Field Report

GLOBAL REEF EXPEDITION:
Tuamotu Archipelago, French Polynesia

14/11/12 - 9/12/12

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Front cover: Aerial photograph of the west coast of Toau. Photo by Andrew Bruckner.

Back Cover: Four different patch reefs in Fakarava lagoon. Images on the left are aerial photographs of patch reefs in various stages of development. The patch reef on the top is partially exposed only at very low tides while the other three have small emergent islands. Images on right show the transition from a system dominated by *Porites lobata* to a mixed community and finally an *Acropora* dominated community in shallow water. All photos by Andrew Bruckner.

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EXECUTIVE SUMMARY

Between November 14, 2012 – December 9, 2012 the Khaled bin Sultan Living Oceans Foundation conducted a research mission to Tuamotu Archipelago, French Polynesia as part of the Global Reef Expedition. The research focused on coral reefs surrounding the islands of Tahiti, Rangiroa, Toau, Aratika, Raraka, and Fakarava. Surveys in Niau were cancelled due to bad weather and Tahiti was substituted for three days originally scheduled for Rangiroa due to mechanical problems. The mission included coral reef assessments, coral reef research, habitat mapping, and educational activities. 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), Le Centre national de la recherche scientifique (CNRS), Nova Southeastern University, University of the Azores, University of the Philippines, NOAA/University of Miami, Florida Aquarium, University of Queensland, Florida Aquarium, 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.

Groundtruthing: A total of 4958 sq km of WorldView 2 satellite imagery was acquired. To characterize shallow marine habitats, 621 videos (drop cameras) and 3,209,721 depth soundings were taken across the six locations, covering a distance of 1477 km.

Coral Reef Assessments: Reefs off six islands were assessed. A total of 502 Fish transects, 612 benthic surveys, 179 coral assessments and phototransects were completed in 68 locations from 5-30 m depth. The surveys included an assessment of 17,062 corals 4 cm or larger in diameter.

Coral Reef Research:

- A total of 200 cores were collected at 10-12 m depth in five locations consisting of 171 *Porites lobata*, 5 *Cyphastrea serailia*, 3 *Favia favites*, and 21 *Pavona clavus*. These will be sectioned and examined using a CT scan to quantify variations in coral growth rates and relationship with ocean chemistry.
- Sediment samples (n=143) were collected from the lagoon and fore reef in five islands/atolls.
- Small (each=1 cm^3) tissue and skeleton samples were collected from five species of *Pocillopora* (n=349) at different depths and habitats to characterize variations in the type of symbionts between environments.
- Surveys of commercially valuable invertebrate resources focused on sea cucumbers, giant clams, Turbo snails and Trochus snails. *Turbo marmoratus* was not found in the Tuamotu Archipelago, despite a history of introduction. *Trochus niloticus* was recorded from Fakarava, Aratika, Rangiroa, and Hao. New records of *Tridacna squamosa* giant clams were obtained. In total 14 specimens were identified in fore reef locations off 3 islands.
- A total of 134 specimens of butterflyfish, consisting of18 species, were collected for parasites. Mean infection rate per fish was 0- 372 monogean parasites, with higher parasite load seen that that observed in the Australs. A new species of trematode parasite, *Transversotrema polynesiae*, was discovered in two species of butterflyfish collected in Tuamotu

Summary of general findings

CORALS

- **General trends:** The reefs in Tuamotu contained a higher diversity of corals species (30-40 corals per location) and many corals that were older and larger than those found in the Society Islands. There was much less mortality from predators and storms, with exception of a few reefs.
- **Coral reef zonation:** At least three distinct zones were identified on the fore reef. Dense assemblages of stout, short branching corals (primarily *Pocillopora*, digitate and tabular *Acropora*) begin near the shore and continue down the slope to 5-10 m. These are mixed with submassive, encrusting and massive corals at 10-15 m depth, with plates and shingles of pore corals (*Porite*s) and other species (*Montipora* and *Astreopora*) extending down the fore reef slope (15-20 m). Below 20 m of elephant skin corals (*Pachyseris*) and other encrusting corals increase in abundance and dominate to 40+ m depth.
- **Benthic cover:** Coral cover can range from very high (80-100%) to low (<5%), often with an inverse relationship with macroalgae. Many deeper sites had carpets of feather-like and grape-like green algae (*Caulerpa)* and mats of lettuce algae (*Microdictyon*), and some wave-exposed sites had large accumulations of rubble.
- **Intrareef differences:** The general zonation varies considerably depending on the location and wave exposure, and the dominant species and growth form of corals changes between windward, swellward, stormward and leeward sides of an atoll. Physical factors affecting coral composition included the inclination of the reef slope, wave exposure, proximity to channels and passes between the lagoon and fore reef, width of the reef flat, and presence or absence of islands. Some areas had very high amounts of fleshy seaweed (macroalgae) and less coral; others were covered in fine sediment. Coral communities on some reefs were dominated by branching species, while others were primarily plating and massive corals. Although there are a few common species found in every location, the abundance and size of these corals varied between reefs. Unique species assemblages were also found in specific locations, such as a species of branching Porites, certain free living corals, and thickets of thick-branched acroporids.
- **Rangiroa lagoonal reefs** in varied considerably in condition. Most were built on a framework of *Porites*, with living *Porites* forming massive boulders that may be over 5 meters across, with a mix of erect, finely branched and bushy acroporids, plates and crusts of rice coral, encrusting and foliose corals in shallow water. Reefs near the channel had the highest abundance and cover of living corals. These were dominated by large massive *Porites* with high numbers of branching corals in shallow water, including cauliflower coral (*Pocillopora*). Other patch reefs had a flourishing coral community in very shallow water (0-3 m depth) dominated by branching acroporid corals, and a rim of massive Porites that extended to 3-4 m depth, with an absence of *Pocillopora*. The sides of these patch reefs was steeply sloping and had little live coral, except under overhangs and in crevices and caves where crustose corals dominated. This may be because of all the debris, rubble and sediment produced on the tops of the patch reef that flows down the sides and accumulates at the base. Unlike fore reef communities that see considerable flushing due to high water movement, this material is unstable and likely to smother corals that settle here. The base of these patch reefs, extending into deeper water, had large boulders separated by sand. These often had small massive and encrusting corals and a single species of *Acropora*, but macroalgal cover (mostly lettuce algae, *Microdictyon*) was very high (50-80%).
- **Fakarava lagoonal habitats** were quite unique. There are thousands of small patch reefs that reach from depths as great as 55 m up to or near sea level (<1 m) and can have pinnacle or mounding morphologies.

These can have an emergent island with vegetation, a small emergent sand patch with some rubble and coral boulders, or be submerged. The submerged patch reefs may come to within 10-20 cm of the surface, may be a few meters under the surface or are 10s of meters below the surface. In cases where the top of the submerged reef is 2-4 m below the surface, there is a community dominated by unusually large Porites with *Acropora* and *Pocillopora* colonies on the tops of these colonies in cases where the top of coral is close to the water's surface. In cases where the structures have grown to sea level, a rind of living coral colonies occurs on the reef top's outer edge, and the center resembles reef flats found on the atoll's outer rim with dense stands of small *Acropora* colonies and fields of large tree-like *Acropora* at 1-4 m depth. The surrounding slope and base of these structures is comprised of old, dead coral colonies covered by *Microdictyon* spp. interspersed with sand. These areas have very little coral growth, presumably because recruitment is inhibited by steep slopes and debris shed down the slope. The water is also much more turbid than outer reefs at the same depth due to the high productivity of the benthic communities and the poor flushing of the atoll.

- **Coral predators:** Crown of thorns starfish were found in low numbers on the lagoonal reefs of Rangiroa, Aritika, Raraka and Fakarava and were absent from fore reef sites. Several lagoonal reefs in Toau had high numbers of COTS and 30-50% of the coral was recently eaten and dead. Isolated lagoonal reefs in Rangiroa, Fakarava and Toau had an unusually high population of coral eating snails (*Drupella*). In some cases, thousands of snails were seen on individual corals and large patches (2-5 m) of coral were dead (white skeletons), and recently eaten by snails. A high number of *Pocillopora* colonies on fore reef locations were also affected by snail predation.
- **Coral diseases:** Many of the same coral diseases are present in both the Society and Tuamotu islands, including an unidentified yellow syndrome, pink lesions, and tumors, but in general coral disease was relatively uncommon. The only exception was white syndrome, which affected a large proportion of the cauliflower corals throughout Tuamotu; this was rare in Society Islands and Gambier. Between 3-15% of the *Pocillopora* colonies were affected on most fore reef locations; colonies typically exhibited partial recent mortality and patches of exposed skeleton that had been denuded several weeks to months earlier. Also, 5-50% of the *Pocillopora* colonies were completely dead. One species of *Acropora* was most commonly affected by this condition in the lagoon.

