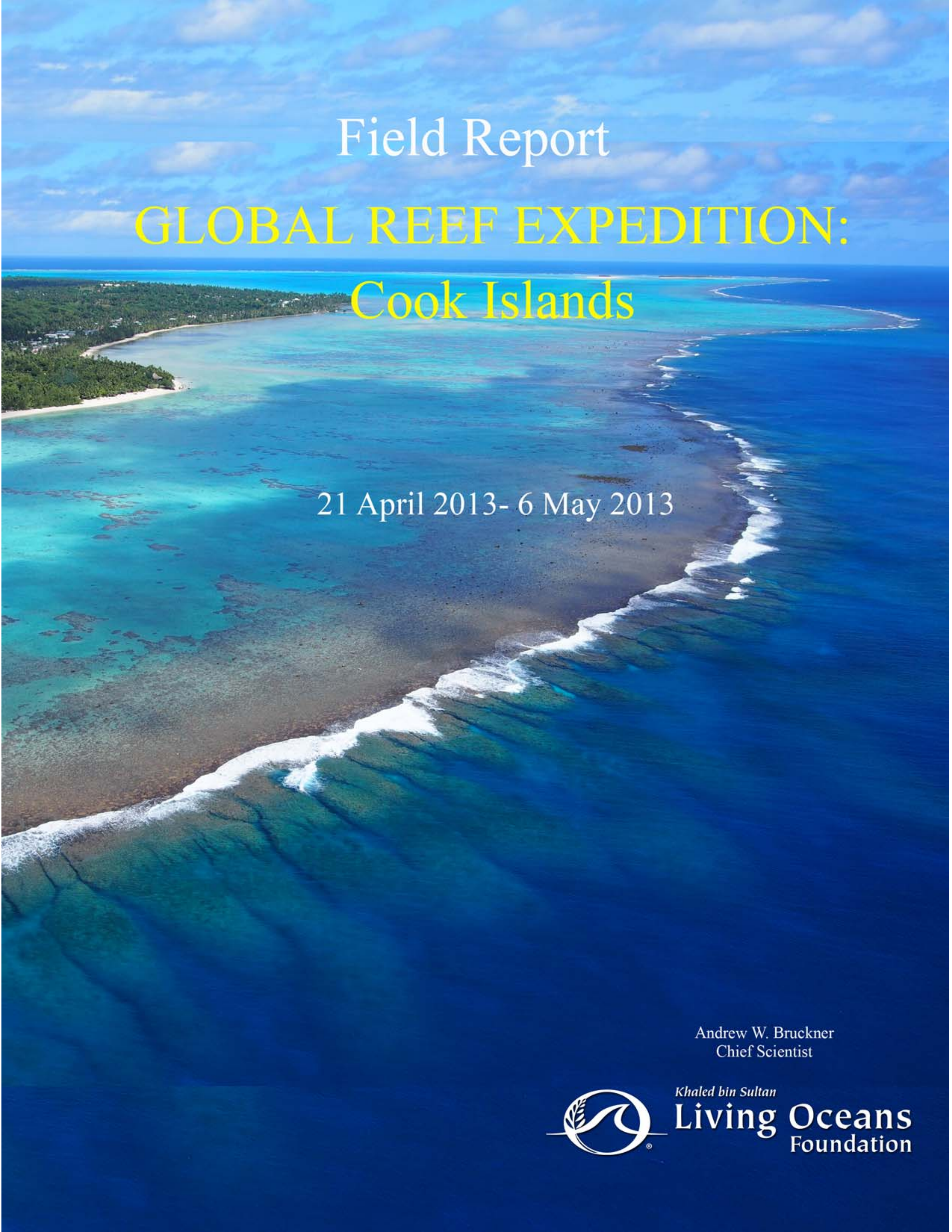
Field Report

GLOBAL REEF EXPEDITION: Cook Islands

21 April 2013- 6 May 2013



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Front cover: Aerial view of the fore reef and lagoon at Aitutaki, Cook Islands. Photo by Andrew Bruckner.

Back Cover: Unusually large colonies of *Porites lobata* off the northeast coast Rarotonga. Photo by Andrew Bruckner.

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This field report summarizes the activities undertaken by the Khaled bin Sultan Living Oceans Foundation in the Cook Islands. It was developed as one of the products of the Global Reef Expedition: Cook Islands research project to meet one of the requirements of the research permit issue #35/12 approved by the Foundation for National Research and the Office of the Prime Minister as stated in File ref. 510.3, Letter No. 152 dated 27 December 2012.

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The Khaled bin Sultan Living Oceans Foundation (KSLOF) was incorporated in California as a 501(c)(3), public benefit, Private Operating Foundation in September 2000. KSLOF headquarters are in Washington DC. The Living Oceans Foundation is dedicated to the conservation and restoration of oceans of the world, and champions their preservation through research, education, and a commitment to *Science Without Borders*®.

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EXECUTIVE SUMMARY

From 20 October, 2013 – 5 May, 2013, the Khaled bin Sultan Living Oceans Foundation conducted a research mission to the Cook Islands as part of the Global Reef Expedition. The research focused on coral reefs surrounding the islands of Rarotonga, Aitutaki and Palmerston. The project was conducted in partnership with the , with involvement of scientists from Nova Southeastern University, University of the Philippines, NOAA/University of Miami, Atlantic and Gulf Rapid Reef Assessment Program (AGRRA), the National Museum of Marine Biology and Aquarium (Taiwan), and University of Tasmania. Additional support was provided to the Cook Islands Marine Park Steering Committee to assist in discussions of the zoning and management of the new Marine Park. The objectives of the mission were to:

1) Identify and characterize shallow marine habitats and develop habitat and bathymetric maps;
2) Evaluate the composition, structure and health of coral reefs using a standardized assessment protocol;
3) Assess the diversity, abundance and population structure of fishes, corals and other invertebrates, and algae, including commercially valuable species;
4) Document the impacts of broad scale disturbances and patterns of recovery with emphasis on storm damage and crown of thorns predation impacts;
4) Evaluate the effects of environmental stressors on coral health and subcellular changes through biomarker expression; and
5) Measure ocean chemistry (pH) and effects on coral growth.

Groundtruthing: A total of 406 sq. km of WorldView 2 satellite imagery was acquired. To characterize shallow marine habitats, 166 videos (drop cameras) and 1,055,627 depth soundings were taken across the three islands, covering a distance of 260 km. Georeferenced WorldView-2 imagery was used to plan bathymetric tracks to sample habitat locations of interest to drop video cameras. The bathymetric information will be used to calibrate a model which will assign a depth value to each pixel in the imagery data. Similarly, information from the camera drops will be used to assign a habitat type to the imagery data. Together, detailed maps of bathymetry and habitat type will be produced for the three locations visited.

Coral Reef Assessments: Surveys were conducted across the fore reefs surrounding three islands and in lagoonal areas, when possible. A total of 186 fish transects, 196 benthic surveys, 84 coral assessments and 204 phototransects were completed in 30 locations from 5-30 m depth. The population dynamics and health of over 5,800 corals, 4 cm diameter and larger were examined.

Coral Reef Research:

- Crown of thorns (COTS) removal: A total of 530 starfish were collected from 10 locations. These animals were 9-38 cm in length (mean=26.8 cm). Starfish from the west coast were slightly smaller (mean= 26 cm) than starfish collected from the east side within the outbreak (mean=28 cm). Details on COTS impacts and removal program are included in the first report provided to the Cook Islands Government (**Mitigating the impacts of an *Acanthaster planci* (crown-of-thorns starfish, COTS) outbreak on coral reefs in Aitutaki, Cook Islands,** Bruckner 2013).
- Ocean Acidification: Water samples, coral coring and measurements of water chemistry were undertaken to evaluate effects of recent changes in ocean chemistry. A total of 34 cores were collected at 10-12 m depth off the three islands. These included *Porites lobata* and *Pavona clavus*. These will be sectioned and

examined using a CT scan to quantify variations in coral growth rates and relationship with ocean chemistry.

