Field Report

GLOBAL REEF EXPEDITION: Gambier Archipelago, French Polynesia

14/01/13 - 12/02/13

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

Back Cover: Shallow reef scene at Marie Est, Gambier Archipelago. Photo by Joao Monteiro.

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EXECUTIVE SUMMARY

Between January 14, 2013 – February 12, 2013, the Khaled bin Sultan Living Oceans Foundation conducted a research mission to the Gambier Archipelago, French Polynesia as part of the Global Reef Expedition. The research focused on coral reefs surrounding the islands of Hao, Mangareva, Temoe, Maria Est, Vahanga, Tenarunga, Tenararo, and Matureivavao. 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), Louis Malardé Institute (ILM), Université de la Polynésie française, SCRIPPS/Florida Museum of Natural History, Nova Southeastern University, University of the Azores, University of the Philippines, NOAA/University of Miami, and University of Tasmania. 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 1703 sq. km of WorldView 2 satellite imagery was acquired. To characterize shallow marine habitats, 434 videos (drop cameras) and 1,496,437 depth soundings were taken across the eight islands, covering a distance of 701 km.

Coral Reef Assessments: Surveys were conducted across eight islands/atolls. A total of 388 fish transects, 852 benthic surveys, coral assessments and phototransects were completed in 71 locations from 5-30 m depth. Over 19,000 corals, 4 cm diameter and larger were examined.

Coral Reef Research:

- Ocean Acidification: Water samples, coral cores and measurements of water chemistry were completed to evaluate effects of recent changes in ocean chemistry. A total of 236 cores were collected at 10-12 m depth in five locations consisting of 180 *Porites lobata*, 24 *Astreopora*, 5 *Millepora*, and 13 *Pavona clavus*. These will be sectioned and examined using a CT scan to quantify variations in coral growth rates and relationship with ocean chemistry.
- Invertebrate diversity: Coral reef invertebrate biodiversity, with emphasis on cryptic species, was characterized at Hao Atoll and Gambier Islands. Samples of 818 specimen lots represented by 211 annelids (54 species), 254 arthropods (127 species), 69 echinoderms (46 species), 165 molluscs (96 species) and a small number of Bryozoa, Cnidaria, Chordata, Hemichordata, Nemertea, Platyhelminthes, Porifera, and Sipuncula were collected and processed during the expedition.
- Ciguatera outbreaks: Sampling of shallow marine environments was undertaken to better understand the potential for Ciguatera outbreaks in Mangareva. The habitat quality and species composition of seven lagoonal reefs and two fore reefs exposed to high, med/low and no human activity near Mangareva and Temoe were characterized. A total of 266 samples of fish (13 species) were collected in these areas for toxicological data. In addition, 83 algal specimens (5 species) were assessed for the presence of three taxa of dinoflagellates and additional samples of giant clams and cyanobacteria were collected.
- Coral symbiosis: Tissue samples from *Pocillopora* were collected to evaluate photosynthetic potential of corals. Small (each=1 cm^3) tissue and skeleton samples were collected from six species of *Pocillopora* (n=401) between 5-30 m depth in fore reef and back reef locations to characterize variations in the type of symbionts between depths and environmental conditions.
- In total 47 specimens of *Tridacna squamosa* giant clams were identified in fore reef locations off 7 islands. All were photographed and two were collected for genetic verification.

Summary of general findings

Coral: Most lagoonal and fore reef locations exhibited very high coral cover. The fore reef communities of remote atolls often had 50-90% live coral cover extending from just below the water's surface to 30+ meters depth. There was also a high diversity of species with 40-60 species identified per dive.

Coral diseases: Black band disease was documented in Mangareva on two lagoonal reefs. Other conditions included skeletal eroding band, pink line disease, yellow band, white syndrome and tumors. In general prevalence of disease was lower than Society and Tuamotu.

Coral Predators: Crown of thorns sea stars were rare, occurring at low numbers in two lagoonal reefs and on one outer reef. Higher numbers of *Culcita* starfish were seen in lagoonal reefs of Mangareva. A sea star predator (trumpet triton *Charonia*) was observed consuming a *Culcita*. Snails were present but at low abundances. Moderate numbers of *Coralliophila* were seen on *Porites* colonies, but these caused minimal damage to corals.

Hao

- Lagoonal patch reefs had high cover of live coral on the tops of pinnacles (1-3 m depth) consisting of small branching corals, small massive and submassive corals with larger massive colonies of *Porites* on the slopes, to about 5 m depth. There is much less coral on the deeper parts of the reef slope, although the bases of the reef often had small to medium-sized fields of finely branching acroporids and some larger table acroporids. Many of the deeper locations had high cover of *Caulerpa* and *Microdictyon* algae.
- Fore reef communities often had well-developed spur and groove system and a steep slope. Coral cover was lowest on the north coast, near the airport and populated areas, and higher on leeward areas to the west.
- Most for reef communities were dominated by small corals, especially *Pocillopora* and 10-15 cm table acroporids (*A. hyacinthus*) and small massive corals; considerable amount of old dead coral, often colonized by red turf algae, large accumulations of coral rubble, crusts of *Millepora*, piles of *Fungia*, and occasionally, large encrusting *Leptastrea* and *Pavona varians* colonies, high amounts of macroalgae in deeper areas.
- In many places there was a lot of recent mortality on *Pocillopora* from snails. A black sponge was frequently seen overgrowing corals. COTS were present, but in low numbers.

Acteon Group

- The hard coral communities contained at least some 60 species of corals and live cover ranged from 60-100%. These reefs are good examples of a climax community where a small suite of species have successfully out-competed other species and have dominated the reef. There was no evidence of impacts from mass bleaching, predation (*i.e.* crown of thorns starfish or *Drupella* sp.), or cyclones.
- In Tenarunga and Maria Est a species of cauliflower coral that had not been previously described to occur in French Polynesia was discovered. *Pocillopora zelli,* is similar in size to *P. eydouxi,* the largest growth form of a *Pocillopora* taxon found in French Polynesia*.* It is distinguished *by* a unique hexagonal pattern surrounding tightly packed branches packed colonies of one of the larger varieties of *Pocillopora.* This feature is a unique character of a species here.
- Notably very few fish compared to other fore reefs surveyed in Tuamotu and other islands in the Gambier Archipelago. Sharks and other large predators and large herbivorous fish such as surgeonfishes and parrotfishes were very few in numbers and absent from many sites. The fish assemblages were largely dominated by small-bodied species such as damselfishes, and wrasses, and butterflyfishes. Potential reasons for this include: 1) Despite the very high cover of live corals, the physical complexity of the reef was rather poor, with very little suitable habitat and shelter for large fish; 2) due to the large distances between the Acteon islands the other major island groups, recruitment of fish larvae and immigration of adult fish into

the islands from other major island groups is limited. The Acteon islands may virtually be a self-seeding location; 3) may be vulnerable to poaching. Both local and foreign fishing vessels may target tuna, jacks, groupers and snappers, and also sharks for the fin trade.

Mangareva

- Mangareva contained more diverse coral habitats than anywhere else examined with emergent fore reef communities, a submerged barrier reef, lagoonal fringing reefs, patch reefs, coral pinnacles, reticulate reefs, and an extensive deep water coral-encrusted lagoonal floor.
- Unlike other lagoonal habitats, vigorous coral growth occurs at the water's surface, and many of the corals are periodically exposed at low tide. Coral growth extends down the pinnacles, spurs or mounds to the lagoonal floor (25-30 m deep), and a deep coral framework on the lagoon floor supports a proliferant coral community to depths of 40 m or more.
- **Coral zonation:** The shallowest part of the lagoonal reef has the highest diversity of corals, with over 25 species of Acropora along with a number of other species. In deeper water, these corals form dense assemblages or thickets tens to hundreds of meters in length. *Acropora cytherea*, a table coral that was rare or absent in all other locations was abundant on fore reef locations from 10-30 m and at intermediate depths (5-10 m) in the lagoon. Below this, tall, thinly branched staghorn-type acroporids dominated, except in some areas with large foliose Montipora colonies. Below 25 m, the acroporids become less common and piles of free living mushroom corals (*Fungia, Herpolitha, Sandolitha*) occur. At 30 m and deeper, corals form delicate plates, with high numbers of rarer species like the elephant nose coral (*Mycedium*), lettuce corals (Pavona and Leptoseris), foliaceous *Montipora* and *Alveopora*. Some lagoonal habitats had unusually large massive *Porites* colonies in deep water at the base of the reef.
- This is the first location in French Polynesia where we have seen *Leptoria phyrigia* (a meandroid brain coral) and *Alveopora* a relative of *Porites*. The dominant table coral seen both inside and outside the lagoon, *Acropora cytherea*, was absent from the two other archipelagos and other locations in Gambier.
- Several common coral species seen in other Gambier locations and in Society Islands and Tuamotu were absent from Mangareva, including a massive star coral (*Favia stelligera*) and an elkhorn-like acroporid corals (*Acropora abrotanoides*).

Fishes

- Large aggregations of groupers and Napoleon wrasse were recorded at Mangareva, and these were suspected to be spawning aggregations. Schools of snappers, jacks, breams, parrotfish and surgeonfish were also commonly found in Gambier, with the exception of the islands composing the Acteon group.
- Range extension of the Orangehead Pygmy Angelfish, *Centropyge hotumatua*. This species was previously known to only occur the Austral Islands, Rapa Island, Pitcairn Island and Easter Island. The closest know locations are ~700km to the southwest (Pitcairn's) and ~1,000km to the east (Austral's).