FISHES

- Fish assemblages on the fore reef were much more diverse than in Society Islands and Gambier Archipelago. The overall fish biomass is greater – more total individuals and more large individuals. Typically each dive site hosts a greater diversity of fish. There are more apex predators (sharks, groupers, snappers, etc.), the individuals are generally larger and there is a greater diversity of species. Schools of snappers are more common for instance. Parrotfish are also more diverse and larger.
- There were many more fish near channels and on reefs with very high relief and high coral cover. Reefs dominated by fleshy algae, especially the lagoonal reefs, and areas damaged by storms had many fewer fish, but in general still more than in Society.
- Tuamotu reefs had a more diverse assemblage of parrotfish, and fish were seen in higher numbers and larger sizes than in Society Islands. Bullethead parrotfish (*Chlorurus sordidus*) make up a smaller percentage of the parrotfish population than that seen on other archipelagos.
- Tuamotu had the largest number of large piscivorous fish species, followed by the Gambier and Society Islands.

- Shallow reef communities of Tuamotu islands contained much larger fish populations, especially schooling herbivores and more predators like sharks, groupers and snappers, and larger individual fish of all types than that seen in Society Islands.
- There were many more fish near channels and on reefs with very high relief and high coral cover. Reefs dominated by fleshy algae, especially the lagoonal reefs, and areas damaged by storms had many fewer fish, but in general still more than in Society.
- Schools of jacks, snappers and parrotfishes, as well as sizable aggregations of groupers and sharks were often encountered. These were also found in some sites at the Society Islands, but were conspicuously absent at the Acteon Group of islands of the Gambier.
- At Tuamotu dense schools of large-bodied fish species were often encountered: glasseyes, breams, parrotfish, surgeonfish at Raiatea-Tahaa, and snappers, breams, jacks and Napoleon wrasse at several sites in Fakarava.
- Lagoonal sites in Fakarava had relatively depauperate fish populations as compared to outer reefs. In contrast, high diversity and biomass of fishes, including schooling snappers, groupers, and pelagics were very abundant adjacent to the channel.

Fig. 1. Large populations of apex predators and other species such as the endangered humphead (Napoleon) wrasse *Chelinus undulatus* were observed in the channels at Fakarava and Rangiroa.

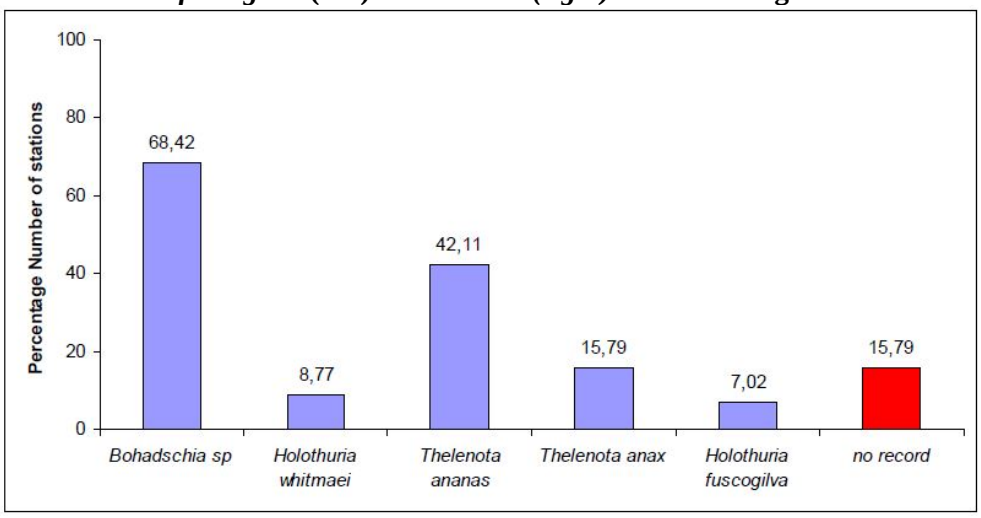
Observations on commercial sea cucumber in Tuamotu atolls

- 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 Tuamotu survey occurred shortly after the closure of the fisheries in the entire French Polynesia in November 2012.

- Two divers conducted timed belt-transects surveys using SCUBA, from 30 meter deep (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 selected reef flats and shallow back reefs, and on many lagoon and pinnacles sites. A total of 57 sites were surveyed in Rangiroa, Aratika,Raraka, Fakarava and Toau. The four later atolls belong to the UNESCO Fakarava Biosphere Reserve.
- Nine stations, of which eight were fore reefs, had no records of commercial species. The dominant taxon overall was the genus *Bohadschia.* It was the dominant sea cucumber in most lagoons, and generally -but not always - found in high density around the pinnacles. This genus was seen in 39 stations. The most valuable species (*Holothuria fuscogilva, H. whitmaei* and *Thelenota anax*) were found mostly in lagoons, but never in high densities. The only exception were high numbers of *T. anax* in some locations, in particular in the central part of Raraka lagoon which was never fished. *Thelenota ananas* was well present on the fore reefs and passes, at all depth range and in all atolls, but in variable densities. Aratika, which was never fished, had the highest densities even in sites close to the pass and village, and in shallow water (5 meter). Remote locations away from the villages in Rangiroa and Fakarava also had the highest densities of valuable species.
- The results suggest that populations of valuable species are still present in the surveyed Tuamotu lagoons on suitable habitats, but that fishing pressure has started to impact the populations in fished atolls. French Polynesia reopened the fishery in five lagoons in March 2014, thus it is expected that the situation will quickly deteriorate except, theoretically, in the protected no-take-areas of the Biosphere Reserve.

***H. fuscogilva* (left) and *T. anax (right)* in Raraka lagoon**



The percentage of stations where commercial species were recorded, e.g. *H. fuscogilva* was seen on7% of the stations, out of 57 stations.

