VOL 7

FRENCH POLYNESIA

GLOBAL REEF EXPEDITION FINAL REPORT

Khaled bin Sultan Living Oceans Foundation

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This final report is submitted to fulfill the requirements of the Final Report for the Global Reef Expedition: French Polynesia Research Mission. This is in accordance with the research permit under an agreement between KSLOF and Présidence de La Polynésie française, Ministére en Charge de la Recherche and Délégation à la Recherche.

Khaled bin Sultan Living Oceans Foundation (KSLOF) was incorporated in California as a 501 (c)(3), public benefit, Private Operating Foundation in September 2000. The Living Oceans Foundation is dedicated to providing science-based solution to protect and restore ocean health.

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EXECUTIVE SUMMARY

In April 2011 the Khaled bin Sultan Living Oceans Foundation embarked on the Global Reef Expedition (GRE)- the largest coral reef survey and mapping expedition in history. The GRE was a five-year rigorous scientific mission to study coral reefs around the world. The expedition was designed to assess the impact of anthropogenic and natural disturbances such as runoff, climate change, storm damage, and Crown-of-Thorns Starfish (COTS) outbreaks. The ultimate goal of the Foundation's research is to provide scientists, managers, and stakeholders with recommendations that are indispensable for formulating an effective management strategy for coral reefs and surrounding habitats. Herein, we report on a study that KSLOF has undertaken to assess the health and resilience of the coral reefs in the Overseas Lands of French Polynesia. The study spanned a seven-month period from September 2012 through April 2013. The Foundation quantitatively measured and categorized coral reef environments in four of the five major archipelagoes of French Polynesia: Society, Tuamotu, Gambier, and Austral Archipelagoes.

This unprecedented scientific mission involved 73 scientists from numerous organizations around the world who worked side by side with French Polynesian marine scientists to gather the highest quality data. The mission in French Polynesia was conducted with the following objectives:

1. **Collect vital data contributing to our global assessment of coral reef health and resilience.**
2. **Document the impacts of broad-scale disturbances and patterns of recovery with an emphasis on storm damage and Crown-of-Thorns Starfish predation impacts.**
3. **Provide recommendations to help guide Marine Protected Area (MPA) delineation and zoning for protection of French Polynesian reef resources.**
4. **The study on the GRE utilized standardized sampling methods[1] to map and survey coral reef benthic and fish communities around 29 islands in French Polynesia. Over 1,600 benthic coral reef surveys and 2,200 fish surveys were completed on SCUBA at 264 dive sites throughout the country, and over 9,300 km^2 of satellite imagery was collected and mapped.**

HABITAT MAPPING

High resolution habitat and bathymetric maps were created for each of the locations surveyed in French Polynesia. The images have a resolution of 2 m x 2 m. The habitat classifications (total of 33 habitats) very clearly define different substrate and reef habitats in the lagoon and fore reefs, as well as vegetation and sand flats found on the emergent land. Of great value to marine spatial planning efforts, the habitat maps were used in conjunction with the bathymetric maps to calculate total area of each habitat type. The maps can be used by scientists and the public, but marine managers may find them particularly helpful in establishing areas for protection. These maps are freely accessible on the KSLOF online map portal (http://maps.lof.org/lof).

BENTHIC COVER ASSESSMENT

The health of the reefs in French Polynesia were generally very good, but varied greatly by archipelago and atoll surveyed.

The Gambier Archipelago had, by far, the highest average coral cover recorded in all of French Polynesia (58% live coral). When compared to other reef habitats surveyed on the GRE, the live coral cover recorded at Gambier was an astounding 20% higher than the next highest region in French Polynesia. The Tuamotu Archipelago had moderate coral cover with an average of 30% live coral which is slightly lower, but comparable to the condition of other reefs surveyed by the GRE in the South Pacific. The Society and Austral Archipelagoes had moderate to low coral cover with an average of 20% and 27% coral cover respectively, although some locations had alarmingly low coral cover ranging from 5-8%. Across all islands, the calculated coral diversity was ranked moderate to low. The region with the highest diversity we surveyed was the Austral Archipelago. One possible explanation for this trend in coral diversity is that the Austral Archipelago is closer to other high diversity areas, such as the Coral Triangle, than the other sites visited, leading to a greater influx of coral species. The dominant algae at nearly all locations was crustose coralline algae which offers a good substrate for juvenile corals to settle. Only a few islands were dominated by either turf algae or fleshy macro algae. Natural and anthropogenic disturbances in both the Society and Austral Archipelagoes were reflected in the benthic communities at these locations.

> The health of the reefs in French Polynesia were **generally very good,** but varied greatly by archipelago and atoll surveyed.

FISH COMMUNITY ASSESSMENTS

The fish communities in French Polynesia had moderate species richness, density, and biomass. The Tuamotu Archipelago had the healthiest reef fish communities with the highest species richness, density, and biomass recorded, with a biomass of 50 kg/100 m^2, nearly five times that observed in the Austral Archipelago. There was a high abundance of large target species and top predatory fish in this archipelago and it is believed that with the implementation of effective management measures, these reef fish communities will continue to thrive. In the Gambier Archipelago, economically important fish species were diverse and plentiful compared to the four other regions. The Society Archipelago fish communities mimicked the trends of the coral communities. Locations that had the highest coral cover had relatively healthy fish communities, and locations with the lowest coral cover had poor fish communities. The trends seen in the Society Archipelago are also correlated with human population centers where the higher the human population, the more degraded the fish and benthic communities. The densities of fish in the Society Archipelago ranged from 107 – 328 fish/100 m^2, the third highest of the archipelagoes surveyed in French Polynesia. The Austral Archipelago had the lowest fish species richness, abundance, and biomass compared to the other archipelagoes. The density of fish in the Austral Archipelago was very low with an average of 118 fish/100 m^2, nearly 3 times less than the average observed in Tuamotu.

EFFECTS OF DISTURBANCE ON CORAL REEF COMMUNITIES

The coral reef communities, particularly in the Society and Austral Archipelagoes were severely damaged in the early 2000s by outbreaks of Crown-of-Thorns Starfish (COTS) and tropical cyclones[2,3]. These disturbances were evident as many locations had coral cover which was reduced to only 5-8% with new recruitment and recovery only noted in the Society Archipelago. The marine spatial connectivity is a critical component in the recovery of these reefs, and with management of the upstream and local coral and fish populations, there is hope that these regions can recover.

The Khaled bin Sultan Living Oceans Foundation hopes the data presented in this report will be used by the people of French Polynesia to effectively protect and manage the benthic and fish community resources of the region. While there have been some reported changes to the reefs visited on the GRE, this baseline dataset provides optimism that in the face of continued natural and anthropogenic disturbance, the reefs of French Polynesia will continue to flourish.

INTRODUCTION

1.0

Over a seven-month period from September 2012 through April 2013, the Khaled bin Sultan Living Oceans Foundation's (KSLOF) Global Reef Expedition (GRE) visited the Overseas Lands of French Polynesia with the goal of broadening baseline knowledge of the health and resiliency of the region's coral reefs. The GRE covered well over 8,000 km of French Polynesian waters on this research mission, thoroughly studying large portions of four of the five archipelagoes making up the territory. There have been no other comprehensive coral reef surveys in French Polynesia that cover the vast area the GRE was able to encompass.

The GRE was conducted to determine the composition and condition of the benthic and fish communities in four major archipelagoes of French Polynesia: Society, Tuamotu, Gambier, and Austral. The Global Reef Expedition set out to accomplish three primary objectives while surveying the reefs of French Polynesia:

1. Collect vital data contributing to our global assessment of coral reef health and resilience.
2. Document the impacts of broad scale disturbances and patterns of recovery with an emphasis on storm damage and Crown-of-Thorn Starfish (COTS) predation impacts.
3. Provide recommendations to help guide Marine Protected Area (MPA) delineation and zoning for protection of French Polynesian reef resources.

French Polynesia covers an immense area in the southern Pacific Ocean (7°50' - 27°36' S, 134°28' - 154°40' W). It is comprised of 118 atolls of which 34 host high volcanic islands distributed throughout the almost 5 million km^2 Exclusive Economic Zone (EEZ)[4]. In total, these include an estimated 4,000 km^2 of emergent land[5], over 7,000 km^2 of lagoonal waters[6], and 12,800 km^2 of coral reefs[4], as shown in **Figure 1**.

The atolls of French Polynesia are separated into five distinct archipelagos: Society, Tuamotu, Gambier, Marquesas, and Austral[4]. The majority of the islands are the result of a volcanic hotspot specific to each island group[7] with the exception being the Tuamotu Archipelago. The atolls of the Tuamotu Archipelago have formed along a plateau on the East Pacific Ridge that is currently still spreading[4].

The distance between the four island groups visited on the GRE was expansive. The Austral Archipelago is the southernmost of the island groups, falling at and below the Tropic of Capricorn, creating a unique marine environment that is notably different than the rest of the tropical islands to the north[8]. The Tuamotu Archipelago is approximately

Figure 1 DELINEATION OF FRENCH POLYNESIA'S EEZ.

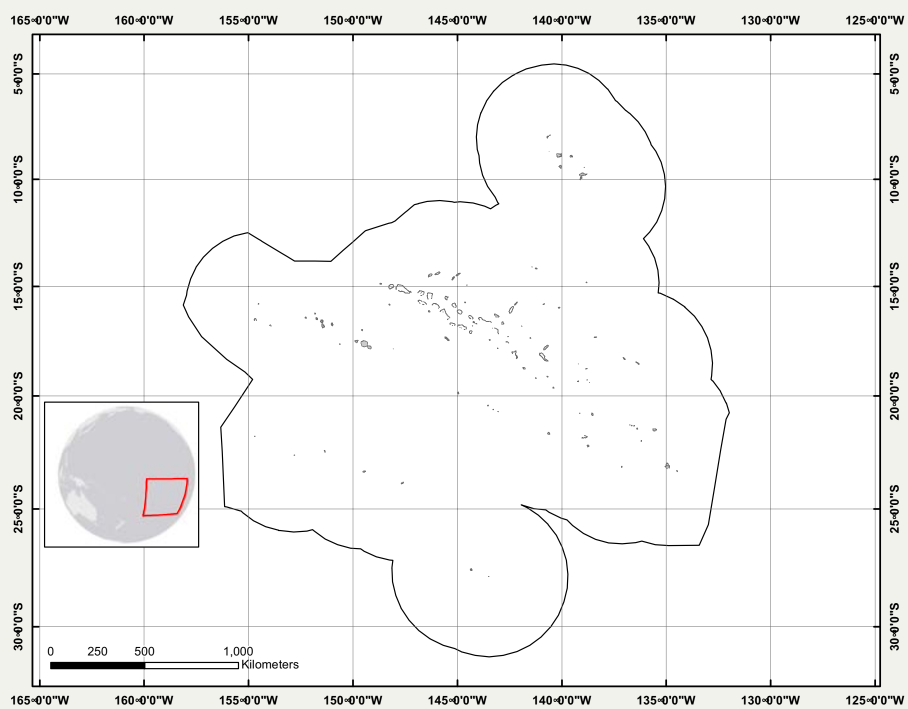
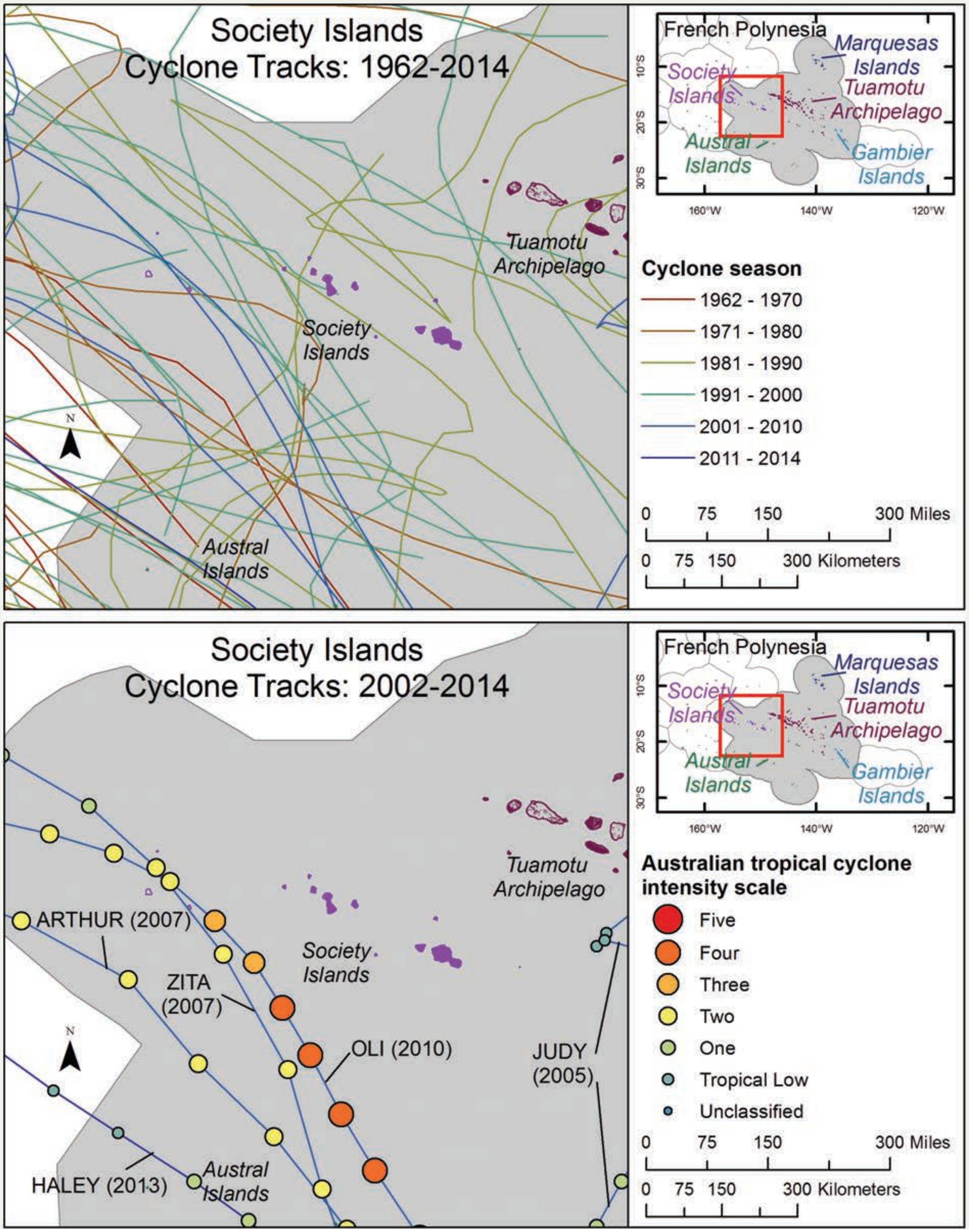


Figure 2 HISTORICAL TRACKS OF CYCLONES IMPACTING THE SOCIETY ARCHIPELAGO. THE TOP MAP SHOWS ALL CYCLONES FROM 1962-2014, THE BOTTOM MAP SHOWS CYCLONE TRACKS FROM 2002-2014.



