Field Report

GLOBAL REEF EXPEDITION: TONGA

10/09/13-30/09/13

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Front cover: Shallow fore reef community in Vava'u. Photo by Andrew Bruckner.

Back Cover: A patch reef located close to shore in the Ha'apai group. Photo by Ken Marks.

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Executive Summary

Between September 10, 2013 – October 3, 2013 the Khaled bin Sultan Living Oceans Foundation conducted a research mission to Tonga, focusing on coral reefs surrounding the islands in the Ha'apai group (Sep 11-21), Vava'u (Sep 22-28) and Niuaatoputapu (Sep 29-Oct 1). The mission included coral reef assessments, coral reef research, habitat mapping, and educational activities. The project was conducted in partnership with the Ministry of Lands, Environment, Climate Change & Natural Resources (MLECCNR), Ministry of Agriculture, Forests and Fisheries (MAFF) and Vava'u Environmental Protection Association (VEPA), with involvement of scientists from Nova Southeastern University, University of the Azores, University of the Philippines, NOAA/University of Miami, Atlantic and Gulf Rapid Reef Assessment Program (AGRRA), and the National Museum of Marine Biology and Aquarium (Taiwan). 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 stressors on coral health and subcellular changes through biomarker expression;
4) Assess the diversity, abundance and population structure of fishes, corals and other invertebrates, and algae, including commercially valuable species;
5) Document the impacts of broad scale disturbances and patterns of recovery with emphasis on Tsunami damage in Niua;
6) Measure ocean chemistry (pH) and effects on coral growth; and
7) Characterize the types of symbionts in reef building corals and variations in their photosynthetic efficiency under different environmental conditions.

Groundtruthing: A total of 2212 sq km of WorldView 2 satellite imagery was acquired. To characterize shallow marine habitats, 524 videos (drop cameras) and 1.6 million soundings were taken across the three locations; covering a distance of 357 km. Georeferenced WorldView-2 imagery was used to plan bathymetric tracks to sample, and habitat locations of interest to drop video cameras. The bathymetric information will be used to calibrate a model which will assign a depth value to each pixel in the imagery data. Similarly, information from the camera drops will be used to assign a habitat type to the imagery data. Together, detailed maps of bathymetry and habitat type will be produced for the three locations visited.

Coral reef assessments: A total of 203 Fish transects, 365 benthic surveys, 311 coral assessments and 355 photo-transects were completed in 60 locations, from 5-30 m depth. The population structure and health of 27,308 corals (4 cm or larger) was assessed. Additional roving surveys for commercially important macroinvertebrates were conducted.

Coral reef research

- A total of 188 sediment samples were collected to characterize sediment composition and grain size.
- Cores (99 total) were taken from four genera of massive corals (*Porites, Astreopora, Pavona* and *Diploastrea*) to evaluate growth rates (skeletal density and linear extension) and compare to measurers of ocean chemistry (pH and CO_2 levels).
- Tissue samples (351 total) from six species of *Pocillopora* were collected to evaluate symbiont composition and variation in photosynthetic efficiency for corals exposed to different environmental parameters.

- Tissue samples from 115 colonies of *Pocillopora damicornis* were collected to assess subcellular levels of stress.
- An assessment of the impacts of coral predators was undertaken during each survey. An unusually high abundance of *Culcita* starfish were documented. Low levels of crown of thorns sea stars (COTS) were recorded. A single small outbreak was noted in Vava'u. All COTS found during dives were collected and measured and samples of tube feet were taken for genetic identification.
- A processing station for sea cucumbers was examined in Ha'apai, with photographs taken of representative species.

Fig. 1. Sea cucumbers being prepared for export from Ha'apai

Summary of general findings

Shallow marine habitats identified in Tonga include diverse coral reef assemblages, sea grass beds, mangrove communities, sand flats, algal communities, and reef flat, fore reef and lagoonal coral reefs. Coral reefs included emergent fringing and barrier reefs surrounding the outside of the island groups, as well as extensive submerged and emergent patch reefs, fringing reefs, pinnacles, and soft bottom coral communities within the lagoon. In general, we found the underwater topography of the three locations visited to be quite different from one another.

Ha'apai

- The marine environment is characterized by fringing reefs to the east that steeply drop off, with islands and other reef sites to the west of the fringing reef. A sand apron was present near most shallow reef systems. Some locations, especially to the south of the island group, had deeper reef patches that crested between 10 and 20 meters with no associated island or sand apron.
- The best developed reefs consist predominantly of patch reefs within lagoonal areas and fore reefs off the west side of the island group. Coral diversity is high, but individual reefs often have large areas with monospecific assemblages of coral monopolizing large areas. Many of the colonies at intermediate depths (10-20 m) are medium to large size, with smallest corals in shallow water and a rapid decline in live coral cover below 20 m depth.
- Lagoonal reefs tend to have relatively high abundances of branching and table and bottlebrush acroporids with many medium to large tables and extensive thickets of branching colonies, indicating an extended period without large scale disturbances.
- Shallow sites tend to have 20-30% live coral consisting of small acroporids, Pocillopora and small to medium massive corals (especially *Goniastrea* and *Favia*).
- Several fringing reefs within the lagoon (on the east side) had flourishing reef slopes from 5-20 m depth dominated by very large overlapping plates and folios colonies of *Coscinarea, Merulina, Montipora, Pachyseris* and other species.
- Lagoonal reefs at mid depths, especially in areas with moderate turbidity often had large colonies of *Porites rus*.
- Several locations, especially sites that had been damaged had very high (50-60%) cover of soft corals.
- The substrate of deeper reefs, especially in the lagoon, often had a cover dominated by cyanobacteria with scattered patches of turf and macroalgae. Higher amounts of cyanobacteria were noted in sites with fewer sea cucumbers.
- Windward fringing reefs off the northwest coast of the island group generally had low coral cover. These areas often had a scoured hardground habitat in shallow water with high cover of turf algae and macroalgae, patches of rubble and only small corals.
- A considerable amount of partial mortality was noted on corals in many locations. This was attributed to high abundances of damselfish algal lawns, an unusually high abundance of *Culcita,* and extensive damage by *Drupella* snails.

Fish observations

- Majority of species diversity and abundance comprised damselfishes.
- At survey sites along walls large schools of fusiliers (100+ individuals) were common
- Herbivore (parrotfish and surgeonfish) abundance was low

- Piscivores, particularly large individuals were uncommon.
- Small groupers, *Cephalopholis urodeta* (flagtail grouper) and *Cephalopholis argus* (peacock grouper) were present but not common.
- Snappers and sharks were very uncommon.
- **Site 16 and Site 20 (inside and outside reserve, respectively):** Slightly higher species diversity was observed at Site 16 (reserve) than at Site 20 (outside the reserve). Small piscivores, in low abundance were noted inside the reserve while no piscivores were recorded outside the reserve. Larger parrotfish were found inside the reserve.

Fig. 2. An unusually large foliose colony of *Merulina* on the slope of a lagoonal reef in Ha'apai at 25 m depth.

Vava'u

- The southern part of Vava'u had very similar topography to Ha'apai as described above, however the northern parts of Vava'u, with the coves and bays, are different. In general, the coves and bays in Vava'u are characterized by small patches of live coral, however mostly limestone rocky coastline with little live coral cover. The inner parts of these bays have mangroves lining some portions. In addition, many parts of Vava'u have very steep drop-offs and walls around islands, some of which have live coral cover, but other areas do not.

- Several lagoonal reefs in the central part of Vava'u had unusually large, diverse assemblages of branching acroporids extending from 5 m depth to about 30 m.
- Vava'u had unusually large and abundant massive *Porites lobata* colonies on both fore reef and lagoonal sites, some estimated at more than 500 years; these were rare in Ha'apai and present but much smaller on deeper sites off Niua.
- Outer fringing reefs off the northwest side of the island tended to have a shallow, flat-topped terrace and a steep drop to mid depths followed by a more gradual slope. These sites tended to have low coral cover mostly consisting of *Porites, Pocillopora, Acropora, Stylophora, Leptastrea* crusts and *Montipora*.
- Coral predators were again dominated by *Culcita*, and areas with high numbers of *Drupella* gastropods. Localized outbreaks of crown of thorns sea stars were seen within the central part of the lagoon in shallow water among large monospecific stands of *Pocillopora damicornis* and around Treasure Island.
- We circumnavigated Treasure Island using scooters to evaluate impacts of COTS. A total of 25 sea stars were collected. Damage was mostly concentrated on the west side, near the dock. The reef community of Treasure Island was very diverse and worthy of protection. It had one of the most diverse fish communities with many larger piscivores including the endangered Napoleon Wrasse. Shallow areas had had some densely colonized reef flat communities, gently sloping mid depth areas with large stands of branching acroporids, as well as other areas with large massive faviid corals, areas dominated by *Mycedium* and *Montipora* plates, *Merulina, Favites* and *Leptastrea* and small patches of *Pachyseris rugosa*. Around the west side, there were a number of small coves with extensive shallow areas at 4-10 m that had 60-80% live coral cover. These dropped off near vertically to 15-20 m depth, and then sloped more slowly to deeper water.

Fig. 3. Unusually large colonies of *Porites lobata* occurred on several lagoonal reefs in Vava'u

Fish observations:

- The majority of species diversity and abundance was represented by damselfishes. Larger piscivores more common than Ha'apai, but still less common than other locations we examined in French Polynesia, Cook Islands and Fiji. Large individuals of *Lutjanus bohar* (red snapper) noted at two sites only (36 and 47). Large individuals of *Macolor macularis* (midnight snapper) at three sites 36, 38 and 47. A single large mixed school of snapper was recorded at one site (37) made up of *Lutjanus gibbus* (humpback snapper) and *Lutjanus kasmira* (bluestripe snapper). Juveniles of snapper were relatively common, suggesting species are heavily targeted by fisheries.
- Sharks were not recorded on transects or in any roving surveys; a single white tip reef shark was seen.
- Parrotfish were more diverse and more abundant than at Ha'apai. One large grazing school (around 80 individuals) of *Scarus altipinnis* (filament-finned parrotfish, 40cm in length) was recorded at site 43.
- Surgeonfish diversity and abundance was also slightly higher than at Ha'apai.

