# Field Report

# GLOBAL REEF EXPEDITION: Austral Islands, French Polynesia

9/04/13-20/04/13

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Front cover: Aerial photograph of Maria Ouest Atoll. Photo by Andrew Bruckner.

Back Cover: A large pinnacle on the fore reef at Maria Ouest. Photo by Ken Marks.

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# Executive Summary

Between April 10, 2013 – April 20, 2013, the Khaled bin Sultan Living Oceans Foundation conducted a research mission to the Austral Islands, French Polynesia as part of the Global Reef Expedition. The research focused on coral reefs surrounding the islands of Maria, Rimatara, Tubuai, Rurutu and Raivavae. The project was conducted in partnership with Le Centre de Recherches Insulaires et Observatoire de l'Environnement de Polynésie française (CRIOBE), with involvement of scientists from Le Centre national de la recherche scientifique (CNRS), Pierre and Marie Curie University (Paris 6), Consultancy PROGEM, Direction des Ressources Marines, Smithsonian Museum of Natural History, Université de la Polynésie Française, Nova Southeastern University, University of the Philippines, University of Queensland, NOAA/University of Miami, National Museum of Marine Biology and Aquarium (Taiwan), and Atlantic and Gulf Rapid Reef Assessment Program (AGRRA). 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; 4) identify and characterize coral diseases; and 5) measure ocean chemistry (pH) and effects on coral growth. In addition, local partners 1) sampled giant clams in Tubuai and Raiavave for genetic analyses and population dynamics; 2) completed an inventory of fish species diversity and population genetics; 3) identify parasites of butterflyfishes; and 4) conducted a scleractinian coral species inventory and genetic analysis.

**Groundtruthing:** A total of 578 sq. km of WorldView 2 satellite imagery was acquired. Prior to the start of the field research an aerial overflight was conducted to document coastal areas around each of the islands (Fig. 1). Shallow marine habitats were characterized using 341 videos (drop cameras) and 1,528,525 depth soundings, taken across the five locations, covering a total of 315 km.

**Coral reef assessments:** Within the five islands, 30 locations were assessed using SCUBA. A total of 177 Fish transects, 360 benthic surveys, 42 coral assessments and 37 phototransects were completed at depths of 5-30 m.

**Coral reef research and sampling:**

- Two new coral diseases were identified in Raivavae on *Astreopora* (unnamed condition) and *Montastrea* (yellow band disease). Twenty four samples were collected for histology.
- A total of 90 sediment samples were collected in fore reef and lagoonal environments.
- *Pocillopora* samples (61) were taken to assess the expression of biomarkers as a measure of health.
- A total of 27 cores were collected at 10-12 m depth in five locations consisting of 26 *Porites lobata*, and 1 *Astreopora*. These will be sectioned and examined using a CT scan to quantify variations in coral growth rates and relationship with ocean chemistry.
- A total of 130 butterflyfishes were sampled for parasites. Between 2-15 representatives of each reported species of butterflyfish known to occur in the Australs were examined. Parasites included 1) an estimated 17 species of trematode parasites, several of which are new species; and 2) monogeans, which are being identified in Moorea. Initial observations suggest lower numbers of parasites than that found in Tuamotu.
- Giant clam populations were assessed off two islands and a total of 200 samples were collected for genetic analysis.
- To assess fish species biodiversity, a total of 2233 specimens representing 471 taxa were collected and sampled at 25 fish sampling stations in five islands.

# Site Descriptions

**Raivavae**

A very wide shelf extended around the island, sloping very gradually from the reef crest to the edge of the slope at 20-25 m. The mid depth, from 10-20 m extended hundreds of meters out, before plunging more steeply to the depths. The shallows transitioned from a high energy reef crest dominated by branching acroporids and pocilloporids, to a spur and groove structure with narrow scoured hard-bottom channels and wide, flattened spurs. The spurs were constructed mostly of low-relief massive corals in the genus *Astreopora*, with some larger outcrops containing other massive species such as *Favia* and *Leptoria*, short, stout branched and digitate acroporids and *Pocillopora.* On many reefs the grooves at mid depths were colonized by *Porites* and massive *Hydnophora*, while other species especially *Leptoria, Astreopora, Montastrea, Acropora* and *Pocillopora* were found on the tops of the spurs and *Turbinaria* occurred on the sides and bases. Many areas from 5-15 m depth had high numbers of soft corals, mostly large *Sinularia*, but mixed with *Sarcophyton, Lobophytum* and *Cladiella*. The reef gradually transitions from *Astreopora* to other massive corals, especially 1-2 m *Favia stelligera, Pavona clavus, Lobophyllia* and large 2-3 m *Porites*. At 20-25 m depth large tables of *Acropora cytherea* become abundant and continue to 30-35 m, gradually being replaced by large flattened domes of *Porites*.

**Tubuai**

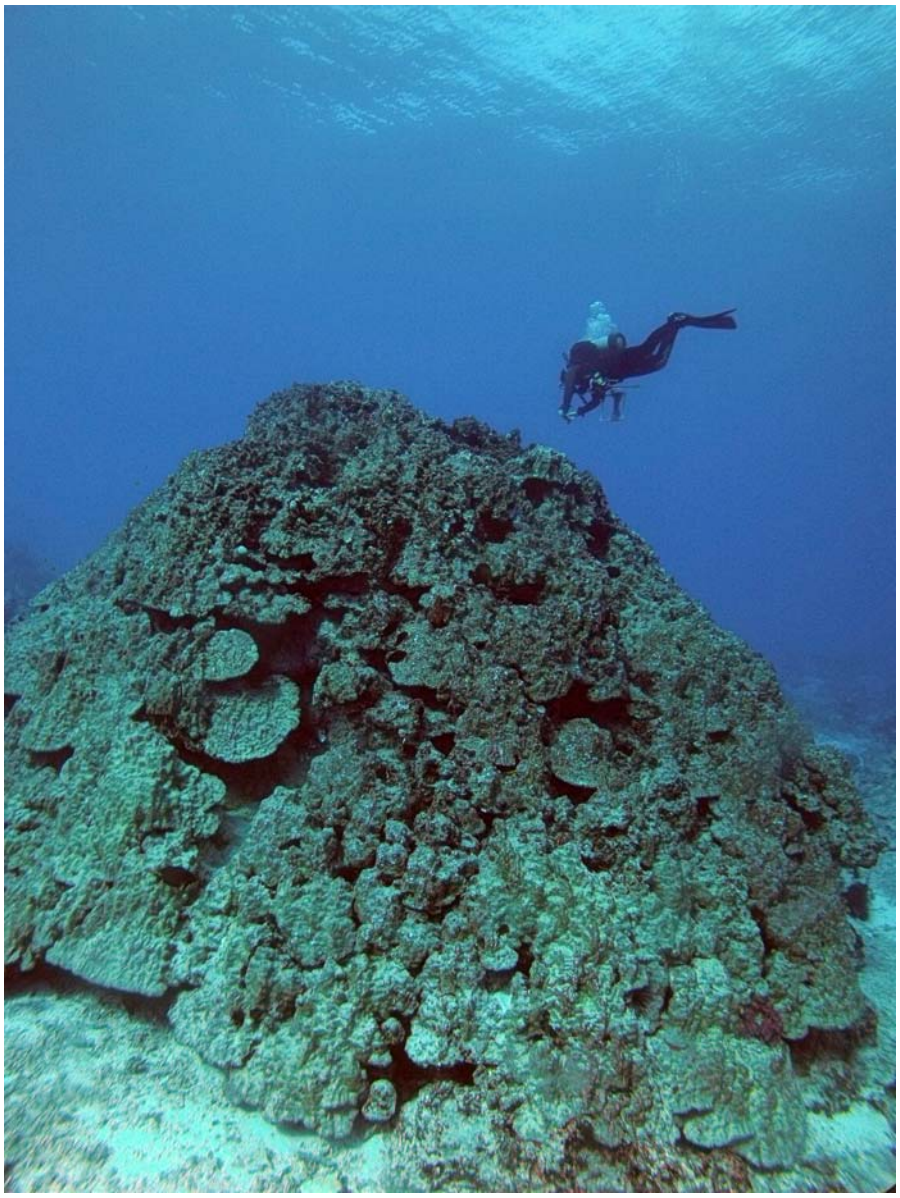
The reef structure consists largely of shallow spur and groove framework that is low-relief with wide spurs and narrow channels extending from 3-5 m to 10 m, with a very gradual slope. The slopes are dominated by *Astreopora* with a mix of smaller branching, digitate and table *Acropora*, some *Pocillopora* including 30-50 cm *P. verrucosa*, *Leptoria, Hydnophora, Montastraea* and *Favia stelligera*, with some rarer corals like *Turbinaria*. Shallow areas often have large patches of soft corals and *Millepora*. Deeper areas typically are dominated by large stands of very thick stout, short branching acroporids that can form thickets tens of meters in diameter, intermixed with low-relief massive *Pavona, Favia* colonies, *Lobophyllia*, plates of *Leptastrea* and *Echinopora* and scattered massive *Porites*. Generally, large mounding *Porites* were found on the deep reef and the community becomes dominated by large tables of A. *cytherea*. No surveys were conducted on the northeast end of the island because this was damaged severely by Hurricane Oli and is reported to have very little recovery as of 2012.

