Field Report

GLOBAL REEF EXPEDITION:
Society Islands, French Polynesia

15/09/12-12/10/12

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Front cover: Aerial photograph of Huahine. Photo by Andrew Bruckner.

Back Cover: Shallow coral reef at Mopelia (top) in good condition and reef at the same depth at Bellingshausen that has been damaged by crown of thorns sea stars (COTS). Most of the coral is dead, in growth position, and covered in crustose coralline algae. A COTS is searching for food (bottom). Photos by Andrew Bruckner.

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Executive Summary

Between September 15, 2012 – October 13, 2012 the Khaled bin Sultan Living Oceans Foundation conducted a research mission to Society Islands, French Polynesia as part of the Global Reef Expedition. The research focused on coral reefs surrounding the islands of Mopelia, Scilly, Bellinghausen, Tupai, Huahine, Raiatea/Tahaa, Maiao, and Tetiaroa. The project was conducted in partnership with the Institut de Recherche pour le Développement (I.R.D.), with involvement of scientists from Direction des Ressources Marines (DRM), Direction des Ressources Naturelles (DIREN), Nova Southeastern University, University of the Azores, University of the Philippines, NOAA/University of Miami, Atlantic and Gulf Rapid Reef Assessment Program (AGRRA), Michigan State University, College of Veterinary Medicine, University of Queensland, Florida Aquarium, University of Tasmania, and Victoria University. 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) evaluate the effects of environmental stressor on coral health; and 4) measure ocean chemistry (pH) and effects on coral growth. Researchers from IRD and DIREN also 1) conducted surveys of commercially important invertebrate resources (gastropod molluscs, giant clams and sea cucumbers); 2) evaluated population genetics of the black lipped pearl oyster (*Pinctada margaritifera)*; 3) conducted a sponge inventory and collected samples for genetic verification and chemical compounds; and 4) evaluated turtle nesting beaches.

Groundtruthing: A total of 1105 sq km of WorldView 2 satellite imagery was acquired. To characterize shallow marine habitats, 316 videos (drop cameras) and 2,415,947 soundings were taken across the 8 islands, covering a track of 731 km.

Coral reef assessments: A total of 461 Fish transects, 546 benthic surveys, 116 coral assessments and phototransects were completed in 64 locations from 5-30 m depth. Detailed information on the population dynamics (size structure) and condition (amount and cause of mortality) was collected for 16,825 corals.

Coral reef research:

- Colonies of *Favia stelligera* (n=30) and *Herpolitha limax* (n=14) with undescribed yellow lesions and *Porites lobata* (n=44) with pink line disease were sampled for histology. Three species of *Pocillopora* (n=18 total) with unusual color patterns were also sampled.
- Sediment samples (n=128) were collected from the lagoon and fore reef around eight islands/atolls.
- A total of 91 cores were collected at 10-12 m depth in nine locations consisting of 90 *Porites lobata* and one *Pavona clavus*. These will be sectioned and examined using a CT scan to quantify variations in coral growth rates and relationship with ocean chemistry.
- Small (each=1 cm^3) tissue and skeleton samples were collected from six species of *Pocillopora* (n=435) between 5-30 m depth in fore reef and back reef locations to characterize variations in the type of symbionts between depths and environmental conditions.
- Stationary video cameras (10/dive) were deployed in 15 sites across the Society Islands to characterize patterns of herbivory.
- Two 10 m x 10 m Legacy Sites on the fore reef at 10 m depth at Raiatea were permanently marked and photographed to document recovery from a crown of thorns outbreak.
- The distribution and size structure of giant clams, sea cucumbers, and introduced gastropods (*Turbo marmoratus* and *Trochus niloticus*) were quantified in fore reef, back reef and reef crest habitats.
- Sponge diversity was catalogued and specimens were collected for analysis of biologically active chemical compounds.

Summary of general findings

A. CORAL CONDITION AND THREATS

- **Storm damage:** The three most remote atolls (Mopelia, Scilly and Bellingshausen) all had flourishing coral communities on the fore reef, with live coral cover often approaching or exceeding 80% in shallow water (1-15 m depth). Most of the corals in shallow water on the fore reef that made up most of the living cover - generally 10-30 cm. These were dominated by short-lived and branching corals like *Pocillopora* and *Acropora*. Based on the growth rates of the most common species (the branching corals), this suggests that a large percentage of the colonies were young - 5-6 years up to about 10 years old. These sites appear to be frequently disturbed by high wave surge and storms, but they are very resilient and able to rebound quickly.
- **Past Crown of thorns (COTS) predation:** Fore reefs around Tupai, Huahine and Raiatea/Tahaa had very few remaining large corals. The typical dense stands of branching corals seen in other locations were absent, and the bottom was covered in rubble (broken branches of dead coral). In several places, the reef was dominated by large (meter tall) dead colonies of *Porites* and patches of cauliflower corals (*Pocillopora*) in growth position, with skeletons heavily colonized by crustose coralline algae. Nevertheless, the bottom was colonized by small sexual recruits, mostly *Pocillopora*, and juvenile corals (branching pocilloporids and acroporids, massive *Porites* and faviid corals, and plate-like and encrusting Montipora and Pavona colonies) most of which were from less than 1 cm in diameter up to about 3-4 cm. Often, there were 20-30 new recruits per square meter. These reefs had high amounts of encrusting calcareous red algae and sparse fleshy macroalgae, lots of small herbivorous reef fishes, and few nuisance species. In Tupai, Huahine and Raiatea, entire reef tracks had been denuded by the starfish several years earlier (outbreaks were reported from these areas in 2008). In shallow water, most of the coral skeletons were also gone and replaced by fields of rubble, likely due to Hurricane Oli, while skeletons of the hardier massive corals were still in growth position in deeper water. Even though all of the older corals had been killed, these reefs were carpeted with small corals that were generally less than 1-2 years old. The community characteristics suggest that they are undergoing rapid recovery.
- **Ongoing COTS predation:** Active outbreaks of COTS were noted on one reef in Bellingshausen and lower numbers of starfish were seen in deep water (15-30 m) on Scilly and Mopelia. Most of the deeper areas were dominated by large massive pore coral (*Porites*) mixed with the branching Pocillopora and other species. In many locations deeper areas had little coral, and often many of the colonies were stark white - recently dead. These areas were being affected by predation from crown of thorns sea stars. Wherever we saw COTS, there were extensive amounts of recently killed corals, and large stands of corals that had died a few years earlier - only the skeletons remained.
- **Secondary outbreaks of COTS:** Reefs around Tetiaroa appear to have been devastated by COTS several years earlier as evidenced by high numbers of dead skeletons of preferred coral species, yet the starfish appeared to have avoided many of the massive corals. A second outbreak appeared to be underway, as we observed dozens of starfish on these reefs. They were consuming the remaining corals - high numbers of *Porites* and *Gardinoseris*, two massive coral species had recent lesions from predation. In addition, the starfish were found in shallow water, consuming the remaining live coral which consisted mostly of small juveniles of *Pocillopora* and *Acropora* that had recolonized the area within the last one to two years.
- **Other coral predators:** A high amount of fish biting was noted on *Pocillopora* and *Porites*; these lesions tend to heal quickly. *Drupella* and *Coralliophila* snail predation was present, but restricted to individual

colonies; *Pocillopora* on the fore reef often had signs of predation and *Acropora* in certain lagoonal habitats. Generally, less than 1% of colonies were affected.

- **Coral diseases:** In general, very little disease was seen on the fore reef. An undescribed syndrome (termed yellow band) was observed on *Favia stelligera*; *Porites* colonies, especially in lagoonal habitats were affected by pink line disease; numerous tumors were seen on *Montipora, Acropora* and *Astreopora*; and isolated cases of white syndrome were noted. Recent mortality from disease was low.
- **Tahiti:** Reefs were similar to other high islands in Society Archipelago. A major disturbance, presumably COTS, killed much of the coral and few large, older colonies remained. Moderate levels of replacement with new corals- in shallow water high numbers of recruits and juveniles of the early colonizing species, except near Papeete. The losses were compounded in one site on the west by storm damage - all of the dead coral had been removed and the bottom had little relief. Deeper areas at this site had a framework of large old *Porites* colonies with patches of living tissue and fairly good colonization of substrates by other coral species. A third fore reef on the southern end of Tahiti does not appear to have been impacted by storms or COTS. Shallow areas had a very high cover and abundance of branching corals and more massive corals in deeper water. The reefs closest to Papeete had much higher amount of fleshy algae and fine sediments on the substrate and a depauperate fish community (low numbers of species, low abundance and small sizes). The south had a more diverse fish community, including numerous apex predators and large populations of herbivores.

OTHER INVERTEBRATES

- **Species targeted by fisheries:** High numbers of imported *Trochus* and *Turbo* snails were seen at Bellingshausen and in high islands; they were present in lower numbers in other areas, being most common on reef flat and shallow fore reef zones. *Tridacna* were present, with highest numbers in lagoonal areas; these clams were mostly juveniles (<12 cm); the lack of large individuals suggests they are harvested as soon as they reach legal size. Sea cucumbers were rare. A few deep (>25 m) reefs had densities that are typical of unfished areas, but most sites were depleted.
- **Sponges:** Over 30 species of sponges identified in five atolls in Society Islands with the highest number of different species on the fore reef, far fewer in the lagoon, and most occurring from 20-30 m depth. Two sponges are new species, four of the 30 are found throughout the four archipelagos (Society Islands, Tuamoto, Gambier and Marquesas), and the rest are unique to Society Islands.

FISHES

- Outer atolls had a healthy fish community with sharks, groupers, snappers, a host of invertebrate feeders, parrotfish, surgeonfishes and other herbivores, with both juveniles and adults seen. In Tetiaroa, Huahine, Tahaa/Raiatea and Maiao there were very few large predators. These reefs had a high diversity of juveniles and smaller reef fishes, but an absence of larger individuals possibly due to the lack of structure. Because of an absence of high relief corals, these species may have disappeared, since there is no refuge.
- Parrotfish diversity was lower at Society Islands than in Tuamotu and Gambier. Bullethead parrotfish were the most common parrotfish around the Society Islands, which was not the case in other areas.

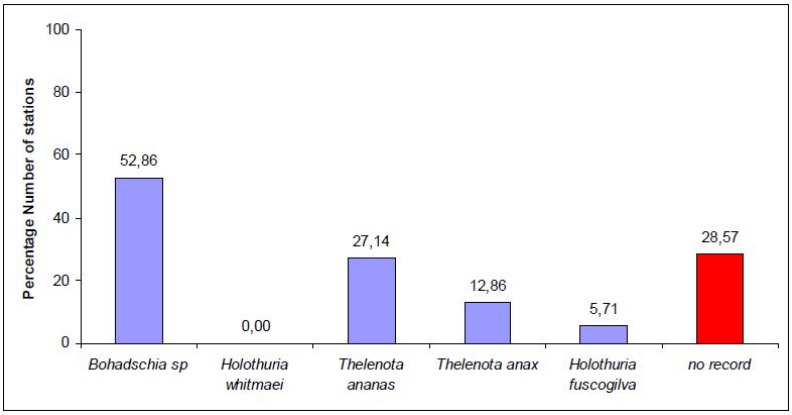
UNUSUAL HABITAT CHARACTERISTICS AND VALUES

- Scilly was found to contain large expanse of stromatolites.
- Important turtle nesting beaches were surveyed on outer atolls.