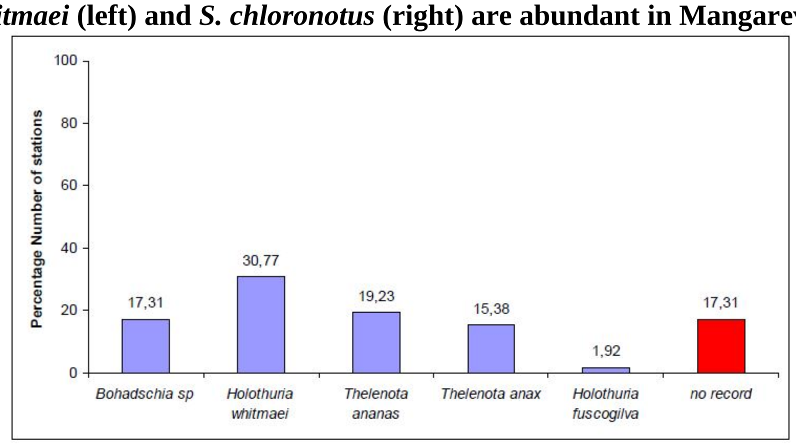
Fish poisoning

- Ciguatera fish poisoning (CFP), a seafood intoxication caused by the consumption of tropical reef fishes contaminated with a dinoflagellate (*Gambierdiscus*), was first identified in the Gambier Islands after a severe outbreak in the late 1960s. The dinoflagellate occurs in disturbed areas with high biomass of the fleshy algae *Amphiroa rigida*. A bloom of the *Gambierdiscus* was identified in one location near Rikatea. This is the first time high enough numbers of the *Gambierdiscus* were collected to allow identification of the variety of species of toxic dinoflagellates found here.

Commercial sea cucumbers in Hao, Gambier-Acteon atolls and Mangareva Island

- The survey was undertaken as a collaboration between DRM and IRD. The goal was to assess the status of commercial populations of sea cucumbers, 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 January-February 2013 Tuamotu- Gambier survey occurred 3 months after the closure of French Polynesia fisheries.
- 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 in Hao and Mangareva. A total of 17 sites in Hao and 52 sites in Gambier (Tenararo, Tenarunga, Vahanga, Matureivavao, Maria Est, Temoe, and Mangareva) were surveyed.
- Hao is a peculiar atoll compared to other Tuamotu atolls. Thirteen stations out of seventeen had no records, and only two species were recorded (*Thelenota ananas* and *Bohadschia argus*). The atoll lagoon was virtually depleted of sea cucumber communities. Elsewhere, in the Acteon group and in Mangareva, the situation is different. Gambier is a "hot-spot" of diversity, including several species only seen in Acteon and Gambier during the three first French Polynesia expeditions. For instance *Stichopus chloronotus* was abundant in Mangareva, but never seen elsewhere. *Holothuria whitmaei* was also much more abundant in Mangareva than anywhere else in French Polynesia. On the other hand *H. fuscogilva* was only seen once in Temoe atoll. Overall, the records are more balanced between species in other archipelagos, for instance without the dominance of the *Bohadschia* genus. Mangareva Island displays the characteristics of an island spared from any significant fishing, with high value commercial species (*T. whitmaei*) fairly abundant in shallow reefs close to the main village. All other commercially important species (*T. ananas, T. anax, Actinopyga varians*) are present in their habitats.
- The results suggest that Gambier is a sanctuary for sea cucumber communities, and hopefully this status will be preserved by discouraging fishing. This is a unique situation compared to other French Polynesia sites (especially in Society), but also compared to the vast majority of Pacific Islands.

***H. whitmaei* (left) and *S. chloronotus* (right) are abundant in Mangareva Island**



The percentage of stations with records of commercial species in Gambier atolls and island (Hao is not included), e.g. *H. fuscogilva* was seen on 1.9% of the stations, out of 52 stations.

Fig. 1. Route taken by the GoldenEye seaplane during the aerial surveys.

Table 1. Research Schedule

Date	Location
11-13 January 2013	Aerial surveys
13 January	Midnight departure from Papeete for Hao
15 January	Arrive Hao
15-21 January	Hao research
22 January	Transit to Groupe Acteon
23 January	Tenaravo
24 January	Vahanga
25 January	Tenarunga
26-27 January	Matureivavao
28 January	Maria Est
29 January-6 February	Mangareva
7-9 February	Temoe
9-11 February	Mangareva
12 February	Scientists fly from Gambier, Shadow departs for Papeete
14 February	Shadow arrives in Papeete

Research Completed

1. Habitat mapping and groundtruthing:

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

Satellite imagery

A total of 1703 sq km of WorldView 2 (8 band) satellite imagery was acquired for this project (Table 2). The satellite images had a spatial resolution of 2-m by 2-m (i.e., each pixel covers a 4-m^2 area) enabling real-time navigate in the field to locate features of interest and to avoid dangerous features (e.g., emergent reefs). In order to navigate, the team used the scenes in conjunction with a differential GPS device (dGPS). The imagery is being used 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). The acquired videos are being used to create the benthic habitat maps by providing the necessary information for the development of a habitat classification scheme and training of classification models. A minimum of 30 drop-cam videos were gathered per day.

Acoustic depth soundings

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

Acoustic sub-bottom

Profiles of the seafloor's sub-bottom were also gathered along transects using the Stratabox acoustic sounder, also developed by Syqwest. Similar to the bathymetric soundings, the sub-bottom profile emits an acoustic ping which reflects off the seafloor. However, the pulse has a lower frequency (3.5 Khz) enabling it to penetrate the seafloor. The instrument provides observations on striatal 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 varied with the slope's angle; steeper slopes resulted in shorter transect lines.

Archipelago	Site	Imagery (sq km)	No. dropcams	No. depth soundings	Track length (km)
Gambier	Hao	708	105	250376	195.0
	Mangareva	598	207	1129116	406.4
	Maria Est	290	24	9274	15.3
	Matureivavao	34	14	10336	22.0
	Temoe	31	27	79927	22.5
	Tenararo	9	12	5436	12.7
	Tenarunga	17	22	7256	14.4
	Vahanga	16	23	4716	12.7
	Total	**1703**	**434**	**1496437**	**701**

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.

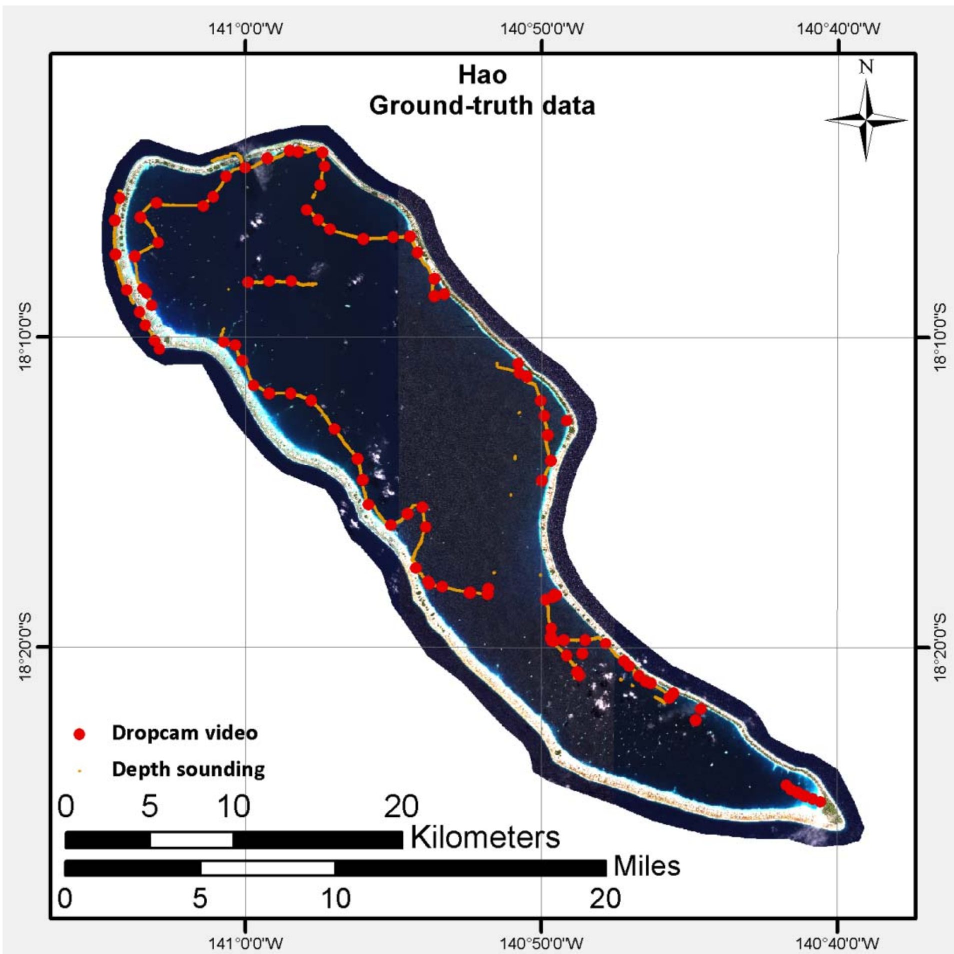
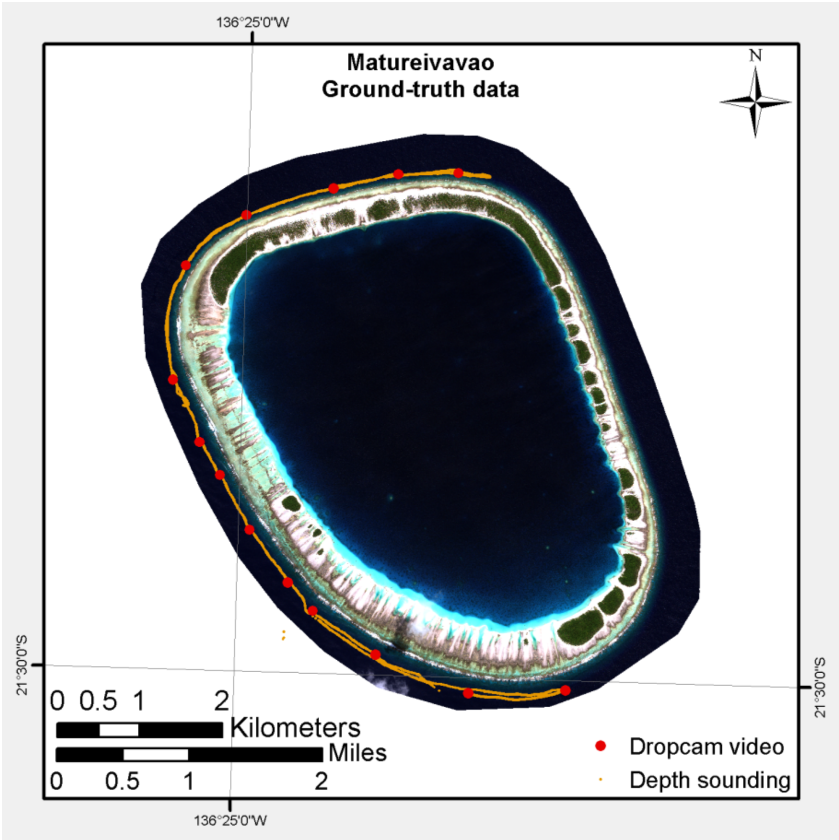