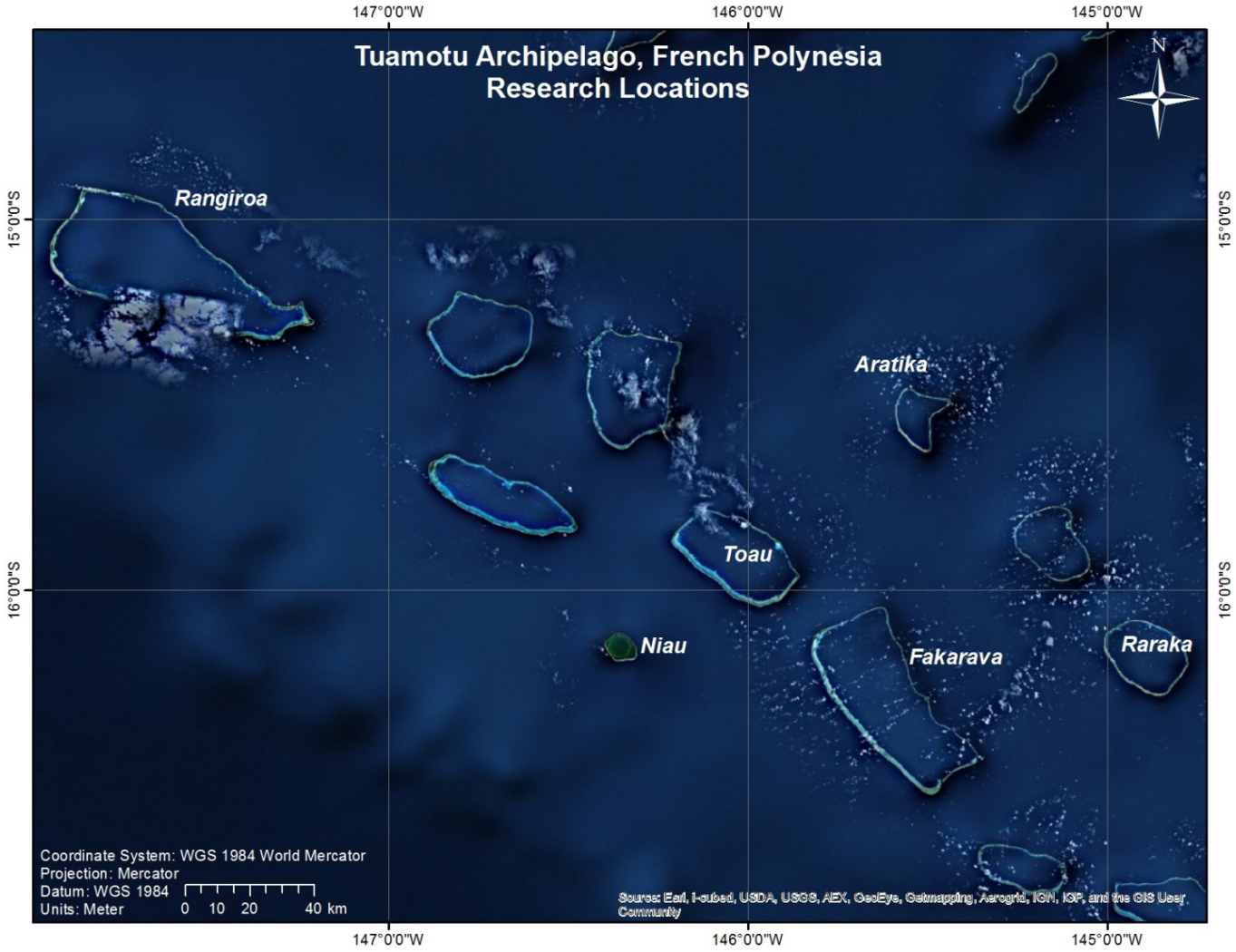


Fig. 2. Location of study sites examined during the mission. Niau was not examined due to bad weather.

Table 1. Research Schedule

Date	**Location**
14 November, 2012	Aerial Reconnaissance
14 November	Scientist arrival
15-16 November	Tahiti
16 November	**Transit to Rangiroa**
17-20 November	Rangiroa
21-22 November	Aratika
23-26 November	Raraka
27 November-5 December	Fakarava
6-10 December	Toau
10 December	**Overnight transit to Papeete**
11 December	Scientists depart

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 4958 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 in conjunction 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). A minimum of 30 drop-cam videos were gathered per day. The 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.

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.

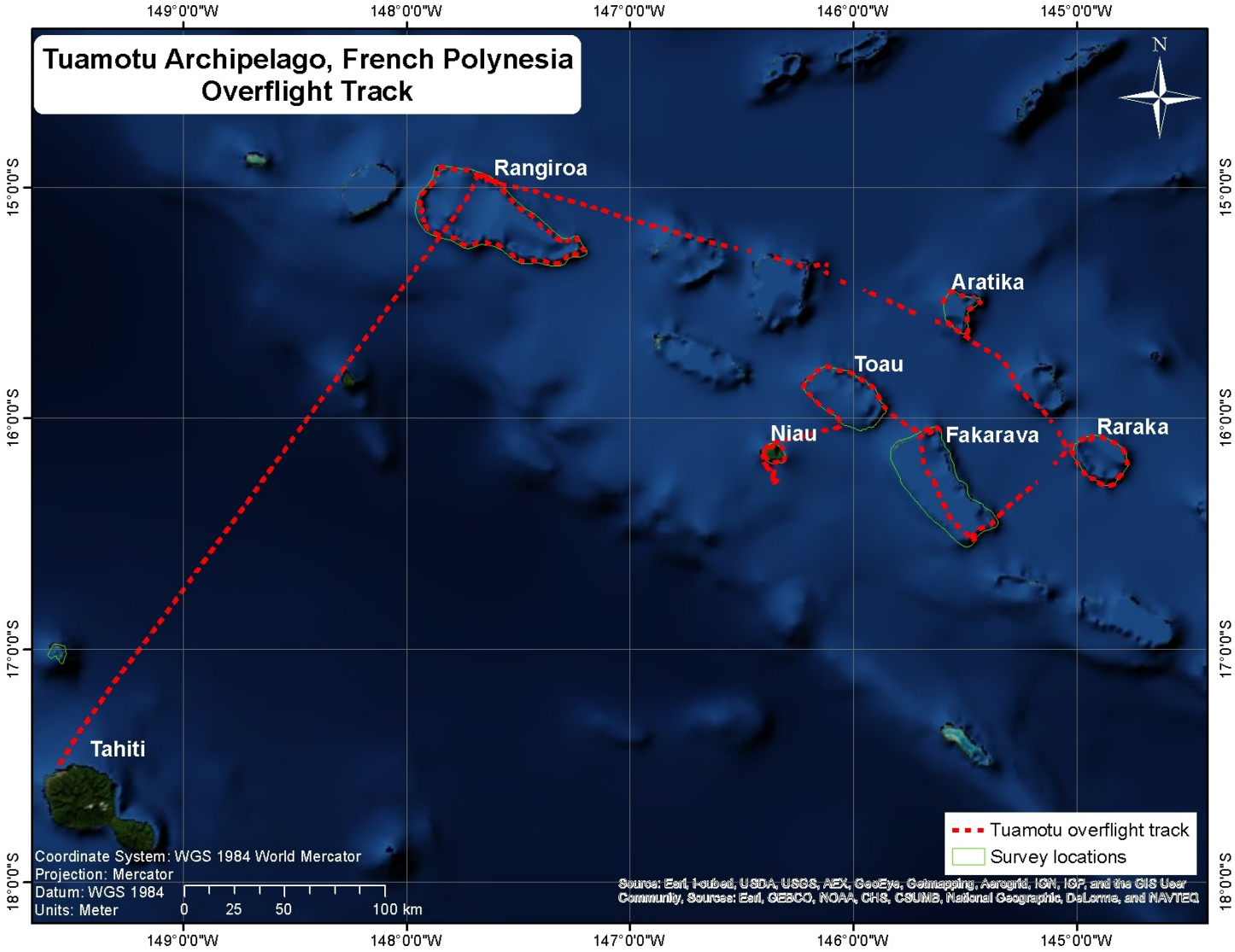


Fig. 3. Track of the Tuamotu overflight undertaken using the GoldenEye sea plane.

Archipelago	Location	Area (sq km)	No. dropcams	No. depth soundings	Distance covered
Tuamoto	Raraka	440	89	421553	224.490
	Rangiroa	2113	189	1118612	573.600
	Aratika	211	59	286722	90.693
	Niau	77	-	-	-
	Toau	740	79	410743	133.660
	Fakarava	1377	205	972091	454.120
	Total	4958	621	3209721	1476.563

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.