Observations on commercial sea cucumber in Society islands and atolls

- The survey was undertaken as a collaboration between DRM and IRD. The goal was to assess the status of the sea cucumber commercial population, after 3 years of intense fishing in several islands. Indeed, exports of processed sea cucumbers soared from 3 tons in 2008 to 125 tons in 2011. The Society lagoons and reefs seem to have been heavily exploited. The September-October 2012 Society survey occurred shortly before the closure of the fisheries (November 2012).
- Two divers conducted timed belt-transects surveys using SCUBA, from 30 meter deep (the fore reef and deep sand plains) to the surface (the spur and grooves and along the crest when the waves condition were suitable). Shallow surveys were also performed on reef flats and shallow back reefs, as well as walks along the reef crests at low tide. A total of 70 sites were surveyed (Tahiti was surveyed in November 2012).
- Twenty stations had no records of commercial species. Large commercial sea cucumbers were absent for most high islands lagoons (Raiatea, Tahaa, Huahine). The dominant species was *Bohadschia argus*, but in low density. This species was seen on 37 stations. The most valuable species (*Holothuria fuscogilva* and *Thelenota anax*) were found only on the exposed eastward forereef and in the deeper sand plains by at least 30 meter deep. *Holothuria whitmaei* was not seen at all. *Thelenota ananas* was also present on the forereefs, at all depth range, in most atolls and islands, but in low numbers. *Actinopyga mauritiana* (now named *A. varians*) juveniles were very abundant on the algal crests that characterize the high island barrier reefs, but rarely seen as adults. The atolls were contrasted. Both Mopelia and Scilly lagoons lacked the *Holothuria atra* which was extremely abundant in Tupai. The western atolls appeared mostly depauperate, but this was already reported in the 1970s. Tetiaroa atoll had a good population of *T. ananas* on its forereef.
- The results suggest that populations of valuable species have been overfished around the main islands since they were either not found or only very deep.

***T. ananas* on a deep forereef, and *T. anax* on a deep rubble plain, in Raiatea Island.**



The percentage of stations where commercial species were recorded, e.g. *H. fuscogilva* was seen on 5.7% of the stations, out of a total of 70 stations.

Table 1. Research Schedule

Date	Location/Activity
14 –Sep-2012	Press conference/reception/ship tour
15-Sep	Overflights
16-Sep	Tahiti dives/checkout/orientation
17-19 Sep	Mopelia
20-21 Sep	Scilly
22 Sep	Bellingshausen
23 Sep	Tupai
24-26 Sep	Huahine
27 Sep -10 Oct	Tahaa/Raiatea
11-12 Oct	Tetiaroa
13 Oct	Maiao

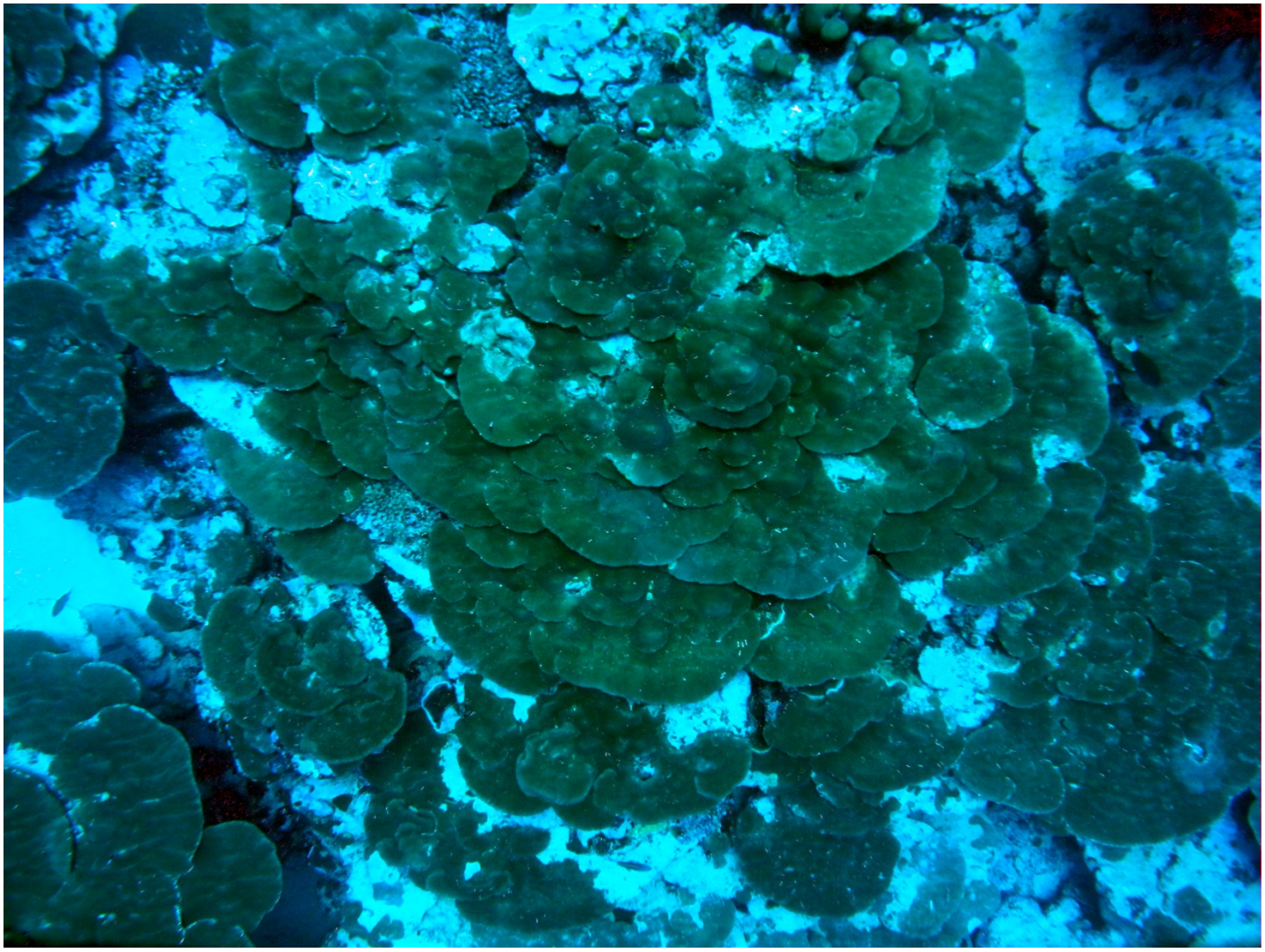


Fig. 1. Deep (30-40 m) fore reef community off the west side of Raiatea. Overlapping sheets of *Porites lobata* covered the substrate at the base of the fore reef slope. In a similar environment off the northeasdt side of Huahine, dense stands of unusually large colonies of *P. lobata* also occurred, although most colonies were now dead due to COTS predation.

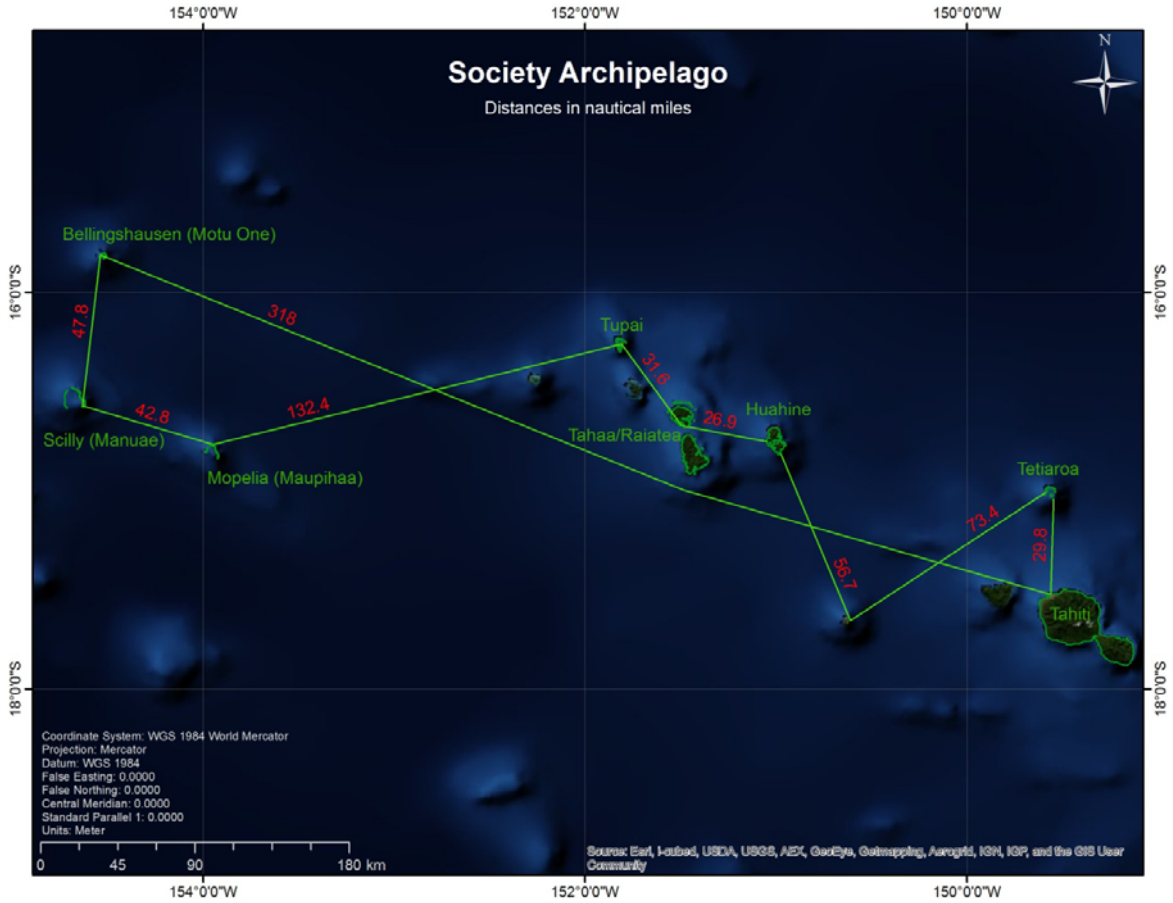


Fig. 2a. Track undertaken by the GoldenEye during aerial surveys of the study locations.