**Rurutu**

Reefs have been devastated by a bad outbreak of crown of thorns sea stars (COTS). The outbreak was reported to occur in 2006-2007. All corals were consumed nearly in their entirety from very shallow water to 40 m or deeper. Colonies remain in growth position, although rubble is present in sand channels and grooves between coral heads and coral spurs. There were very few tissue remnants left on colonies, and only low numbers of recruits present. The only survivors were some larger colonies of *P. eydouxi* and *P. verrucosa* and digitate *A. humilis*. Coral cover is less than 0.1%. Fish life was greatly reduced. In some areas were unusually large populations of *Diadema*.

**Rimatara**

Reefs have been devastated by a bad outbreak of crown of thorns sea stars. The majority of the corals were consumed from just below the water's surface to over 40 m depth. Coral cover is less than 0.1% except in isolated shallow areas, where it ranges up to 0.5%. Survivors include isolated larger *P. eydouxi* and *P. verrucosa*, A. *humilis* and *Hydonophora*, along with a few encrusting plates of *Acropora* in 3-4 m depth, and a very low number of isolated larger *Porites* colonies. The last COTS were reported to be seen in 2012.



Minimal to no recruitment observed. Higher numbers of tissue remnants were noted on certain corals on some of the reefs, especially *Favia stelligera, Leptoria* and *Astreopora* in the shallows. Fish life was greatly reduced, except for increased numbers and biomass of surgeonfishes and parrotfish, and soldier fish around ledges and at the base of large corals. There were few groupers and no snapper, but numerous white-tip sharks.

**Fig. 1. Large, centuries old, dead *Porites lobata* colony at Rimatara that was killed during the COTS outbreak.**

**Marie Ouest**

The fore reef communities of Marie are typical of French Polynesian atolls with a shallow reef flat that is partially emergent at low tide, prominent spur and groove habitat in shallow consisting of coralline algae dominated spurs with isolated low-lying acroporids, *Pocillopora*, and various encrusting corals and deep, narrow scoured hard-bottom channels with some rubble. The spurs extend out most prominently to 3-5 m depth, then are much more low-relief wide spurs with shallow channels, sand and rubble, with 30-50 cm relief. The shallow fore reef from 5-10 m has a dense coral community dominated by *Pocillopora*, digitate and table acroporids, some heavy branched acroporids, encrusting *Leptastrea,* plates of *Montipora*, and low-lying *Favia* colonies. Slightly deeper, 10-15 m depth, coral cover varies with some spurs and mounds with dense coral assemblages and some low-lying areas with a mix of coral and open substrate. The reef slopes gradually to about 18-20 m before dropping steeply to 30 + meters. There is a coral build-up before the drop, dominated by large *Favia stelligera, Lobophyllia, Pocillopora*, thick branched and digitate acroporids, *Montipora* plates, sheets of *Astreopora* and small to medium *Montastrea* colonies. The deeper reef is a mix of faviids, acroporids, pocilloporids, *Astreopora, Hydonophora, Montipora* and few medium to large *Porites*. Below 30 m are larger *Porites*, but these are less dense than seen in other areas. Much of the framework was heavily bioeroded, jagged and consisted of plates and shingles with *Pocillopora* colonies on the tops. *Diadema* were unusually abundant in all locations. More groupers were seen than in other areas, but in general fish communities were low in diversity and biomass.

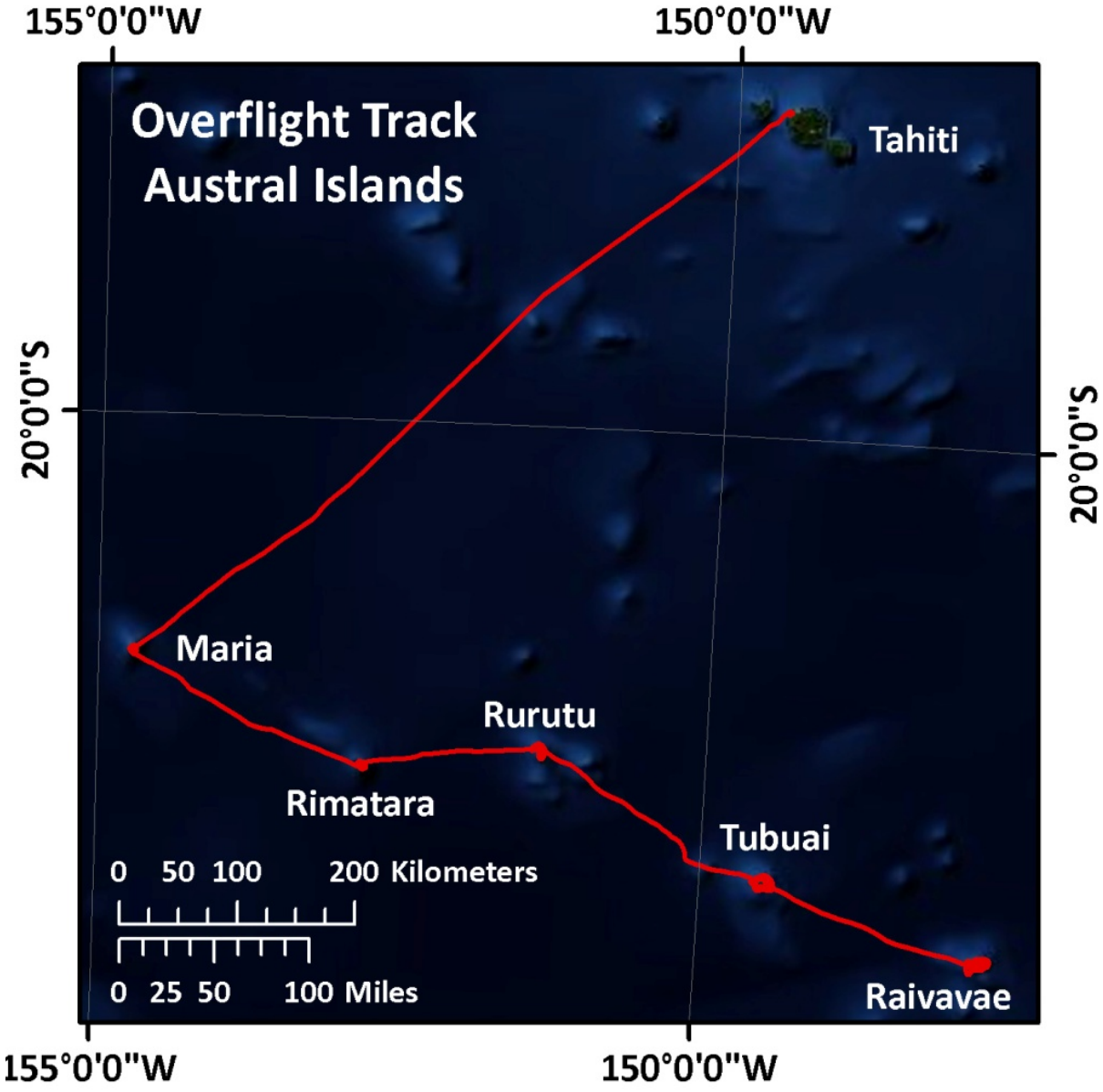



**Fig. 2. Route of the overflight.**

**Table 1. Research Schedule**

| **Date** | **Location** |
|---|---|
| 9 April, 2013 | Scientist arrival |
| **9-10 April** | Aerial surveys |
| **10 April** | **Golden Shadow Transit to Raivavae** |
| 11-13 April | Raivavae |
| 14-16 April | Tubuai |
| 17-19 April | Rurutu |
| 20-22 April | Rimatara |
| 23-24 April | Maria Ouest |