1,000 km north of the Austral Archipelago with the Gambier Archipelago adjacent to the south east, and Society Archipelago to the south west (Figure 1).

The Society Archipelago is the most densely populated with about 235,000 inhabitants, of which nearly 75% live on the island of Tahiti. The next most populous archipelagoes are Tuamotu with a population of 15,800, followed by the Austral Archipelago with a population of 6,800, and finally Gambier with a population of 1,600[9]. This concentration of human populations around only a few islands makes French Polynesia an ideal study site. KSLOF specifically chose to visit both highly populated and uninhabited islands to compare the impacts of anthropogenic stressors on fish and benthic coral reef communities.

French Polynesian reef communities have experienced many disturbances in recent years including bleaching events related to increasing sea surface temperatures, cyclones (Figure 2), and COTS *(Acanthaster planci)* outbreaks (Figure 3)[2,3,10–13]. These disturbances have contributed to major declines in coral reef health. Besides natural disturbances, the reef communities have experienced anthropogenic disturbance as well. Some of the economically important fish species had previously been exploited by the fishing industry in the area[14], including French Polynesian fishing vessels, permitted international fishing vessels, and poachers fishing in French Polynesia's EEZ. Nearly all of the local large fishing vessels are based in Papeete, Tahiti, and with its proximity within the archipelagoes, most fishing occurs in the Society and

Figure 3 PICTURE OF THREE CROWN-OF-THORN STARFISH (COTS). PHOTO BY KEN MARKS.

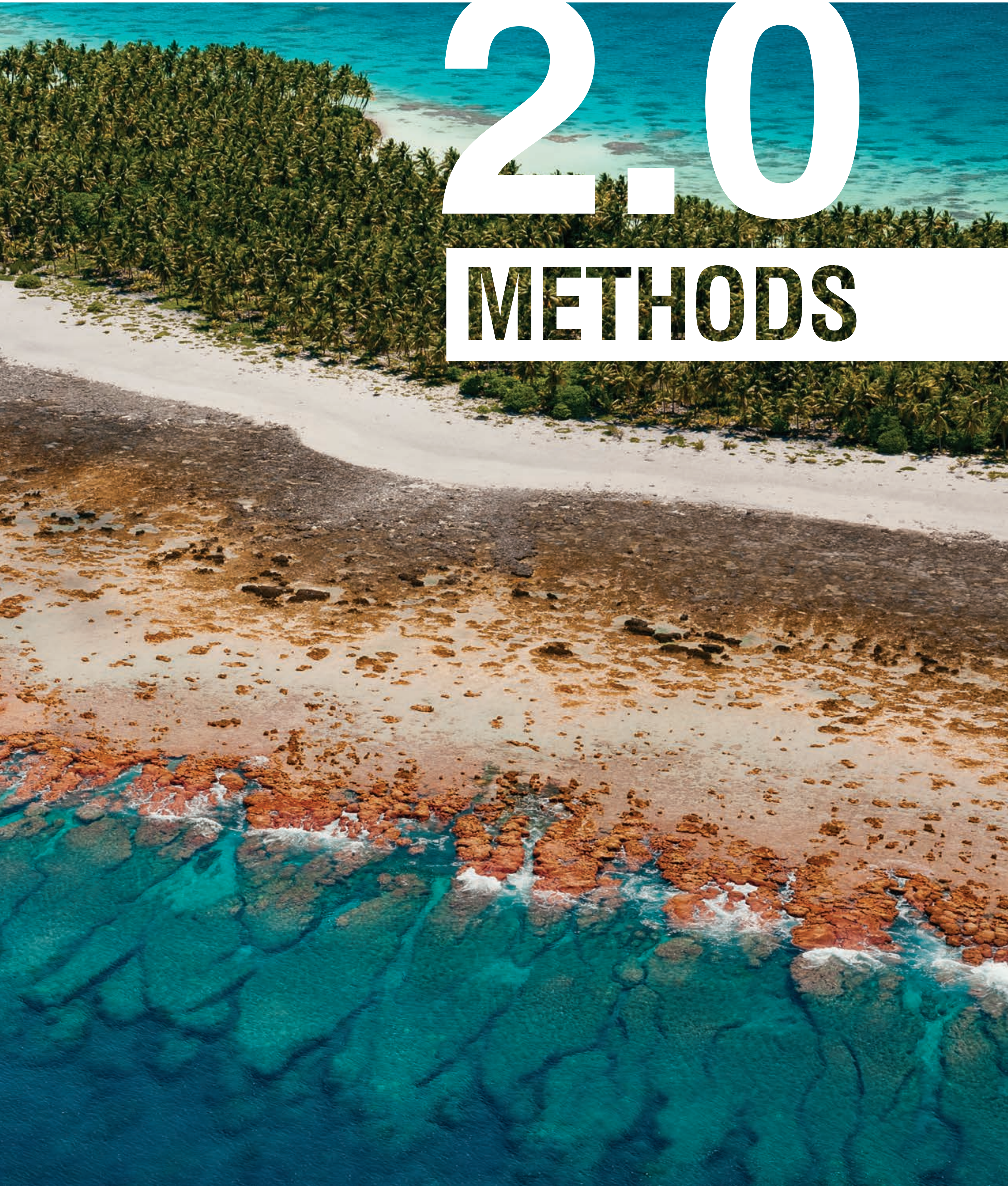
Tuamotu island groups[15]. The majority of the fish caught in French Polynesian waters are retained within the islands[5], and with the decline in fishing interest with the younger generations of native Polynesians, some of these fisheries have begun to recover.

French Polynesia's marine environment is interesting because it covers a large spatial area, yet is still somewhat isolated from the rest of the eastern Indo-Pacific coral ecosystems[16]. Despite this isolation, marine spatial ecosystem models show high connectivity within the islands[16,17]. This allows for retention of marine larval organisms, essentially allowing them to re-seed themselves after a disturbance[18–20].

The Global Reef Expedition was conducted to gain a thorough census of reef health throughout French Polynesia.

The GRE was conducted to gain a thorough census of reef health throughout French Polynesia. The majority of the current coral reef community research is centered around the islands of Tahiti and Moorea in the Society Archipelago and portions of the Tuamotu Archipelago. The remoteness of the Gambier and Austral Archipelagoes limits the ability to conduct research, so the historical data available are minimal. We hope the valuable information collected on this Expedition will be used and applied by managers in the establishment of successful management practices, such as development of MPAs. In 2009, France declared they would begin implementing more MPAs in their EEZ, suggesting that by 2020, 20% of all seas under the sovereignty of France will be designated MPAs. These MPAs will include portions of French Polynesia and there is a large area proposed in the Austral Archipelago. Currently there are only three islands with designated MPAs, two of which (Scilly and Bellinghausen) were visited by the GRE. In 1977, a United Nations Educational, Scientific, and Cultural Organization (UNESCO) Man and the Biosphere Reserve was established and included seven atolls in the Tuamotu Archipelago, of which four were surveyed on the GRE. The government of French Polynesia has also established locally managed areas, particularly in Tuamotu which focus on specific fisheries including giant clams and lobsters[21]. The protection of these marine habitats is critical to ensure the marine spatial connectivity between French Polynesia's islands is retained. The Khaled bin Sultan Living Oceans Foundation hopes the data presented in this report will aid managers in the decision making process of defining these Marine Protected Areas.

2.0 METHODS



METHODS

2.1 SITE DESCRIPTIONS

A total of 264 dive sites were surveyed throughout the four major Archipelagoes, among which 1,620 benthic habitat transects and 2,251 fish surveys were completed. **Appendix 1** provides a list of each dive site visited. These lists will include island name, date visited, latitude, longitude, hydrodynamic exposure, and reef type. The dive sites were chosen based on accessibility by boat and with the goal of including all reef habitats (as defined in the following habitat maps). **Table 1** reports the total number of surveys conducted in each archipelago.

1,620 benthic habitat transects and **2,251 fish surveys** were completed.

Table 1 TOTAL NUMBER OF DIVES AND TRANSECTS COMPLETED AT EACH ISLAND.

ISLAND GROUP	ISLAND	DIVE SITES	NUMBER OF BENTHIC TRANSECTS	NUMBER OF FISH TRANSECTS
Society	Mopelia	8	38	39
	Raiatea	6	28	37
	Tahaa	3	18	18
	Scilly	3	14	23
	Tahiti	7	30	47
	Tetiaroa	7	29	58
	Tupai	24	121	195
	Moorea	3	20	22
	Huahini	3	17	21
	Bellinghausen	5	27	35
	Maiao	3	25	12
Total		72	367	507
Tuamotu	Aratika	40	395	148
	Rangiroa	6	23	22
	Raraka	12	51	64
	Fakarava	24	81	129
	Toau	8	30	38
	Hao	17	94	85
Total		107	674	486
Gambier	Mangareva	3	20	12
	Maria Est	3	23	12
	Maturei Vavao	3	29	12
	Temoe	3	24	15
	Tenarunga	3	30	18
	Tenararo	33	150	198
	Vahanga	6	39	35
Total		54	315	302
Austral	MariaOeste	8	64	61
	Rimatara	9	74	44
	Raivavae	3	29	14
	Rurutu	5	40	22
	Tubuai	5	57	36
Total		30	264	177
Grand Total		263	1,620	1,472

2.2 HABITAT MAPPING

Using multispectral WorldView-2 satellite imagery obtained from DigitalGlobe Inc., in combination with data obtained from aerial surveys and ground-truthing, high resolution bathymetric maps and habitat maps were created for shallow marine environments within the lagoon and fore reefs (see examples of map outputs in **Figure 4**). These maps provide valuable data that portrays the most accurate habitat classifications of the islands surveyed. These data will be useful for not only marine spatial planning, but as a reference for future research on French Polynesia's coral reefs. The maps extend from the shoreline to approximately 25 m depth. Prior to the field surveys, an aerial survey of each island's coastline and adjacent shallow marine habitat was undertaken. Ground-truthing efforts used to help define the map classes included continuous acoustics soundings, drop-camera deployment, samples of sediment and hard substrates, snorkel and dive assessments, and fine-scale photo transect surveys.

Figure 4a EXAMPLES OF HABITAT MAP OUTPUTS, SPECIFICALLY OF TUBUAI, AUSTRAL ARCHIPELAGO. (A) SATELLITE IMAGE.

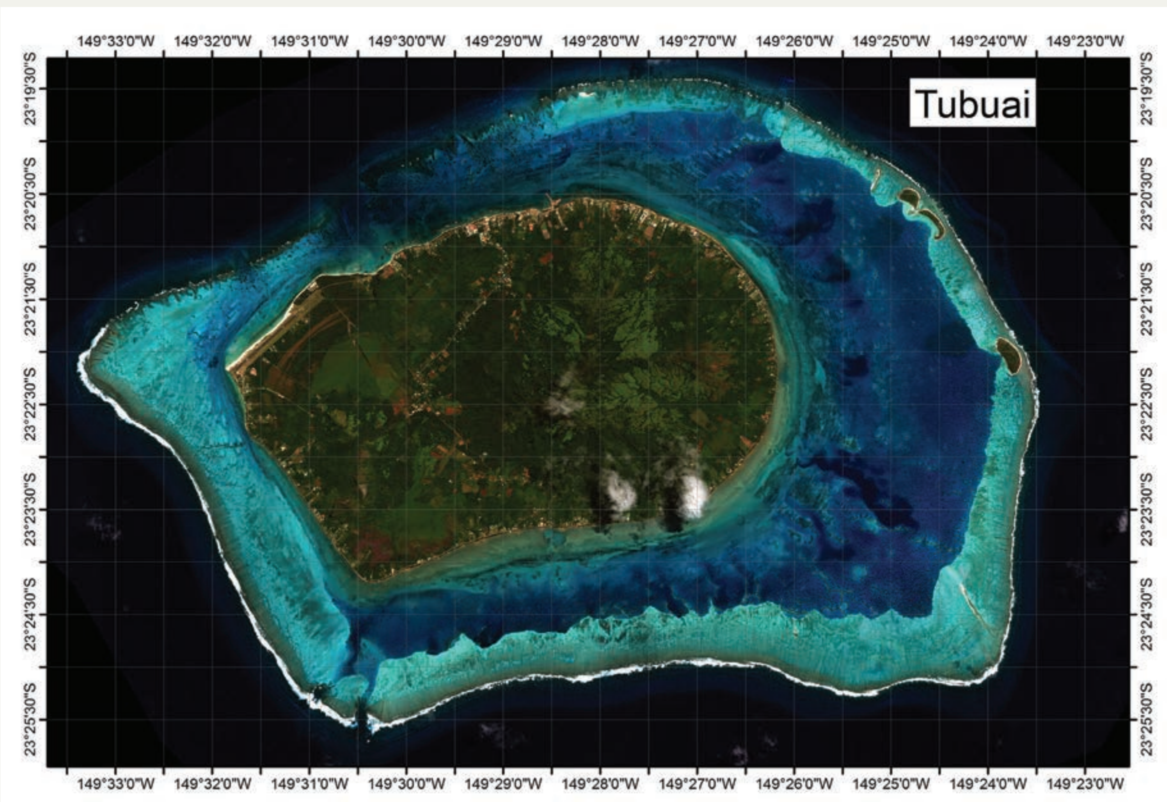


Figure 4b HABITAT MAP WITH DIFFERENT HABITATS CLASSIFIED.