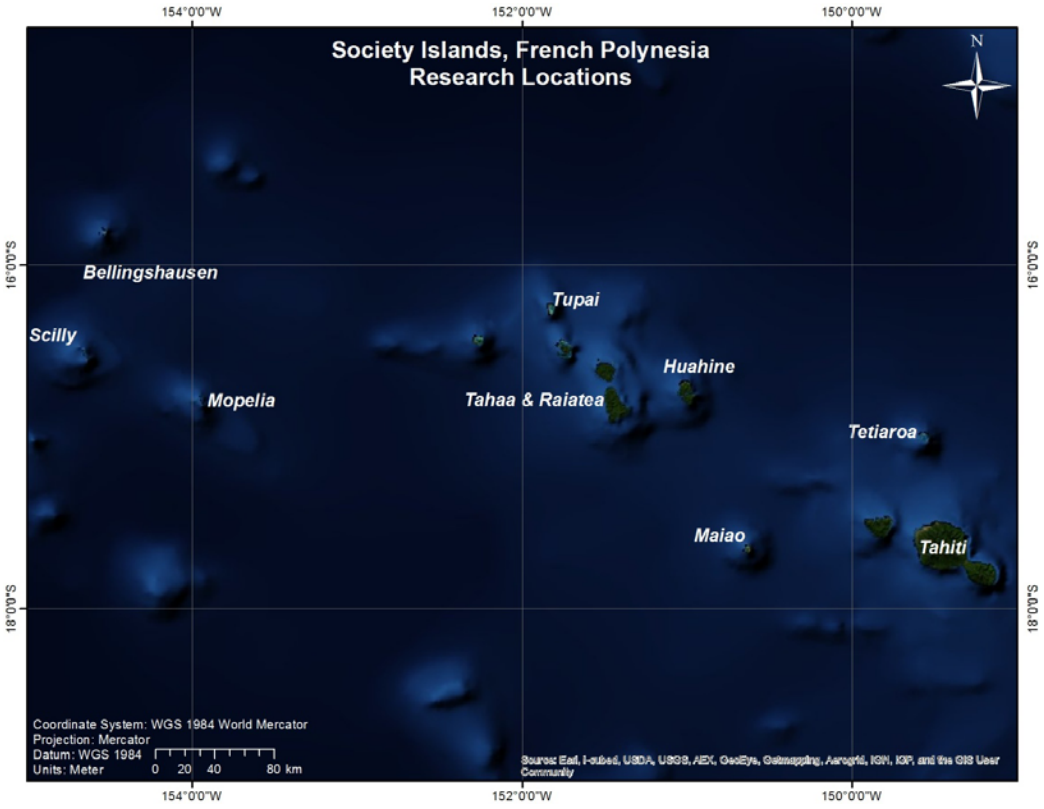


Fig. 2b. Eight locations examined during the Society Islands research mission.

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.

Satellite imagery

A total of 1105 sq. km of WorldView 2 (8 band) satellite imagery was acquired (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 navigation 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 used in conjunction with groundtruth data to create bathymetric and benthic habitat maps.

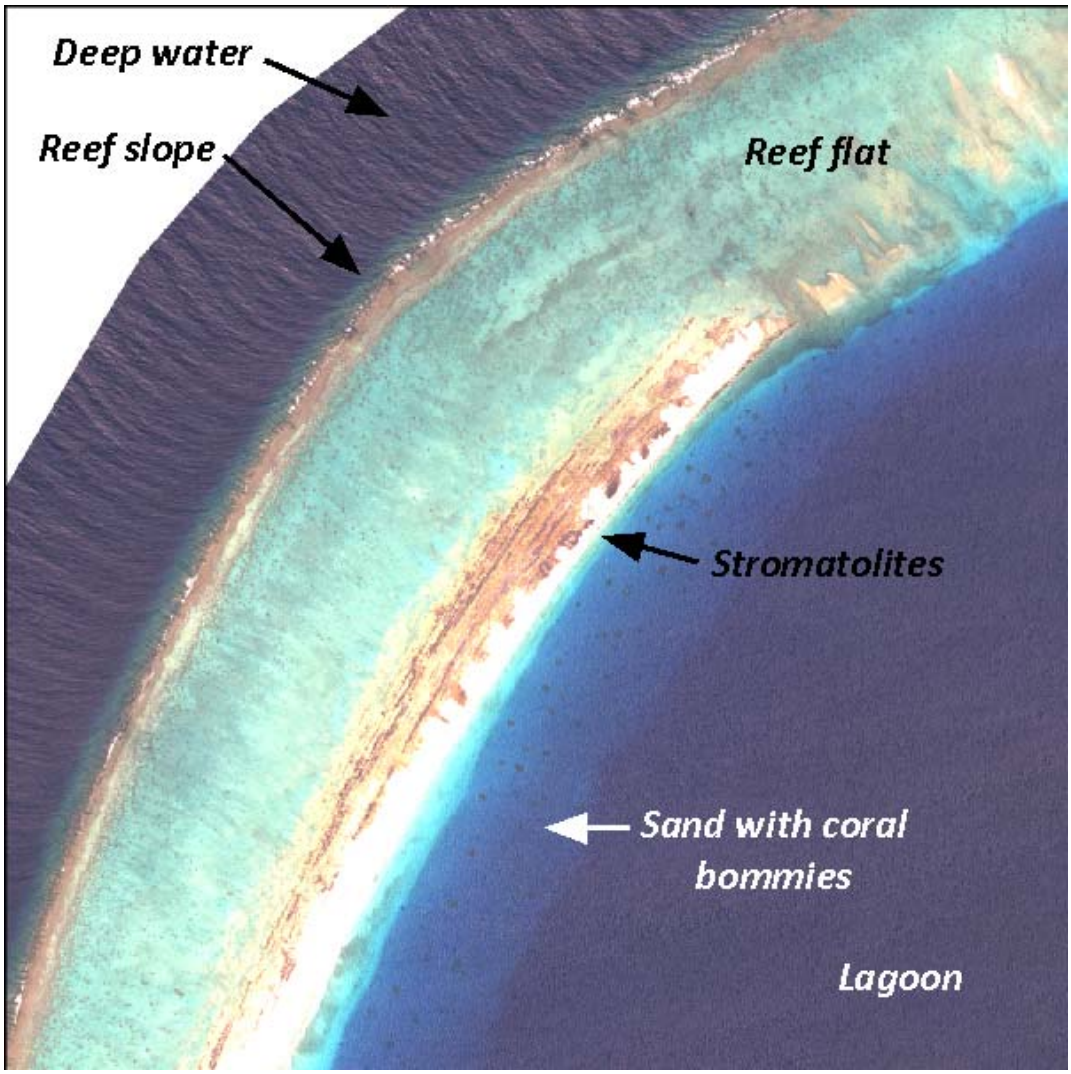


Fig. 3. A close-up of the Worldview-2 satellite image of Scilly showing a field of stromatolites.

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

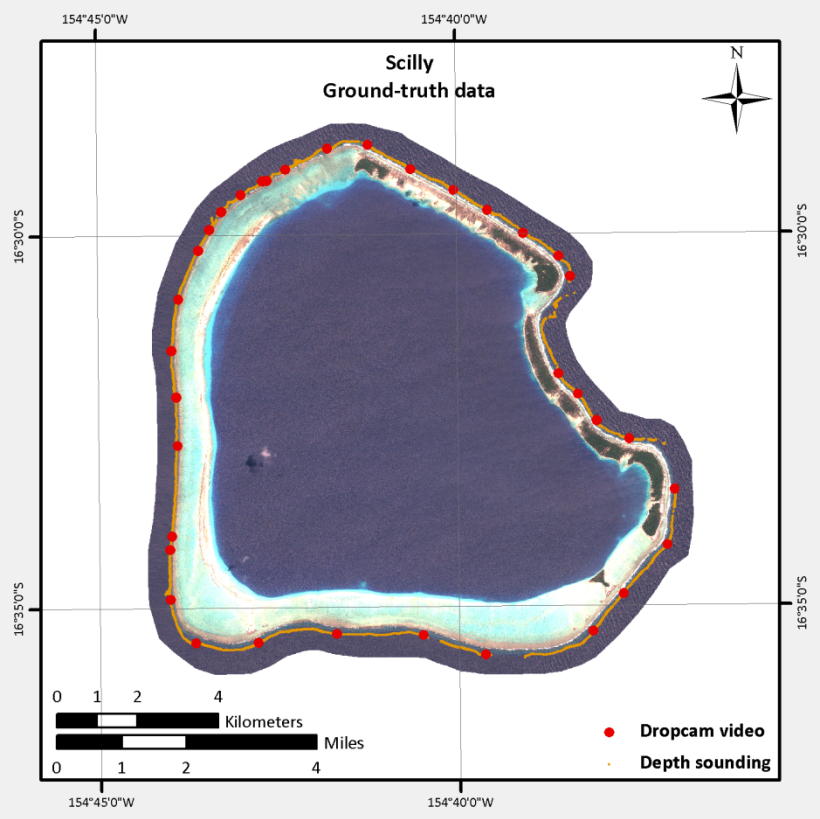
Depth soundings were gathered along transects between survey sites using Hydrobox, a single-beam acoustic transducer, developed by Syqwest. The instrument emits 3 pings per second. Depths were estimated based on the time the return-pulse's reaches the sounder's head. Geopositional data were simultaneously 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.

Archipelago	Location	Area (sq km)	No. dropcams	No. depth soundings	Distance covered
Society Islands	Bellingshausen	20	15	72724	15.167
	Scilly	141	35	181088	46.899
	Huahine	162	64	464478	109.49
	Tahaa&Raiatea	596	125	1213664	445.28
	Maiao	27	16	58897	14.326
	Mopelia	65	33	258233	56.979
	Tetiaroa	50	8	63986	18.889
	Tupai	44	20	102877	24.082
	Total	1,105	316	2,415,947	731.112

Table 2. Summary of groundtruthing datasets: 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.