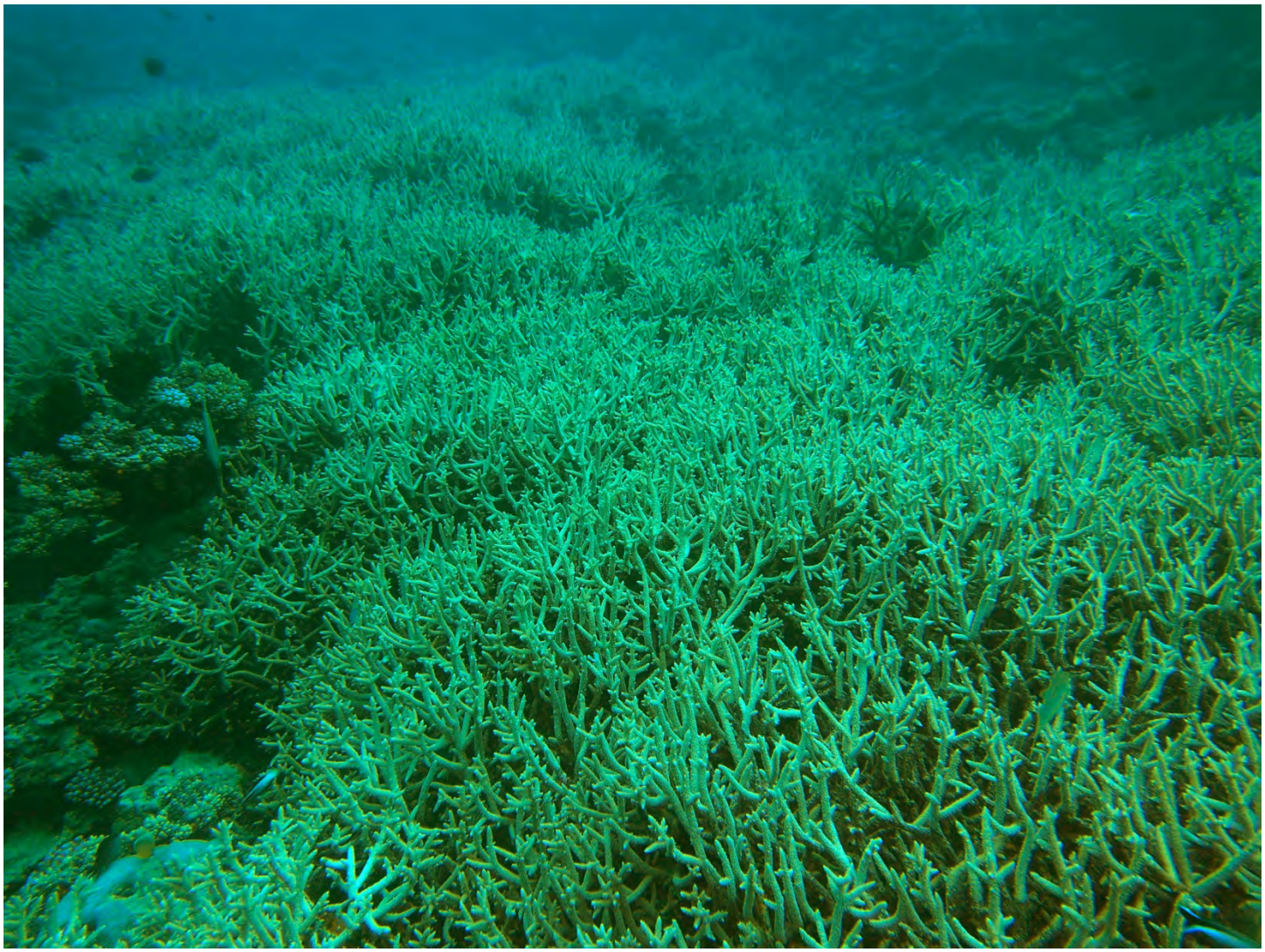


Fig. 4. Extensive monospecific stands of *Acropora* were recorded in many locations in Vava'u including this one off Treasure Island.

Niua

- Niuatoputapu has extensive spur and groove coral formations off the northern shore of the island and fringing reef around the rest of the islands coastline. The reefs around the island show a limited amount of live coral cover, depending on depth and location, potentially due to the effects of the tsunami in 2009.
- The lagoon contains very few patches of live coral with mostly dead framework, and a large amount of land debris including large trees and signs due to the tsunami.
- Deeper fore reef areas were not damaged as severely as the shallow reef; these have many very large (1-2 m) 10-20 year old table acroporids and large massive dome-shaped *Porites*.
- There has been rapid recolonization of reefs since the tsunami. Most shallow areas on the north coast are largely dead framework with coral skeletons heavily encrusted in CCA. The framework is being quickly recolonized by *Montipora*, and high numbers of small to medium table acroporids.
- Coral communities were slightly different than the other two island groups. *Turbinaria* stands were large and very abundant, and much more common than in Vava'u and Ha'apai. *Stylophora* was absent.
- A high prevalence of coral disease was recorded on *Pocillopora*; other species were not affected.
- Reefs on the north coast have very high cover of cyanobacteria on sand, Halimeda and reef substrate; cyanobacteria was present at very low levels in Ha'apai and Vava'u
- Very few corallivorous snails and *Culcita* starfish; no COTS found.

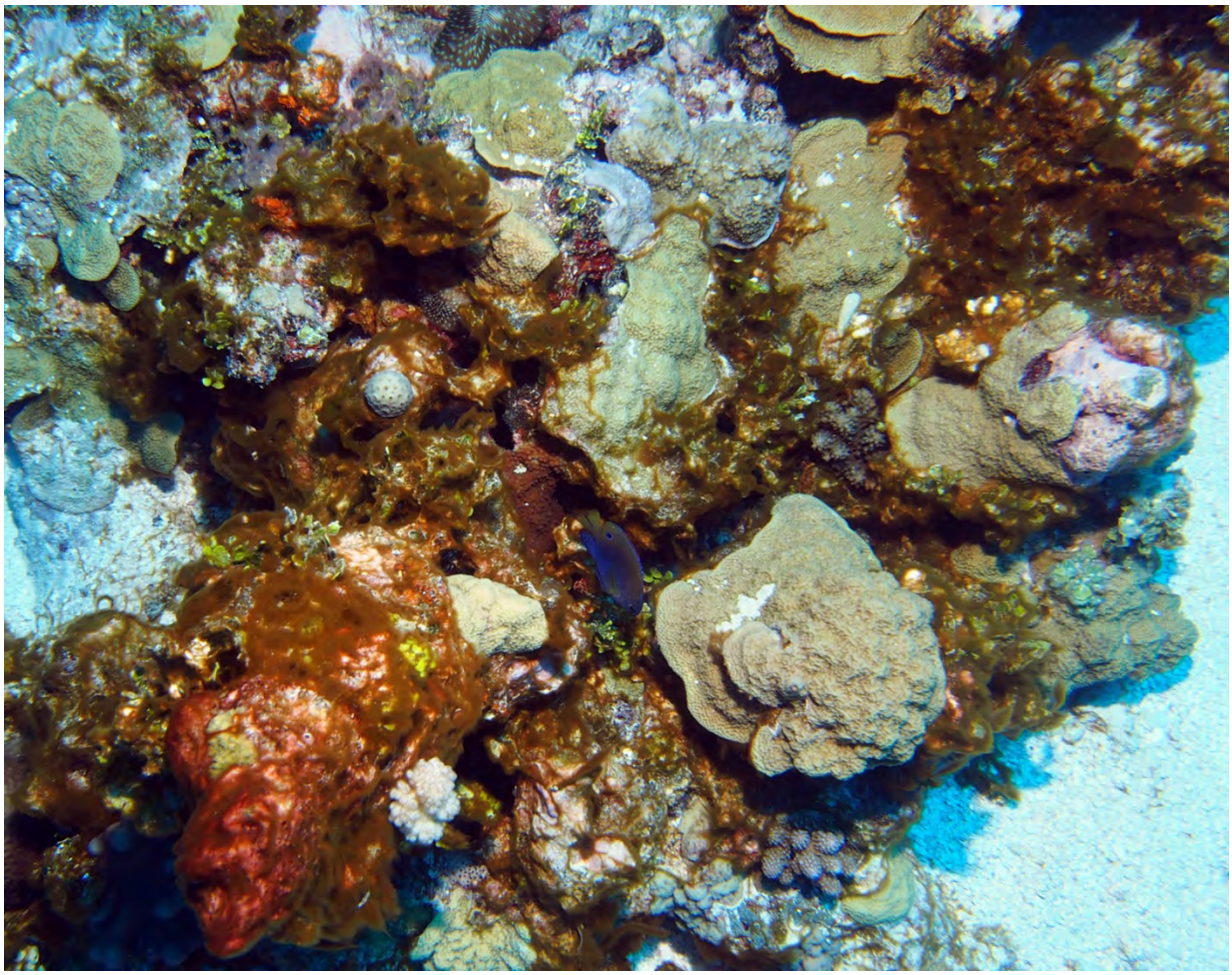


Fig. 5. Deeper reef communities in Niua had a high cover of cyanobacteria on the substrate and overgrowing corals.

***Fish observations**:*

- Notably higher species diversity than both Ha'apai and Vava'u. New species were observed in the Niau, that were not noted in the more southern island groups: *Caesio tile* (blue and yellow fusilier), *Lutjanus fulva* (blacktail snapper), *Lutjanus fulviflammus* (longspot snapper), *Mulloidichthys vanicolensis* (yellowfin goatfish), *Plectorhinchus vittatus* (oriental sweetlips), *Calotomus carolinus* (stareye parrotfish), *Hipposcarus longiceps* (pacific longnose parrotfish), *Anampses melanurus* (white spotted wrasse), *Chaetodon semeion* (dotted butterflyfish), *Acanthurus xanthopterus* (yellowfin surgeonfish).
- Damselfishes dominate in terms of abundance and diversity.
- Generally, predators were more common here than at Ha'apai and Vava'u, but still not abundant; sharks were rare.
- A single site (NI54) was outstanding for its overall biomass and presence of predatory fish species, particularly around 15m depth. This is the only site at which jacks (*Caranx melampygus*, Bluefin Jack) were recorded on transects. A large school (100+) of *Lutjanus gibbus* (humpback snapper) noted, as well as about 50 *Lutjanus fulviflammus* (longspot snapper) and about 50 *Lutjanus fulva* (blacktail snapper). Large individual parrotfish were also noted at this site: *Cetoscarus bicolor* (bicolour parrotfish). Two large red snapper (*Lutjanus bohar*) were also recorded here. Schools (approx. 80) of blue and yellow fusilier (*Caesio tile*) were recorded at this site and nowhere else.