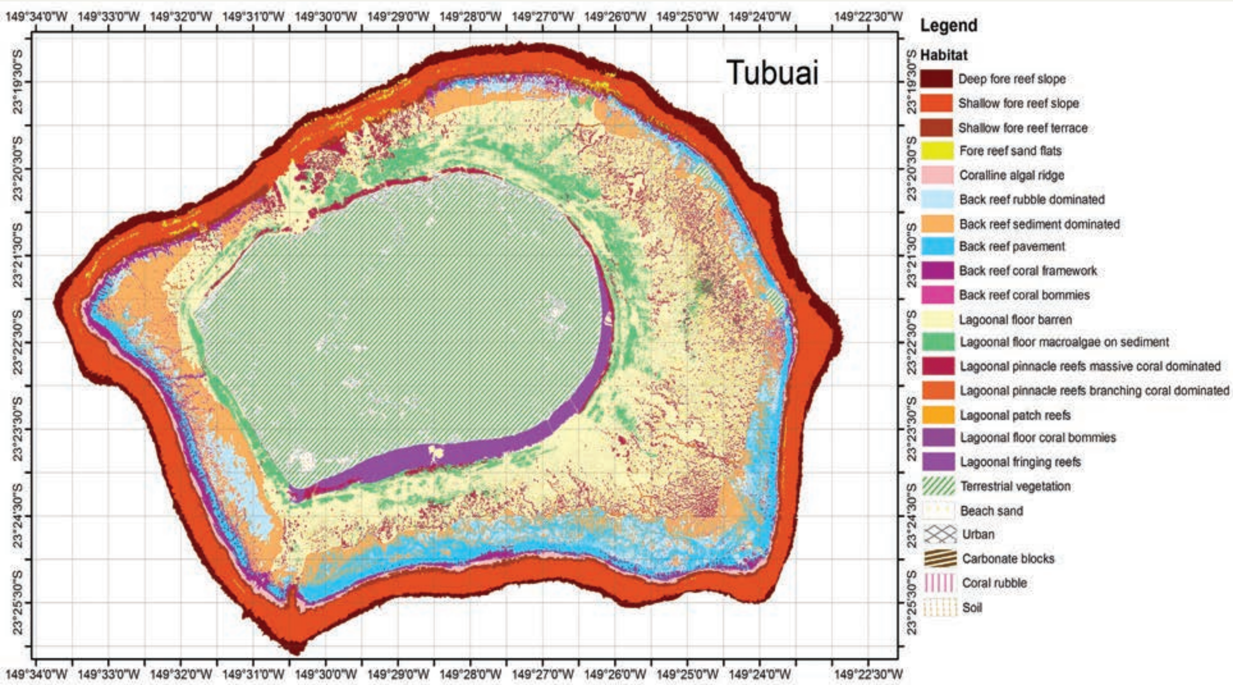
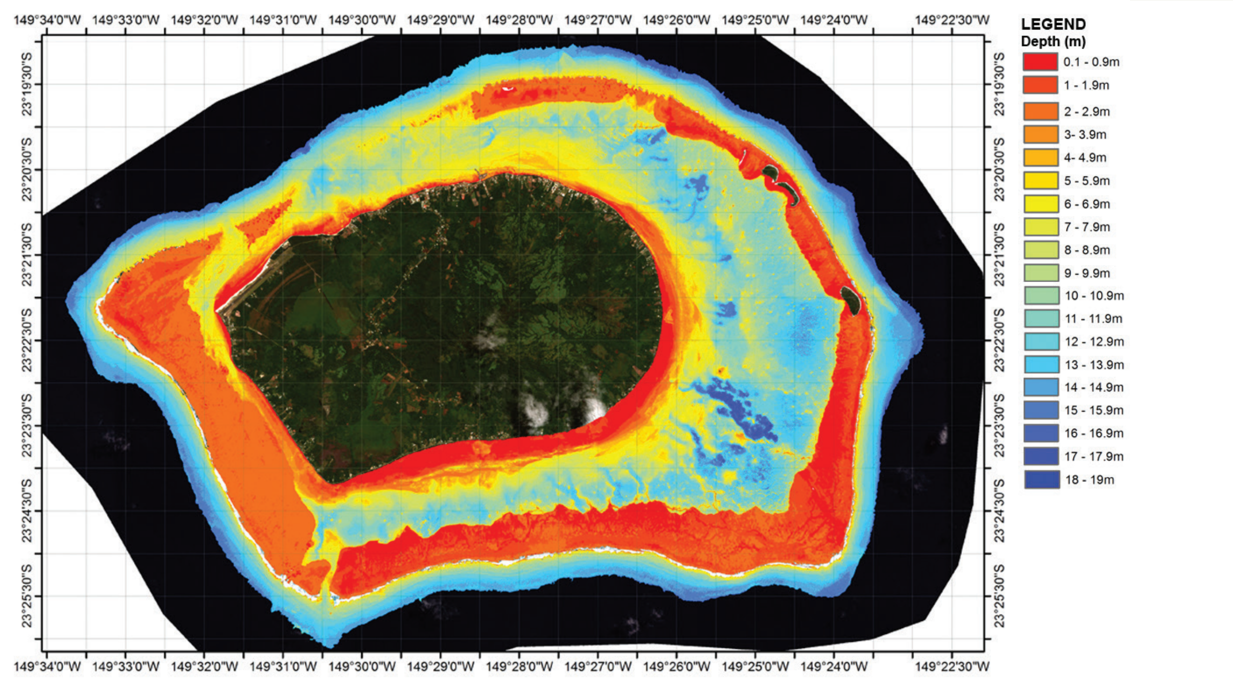


Figure 4c BATHYMETRY MAP DEFINING DEPTHS SURROUNDING THE ISLAND.



2.2 a SATELLITE IMAGERY

A total of 9,332 km^2 of WorldView-2 (8 band) satellite imagery was acquired for the 29 islands mapped. The satellite images had a spatial resolution of 2 m x 2 m (each pixel covers a 4 m^2 area) enabling real-time navigation in the field to locate features of interest. The team used the satellite scenes in conjunction with a differential GPS device (dGPS) to navigate throughout the archipelagoes. Modelers used the imagery combined with the ground-truthing data to create bathymetric and benthic habitat maps that can be found on the KSLOF World Web Map Portal (http://maps.lof.org/lof).

2.2 b BENTHIC VIDEO

A tethered underwater video camera termed a “drop-cam”, was used to gather video of the benthic composition at each survey site (Figure 5). At each point, the drop-cam was lowered from the survey boat enabling it to “fly” along the seafloor recording video for 15-60 seconds. During this time, the laptop operator both recorded the video stream and watched it in real-time to guide the drop-cam operator to raise or lower the camera in order to maintain a constant altitude above the seafloor. In this manner, we were able to prevent damage to marine life and the camera. The video was recorded on a ruggedized laptop and the geographic position, time, date, boat heading, and boat speed were convolved into the recording. Drop-cam deployment was limited to depths shallower than 40 m due to the length of the tether cable (50 m). Clips of selected drop-cams are also included as a layer of the GIS maps produced on the KSLOF online Map Portal.

Figure 5 SEAVIEWER UNDERWATER VIDEO SYSTEM, OR DROP-CAM, USED TO RECORD BENTHIC COMPOSITION AROUND EACH ISLAND.

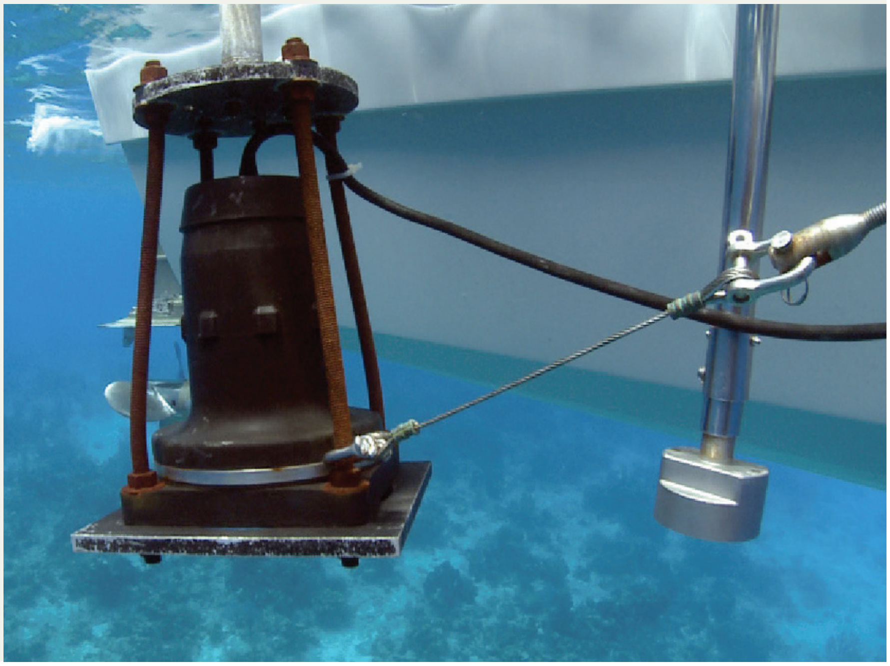
2.2 c HABITAT CLASSIFICATIONS

Habitat classifications of all the marine and terrestrial habitat types were determined using the satellite imagery, ground-truthing, and benthic video surveys. The combination of all data collected was used for development of a habitat classification scheme and training of eCognition® software to develop object-based classification models. A total of 33 habitat types were defined **(Appendix 2)**. When calculating and presenting total area coverage of the different habitat classifications, we sometimes combined multiple habitat types. For example, backreef coral was defined by combining backreef coral bommies and backreef coral framework. Appendix 2 shows the breakdown of each classification group. A more detailed description of each habitat classification can be found online in the KSLOF interactive World Web Map portal under the information tab.

2.2 d ACOUSTIC DEPTH SOUNDINGS

Depth soundings were gathered along transects using a Syqwest Hydrobox, a single-beam acoustic sonar which emits 50 pings per second **(Figure 6)**. 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 maps have the same spatial resolution as the satellite imagery and can also be found as a bathymetry layer in the online Map Portal.

Figure 6 ACOUSTIC SUB-BOTTOM PROFILING EQUIPMENT, STRATABOX (LEFT) AND HYDROBOX (RIGHT).



2.3 CORAL REEF COMMUNITY SURVEYS

The GRE used a combination of quantitative methods, including belt transects, point intercept transects, and quadrats to assess benthic and fish communities of reefs located in French Polynesia. This standardized collection methodology provides robust data that can be compared regionally and globally, although this report provides a broad discussion of trends and patterns as a prelude to more in depth analysis.

2.3 a BENTHIC COVER ASSESSMENT

Cover of major functional groups and substrate type (Table 2) were assessed along 10 m transects using recorded observations and/or photographic assessments. The major functional groups included: corals identified to genus, other sessile invertebrates identified to phylum or class, and six functional groups of algae. At least two surveyors using SCUBA recorded observations using a point intercept method. This technique required the surveyor to lay out a 10 m transect line and record the organism and substrate type at every 10 cm mark (total 100 points per transect). A minimum of four transects were completed at each dive site (Figure 7), and when possible, surveys were completed at 25, 20, 15, 10, and 5 m depths.

At some locations, it was necessary to conduct a photographic assessment to supplement the point intercept surveys. In this sampling technique, a scientific diver used a 1 m x 1 m quadrate, flipping it over a total of 10 times per transect to photograph a full 1 m^2 x 10 m photo transect (Figure 8). The diver completed one survey at 20, 15, 10, and 5 m depth at

Figure 7 PHOTO OF A DIVER CONDUCTING A BENTHIC SURVEY. PHOTO BY KEN MARKS.

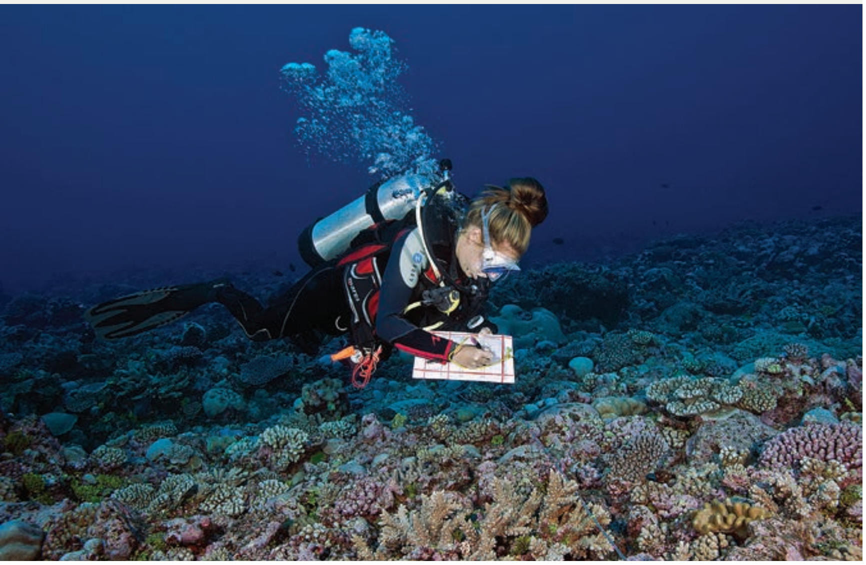


Table 2 CLASSIFICATION OF THE BENTHOS RECORDED DURING SCUBA SURVEYS.

BENTHIC HABITAT
SUBSTRATE TYPE
Live Coral
Dead Coral
Fused Rubble
Pavement
Rubble
Sand/Sediment
Recently Dead Coral
SUBSTRATE TYPE
Algae
Macroalgae
Crustose Coralline Algae (CCA)
Erect Coralline Algae
Turf Sediment
Turf
Cyanobacteria
Other Invertebrates
Coral (to Genus)

each site when possible. Images were downloaded and analyzed using Coral Point Count with Excel Extensions (CPCe) software developed by Nova Southeastern University's National Coral Reef Institute (NCRI) in order to determine benthic community composition, coral cover, and algae cover[22]. The 1 m x 1 m images were imported into the software where 50 randomly selected points were overlaid on each photograph. A scientist then defined the organism and substrate type directly underneath the point **(Figure 9)**. These data were then exported into a Microsoft Excel (2013) spreadsheet, and added to the benthic survey database for analysis.