- Sediment: A total of 39 sediment samples were collected to characterize sediment composition and grain size. In the lab, samples are analyzed using a Camsizer® instrument to determine the size and shape of sediment grains.
- Coral health: Tissue samples from 60 colonies of *Pocillopora damicornis* were collected to assess subcellular levels of stress. Simultaneous measurement of light, salinity, temperature, depth, time and appearance of sampled corals. In the lab tissue will be examined for changes in gene/protein biomarker expression in response to differences in the environment.

Fig. 1. A Napoleon wrasse (*Chelinus undata*) at a cleaning station in Aitutaki. Two small cleaner gobies are visible on the wrasse

Summary of General Observations

1. Rarotonga

The reefs of Rarotonga have a history of disturbance including: 1) a severe COTS outbreak in the mid 1970s and a second outbreak from 1995-2001; 2) several major cyclones in the early 2000s; and 3) minor bleaching during recent El Niño years. During the present surveys, sites on the north coast still show evidence of storm damage as large accumulations of rubble were observed from 10-12 m depth to the base of the reef at 25, and continuing down the slope. The fore reef lacks a prominent spur and groove structure. Generally the shallows (5-10 m) are a sloping hardground with some micro relief. Below this is a highly eroded framework with large scattered boulders constructed primarily of large *Porites* skeletons. Many very large overturned boulders were apparent, some still had living remnants of *Porites*. Some reefs had a framework of large Porites skeletons intermixed with living colonies to about 25 m, followed by a deeper gently sloping rubble field. The shallow fore reef slope was dominated by small massive corals, especially *Goniastrea, Favia, Montastrea, Leptoria,* and *Porites*, with scattered small branching acroporids (most digitate and small tables) and *Pocillopora*. Most corals in shallow water were from 5-15 cm diameter and live cover was 2-10%. Deeper, the community was dominated by *Porites* but these have extensive patches of old mortality; colonies consist predominantly of medium to large sized remnants that have grown up 8-15 cm. On many of the larger *Porites* are dead acroporids and other species, 30-50 cm diameter, intermixed with large numbers of juveniles corals that settled in the last 3-5 years. A high diversity of massive, plating and branching corals also occurs on the tops and sides of dead parts of the *Porites* colonies. The majority of all corals are 5-20 cm in diameter with only a few larger *P. eydouxi* colonies. Some reefs have much more surviving *Porites*, and in several cases the slope consists of medium to large massive *Porites* that are 50-100 cm wide and 50-100 cm tall, with larger scattered Porites (up to 5 m across) in deeper water (20-25 m).

Fig. 2. Several reefs on the north coast of Rarotonga had healthy assemblages of *Porites lobata*.

Reef fish communities in Rarotonga were dominated by species assemblages that were very different from Aitutaki and Palmerston. The most abundant taxa identified along transects were triggerfish (*Sufflamen*), sergeant majors (*Abudefduf*), whitemouth moray (*Gymnothorax*), copper sweeper (*Pempheris*), and parrotfish (*Chlorurus*), chubs (*Kyphosus*), squirrelfish (*Sargocentron*) and jacks (*Carynx*) respectively. Fish were smaller than both Aitutaki and Palmerston (most up to 10 cm, followed by 11-20 cm fishes), although isolated larger jacks, snappers, parrotfishes and groupers were seen. Rarotonga also had a higher abundance and diversity of groupers than Aitutaki.

2. Aitutaki

Outer reef (fore reef) communities surrounding Aitutaki have been impacted by a severe outbreak of *Acanthaster planci* crown of thorns seastars (COTS). This outbreak was reported to have started at least a year ago, and is still ongoing. Additional damage was caused by Cyclone Pat, which passed directly over the island in Feb, 2010. Coral cover has declined substantially throughout the fore reef as a result of COTS predation, with some additional damage possibly attributed to Cyclone Pat. Coral cover has declined by 80-99.9% throughout deep (15-30 m) fore reef sites surrounding the atoll, with <0.05% live cover remaining in most locations. Similar declines were noted at shallower depths (3-15 m) off the west, north, northeast and south sides. In these degraded areas, a very low number of intact, undamaged corals remain. Survivors are predominantly coral taxon that are not preferred food sources: deep populations of plating/foliaceous *Porites rus* were mostly intact; low numbers of plating/columnar *Coscinarea*, finger corals in the genus *Acropora* and large-branched cauliflower corals in the genus *Pocillopora* remained. Much of the shallow reef in these locations is now completely covered in a thick layer of red crustose coralline algae and very low numbers of coral recruits. The only healthy fore reef communities with high diversity coral populations identified during these surveys were located along an 8.2 km stretch of reef off the southeast coast, in shallow water (3-10 m). Lagoonal reefs have been unaffected by these disturbances and are still mostly in good shape. One nearshore community was dominated by very large (1-4 m) *Pocillopora damicornis* colonies intermixed with acroporids and other branching corals. Many of the upper surfaces of these colonies had died within the last two months, possibly due to a recent bleaching event associated with aerial exposure during an unusually low spring tide.

Coral cover on fore reef communities (3-30 m depth) off the west and northeast has declined below 0.1% in most locations. These communities have very few remaining intact corals and low numbers of new recruits. The only survivors are the non-preferred species (several reefs had large populations of *Porites rus* below 15 m depth) and small (< 5 cm diameter) tissue remnants on larger skeletons. In some sites, shallow areas (1-3 m) had scattered live corals (2-10% live coral cover, predominantly encrusting acroporids), dispersed among older dead corals, recently killed (white) corals, and soft corals. Large expanses of pink, crustose coralline algae (CCA) encrusted coral skeletons and reef substrate from 1-20 m depth. Coral colonies off the east and south coast were mostly dead (< 2% intact colonies remained) from 12-30 m depth. The survivors coral consisted of 1) small living tissue remnants (most < 5 cm diameter) on larger skeletons of important frame-building massive corals (*Goniastrea, Favia Leptoria*, and *Porites*); 2) isolated colonies (<1 colony per 10 m^2 area) of less preferred species (predominantly *Coscinarea*, digitate corals in the *Acropora humilis* group, and large erect "elephant ear" or cauliflower corals of the species *Pocillopora eydouxi* and *P. verrucosa*), and 3) very low numbers of recruits (<1/m^2). Dead, algal-encrusted skeletons of branching, tabular, submassive, and massive corals, in growth position, formed a prominent band from 8-15 m depth. In some areas, living coral colonies, predominantly encrusting and digitate acroporids, were seen on the tops of the spurs in very shallow water (1-3 m). Colonies on the lower edge (2-3m) of this zone were dead and covered with filamentous algae, or partially dead with patches of white, recently denuded skeletal surfaces.

Shallow fore reef sites (3-8 m) along an 8.2 km stretch, beginning midway along the east coast and continuing to the southeastern tip of the atoll (located between CIATS-06 and CIAT-21), were the only locations that still contained thriving, high diversity coral communities. These communities were dominated by a high diversity and wide variety of growth forms of *Acropora*, as well as *Pocillopora, Goniastrea, Lobophyllia, Favia, Montastraea, Echinopora, Leptoria, Hydnophora* and many other species of branching, encrusting, massive, plating and submassive corals. Unfortunately, these communities also had the highest number of COTS, and live coral was intermixed with large patches of white, recently eaten corals.

The most common genera of fish recorded along transects were butterflyfish (*Chaetodon*), wrasses (*Thalassoma*), surgeonfish (*Acanthurus*), chromis (*Chromis*) and parrotfishes (*Scarus*) respectively. Surgeonfish were often recorded in small schools (30-50 fish). Most of the fish were small (up to 20 cm), although individual larger parrotfish (20-40 cm and peacock grouper (*Cephalopholis argus*) were seen on most reefs. No sharks were recorded during surveys.