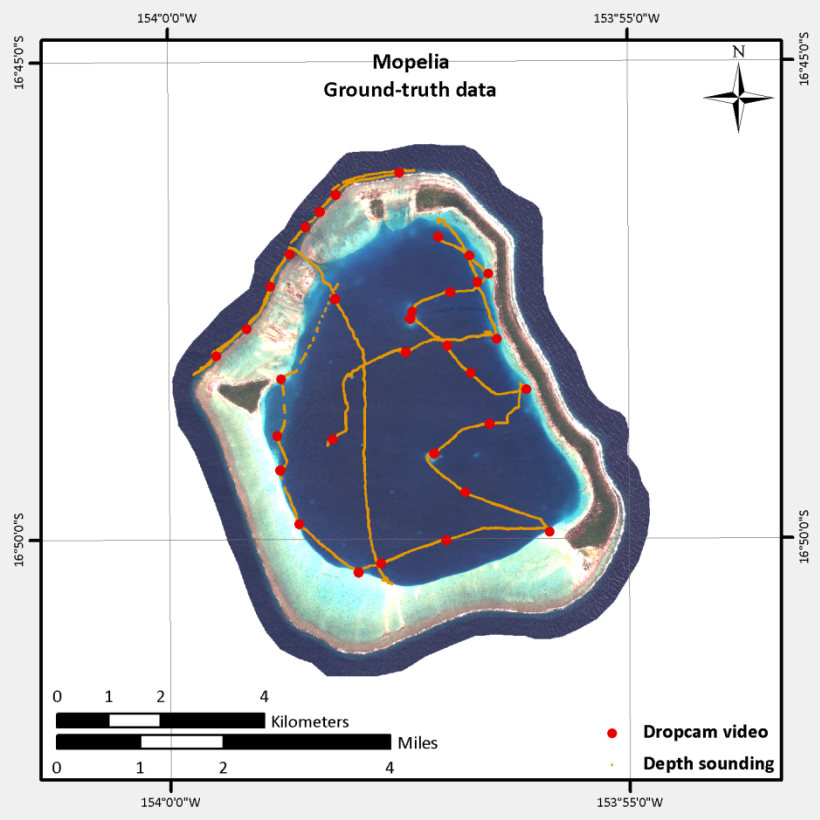


Fig. 4. Track of the groundtruthing team and locations of drop camera deployments. Scilly (top image) and Mopelia (bottom image).

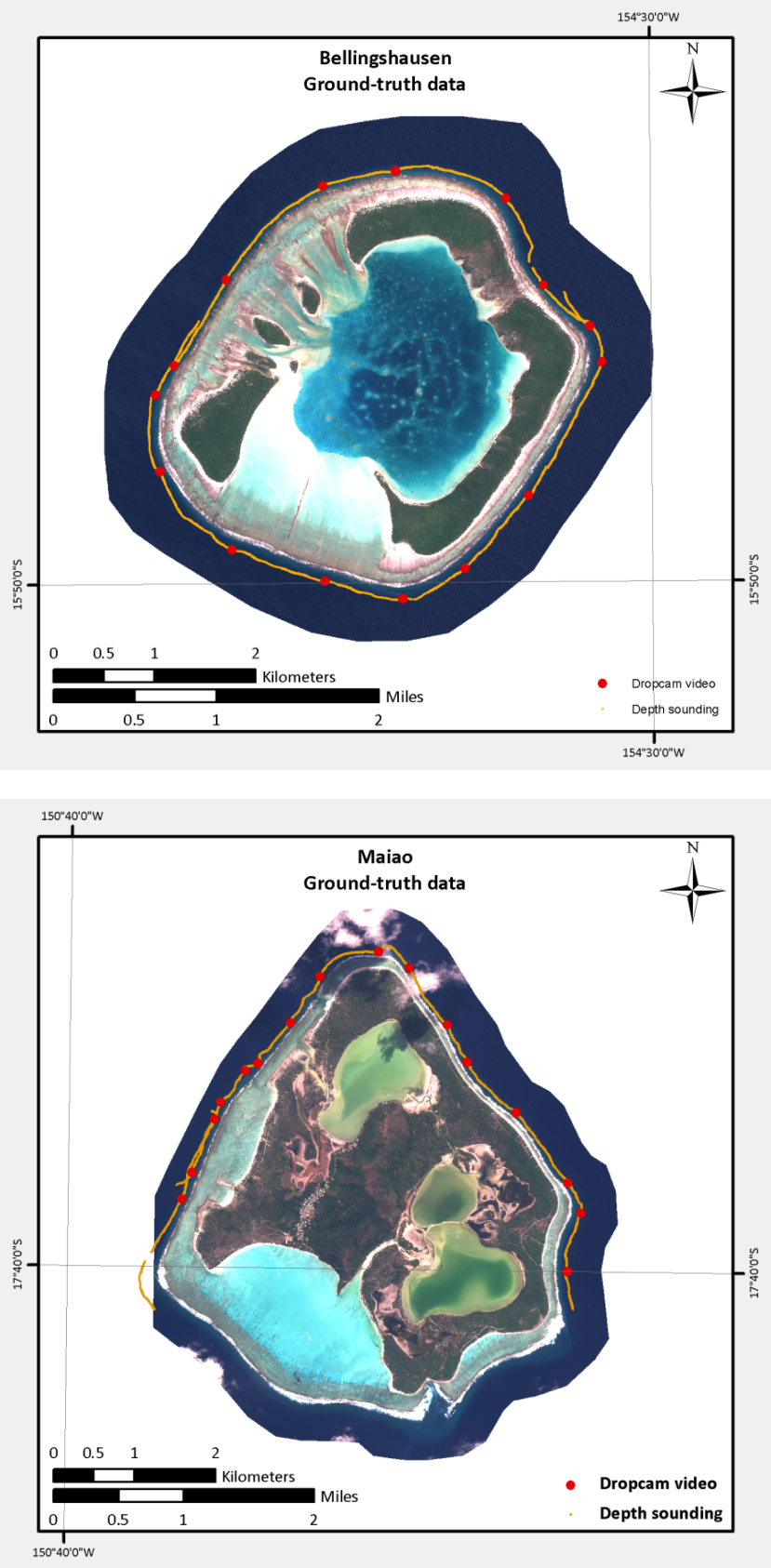


Fig. 5. Track of the groundtruthing team and locations of drop camera deployments. Bellingshausen (top image) and Maiao (bottom image).

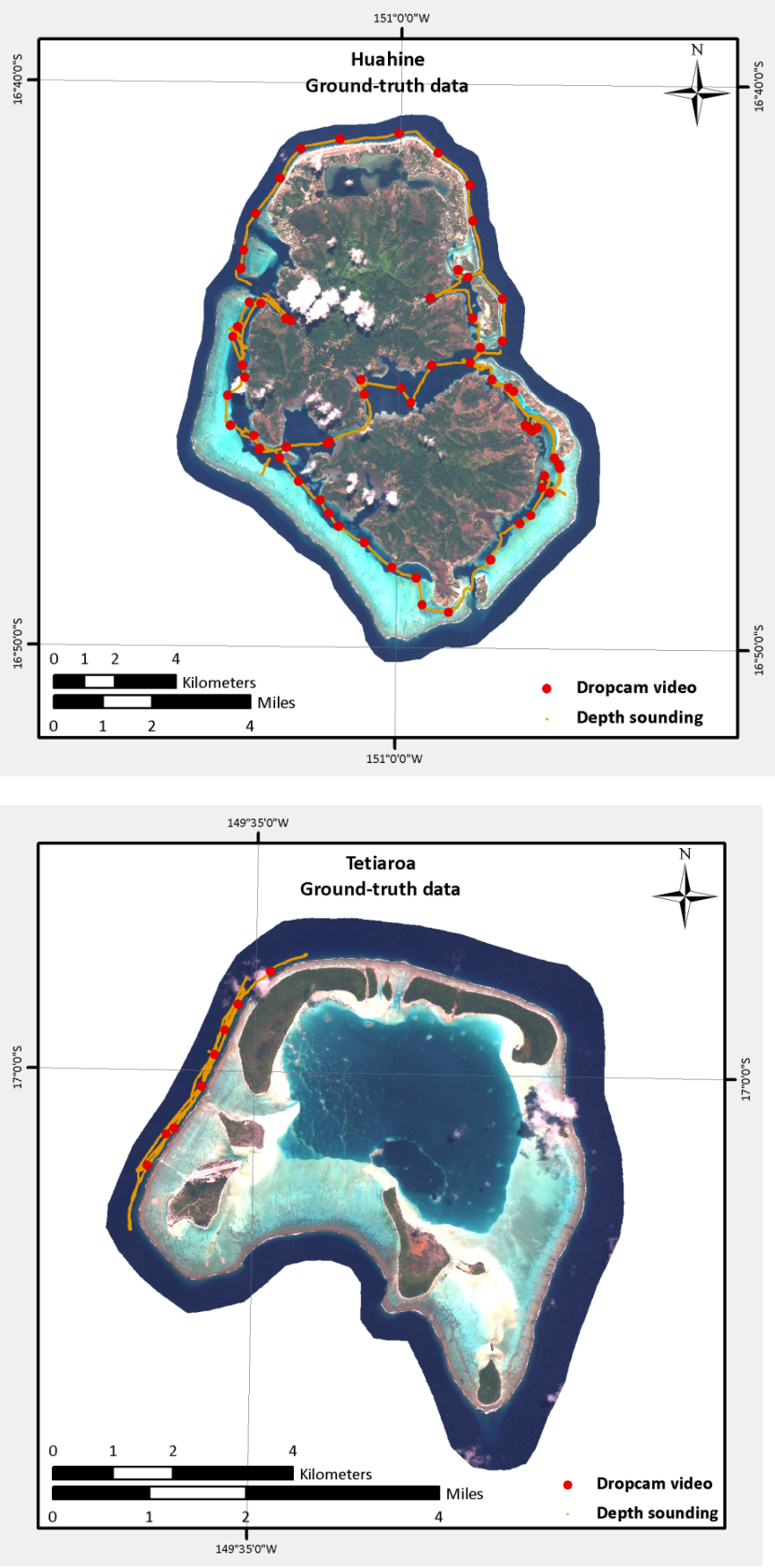


Fig. 6. Track of the groundtruthing team and locations of drop camera deployments. Huahine (top image) and Tetiaroa (bottom image).