The benthic cover percentages were calculated for each island as the average percentage of all transects collected at that island, binned first by depth, then by site. The percentage of each substrate type was calculated by dividing the total number of samples observed in each depth on each transect by the total number of points recorded, multiplied by 100. The average percentage of all transects at the island is presented as the measure of each substrate type. To further analyze the coral and algal cover, the sum of the specific algae types or coral genus recorded on each transect was divided by the total number of algae or coral observed per transect. The average of the percentages for each algae type is presented in the figures in the results.

To measure overall coral diversity (by genus), we used the Shannon-Weiner Index which is commonly used to characterize species diversity in a community. This index uses the total number of individual coral colonies of a specific genus observed per island, and the total number of genus' to provide a number to represent the total diversity of the island community. In most ecological surveys, diversity typically ranges from 1.5 to 3.5, with more than 4 rarely, if ever, being seen[23].

Figure 8 A DIVER TAKES A PHOTO OF A 1 M BY 1 M SQUARE QUADRAT. PHOTO BY PHILIP RENAUD.

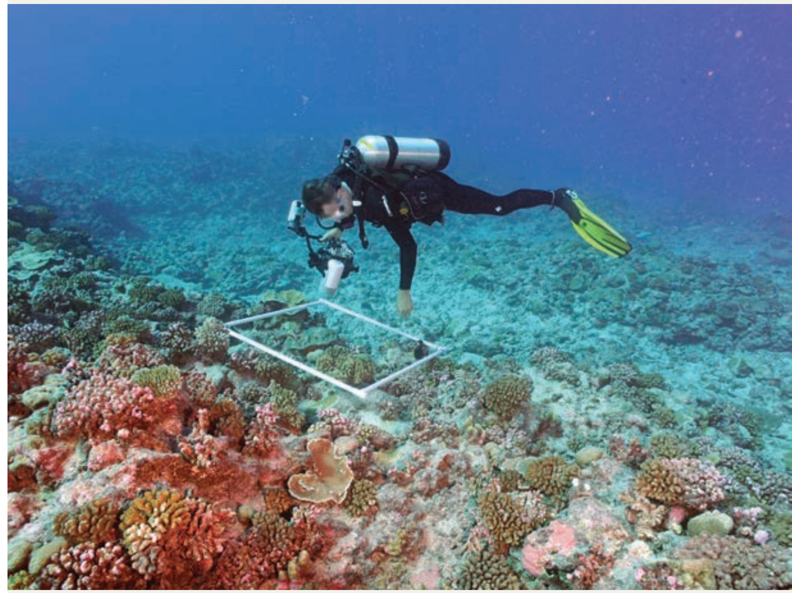
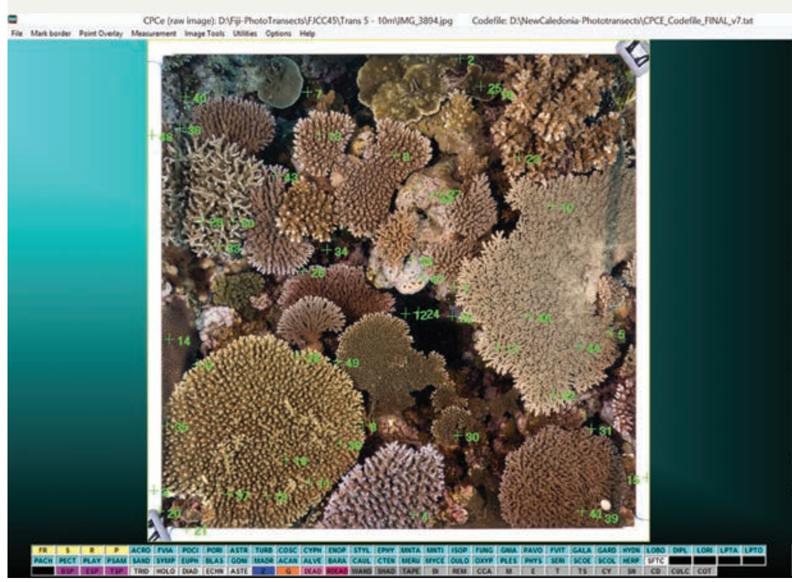


Figure 9 EXAMPLE OF A PHOTOGRAPHED QUADRAT IMPORTED INTO CPCE SOFTWARE, WITH RANDOMLY PLACED POINTS FOR IDENTIFICATION.



2.3 b

FISH COMMUNITY ASSESSMENTS

Reef fish surveys were conducted by at least two surveyors at selected locations at each of these four island groups, except at Rangiroa where only one surveyor was present for majority of the surveys. The survey transects covered depths between 1 and 22 m, and the majority of the transects were within the range of 5 to 20 m depth.

The fish assemblages at the dive sites were surveyed following a fish visual census technique modified from the survey principles described by English *et al.* (1994)[24]. Each diver identified and counted fish along a 30 m x 4 m transect **(Figure 10)**. Each transect survey was completed in about 10 to 15 minutes. Transects were deployed at deep (>12 m) and shallow (<10 m) sections of the reefs whenever possible. At least two transects of the deep reefs and another two transects of the shallow reefs were surveyed by each diver.

The fish assemblages were characterized in terms of species richness, abundance and standing stock biomass. Fish were identified to species level whenever possible with the aid of photographic fish guides[25–28]. Total lengths of fish were estimated to the nearest centimeter. The abundance of each species of a particular size was estimated by actual counts or by cluster. The biomass of each species was then computed using the formula $W = aL^b$ where **W** is the weight in grams, **L** is the length in centimeters, and ***a*** and ***b*** are the species specific growth constants from literature-derived length-weight relationships[29–33]. Abundance and biomass data were then converted and represented as density by individuals/100 m^2 and biomass by kg/100 m^2. Fish species richness values were expressed in units of number of species per 120 m^2.

Reef fishes were also categorized as either indicator, major, minor, target, or target/indicator species according to their importance for local fisheries and reef health and diet information from FishBase (www.fishbase.org). Indicator species include corallivores whose numbers and richness may give an indication of the relative condition of the reef[34]. Species which are highly associated with live corals for shelter, and small herbivores that "farm" algal patches, also fall under this category. This category includes most butterflyfishes, some wrasse, damselfishes, and triggerfish among others. Major species are those considered to have considerable ecological importance based on their function as trophic links and their relatively large body size and abundance on reefs. Some examples are a few surgeonfish, some triggerfish and the majority of wrasses. Minor species also play important ecological roles but they are mostly small in size compared to major species. Examples include cardinalfishes and many damselfish. Target fish are those taken in fisheries and include species that are caught for sustenance and/or are sold for consumption. Most groupers, snappers, jacks, parrotfish, and some wrasses represent this group. Target/indicator species are fish also taken in fisheries but are known to be environmental indicators such as some parrotfishes and triggerfish.

Figure 10 A DIVER RECORDING FISH ALONG A TRANSECT. PHOTO BY ©MICHELE WESTMORLAND/ILCP.

FRENCH POLYNESIA

3.0 RESULTS

3.1 SOCIETY ARCHIPELAGO

Society is both the most populated and best studied of the five French Polynesian archipelagoes. The archipelago is comprised of atolls and atolls with high volcanic islands, with most of the population concentrating on the islands of Tahiti, Moorea, and Raiatea. Three of the atolls visited (Mopelia, Scilly, and Bellinghausen) are uninhabited, two of which (Scilly and Bellinghausen) are designated MPAs.

Most of the coral reef research in the Society Archipelago has been centralized around the islands of Moorea and Tahiti, especially after the establishment of the Centre de Recherches Insulaires et Observatoire de l'Environnement de Polynésie Française (CRIOBE) research station in the early 1970s and the University of California, Berkley, Gump Research Station in the early 1980s. Long-term monitoring conducted by this pair of stations as well as other research groups has proven critical in understanding the anthropogenic impacts on coral reefs, as well as natural disasters such as COTS outbreaks, cyclone damage, and climate change[35–40].

Two major natural disturbances have had an impact on islands in the Society Archipelago in the five years prior to the GRE missions. Elevated densities of COTS reportedly started in 2002 and lasted until 2010, impacting the islands of Tūpai, Raiatea, Taha'a, Tetiaroa, and Huahine[2]. In 2010, Cyclone Oli, a category four cyclone, almost directly hit the outer atolls (Bellinghausen, Scilly, and Mopelia) causing severe degradation of the reefs. High waves caused particular damage to the reefs[41]. During the GRE, an active COTS outbreak was observed at Bellinghausen atoll, and a secondary outbreak was actively occurring at Tetiaroa.

In September-October 2012 and March 2013, scientists on the GRE surveyed coral reef health at 11 of the islands in the Society Archipelago, visiting 72 dive sites, completing a total of 367 benthic surveys and 1,078 fish surveys. Table 1 shows the total number of dive sites and surveys per island and the online map portal allows each dive site to be interactively located.

3.1a HABITAT MAPPING

The satellite imagery used to profile the islands visited in the Society Archipelago covered 1,105 km^2. A total of 316 drop-cams were deployed throughout the islands, and nearly 2.5 million depth soundings were made to create high-resolution bathymetric maps.

The islands mapped in the Society Archipelago classified the total reef habitat types (i.e. substrate with meaningful coverage of live coral colonies) including backreef coral, lagoonal coral, lagoonal pinnacle reefs, and shallow fore reef communities as covering about 110 km^2. The fore reef communities accounted for 28 km^2, while reef habitats located on the backreef and lagoon accounted for the remainder. The average total square kilometers of shallow fore reef communities ranged from 0.8-11 km^2 with Raiatea-Taha'a having the most area (Table 3), followed by Huahine with 5 km^2 of fore reef area. The lagoonal reefs were most prevalent in the shared lagoon surrounding Raiatea and Taha'a with just over 10 km^2 of reef area. It is worth noting that the total area mapped for Raiatea-Taha'a is nearly five times the area of the next highest mapped region, which explains why it has the highest reef area. Algal substrate dominated habitats were relatively small, only covering from <0.5-2.3 km^2 throughout all islands. Across all locations lagoonal substrate was the dominant marine habitat mapped, however this varied greatly depending on the size of the lagoon.

Detailed maps of the locations visited on the GRE to French Polynesia, which include detailed descriptions of the habitat classifications, can be found on the KSLOF interactive map portal (http://maps.lof.org/lof). GIS data is available upon request.

Table 3

TOTAL AREA (KM²) OF THE HABITAT TYPES BY ISLAND IN THE SOCIETY ARCHIPELAGO.

THE SOCIETY ARCHIPELAGO	TOTAL AREA SQUARE KM							
HABITAT CLASSIFICATION	Bellinghausen	Huahini	Maiao	Mopelia	Scilly	Tahaa-Raitea	Tetiaroa	Tupai
Back reef coral bommies	0.004	0.07	0.004	0.013	0.004	0.202	0.034	0.011
Back reef coral framework	0.769	5.547	1.977	3.813	4.112	14.603	3.42	3.195
Back reef pavement	0.825	2.583	0.767	2.099	7.836	10.831	0	0.642
Back reef rubble dominated	0.295	5.666	2.685	3.186	3.661	16.395	2.309	--
Back reef sediment dominated	1.818	11.179	--	5.005	6.341	52.867	10.028	2.506
Beach sand	0.316	0.24	0.806	0.668	1.483	0.177	0.461	1.2
Carbonate blocks	--	--	--	--	--	--	--	--
Coral rubble	0.687	0.333	0.194	0.644	0.535	0.833	0.184	0.458
Coralline algal ridge	0.345	1.049	0.546	0.768	1.143	2.319	0.859	0.769
Deep fore reef slope	0.652	2.859	0.989	0.736	1.137	8.242	2.02	1.39
Deep lagoonal water	0.409	15.385	--	23.243	73.017	116.254	5.603	--
Fore reef sand flats	--	0.014	--	--	--	--	--	--
Inland waters	0.015	0.048	3.525	--	--	0.134	--	--
Mud	--	--	0.734	--	--	--	--	--
Lagoonal Acropora framework	--	--	--	--	--	--	--	--
Lagoonal coral framework	--	--	--	--	--	--	--	--
Lagoonal floor barren	2.158	4.433	--	5.477	7.75	13.071	4.415	8.118
Lagoonal floor coral bommies	0.001	0.01	--	0	0.003	0.03	0.006	0.002
Lagoonal fringing reefs	--	7.21	--	--	--	16.684	--	--
Lagoonal floor macroalgae on sediment	0.041	--	--	--	--	0.046	0	--
Lagoonal patch reefs	0.064	0.237	--	0.046	0.023	0.665	0.139	0.054
Lagoonal pavement	--	--	--	--	--	--	--	--
Lagoonal pinnacle reefs branching coral dominated	0.648	--	--	--	--	0.896	--	--
Lagoonal pinnacle reefs massive coral dominated	--	2.673	--	0.42	0.304	13.42	1.071	0.229
Lagoonal sediment apron macroalgae on sediment	--	--	--	--	--	--	--	--
Lagoonal sediment apron sediment dominated	0.468	--	--	1.294	2.598	--	0	3.058
Reef-top algal mats	--	--	--	--	0.063	--	--	--
Rock	0.596	2.514	0.136	0.672	2.098	4.775	0.92	0.855
Shallow fore reef slope	0.463	3.309	1.106	1.261	1.33	6.42	0.964	1.279
Shallow fore reef terrace	0.337	2.286	0.414	1.076	1.89	4.575	0.695	0.506
Soil	--	4.094	--	--	--	--	--	--
Terrestrial vegetation	2.549	66.279	7.315	3.035	2.524	248.418	4.371	8.531
Urban	--	1.742	0.043	0.001	0.001	8.373	0.099	0.06

3.1 b BENTHIC COVER ASSESSMENT

Overall, the dominant substrate type recorded using SCUBA surveys in the Society Archipelago was hard bottom or pavement, with the coral and algae cover varying by island, as shown in Figure 11. The two most dominant algae types throughout all of the locations surveyed in the Society Archipelago were crustose coralline algae (CCA) and turf algae (Figure 12).