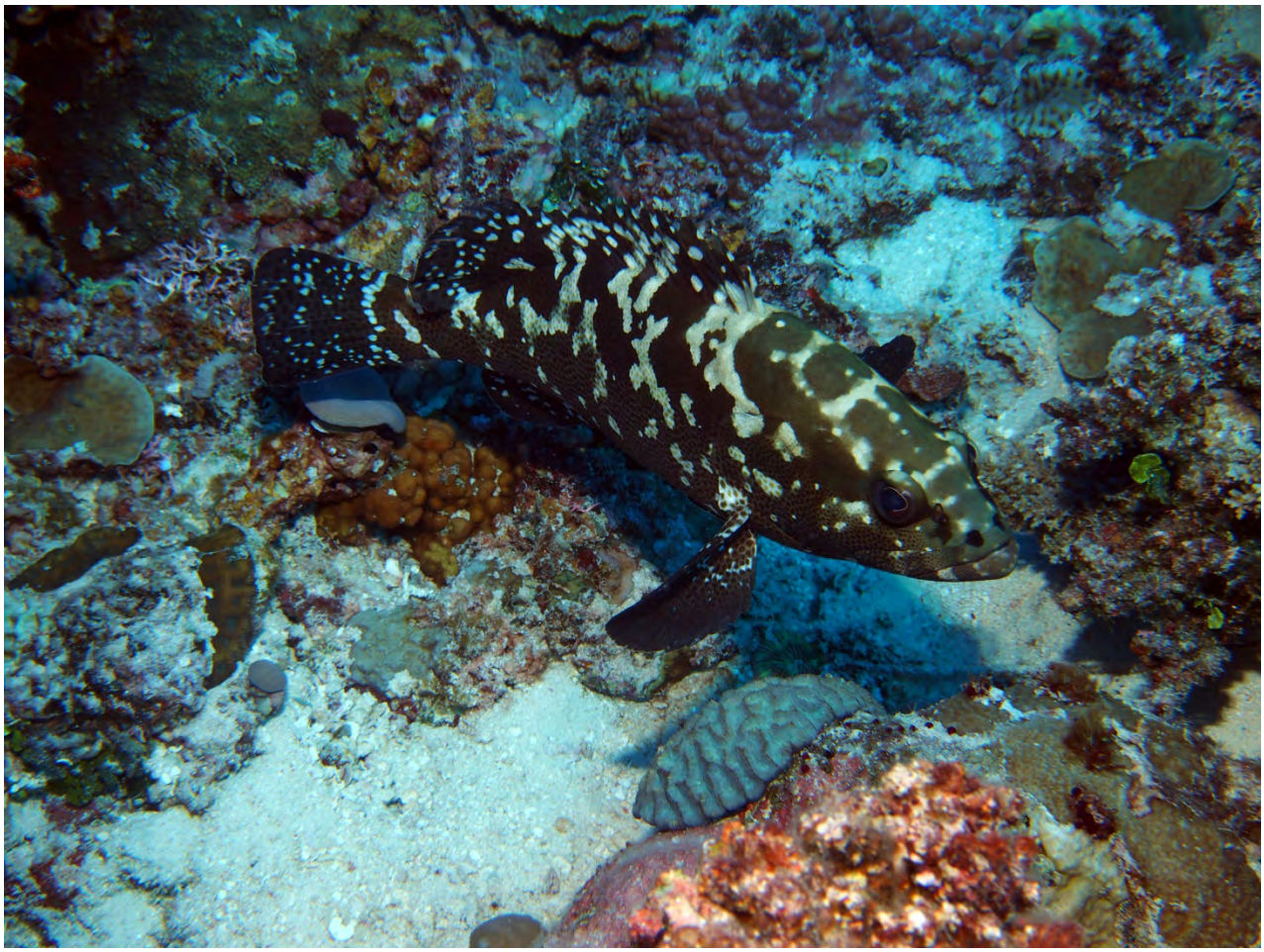


Fig. 6. Although piscivores were still relatively uncommon in Niua, the abundance of small grouper (above) snapper and other species was higher than in Ha'apai and Vava'u.

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 2212 sq. km of WorldView 2 (8 band) satellite imagery was acquired for this project (Table 1). 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 these scenes in conjunction with a differential GPS device (dGPS). The imagery is being used in concurrence 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 tethered cable (50 m). The acquired videos are being used to create the benthic habitat maps by providing information needed 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.

Location	Satellite Imagery	Number of Camera Drops	Number of Bathymetric Soundings	Distance Surveyed (km)
Ha'apai	129	323	914,073	206.741
Vava'u	772	174	549,787	124.902
Niuatoputapu	1311	27	139,071	26.195
TOTAL	**2212 sq km**	**525**	**1,602,931**	**357 km**

Table 1. Summary of satellite imagery and groundtruthing data.

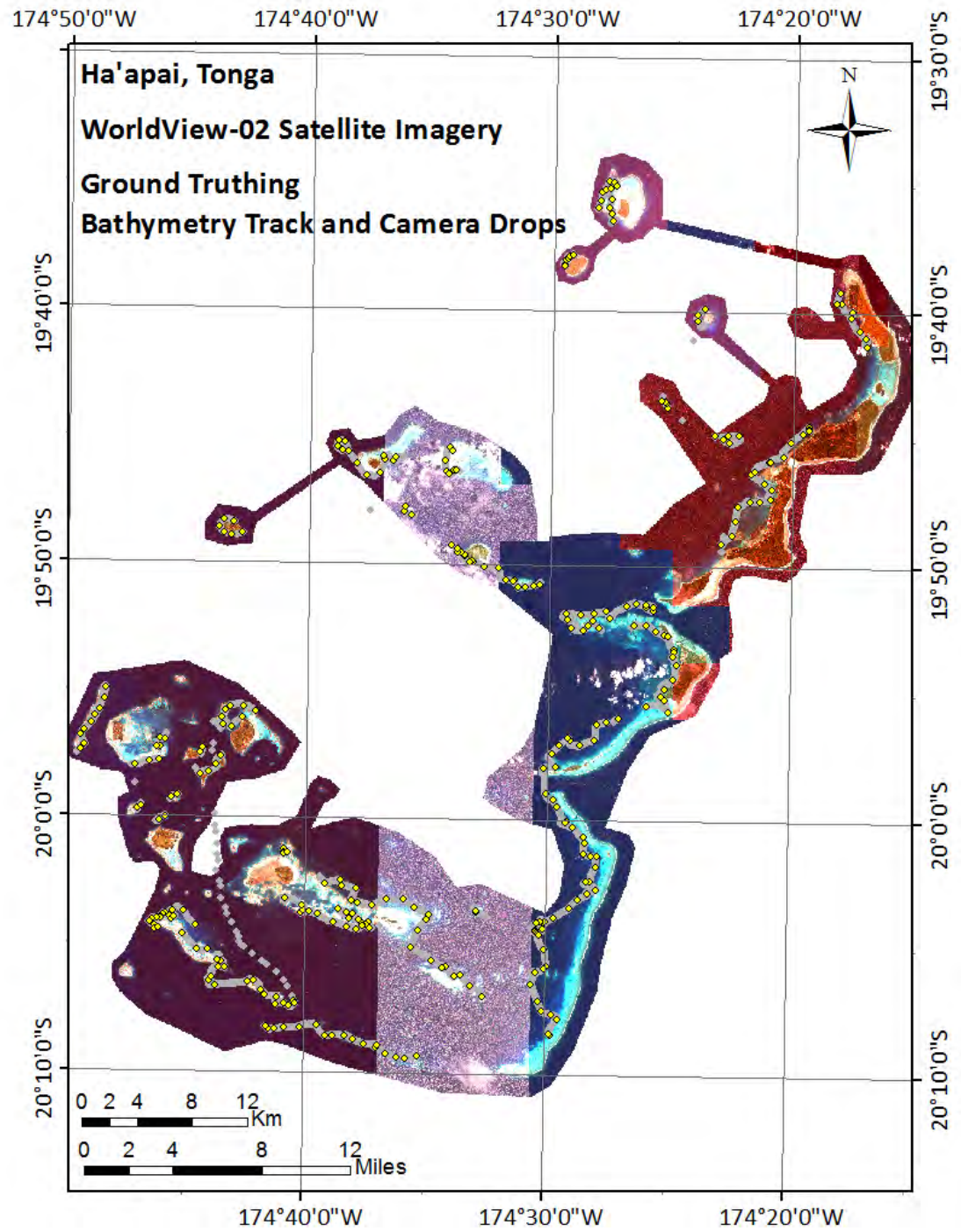


Fig. 7. Groundtruthing track in Ha'apai, Tonga showing locations of depth soundings and camera deployments.

