance and directives of the DMCR and PSU. In 2012, the area was designated as a 'Coral Restoration Zone' by the DMCR (see map at right), which was found to be a positive action for the site (Hein 2014, Couture 2014, Cabral 2014). Additional protective measures have also been implemented, giant clam nurseries and restocking programs (2010-2015), mooring buoy installations and repairs (2009-2019), and more. Since 2010, the area has also served as the pilot site for our coral larval culturing and rehabilitation program, which has been conducted in conjunction with Dr. James True and Dr. Srisakul Piromvaragorn, both of the Prince of Songkla University (Scott 2013, Scott and True 2014). Through this program, coral gametes are collected during spawning, then fertilized and cultured according to specific methods and then transplanted back to the reef.



All of the measurers described above have been critical to the protection and restoration of the bay following a history of chronic and acute disturbances that have led to major changes in the structure and function of the coral community and related ecosystem. The full extent of these measures may be quantified in a number of ways including thousands of man hours of active restoration, deployment of dozens of metal structures and over 150 concrete and glass bottle units, regular coral gardening, three dedicated coral nurseries, over 50 independent giant clam nursery enclosures and much more. As the primary restoration site for the NHRCP, over 13 years of dedicated work has been done to bring back corals and other reef organisms to the site. The growth and improvement observed compare very positively with reefs to the East and West of the bay, and to other locations around the island which did not receive such stewardship.

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Boat Grounding Incident

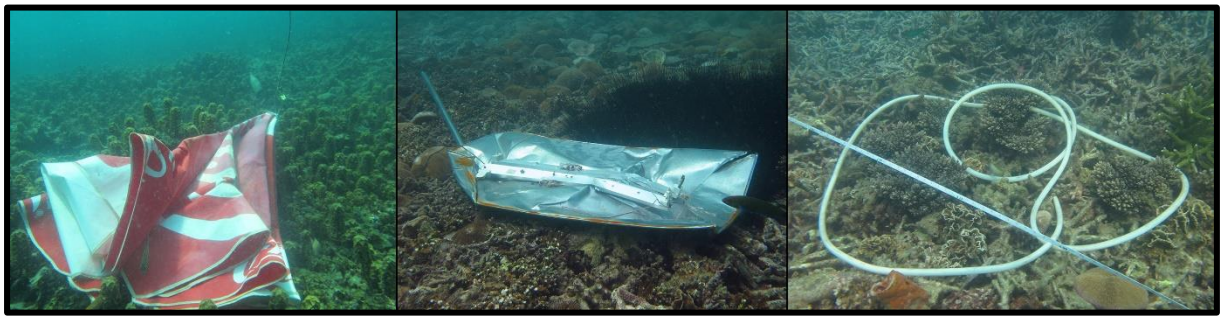
On January 27th of 2015, a fishing boat sank, and was subsequently dragged through the shallow reef of the bay in an attempt to lift it out of the water. This caused significant damage to the shallow reef area, crushing and killing entire stands of branching *Acropora* corals. The event was witnessed by our team, but due to storms we were not able to assess the damage until February 2nd, 2015. The NHRCP team performed several surveys of the damaged areas, and reported the incident to the Department of Marine and Coastal Resources, who did their own assessment of the area. It was determined that the area needed to be restored, and the NHRCP team began such work the same

week, however no financial or any other support was provided by the DMCR other then permissions to go forward.

This report outlines the methods and techniques used by the NHRCP to assess the damage at the site, and restore the broken and dying corals at the site. It has been prepared as a record of the incident, and also to comment on the strengths and weaknesses of the actions taken to serve as a guide to other groups.

Methods

An initial roving diver survey was completed on the morning February 2nd, 2019 to assess the damaged areas and create a plan. As there was a high amount of debris in the area that had come from the boat, one team was left in the water to perform a clean-up to prevent the debris from causing further damage to the reef through wave action.



Monitoring Methods

Due to the high abundance of broken corals, it was decided that a rapid transect survey would be performed, in order to allow the team to dedicate limited divers and resources to restoration activities. A flexible measuring tape was used to run the length of the drag mark to map the extent of the damage, widths of the drag mark we taken at 5 meter intervals down the entire length of the transect line, yielding 55 measurements of width. Subsequently, a second diver performed a photographic survey, taking a picture every meter along the line, from a height of approximately 1 meter from the substrate (Scott 2009).

A second transect line was laid in parallel to the first, 5 meters to the West in the undisturbed reef, in order to act as a control. Photos were also taken every 1 meter along this line from a height of 1 meter. Photographs were also taken randomly along the area to document the genera of corals that were affected and record any other observations.