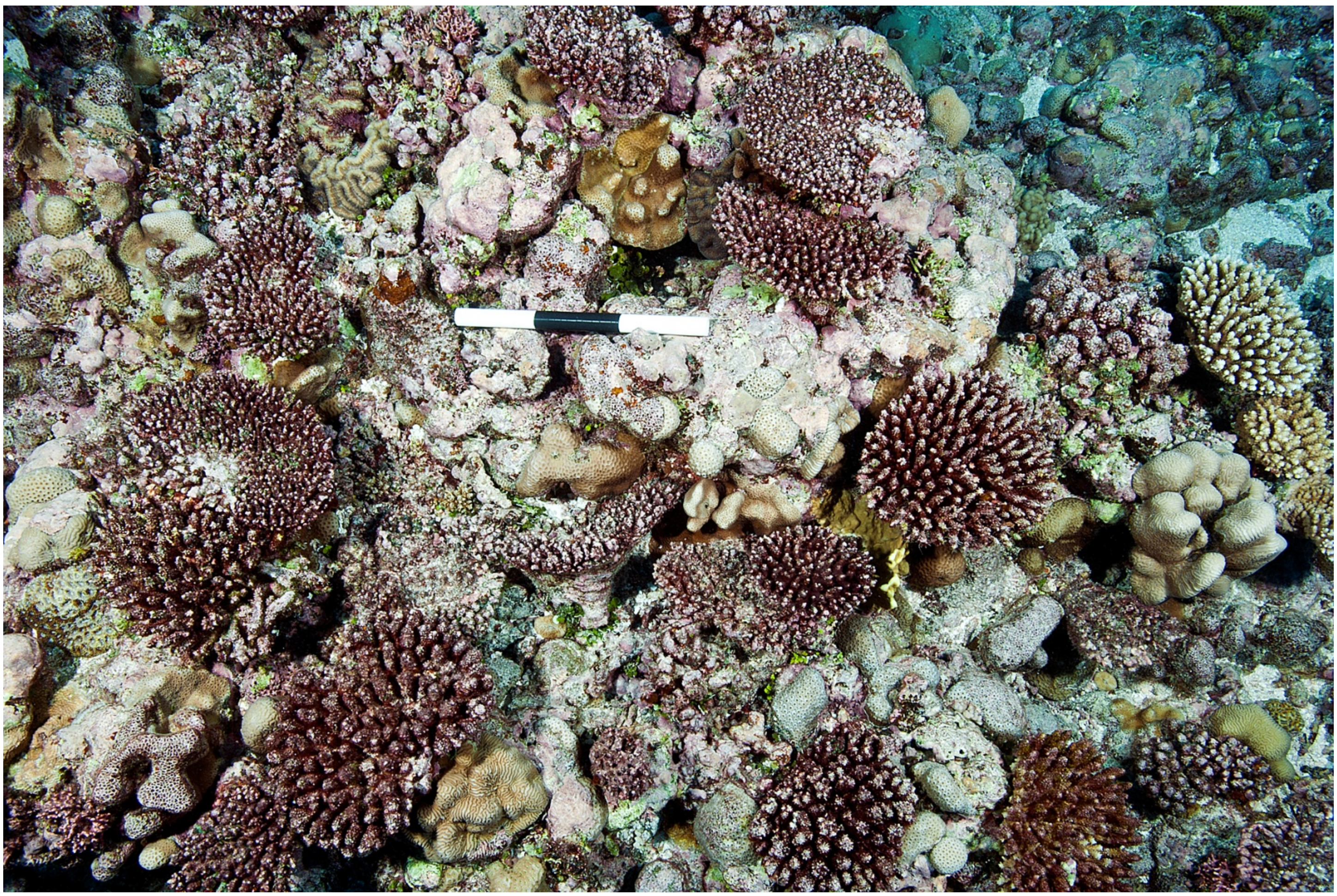

Fig. 3. Extensive sections of the fore reef at Aitutaki had been devastated by crown of thorns sea stars. The dead corals remain in growth position; their skeletons are colonized by turf algae and crustose coralline algae.

3. Palmerston

The fore reef communities of Palmerston appear to have been spared damage from cyclones, crown of thorns starfish, bleaching events or other disturbances, and most areas had very high cover of living corals. Reefs tend to have a fairly wide, gently sloping fore reef terrace extending from 5-10 m depth, followed by a gradual slope to 20 m, and then a steeper slope. Two very narrow channels allow access to the lagoonal areas. Small coral bommies occur in shallow water near the margins of the reef crest. Within the lagoon there are a few isolated patch reefs. These tend to have a high cover of small branching and table acroporids on the upper surfaces (1-2 m depth) and steeply sloping sides with very little coral. On the fore reef, shallow reef communities are dominated by large, massive colonies of *Astreopora*, while mid depths (15-20 m) have a band of *Favia stelligera* and large *Lobophyllia.* On some reefs, just before the fore reef slope are areas with large stands of finely branched bottlebrush acroporids, with a dominance of *P. maldivensis* on the fore reef slope and a deep reef community dominated by *P. clavus*. There is a high abundance and cover of erect CCA, especially in shallow water. In many shallow locations, the substrate is covered in a thick layer of CCA and many corals are being overgrown. Between 5-20% cover of fleshy macroalgae, especially *Microdictyon,* occurs on most reefs and deeper areas have large patches of green *Caulerpa* algae. Giant clams are low in abundance on fore reef sites. Few sea cucumbers were found on the fore reef.

Reef fish assemblages were dominated numerically by butterflyfish (*Chaetodon*), surgeonfishes (*Acanthurus*), wrasses (*Thalassoma* and *Halichoeres*), chromis (*Chromis*), bristletooth (*Ctenochaetus*), angelfish (*Centropyge*), grouper (*Cephalopholis*) and damselfish (*Plectroglyphidodon*) respectively. Fish were more abundant and slightly larger in size than both Aitutaki and Rarotonga. It was common to see 20-40 cm unicorn fish, wrasses, parrotfishes, jacks and grouper. There were also numerous sightings of sharks.

Fig. 4. Massive *Coscinarea columna* surrounded by green macroalgae, *Caulerpa* at 20 m depth on the fore reef off Palmerston Island.

Research Completed

1. Habitat mapping and groundtruthing:

Using multispectral satellite imagery obtained from DigitalGlobe WorldView 2 satellite, high resolution bathymetric maps and habitat maps are being created for shallow coral communities. Groundtruthing efforts necessary to develop these maps focused on aerial surveys of each island's coastline and adjacent shallow marine habitat, continuous bathymetry measures, drop camera analysis, characterization of sediment and hard substrates and habitat features using two acoustic sub-bottom profiling equipment (Stratabox and Hydrobox) and fine scale photo-transect surveys.

Aerial surveys

Overflights of Rarotonga and Aitutaki were undertaken to aid in identification of sites for surveys and groundtruthing. The plane circled each of the islands at an elevation of approximately 500-1000 feet. In Rarotonga a second track was completed on the south side across the lagoon. In Aitutaki, the overflight covered the shallow fore reef with additional surveys within the lagoonal areas. Digital images were taken of the near shore environments.