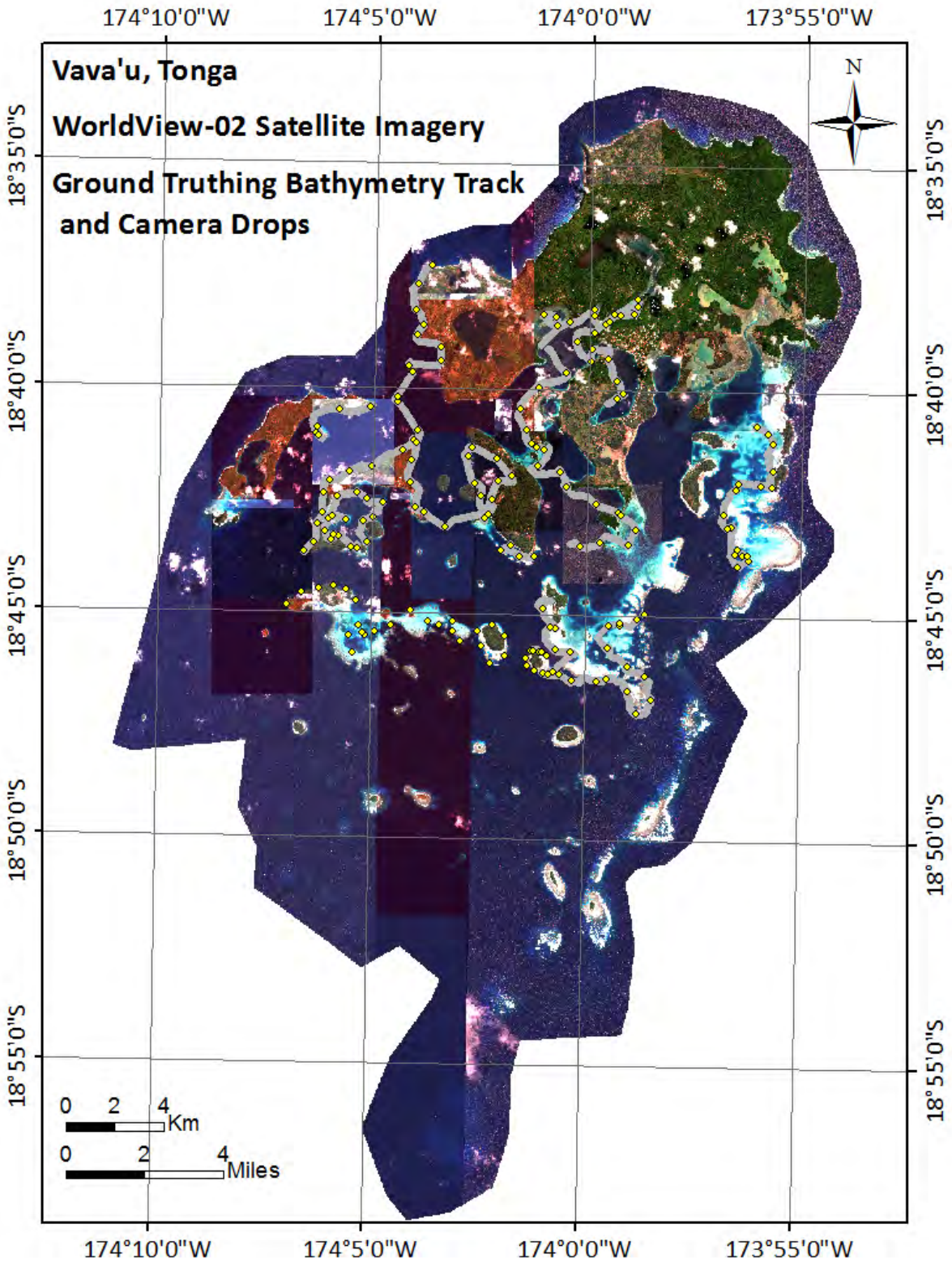


Fig. 8. Groundtruthing track in Vava'u, Tonga showing locations of depth soundings and camera deployments.

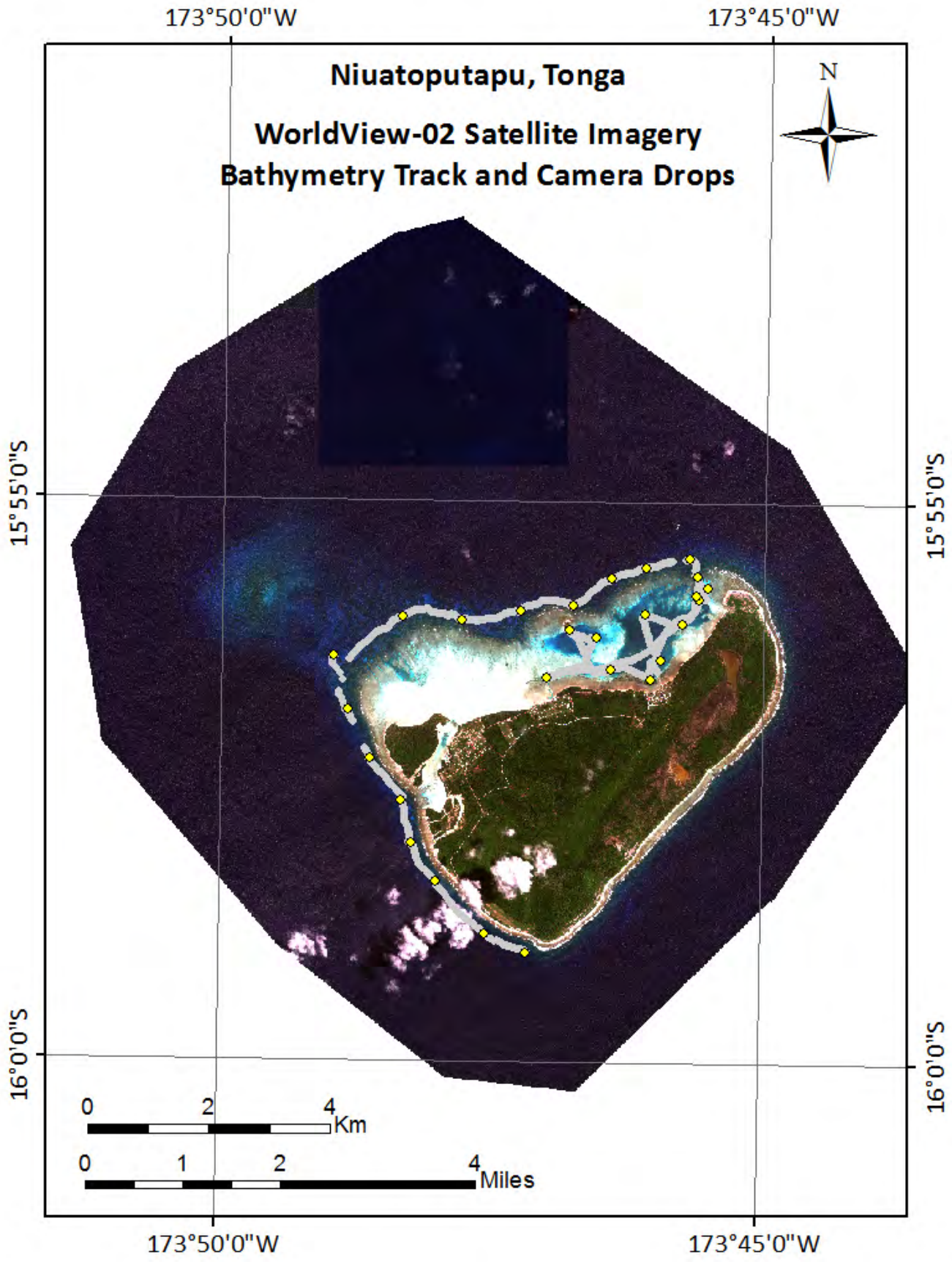
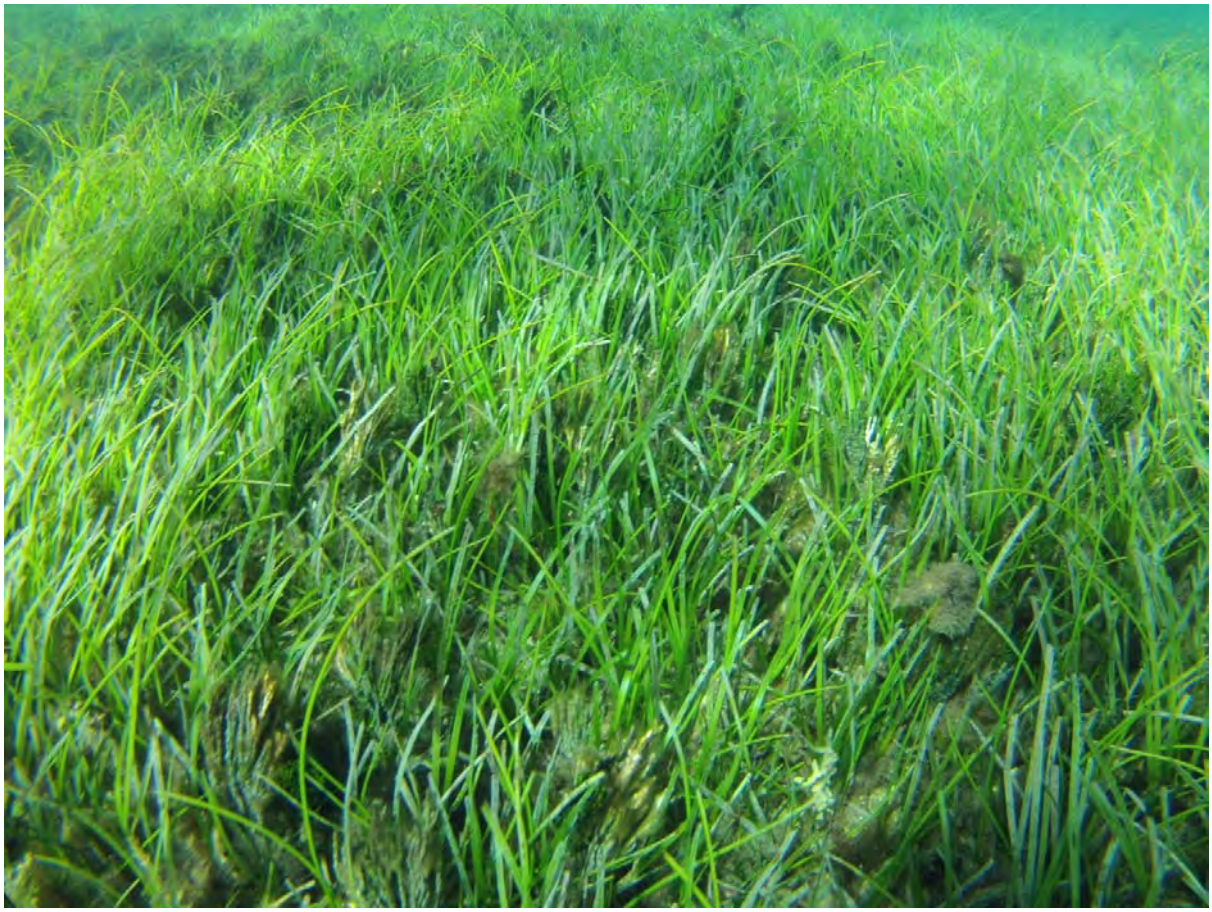


Fig.9. Groundtruthing track in Niua, Tonga showing locations of depth soundings and camera deployments.