On March 25th, the transect line and photographs were repeated along the boat drag mark to assess mortality following the initial event. All photographs were analyzed using CPCe to assess coral cover, hand health states, marked as Healthy, Partially Bleached, Fully Bleached, Recently Killed (skeleton not yet covered in macroalgae), Dead (skeleton covered in macroalgae but not degraded or worn), and broken (those resulting from the event).

Restoration Methods

Several methods were used by the trained staff and members of the NHRCP team, including coral gardening techniques, deployment of artificial substrates, and collection of coral predators.

1. **Coral Gardening**

The boat grounding caused most of the branching, corymbose, and plate corals in the area to be broken into fragments, which if left unmanaged would most likely die through abrasion, smothering, or predation. Divers worked quickly to secure the fragments in place using coral gardening techniques. Large fragments where righted, and secured in the coral rubble using wedges (i.e. pieces of dead coral) or other techniques that did not require any additional materials. In other cases, a pneumatic drill was used to create holes in existing substrate (dead massive and tabulate corals from previous bleaching events) and were secured using underwater epoxy, as shown in the photos below.

A diver uses a pneumatic drill to create holes in existing dead coral substrate, and then uses marine epoxy to affix fragments created by the boat grounding, Chalok Ban Kao, February 2015.

2. **Deployment of Artificial Substrates**

Artificial substrates were used to supplement the availability of existing stable substrate which was available, as the area was primarily unconsolidated rubble that had become even less stable following the boat drag incident. Two methods were used, the first being our proprietary bottle nursery design, which utilizes simple molds to create small, yet effective substrates for rehabilitation of branching corals created from concrete and glass bottles. The

second, was welded steel rebar structures which were designed to fit into the drag mark and upon which the broken coral fragments were attached using small nylon rope and a hitching technique. The nylon line is either grown over by coral tissue and integrated into the skeleton, or removed later on. The structures were made in the shape of tunnels to increase the 3-dimensional complexity of the reef and provide habitat for a variety of reef fishes. Both substrates were used to attach and secure only larger (>15 cm), visually healthy fragments of coral. All coral growth forms/genera present were utilized in order to preserve reef diversity on a genetic and species level.

Members of the NHRCP work to create, deploy, and transplant corals to artificial substrates in the area of the boat grounding/dragging area, February 2015.

3. Coral Nursery

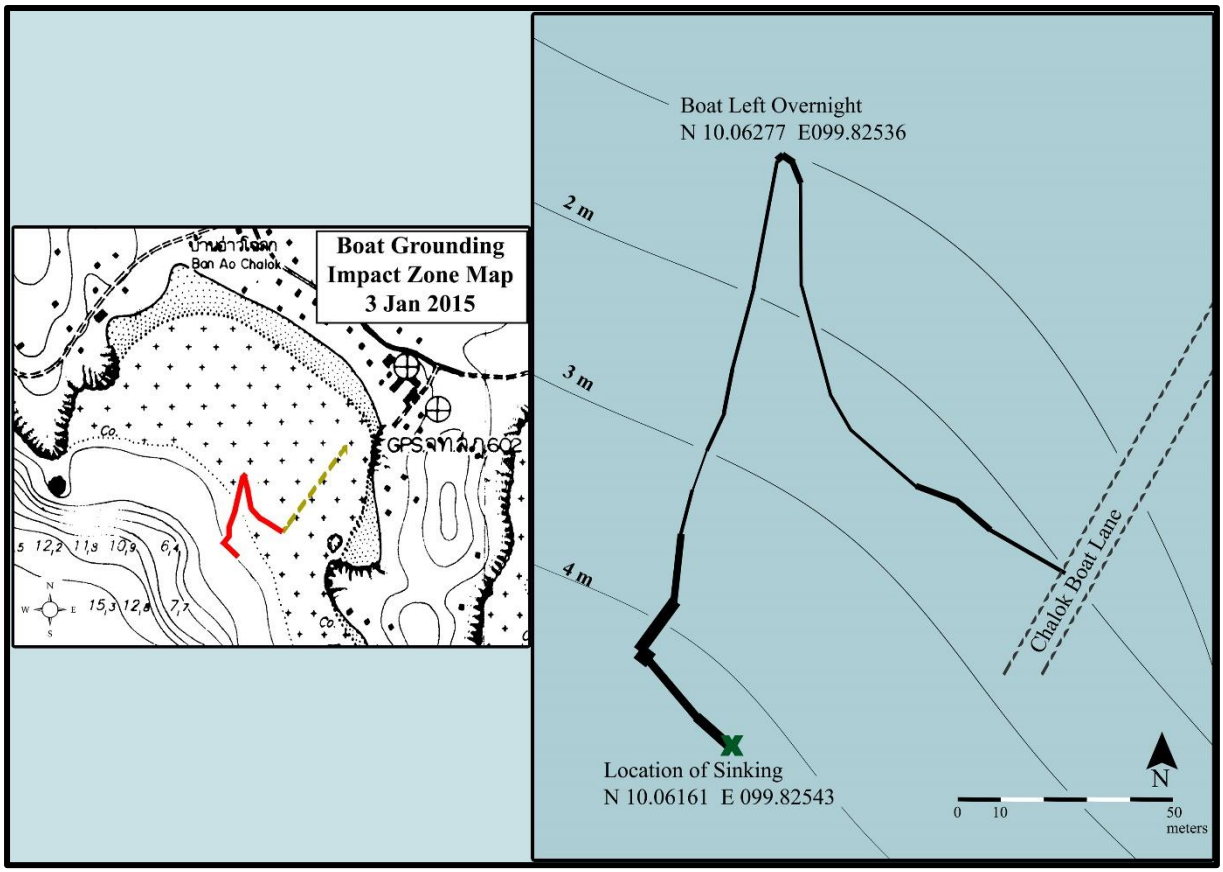
A floating mid-water nursery was installed on the adjacent reef slope, and set to the same depth as the boat drag mark. Here, smaller (<15 cm) or visually unhealthy corals were secured using the rope nursery method in order to allow for their rehabilitation and growth before later transplantation back to the reef and artificial substrates. The nursery was filled with the fragments of corals found broken within the drag mark, regardless of species or growth form. Care was taken to preserve genetic and species diversity by collecting a broad range of fragments from across the entire span of the boat drag mark area.