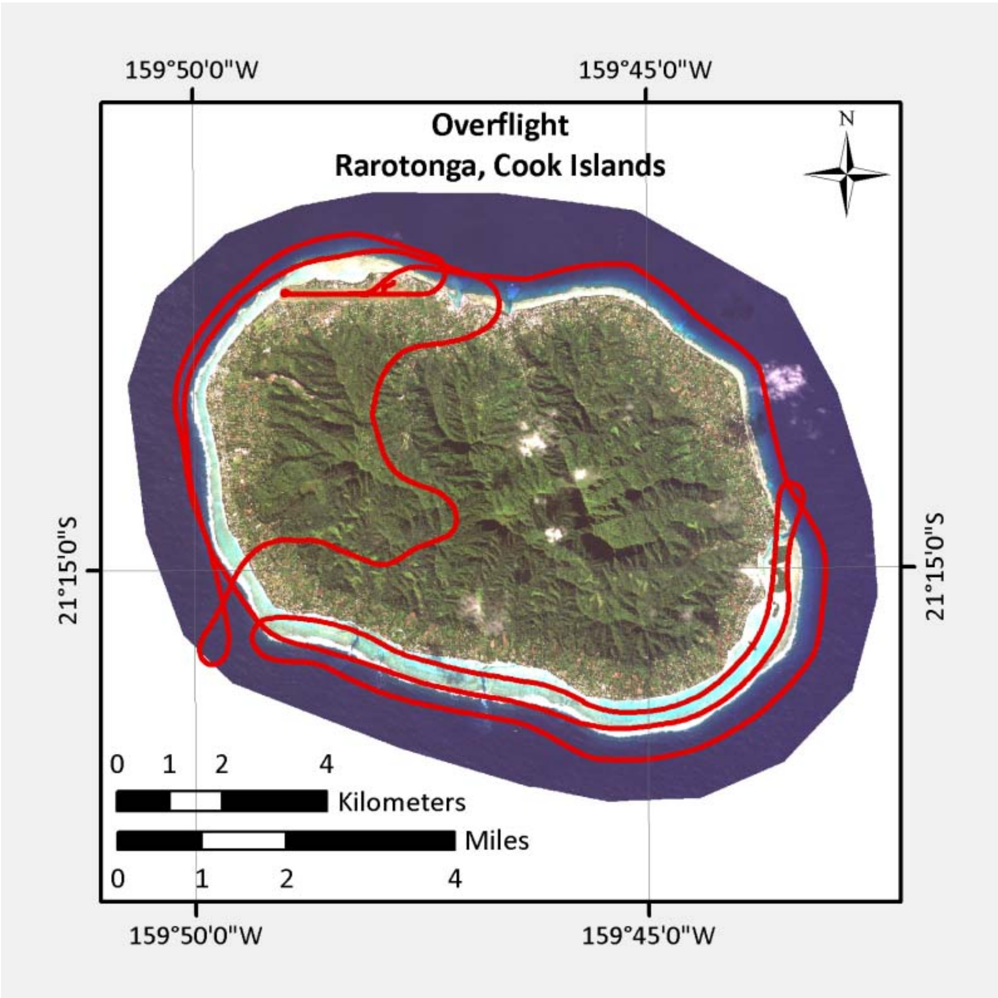

Fig. 5. Track of the overflight of Rarotonga, Cook Islands.

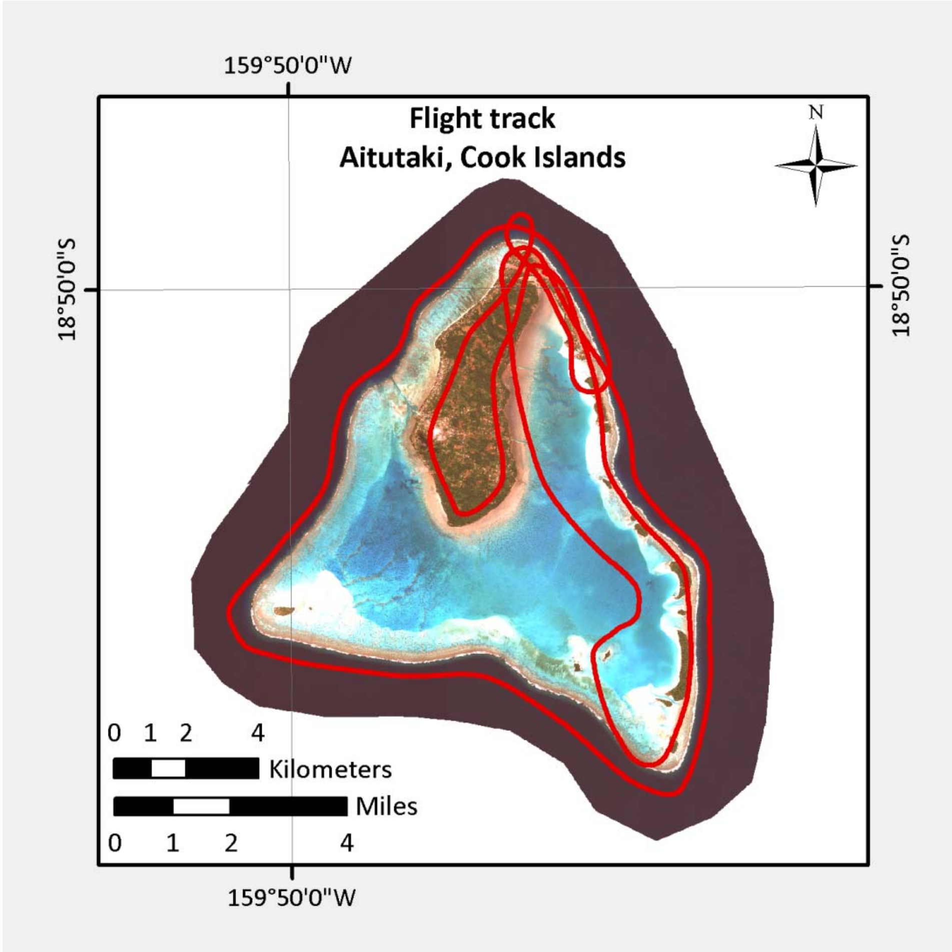

Fig. 6. Track of aerial overflight of Aitutaki

Satellite imagery

A total of 1703 sq. km of WorldView 2 (8 band) satellite imagery was acquired for this project (Table 2). The satellite images had a spatial resolution of 2-m by 2-m (i.e., each pixel covers a 4-m^2 area) enabling real-time navigate in the field to locate features of interest and to avoid dangerous features (e.g., emergent reefs). In order to navigate, the team used the scenes in conjunction with a differential GPS device (dGPS). The imagery is being used with ground truth data to create bathymetric and benthic habitat maps.

Benthic Video

An underwater video camera attached to a cable, called a drop-cam, was used to gather video on the benthic composition at each survey site. At each point, the drop-cam was held from the survey boat enabling it to ‘fly’ along the sea floor as it records video for 15 to 60 seconds. During this time, the laptop operator watched the video in real-time and guided the drop-camp operator to raise or lower the camera. In this manner, we were able to prevent damage to marine life. The video was recorded on a ruggedized laptop, and the geographic position, time, date, boat heading, and boat speed were burned into the video. Drop-cam deployment was limited to depths above 40 m due to the limited length of the tether cable (50 m). The acquired videos are being used to create the benthic habitat maps by providing the necessary information for the development of a habitat classification scheme and training of classification models. A minimum of 30 drop-cam videos were gathered per day.

Acoustic depth soundings

Depth soundings were gathered along transects between survey sites using Hydrobox, a single-beam acoustic transducer, developed by Syqwest. The instrument emits 3 pings per second. Depths were estimated based on the time the return-pulse's reaches the sounder's head. Geopositional data were simultaneously acquired by the dGPS unit. The estimated depth values and their geographic location were recorded in the ruggedized laptop. The soundings were used to train a water-depth derivation model, which is based on the spectral attenuation of light in the water column. The final topographic map will have the same spatial resolution as the satellite imagery. An average of 100,000 acoustic depth soundings was gathered during a full work day.

Acoustic sub-bottom

Profiles of the seafloor's sub-bottom were also gathered along transects using the Stratabox acoustic sounder, also developed by Syqwest. Similar to the bathymetric soundings, the sub-bottom profile emits an acoustic ping which reflects off the seafloor. However, the pulse has a lower frequency (3.5 Khz) enabling it to penetrate the seafloor. The instrument provides observations on stratal geometry beneath the seafloor along the transect lines, allowing estimates of Holocene reef-growth and sediment accumulation to be made. Geopositional data for each ping was simultaneously acquired by dGPS unit; it was recorded in the SEGY file. Profiles were run shore-perpendicular to capture the geometry of the bank flanks and span a depth range of 300 m to 5 m. Total transect length varies with the slope's angle; steeper slopes resulted in shorter transect lines.

Site	Imagery (sq km)	No. dropcams	No. depth soundings	Track length (km)
Aitutaki	190	58	423,017	107.4
Palmerston	85	75	352,428	81.7
Rarotonga	131	33	280,182	70.5
Total	**406**	**166**	**1,055,627**	**259.6**

Table 1. Summary of groundtruthing data: total area of satellite imagery acquired number of deployments of the drop camera, number of depth soundings and total distance covered by the groundtruthing team.