## 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 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.

| Archipelago | Site | Imagery (sq km) | No. dropcams | No. depth soundings | Track length (km) |
|---|---|---|---|---|---|
| Austral Islands | Maria Ouest | 30 | 39 | 85999 | 15.8 |
| | Raivavae | 191 | 110 | 563457 | 121.1 |
| | Rimtara | 32 | 33 | 99718 | 17.5 |
| | Rurutu | 76 | 36 | 158786 | 33.8 |
| | Tubuai | 249 | 123 | 620625 | 126.4 |
| | **Total** | 578 | 341 | 1,528,585 | 314.6 |

**Table 2. Summary of groundtruthing datasets including 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.**

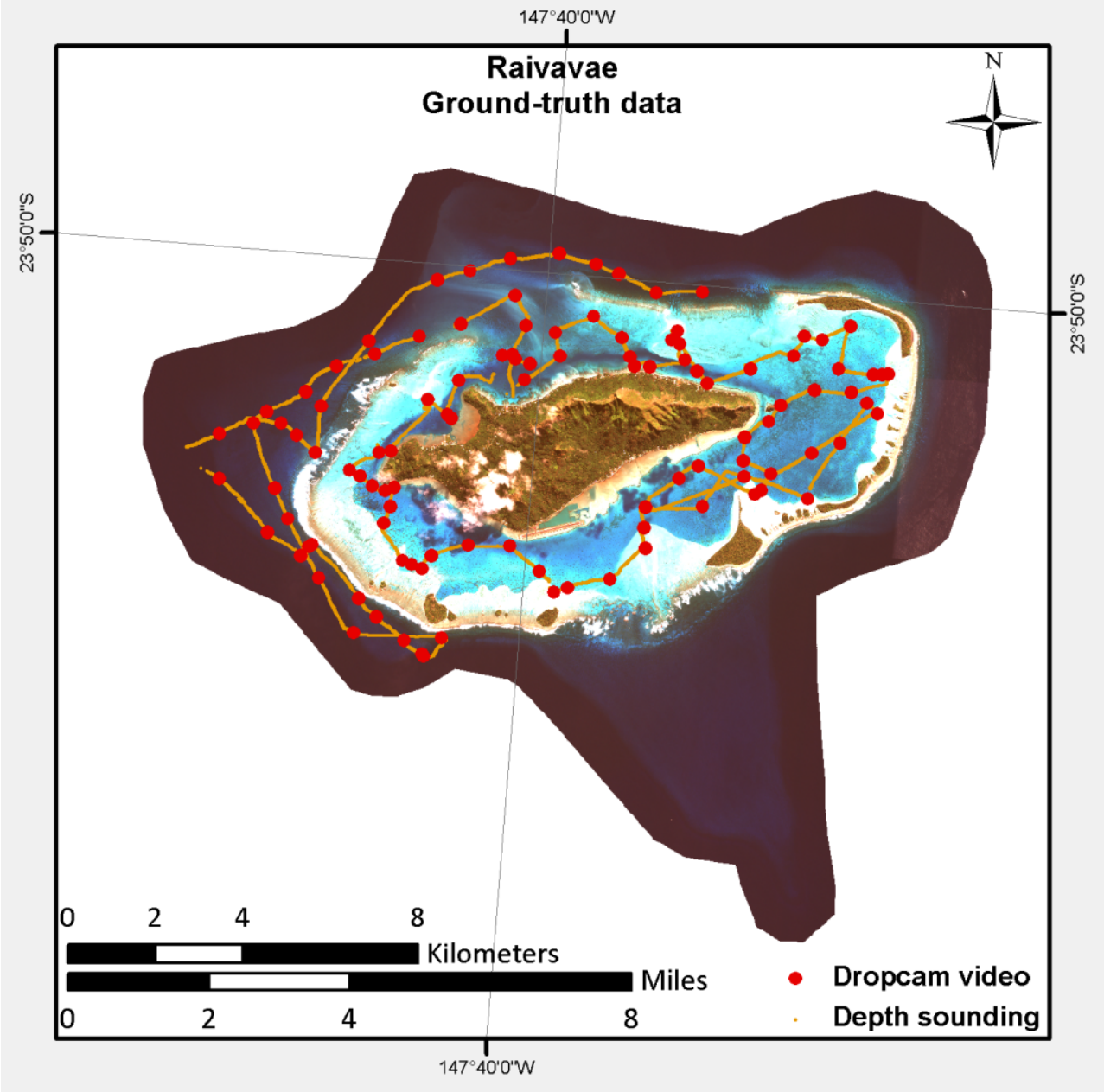



**Fig. 3. Track of the groundtruthing team and locations of drop camera deployments at Raivavae.**

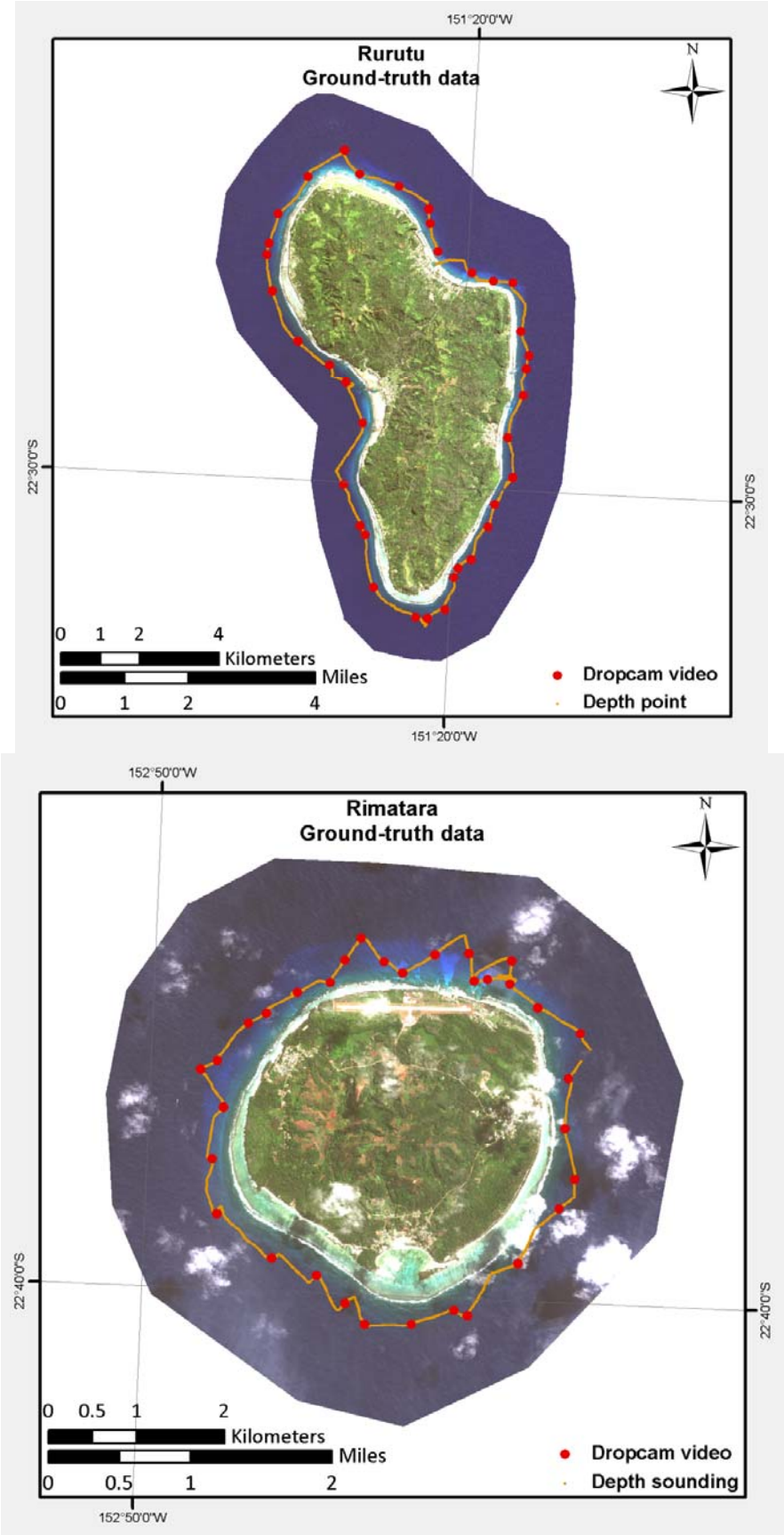
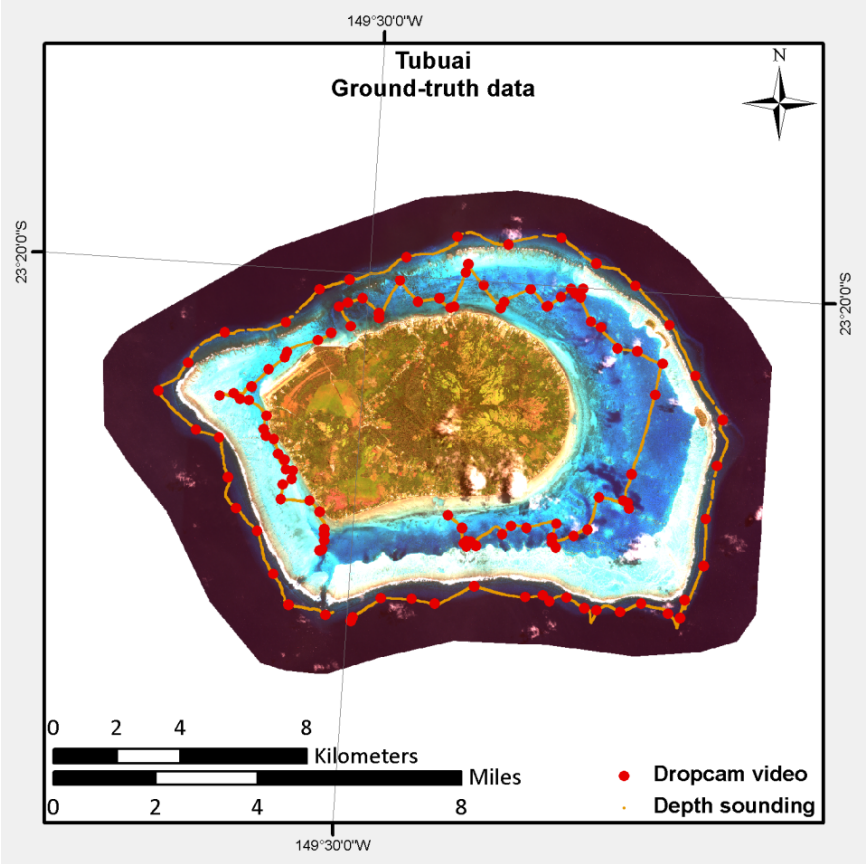