Fig. 2. Track of the groundtruthing team and locations of drop camera deployments in Hao.



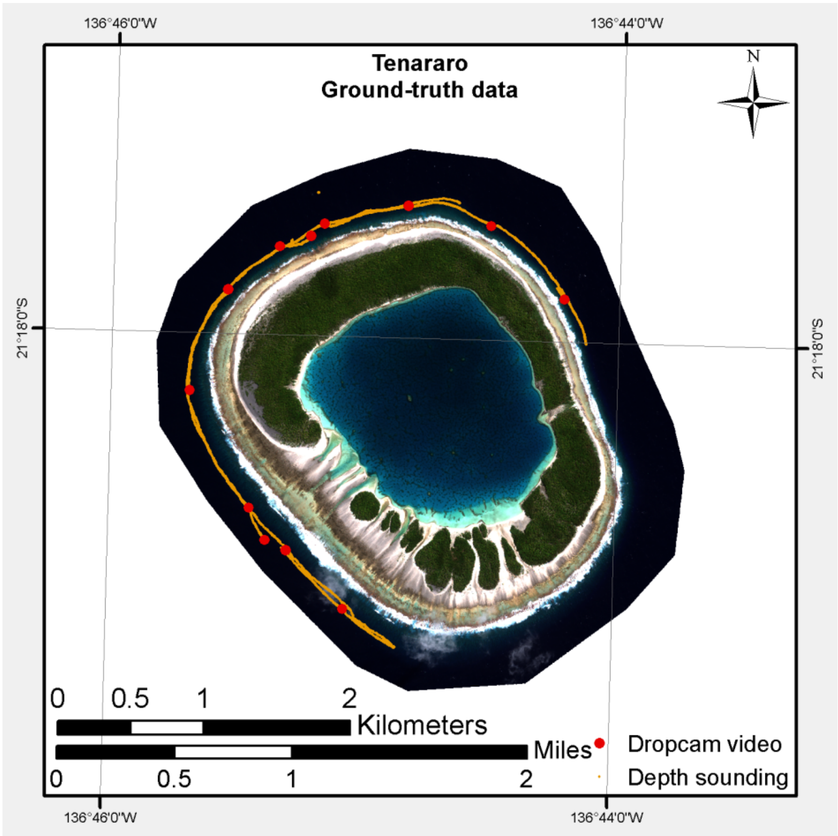
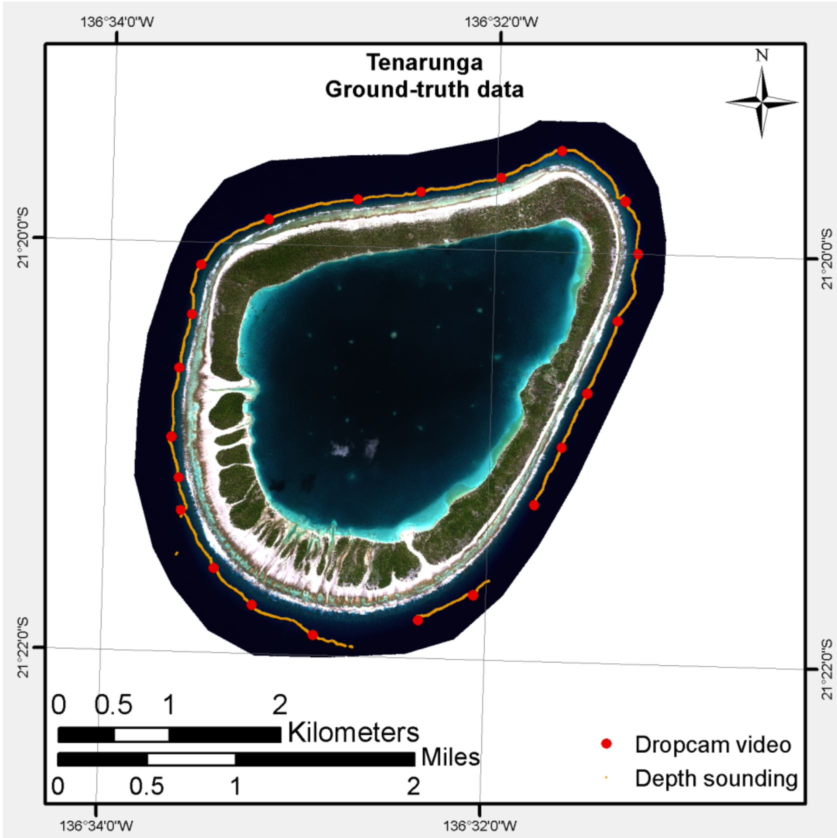


Fig. 3. Track of the groundtruthing team and locations of drop camera deployments in Matureivavao (top) and Tenararo (bottom).



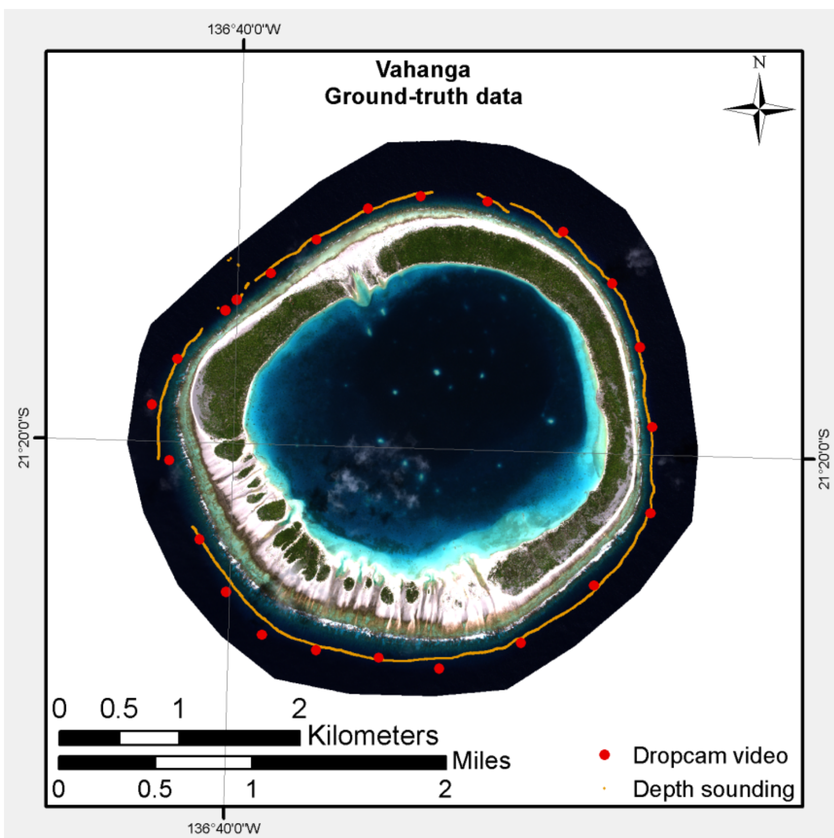
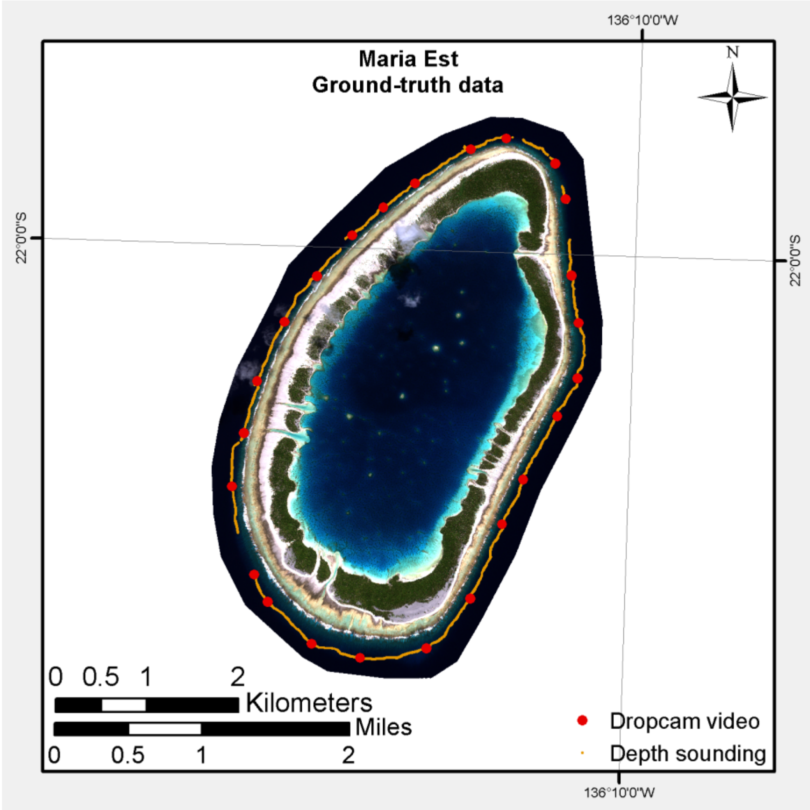