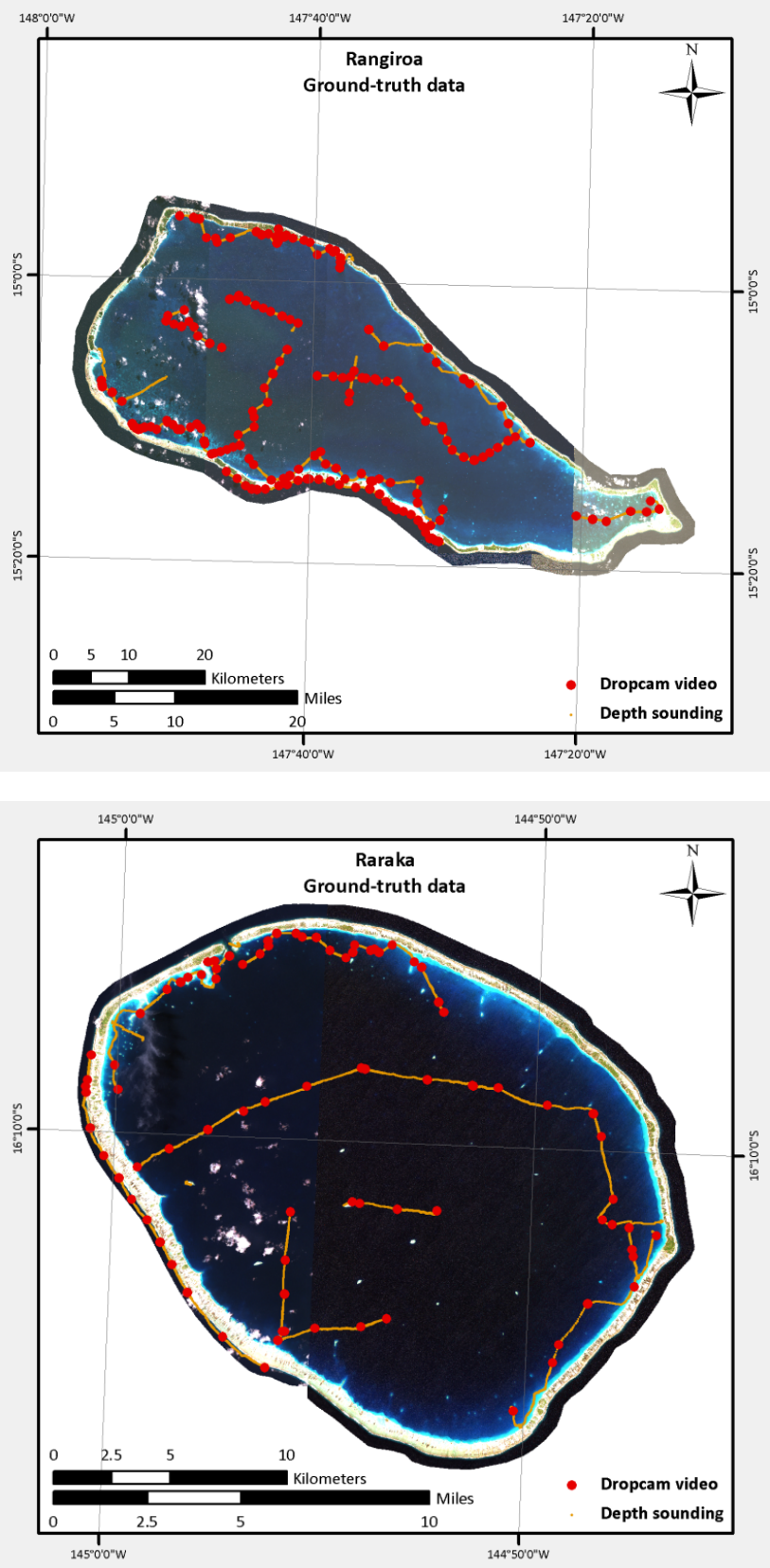


Fig. 4. Track of the groundtruthing team and locations of drop camera deployments. Rangiroa (top image) and Raraka (bottom image).

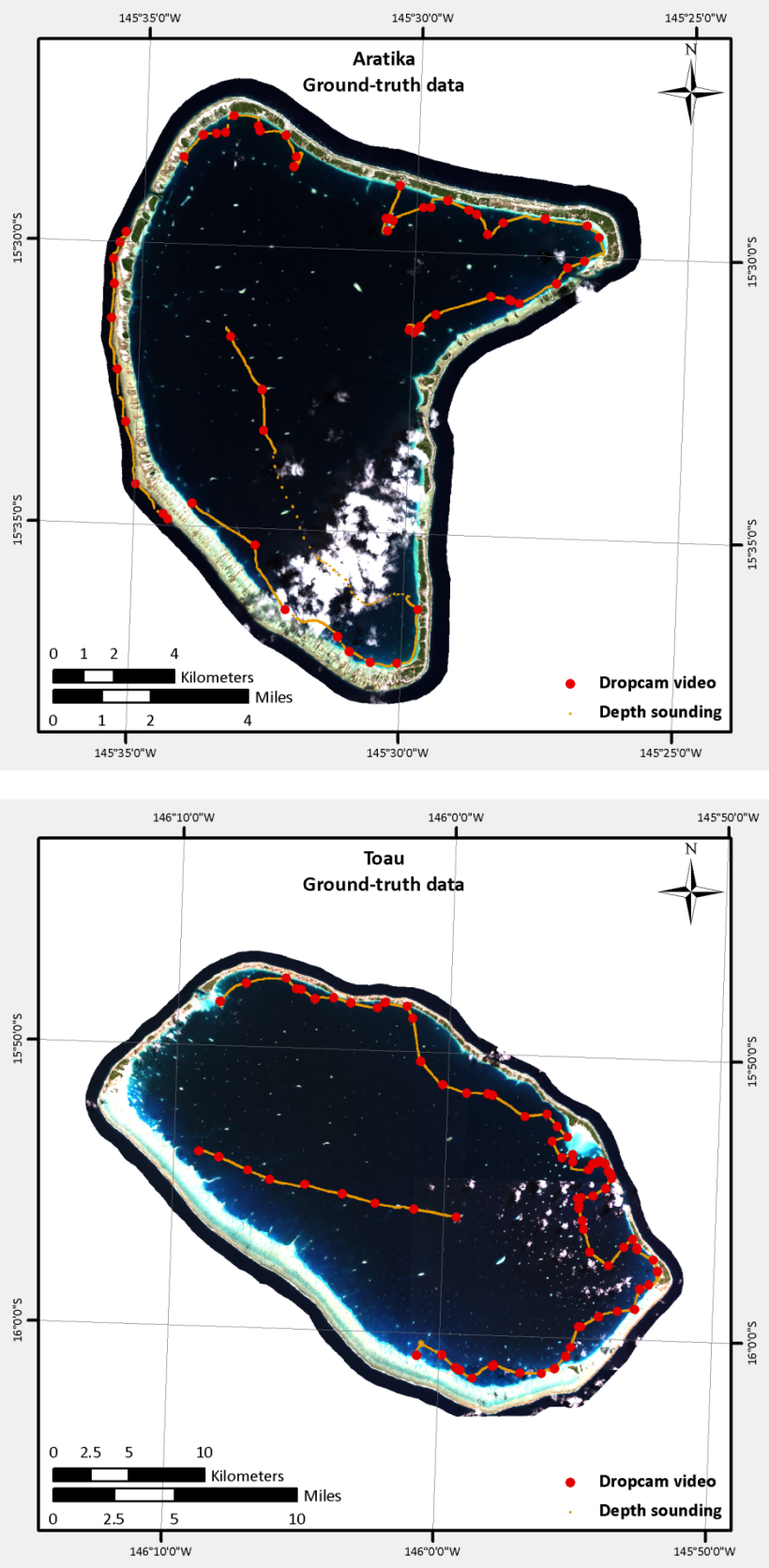


Fig. 5. Track of the groundtruthing team and locations of drop camera deployments. Aratika (top image) and Toau (bottom image).