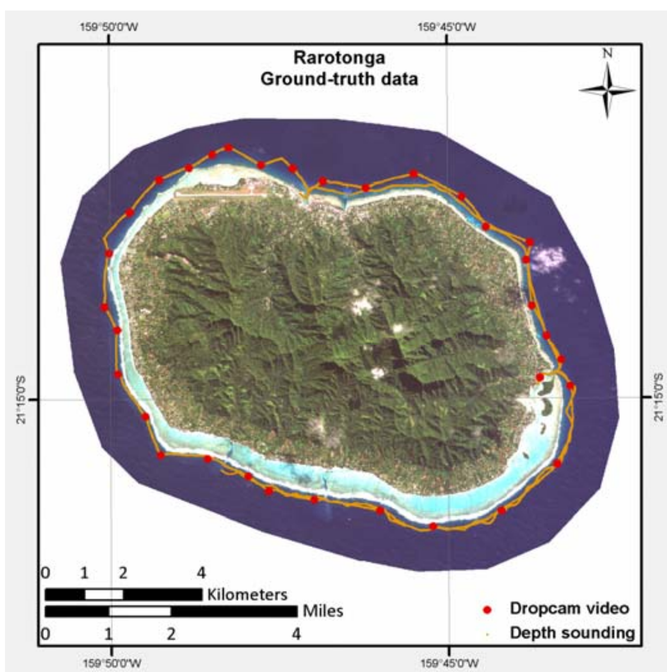

Fig. 7. Groundtruthing track in Rarotonga, Cook Islands showing locations of depth soundings and camera deployments. Due to the shallow depth of the lagoon, no groundtruthing was done within lagoonal areas.

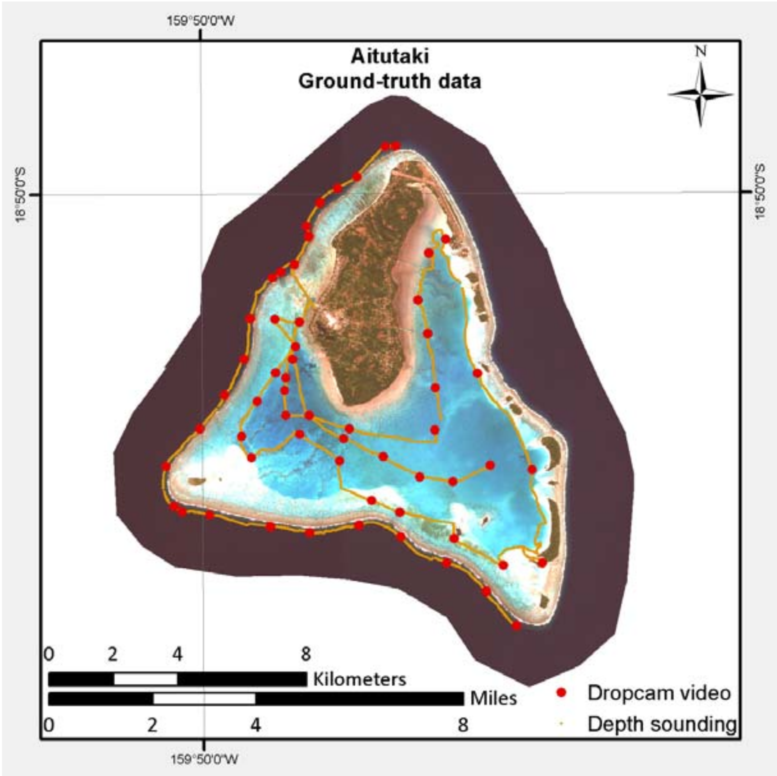

Fig. 8. Groundtruthing track in Aitutaki, Cook Islands showing locations of depth soundings and camera deployments.

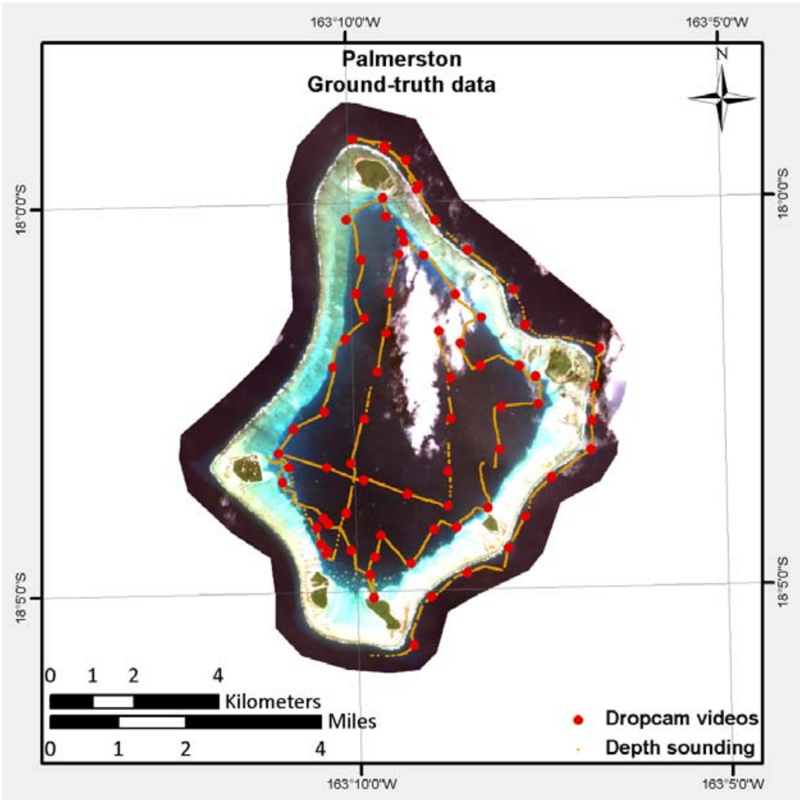

Fig. 9. Groundtruthing track in Palmerston, Cook Islands showing locations of depth soundings and camera deployments.

2. General Approach of SCUBA assessments:

Fish Assessments

For fish, abundance and size structure was collected for over 200 species of fishes (Appendix 1), targeting species that have a major functional role on reefs or are major fisheries targets. Reef fishes were assessed along 4 m X 30 m belt transects. A T square marked in 5 cm increments was used to gauge fish size. A minimum of 6 transects were conducted by each "fish" diver per site. A roving survey was also completed to assess the total diversity and relative abundance (rare, common, and abundant) of reef fishes at each site.

Benthic cover

Cover of major functional groups (corals identified to genus, sponges, other invertebrates, and six groups of algae including macroalgae, crustose coralline algae, erect coralline algae, fine turfs, turf algae with sediment and cyanobacteria) and substrate type (hardground, sand, mud, rubble, recently dead coral, bleached coral, live coral) were assessed along 10 m transects using recorded observations and/or photographic assessments. Recorded observations involved a point intercept method, whereas the organism and substrate was identified every 10 cm along a 10 m transect (total 100 points/transect), with a minimum of six transects examined per location. When possible, surveys were completed at 30, 25, 20, 15, 10 and 5 m depth.

Photographic assessment

A 10 m long transect tape was extended along depth contours at 30, 20, 15, 10 and 5 m depth. Continuous digital still photographs were taken of the reef substrate from a height of approximately 0.6-0.75 meters above the substrate, using a one meter bar divided into 5 cm increments placed perpendicular to the transect tape as a scale bar. Approximately 20 photographs were taken per transect to allow for overlap between adjacent images with two photo transects (each 10 m in length) per depth. Images were downloaded onto a computer, and benthic community composition, coral cover and cover of other organisms and substrate type, and to determine the size (planar surface area) of corals were analyzed using Coral Point Count (CPCE) software developed by the National Coral Reef Institute (NCRI). Cover was determined by recording the benthic attribute located directly below random points (30-50 points per photograph). Planar surface area was measured by tracing the outline of individual corals.

Coral assessments

A combination of quantitative methods including: belt transects, point intercept transects, radial plots and quadrats were used to assess corals, fish and other benthic organisms. Five measures were recorded for corals: 1) benthic cover (point intercept, see above); 2) coral diversity and abundance (by genus, except certain common species); 3) coral size class distributions; 4) recruitment; and 5) coral condition. Additional information was collected on causes of recent mortality, including signs of coral disease and predation. Assessment of corals smaller than 4 cm was achieved by using a minimum of five 0.25 m^2 quadrats per transect, with each quadrat located at fixed, predetermined intervals (e.g. 2, 4, 6, 8, 10 m), alternating between the right and left side of the transect line. Recruits were identified in both point intercept surveys and belt transects. Recruits were divided into two categories: corals up to 2 cm diameter and larger corals, 2-3.9 cm diameter.