Mopelia, Scilly, and Bellinghausen atolls had the highest overall coral cover (30-34%) of all of the surveyed Society sites. The dominant coral genus found at Mopelia and Scilly was *Pocillopora*, and *Porites* at Bellinghausen. The island of Mopelia had the highest coral cover recorded above the 15 m depth on the fore reefs. In the lagoon, the sites were dominated by massive boulder corals *(Porites)* on sediment. The total algae cover at Mopelia accounted for 38% (± 20.9 % S.D.) of the overall live substrate, of which 54% (± 21.2% S.D.) of the total algae was CCA. Bare substrate was recorded as 27% (± 21% S.D.) of the overall benthic habitat which was likely higher due to the lagoon sites sampled. Scilly had more algae (45 ± 14% S.D. total algae) and less bare substrate (20 ± 17% S.D.) than Mopelia with CCA being the dominant algae type. Bellinghausen had noticeably more CCA (65± 11% S.D. of the total algae recorded) than the other two islands. There was high coral recruitment observed at these outer islands, including some of the highest overall coral recruitment

Figure 11

BENTHIC COVER (%) OF THE ISLANDS SURVEYED IN THE SOCIETY ARCHIPELAGO. THE SUBSTRATE TYPES ARE BARE SUBSTRATE, ALGAE, LIVE CORAL, AND INVERTEBRATES.

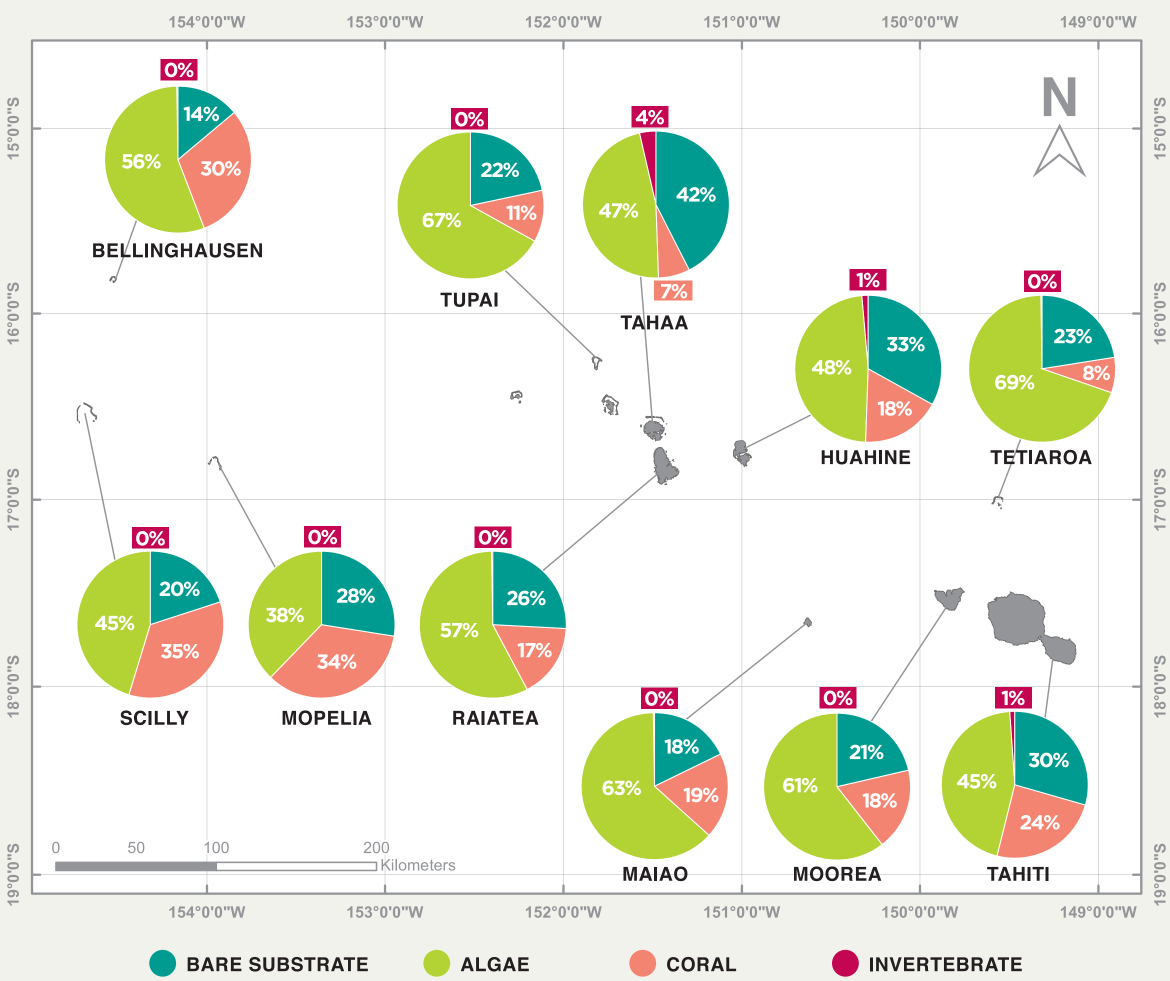


Figure 12

RELATIVE COMPOSITION OF ALGAE (%) AT EACH ISLAND IN THE SOCIETY ARCHIPELAGO.

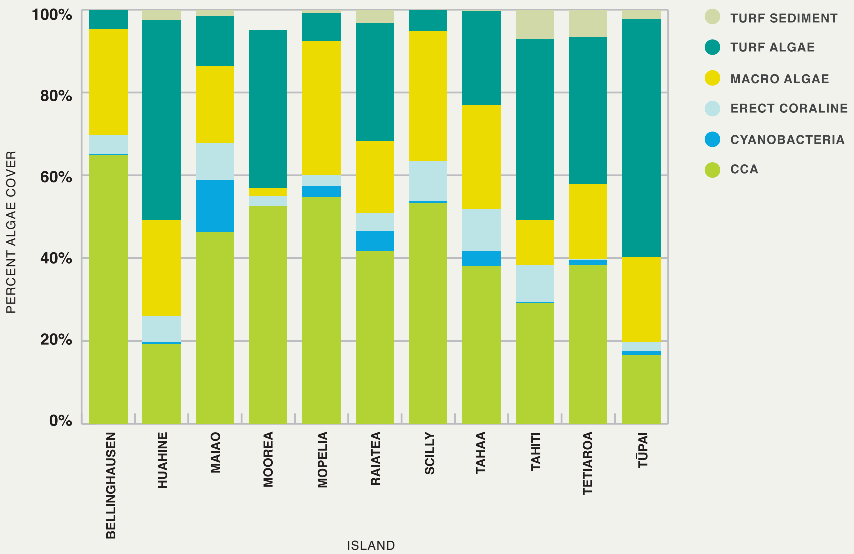


Table 4

SHANNON-WEINER INDEX VALUES FOR DIVERSITY OF CORAL FOR EACH ISLAND SURVEYED.

GROUP	ISLAND	S-W INDEX
Society	Mopelia	1.76
	Raiatea	1.60
	Tahaa	1.46
	Scilly	1.98
	Tahiti	1.84
	Tetiaroa	2.08
	Tupai	1.76
	Moorea	1.94
	Huahini	1.22
	Bellinghausen	1.74
	Maiao	1.99
Tuamotu	Aratika	1.63
	Rangiroa	1.96
	Raraka	1.89
	Fakarava	1.77
	Toau	1.20
	Hao	1.95
Gambier	Mangareva	1.64
	Maria Est	1.74
	Maturei Vavao	1.87
	Temoe	1.96
	Tenarunga	1.88
	Tenararo	1.80
	Vahanga	1.93
Austral	MariaOeste	1.96
	Rimatara	2.20
	Raivavae	2.20
	Rurutu	2.08
	Tubuai	2.23

observed in all of French Polynesia. This metric was not specifically recorded.

Moorea, Tahiti, Maiao, Huahine, and Raiatea all had relatively similar coral cover ranging between 16-24%. Algae covered between 47-63% of the overall live cover at the sites, with CCA being the dominant algae type at Moorea, Maiao, and Raiatea (34-40%). Turf was the dominant algae type in Tahiti and Huahine, accounting for 43% (± 24% S.D.) and 48% (± 33% S.D.) of the total algae recorded respectively. The dominant coral genera at Moorea, Maiao, and Raiatea was *Pocillopora* comprising between 36-40% of the total coral recorded at these islands. At Tahiti and Huahine, *Porites* dominated the substrate, accounting for 39% (± 22% S.D.) and 47% (± 33% S.D.) of the total coral respectively.

The three islands with the lowest coral cover were Taha'a, Tetiaroa, and Tūpai accounting for only 7-11% of the total substrate. Taha'a had higher sessile invertebrates (dominated by Zooanthids) covering 4% (± 9% S.D.) of the benthic substrate which was the most recorded at any island. The dominant algae at both Taha'a and Tetiaroa was CCA which comprised about 33% (± 17%, 24% S.D.) of the total algae. At Tūpai, turf algae were dominant measuring 50% (± 31% S.D.) of the overall live cover recorded. Of the coral observed at Taha'a and Tetiaroa, *Pocillopora* was the most common genus, measuring 45% (± 21% S.D.) and 33% (± 17% S.D.) of the total coral cover, respectively, while *Porites* was dominant at Tūpai measuring 48% (± 21% S.D.) of the coral recorded. Tetiaroa was affected by a COTS outbreak in 2008 and was actively experiencing a secondary COTS outbreak at the time of sampling[2]. There was also evidence of high sedimentation on the west side of the atoll due to development and construction on the island, and when compounded with the COTS outbreak was the likely cause of the low coral cover.

In the Society Archipelago, Tetiaroa, Maiao, Scilly, and Moorea, had the highest coral diversity, ranging from 1.9-2.1. The islands with the lowest diversity were Huahine (1.2) followed by Taha'a (1.4). The rest of the islands ranged between 1.6-1.8 on the Shannon-Weiner index. Table 4 shows the diversity of each island sampled, separated by archipelago.

3.1c FISH COMMUNITY ASSESSMENT

The fish communities at the islands surveyed in the Society Archipelago were dominated by small-bodied reef fish species in terms of composition and density. Fish species commonly found under this general description were mostly wrasses (Labridae) and damselfish (Pomacentridae). Large predators such as sharks (Carcharhinidae), groupers (Serranidae) and jacks (Carangidae) were quite varied, but occurred less frequently and in small numbers. Of these three families, Serranidae was the most common and most abundant. Large herbivorous fish such as surgeonfish (Acanthuridae) and parrotfish (Scaridae) were speciose and occurred in moderate to high numbers. Coral reef health indicator species such as butterflyfish (Chaetodontidae) had high species richness and occurred commonly suggesting moderate reef health at most sites.

SPECIES RICHNESS OF THE FISH ASSEMBLAGE

Overall, a total of 269 unique species of fish distributed among 41 families were identified in the Society Archipelago (Table 5). Total species richness at each island ranged from 66 species at Moorea up to 211 species at Raiatea. Of the total number of species, 29 were considered to be indicator species, 57 were major species, 76 were minor species, while 101 were target species and only six were target/indicator species.

> The fish communities of the Society Archipelago were **dominated by small-bodied reef fish species.**

The estimated mean species richness varied across islands, ranging from 18 (±3 S.D.) species/120 m^2 at Moorea to 39 (±9 S.D.) species/120 m^2 at Tetiaroa (Table 5). The mean total species richness for the Society Archipelago islands was 28 (±9 S.D.) species/120 m^2. Estimated mean species richness of five of the islands fell below the mean total, namely: Huahine, Moorea, Raiatea, Taha'a, and Tahiti (Table 5). Bellinghausen, Maiao, Mopelia, Scilly, Tetiaroa and Tūpai each had mean species richness which was greater than the mean total. The total number of species and mean total estimated species richness in the Society Archipelago was greater than those in the Austral Archipelago, but less than the estimates in the Tuamotu and Gambier Archipelagoes (Table 6).

The composition of the fish assemblages varied across islands, but with similar general patterns. Mean number of target species was the lowest at Moorea, with only 3 (±2 S.D.) species, and highest at Scilly and Tetiaroa with 11 (±4 S.D.) target species each (Figure 13). The compositions of major and minor

Figure 13 MEAN ESTIMATED SPECIES RICHNESS OF FISH (SPECIES/120 M^2) BY CATEGORY IN THE SOCIETY ARCHIPELAGO.

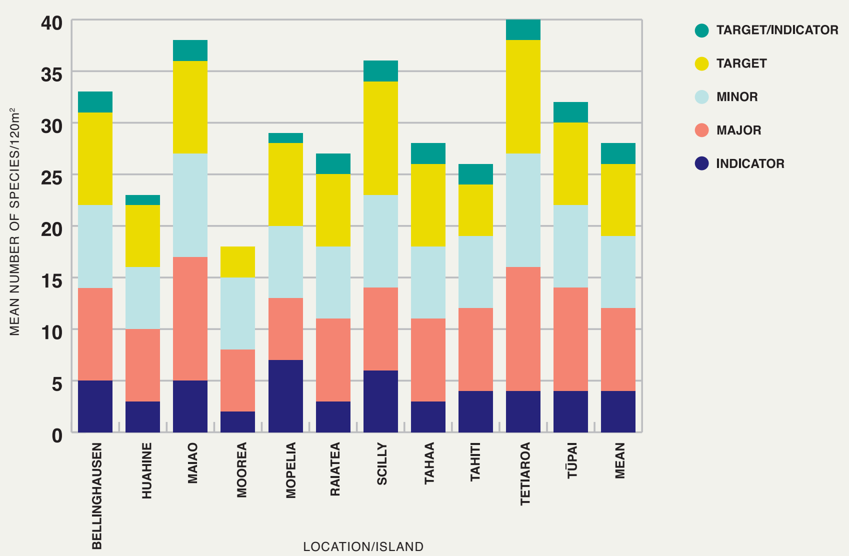


Table 5 MEAN FISH SPECIES RICHNESS (# SPECIES/120 M² ±S.D.), MEAN FISH DENSITY (# INDIVIDUALS/100 M² ±S.D.), MEAN FISH BIOMASS (KG/100 M² ±S.D.) IN THE SOCIETY ARCHIPELAGO.