Fig. 10. Extensive mangroves habitats (top) and seagrass beds (bottom) were observed in lagoonal areas.



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 involve 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 done 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. A total of 199 photo-transects were taken at Ha'apai, 120 at Vava'u, and 36 at Niua.

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 (giant clams, large gastropods, sea cucumbers) were recorded using roving, timed surveys within each of the dive locations. Motile invertebrates were also identified and counted along coral belt transects and benthic point intercept surveys.

Organism	Number of species
Giant clam	6
Sea cucumber	9
Sea urchins	2
Starfish	*Acanthaster*
	Culcita
Large Molluscs	Spider conch
	Trumpet triton
	Trochus
Total	22 species

Table 2. Species of large motile invertebrates identified and counted on coral reefs in three island groups.

Fig. 11. A high diversity but low abundance of sea cucumbers were seen in most survey locations. With exception of deeper habitats and areas distant from populated islands, sea cucumber populations appear to be exploited.

Fig. 12. A single species of sea snake, the banded sea krait (*Laticauda colubrina*) was observed in moderately high numbers on several reefs in Ha'apai and Vava'u.

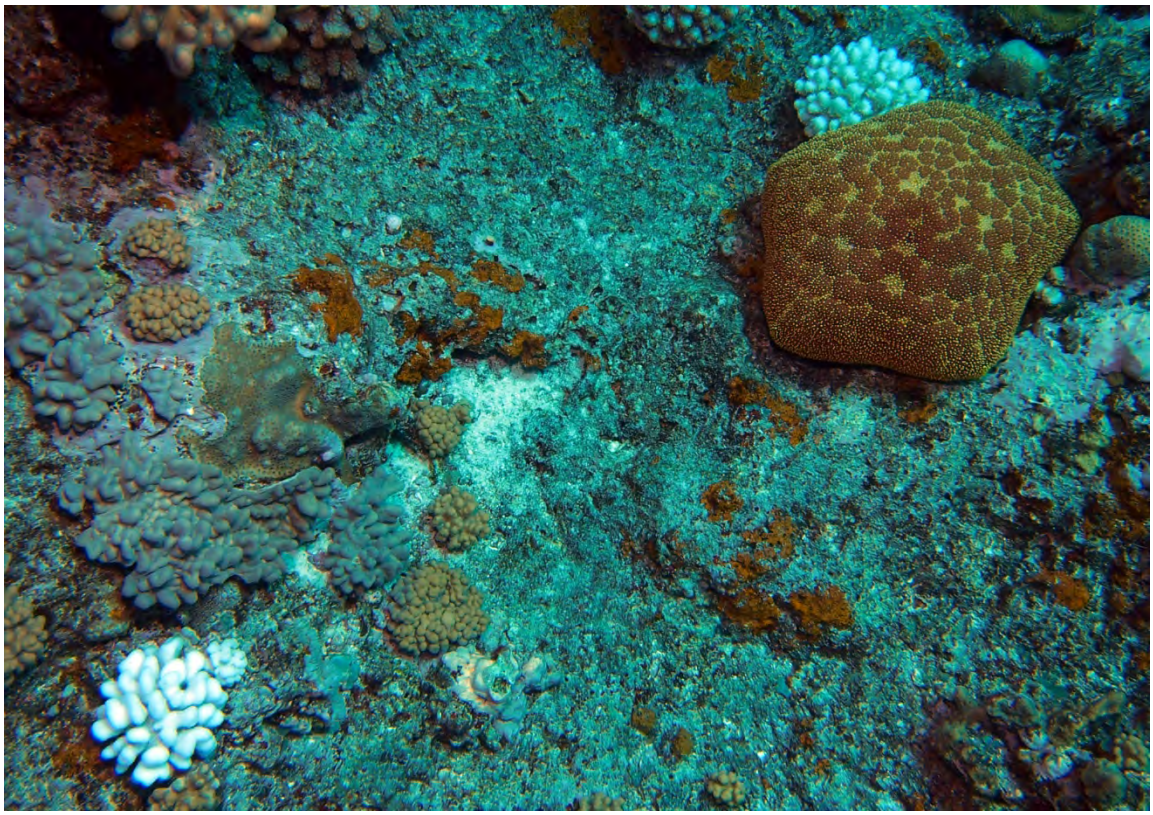


Fig. 13. Both Ha'apai and Vava'u had an unnaturally high abundance of *Culcita* starfish. The two white corals visible in this photo were eaten by this starfish.

Table 3. Coral reefs examined in the Ha'apai group, Vava'u and Niuatoputapu Tonga.

Date	Lat	Long	site name	Island	exposure	reef zone	reef type
11-Sep-13	-19.8064	-174.3803	TOHA 01	Ha'apai	leeward	lagoonal	patch reef
11-Sep-13	-19.7979	-174.3845	TOHA 02	Ha'apai	leeward	lagoonal	patch reef
12-Sep-13	-19.8561	-174.4268	TOHA 03	Ha'apai	leeward	lagoonal	channel edge
12-Sep-13	-19.8668	-174.4824	TOHA 04	Ha'apai	leeward	lagoonal	patch reef
12-Sep-13	-19.8198	-174.4426	TOHA 05	Ha'apai	leeward	lagoonal	patch reef
13-Sep-13	-19.985	-174.5085	TOHA 06	Ha'apai	leeward	lagoonal	patch reef
13-Sep-13	-20.0581	-174.4856	TOHA 07	Ha'apai	leeward	lagoonal	patch reef
13-Sep-13	-20.0668	-174.5032	TOHA 08	Ha'apai	leeward	lagoonal	patch reef
14-Sep-13	-20.0669	-174.5034	TOHA 08b	Ha'apai	leeward	lagoonal	patch reef
14-Sep-13	-20.0714	-174.5074	TOHA 09	Ha'apai	leeward	lagoonal	patch reef
14-Sep-13	-20.0566	-174.5468	TOHA 10	Ha'apai	leeward	lagoonal	patch reef
15-Sep-13	-19.9271	-174.8158	TOHA 11	Ha'apai	leeward	lagoonal	patch reef
15-Sep-13	-19.9155	-174.8055	TOHA 12	Ha'apai	leeward	lagoonal	patch reef
15-Sep-13	-19.9071	-174.7584	TOHA 13	Ha'apai	leeward	lagoonal	patch reef
16-Sep-13	-20.0938	-174.7885	TOHA 14	Ha'apai	leeward	fore reef	barrier reef
16-Sep-13	-20.0817	-174.7574	TOHA 15	Ha'apai	leeward	fore reef	fringing reef
16-Sep-13	-20.06	-174.6799	TOHA 16	Ha'apai	leeward	lagoonal	fringing reef
16-Sep-13	-19.9261	-174.72787	TOHA 17	Ha'apai	windward	fore reef	linear reef
17-Sep-13	-20.0016	-174.7918	TOHA 18	Ha'apai	leeward	fore reef	barrier reef
17-Sep-13	-19.9478	-174.6852	TOHA 19	Ha'apai	windward	fore reef	fringing reef
17-Sep-13	-20.0623	-174.6646	TOHA 20	Ha'apai	leeward	lagoonal	fringing reef
18-Sep-13	-19.8148	-174.7138	TOHA 21	Ha'apai	leeward	fore reef	fringing reef
18-Sep-13	-19.7542	-174.6488	TOHA 22	Ha'apai	leeward	fore reef	fringing reef
18-Sep-13	-19.8429	-174.5321	TOHA 23	Ha'apai	leeward	lagoonal	patch reef
19-Sep-13	-19.8334	-174.3369	TOHA 24	Ha'apai	windward	fore reef	fringing reef
19-Sep-13	-19.8923	-174.3881	TOHA 25	Ha'apai	windward	fore reef	fringing reef
19-Sep-13	-19.8413	-174.5209	TOHA 26	Ha'apai	leeward	lagoonal	fringing reef
20-Sep-13	-19.7457	-174.3773	TOHA 27	Ha'apai	leeward	lagoonal	patch reef
20-Sep-13	-19.7176	-174.4283	TOHA 28	Ha'apai	leeward	lagoonal	patch reef
20-Sep-13	-19.6711	-174.4013	TOHA 29	Ha'apai	leeward	lagoonal	patch reef
21-Sep-13	-19.5992	-174.4702	TOHA 30	Ha'apai	leeward	fore reef	fringing reef
21-Sep-13	-19.6309	-174.4875	TOHA 31	Ha'apai	leeward	fore reef	fringing reef
21-Sep-13	-19.643	-174.4929	TOHA 32	Ha'apai	leeward	fore reef	fringing reef
22-Sep-13	-18.757	-174.1228	TOVA 33	Vava'u	leeward	lagoonal	fringing reef
22-Sep-13	-18.7244	-174.1064	TOVA 34	Vava'u	leeward	lagoonal	fringing reef
22-Sep-13	-18.7328	-174.0845	TOVA 35	Vava'u	leeward	lagoonal	patch reef
23-Sep-13	-18.6574	-174.07	TOVA 36	Vava'u	leeward	fore reef	fringing reef
23-Sep-13	-18.661	-174.0677	TOVA 37	Vava'u	leeward	fore reef	fringing reef
24-Sep-13	-18.638	-174.0675	TOVA 38	Vava'u	leeward	fore reef	fringing reef
24-Sep-13	-18.647	-174.067	TOVA 39	Vava'u	leeward	fore reef	fringing reef
24-Sep-13	-18.7308	-174.0098	TOVA 40	Vava'u	leeward	lagoonal	fringing reef
25-Sep-13	-18.6688	-174.1035	TOVA 41	Vava'u	leeward	fore reef	fringing reef
25-Sep-13	-18.6909	-174.0289	TOVA 42	Vava'u	leeward	lagoonal	coral bommies on sand
25-Sep-13	-18.6883	-174.0699	TOVA 43	Vava'u	leeward	lagoonal	fringing reef
25-Sep-13	-18.7434	-174.1119	TOVA 44	Vava'u	leeward	lagoonal	fringing reef
26-Sep-13	-18.7966	-174.1095	TOVA 45	Vava'u	windward	lagoonal	fringing reef
26-Sep-13	-18.7192	-174.1512	TOVA 46	Vava'u	leeward	lagoonal	barrier reef
26-Sep-13	-18.7989	-174.0451	TOVA 47	Vava'u	leeward	lagoonal	fringing reef
27-Sep-13	-18.583	-174.0057	TOVA 48	Vava'u	leeward	fore reef	fringing reef
27-Sep-13	-18.6162	-174.0286	TOVA 49	Vava'u	leeward	fore reef	pinnacles
27-Sep-13	-18.7386	-174.04237	TOVA 50	Vava'u	leeward	lagoonal	patch reef
27-Sep-13	-18.7634	-174.0206	TOVA 51	Vava'u	leeward	lagoonal	fringing reef
28-Sep-13	-18.774	-174.0054	TOVA 52	Vava'u	windward	lagoonal	patch reef
28-Sep-13	-18.7705	-174.0207	TOVA 53	Vava'u	windward	lagoonal	fringing reef
29-Sep-13	-15.9819	-173.7913	TONI 54	Niuatoputapu	windward	fore reef	fringing reef
29-Sep-13	-15.9751	-173.8108	TONI 55	Niuatoputapu	leeward	fore reef	fringing reef
29-Sep-13	-15.938	-173.8299	TONI 56	Niuatoputapu	leeward	fore reef	fringing reef
30-Sep-13	-15.9256	-173.767	TONI 57	Niuatoputapu	leeward	fore reef	barrier reef
30-Sep-13	-15.9329	-173.7977	TONI 58	Niuatoputapu	leeward	fore reef	barrier reef
30-Sep-13	-15.9308	-173.78	TONI 59	Niuatoputapu	leeward	fore reef	barrier reef