**Fig. 4. Track of the groundtruthing team and locations of drop camera deployments at Rurutu (top image)) and Rimatara (bottom image).**



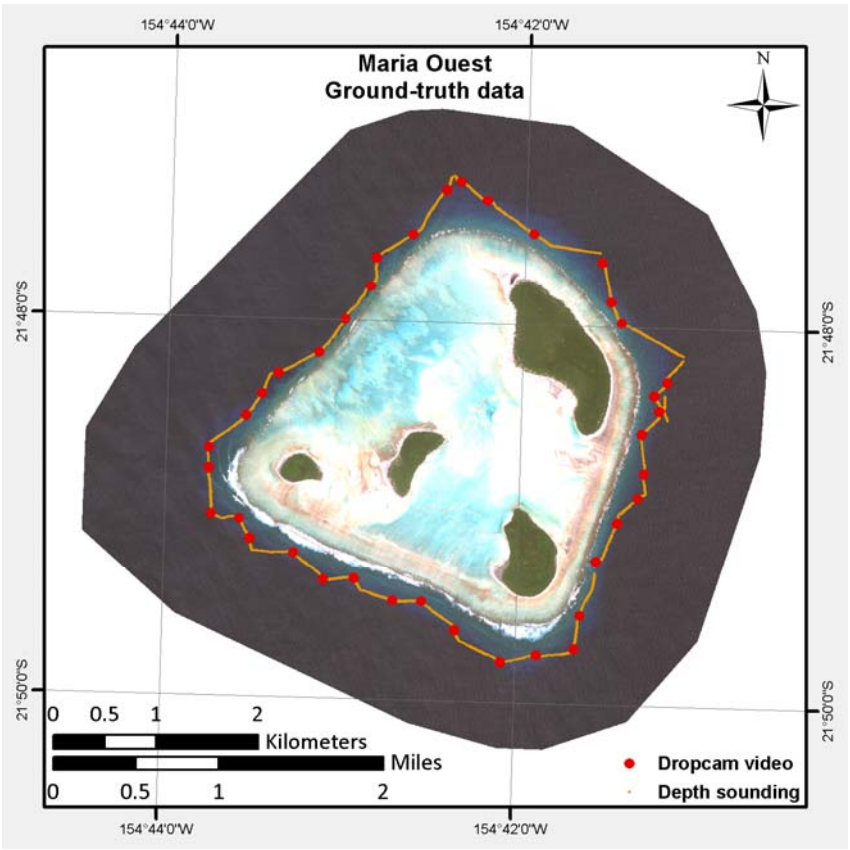




**Fig. 5. Track of the groundtruthing team and locations of drop camera deployments at Tubuai (top image) and Maria Ouest (bottom image).**

## 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 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 |
|---|---|---|---|---|---|---|
| 5 | 30 | 360 | 177 | 42 | 3,475 | 37 |

**Table 3. 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.**

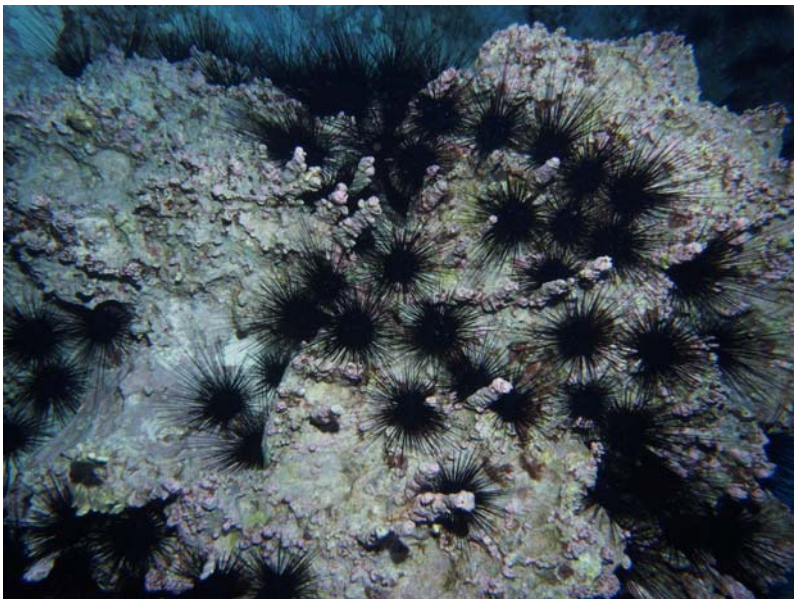
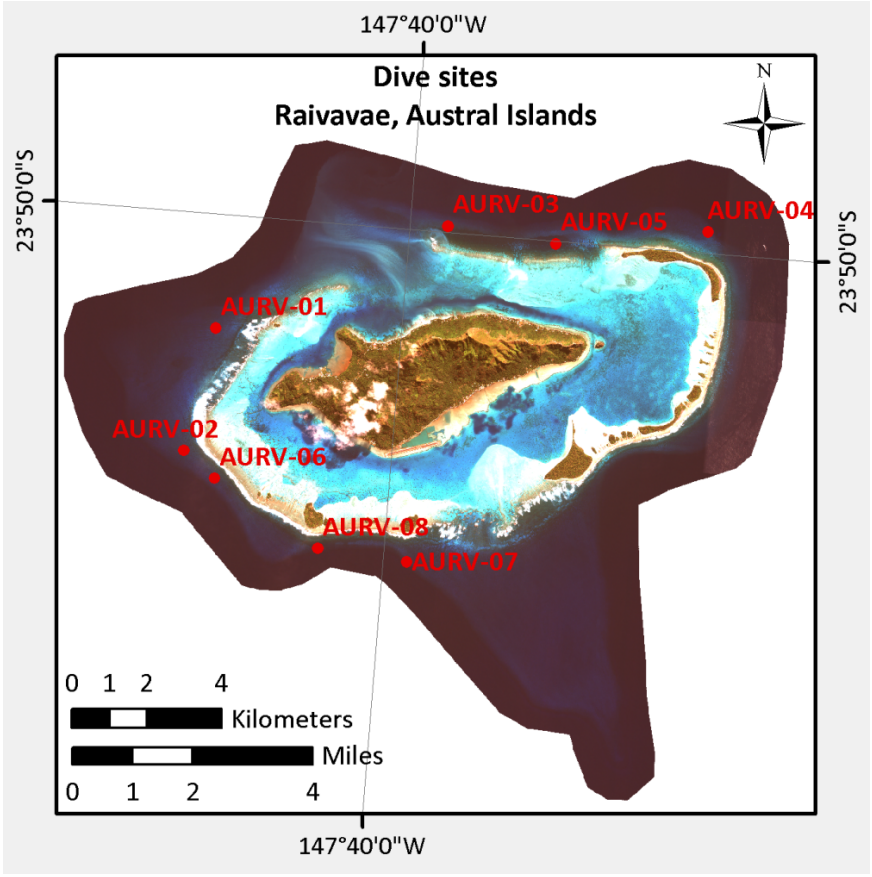