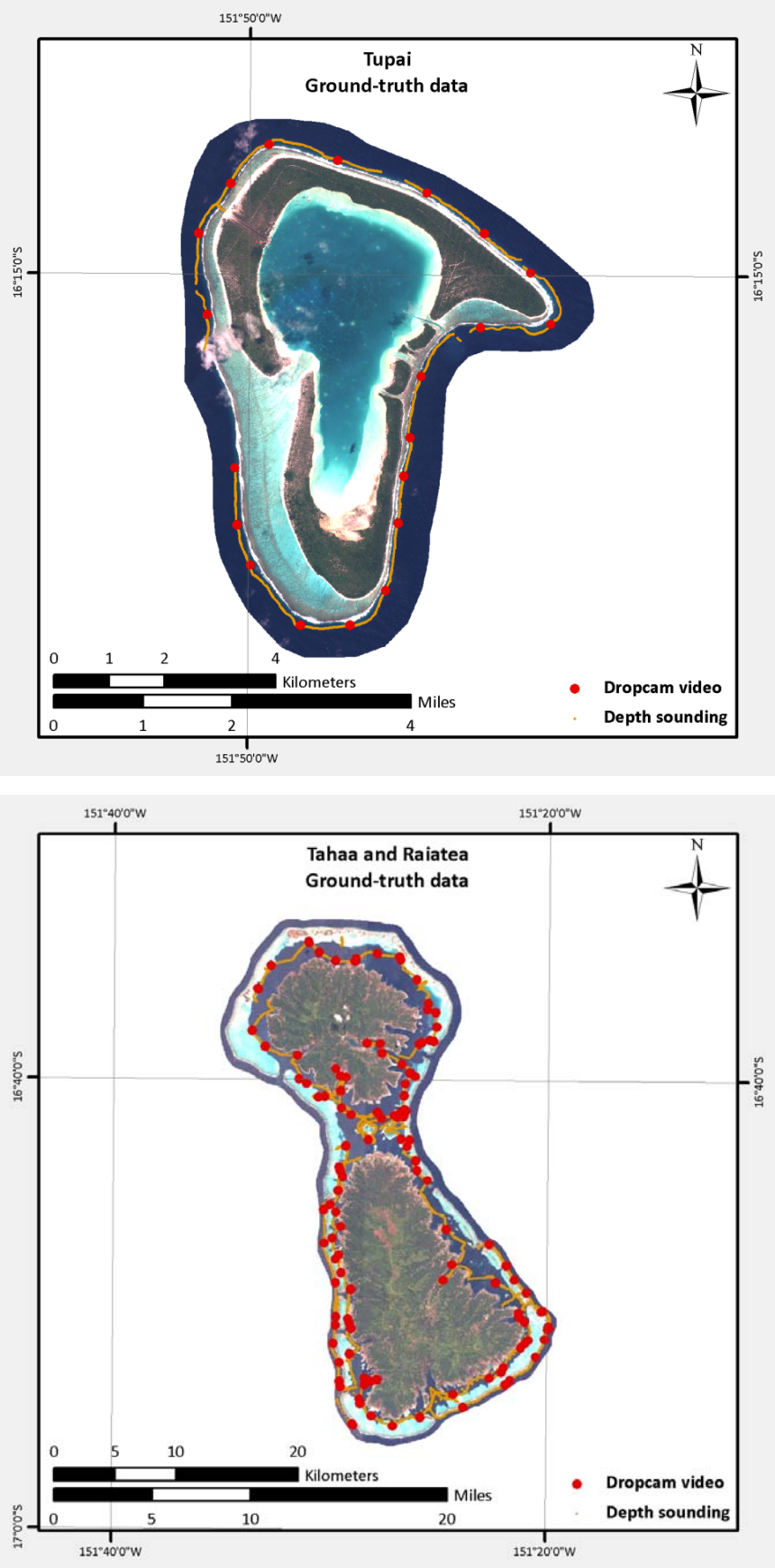


Fig. 7. Track of the groundtruthing team and locations of drop camera deployments. Tupai (top image) and Tahaa/Raiatea (bottom image).

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 either recorded observations and/or photographic assessments. Recorded observations were completed using a point intercept method, whereas the organism and substrate was identified every 10 cm along a 10 m transects (total 100 points/transect), with a minimum of six transects examined per location. When possible surveys were conducted 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 from 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 done 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 right and left side of the transect. 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 x 1), with a minimum of two transects done 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
8	64	546	461	116	16,825

Table 3. Summary of the coral reef assessments. The total number of benthic, fish and coral transects and number of corals assessed around eight islands are shown.

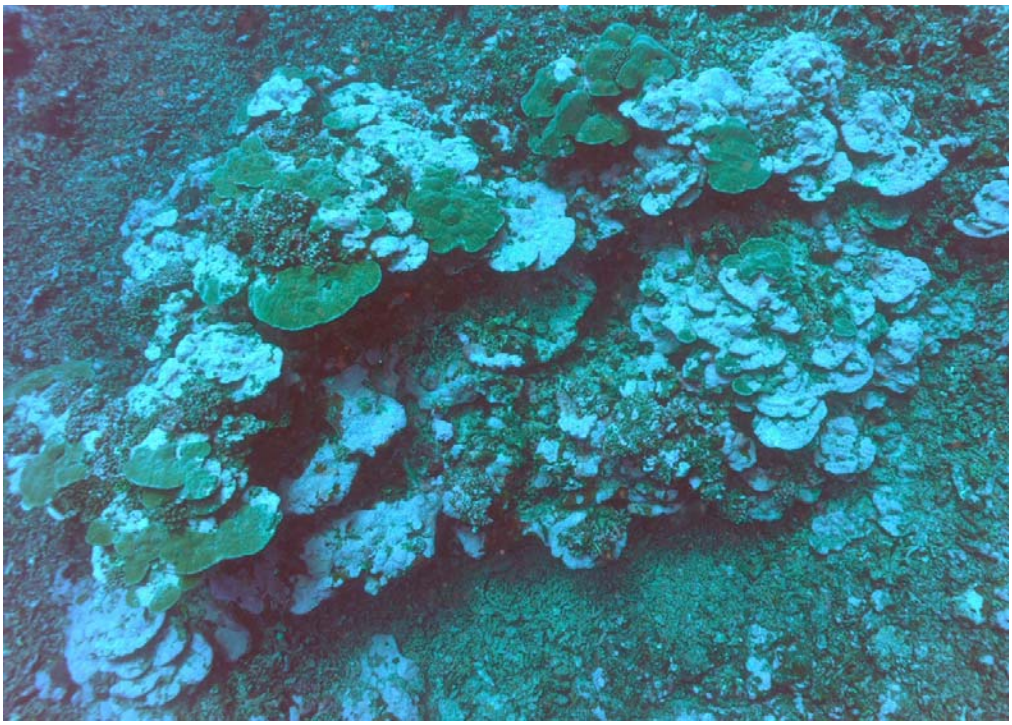
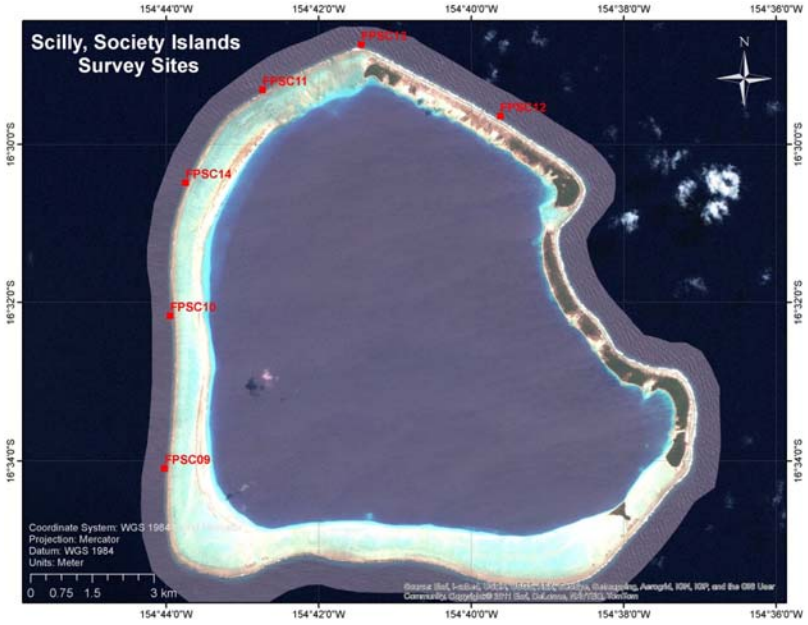


Fig. 8. Crown of thorns seastars were the number one threat to reefs in Society Islands, with high levels of old mortality recorded at Huahine, Taha'a/Raitae, Tahiti, Moorea, Tupai and Tetiaroa; and recent, ongoing outbreaks at Bellingshausen and Tetiaroa. At Tetiaroa, most of the branching and fast growing corals (*Acropora, Pocillopora, Montipora* had been consumed and the sea stars returned to target the massive corals such as the *Porites* shown above. All white areas were recently eaten.

Table 4. Coordinates of locations examined using SCUBA.

Date	Lat_S	Long_W	Site	Location	Exposure	Reef Type
9/16/2012	-17.56466667	-149.6268833	CHECKOUT	Tahiti		lagoonal
9/17/2012	-16.7856	-153.9803	FPMO01	Mopelia	leeward	fore reef
9/17/2012	-16.7733	-153.9703	FPMO02	Mopelia	leeward	fore reef
9/18/2012	-16.8031	-153.9937	FPMO03	Mopelia	leeward	fore reef
9/18/2012	-16.7721	-153.9689	FPMO04	Mopelia	leeward	fore reef
9/18/2012	-16.7862	-153.9697	FPMO05	Mopelia	protected	lagoon patch reef
9/19/2012	-16.8154	-153.9952	FPMO06	Mopelia	leeward	fore reef
9/19/2012	-16.7811	-153.9768	FPMO07	Mopelia	leeward	fore reef near channel
9/19/2012	-16.8205	-153.953	FPMO08	Mopelia	protected	lagoon patch reefs
9/20/2012	-16.5683	-154.7337	FPSC09	Scilly	leeward	fore reef
9/20/2012	-16.5362	-154.7325	FPSC10	Scilly	leeward	fore reef
9/20/2012	-16.4885	-154.7123	FPSC11	Scilly	leeward	fore reef
9/21/2012	-16.494	-154.6603	FPSC12	Scilly	windward	fore reef
9/21/2012	-16.4789	-154.6907	FPSC13	Scilly	windward	fore reef
9/21/2012	-16.5081	-154.7291	FPSC14	Scilly	leeward	fore reef
9/22/2012	-15.7968	-154.5277	FPBE15	Bellingshausen	windward	fore reef
9/22/2012	-15.7986	-154.5135	FPBE16	Bellingshausen	windward	fore reef
9/22/2012	-15.8171	-154.5463	FPBE17	Bellingshausen	leeward	fore reef
9/23/2012	-16.2588	-151.7954	FPTU18	Tupai	windward	fore reef
9/23/2012	-16.2836	-151.8361	FPTU19	Tupai	windward	fore reef
9/23/2012	-16.2285	-151.83	FPTU20	Tupai	leeward	fore reef
9/24/2012	-16.6904	-150.9835	FPHU21	Huahine	windward	fringing reef
9/24/2012	-16.7173	-151.049	FPHU22	Huahine	leeward	barrier reef
9/24/2012	-16.7692	-151.0458	FPHU23	Huahine	protected	lagoonal fringing reef
9/25/2012	-16.7682	-150.9596	FPHU24	Huahine	protected	lagoonal patch reef
9/25/2012	-16.7976	-151.0136	FPHU25	Huahine	protected	lagoonal patch reef
9/26/2012	-16.7363	-151.0572	FPHU26	Huahine	leeward	fore reef
9/26/2012	-16.7476	-151.0484	FPHU27	Huahine	protected	lagoonal patch reef
9/26/2012	-16.7036	-151.4828	FPTA28	Tahaa	protected	lagoonal patch reef
9/27/2012	-16.625	-151.5799	FPTA29	Tahaa	leeward	fore reef
9/27/2012	-16.5717	-151.552	FPTA30	Tahaa	leeward	fore reef
9/28/2012	-16.6814	-151.5255	FPTA31	Tahaa	windward	fore reef
9/28/2012	-16.6607	-151.4403	FPTA32	Tahaa	protected	lagoonal patch reef
9/29/2012	-16.8329	-151.4962	FPRA33	Raiatea	leeward	fore reef
9/29/2012	-16.8986	-151.4718	FPRA34	Raiatea	protected	lagoonal patch reef
9/30/2012	-16.8746	-151.4938	FPRA35	Raiatea	leeward	fore reef
9/30/2012	-16.89502	-151.49214	FPRA36	Raiatea	leeward	fore reef
9/30/2012	-16.91732	-151.46751	FPRA37	Raiatea	protected	lagoonal patch reef
10/1/2012	-16.80644	-151.49919	FPRA38	Raiatea	leeward	fore reef
10/1/2012	-16.8479	-151.4952	FPRA39	Raiatea	leeward	fore reef
10/1/2012	-16.9035	-151.4738	FPRA40	Raiatea	protected	lagoonal patch reef
10/2/2012	-16.9198	-151.4602	FPRA41	Raiatea	protected	lagoonal patch reef
10/2/2012	-16.8794	-151.4759	FPRA42	Raiatea	protected	lagoonal patch reef
10/2/2012	-16.9095	-151.4196	FPRA43	Raiatea	leeward	fore reef
10/3/2012	-16.922	-151.4817	FPRA44	Raiatea	windward	fore reef
10/4/2012	-16.8251	-151.3479	FPRA45	Raiatea	windward	fore reef
10/4/2012	-16.9027	-151.4282	FPRA46	Raiatea	protected	lagoonal fringing reef
10/4/2012	-16.922	-151.4817	FPRA47	Raiatea	leeward	fore reef
10/5/2012	-16.934	-151.4582	FPRA48	Raiatea	windward	fore reef
10/5/2012	-16.9313	-151.4761	FPRA49	Raiatea	windward	fore reef
10/7/2012	-16.8502	-151.3328	FPRA50	Raiatea	windward	fore reef
10/7/2012	-16.7901	-151.3765	FPRA51	Raiatea	windward	fore reef
10/7/2012	-16.8066	-151.3638	FPRA52	Raiatea	windward	fore reef
10/8/2012	-16.7032	-151.4385	FPRA53	Raiatea/Tahaa	windward	fore reef
10/8/2012	-16.765	-151.4004	FPRA54	Raiatea	windward	fore reef
10/8/2012	-16.8135	-151.3778	FPRA55	Raiatea	protected	lagoonal patch reef
10/9/2012	-16.5627	-151.4461	FPTA56	Tahaa	windward	fore reef
10/9/2012	-16.5527	-151.4982	FPTA57	Tahaa	windward	fore reef
10/9/2012	-16.8011	-151.3847	FPRA58	Raiatea	protected	lagoonal patch reef
10/10/2012	-17.6489	-150.6498	FPMA59	Maiao	leeward	fore reef
10/10/2012	-17.6315	-150.6356	FPMA60	Maiao	leeward	fore reef
10/10/2012	-17.6361	-150.6252	FPMA61	Maiao	windward	fore reef
10/11/2012	-16.9852	-149.5829	FPTE62	Tetiaroa	leeward	fore reef
10/11/2012	-17.0042	-149.5931	FPTE63	Tetiaroa	leeward	fore reef
10/11/2012	-16.9816	-149.5671	FPTE64	Tetiaroa	windward	fore reef