Coral population structure and condition was assessed within belt transects (each 10 m x1), with a minimum of two transects completed per depth. Each coral, 4 cm or larger was identified (to genus at minimum) and its growth form was recorded. Visual estimates of tissue loss were recorded for each colony over 4 cm in diameter using a 1 m bar marked in 1 cm increments for scale. If the coral exhibited tissue loss, estimates of the amount of remaining tissue, percent that recently died and percent that died long ago were made based on the entire colony surface. Tissue loss was categorized as recent mortality (occurring within the last 1-5 days), transitional mortality (filamentous green algae and diatom colonization, 6-30 days) and old mortality (>30 days).

For each coral with partial or whole colony mortality, the cause of mortality is identified if possible. The diagnosis included an assessment of the type of disease, extent of bleaching, predation, competition, overgrowth or other cause of mortality. Each coral was first carefully examined to identify cryptic predators. Lesions were initially diagnosed into four categories: recent tissue loss, skeletal damage, color change, and unusual growth patterns; an individual colony could have multiple characteristics (e.g. color change and recent tissue loss). The location (apical, basal, and medial) and pattern of tissue loss (linear, annular, focal, multifocal, and coalescing) was recorded and when possible a field name was assigned. If an outbreak of coral disease was documented, sampling of the affected corals was undertaken to further characterize the disease (see below).

Motile invertebrates

Large motile invertebrates (urchins, octopus, lobster, large crabs, large gastropods, sea cucumbers) were identified and counted along coral belt transects and benthic point intercept surveys. In addition, one or two divers conducted timed swims at different depths to document the species diversity and abundance of sea cucumbers at each site assessed. This assessment included a documentation of the type of habitat occupied by these organisms.

Number of Islands	Number of dives	Benthic transects	Fish transects	Coral transects	Corals	Phototransects
3	30	196	186	84	5,738	204

Table 2. Summary of the coral reef assessments. The total number of benthic, fish and coral transects and number of corals assessed in five islands are shown.

Fig. 10. A high number of triggerfish were recorded in transects at Rarotonga, while motile invertebrates especially sea urchins, were rare.

Table 3. Coral reefs examined in the Cook Islands.

Date	Lat	Long	Site name	Island	Reef zone	Reef type	Exposure
22-Apr-13	-21.1941	-159.8091	CIRR-01	Rarotonga	fore reef	fringing reef	leeward
23-Apr-13	-21.2513	-159.8290	CIRR-02	Rarotonga	fore reef	fringing reef	windward
23-Apr-13	-21.2136	-159.8331	CIRR-03	Rarotonga	fore reef	fringing reef	windward
24-Apr-13	-21.2417	-159.7225	CIRR-04	Rarotonga	fore reef	fringing reef	leeward
24-Apr-13	-21.2136	-159.7330	CIRR-05	Rarotonga	fore reef	fringing reef	windward
24-Apr-13	-21.1993	-159.7569	CIRR-06	Rarotonga	fore reef	fringing reef	leeward
26-Apr-13	-21.2642	-159.8165	CIRR-07	Rarotonga	fore reef	reef flat	windward
26-Apr-13	-21.2745	-159.7725	CIRR-08	Rarotonga	fore reef	reef flat	windward
26-Apr-13	-21.2719	-159.7299	CIRR-09	Rarotonga	fore reef	fringing reef	windward
27-Apr-13	-21.2007	-159.7714	CIRR-10	Rarotonga	fore reef	fringing reef	windward
27-Apr-13	-21.2300	-159.8335	CIRR-11	Rarotonga	fore reef	reef flat	windward
27-Apr-13	-21.1935	-159.7965	CIRR-12	Rarotonga	fore reef	fringing reef	leeward
28-Apr-13	-18.9043	-159.7236	CIAT-13	Aitutaki	fore reef	fringing reef	windward
28-Apr-13	-18.8184	-159.7735	CIAT-14	Aitutaki	fore reef	fringing reef	windward
29-Apr-13	-18.8897	-159.8272	CIAT-15	Aitutaki	fore reef	fringing reef	leeward
29-Apr-13	-18.8672	-159.8188	CIAT-16	Aitutaki	fore reef	fringing reef	leeward
30-Apr-13	-18.8331	-159.7941	CIAT-17	Aitutaki	fore reef	fringing reef	leeward
30-Apr-13	-18.9173	-159.8452	CIAT-18	Aitutaki	fore reef	fringing reef	windward
30-Apr-13	-18.8517	-159.8054	CIAT-19	Aitutaki	fore reef	fringing reef	leeward
1-May-13	-18.9283	-159.7943	CIAT-20	Aitutaki	fore reef	fringing reef	windward
1-May-13	-18.9519	-159.7445	CIAT-21	Aitutaki	lagoon	reef flat	windward
1-May-13	-18.9271	-159.7250	CIAT-22	Aitutaki	lagoon	reef flat	windward
3-May-13	-17.9926	-163.1535	CIPA-23	Palmerston	fore reef	fringing reef	windward
3-May-13	-18.0291	-163.1178	CIPA-24	Palmerston	fore reef	fringing reef	windward
3-May-13	-18.0489	-163.1128	CIPA-25	Palmerston	fore reef	fringing reef	windward
4-May-13	-18.0885	-163.1521	CIPA-26	Palmerston	fore reef	fringing reef	windward
4-May-13	-18.0697	-163.1293	CIPA-27	Palmerston	fore reef	fringing reef	windward
5-May-13	-18.0412	-163.1876	CIPA-28	Palmerston	fore reef	fringing reef	leeward
5-May-13	-18.0057	-163.1757	CIPA-29	Palmerston	fore reef	fringing reef	leeward
5-May-13	-18.079	-163.1817	CIPA-30	Palmerston	fore reef	fringing reef	leeward

Fig. 11. Commercially valuable giant clams were recorded infrequently in all surveys.

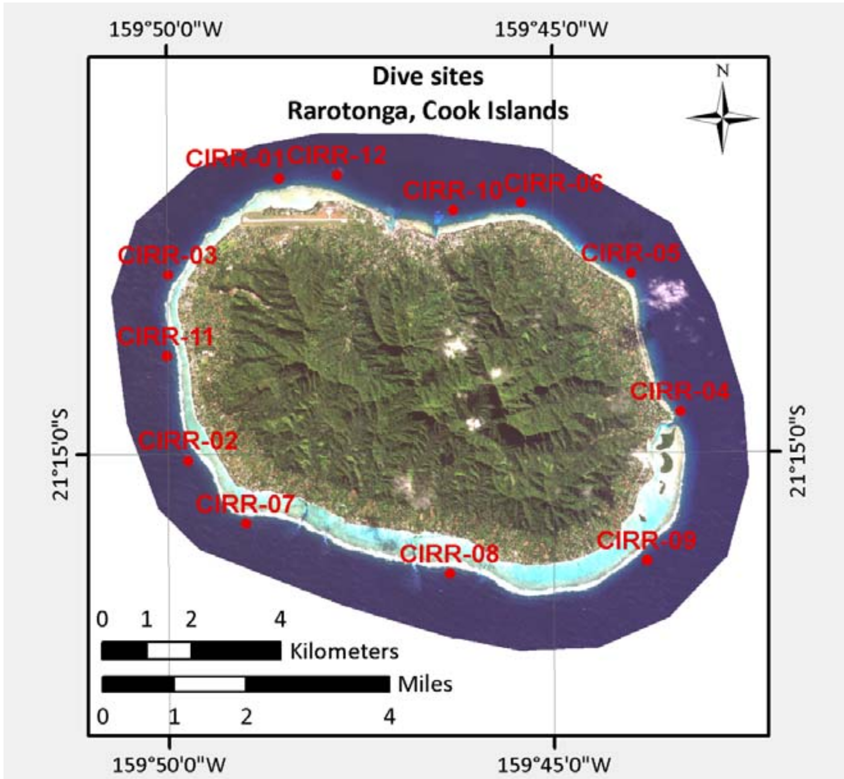

Fig. 12. Locations of SCUBA assessments in Rarotonga, Cook Islands.