Fig. 4. Track of the groundtruthing team and locations of drop camera deployments in Tenarunga (top) and Vahanga (bottom).



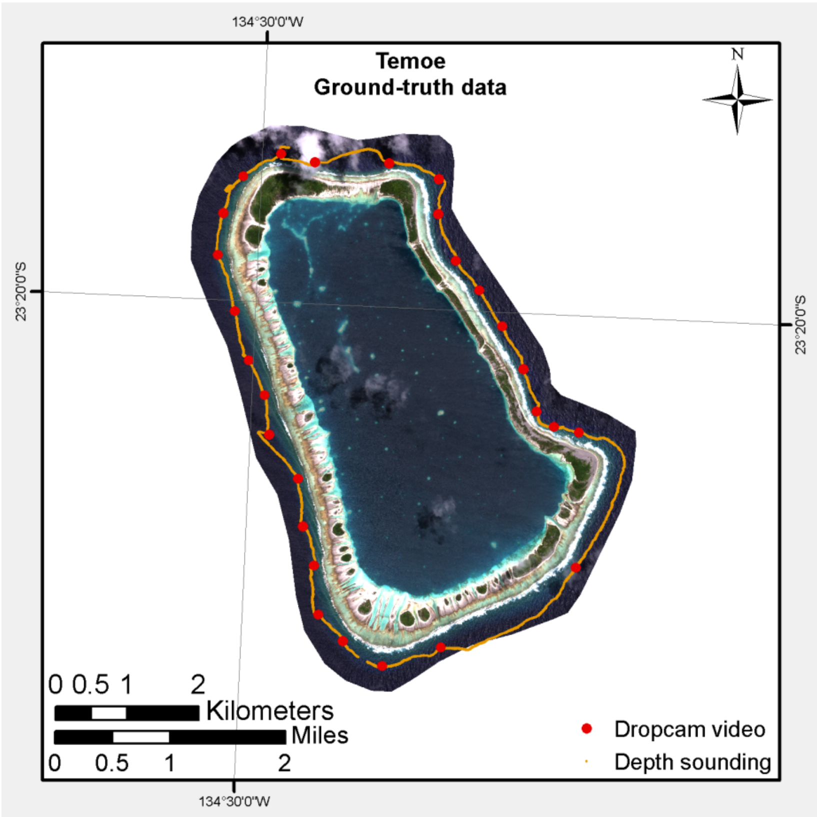


Fig. 5. Track of the groundtruthing team and locations of drop camera deployments in Maria Est (top) and Temoe (bottom).

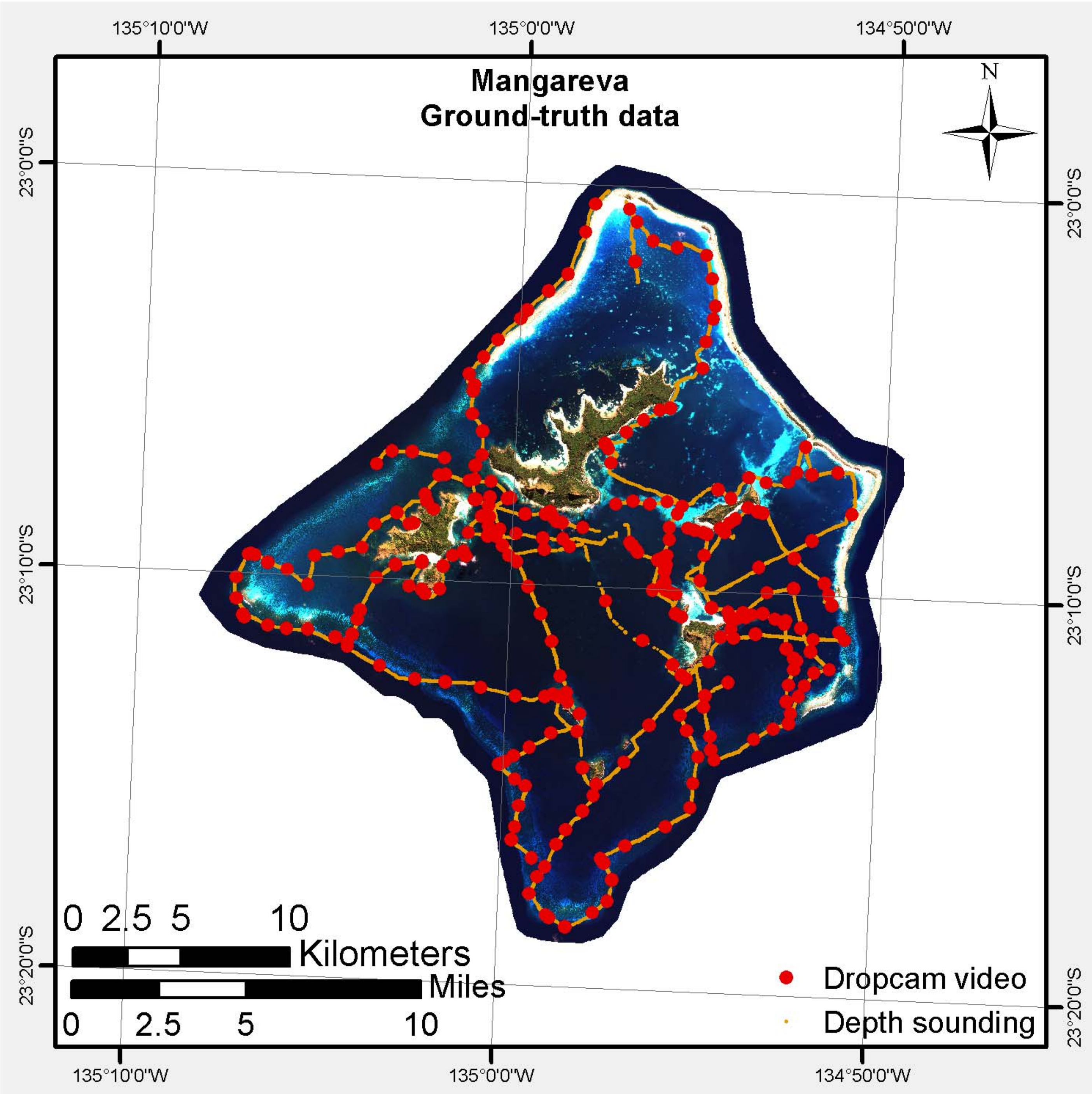


Fig. 6. Track of the groundtruthing team and locations of drop camera deployments in Mangareva.

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, 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, medial) and pattern of tissue loss (linear, annular, focal, multifocal, and coalescing) was recorded and when possible a field name was assigned. If an outbreak of coral disease was documented, sampling of the affected corals was undertaken to further characterize the disease (see below).

Motile invertebrates

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

Number of Islands	Number of dives	Benthic transects	Fish transects	Coral transects	Corals
8	71	852	388	176	19,402

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

Fig. 7. Example of the color variation seen in *Culcita*, an echinoderm that consumes coral. Photo by Serge Andrefouet.

Table 4. Coordinates of coral reefs examined using SCUBA.