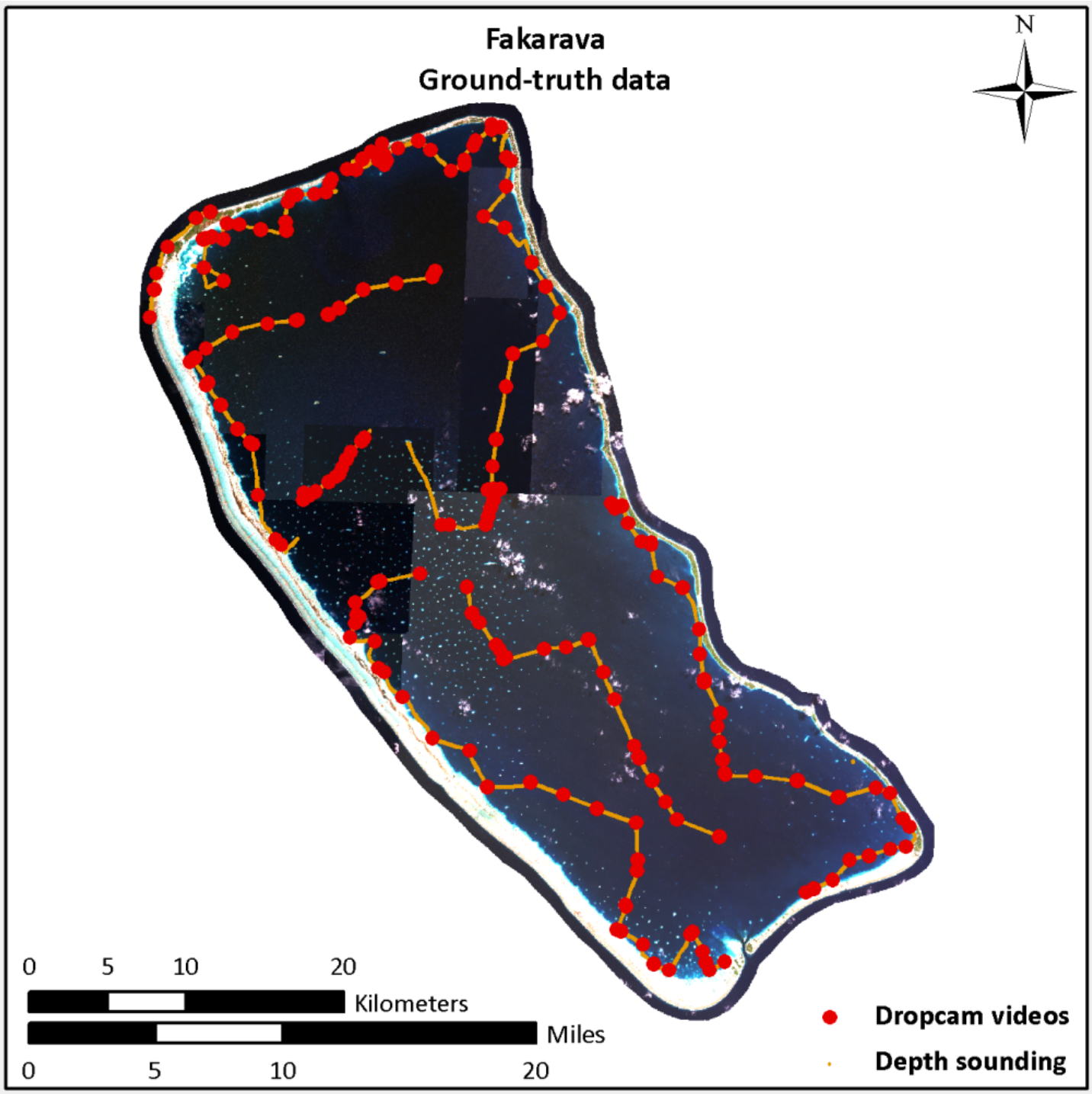


Fig. 6. Track of the groundtruthing team and locations of drop camera deployments in Fakarava.

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.

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.

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.

Region	Number of Islands	Number of dives	Benthic transects	Fish transects	Coral transects	Corals
Tuamotu	5	63	612	484	164	15,854
Tahiti	1	5	12	18	15	1,208

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 of Tuamotu and Tahiti are shown.

Fig. 7. Many of the shallow fore reef communities, especially those located distant from human settlements exhibited high cover of stony corals.

Table 4. Coordinates of coral reefs examined using SCUBA.

Date	Lat	Long	site name	Island	Reef type
15-Nov-12	-17.4988	-149.5041	SOTH-01	Tahiti	leeward bank reef
16-Nov-12	-17.7887	-149.4195	SOTH-02	Tahiti	windward fore reef
16-Nov-12	-17.7786	-149.4332	SOTH-03	Tahiti	fore reef
16-Nov-12	-17.7808	-149.4228	SOTH-04	Tahiti	lagoonal patch reef
17-Nov-12	-17.6924	-149.5912	SOTH-05	Tahiti	Leeward fore reef
18-Nov-12	-14.9723	-147.6221	TURA-06	Rangiroa	windward fore reef
18-Nov-12	-14.9554	-147.7099	TURA-07	Rangiroa	lagoonal patch reef
18-Nov-12	-15.0192	-147.7572	TURA-08	Rangiroa	lagoonal patch reef
18-Nov-12	-14.9339	-147.714	current meter	Rangiroa	current meter
19-Nov-12	-14.9321	-147.8594	TURA-09	Rangiroa	Leeward fore reef
19-Nov-12	-14.9567	-147.867	TURA-10	Rangiroa	Leeward fore reef
19-Nov-12	-14.9562	-147.788	TURA-11	Rangiroa	Leeward fore reef
20-Nov-12	-15.1409	-147.8095	TURA-12	Rangiroa	lagoonal patch reef
20-Nov-12	-15.1987	-147.7607	TURA-13	Rangiroa	lagoonal patch reef
20-Nov-12	-14.9351	-147.706	TURA-14	Rangiroa	Windward fore reef
21-Nov-12	-15.4902	-145.5865	TUAR-15	Aratika	Leeward fore reef
21-Nov-12	-15.4633	-145.5712	TUAR-16	Aratika	Leeward fore reef
21-Nov-12	-15.5934	-145.561	TUAR-17	Aratika	Leeward fore reef
21-Nov-12	-15.4895	-145.5864	current meter	Aratika	current meter
22-Nov-12	-15.6273	-145.5187	TUAR-18	Aratika	windward fore reef
22-Nov-12	-15.623	-145.4911	TUAR-19	Aratika	Windward fore reef
22-Nov-12	-15.5096	-145.5186	TUAR-20	Aratika	Lagoonal patch reef
23-Nov-12	-16.2701	-144.9073	TURK-21	Raraka	windward fore reef
23-Nov-12	-16.2871	-144.8584	TURK-22	Raraka	windward fore reef
23-Nov-12	-16.0889	-144.9563	TURK-23	Raraka	Leeward fore reef
23-Nov-12	-16.0894	-144.9581	current meter	Raraka	current meter
24-Nov-12	-16.0956	-144.9539	TURK-24	Raraka	lagoonal patch reef
24-Nov-12	-16.1171	-145.0056	TURK-25	Raraka	Leeward fore reef
24-Nov-12	-16.0944	-144.9525	TURK-26	Raraka	lagoonal patch reef
25-Nov-12	-16.1117	-144.8296	TURK-27	Raraka	windward fore reef
25-Nov-12	-16.097	-144.864	TURK-28	Raraka	windward fore reef
25-Nov-12	-16.0884	-144.9393	TURK-29	Raraka	lagoonal fringing reef
26-Nov-12	-16.2518	-144.8106	TURK-30	Raraka	windward fore reef
26-Nov-12	-16.202	-144.7741	TURK-31	Raraka	windward fore reef
26-Nov-12	-16.0963	-144.9452	TURK-PI	Raraka	lagoonal pinnacle
27-Nov-12	-16.0741	-145.7056	TUFK-32	Fakarava	leeward fore reef
27-Nov-12	-16.0514	-145.6568	TUFK-33	Fakarava	leeward fore reef
27-Nov-12	-16.1877	-145.8216	TUFK-34	Fakarava	leeward fore reef
29-Nov-12	-16.1523	-145.8247	TUFK-35	Fakarava	leeward fore reef
29-Nov-12	-16.124	-145.815	TUFK-36	Fakarava	leeward fore reef
29-Nov-12	-16.1484	-145.703	TUFK-37	Fakarava	lagoonal patch reef
29-Nov-12	-16.0766	-145.7099	current meter	Fakarava	current meter
30-Nov-12	-16.0469	-145.6355	TUFK-38	Fakarava	Leeward fore reef
30-Nov-12	-16.1037	-145.7856	TUFK-39	Fakarava	Leeward fore reef
30-Nov-12	-16.0834	-145.6942	TUFK-40	Fakarava	lagoonal patch reef
1-Dec-12	-16.2338	-145.6738	TUFK-41	Fakarava	lagoonal patch reef
1-Dec-12	-16.2438	-145.6423	TUFK-42	Fakarava	lagoonal patch reef
1-Dec-12	-16.2415	-145.6284	TUFK-43	Fakarava	lagoonal patch reef
1-Dec-12	-16.2584	-145.6185	TUFK-snorkel 1	Fakarava	lagoonal patch reef
2-Dec-12	-16.2895	-145.7363	TUFK-44	Fakarava	lagoonal patch reef
2-Dec-12	-16.2845	-145.7037	TUFK-45	Fakarava	lagoonal patch reef
2-Dec-12	-16.3018	-145.62	TUFK-46	Fakarava	lagoonal patch reef
3-Dec-12	-16.3557	-145.6087	TUFK-snorkel 2	Fakarava	lagoonal patch reef
3-Dec-12	-16.4456	-145.5296	TUFK-47	Fakarava	lagoonal patch reef
3-Dec-12	-16.5035	-145.4627	TUFK-48	Fakarava	lagoonal patch reef
3-Dec-12	-16.532	-145.465	TUFK-49	Fakarava	windward fore reef
4-Dec-12	-16.441	-145.3622	TUFK-50	Fakarava	windward fore reef
4-Dec-12	-16.5167	-145.4553	TUFK-51	Fakarava	windward fore reef
4-Dec-12	-16.5162	-145.4629	TUFK-52	Fakarava	channel
5-Dec-12	-16.367	-145.6734	TUFK-53	Fakarava	lagoonal patch reef
5-Dec-12	-16.2817	-145.5584	TUFK-54	Fakarava	lagoonal patch reef
5-Dec-12	-16.0785	-145.7152	TUFK-55	Fakarava	channel
6-Dec-12	-15.9293	-145.9535	TUTO-56	Toau	lagoonal patch reef
6-Dec-12	-15.9289	-145.9903	TUTO-57	Toau	lagoonal patch reef
6-Dec-12	-15.9065	-145.8987	TUTO-58	Toau	lagoonal patch reef
7-Dec-12	-15.9135	-145.8888	TUTO-59	Toau	channel
7-Dec-12	-15.9129	-145.8892	TUTO-current meter	Toau	
7-Dec-12	-15.912	-145.8955	TUTO-60	Toau	lagoonal patch reef
8-Dec-12	-15.8982	-145.9108	TUTO-61	Toau	lagoonal patch reef
9-Dec-12	-15.8907	-146.0718	TUTO-62	Toau	lagoonal patch reef
9-Dec-12	-15.8859	-146.0357	TUTO-63	Toau	lagoonal patch reef