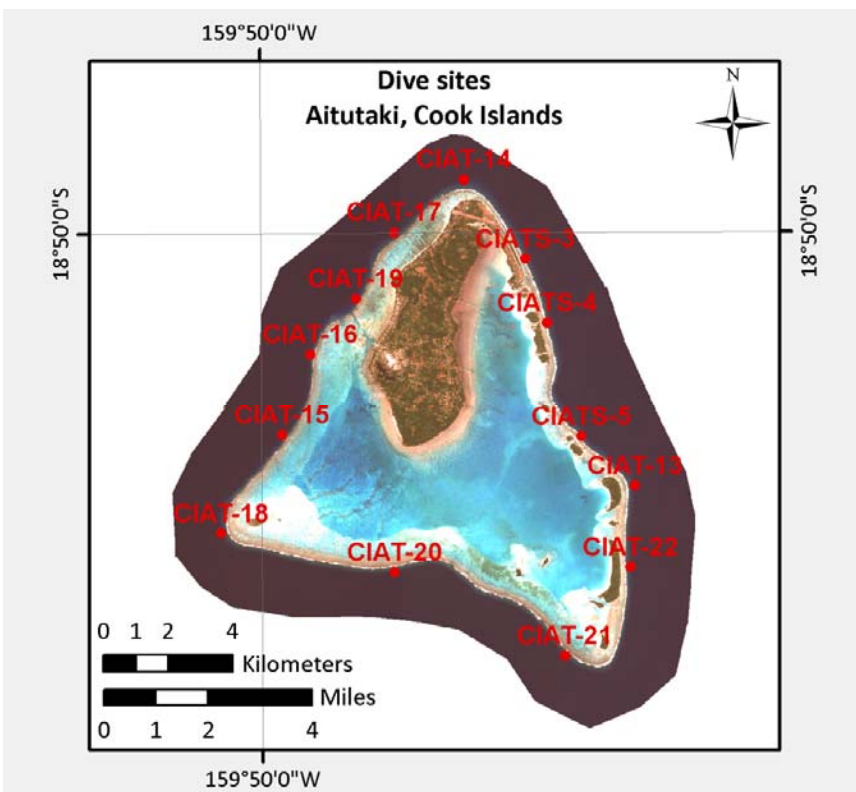

Fig. 13. Locations of SCUBA assessments in Aitutaki, Cook Islands.

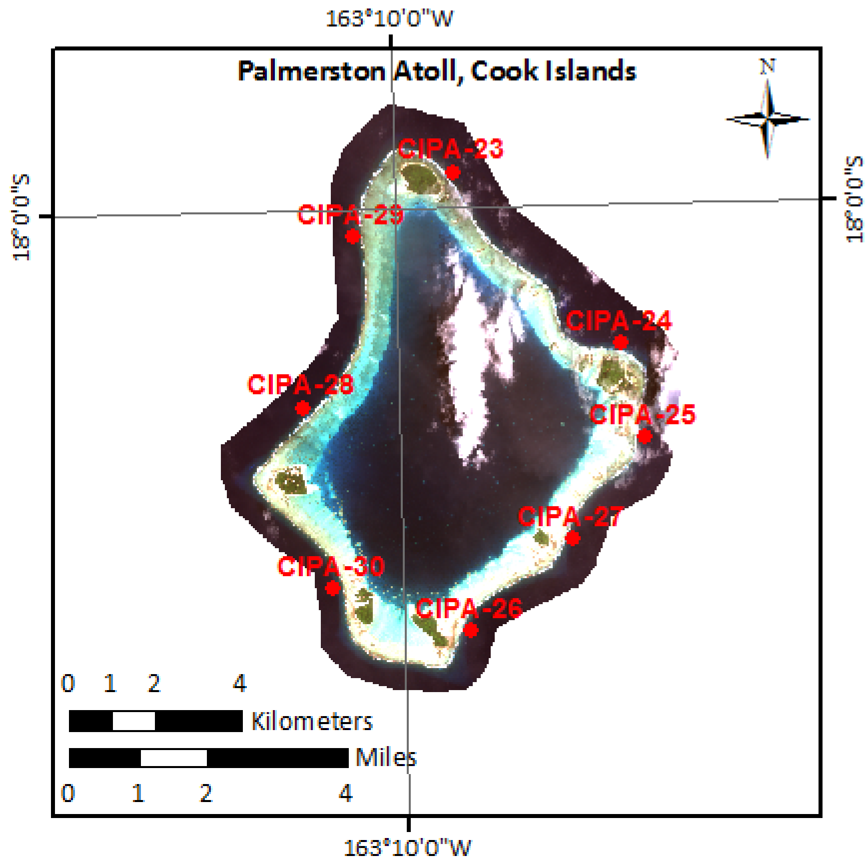

Fig. 14. Locations of SCUBA assessments in Palmerston, Cook Islands.

Fig. 15. Large parrotfish were relatively common on fore reefs off Palmerston.

3. Coral reef research

Crown of thorns assessment and mitigation:

In each location examined in Aitutaki, two divers collected every COTS encountered during a roving swim over a 50 minute period, except for CIAT-13 where four divers collected starfish over the same period. Starfish were measured on board the M/Y Golden Shadow to get information on size structure and condition.

Sediment collection:

Sediment samples were collected using two different methods. The first method used SCUBA and concentrates on the sloped outer flanks of the reef, whilst the second employs a grab sampler to investigate the sediment composition inside the reef lagoon. At each sample station, approximately 100 ml of sediment was shoveled by hand into a 125 ml plastic bottle. Stations were selected so that no benthic life is disturbed or injured. Digital pictures of underwater landscapes surrounding the sampling site were also gathered to provide a visual record of the station. Up to ten samples were collected per day.

In the lagoons, sediment was collected using a Petite Ponar® Grabber. The grabber was attached to an electronic winch wound with 50m of braided polyester line. The grabber was slowly deployed over the side of the boat until it settles on the seafloor, causing the winch line to slacken and the grab to shut. Once the grab is retrieved, it was lifted into the boat and the sediment collected. For each deployment, 100 ml of sediment was shoveled by hand into a 125 ml plastic bottle. A maximum of five samples were taken per day.

In the laboratory, the samples were rinsed with a weak bleach solution (30% bleach and 70% tap water) and allowed to set for several days. This process halts biological activity and preserves the sediments. The samples were dried in an oven at low heat (50°-70°c) for 24 hours, and then analyzed using a Camsizer® instrument to determine the size and shape of sediment grains. The data are being used to create sediment maps akin to the benthic habitat maps.

Island	Number of samples
Aitutaki	16
Palmerston	12
Rarotonga	11
Total	**39**

Table 4. Total number of sediment samples.

Ocean acidification:

This research involved two components, characterizing water chemistry and collecting coral samples to correlate water chemistry to coral growth rates. Water chemistry analysis involved three aspects: 1. Three to four seawater bottle samples (500 ml) were collected from each site visited. Seawater samples were preserved with 2 µl of saturated HgCl2 and sealed with large rubber bands to prevent any changes to the carbonate system before analysis. Total CO_2 (TCO_2) is being measured coulometrically and total alkalinity (TA) measured utilizing a gran titration by Dr. Derek Manzello (NOAA/AOML) at his laboratory in Miami, Florida (USA). 2. An autonomous pH sensor was deployed on the bottom for the duration of our visit to each site. This instrument measured the diel variability in seawater CO_2, to complement the bottle samples obtained. 3. At each dive location, we sampled the water for the duration of a dive to obtain instantaneous measures of TCO2, TA and temperature. These parameters allowed calculation of the carbonate system of seawater (i.e., partial pressure of CO2 (pCO2), pH and Ω).

During each dive, one diver collected small coral cores from massive coral species (*Porites lobata, Pavona clavus*) using a pneumatic drill, to examine long-term patterns in coral growth rates. Up to ten cores were per location (species will depend on local abundance of retrievable cores). These cores are small, approximately 3 cm in diameter and 7 cm in maximum length. All core holes were filled with cement plugs and epoxy to aid tissue recovery of the parent colony. Samples were carried back to Miami and are being assessed using a micro-CT machine to determine linear extension, bulk-density, and calcification.

Island	Species	Number	Size	Fixation
Rarotonga	*Porites lobata*	19	~3cm diam. X 9 cm length	Dry
Aitutaki	*Porites lobata*	6	~3cm diam. X 9 cm length	Dry
Palmerston	*Porites lobata*	7	~3cm diam. X 9 cm length	Dry
Palmerston	*Pavona clavus*	2	~3cm diam. X 9 cm length	Dry
Total		34		

Table 5. Coral cores collected for calcification and growth studies.