LOCATION/ISLAND	# of Survey Stations	# of Replicate Transects	Total Families	Total Species	Mean # of Species	Mean Density	Mean Biomass
Bellinghausen	3	18	21	103	33 (±8)	222 (±103)	14.6 (±23.3)
Huahine	7	47	28	156	24 (±7)	139 (±85)	4.6 (±3.5)
Maiao	3	22	22	133	38 (±8)	256 (±68)	6.4 (±3.5)
Moorea	3	12	20	67	18 (±3)	98 (±52)	5.4 (±9.4)
Mopelia	8	39	27	138	29 (±8)	191 (±93)	16.9 (±18.6)
Raiatea	24	195	32	211	27 (±7)	168 (±106)	6.4 (±7.3)
Scilly	6	37	24	123	36 (±8)	246 (±122)	14.2 (±13.5)
Tahaa	7	58	31	169	27 (±9)	174 (±118)	5.7 (±4.9)
Tahiti	5	35	27	141	25 (±6)	107 (±49)	3.9 (±1.9)
Tetiaroa	3	21	24	129	39 (±9)	328 (±114)	9.3 (±3.9)
Tupai	3	23	22	121	32 (±5)	244 (±95)	4.9 (±2.9)
TOTAL/MEAN	**72**	**507**	**41**	**269**	**28 (±9)**	**183 (±111)**	**7.7 (±10.0)**

species were largely below 10 species at each island except at Maiao and Tetiaroa, where it was 1-2 species higher. The islands with the overall highest mean species richness were Bellinghausen, Maiao, Scilly, Tetiaroa, and Tūpai with between 32 (±5 S.D.) species and 39 (±9 S.D.) species/120 m².

FISH DENSITY

Mean fish density among the islands ranged from 98 (±52 S.D.) individuals/100 m² at Moorea up to 328 (±114 S.D.) individuals/100 m² at Tetiaroa. Bellinghausen, Maiao, Scilly, Tetiaroa and Tūpai had the highest mean fish densities in the Society Archipelago. Across all islands, minor fish species were numerically dominant with a mean total density of about 102 (±87 S.D.) individuals/100 m² (Figure 14). The Society Archipelago had the second highest mean total density relative to Tuamotu, Gambier, and Austral Archipelagoes (Table 6).

Figure 14 MEAN DENSITY OF FISH (# INDIVIDUALS/100 M²) BY CATEGORY IN THE SOCIETY ARCHIPELAGO.

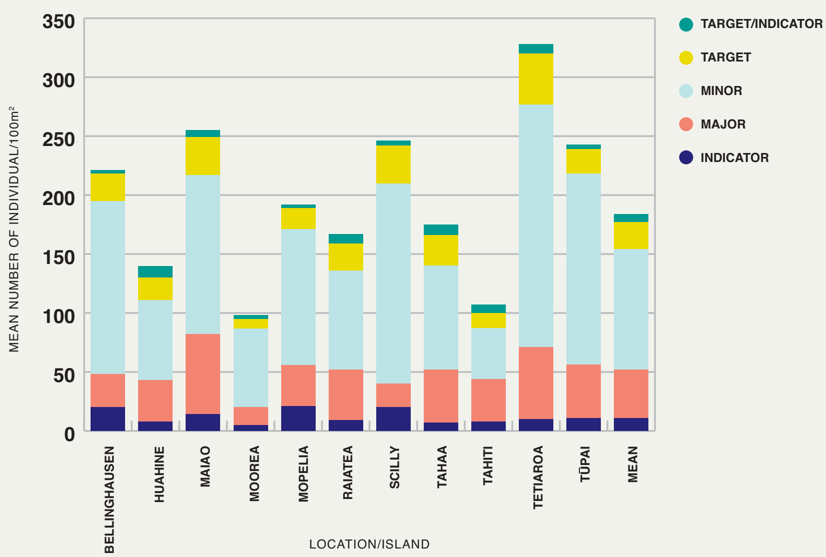


Table 6 TOTAL NUMBER OF FISH SPECIES, MEAN SPECIES RICHNESS (# SPECIES/120 M^2 ±S.D.), MEAN FISH DENSITY (# INDIVIDUALS/100 M^2 ±S.D.), MEAN FISH BIOMASS (KG/100 M^2 ±S.D.) FROM EACH ARCHIPELAGO.

MISSION LOCATION	Total Species	Mean Species	Mean Abundance	Total Species	Mean Biomass	Mean Biomass
Society	269	28 (±9)	183 (±111)	7.7 (±10.0)	33 (±8)	14.6 (±23.3)
Tuamotu	299	34 (±15)	283 (±227)	52.5 (±81.9)	24 (±7)	4.6 (±3.5)
Gambier	272	32 (±12)	162 (±94)	17.1 (±26.8)	38 (±8)	6.4 (±3.5)
Austral	223	27 (±11)	110 (±55)	8.8 (±17.8)	18 (±3)	5.4 (±9.4)

Despite having relatively high species richness, target fish were few in numbers. There were only about 8 (±5 S.D.) to 43 (±22 S.D.) individuals/100 m^2 at each of the islands. The highest abundances of target species were found at Maiao, Scilly, Taha'a, and Tetiaroa **(Figure 14)**. Indicator species were relatively speciose, but only comprised a small portion of the fish densities across all islands in the Society Archipelago. The densities of indicator species were highest at Bellinghausen, Mopelia and Scilly reaching 21 (±10 S.D.) individuals/100 m^2 at Mopelia. The density of indicator species did not exceed 15 individuals at the other islands **(Figure 14)**.

> Of the ecologically and economically important fish size classes were dominated by **mostly small fish.**

FISH BIOMASS

The overall mean total biomass of fish in the Society Archipelago was 7.74 (±10.0 S.D.) kg/100 m^2 **(Table 5)**. Estimated mean fish biomass ranged from a low of 3.9 (±1.9 S.D.) kg/100 m^2 at Tahiti to a high of 16.9 (18.6 S.D.) kg/100 m^2 at Mopelia. The islands with the highest biomass estimates were Mopelia, Scilly, and Bellinghausen. The mean total biomass of fish in the Society Archipelago was the least of the four mission locations following the Austral, Gambier and Tuamotu Archipelagoes **(Table 6)**.

Target species contributed the bulk of the mean biomass throughout all of the Society Archipelago, except at Tahiti where major species contributed slightly more biomass over target species. Target species contributed as much as 14 (±18 S.D.) kg/100 m^2 of fish biomass at Mopelia and as low as 1.0 (±0.7 S.D.) kg/100 m^2 at Tahiti **(Figure 15)**. Other islands with high biomass contributions from target fish were Bellinghausen, and Scilly. Major species contributed far less biomass compared to target species but they were quite important at Huahine, Maiao, Raiatea, Taha'a, Tahiti and Tetiaroa where their biomass exceeded 1 kg/100 m^2 **(Figure 15)**. The biomass of minor and indicator species was less than 1 kg across all islands except at Bellinghausen and Mopelia for indicator species **(Figure 15)**.

Of the ecologically and economically important fish families (Acanthuridae, Carangidae, Lethrinidae, Lutjanidae, Scaridae and Serranidae), the size classes were dominated by mostly small fish with majority falling below 20 cm in size. **Figure 16** excludes fish smaller than 10 cm because they were too numerous to better highlight trends in the larger fish, and fish greater than 50 cm were excluded because they were too few to be seen on the graph. When excluding these two size classes (<10 cm and >50 cm) the next most dominant size class were those between 11-20 cm in size. At nearly all islands, with the exception of Mopelia and Scilly, over 70% of the larger fish fell in this size class, with nearly 100% of the fish observed falling within this relatively small size class. Fish between 21-30 cm were most abundant at

Mopelia, Scilly, Bellinghausen and Tūpai, while fish within the 31-40 cm size category were only notable at Scilly.

Overall, Scilly, Bellinghausen, and Mopelia showed some of the highest mean densities and biomass of fish as well as moderately good fish species richness (Table 5). On the other hand, Huahine, Taha'a, Tahiti and Tūpai had poor mean biomass estimates. This pattern was further supported by the relative size class distribution of fish wherein larger fish of sizes ranging from 21-30 cm and 31-40 cm were most abundant at Scilly, Bellinghausen, and Mopelia. The abundances of larger fish at these three locations account for the higher biomass estimates at these eastern locations.

Figure 15 MEAN FISH BIOMASS (KG/100 M²) BY CATEGORY IN THE SOCIETY ARCHIPELAGO.

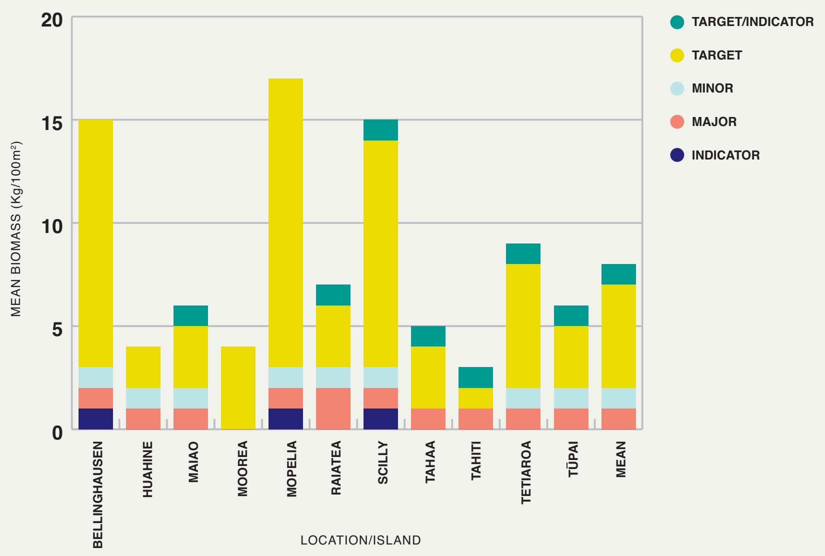
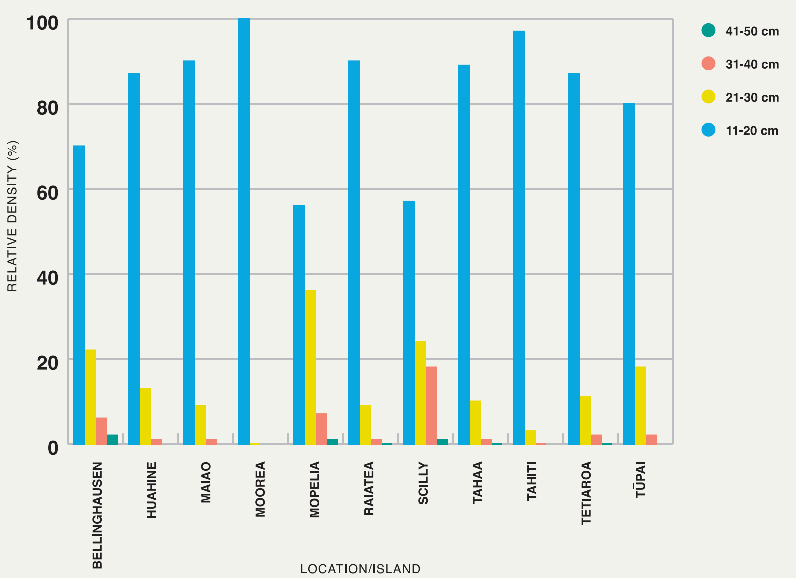


Figure 16 RELATIVE SIZE CLASS DISTRIBUTION (%) BASED ON TOTAL DENSITIES OF SELECTED IMPORTANT SPECIES IN THE SOCIETY ARCHIPELAGO.



3.2 TUAMOTU ARCHIPELAGO

The second island group visited in French Polynesia was the Tuamotu Archipelago. In November-December 2012 the GRE visited the islands of Rangiroa, Aratika, Raraka, Fakarava, and Toau; Hao in January 2013; and another sampling effort at Rangiroa in March 2013. All of the islands in the Tuamotu Archipelago are coral atolls lacking central islands, a characteristic which sets Tuamotu apart from the other French Polynesian archipelagoes visited on the GRE. The Tuamotu Archipelago is the second most populous island group in French Polynesia, with the local economy primarily relying on tourism, pearl farming in the lagoons, and fishing, of which most of the catch is sent to Tahiti.

UNESCO has established a Man and the Biosphere Reserve around the atolls of Aratika, Fakarava, Kauehi, Niau, Raraka, Taiaro, and Toau. On this research excursion we visited four of these UNESCO sites, and a total of six of the atolls in the Tuamotu Archipelago, sampling at 108 dive sites, conducting 674 benthic surveys and 450 fish surveys[42].

The Tuamotu Archipelago was severely impacted by a bleaching event caused by the 1997-1998 El Niño Southern Oscillation event. At the time of the bleaching, approximately 16% global coral mortality occurred and the reefs found in the Tuamotu Archipelago were not spared.

3.2 a HABITAT MAPPING

A total of 5,000 km^2 of satellite imagery, 621 drop-cam videos and 3.2 million depth soundings were used to classify the marine habitats of the atolls visited in the Tuamotu Archipelago.

Total reef area (i.e. substrate hosting meaningful quantities of live coral colonies) of the atolls mapped in the Tuamotu Archipelago, including backreef coral, lagoonal coral, lagoonal pinnacle reefs, and shallow fore reef communities covered over 200 km^2 **(Table 7)**. The atolls mapped in the Tuamotu Archipelago were on average much larger than those in the three other archipelagoes visited. The total area mapped of each atoll ranged from 185-1,775 km^2 with Rangiroa being the largest and Aratika being the smallest. The atoll with the highest area of fore reef community was Rangiroa, covering 25 km^2, followed by Fakarava and Hao with 19 km^2 reef area, each. Since the Tuamotu Archipelago is solely comprised of atolls, the deep lagoonal water and lagoonal substrate were the most dominant habitat types classified. Within the lagoons, the dominant habitat type varied greatly by atoll. The most dominant habitat classification at Fakarava and Toau was backreef coral, covering 22 and 11 km^2 respectively. At Aratika and Raraka, the dominant lagoonal reef habitat was lagoonal pinnacle reef with 7 km^2 and 12 km^2 of coverage. Hao and Rangiroa were dominated by lagoonal coral which covered 3 km^2 and 13 km^2 respectively.