**Fig. 6. In Rimatara unusually high abundances of *Diadema* were seen at mid depths and deeper reefs in areas where corals had been killed by COTS. While these animals are important at maintaining clear substrates by removing macroalgae, an overabundance can lead to excessive bioerosion and any newly settled coral larvae may be scraped off the rocks as the urchins feed.**

**Table 4. Coordinates, island, reef type and exposure of survey locations.**

| Date | Lat | Long | Site name | Island | Exposure | Reef type |
|---|---|---|---|---|---|---|
| 11-Apr-13 | -23.8605 | -147.7151 | AURV-01 | Raivavae | Leeward | Fore reef |
| 11-Apr-13 | -23.8902 | -147.7208 | AURV-02 | Raivavae | Leeward | Fore reef |
| 11-Apr-13 | -23.8318 | -147.6574 | AURV-03 | Raivavae | Windward | Fore reef |
| 12-Apr-13 | -23.8282 | -147.5901 | AURV-04 | Raivavae | Windward | Fore reef |
| 12-Apr-13 | -23.8339 | -147.6291 | AURV-05 | Raivavae | Windward | Fore reef |
| 12-Apr-13 | -23.8962 | -147.7123 | AURV-06 | Raivavae | Leeward | Fore reef |
| 13-Apr-13 | -23.9123 | -147.6609 | AURV-07 | Raivavae | Leeward | Fore reef |
| 13-Apr-13 | -23.9108 | -147.6843 | AURV-08 | Raivavae | Leeward | Fore reef |
| 14-Apr-13 | -23.4213 | -149.4402 | AUTB-09 | Tubuai | Leeward | Fore reef |
| 14-Apr-13 | -23.3827 | -149.5493 | AUTB-10 | Tubuai | Leeward | Fore reef |
| 14-Apr-13 | -23.4253 | -149.5184 | AUTB-11 | Tubuai | Leeward | Fore reef |
| 15-Apr-13 | -23.4251 | -149.4057 | AUTB-12 | Tubuai | Windward | Fore reef |
| 15-Apr-13 | -23.3786 | -149.3853 | AUTB-13 | Tubuai | Windward | Fore reef |
| 15-Apr-13 | -23.3339 | -149.4361 | AUTB-14 | Tubuai | Leeward | Lagoon |
| 16-Apr-13 | -23.3485 | -149.5313 | AUTB-15 | Tubuai | Leeward | Fore reef |
| 16-Apr-13 | -23.3561 | -149.5518 | AUTB-16 | Tubuai | Leeward | Fore reef |
| 16-Apr-13 | -23.4242 | -149.4837 | AUTB-17 | Tubuai | Leeward | Fore reef |
| 17-Apr-13 | -22.4522 | -151.3235 | AURR-18 | Rurutu | Windward | Fore reef |
| 17-Apr-13 | -22.4323 | -151.3760 | AURR-19 | Rurutu | Leeward | Fore reef |
| 17-Apr-13 | -22.5204 | -151.3327 | AURR-20 | Rurutu | Windward | Fore reef |
| 18-Apr-13 | -22.6406 | -152.8223 | AURM-21 | Rimatara | Leeward | Fore reef |
| 18-Apr-13 | -22.6665 | -152.7958 | AURM-22 | Rimatara | Windward | Fore reef |
| 18-Apr-13 | -22.644 | -152.7882 | AURM-23 | Rimatara | Windward | Fore reef |
| 19-Apr-13 | -22.6648 | -152.8163 | AURM-24 | Rimatara | Leeward | Fore reef |
| 19-Apr-13 | -22.6592 | -152.8163 | AURM-25 | Rimatara | Windward | Fore reef |
| 20-Apr-13 | -21.8130 | -154.6891 | AUMA-26 | Maria | Windward | Fore reef |
| 20-Apr-13 | -21.7901 | -154.7037 | AUMA-27 | Maria | Windward | Fore reef |
| 20-Apr-13 | -21.8200 | -154.7239 | AUMA-28 | Maria | Leeward | Fore reef |
| 21-Apr-13 | -21.7972 | -154.6917 | AUMA-29 | Maria | Windward | Fore reef |
| 21-Apr-13 | -21.8008 | -154.7180 | AUMA-30 | Maria | Leeward | Fore reef |