Coral health:

This research seeks to understand if it is possible to detect sub-lethal levels of stress in corals using molecular biomarkers. Currently, the only way to know if the corals are stressed is if they show signs of stress (e.g. partial colony mortality) which usually occurs after the environmental conditions have already changed. By using expression levels of certain genes, proteins, and metabolites, an index of health will be developed that can be used to forecast the future condition of a reef and identify a potential environmental perturbation before it manifests through coral mortality. One of the dominant reef building coral genera found throughout the Indo-Pacific, *Pocillopora*, is the model animal that was sampled.

In each location, oceanographic measurements (light, temperature, and salinity) are recorded. Replicate samples of Pocillopora are identified at different depths (5-30 m). The colonies are first assessed for visible signs of stress. A small biopsy (100 mg) consisting of 3-5 polyps is removed from a branch tip. The sample is divided in half: 50% for molecular work, 50% for microscopy. Half the sample is placed in RNALater® or frozen in liquid nitrogen; the other half is fixed in paraformaldehyde and decalcified. All processing is done in the laboratory in Taiwan. Total number of samples collected are shown in Table 6.

Island	Species	Number	Size	Quantity taken (mg)
Rarotonga	*Pocillopora verrucosa*	19	50 mg each	950
Rarotonga	*Pocillopora* sp.	9	50 mg each	450
Rarotonga	*Pocillopora damicornis*	2	50 mg each	100
Rarotonga	*Pocillopora meandrina*	4	50 mg each	200
Aitutaki	*Pocillopora verrucosa*	7	50 mg each	350
Aitutaki	*Pocillopora* sp.	2	50 mg each	100
Aitutaki	*Pocillopora damicornis*	3	50 mg each	150
Palmerston	*Pocillopora verrucosa*	12	50 mg each	600
Palmerston	*Pocillopora sp.*	2	50 mg each	100
Total from Cooks		**60**		~3 g

Table 6. Summary of coral samples collected for biomarker assessment. Samples were fixed in RNALater or paraformaldehyde. After fixation, samples were washed, decalcified, washed again, and transported in buffered saline, so as not to have to transport them in a toxic fixative (i.e., formaldehyde).

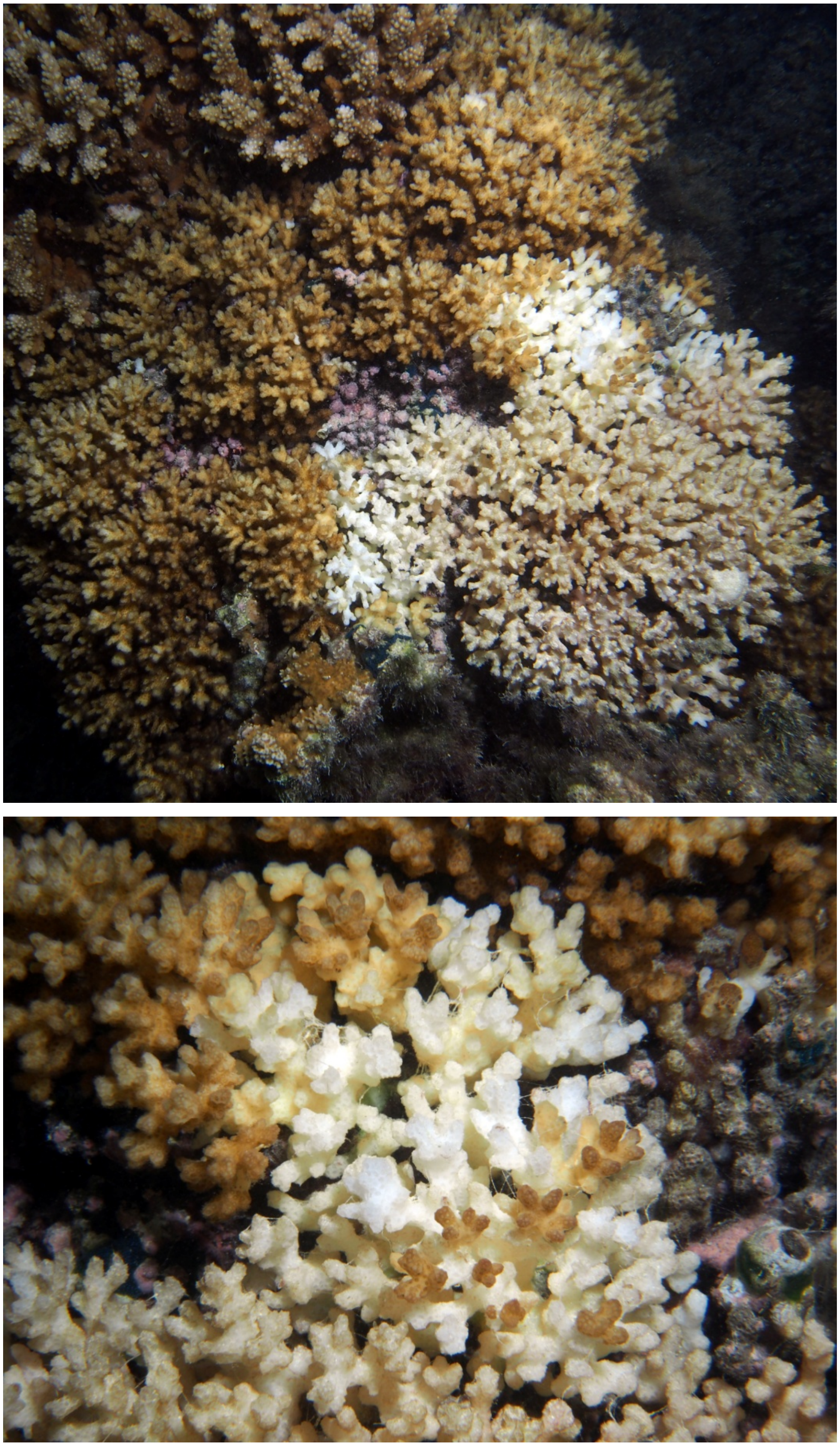

Fig. 16. ***Pocillopora damicornis*** **colonies within the lagoon of Aitutaki. Colonies are located in < 1 m depth. Colonies form very large assemblages intermixed with branching acroporids,** ***Montipora*****, massive** ***Porites*** **and other species. A large number of the** ***P. damicornis*** **colonies showed signs of recent mortality possibly due to aerial exposure. A whole colony (top) and close-up of a colony are shown. White skeletal areas are devoid of tissue. No crown of thorns starfish were identified on this reef.**

Appendix 12. List of participants and their role.

Name	Institution	Function
Andy Bruckner	Khaled bin Sultan Living Oceans Foundation	Chief Scientist, coral surveys
Brian Beck	Khaled bin Sultan Living Oceans Foundation	Benthic surveys
Alison Barrat	Khaled bin Sultan Living Oceans Foundation	Director of Communication
Badi Samaniego	University of the Philippines, KSLOF Fellow	Fish surveyor
Anderson Mayfield	National Museum of Marine Biology and Aquarium, KSLOF Fellow	Coral genetics
Jeremy Kerr	Nova Southeastern University, KSLOF Fellow	Groundtruthing / habitat mapping
Ken Marks	Atlantic and Gulf Rapid Reef Assessment Program (AGRRA)	Photo transects
Alex Dempsey	Nova Southeastern University	Benthic surveyor
Renee Carlton	NOAA	Ocean acidification
Anesti Stathakopoulos	Nova Southeastern University	Groundtruthing
Marine Couraudon-Reale	Independent contractor	Benthic surveyor
Kate Fraser	Independent contractor	Fish surveyor
Nick Cautin	Dive Safety Officer	Diving operations
Ernie Kovaks	Independent	Video documentation
Jacqueline Evans	Te Ipukarea Society	Outreach
Tou Ariki	Cook Islands Marine Park Steering committee	Outreach
Kevin Iro	Cook Islands Marine Park Steering committee	Outreach
Ted Nia	Cook Islands Marine Park Steering committee	Outreach
Michael Henry	Cruise Cook Islands	Logistics and coordination

The Science Team