Date	Lat	Long	Site name	Island	Exposure	Reef type
16-Jan-13	-18.0653	-140.9966	TUHA-01	Hao	leeward	fore reef
16-Jan-13	-18.0695	-141.0102	TUHA-02	Hao	leeward	fore reef
16-Jan-13	-18.0759	-141.0055	TUHA-03	Hao	leeward	lagoonal patch reef
17-Jan-13	-18.1730	-141.0480	TUHA-04	Hao	leeward	fore reef
17-Jan-13	-18.0826	-141.0680	TUHA-05	Hao	leeward	fore reef
17-Jan-13	-18.0632	-140.9876	TUHA-06	Hao	leeward	fore reef
17-Jan-13	-18.0686	-141.0067	TUHA-current meter	Hao		
18-Jan-13	-18.3069	-140.9068	TUHA-07	Hao	leeward	fore reef
18-Jan-13	-18.0729	-141.0197	TUHA-08	Hao	leeward	fore reef
18-Jan-13	-18.1157	-141.0490	TUHA-09	Hao	leeward	lagoonal patch reef
19-Jan-13	-18.3901	-140.7982	TUHA-10	Hao	leeward	lagoonal patch reef
19-Jan-13	-18.3806	-140.7674	TUHA-11	Hao	leeward	lagoonal patch reef
19-Jan-13	-18.3040	-140.8639	TUHA-12	Hao	leeward	lagoonal patch reef
20-Jan-13	-18.3503	-140.8144	TUHA-13	Hao	leeward	lagoonal patch reef
20-Jan-13	-18.3418	-140.8414	TUHA-14	Hao	leeward	lagoonal patch reef
20-Jan-13	-18.3452	-140.8609	TUHA-15	Hao	leeward	lagoonal patch reef
21-Jan-13	-18.0642	-140.9526	TUHA-16	Hao		fore reef
21-Jan-13	-18.0958	-140.9095	TUHA-17	Hao		fore reef
23-Jan-13	-21.3079	-136.7322	GATR-18	Tenararo	windward	fore reef
23-Jan-13	-21.3135	-136.7548	GATR-19	Tenararo	leeward	fore reef
23-Jan-13	-21.2967	-136.7591	GATR-20	Tenararo	leeward	fore reef
24-Jan-13	-21.315	-136.6555	GAVA-21	Vahanga	leeward	fore reef
24-Jan-13	-21.3375	-136.6714	GAVA-22	Vahanga	leeward	fore reef
24-Jan-13	-21.3340	-136.6328	GAVA-23	Vahanga	windward	fore reef
25-Jan-13	-21.3562	-136.5310	GATG-24	Tenarunga	windward	fore reef
25-Jan-13	-21.3518	-136.5610	GATG-25	Tenarunga	leeward	fore reef
25-Jan-13	-21.3276	-136.5391	GATG-26	Tenarunga	leeward	fore reef
26-Jan-13	-21.4817	-136.3659	GAMV-27	Maturei Vavao	windward	fore reef
26-Jan-13	-21.4445	-136.4037	GAMV-28	Maturei Vavao	leeward	fore reef
26-Jan-13	-21.4841	-136.4157	GAMV-29	Maturei Vavao	leeward	fore reef
27-Jan-13	-22.0175	-136.2081	GAME-30	Maria Est	leeward	fore reef
27-Jan-13	-22.0228	-136.1779	GAME-31	Maria Est	windward	fore reef
27-Jan-13	-21.9928	-136.1895	GAME-32	Maria Est	leeward	l fore reef
28-Jan-13	-23.0977	-135.0399	GAMG-33	Mangareva		submerged barrier reef
28-Jan-13	-23.0975	-135.0346	GAMG-34	Mangareva		submerged barrier reef
28-Jan-13	-23.1589	-134.9639	GAMG-35	Mangareva	leeward	lagoonal patch reef
30-Jan-13	-23.0144	-134.9723	GAMG-36	Mangareva	leeward	fore reef
30-Jan-13	-23.0566	-134.9989	GAMG-37	Mangareva	leeward	fore reef
30-Jan-13	-23.1440	-135.0968	GAMG-38	Mangareva		submerged barrier reef
31-Jan-13	-23.1911	-135.0927	GAMG-39	Mangareva	leeward	fore reef
31-Jan-13	-23.1780	-135.0923	GAMG-40	Mangareva	leeward	lagoonal patch reef
31-Jan-13	-23.1697	-135.0608	GAMG-41	Mangareva	leeward	lagoonal patch reef
1-Feb-13	-23.1489	-134.8460	GAMG-42	Mangareva	leeward	fore reef
1-Feb-13	-23.1374	-134.9014	GAMG-43	Mangareva	leeward	lagoonal patch reef
1-Feb-13	-23.1890	-134.9030	GAMG-44	Mangareva	leeward	lagoonal patch reef
2-Feb-13	-23.2164	-134.8582	GAMG-45	Mangareva	leeward	leeward fore reef
2-Feb-13	-23.2241	-134.9646	GAMG-46	Mangareva	leeward	lagoonal patch reef
2-Feb-13	-23.1548	-135.0189	GAMG-47	Mangareva	leeward	lagoonal patch reef
3-Feb-13	-23.1675	-134.9306	GAMG-48	Mangareva	leeward	lagoonal patch reef
3-Feb-13	-23.1763	-134.9023	GAMG-49	Mangareva	leeward	lagoonal patch reef
3-Feb-13	-23.2017	-134.9234	GAMG-50	Mangareva	leeward	lagoonal patch reef
4-Feb-13	-23.2360	-134.9014	GAMG-51	Mangareva	windward	fore reef
4-Feb-13	-23.2017	-134.9234	GAMG-50B	Mangareva	leeward	lagoon floor
4-Feb-13	-23.0791	-135.0039	GAMG-52	Mangareva	leeward	lagoon floor
5-Feb-13	-23.1694	-135.0322	GAMG-53	Mangareva	leeward	lagoon floor
5-Feb-13	-23.1418	-134.9174	GAMG-54	Mangareva	leeward	lagoon floor
5-Feb-13	-23.2607	-134.9958	GAMG-55	Mangareva	windward	fore reef
6-Feb-13	-23.0776	-134.8884	GAMG-56	Mangareva	windward	fore reef
6-Feb-13	-23.1104	-134.8464	GAMG-57	Mangareva	windward	fore reef
6-Feb-13	-23.1772	-134.8436	GAMG-58	Mangareva	windward	fore reef
7-Feb-13	-23.1691	-134.8591	GAMG-59	Mangareva	leeward	lagoonal fringing reef
7-Feb-13	-23.0711	-134.9108	GAMG-60	Mangareva	leeward	lagoonal patch reef
8-Feb-13	-23.1984	-134.8733	GAMG-61	Mangareva	leeward	lagoonal fringing reef
8-Feb-13	-23.1271	-134.9097	GAMG-62	Mangareva	leeward	lagoonal patch reef
8-Feb-13	-23.1451	-134.8559	GAMG-63	Mangareva	leeward	lagoonal fringing reef
9-Feb-13	-23.3158	-134.4848	GATE-64	Temoe	leeward	fore reef
9-Feb-13	-23.3574	-134.4934	GATE-65	Temoe	leeward	fore reef
9-Feb-13	-23.3290	-134.5060	GATE-66	Temoe	leeward	fore reef
10-Feb-13	-23.3436	-134.4620	GATE-67	Temoe	windward	fore reef
10-Feb-13	-23.3248	-134.4751	GATE-68	Temoe	windward	fore reef
10-Feb-13	-23.3152	-134.4956	GATE-69	Temoe	leeward	fore reef
11-Feb-13	-23.1973	-135.0646	GAMG-70	Mangareva	windward	fore reef
11-Feb-13	-23.1690	-135.1252	GAMG-71	Mangareva	leeward	lfore reef