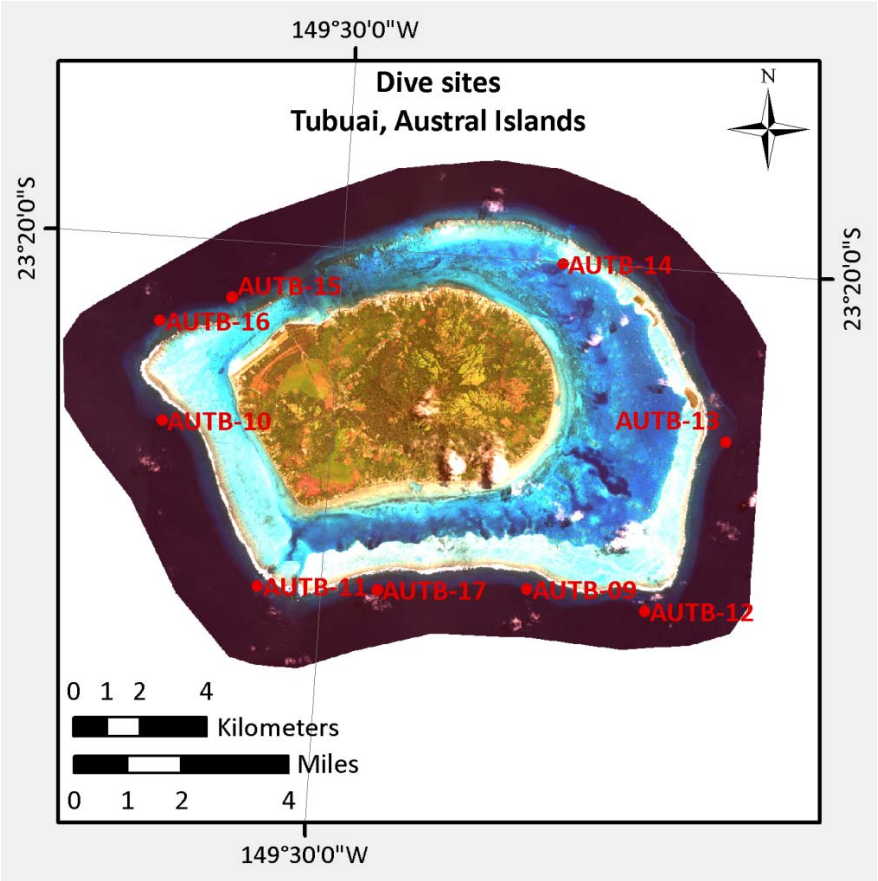




**Fig. 7. Location of SCUBA assessments off Raivavae (top) and Tubuai (bottom).**

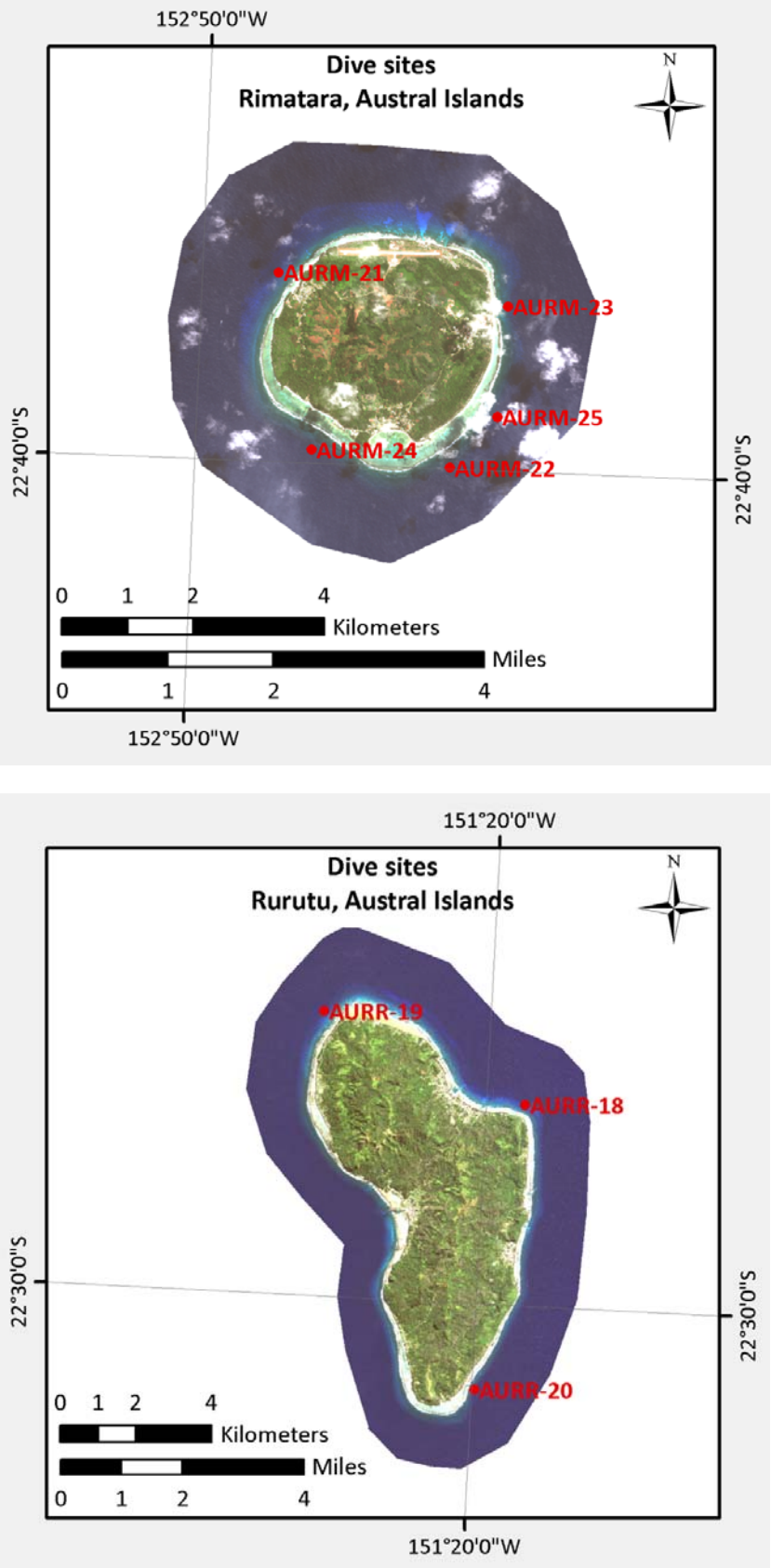



**Fig. 8. Location of SCUBA assessments off Rimatara (top) and Rurutu (bottom).**

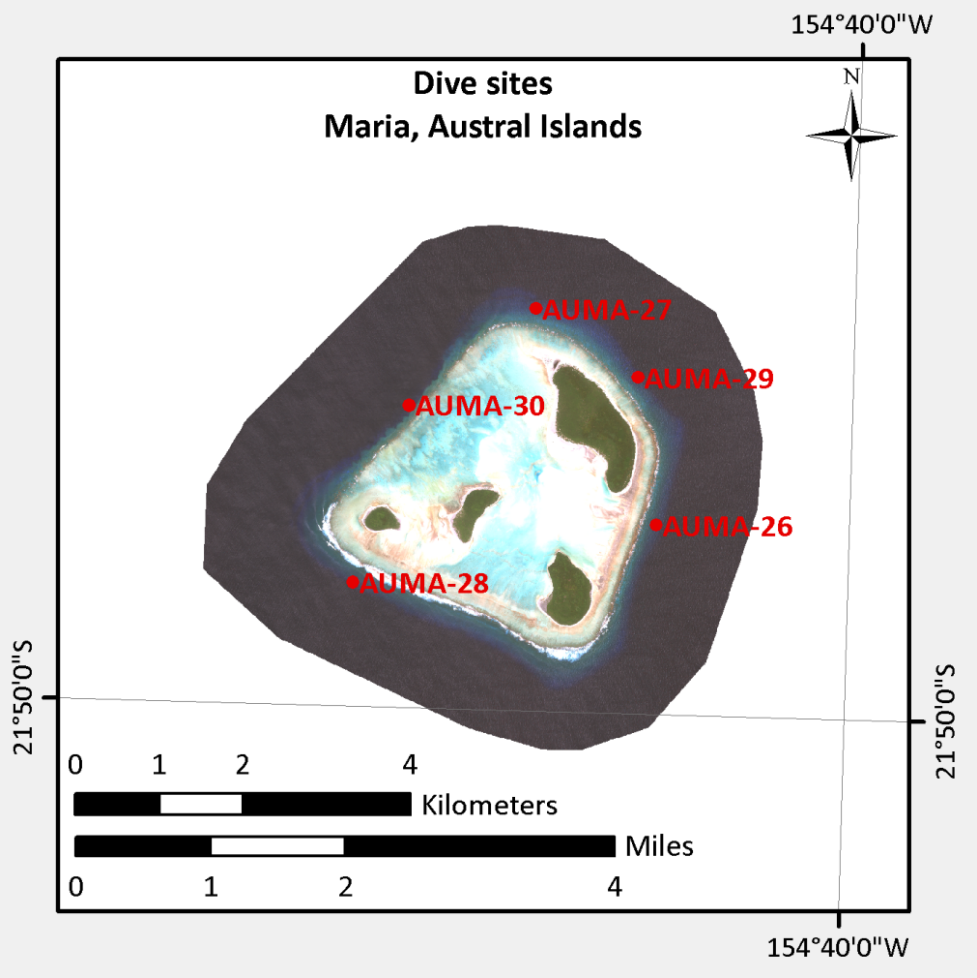



**Fig. 9. Location of SCUBA assessments off Maria Ouest.**

**Fig. 10. Uplifted reef and submerged spur and groove reef habitats found at Rurutu, Austral Islands.**

## 3. Coral reef Research

**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 | No. Samples |
|---|---|
| Maria Ouest | 18 |
| Raivavae | 40 |
| Rimatara | 2 |
| Rurutu | 1 |
| Tubuai | 29 |
| **Total** | 90 |

**Table 5. 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) 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 |
|---|---|---|---|---|
| Raivavae | *Porites lobata* | 9 | ~3cm diam. X 9 cm length | Dry |
| Rimatara | *Porites lobata* | 3 | ~3cm diam. X 9 cm length | Dry |
| Tubuai | *Porites lobata* | 10 | ~3cm diam. X 9 cm length | Dry |
| Tubuai | *Astreopora* sp. | 1 | ~3cm diam. X 9 cm length | Dry |
| Maria Ouest | *Porites lobata* | 4 | ~3cm diam. X 9 cm length | Dry |
| Total | | 27 | | |