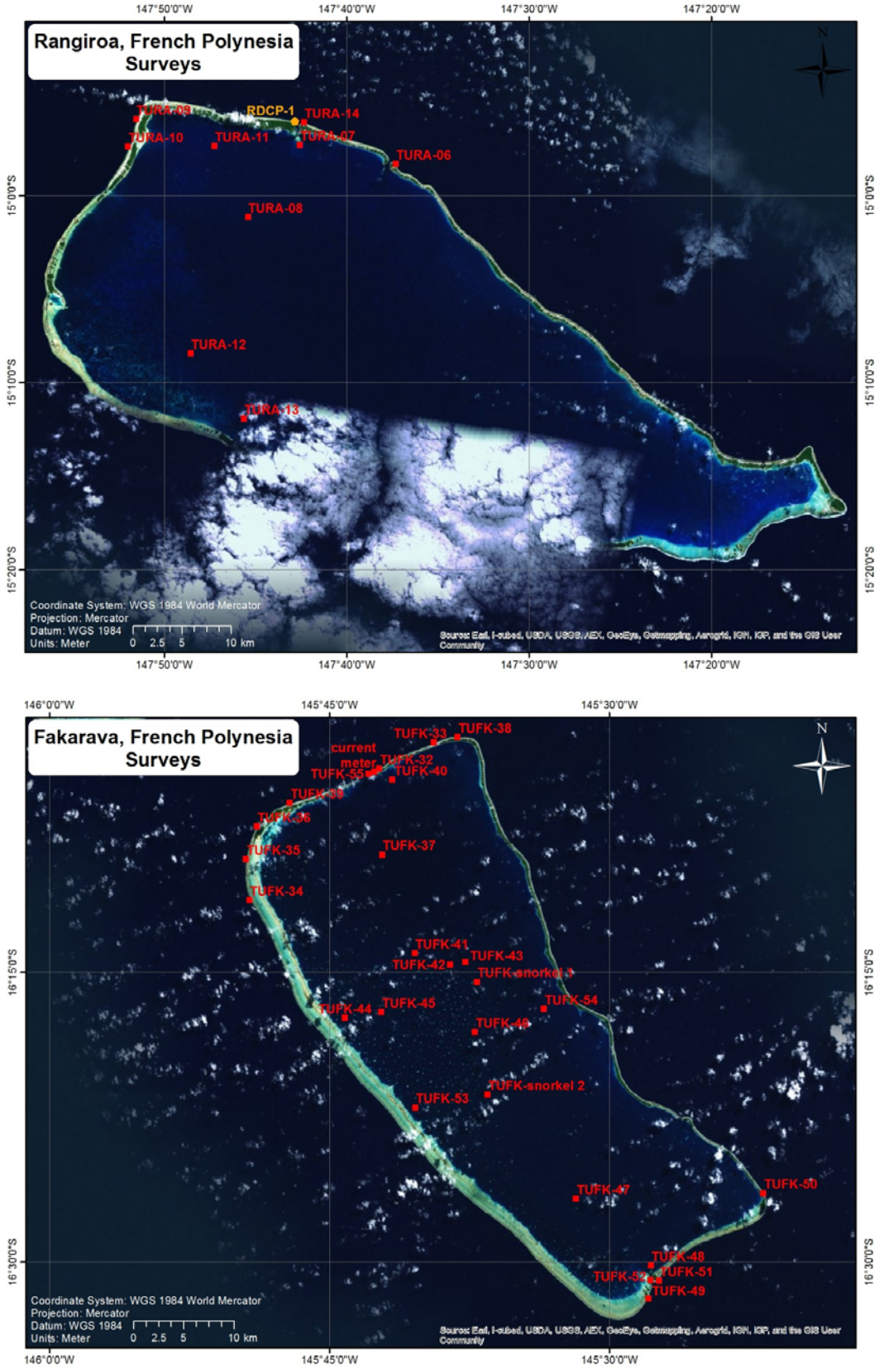


Fig. 8. Location of SCUBA assessments in Rangiroa (top) and Fakarava (bottom).

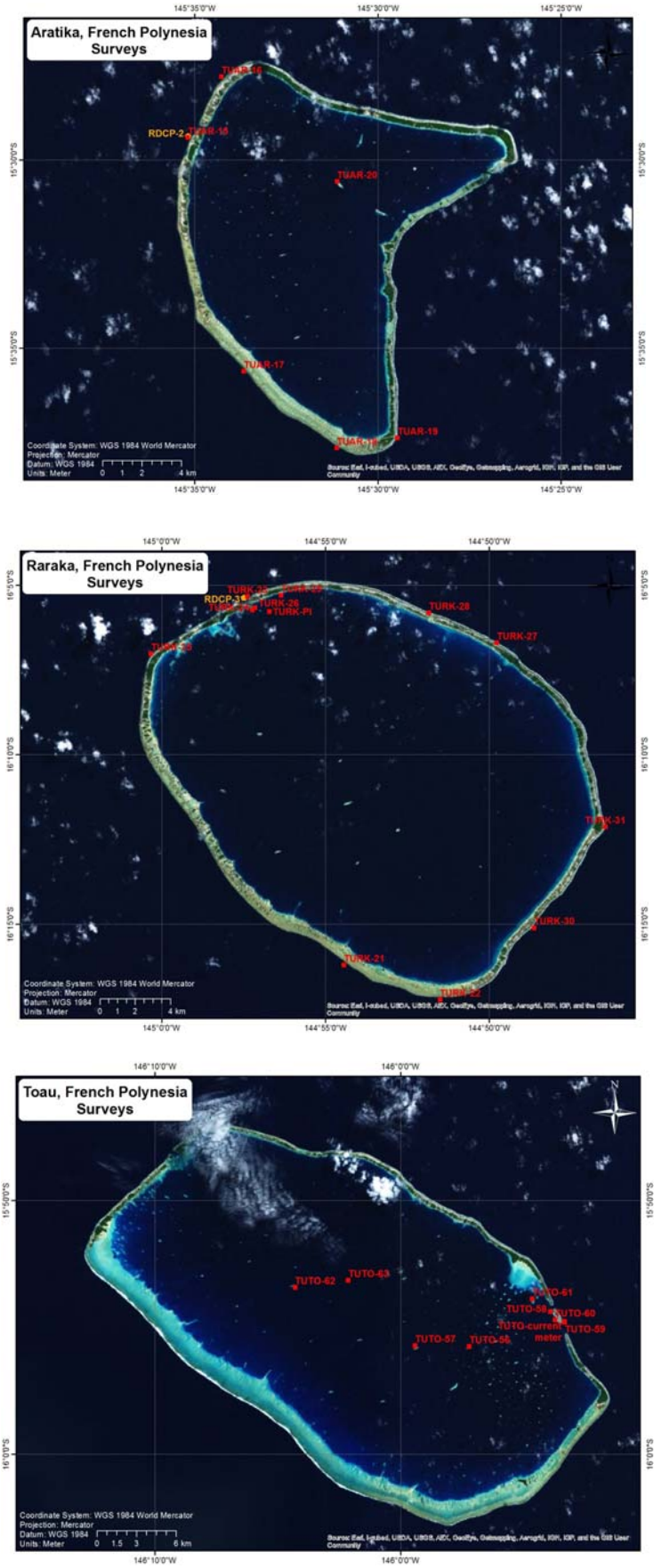


Fig. 9. Location of SCUBA assessments in Aratika (top), Raraka (middle) and Toau (bottom).