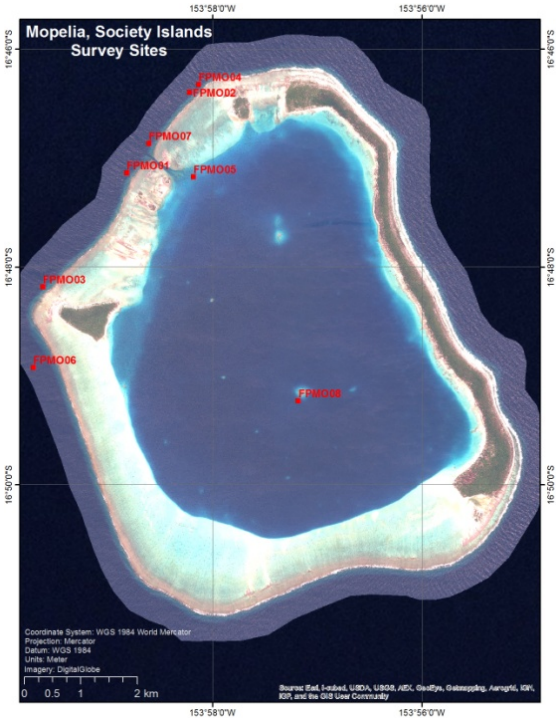


Fig. 9. Study sites examined off Scilly (top left), Bellingshausen (center) and Mopelia (bottom left) using SCUBA.

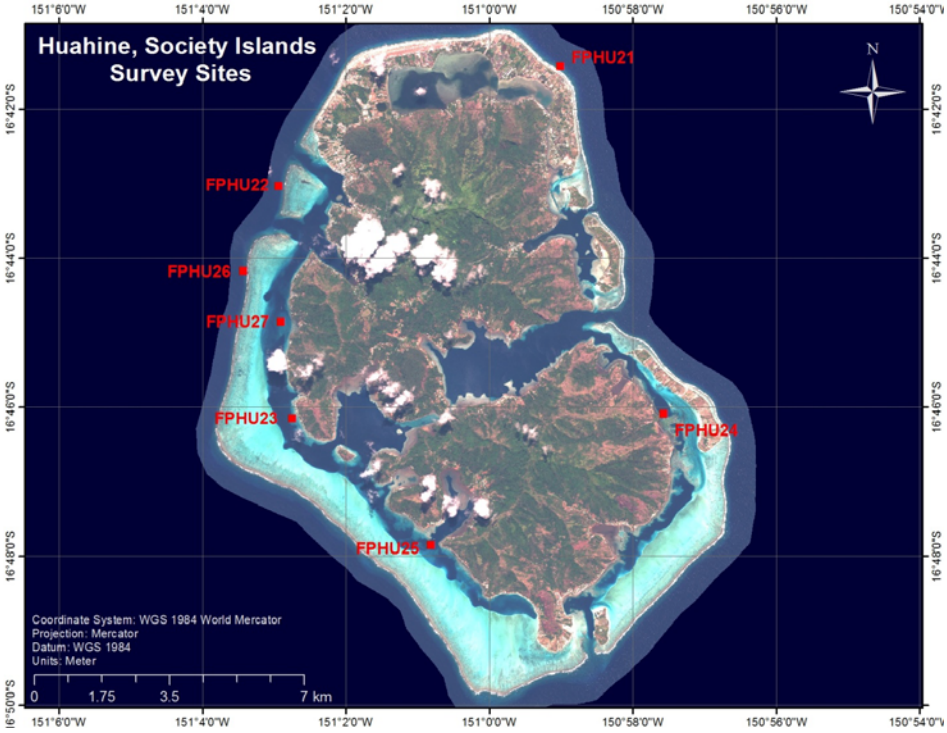
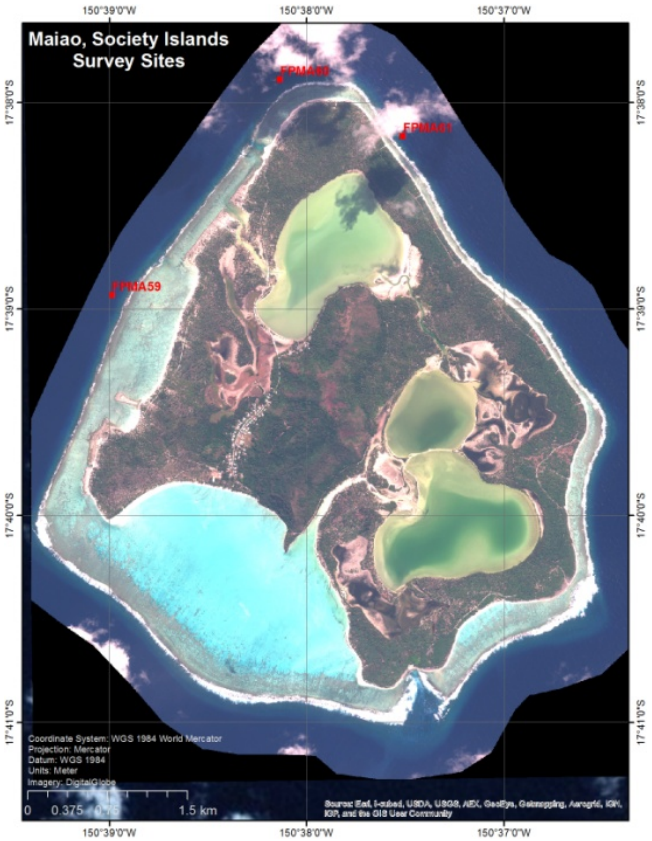


Fig. 10. Study sites examined off Huahine (top left) Maiao (bottom left) and Tupai (bottom right) using SCUBA.