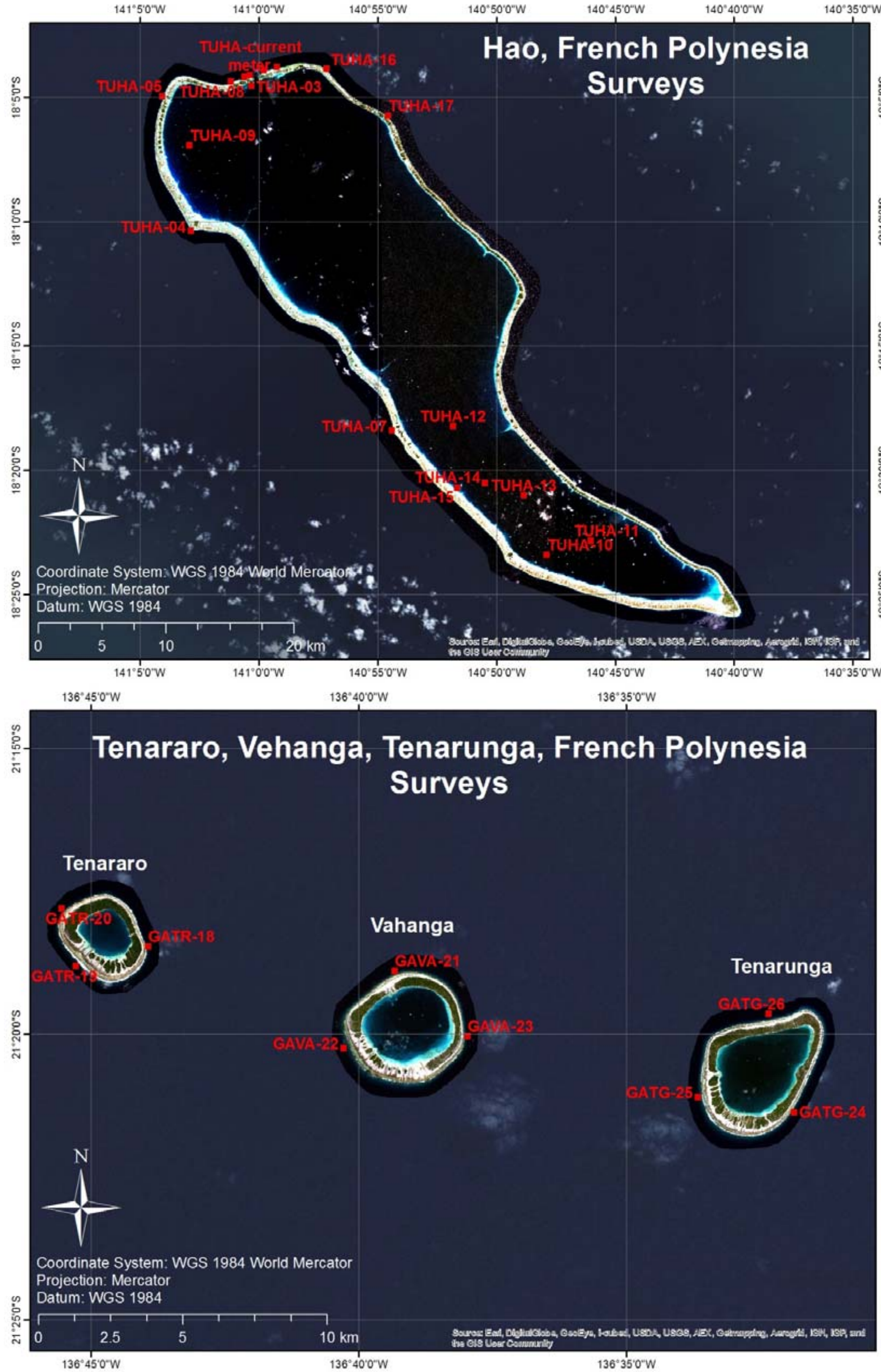


Fig. 8. Location of SCUBA assessments in Hao (top) and Tenararo, Tanarunga and Vahanga (bottom).

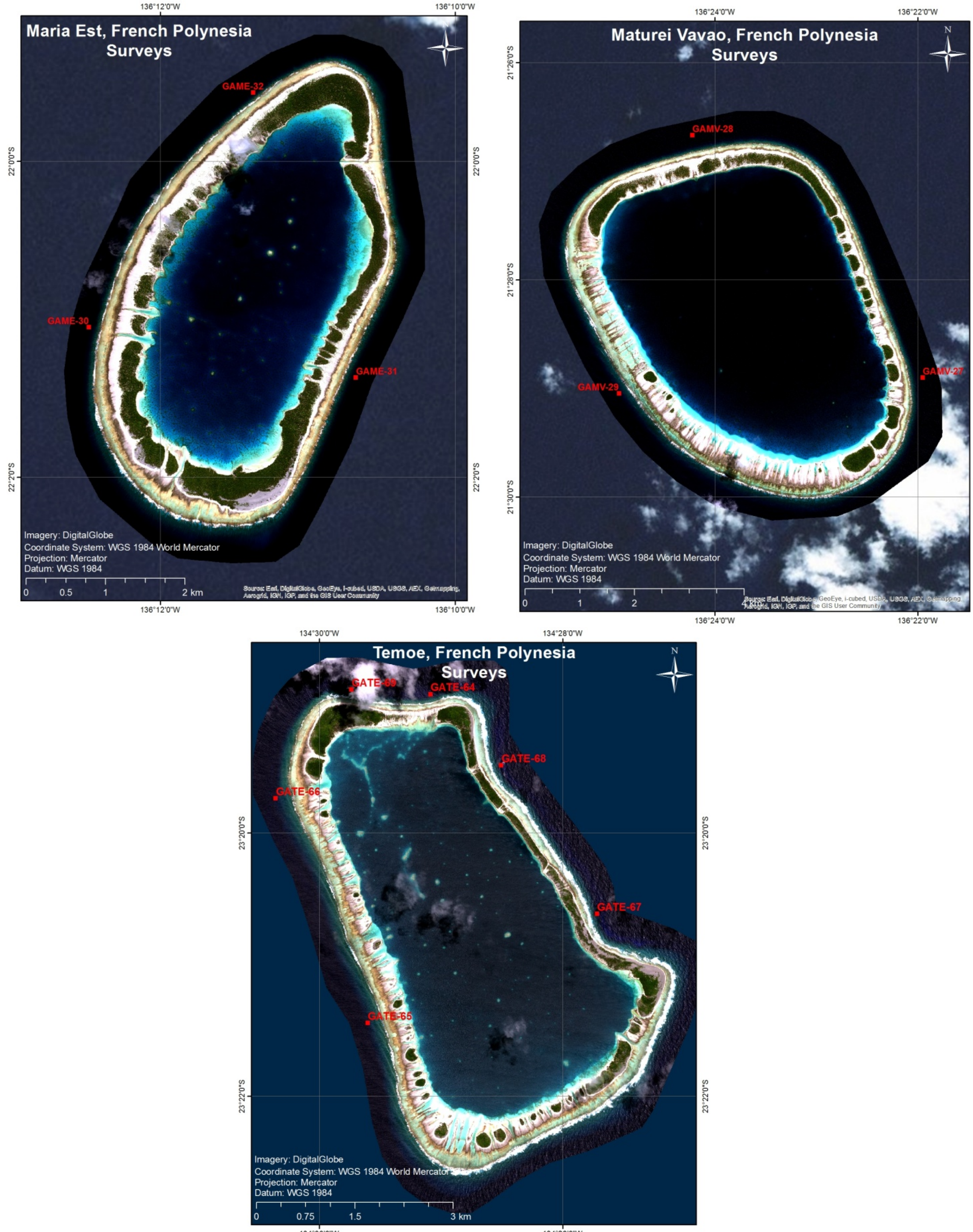


Fig. 9. Location of SCUBA assessments in Maria Est (top left), Maturei Vavao (top right) and Temoe (bottom).

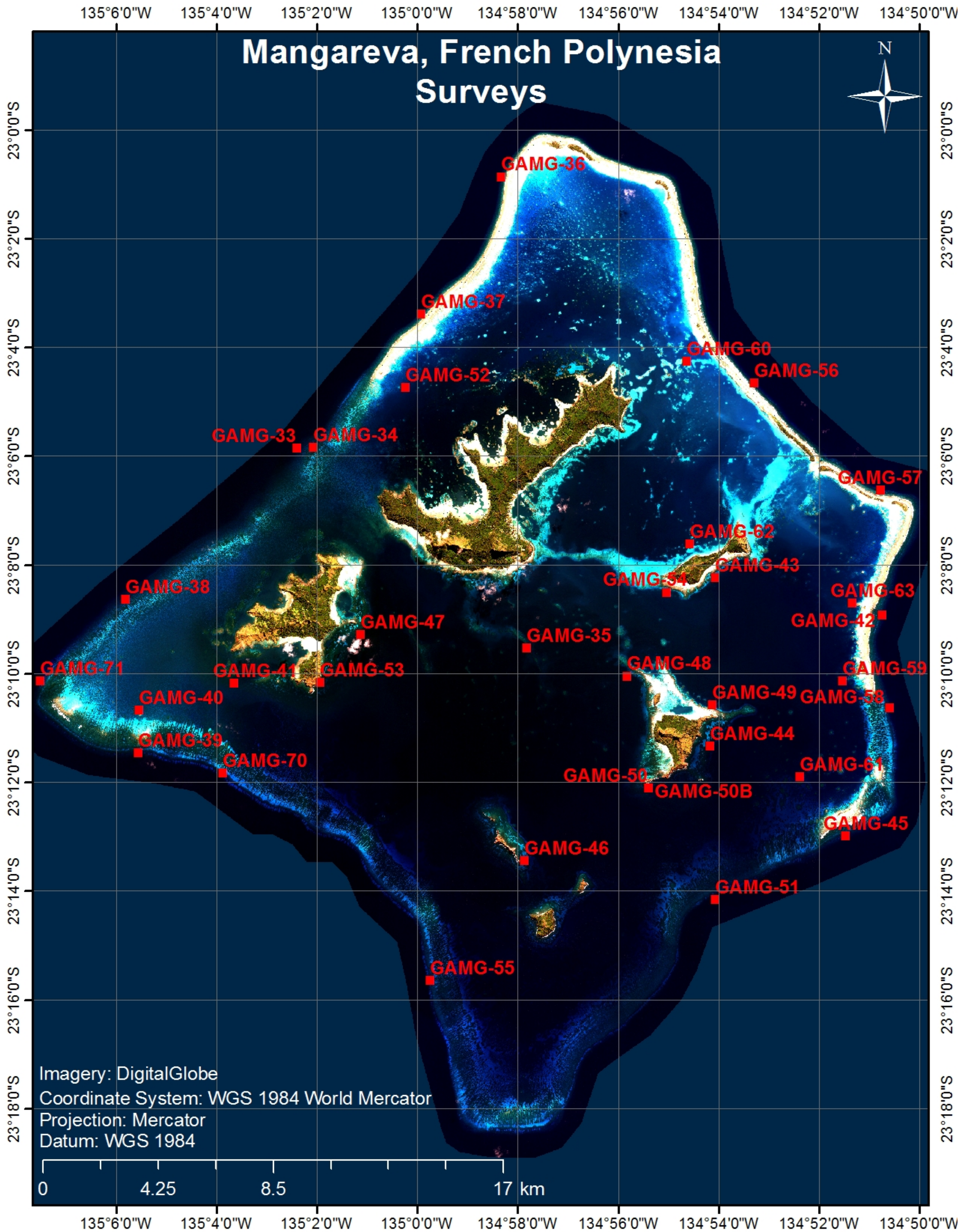


Fig. 10. Location of SCUBA assessments in Mangareva.