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	Number of samples
Raraka	14
Rangiroa	71
Aratika	14
Niau	-
Toau	8
Fakarava	36
Total	143

Table 5. Total number of sediment samples.

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 be 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.

	Acropora	*Pocillopora*						
Islands	**sp.**	***eydouxi***	***damicornis***	***danae***	***verrucosa***	***meandrina***	**sp.**	**Total**
Aratika		14		15		13	2	44
Fakarava		25	5	27	17	23	10	107
Rangiroa	1	24		14	1	20	3	63
Raraka		24		29	3	21	9	86
Tahiti		9	1	6	1	6		23
Toau		10			13		3	26
Total	1	106	6	91	35	83	27	349

Table 6. Samples of *Pocillopora* and *Acropora* collected for *Symbiodinium* assessment. All samples (approx. 1 cm^3) were preserved in 20% DMSO solution at -20ºC.

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. 3. At each dive location, water was sampled 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
Tahiti	*Porites lobata*	13	~3cm diam. X 9 cm length	Dry
Rangiroa	*Porites lobata*	25	~3cm diam. X 9 cm length	Dry
Rangiroa	*Pavona clavus*	7	~3cm diam. X 9 cm length	Dry
Aratika	*Porites lobata*	22	~3cm diam. X 9 cm length	Dry
Aratika	*Pavona clavus*	2	~3cm diam. X 9 cm length	Dry
Fakarava	*Porites lobata*	70	~3cm diam. X 9 cm length	Dry
Fakarava	*Pavona clavus*	6	~3cm diam. X 9 cm length	Dry
Fakarava	*Cyphastrea serailia*	2	~3cm diam. X 9 cm length	Dry
Fakarava	*Favia favites*	1	~3cm diam. X 9 cm length	Dry
Raraka	*Porites lobata*	41	~3cm diam. X 9 cm length	Dry
Raraka	*Pavona clavus*	6	~3cm diam. X 9 cm length	Dry
Raraka	*Cyphastrea serailia*	3	~3cm diam. X 9 cm length	Dry
Raraka	*Favia favites*	2	~3cm diam. X 9 cm length	Dry
Total		200		

Table 7. Total number of cores collected off 5 islands.

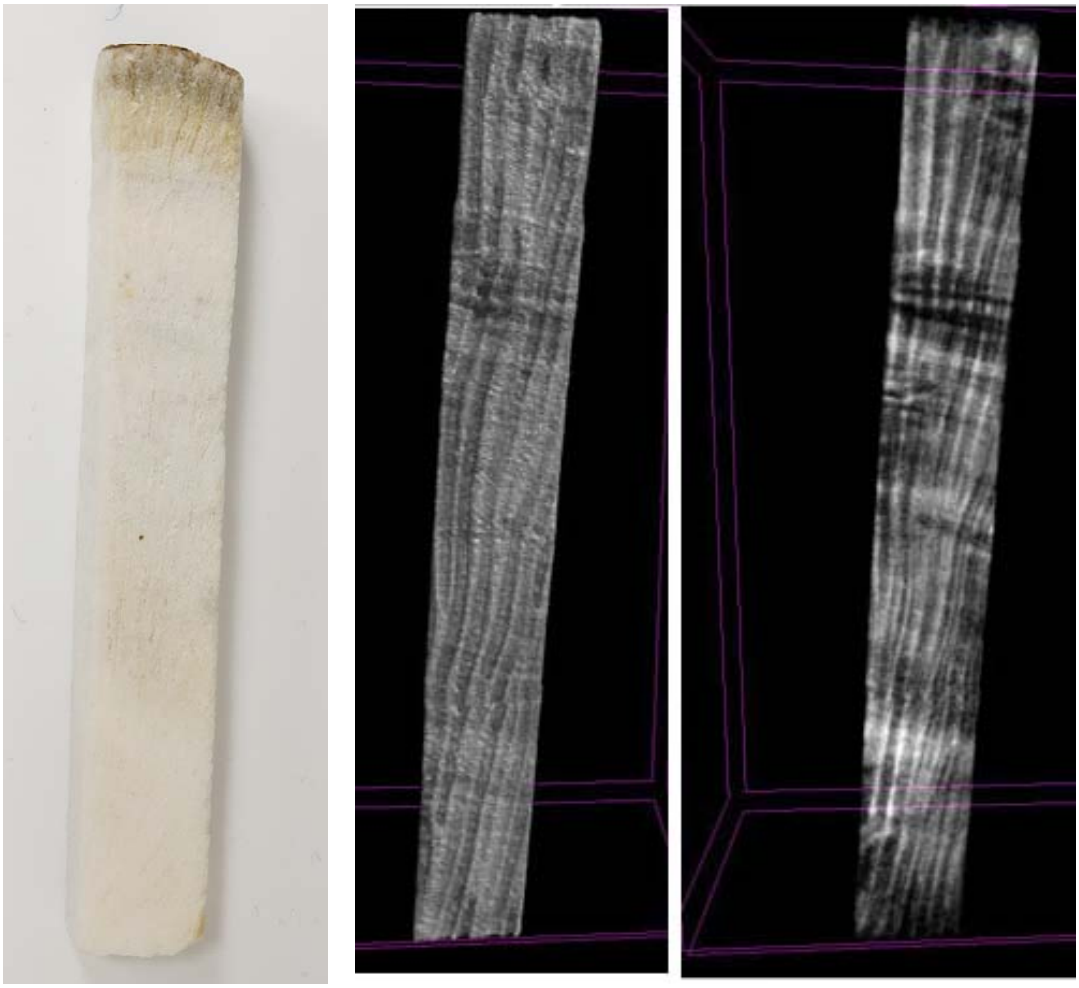


Fig. 10. Cores taken from *Porites lobata*. Unprocessed core (left), CT scan of the core (center), and CT of a section of the core (right).

Invertebrate surveys: Targeted timed plotless 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 (giant clams) and echinoderms (sea cucumbers). Surveys were done across different habitats and depth zones including deep oceanic sand plain, forereef slopes, spur and grooves, crests, passes, lagoon floors and slopes, patch reefs, sheltered and exposed fringing reefs.

One focus was to characterize the distribution of *Tridacna squamosa*, a giant clam species previously reported to be absent from French Polynesia. In total, 13 individuals of this species were identified and photographed in fore reef locations off 3 islands.

Location	Number of samples
Rangiroa	1
Raraka	1
Fakarava	11
Total	13

Table 8. Total number of new records of *Tridacna squamosa* in fore reef locations of Tuamotu Archipelago.

A second component involved a survey for introduced species of gastropods, *Turbo marmoratus* and *Trochus niloticus.* Although several introduction have occurred over the last 40 years, Turbo snails were not observed, suggesting they have been unable to colonize these environments.

Fish parasites:

Butterflyfish were collected using microbarb spears from shallow reef crest and back reef habitats of Fakarava to characterize parasite diversity and abundance. These surveys represent one component of a larger project to evaluate parasite distribution throughout French Polynesia. Two main parasites examined were trematodes contained within the gut and monogeans found attached to the gills.