**Table 6. Total number of cores collected off 4 islands.**

## Fish Collections

A survey of the fish biodiversity was undertaken within 25 sampling locations at five major islands in the Austral Islands chain. Standard fish collecting techniques included the use of hand nets, fish anesthetics and spear fishing. Daily sampling involved a morning collection using hand nets and fish anesthetics, supplemented with spear fishing as time allowed. The morning samples were then processed aboard the M/Y Golden Shadow. A daily afternoon collection was made by spear fishing to obtain specimens of the larger species not susceptible to the anesthetics. A total of 2233 specimens representing 471 taxa were collected and sampled at the 25 fish sampling stations.

| Island | Total fish collected |
|---|---|
| Maria Ouest | 450 |
| Raivavae | 673 |
| Rimatara | 260 |
| Rurutu | 467 |
| Tubuai | 383 |
| **Total** | **2233** |

**Table 7. Total number of fish collected off 5 islands.**

## Giant clam studies

For genetic samples, a piece of mantle was collected and kept in 96% alcohol until lab processing by collaborators in New-Caledonia. Overall, 181 samples were collected at Tubuai, among 8 stations, and 19 samples were collected at Raivavae. The gonads of these sampled clams were also collected for the study of reproductive success (lab processing coming next months, at IFREMER Tahiti).

Twenty 10-meters permanent transects were established on the 8 sampling sites, to monitor growth and mortality for 629 giant clams. Two stations (totaling 140 giant clams) were also established at Raivavae island.

| Island | station | Latitude | Longitude | Number of clams collected for genetic and gonad analyses |
|---|---|---|---|---|
| Tubuai | 1 | -23,379615 | -149,539306 | 23 |
| Tubuai | 2 | -23,403852 | -149,526618 | 24 |
| Tubuai | 3 | -23,417086 | -149,484635 | 23 |
| Tubuai | 4 | -23,413042 | -149,45363 | 22 |
| Tubuai | 5 | -23,418303 | -149,485034 | 23 |
| Tubuai | 6 | -23,416794 | -149,470926 | 23 |
| Tubuai | 7 | -23,40427 | -149,414207 | 22 |
| Tubuai | 8 | -23,353951 | -149,419496 | 21 |
| Raivavae | 1 | -23,889603 | -147,708943 | 12 |
| Raivavae | 2 | -23,877624 | -147,602805 | 7 |
| Total | | | | 200 |

**Table 8. Coordinates of sampling sites for Tubuai and Raivavae Islands and samples collected.**

## 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. Total number of samples collected are shown in Table 9.

| Island | Species | Number | Size | Quantity taken (mg) |
|---|---|---|---|---|
| Raivavae | *Pocillopora damicornis* | 8 | 100 mg each | 800 |
| Raivavae | *Pocillopora* sp. | 10 | 100 mg each | 1,000 |
| Tubuai | *Pocillopora damicornis* | 15 | 100 mg each | 1,500 |
| Tubuai | *Pocillopora meandrina* | 1 | 100 mg each | 100 |
| Tubuai | *Pocillopora* sp. | 3 | 100 mg each | 300 |
| Rurutu | *Pocillopora damicornis* | 1 | 50 mg each | 50 |
| Rurutu | *Pocillopora verrucosa* | 4 | 50 mg each | 200 |
| Rurutu | *Pocillopora* sp. | 3 | 50 mg each | 150 |
| Rimatara | Collected no samples due to crown of thorns sea-star outbreak | | | |
| Maria | *Pocillopora verrucosa* | 10 | 50 mg each | 500 |
| Maria | *Pocillopora meandrina* | 1 | 50 mg each | 50 |
| Maria | *Pocillopora sp.* | 5 | 50 mg each | 250 |
| | Total number | **61** | **Total weight** | **~5 g** |

**Table 9. Corals sampled for coral health examination. The samples were placed in small tubes containing RNA Later, with some also fixed in paraformaldehyde. After fixation, samples containing paraformaldehyde were washed, decalcified, washed again, and transported in buffered saline.**

## Coral Disease

Coral assessments included recorded observations of the taxa, abundance, size structure and condition within belt transects. For each measured coral, the colony was carefully scanned to identify conditions affecting its health, including signs of overgrowth, predation and disease. In general, very few colonies with coral diseases were observed. On the west and south side of **Raivavae** there was an unusually high number of *Astreopora* colonies that were pale, sick and had considerable amounts of recent tissue loss. These corals were affected by a previously unreported coral disease. A small percent of the *Montastraea* colonies also were affected by yellow band disease. This syndrome has been observed on faviids in the

Atlantic Ocean and also on *Diploastrea* in the Pacific, but was not previously reported on *Montastraea*. Small cores (3-5 cm diameter) of *Astreopora* (24) and *Montastraea* (6) were taken from the diseased tissue. These were preserved in small containers containing formaldehyde-based Z-fix.

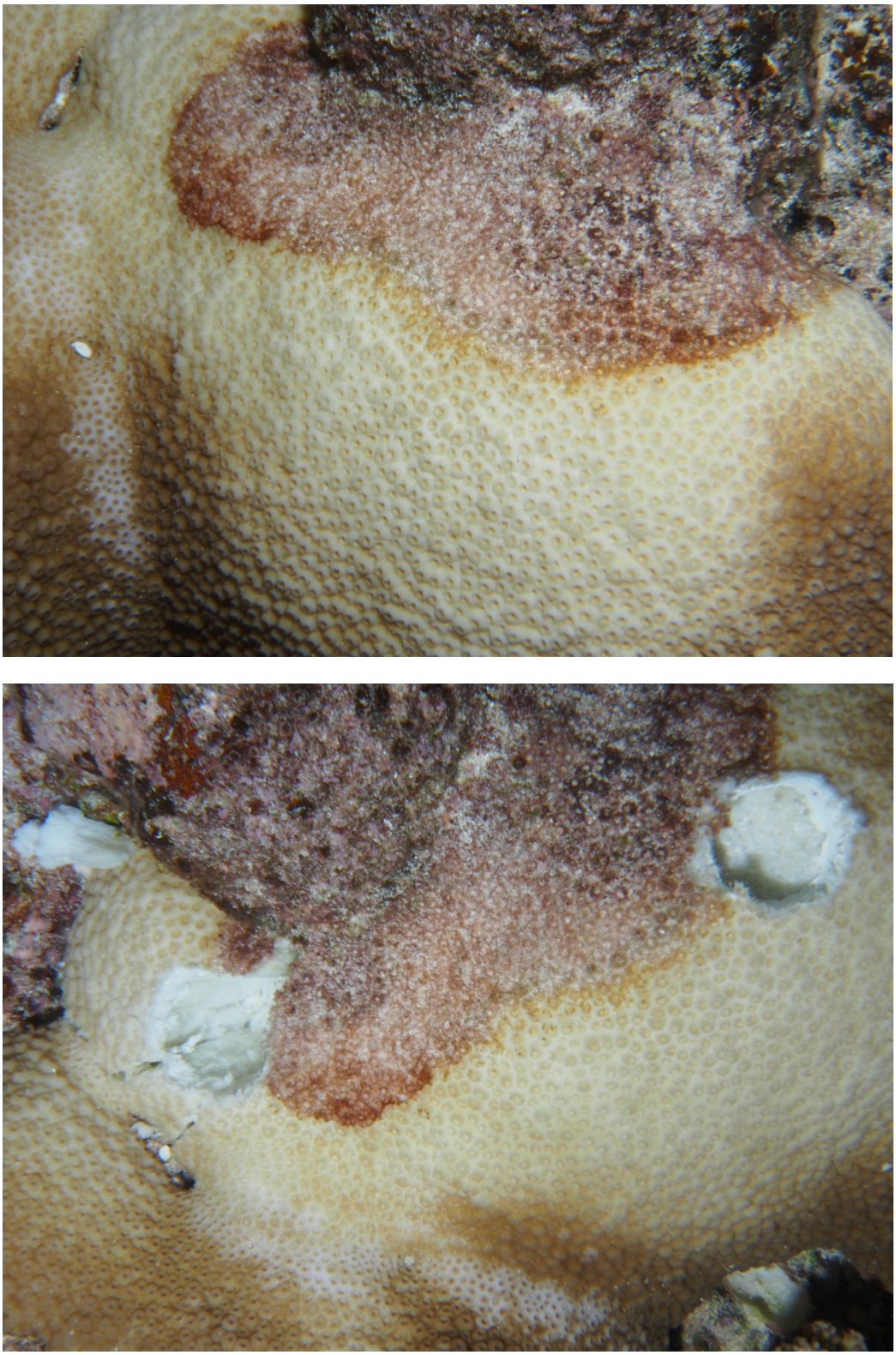


**Fig. 12. Colony of *Astreopora* with an undescribed disease (top). Same coral with two cores removed at the interface between dead, algal colonized skeleton and live, diseased tissue (bottom).**