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

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

Island	Number of samples
Hao	60
Mangareva	100
Maria Est	7
Matureivavao	6
Temoe	11
Tenararo	12
Tenarunga	7
Vahanga	9
Total	212

Table 5. Total number of sediment samples.

Ocean acidification:

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

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

Island	Species	Number	Size	Fixation
Hao	*Porites lobata*	55	~3cm diam. X 9 cm length	Dry
Hao	*Montipora* sp.	1	~3cm diam. X 9 cm length	Dry
Mangareva	*Astreopora* sp.	24	~3cm diam. X 9 cm length	Dry
Mangareva	*Porites lobata*	95	~3cm diam. X 9 cm length	Dry
Mangareva	*Pavona clavus*	1	~3cm diam. X 9 cm length	Dry
Maria Est	*Pavona clavus*	4	~3cm diam. X 9 cm length	Dry
Maturei Vavao	*Porites lobata*	12	~3cm diam. X 9 cm length	Dry
Maturei Vavao	*Pavona clavus*	1	~3cm diam. X 9 cm length	Dry
Temoe	*Millepora* sp.	1	~3cm diam. X 9 cm length	Dry
Temoe	*Pavona clavus*	4	~3cm diam. X 9 cm length	Dry
Temoe	*Porites lobata*	7	~3cm diam. X 9 cm length	Dry
Tenararo	*Montipora* sp.	4	~3cm diam. X 9 cm length	Dry
Tenararo	*Porites lobata*	4	~3cm diam. X 9 cm length	Dry
Tenarunga	*Pavona clavus*	3	~3cm diam. X 9 cm length	Dry
Tenarunga	*Porites lobata*	9	~3cm diam. X 9 cm length	Dry
Vahanga	*Montipora* sp.	3	~3cm diam. X 9 cm length	Dry
Vahanga	*Porites lobata*	8	~3cm diam. X 9 cm length	Dry
Total		236		

Table 6. Total number of cores collected off 8 islands.

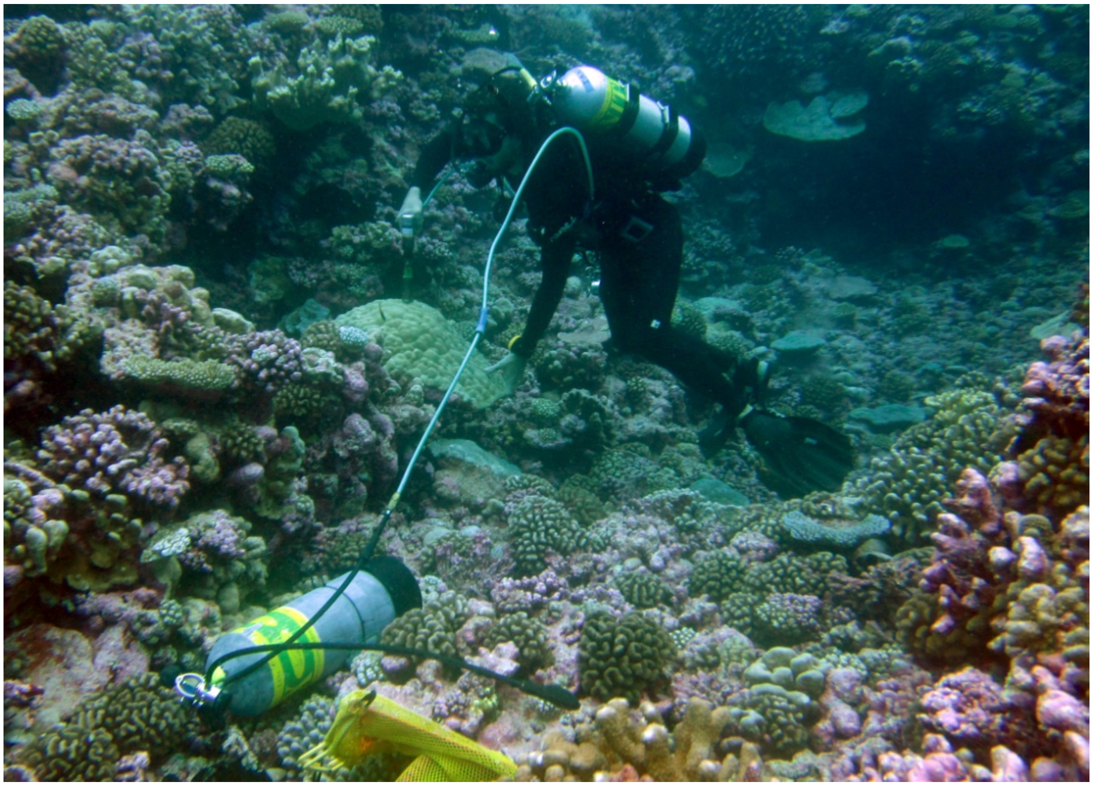


Fig. 11. Removing a core from a *Porites lobata* colony using a hole saw and a pneumatic drill.

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, clippers were used to break off a small fragment of coral tissue (three to four polyps). A photograph was taken of each colony prior to sampling, and colony size was measured in three dimensions (maximum length, width, and height to the nearest 10 cm). A maximum of 30 colonies were collected per species on each reef. Fragments were placed in individual zip-lock bags underwater and then transferred to vials containing DMSO on shore and stored in a -20°C freezer. Typical biopsies were <0.5cm^2 in total surface area. In a subsample of the colonies that were sampled (10 colonies per reef or island, all at 10 m depth), triplicate measurements of fluorescence were taken during the day and again at night using a PAM fluoremeter.

	Pocillopora							
Islands	**eydouxi**	**damicornis**	***danae***	***verrucosa***	***meandrina***	***efusus***	**sp.**	**Total**
Hao	26	11	10	8	10	2	2	69
Mangareva	111	7	2	45	24		1	190
Maria Est	14		2	3	11			30
Maturei Vavao	6				10			16
Temoe	16			17	11			44
Tenararo	5		1		6	1	1	14
Tenarunga	10		1		8	5		24
Vahanga	7		2		3	2		14
Total	195	18	18	73	83	10	4	401

Table 7. Samples of *Pocillopora* collected for *Symbiodinium*. All samples (approx.. 1 cm^3) are preserved in 20% DMSO solution at -20°C.

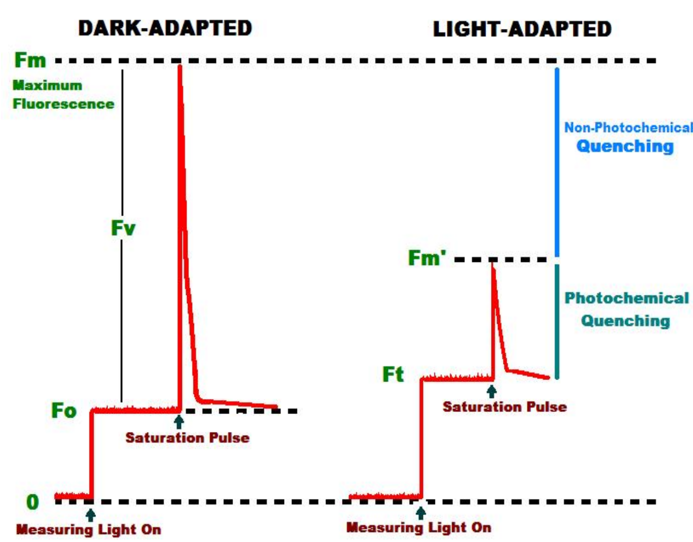


Fig. 12. Measurement of photosynthetic efficiency of *Pocillopora* corals. Use of a PAM fluorometer (left) and example of spectra during the day and night (right).

Coral reef invertebrate biodiversity:

Coral reef invertebrates were sampled during the 2013 Living Oceans Foundation expedition to Hao Atoll and the Gambier Islands, French Polynesia. Several sampling strategies were employed to obtain broad coverage of the reef biodiversity. Large motile and sessile invertebrates were collected individually by hand by turning large pieces of dead coral rock, plucking animals from the surface of corals or other substrate species, and digging into the reef matrix. Smaller motile species were targeted through bulk sampling and subsequent processing of dead coral rubble and algae. Infaunal animals were sampled by digging or by bulk sand collection followed by mixing with a large volume of seawater and decanting through a fine sieve for smaller species.

Specimens were sorted and photographed in the lab, and tissue samples were fixed in 95% ethanol for whole DNA preservation. Voucher specimens were fixed in 20% formalin, 75% ethanol, or dried, and deposited in the division of Invertebrate Zoology at the Florida Museum of Natural History (FLMNH) at the University of Florida (UF). A total of 818 specimens were collected as indicated in table 8. In addition samples included a small number of Bryozoa, Cnidaria, Chordata, Hemichordata, Nemertea, Platyhelminthes, Porifera, and Sipuncula

Taxon	Number of samples	Number of species
annelids	211	54
arthropods	254	127
echinoderms	69	46
molluscs	165	96
Total	818	323

Table 8. Invertebrates collected in Gambier and Hao.