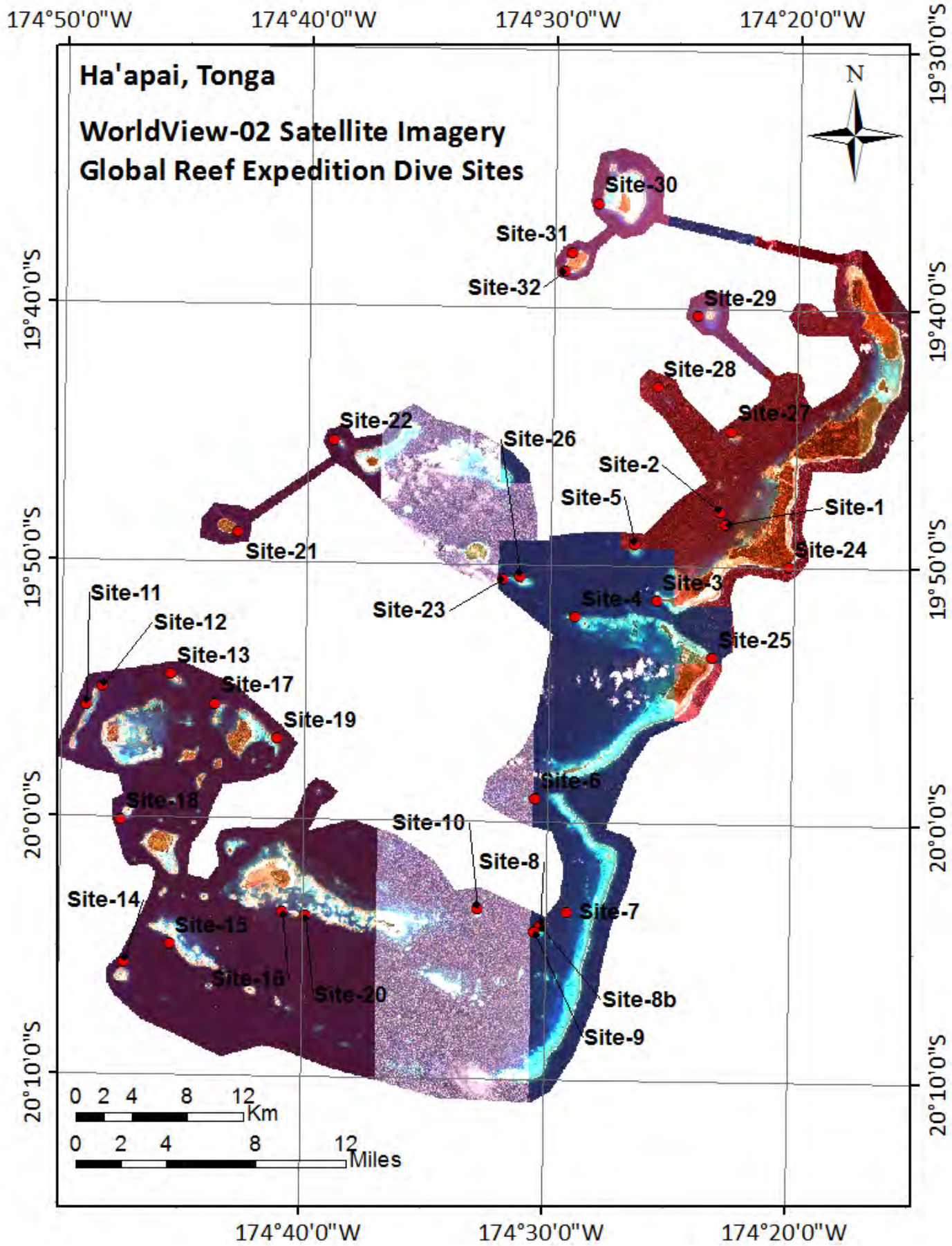


Fig. 14. Locations of SCUBA assessments in the Ha'apai Group, Tonga.

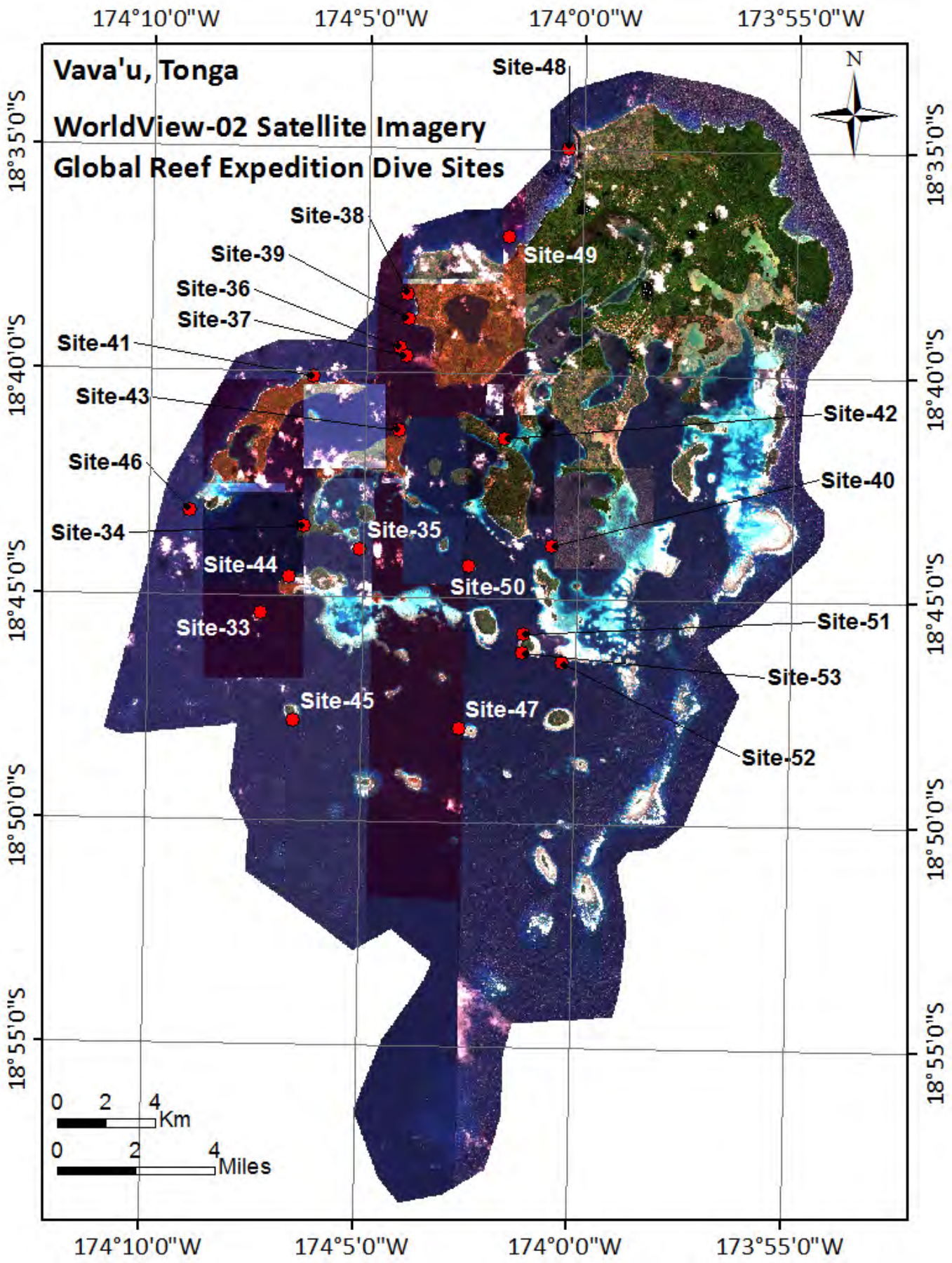


Fig. 15. Locations of SCUBA assessments in Vava'u, Tonga.