Habitats dominated by macroalgae only accounted for 27 km^2 of the total area mapped. There were noticeably more expansive macroalgae habitats such as *Turbinaria, Microdictyon, Enteromorpha, Dictyota,* and *Halimeda* at Rangiroa compared to the other atolls, as it accounted for nearly half of the total macroalgae area measured.

Detailed maps of the islands visited which include a list and description of the habitat classifications can be found on the KSLOF interactive map portal and GIS data is available upon request.

Table 7

TOTAL AREA (KM^2) MAPPED OF HABITAT TYPES FOUND ON EACH ISLAND SURVEYED IN THE TUAMOTU ARCHIPELAGO.

TUAMOTU ARCHIPELAGO	TOTAL AREA SQUARE KM					
HABITAT CLASSIFICATION	Aratika	Fakarava	Hao	Raraka	Toau	Rangiroa
Back reef coral bommies	0.289	4.847	0.263	0.119	3.265	3.166
Back reef coral framework	3.597	17.96	0.382	1.396	8.149	6.407
Back reef pavement	6.31	32.479	23.009	9.365	31.787	17.516
Back reef rubble dominated	0.323	11.855	0.009	0.864	--	16.363
Back reef sediment dominated	1.891	32.678	7.34	2.224	33.973	20.265
Beach sand	1.374	2.989	5.264	3.109	3.118	13.509
Carbonate blocks	2.965	5.88	11.807	4.937	4.312	24.962
Coral rubble	3.153	2.494	6.042	6.348	1.568	4.478
Coralline algal ridge	0.518	2.966	2.521	1.863	3.083	7.025
Deep fore reef slope	0.868	0.414	0.728	1.181	0.074	0.58
Deep lagoonal water	130.945	1003.906	466.028	270.867	431.831	1085.556
Fore reef sand flats	--	--	--	0.001	--	--
Inland waters	0.022	--	--	--	--	--
Mud	--	--	--	--	--	--
Lagoonal Acropora framework	--	5.111	--	--	--	5.705
Lagoonal coral framework	--	--	--	--	--	--
Lagoonal floor barren	12.533	96.403	27.03	68.368	89.11	477.989
Lagoonal floor coral bommies	0.336	1.332	1.436	1.161	2.322	3.764
Lagoonal fringing reefs	--	--	--	--	--	--
Lagoonal floor macroalgae on sediment	--	1.095	0.551	--	--	6.867
Lagoonal patch reefs	0.305	1.06	1.526	0.79	3.281	4.066
Lagoonal pavement	--	--	--	--	--	--
Lagoonal pinnacle reefs branching coral dominated	--	--	--	--	--	--
Lagoonal pinnacle reefs massive coral dominated	7.253	1.498	--	12	--	10.904
Lagoonal sediment apron macroalgae on sediment	--	--	--	0.363	--	--
Lagoonal sediment apron sediment dominated	--	--	--	8.502	--	--
Reef-top algal mats	0.019	0.33		0.02	--	--
Rock	--	--	--	--	--	--
Shallow fore reef slope	4.061	13.676	15.58	5.76	7.13	15.704
Shallow fore reef terrace	2.016	5.449	3.872	1.999	3.628	9.227
Soil	--	--	--	--	--	--
Terrestrial vegetation	6.466	17.289	9.625	5.145	7.502	40.35
Urban	0.241	0.466	0.818	0.025	0.016	1.004

3.2 b BENTHIC COVER ASSESSMENT

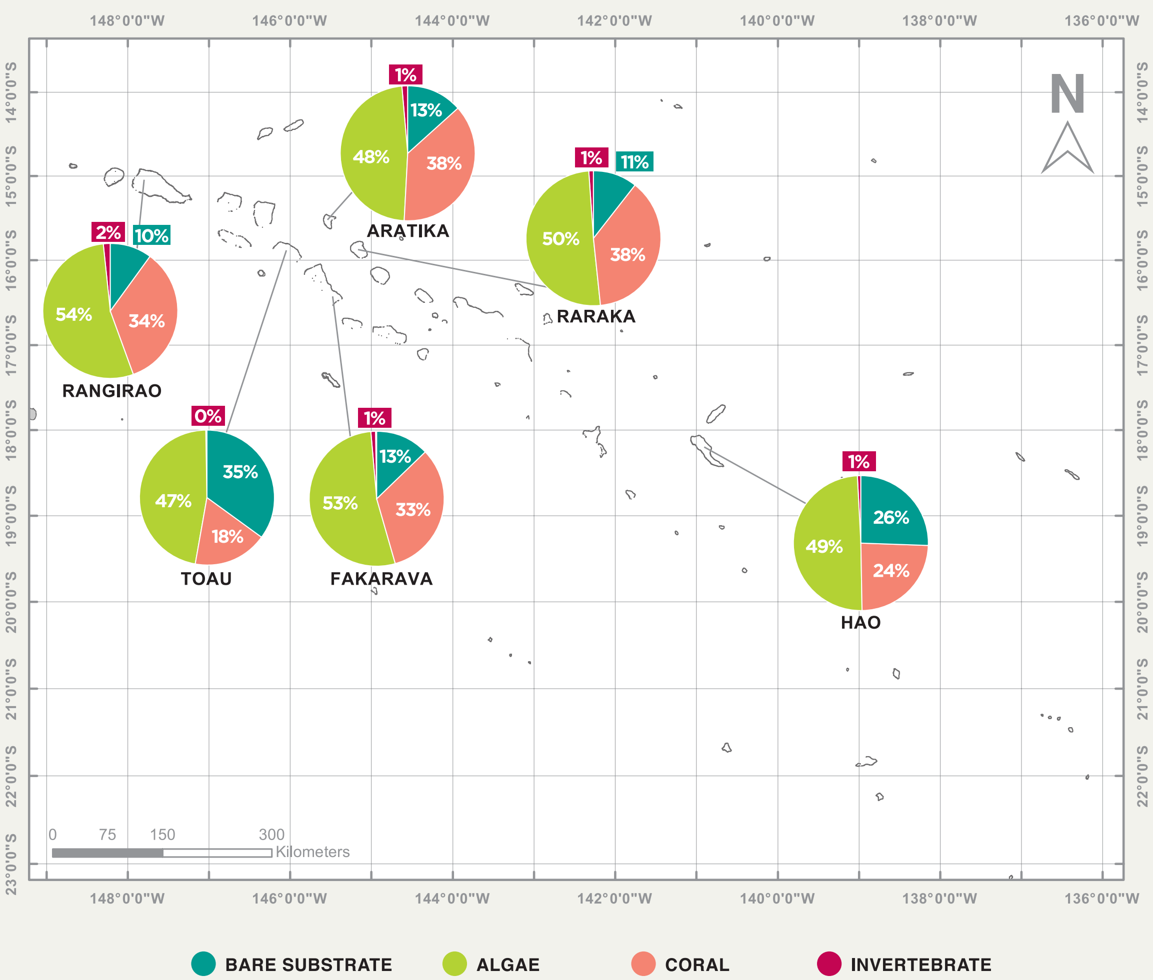
Throughout all of the SCUBA survey sites visited in the Tuamotu Archipelago, the primary substrate type was hard bottom pavement, followed by live coral. Figure 17 shows the average percentage of the dominant benthic cover found at each island. As seen in Figure 17, the coral and algae cover was not highly variable by atoll.

Throughout all of the atolls sampled, between 46-54% of the overall live cover was algae, with CCA being the dominant algae type, except for Toau (Figure 18). Toau was unique as it was dominated by fleshy macroalgae which measured 41% (± 29% S.D.) of the total algae recorded.

Aratika, Rangiroa, Raraka, and Fakarava had nearly identical coral cover, ranging from 33-38% overall live coral. The atolls of Toau and Hao had slightly lower coral cover with 18% (± 14% S.D.) and 24% (± 14% S.D.) coral cover recorded, respectively. The dominant corals in the Tuamotu Archipelago are the same as those found in the Society Archipelago, with *Pocillopora* and *Porites* being the two most dominant coral genera. At Aratika, Rangiroa, and Hao, *Pocillopora* was the dominant coral genus recorded, covering 47% (± 22% S.D.), 42% (± 23% S.D.), and 24% (± 25% S.D.) of the substrate respectively. The three

Figure 17

BENTHIC COVER (%) OF THE ISLANDS SURVEYED IN THE TUAMOTU ARCHIPELAGO. THE SUBSTRATE TYPES ARE BARE SUBSTRATE, ALGAE, LIVE CORAL, AND INVERTEBRATES.

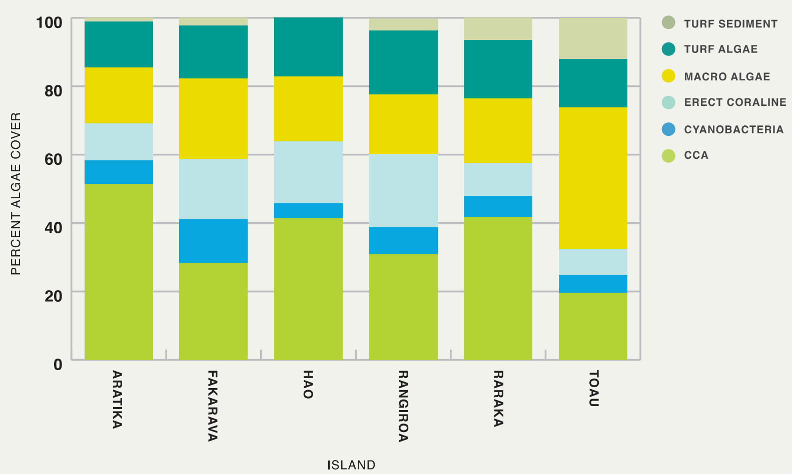


Although the **coral cover** was on average **higher** than in the Society Archipelago, the **overall coral diversity** was slightly **lower** in Tuamotu.

other islands were dominated by *Porites* accounting for 26-32% of the coral, except for Toau in which 45% (± 40% S.D.) of the overall coral cover was recorded. It is important to note that all of the surveys at Toau were conducted within the lagoon due to poor weather preventing surveying on the fore reef. Throughout French Polynesia, nearly all of the lagoon sites are dominated by massive *Porites* colonies.

Overall, coral diversity at the atolls surveyed in the Tuamotu Archipelago was slightly lower than those in the Society Archipelago (Table 4), with the diversity ranging from 1.1-1.9 on the Shannon-Weiner index. The atoll with the lowest diversity was Toau (1.1) which was likely due to the survey site locations within the lagoon. The islands with the highest diversity were Rangiroa and Hao (1.9). The other atolls ranged in coral diversity from 1.6-1.8.

Figure 18 RELATIVE COMPOSITION OF ALGAE (%) AT EACH ISLAND IN THE TUAMOTU ARCHIPELAGO.



3.2 c FISH COMMUNITY ASSESSMENT

The fish communities at the survey locations of the Tuamotu Archipelago were in better condition compared to those found in the Society Archipelago. There were more rare species, and a higher abundance of large sized fish as compared to the other archipelagoes. Top predatory species such as sharks, groupers and barracuda were more prevalent in this archipelago, and large schools of important species such as snappers and parrotfish were also fairly common.

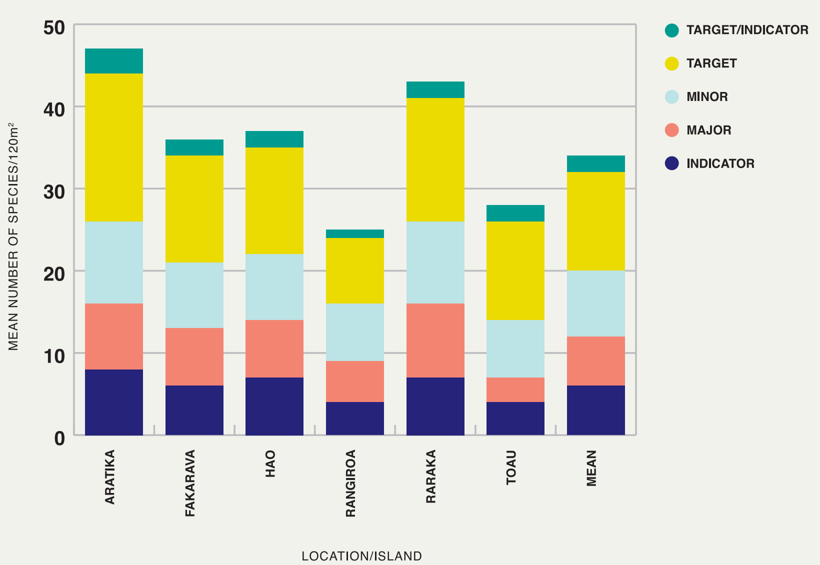
SPECIES RICHNESS OF THE FISH ASSEMBLAGE

A combined total of 299 species of fish belonging to 44 families were identified from the 104 survey stations (Table 8). Total species numbers listed at the survey locations varied with the least number of species observed at Toau (131 species) and greatest at Fakarava (233 species). Aratika and Raraka had the highest mean species richness with 47 (±16 S.D.) species and 43 (±10 S.D.) species/120m^2, respectively. The total number of fish species and mean species richness recorded in the Tuamotu Archipelago were higher than those listed from the Society, Gambier and Austral Archipelagoes (Table 6).

The total fish list was composed of 129 target species, 5 target/indicators, 83 minor species, 51 majors, and 31 indicator species. The compositional patterns of the five fish categories were consistent across locations and varied little within category and between locations (Figure 19). In terms of the composition of these fish categories at each island, target species was the most speciose group, followed closely by minor species and major species. Target species richness ranged from 8 (±5 S.D.) species/120m^2 at Rangiroa up to 18 (±5 S.D.) species/120m^2 at Aratika (Figure 19). Minimal differences in the richness of major, minor, and indicator species of fish were found among the Tuamotu islands. The mean richness of target/indicator species did not exceed 5 species/100 m^2.

> There were more **rare species,** and a higher abundance of **larger sized fish** as compared to the other archipelagoes.