Divers install a mid-water 'rope' nursery to rehabilitate the fragments created by the boat grounding

Results

Mapping the boat drag mark

The boat drag mark was found to have a length of 270 meters from the point of grounding to the intersection with the already established boat lane. The drag mark varied in width from 0.5 m to 7 meters, with a mean width of 2.19 m (SE +/- 0.2m). The total calculated area of reef disturbed by the dragging of the boat was approximately 591.5 m^2. The route taken to drag the boat from the grounding location to the boat lane in shown in the figure below.



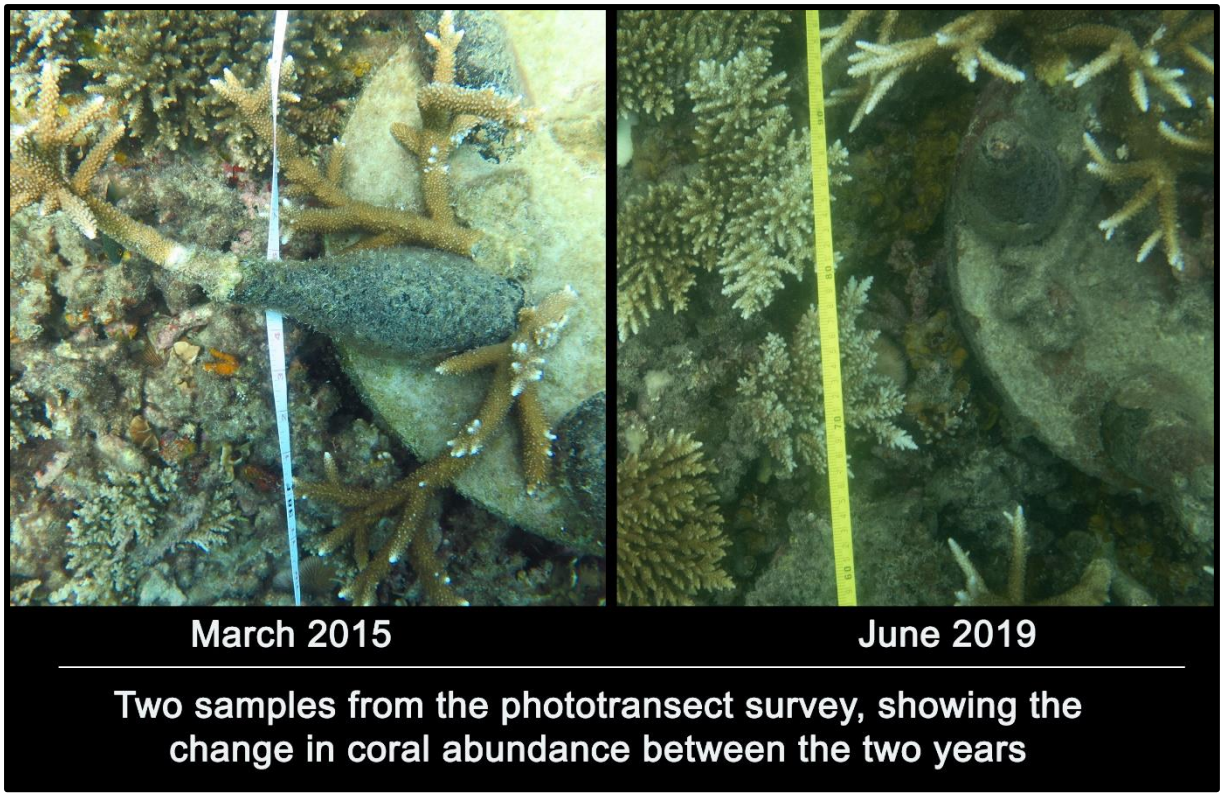
Phototransects

The three photo transects conducted and then analyzed in CPCe showed significant damage to the area impacted by the boat grounding/dragging, as shown in the tables below.

	HARD CORAL (HC)	SOFT CORAL (SC)	SPONGES (SP)	MACROALGAE (NIA)	NON-LIVING SUBSTRATE (NLS)
Boat Drag (Feb. 2nd, 2015)	13.8%	0.0%	0.7%	8.3%	77.2%
Boat Drag (March 25th, 2015)	9.7%	0.0%	0.0%	8.6%	81.7%
Control (Feb. 2nd, 2015)	18.6%	0.0%	0.0%	13.8%	67.6%
Boat Drag (June, 2019)	55.2%	0.0%	0.0%	2.7%	42.1%
Control (June 2019)	46.0%	0.0%	0.0%	1.7%	52.3%

Coral cover in the first set of data collection was 13.8% (including broken or damaged corals), compared with 18.6% in the control reef (5m adjacent to the drag mark). By the time of the second set of data collection, Hard Coral coverage had been reduced by 30% to just 9.7%, which would have been even less if restoration efforts were not implemented.

The results of the restoration efforts become more apparent in the data collected over 4 years later, in June of 2019. As shown in the table above, coral coverage on the reef as a whole increased greatly, with the control reef increasing in coral coverage from 18.6% to 46%, greater than a 2-fold increase. Coral coverage increased even more dramatically in the restored boat drag mark, reaching 55.2% coral. This is most likely due to the effects of adding artificial substrate which provides more effective securement of coral fragments and natural recruits as opposed the coral rubble which was previously the most prevalent substrate type.