**Coral Diversity**

Coral samples were collected from shallow fore reef locations using a hammer and chisel. Specimens, 2-20 cm were photographed, placed into separate, numbered bags and brought onto the boat for processing. Samples were divided into two fractions, one frozen and a second placed in RNA later solution. Genetic analysis is being conducted in the lab at CRIOBE.

| Location | *Acropora* | *Echinopora* | *Cyphastrea* | *Montipora* | *Pavona* | *Leptoseris* | *Turbinaria* | *Pocillopora* | *Porites* | *Distichopora* | *Lithophyllon* | *Echinophyllia* | *Pleuractis* | *Sandolitha* | *Herpolitha* | *Hydnophora* | *Lobactis* | *Platygyra* | *Homophyllia* | *Acanthastrea* | *Astreopora* | *Coscinarea* | *Dipsastrea* | *Fungia* | *Favites* | *Goniastrea* | *Leptastrea* | *Leptoria* | *Lobophyllia* | *Phymastyrea* | *Psammocora* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Raivavae | 19 | 2 | 2 | 9 | 6 | 2 | 1 | 6 | 3 | 1 | | 5 | | 2 | 1 | 3 | 1 | 2 | 2 | 4 | 4 | 1 | 5 | 1 | 1 | 3 | 3 | 2 | 2 | 2 | 2 |
| Tubuai | 9 | | 1 | 4 | 5 | 1 | 2 | 1 | | 1 | 3 | 1 | 1 | 2 | | | | 1 | 1 | 1 | | | | | | | 2 | | | | |
| Rimatara | | | | | | | | 1 | | | | | | | | | | | | | | | | | | | | | | | |
| Rurutu | | | | | | | | | 1 | | | | | | | | | | | | | | | | | | | | | | |
| Maria | 4 | | | 3 | | | | | 1 | | | | | | | | | | | | | | | | | | | | | | |
| Total | 32 | 2 | 3 | 16 | 11 | 3 | 3 | 8 | 5 | 2 | 3 | 6 | 1 | 4 | 1 | 3 | 1 | 3 | 3 | 5 | 4 | 1 | 5 | 1 | 1 | 3 | 5 | 2 | 2 | 2 | 2 |

**Table 10. Summary of coral genera collected for genetic analysis of coral species diversity.**

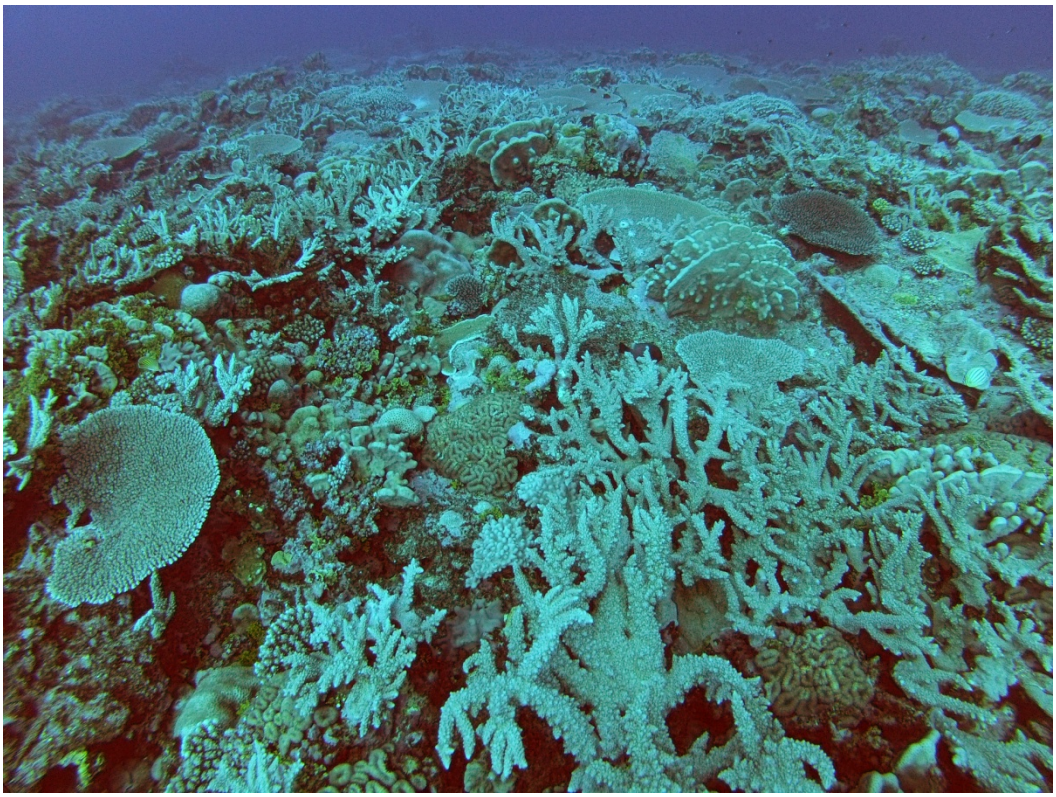


**Fig. 13. High diversity reef community on the southwest fore reef off Raivavae.**

## Appendix 1. Participants

| Name | Institution | Function |
|---|---|---|
| Andy Bruckner | Khaled bin Sultan Living Oceans Foundation (KSLOF) | Chief Scientist |
| Brian Beck | Khaled bin Sultan Living Oceans Foundation | Benthic surveys |
| Anderson Mayfield | National Museum of Marine Biology and Aquarium, KSLOF Fellow | Coral genetics |
| Badi Samaniego | University of the Philippines, Living Oceans Foundation Fellow | Fish surveyor |
| Joao Monteiro | University of the Azores, Living Oceans Foundation Fellow | Coral fluorescence |
| Jeremy Kerr | Nova Southeastern University, Living Oceans Foundation Fellow | Groundtruthing / habitat mapping |
| Alex Dempsey | Nova Southeastern University National Coral Reef Institute | Benthic surveyor |
| Anesti Stathakopoulos | Nova Southeastern University National Coral Reef Institute | Groundtruthing |
| Renee Carlton | NOAA/University of Miami | Ocean acidification |
| Serge Planes | Le Centre de Recherches Insulaires et Observatoire de l'Environnement de Polynésie Française (CRIOBE) | Fish sampling |
| Erwan Delrieu Trotin | Pierre and Marie Curie University (Paris 6) | Fish sampling |
| Gabriel Haumani | Direction des Ressources Marines, | Invertebrate surveys |
| Simon van Wynsberge | Université de la Polynésie française, | Giant Clam genetics |
| Ken Marks | Atlantic and Gulf Rapid Reef Assessment Program (AGRRA) | Photo transects |
| Gilles Siu | Le Centre de Recherches Insulaires et Observatoire de l'Environnement de Polynésie Française (CRIOBE) | Fish surveyor |
| Jeff Williams | Smithsonian Museum of Natural History | Fish taxonomy |
| Laetitia Hedouin | Le Centre de Recherches Insulaires et Observatoire de l'Environnement de Polynésie Française (CRIOBE) | Coral assessments |
| Pauline Boserelle | Le Centre de Recherches Insulaires et Observatoire de l'Environnement de Polynésie Française (CRIOBE) | Benthic surveyor |
| Marine Couraudon-Reale | Independent contractor | Benthic surveyor |
| Kate Fraser | Independent contractor | Fish surveyor |
| Agnes Benet | Consultancy PROGEM | MPA monitoring |
| Tom Cribb | University of Queensland | Fish sampling |
| Pierre Sasal | French National Centre for Scientific Research | Fish sampling |
| Nick Cautin | Dive Safety Officer | Diving operations |