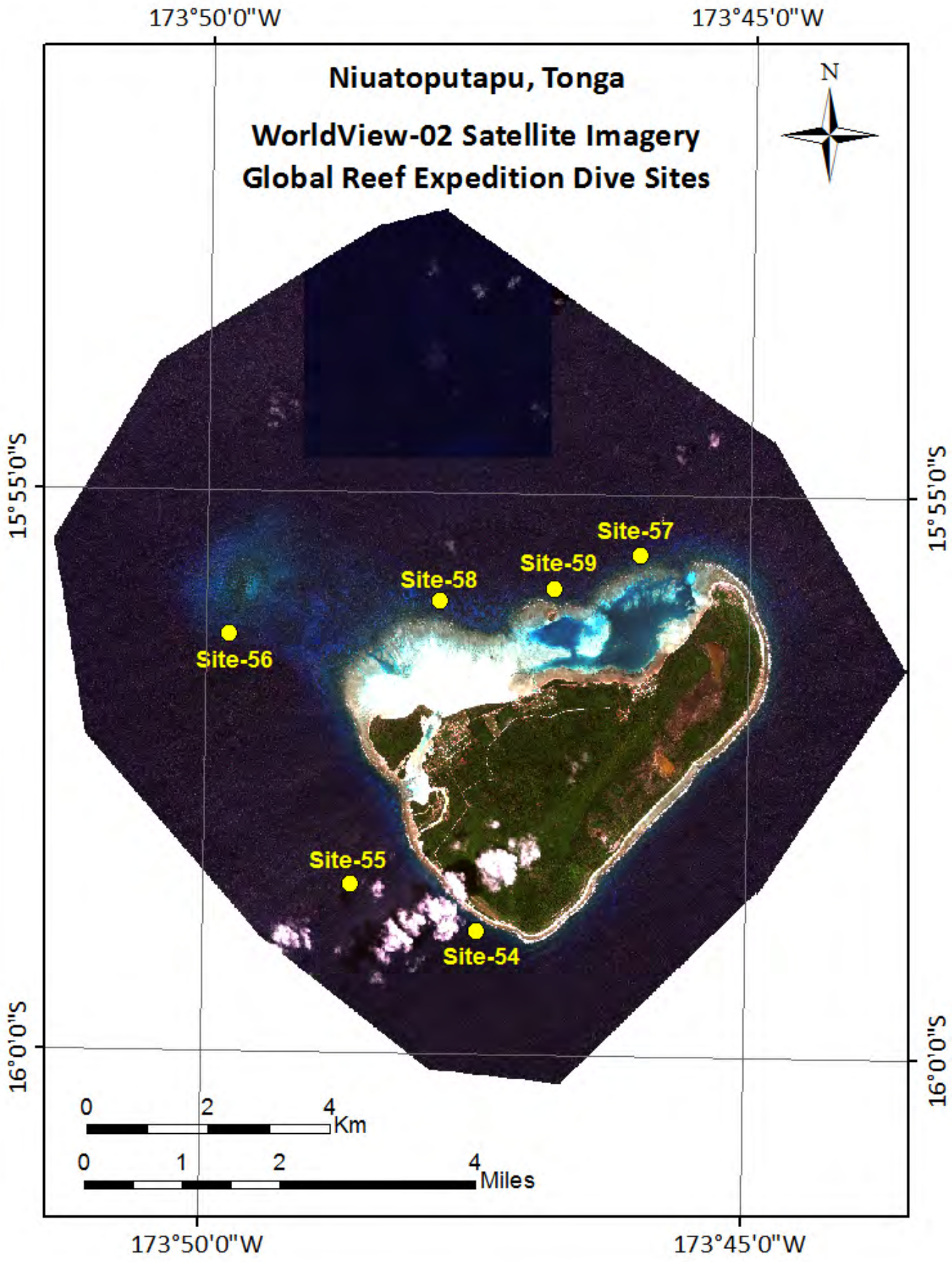


Fig. 16. Locations of SCUBA assessments in Niuatoputapu, Tonga.

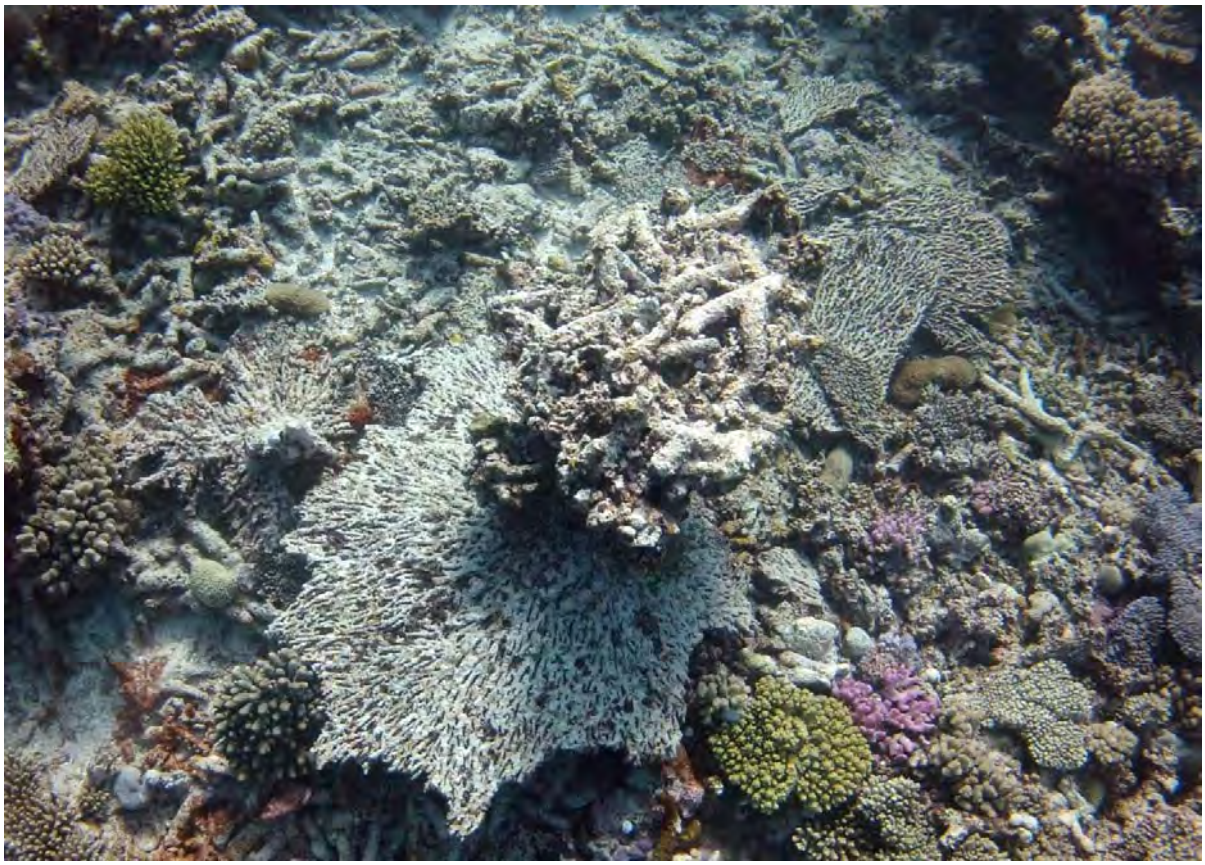


Fig. 17. Shallow reefs in Niua suffered extreme damage from a tsunami in 2009. Signs of coral damage, including large piles of rubble, were still evident. The reefs are beginning to recover, however, as high levels of recruitment and juvenile colonies of fast growing branching corals were documented.

Fig. 18. Fore reef communities at mid depths in Niua had a high abundance of plating and foliaceous *Turbinaria* colonies.

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.

Location	Number
Haapai	98
Vavau	65
Niautoputapu	25
Total	188

Table 4. Number of sediment samples collected in each island group.

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
Ha'apai	*Porites lobata*	53	~3cm diam. X 9 cm length	Dry
Ha'apai	*Porites lobata*	1	~5cm diam. X 30 cm length	Dry
Ha'apai	*Pavona clavus*	7	~3cm diam. X 9 cm length	Dry
Ha'apai	*Diploastrea*	1	~3cm diam. X 9 cm length	Dry
Ha'apai	*Astreopora*	1	~3cm diam. X 9 cm length	Dry
Vava'u	*Porites lobata*	21	~3cm diam. X 9 cm length	Dry
Vava'u	*Porites lobata*	3	~5cm diam. X 30 cm length	Dry
Vava'u	*Astreopora*	2	~3cm diam. X 9 cm length	Dry
Niautoputapu	*Porites lobata*	10	~3cm diam. X 9 cm length	Dry
Total		99		

Table 5. Coral cores collected for calcification and growth studies

Coral symbiont analysis:

This component involved two aspects: 1) sampling colonies of *Pocillopora* from different habitats, depths and locations to characterize their symbionts; and 2) diurnal and nocturnal measurements of the fluorescence of these 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, snippers 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 Dimethyl sulfoxide (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.

	Pocillopora							
Island	***eydouxi***	***damicornis***	***verrucosa***	***kelleheri***	***meandrina***	***elegans***	**sp.**	**Total**
Ha'apai Group	30	21	101	26	6	6	4	194
Niautoputapu	17		20	3	10	1	2	53
Vava'u Group	25	9	50	3	9	3	5	104
Total	72	30	171	32	25	10	11	351

Table 6. Samples collected for *Symbiodinium* assessment during Tonga mission in Global Reef Expedition. All samples (approx. 1 cm^3) are preserved in 20% DMSO solution at -20°C.

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)
Ha'apai	*Pocillopora damicornis*	47	100 mg	4,700
Ha'apai	*Pocillopora* sp.	7	100 mg	700
Va'va'u	*Pocillopora damicornis*	60	50 mg	3,000
Va'va'u	*Pocillopora* sp.	1	50 mg	50
Niuatoputapu	Did not collect (no *P. damicornis*)			
		Total sample mass		**8.5 g**

Table 7. Summary of coral samples collected for biomarker assessment. Samples were fixed in RNA later or paraformaldehyde. After fixation, samples were washed, decalcified, washed again, and transported in buffered saline, so as not to have to transport them in a toxic fixative (i.e., formaldehyde).