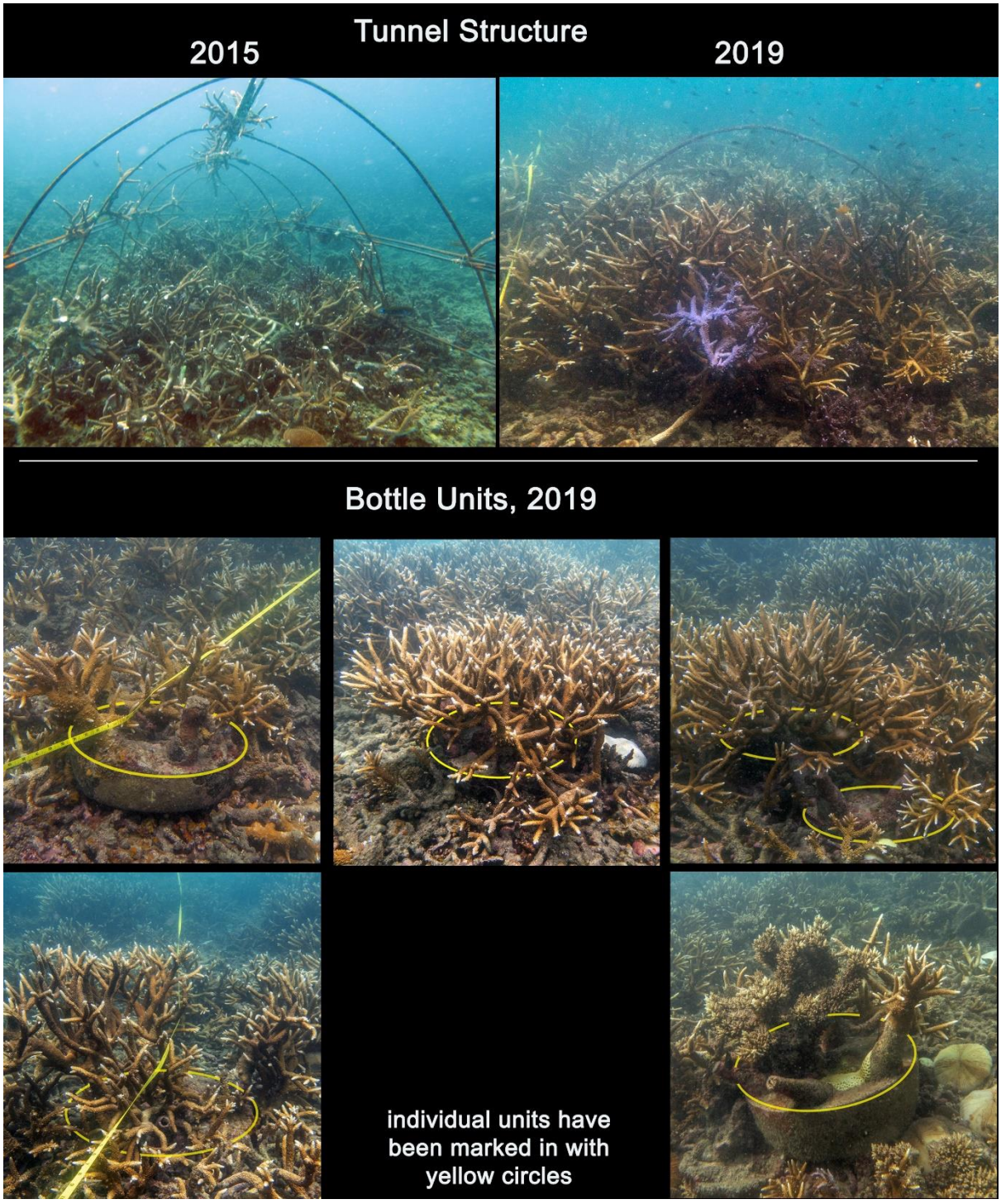


Two samples from the phototransect survey, showing the change in coral abundance between the two years

Also interesting was the decrease in the abundance of macroalgae across all transects from 2015 to 2019, with initial surveys showing 8.3-13.8 % in 2015, and just 1.7-2.7% in 2019. This is most likely the result of two factors, the first being the increase of coral coverage across sites which would reduce available habitat for the macroalgae to grow. Secondly, could be increased shading by the growing coral canopy which would reduce available photo-radiation for macroalgal growth.

Points identified as corals were also coded according to health, as either; Healthy (no signs of damage or stress), Broken (fragments), Partially Bleached (some loss of color, tissue still living), Fully Bleached (No Color, tissue still living), Recently Killed (tissue gone but skeleton not covered in filamentous algae), Dead (tissue gone, covered in filamentous algae, but skeleton not yet degraded). The table below shows that the boat drag mark consisted of primarily broken corals on February 2nd (55.0%), all of which has either been secured and recovered or had died by March 25th (78.6% and 14.3%, Respectively).

	Healthy	Broken	Partially Bleached	Fully Bleached	Recently Killed	Dead
Boat Drag (Feb. 2nd, 2015)	32.5%	55.0%	5.0%	0.0%	7.5%	0.0%
Boat Drag (March 25th, 2015)	78.6%	0.0%	3.6%	0.0%	3.6%	14.3%
Control (Feb 2nd, 2015)	94.4%	1.9%	1.9%	0.0%	1.9%	0.0%



Conclusion