Chaetodon spp.	Collected Tuamotu	Dissected Tuamotu	Mean infection (min-max)
auriga	12	8	44 (0-130)
bennetti	2	1	0
citrinellus	15	8	140 (94-236)
ephippium	10	10	1 (0-2)
lineolatus	1	0	
lunula	10	8	36 (0-98)
lunulatus	10	7	0
ornatissimus	5	3	181 (12-372)
pelewensis	9	7	5 (1-13)
quadrimaculatus	6	4	155 (33-278)
reticulatus	11	6	133 (16-226)
trifascialis	6	3	57 (9-138)
ulietensis	9	9	8 (0-24)
unimaculatus	1	1	4
flavissimus	8	6	9 (0-26)
polylepis	3	3	0
chrysostomus	10	7	10 (4-15)
monoceros	6	3	15 (8-25)
Grand Total	**134**	**94**	

Table 9. Numbers of each species of Chaetodon butterflyfish collected in Fakarava and the number of monogean parasites found on the gills.

Oceanographic data:

At each dive location, a temperature and salinity profile was taken prior to the dive. Light meters were deployed at least one time for 24-96 hours on each island, and this was paired with the deployment of a Seafet pH sensor. Current data was also collected in the channel on the north coast of Rangiroa and Fakarava. The current meter was deployed at 25 m depth and a profile was taken over multiple tidal cuycles from the surface of the water to 1 m off the bottom.

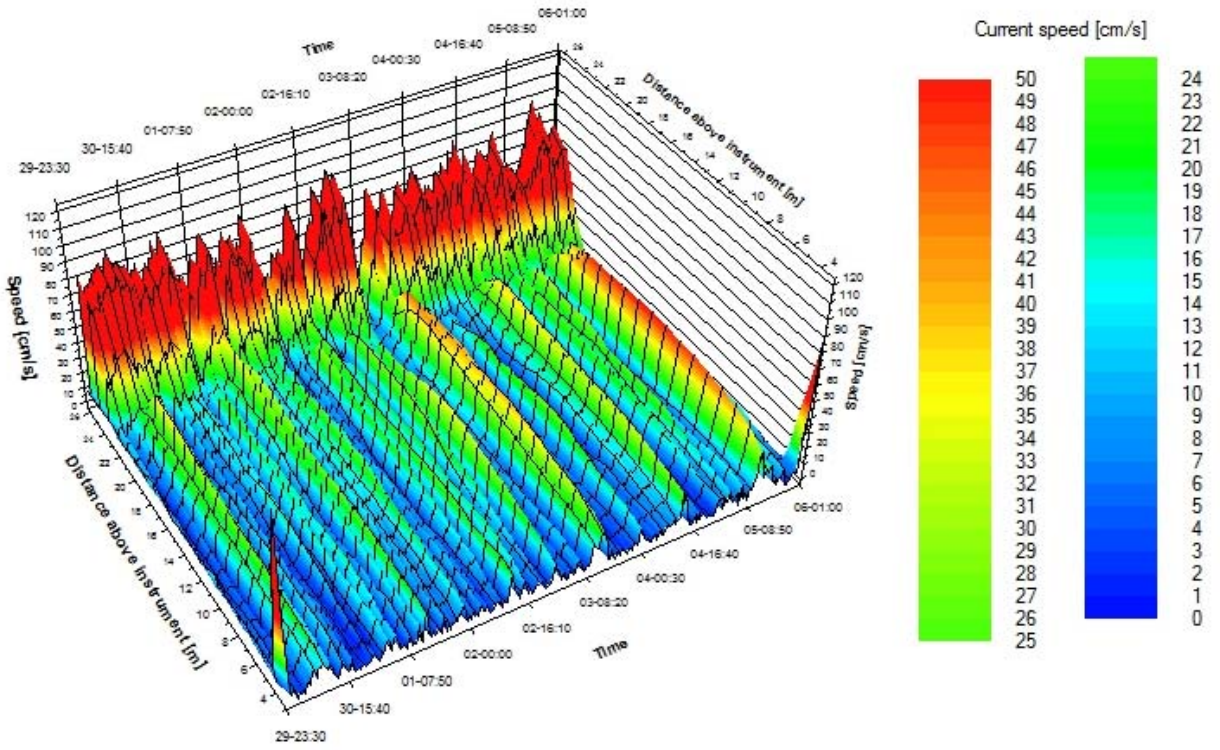


Fig. 11. Horizontal current profile between 29 Nov 2012-06 Dec 2012 for Garuae Pass at Fakarava.

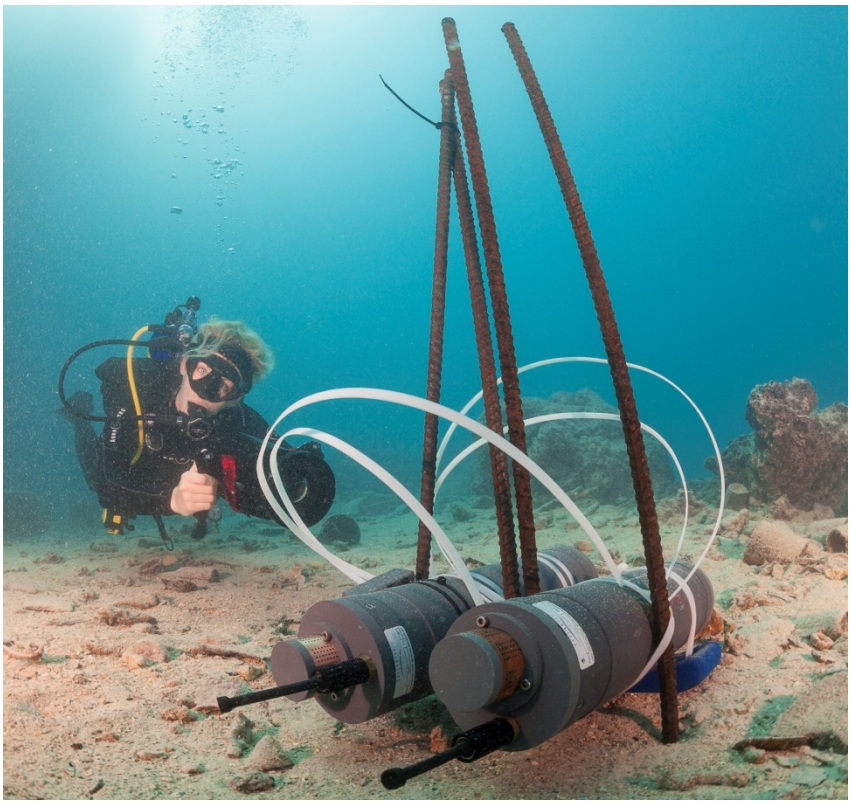


Fig. 12. Deployment of two SeaFET™ Ocean pH Sensors. These instruments determine potentiometrically using an ion sensitive field effect transistor (ISFET).

Appendix I. Participants

Name	Institution	Function
Andy Bruckner	Khaled bin Sultan Living Oceans Foundation	Chief Scientist
Brian Beck	Khaled bin Sultan Living Oceans Foundation	Coral Reef Ecologist
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 (NCRI) Living Oceans Foundation Fellow	Groundtruthing / habitat mapping
Sam Purkis	Nova Southeastern University (NCRI)	NCRI Lead Scientist
Alex Dempsey	Nova Southeastern University (NCRI)	Benthic surveyor
Anesti Stathakopoulos	Nova Southeastern University (NCRI)	Groundtruthing
Derek Manzello	NOAA	Ocean acidification
Serge Andrefouet	Institut de Recherche pour le Développement, New Caledonia	IRD Lead Scientist
Marine Couraudon-Reale	Independent contractor	Photo transects
Gabriel Haumani	Direction des Ressources Marines	Invertebrate surveyor
Bertrand Make	Direction des Ressources Naturelles (DIREN)	Turtle observer
Valetina Piveteau	Direction des Ressources Naturelles (DIREN)	Turtle observer
Laureline Chabran	Institut de Recherche pour le Développement,	Benthic assessments
Dave Grenda	Florida Aquarium, REEF	Fish surveyor
Katie Hillyer	Victoria University , Wellington	Benthic surveyor
John Ruthven	Independent contractor	Film producer
Ernie Kovacs	Independent contractor	Cameraman
Nick Cautin	Dive Safety Officer	Diving operations
Scott Cutmore	University of Queensland	Fish sampling
Pierre Sasal	French National Centre for Scientific Research	Fish sampling
Fabian Tertre	Direction des Ressources Marines	Invertebrate surveyor