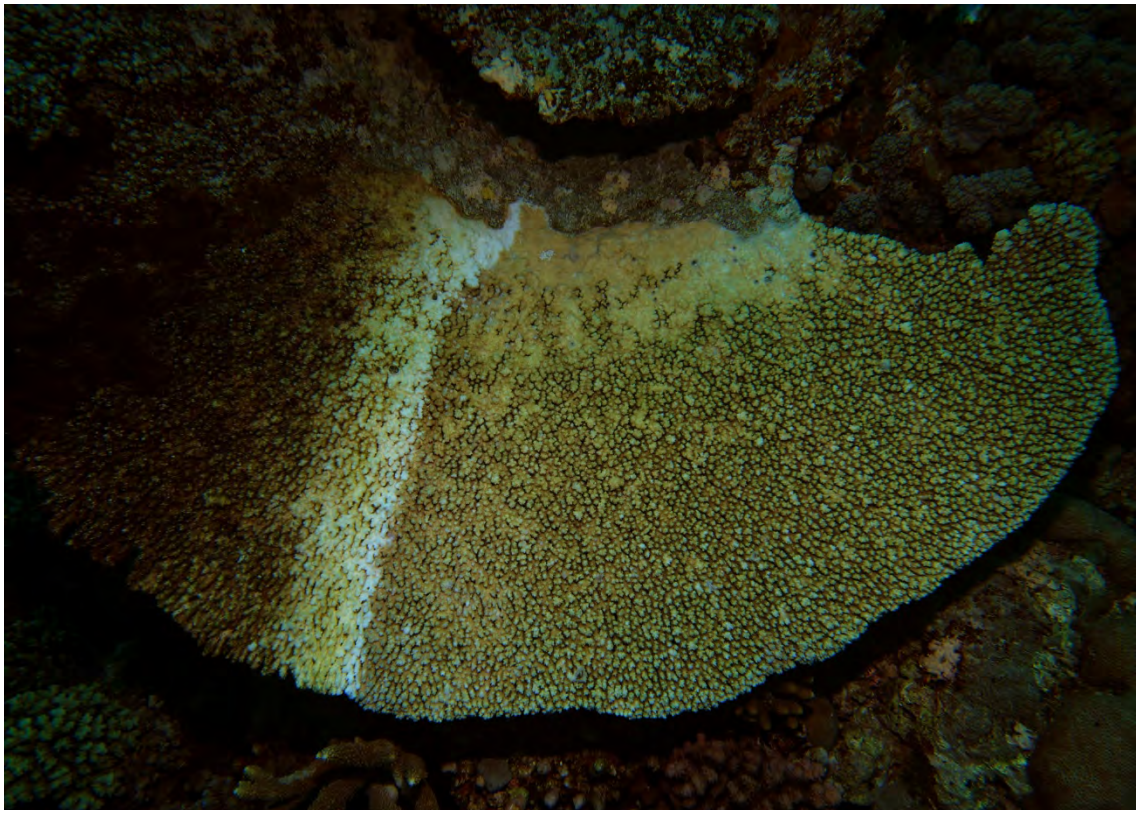


Fig. 19. Although coral diseases occurred at a low prevalence, a number of cases of white syndrome were recorded on acroporids, such as the table acroporids shown above.

Appendix 1. Participants

Name	Institution	Role
Andrew Bruckner	KSLOF Chief Scientist	Lead scientist, coral surveys
Alexandra Dempsey	Nova Southeastern University,	Benthic surveys
Badi Samaniego	KSLOF Research Fellow, University of Philippines,	Fish assessments
Anderson Mayfield	KSLOF research Fellow, Taiwan	Coral health research
Joao Monteiro	KSLOF Fellow, University of Azores, Portugal	Coral symbiont research
Ken Marks	AGRRA	Phototransects
Jeremy Kerr	KSLOF Fellow, Nova Southeastern University	Habitat Mapping
Steve Saul	Nova Southeastern University	Habitat Mapping
Dawn Bailey	Dive-in	Coral Surveys
Kate Fraser	Independent consultant, Australia	Fish Assessments
Robert Gardiner	Nova Southeastern University	Habitat Mapping
Amy Heemsoth	KSLOF Education Coordinator	Education and Outreach
Renee Carlton	U Miami/NOAA	Ocean Acidification
Apai Moala	Ministry of Lands, Environment, Climate Change & Natural Resources	Education and Outreach
Hoifua ‘Aholahi	Ministry of Lands, Environment, Climate Change & Natural Resources	Education and Outreach
Malakai Finau,	Ministry of Lands, Environment, Climate Change & Natural Resources	Education and Outreach
Sione Tui’moala Mailau	Ministry of Agriculture, Forests and Fisheries	Education and Outreach
Karen Stone	Vava'u Environmental Protection Association (VEPA)	Fish surveys, Education, Coordination
Fiona Webster	Australian Volunteer for International Development	Invertebrate Surveys

Appendix II. Tonga Education Report

In September 10-October 3, 2013, the Khaled bin Sultan Living Oceans Foundation conducted research in Tonga as a part of the Global Reef Expedition. During that time, the Education Department provided land-based education seminars throughout Tonga at primary and secondary schools as well as for the general public, tourists, and government representatives. Overall, the Foundation conducted 15 school, 17 community, 1 tourist, 1 government meeting, and 3 ship seminars reaching just over 2,300 people.

These educational efforts were conducted in partnership with local Tongan representatives from the Government of Tonga and a local Non-Governmental Organization (NGO) called Vava'u Environmental Protection Association (VEPA). Representatives include:

Ministry of Lands, Environment, Climate Change & Natural Resources (MLECCNR)

- 'Apai Moala, Senior Geological Assistant
- Hoifua 'Aholahi, Assistant Conservation Officer
- Malakai Finau, Conservation Officer,

Ministry of Agriculture, Forests and Fisheries (MAFF)

- Sione Tui'moala Mailau, Assistant Research Officer

VEPA

- Karen Stone, Coordinator

GENERAL OUTLINE OF THE TOPICS DISCUSSED THROUGHOUT THE KINGDOM OF TONGA:

I. About Living Oceans Foundation
II. Overview of the Global Reef Expedition
    a. Video about the ship
    b. Video showing SCUBA research
III. Benefits of coral reefs
IV. What is a coral?
    a. Relationship between coral, zooxanthallae, and mineral
V. Main threats to coral reefs in Fiji
VI. What can you do to help?

EDUCATION SUMMARY:

15 Schools: (**10 principals; 81 teachers; 1,519 students**)

- 9 primary schools
- 6 secondary schools

17 Communities: (**461 people**)

- 17 seminars

Tourists: (**127 people**)

- 1 seminar

Steering Committee Meeting: (**43 people**)

- 1 seminar

Ship tours (**66 people**)

- 3 ship tours
    - 9/10/13 - 19 people (press and government representatives)
    - 9/23/13 - 11 people (VIP tour Vava'u government representatives)
    - 10/02/13 - 36 people (press and government representatives)

TOTAL NUMBER OF PEOPLE OUTREACHED: 2,307

Table 8. EDUCATION SEMINARS IN TONGA

Date	Island Group	Island/village	Activity Type	# Participants
09/12/2013	Ha'apai	Lifuka	St. Joseph's Secondary School	• 75 students • 10 teachers • 1 Principal
09/12/2013	Ha'apai	Lifuka	Government Primary School (GPS) Koulo	• 45 students • 2 teachers • 1 Principal
09/12/2013	Ha'apai	Lifuka	GPS Hihifo	• 134 students • 3 teachers • 1 Principal
09/12/2013	Ha'apai	Lifuka	Pangai Primary School	• 180 students • 3 teachers • 1 Principal
09/12/2013	Ha'apai	Lifuka	Petani Primary School	• 58 students • 1 teachers • 1 Principal
09/16/2013	Ha'apai	Ha'afeva	Primary School	• 40 students • 2 teachers
09/16/2013	Ha'apai	Ha'afeva	Community talk	• 24 adults
09/17/2013	Ha'apai	'O'ua	Community talk	• 22 people
09/18/2013	Ha'apai	Lofanga	GPS Lofanga	• 18 students • 1 Teacher
09/18/2013	Ha'apai	Lofanga	Community talk	• 16 people
09/19/2013	Ha'apai	Lifuka	Latter Day Saints (LDS) Middle School	• 85 Students • 4 teachers • 1 Principal
09/19/2013	Ha'apai	Lifuka	Tailulu Secondary School	• 17 Students • 2 Teachers
09/19/2013	Ha'apai	Lifuka	Ha'apai Secondary School	• 64 students • 1 Teacher
09/19/2013	Ha'apai	Foa	GPS Fotua	• 35 Students • 4 Teachers
09/19/2013	Ha'apai	Fangale'ounga	Community talk	• 30 people
09/20/2013	Ha'apai	Ha'ano	Community talk	• 42 people
09/20/2013	Ha'apai	Fakakai	Community talk	• 18 people
09/21/2013	Ha'apai	Mo'unga'one	Community talk	• 17 people
09/23/2013	Vava'u	Neiafu	Tailulu Secondary School	• 172 student • 5 Teachers • 1 Principal
09/23/2013	Vava'u	Talihau	Community talk	• 47 people
09/23/2013	Vava'u	Neiafu	Golden Shadow ship tour and seminar	• 11 people
09/23/2013	Vava'u	Neiafu	Aquarium Tourists Talk	• 127 tourists
09/24/2013	Vava'u	Neiafu	Mailefihi/Siu'ilikutapu Secondary School	• 322 students • 26 teachers • 1 principal

Table. 8b. Education seminars continued

Date	Island Group	Island/village	Activity Type	# Participants
09/24/2013	Vava'u	Neiafu	Steering Committee Meeting	• 43 people (8 town officers; 1 chief justice; 11 government officials; Deputy Director of Environment and Secretary of Environment; 13 general public
09/24/2013	Vava'u	Ovaka	Community talk	• 12 men • 5 women
09/25/2013	Vava'u	Matamaka	Community talk	• 9 women • 9 children • 6 men
09/25/2013	Vava'u	Falevai	Community talk	• 24 children • 9 women • 20 men
09/26/2013	Vava'u	Taunga	Community talk	• 7 people
09/27/2013	Vava'u	Noapapu	Community talk	• 17 people
09/27/2013	Vava'u	Lape	Community talk	• 3 people
09/30/2013	Niua	Niuatoputapu	Community talk - Hihifo	• 52 people – mainly women and fishermen
09/30/2013	Niua	Niuatoputapu	Community talk - Vaipoa	• 44 people – 80% female
09/30/2013	Niua	Niuatoputapu	Falehau Community and Primary School	• 31 students • 2 teachers • 1 principal • 28 community
09/30/2013	Niua	Niuatoputapu	Hihifo GPS and Niuatoputapu Secondary schools	• 243 students • 15 teachers • 1 principal

NOTE: The age groups for each grade level:

- Primary schools – Ages 6-11
- Secondary schools – Ages 11-16