The grounding and subsequent dragging of the fishing boat in late July of 2015 caused a significant and long-lasting disturbance to the reef, reducing coral coverage and structural diversity over 591 m^2 in the bay. This occurred in a reef which was still recovering from multiple acute disturbance events, as well as a history of chronic stressors. A significant amount of work using a variety of techniques had already been implemented over a period of 9 years prior to this event, which created a major set-back for the NHRCP in that area. Although the Department of Marine and Coastal Resources did document the event and talk with the boat owner, no additional resources were provided to the NHRCP for restoration, all was done using their own financial and human resources.

It is strongly felt that if no restoration work had been done, the area would have continued to be denudated due to the lack of solid structure and prevalence of Drupella snails. In total, 25 bottle units and 4 metal structures were placed in the area and filled with coral transplants. Additionally, more than 2,920 Drupella snails were removed from the area over the course of 4 days by the NHRCP team, which had likely been attracted by chemical triggers released by the broken fragments of corals. The corals which were placed into nurseries were subsequently transplanted to other metal structures in the bay over the course of 1-2 years. The results show a considerable increase in hard coral coverage for the entire site over the 4-year monitoring period, with coverage increasing from 18% in 2015 to 46% in 2019. However, the growth of corals was even greater in the restoration zone, increase from only 9.7% in March 2015 to 55.2% in June 2019.

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