Fig. 13. Examples of representative annelids collected from Gambier.

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, 46 individuals of this species were identified and photographed in fore reef locations off 7 islands. Two specimens were collected for genetic verification.

Location	Number of samples
Hao	2
Vahanga	2
Tenaranga	5
Maturei Vavao	1
Maria Est	4
Mangareva	4
Temoe	28
Total	46

Table 9. Total number of new records of *Tridacna squamosa* in fore reef locations of Gambier Archipelago.

Ciguatera study:

An evaluation of the environmental and/or anthropogenic factors that may lead to an increased risk of toxic outbreaks of *Gambierdiscus* dinoflagellates in highly exploited lagoons was undertaken in Gambier, with the intent of identifying suitable risk management measures to prevent fish poisoning. Sampling sites (n=9) were selected according to their degree of human impacts. Gatavake Bay, Rikitea Bay, Taku Bay, and Totegegie were classified as high degree of human impacts; Taravai, Akamaru, and Aukena exhibited moderate to low degree of human impacts and three sites, Motu, Tenoko, and Temoe were unaffected by human activity.

Each survey site was characterized (type of substrate, percentage of coral cover, algae cover, abundance of echinoderms, composition of fish assemblages, sediment characteristics) and biological samples were taken for toxicological analysis. A total of 266 samples of 13 distinct species of reef fishes were spear-fished and processed on board the M/Y Golden Shadow (filets were sampled and frozen) with further toxicological analyses performed in the laboratory. A total of 83 macro-algal samples were collected and screened for the presence of benthic dinoflagellates of the genus *Gambierdiscus*, *Ostreopsis* and *Prorocentrum*. The species mostly represented were: *Halimeda* sp., *Gelidiopsis intricata*, *Amphiroa rigida*, *Dictyota* and *Turbinaria ornate*. In addition samples of 30 giant clams were collected from 6 pools in Gatavake, Taku, Akamaru, Aukena, Totegegie and Temoe study sites. Cyanobacterial samples (n=14) were also collected from Gatavake, Motu Tenoko, Taravai, Rikitea, Taku, Akamaru and Aukena.

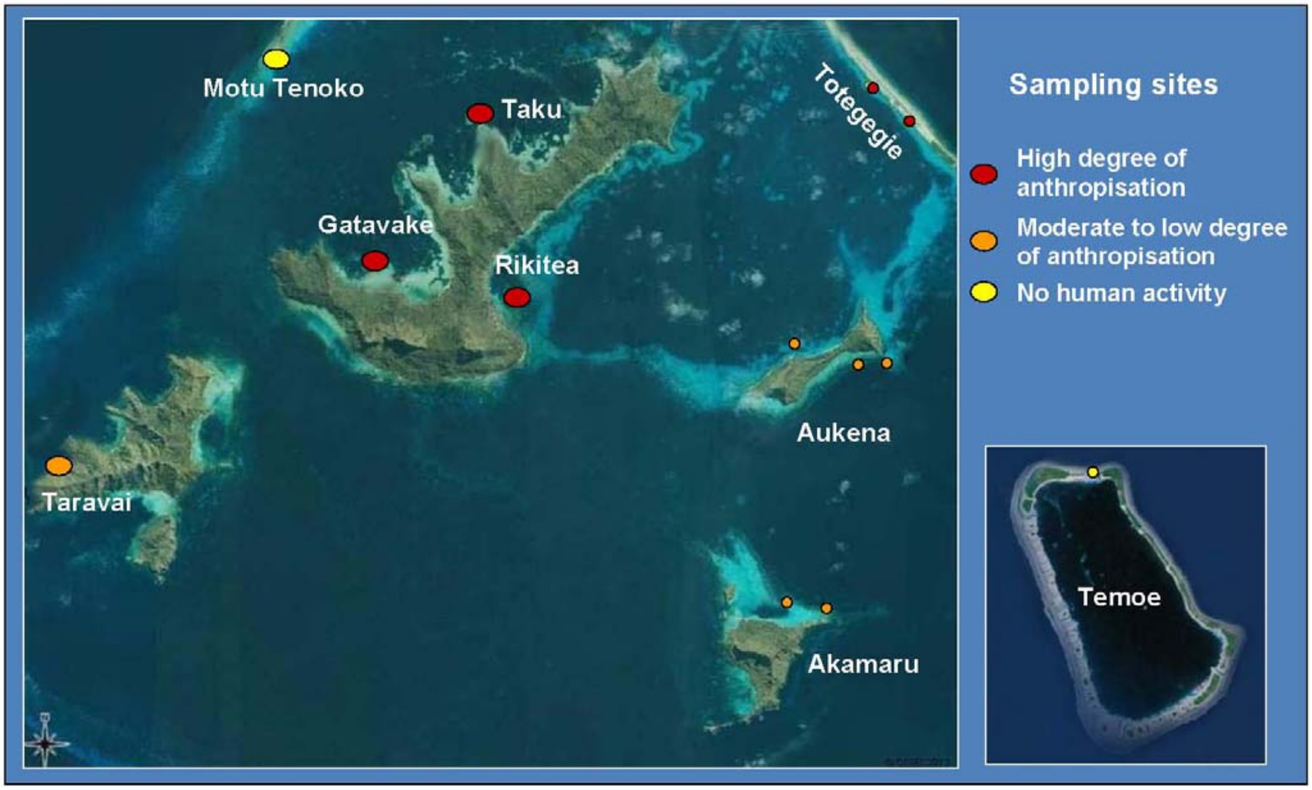


Fig. 14. Location of sites examined as part of the Ciguatera study.

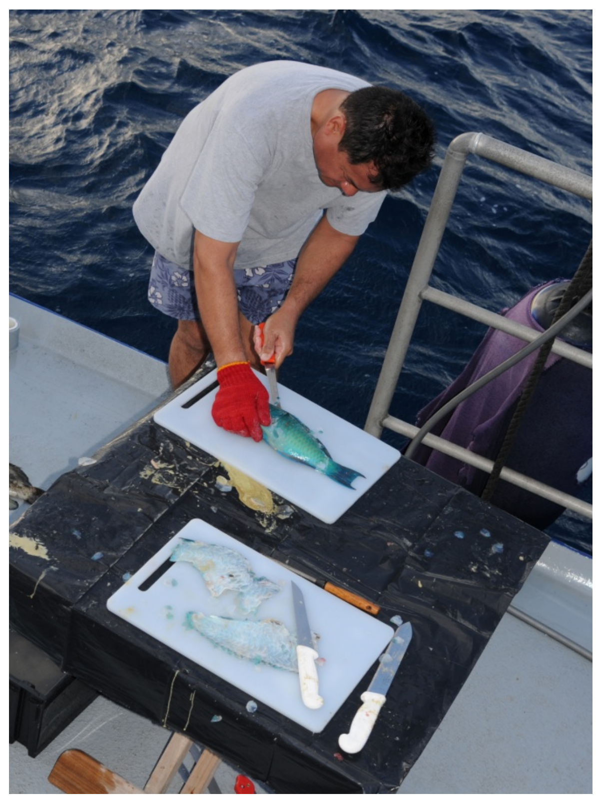


Fig. 15. Collection of fish from one location (left) and processing of a parrotfish (removal of filets) to verify the presence of *Gambierdiscus* (ciguatera toxin).

Appendix 1. Participants.

Name	Institution	Function
Phil Renaud	Khaled bin Sultan Living Oceans Foundation (KSLOF)	Executive Director
Andy Bruckner	Khaled bin Sultan Living Oceans Foundation	Chief Scientist
Brian Beck	Khaled bin Sultan Living Oceans Foundation	Coral Reef Ecologist
Eddie Gonzalez	Khaled bin Sultan Living Oceans Foundation	Director of Education
Badi Samaniego	University of the Philippines, KSLOF Fellow	Fish surveyor
Joao Monteiro	University of the Azores, Living Oceans Foundation Fellow	Coral fluorescence
Jeremy Kerr	Nova Southeastern University, Living Oceans Foundation Fellow	Groundtruthing / habitat mapping
Alex Dempsey	Nova Southeastern University National Coral Reef Institute	Benthic surveyor
Andrew Calhoun	Nova Southeastern University National Coral Reef Institute	Groundtruthing
Ian Enochs	NOAA/University of Miami	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
Eva McClure	University of Tasmania	Fish surveyor
Simon van Wynsberge	Université de la Polynésie française,	Invertebrate surveyor
Marie Kospartov	Independent contractor	Coral surveyor
Melanie Roue	Institut de Recherche pour le Développement	Ciguatera research
Claude Payri	Institut de Recherche pour le Développement, New Caledonia	Algae sampling
Jenna Moore	Florida Museum of Natural History, Scripps Institution of Oceanography	Invertebrate taxonomy
Michele Westmorland	Westmorland Images, LLC	Photographer
Megan Cook	Rolex Scholar	Assistant photographer
Mireille Chinain	Louis Malardré Institute (ILM)	Ciguatera research
Andre Ung	Louis Malardré Institute (ILM)	Ciguatera research
John Butscher	Institut de Recherche pour le Développement	Ciguatera research
Jean-Claude Gaerter	Institut de Recherche pour le Développement	Ciguatera research
Megan Berkle	Linda Esperanza Marquez High School, California	C.R.E.W. teacher
Nick Cautin	Dive Safety Officer	Diving operations