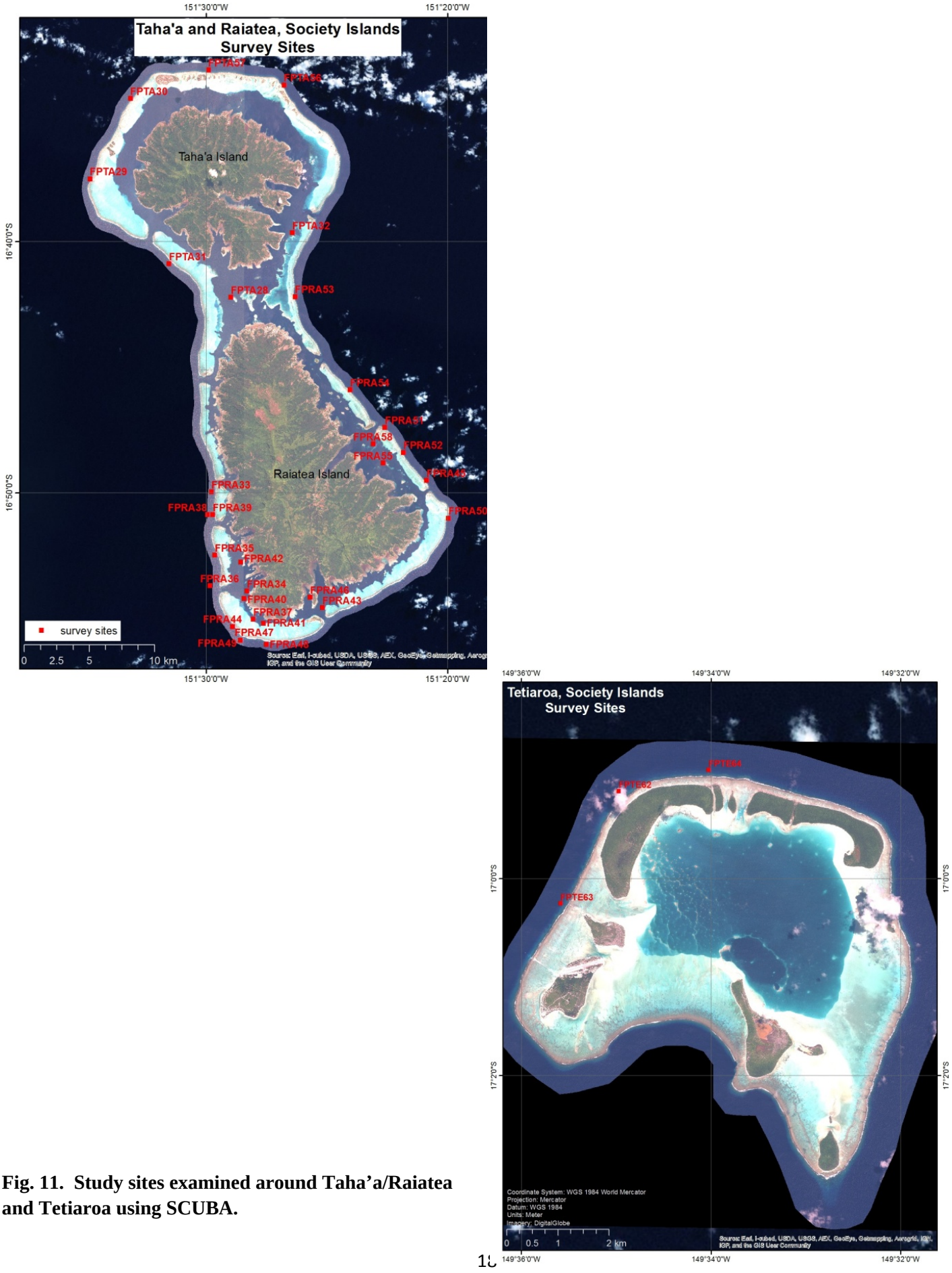


Fig. 11. Study sites examined around Taha'a/Raiatea and Tetiaroa using SCUBA.

3. Coral Reef Research

Establishing Legacy Sites:

Two locations were chosen on Raiatea, one on the east side and one on the west side, to evaluate patterns of recovery from a crown of thorns outbreak. Four permanent stainless steel rebars were inserted into the substrate to mark the four corners of a 10 m X 10 m plot. A temperature logger was attached to one of the rebar. Within the site every coral is measured and catalogued. Several hundred overlapping high resolution photographs were taken of the entire Legacy site to create a mosaic that will serve as a permanent visual record of the baseline condition of the site when first established. The intent is to revisit the sites in 5 years to characterize patterns of recovery.

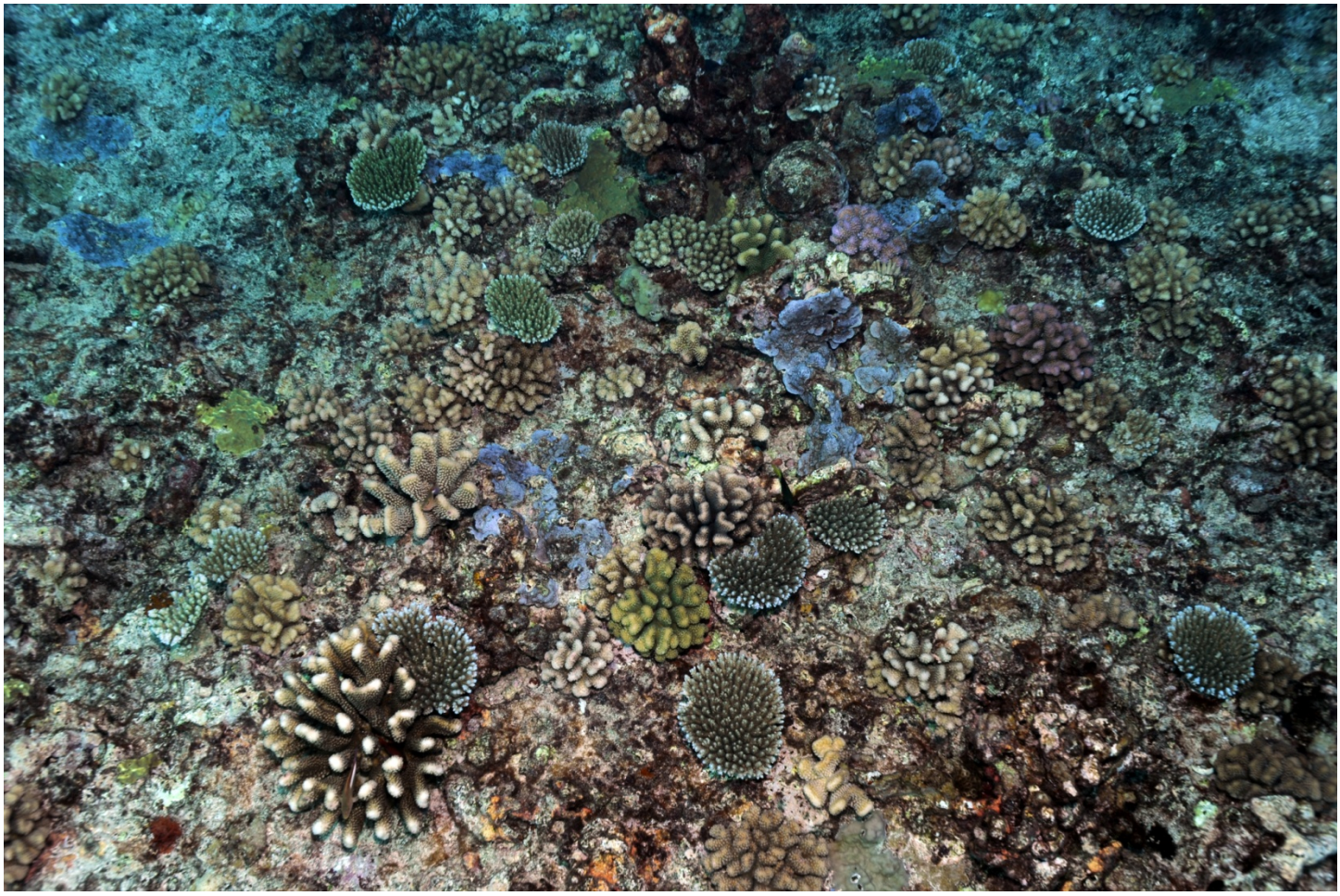


Fig. 12. A small area within the Legacy site with high numbers of small pocilloporid and acroporids corals that settled 2-4 years ago

Characterization of rates of herbivory:

Field surveys of grazing intensity

Grazing intensity was quantified using stationary video cameras in 15 sites across the Society Islands Archipelago (Table 5). Ten high-definition video cameras (GoPro Hero2) fixed to 3-pound dive weights were installed at each site and programmed to record continuously for two hours in the afternoon (13:00 - 16:00), when herbivory is known to be highest. Cameras were placed at least 10 m apart from any other and mounted on relatively high places of the substratum ensuring a well-lit areas dominated by grazable surfaces could be filmed. Filming resolution was adjusted to capture at least a $1m^2$ field of view and the exact boundaries of this

area were marked by briefly showing a gridded $1m^2$ quadrat to each camera at the beginning of each recording. The 10-cm segments of the grid would serve as a size reference to estimate total fish length (TL) during video analyses. Cameras were left recording for a minimum of 70 minutes in the absence of divers.

Fig. 13. Diver deploying a go pro video camera. A 1 m X 1 m quadrat is placed within the camera's field of view as a reference of the size of the area that will be assessed. The quadrat is removed and the camera records fish behavior for 70 minutes.

Footage processing

To minimize the time invested in data extraction while surveying a representative portion of the footage, each video will be subdivided in consecutive 3-minute intervals. Data will be extracted from 8 × 3-min intervals per camera (i.e. 40% of footage). To facilitate the detection of feeding events videos will be played in real time in 23-inch computer screens. Prior to data extraction the quadrats and grids filmed by each camera will be traced on an acetate sheet. Data will be extracted while observing the footage through the corresponding grid overlaid on the computer screen. The surveyor will focus on detecting feeding visits of surgeonfish, parrotfishes, and rabbitfish. A feeding visit is defined here as the entry of an individual fish into the camera's field of view to take bites on the substratum enclosed within the quadrat boundaries. A visit terminates when the individual exited the quadrat boundaries to feed outside the quadrat while consistently moving away from it, or to exit the camera's field of view. For each feeding visit surveyors will record a) the time of entry and time of exit, b) the species (and life phase for parrotfishes), c) the estimated total length (TL), and c) the number of bites taken per visit. The TL of each visiting fish will be estimated using the grid's segments as a reference.

Island	Site name	Latitude	Longitude
Mopelia	FPMO04	-16.7721	-153.9689
	FPMO07	-16.7811	-153.9768
Scilly	FPSC13	-16.4789	-154.6907
Bellingshausen	FPBE16	-15.7986	-154.5135
Tupai	FPTU19	-16.2836	-151.8361
Huahine	FPHU23	-16.7173	-151.0458
Tahaa	FPTA31	-16.6814	-151.5255
Raiatea	FPRA33	-16.8329	-151.4962
	FPRA36	-16.89502	-151.49214
	FPRA39	-16.8479	-151.4952
	FPRA42	-16.8794	-151.4759
	FPRA44	-16.922	-151.4817
	FPRA51	-16.7901	-151.3765
	FPRA55	-16.765	-151.3778
Maiao	FPMA59	-17.6489	-150.6498

Table 5. Sites where grazing intensity was measured high-definition video cameras

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) in our 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, Porites lutea, Pavona clavus, Cyphastrea serailia*) 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
Mopelia	*Porites lobata*	7	~3cm diam. X 9 cm length	Dry
Scilly	*Porites lobata*	8	~3cm diam. X 9 cm length	Dry
Bellingshausen	*Porites lobata*	6	~3cm diam. X 9 cm length	Dry
Huahine	*Porites lobata*	16	~3cm diam. X 9 cm length	Dry
Raiatea	*Porites lobata*	40	~3cm diam. X 9 cm length	Dry
Tahaa	*Porites lobata*	3	~3cm diam. X 9 cm length	Dry
Maiao	*Porites lobata*	6	~3cm diam. X 9 cm length	Dry
Maiao	*Pavona clavus*	1	~3cm diam. X 9 cm length	Dry
Tetiaroa	*Porites lobata*	4	~3cm diam. X 9 cm length	Dry
Total		91		

Table 6. Number of cores taken at each island.

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 is collected using a Petite Ponar® Grabber. The grabber was attached to an electronic winch wound with 50m of braided polyester line. The winch was mounted on the gunnel of the small ground-truthing boat. 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. The sample was then winched back to the surface. Once the grab is retrieved, it was lifted into the boat and the sediment collected. At each deployment of the grabber, 100 ml of sediment was shoveled by hand into a 125 ml plastic bottle. A maximum of five samples were taken per day using this method.

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
Bellingshausen	3
Scilly	15
Huahine	29
Tahaa&Raiatea	51
Maiao	0
Mopelia	26
Tetiaroa	1
Tupai	3
Total	128

Table 7. Total number of sediment samples.

Coral disease analysis:
Samples of *Favia* and *Porites* were collected from five islands to characterize two previously undescribed coral diseases. Tissue/skeleton samples were taken at the interface of exposed skeleton and diseased tissue, with 1 control sample taken on the same colony, 15-20 cm from the disease lesion and one control of the same species of an unaffected colony. A leather punch and a hammer were used to remove a small core. Each sample was up to 2.5 cm diameter. Tissue/skeleton samples were preserved on the M/Y Golden Shadow in Z-fixative, a zinc-formalin based fix for light microscopy. Samples are being decalcified, embedded, sectioned and stained in the laboratory in the United States.

Species	Number of samples	average sample size	disease/process
Herpolitha limax	14	5-7 cm in diameter	yellow spot
Favia stelligera	30	5 cm in diameter, 5 samples 9 cm in diameter	yellow spot
Pocillopora danae	10	3-5 cm in length, 2-3 cm in width	color change
Pocillopora meandrina	4	3-5 cm in length, 2-3 cm in width	color change
Pocillopora eydouxi	4	3-5 cm in length, 2-3 cm in width	color change
Porites lobata	44	5 cm in diameter	pink line
Total	106		

Table 8. Corals sampled for disease. All samples were fixed in formalin based Z-fix for histology.

Fig. 14. Example of two *Herpolitha* with yellow band disease. The coral in the upper right has lost a considerable amount of tissue and approximately 30% is currently affected by the disease. The coral in the lower left shows little mortality, but also exhibits the yellow coloration.

Coral symbiont analysis:

This component involved two aspects: 1) sampling colonies of *Pocillopora* and *Acropora* from different habitats, depths and locations to characterize their symbionts; and 2) diurnal and nocturnal measurements of the

fluorescence of pocilloporid corals using a PAM fluorometer. In each location the diver started at 30 m and progressively works up to 5 m depth, sampling a minimum of three pocilloporid corals per depth gradient (5, 10, 15, 20, 25, and 30). Only pocilloporid corals located under randomly generated coordinates from each depth was be sampled, with three representative samples taken from each colony. Corals were separated each by a minimum of 5 m in attempt to avoid sampling ramets of the same genet. For each sampled coral, clippers were used to break off a small fragment of coral tissue (three to four polyps). A photograph was taken of each colony prior to sampling, and colony size was measured in three dimensions (maximum length, width, and height to the nearest 10 cm). A maximum of 30 colonies were collected per species on each reef. Fragments were placed in individual zip-lock bags underwater and then transferred to vials containing DMSO on shore and stored in a -20°C freezer. Typical biopsies were <0.5cm^2 in total surface area.

In a subsample of the colonies that were sampled (10 colonies per reef or island, all at 10 m depth), triplicate measurements of fluorescence were taken during the day and again at night using a PAM fluorometer. Additional light readings were taken at 10 m depth over the duration of the research in each island.

	Acropora	*Pocillopora*							
Islands	**sp.**	***eydouxi***	***damicornis***	***verrucosa***	***danae***	***meandrina***	***woodjonesi***	**sp.**	**Total**
Bellingshausen	3	11		7		1		2	24
Huahine	2	10	3	17		3		3	38
Maiao		12	3	9	1	15		1	41
Mopelia	2	4		18	2	2		4	32
Raiatea	12	55	7	35	1	20	1	23	154
Scilly	4	1		20	12	1		2	40
Tahaa	14	24	2	27		2		3	72
Tetiaroa		14		2					16
Tupai	1	3		9	1	4			18
Total	38	134	15	144	17	48	1	38	435

Table 9. Samples collected from *Acropora* and *Pocillopora* for *Symbiodinium* assessment. All samples (approx. 1 cm^3) are preserved in 20% DMSO solution at -20°C.

Fig. 15. Sponge sample collected from Bellingshausen.

Sponge assessment:

This research involved a survey of sponges in fore reef and back reef locations. Each reef was carefully searched to locate sponges. The diver started at 30 m depth and slowly worked up to 2-3 m depth, examining the substrate, coral heads and under overhangs, ledges and caves. When a new species was identified, the sponge was photographed and a sample was collected for taxonomic verification. Samples were preserved in ethanol, and later identified to species, or frozen until the chemical compounds can be extracted.

Invertebrate fisheries:

Targeted timed plot less belt-transects, stratified by depth from 30 m to <1 m, were carried out by two divers swimming parallel to the reef to determine the state of the targeted populations of molluscs and echinoderms. Surveys were done across different habitats and depth zones including deep oceanic sand plain, fore reef slopes, spur and grooves, crests, passes, lagoon floors and slopes, patch reefs, sheltered and exposed fringing reefs.

Fig. 16. *Trochus niloticus* is found in abundance on a variety of high rugosity habitats.

Fig. 17. A large green snail *Turbo marmoratus* in its typical habitat, in the crevasses of high energy spur and groove, in the upper forereef.

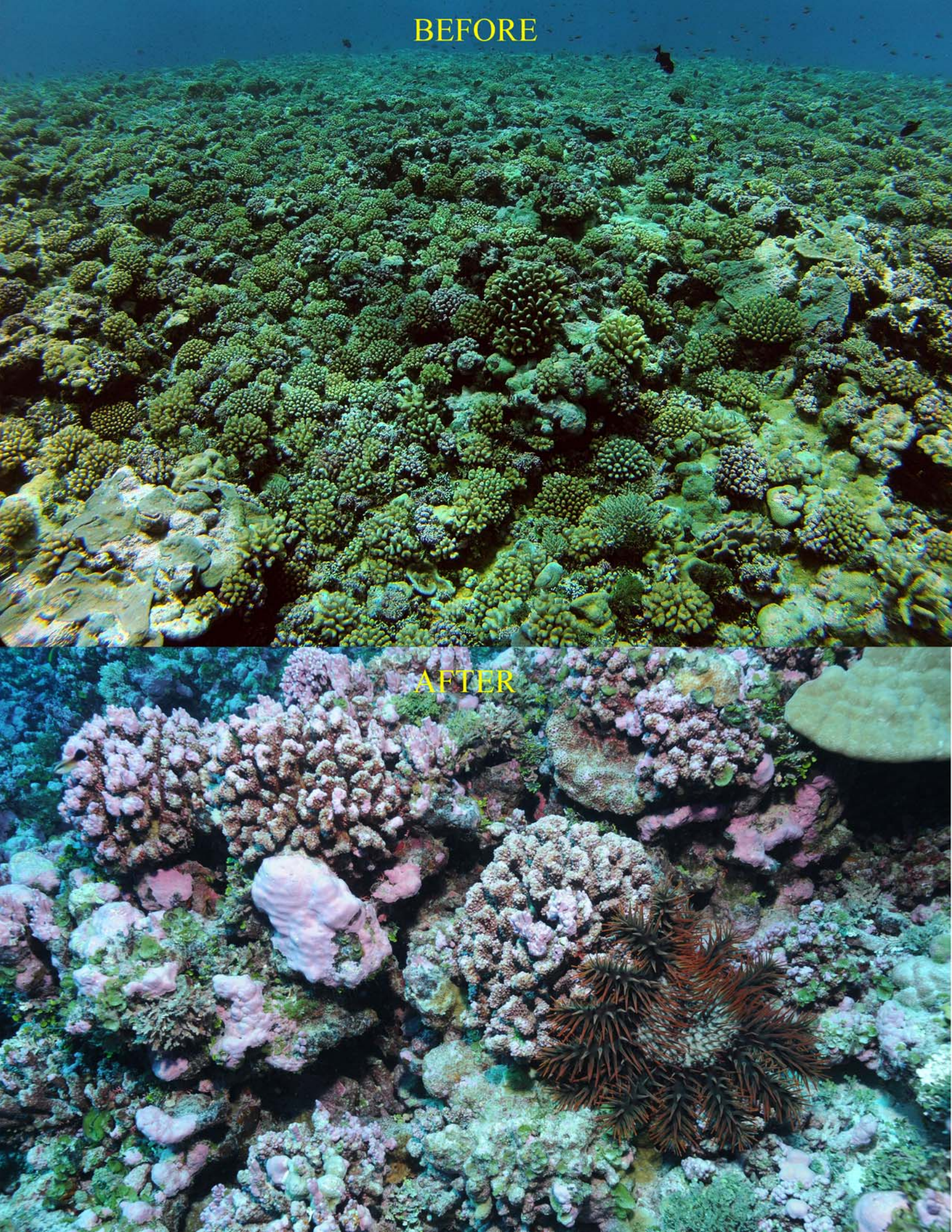
Turtle Surveys

Surveys of possible nesting beaches were conducted on the outer atolls. Two researchers documented the numbers of nesting attempts, and numbers of active and abandoned nests. They also examined old nests to determine the size of the clutch, and successful numbers of hatchlings.

Fig. 18. Two sets of turtle tracks on Scilly.

Appendix 1. Science Team

Name	Institution	Function
Phil Renaud	Khaled bin Sultan Living Oceans Foundation	Executive Director
Andy Bruckner	Khaled bin Sultan Living Oceans Foundation	Chief Scientist
Badi Samaniego	University of the Philippines, Living Oceans Foundation Fellow	Fish surveyor
Joao Monteiro	University of Azores, Living Oceans Foundation Fellow	Coral fluorescence
Jeremy Kerr	Nova Southeastern University, Living Oceans Foundation Fellow	Groundtruthing / habitat mapping
Sonia Bejarano	University of Queensland, Living Oceans Foundation Fellow	Fish herbivory
Sam Purkis	Nova Southeastern University National Coral Reef Institute	NCRI Lead Scientist
Alex Dempsey	Nova Southeastern University National Coral Reef Institute	Benthic surveyor
Anesti Stathakopoulos	Nova Southeastern University National Coral Reef Institute	Groundtruthing
Claire Dolphin	Nova Southeastern University National Coral Reef Institute	Photo transects
Matti Kiupel	Michigan State University, College of Veterinary Medicine	Coral disease
Serge Andrefouet	Institut de Recherche pour le Développement	IRD Lead Scientist
Joseph Campanozzi-Tarahu	Direction des Ressources Marines	Invertebrate surveyor
Gerad Moutham	Institut de Recherche pour le Développement	Invertebrate surveyor
Eve Perrin	Direction des Ressources Naturelles	Turtle surveyor
Laureline Chabran	Institut de Recherche pour le Développement	Benthic assessments
Sylvain Petek	Institut de Recherche pour le Développement	Sponge sampling
Dave Grenda	Florida Aquarium, REEF	Fish surveyor
Eva McClure	University of Tasmania	Fish surveyor
Renee Carlton	NOAA	Ocean acidification
Katie Hillyer	Victoria University, Wellington	Benthic surveyor
Candice Jwaszko	Ecole Paul Kane High School	C.R.E.W teacher
Nick Cautin	Dive Safety Officer	Diving operations


BEFORE
AFTER