Figure 19 MEAN ESTIMATED SPECIES RICHNESS OF FISH (SPECIES/120 M^2) BY CATEGORY IN THE TUAMOTU ARCHIPELAGO.



FISH DENSITY

The mean total estimated density of fish at Tuamotu was 283 (±227) individuals/100 m^2 (Table 8). As with mean species richness, Toau had the lowest mean fish density of all the islands. The highly populated islands of Hao and Rangiroa had mean fish densities lower than average. Raraka and Aratika had the highest estimated mean density of fish with 475 (±279

Table 8 MEAN FISH SPECIES RICHNESS (# SPECIES/120 M² ±S.D.), MEAN FISH DENSITY (# INDIVIDUALS/100 M² ±S.D.), MEAN FISH BIOMASS (KG/100 M² ±S.D.) IN THE TUAMOTU ARCHIPELAGO.

LOCATION/ISLAND	# of Survey Stations	# of Replicate Transects	Total Families	Total Species	Mean # of Species	Mean Density	Mean Biomass
Aratika	6	22	29	159	47 (±16)	442 (±238)	56.2 (±56.2)
Fakarava	22	129	39	233	36 (±15)	313 (±262)	68.9 (±116.4)
Hao	17	85	34	214	37 (±15)	186 (±91)	28.0 (±66.8)
Rangiroa	40	148	35	221	26 (±11)	240 (±176)	59.2 (±65)
Raraka	12	64	33	204	43 (±10)	475 (±279)	34.5 (±30)
Toau	7	38	27	131	27 (±10)	156 (±83)	53.9 (±87.9)
TOTAL/MEAN	**104**	**486**	**44**	**299**	**34 (±15)**	**283 (±227)**	**52.5 (±81.9)**

S.D.) individuals and 442 (±238 S.D.) individuals/100 m², respectively (Table 8). Relative to the fish density estimates of the Society, Gambier and Austral Archipelagoes, the mean total fish density at the Tuamotu Archipelago was the highest (Table 6).

Minor species were numerically dominant across all atolls in the Tuamotu Archipelago, with estimates between 75 (±33 S.D.) individuals and 323 (±227 S.D.) individuals/100 m² (Figure 20). Target fish species were the second most abundant fish group across locations with the lowest density observed at Rangiroa at 45 (±64 S.D.) individuals/100m² and highest at Aratika at100 (±59 S.D.) individuals/100 m² (Figure 20). *Lutjanus gibbus* is an important target species and while they were recorded across all of the islands surveyed, they were observed in large schools (>100 individuals) only at Fakarava and Rangiroa. Reef health indicator species were relatively few but were common across all islands. Their estimated mean density ranged between 8 (±7 S.D.) individuals and 32 (±22 S.D.) individuals/100 m², the highest being at Aratika (Figure 20).

FISH BIOMASS

The mean total estimated biomass of fish at the Tuamotu Archipelago was 52.5 (±81.9 S.D.) kg/100 m² (Table 8). Mean fish biomass varied between locations and ranged from 28 (±66.8 S.D.) kg/100 m² at Hao and up to 68.9 (±116.4 S.D.) kg/100 m² at Fakarava. Aratika, Fakarava, Rangiroa and Toau had the highest mean total biomass recorded in the Tuamotu Archipelago. The mean total biomass of fish at Tuamotu was more than twice the biomass estimates from Society, Gambier, Austral Archipelagoes (Table 6).

Target fish contributed the vast majority of the fish biomass at all atolls surveyed. Target species contributed between 22.9 (±67 S.D.) kg and 61.8 (±113.8 S.D.) kg/100 m² to the biomass at each location (Figure 21). The

Figure 20 MEAN DENSITY OF FISH (# INDIVIDUALS/100 M²) BY CATEGORY IN THE TUAMOTU ARCHIPELAGO.

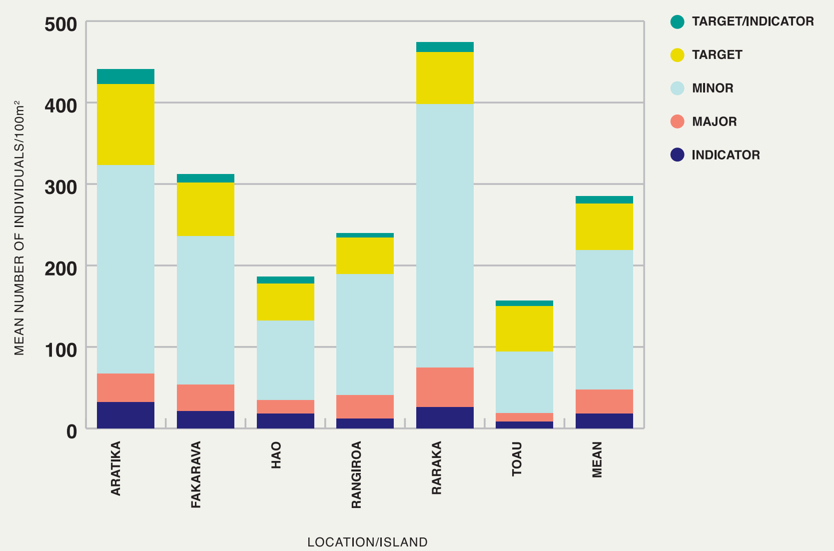
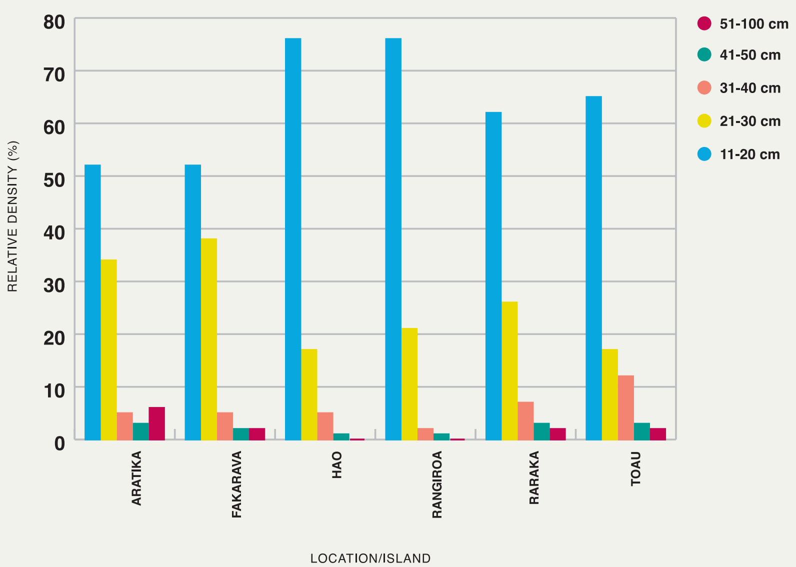


Figure 21 MEAN FISH BIOMASS (KG/100 M²) BY CATEGORY IN THE TUAMOTU ARCHIPELAGO.

Figure 22 RELATIVE SIZE CLASS DISTRIBUTION (%) BASED ON TOTAL DENSITIES OF SELECTED IMPORTANT SPECIES IN THE TUAMOTU ARCHIPELAGO.



relative size frequency distribution of selected important fish families also highlighted the high occurrence of fish of larger sizes between 21-30 cm, and 31-40 cm (Figure 22). This distribution was especially evident at Aratika and Fakarava for the 21-30 cm size class and at Toau for the 31-40 cm size class. Fish between 51-100 cm in length were also notable at Aratika. The fish families included in Figure 22 were mostly important target fish species such as surgeonfish (Acanthuridae), jacks (Carangidae), Maori wrasse (Labridae), emperor (Lethrinidae), snapper (Lutjanidae), parrotfish (Scaridae), groupers (Serranidae), barracuda (Sphyraenidae), sharks (Carcharhinidae), nurse sharks (Ginglymostomatidae), and rays (Myliobatidae). The single most important species in terms of its total accumulated biomass was the blacktip reef shark (Carcharhinidae). This shark was encountered in numerous occasions at Fakarava and Hao.

The fish communities at the survey locations within Tuamotu were impressive. They boasted high species richness, and exceptional densities and biomass especially of important target species. While small-bodied minor, major and indicator reef species were abundant, large target species and top predators such as sharks were common and abundant, and these accounted for the high biomass at Tuamotu.

The Tuamotu Archipelago fish communities boasted **high species richness, and exceptional densities and biomass especially** of important target species. While small-bodied minor, major and indicator reef species were abundant, **large target species and top predators** such as sharks were **common and abundant,** and these accounted for the high biomass at Tuamotu.

3.3 GAMBIER ARCHIPELAGO

The Gambier Archipelago is located in close proximity to the southeast of the Tuamotu Archipelago. The GRE surveyed the low lying atolls that make up the Acteon Group found in the northwest portion of the Gambier Archipelago, including Tenararo, Tenarunga, Vahanga, Maturei Vavao, and Maria Est. The other two atolls surveyed on the GRE, found to the southeast of the Acteon Group, were Mangareva and Temoe. Mangareva, a high volcanic island surrounded by a barrier reef and the largest land mass of all the Gambier Archipelago, suffered substantial deforestation in the 10th to 15th centuries with accompanying dramatic effects on the islands ecology that are still being felt today[43]. By a strict definition, Mangareva, with its high volcanic island and surrounding coral rim can be termed an “atoll”, but that term is variably applied to denote isolated carbonate platforms where the central island has subsided to leave a deep lagoon. The reefs in the lagoon around Mangareva are used by locals for pearl farming, but because there is no known data of pre-farming conditions, the impacts from this industry in Mangareva is currently unknown.

The GRE visited the Gambier Archipelago in January-February 2013. The atolls to the north are all uninhabited but can be temporarily visited by islanders from other atolls that come to harvest coprah and fish, with nearly all of the population of the Gambier Archipelago living on the island of Mangareva. In the Gambier Archipelago, researchers conducted surveys at 54 dive sites, completing a total of 315 benthic habitat surveys and 546 fish surveys.

3.3 a HABITAT MAPPING

The satellite imagery used to profile the atolls visited in the Gambier Archipelago covered 1,700 km^2. A total of 434 drop-cams were deployed throughout the atolls, and nearly 1.5 million depth soundings were made to create bathymetric maps.

Total reef area accounted for 210 km^2 of the atolls mapped in the Gambier Archipelago. Mangareva is by far the largest island in the group being nearly 10 times the size and has the largest reef area. The majority of Mangareva’s reef habitat was lagoonal coral (i.e. substrate hosting meaningful quantities of live coral colonies), measuring 147 km^2 **(Table 9)**. Shallow fore reef community ranged from 0.7-2.5 km^2 throughout the rest of the atolls, with Mangareva, again having the highest total area of this habitat type, measuring 42 km^2. Lagoonal pinnacle reefs were commonly found throughout the three other archipelagoes, but interestingly were absent from the Gambier Archipelago. Habitats that were macroalgae dominated were minimal, totaling only 5 km^2 throughout all of the islands mapped.

Detailed maps of the atolls visited, along with a list and detailed description of the habitat classifications, can be found on the KSLOF interactive map portal. GIS data is available upon request.

Table 9

TOTAL AREA (KM²) MAPPED OF HABITAT TYPES FOUND ON EACH ISLAND SURVEYED IN THE GAMBIER ARCHIPELAGO.

THE GAMBIER ARCHIPELAGO	TOTAL AREA SQUARE KM						
HABITAT CLASSIFICATION	Maria Est	Maturei Vavao	Temoe	Tenararo	Tenarunga	Vahanga	Mangareva
Back reef coral bommies	--	0.065	0.049	0.03	--	0.017	0.308
Back reef coral framework	--	0.775	0.894	0.189	--	0.115	3.355
Back reef pavement	0.71	0.831	0.704	0.223	0.205	0.463	3.002
Back reef rubble dominated	--	--	0.432	--	0.23	--	2.183
Back reef sediment dominated	0.128	0.897	0.952	0.188	0.099	0.003	6.089
Beach sand	0.374	0.384	0.675	0.252	0.232	0.589	0.637
Carbonate blocks	1.745	2.696	1.521	0.629	1.034	1.058	2.039
Coral rubble	0.291	0.152	0.445	0.233	0.486	0.401	0.209
Coralline algal ridge	0.37	0.271	0.803	0.131	0.4	0.226	1.211
Deep fore reef slope	1.016	1.194	1.369	0.719	0.652	0.634	9.94
Deep lagoonal water	--	10.117	11.276		3.405	2.661	113.322
Fore reef sand flats	0.069	0.154	0.058	0.048	0.061	0.097	6.796
Inland waters	--	--	--	--	--	--	--
Mud	--	--	--	--	--	--	--
Lagoonal Acropora framework	1.433	2.188	0.112	0.567	0.312	0.046	130.813
Lagoonal coral framework	--	--	--	--	--	--	--
Lagoonal floor barren	4.362	3.868	1.054	1.316	1.906	1.308	149.027
Lagoonal floor coral bommies	0.345	0.112	0.008	0.049	--	0.05	1.951
Lagoonal fringing reefs	--	--	--	--	--	--	12.46
Lagoonal floor macroalgae on sediment	--	0.173	0.603	--	0.16	0.949	--
Lagoonal patch reefs	0.566	0.323	0.034	0.095		0.055	2.416
Lagoonal pavement	--	--	--	--	--	--	--
Lagoonal pinnacle reefs branching coral dominated	--	--	0	--	--	--	--
Lagoonal pinnacle reefs massive coral dominated	--	--	--	--	--	--	--
Lagoonal sediment apron macroalgae on sediment	0.106	0.085	--	--	0.104	0.146	--
Lagoonal sediment apron sediment dominated	0.587	1.017	--	0.007	0.55	0.662	--
Reef-top algal mats	--	--	--	--	--	--	--
Rock	--	--	--	--	--	--	--
Shallow fore reef slope	0.449	0.774	1.007	0.276	0.559	0.489	36.887
Shallow fore reef terrace	0.749	0.652	1.576	0.454	0.784	0.817	5.116
Soil	--	--	--	--	--	--	1.864
Terrestrial vegetation	2.057	1.476	1.391	1.639	2.484	1.872	23.298
Urban	--	--	--	--	0.001	--	0.443

3.3 b BENTHIC COVER ASSESSMENT

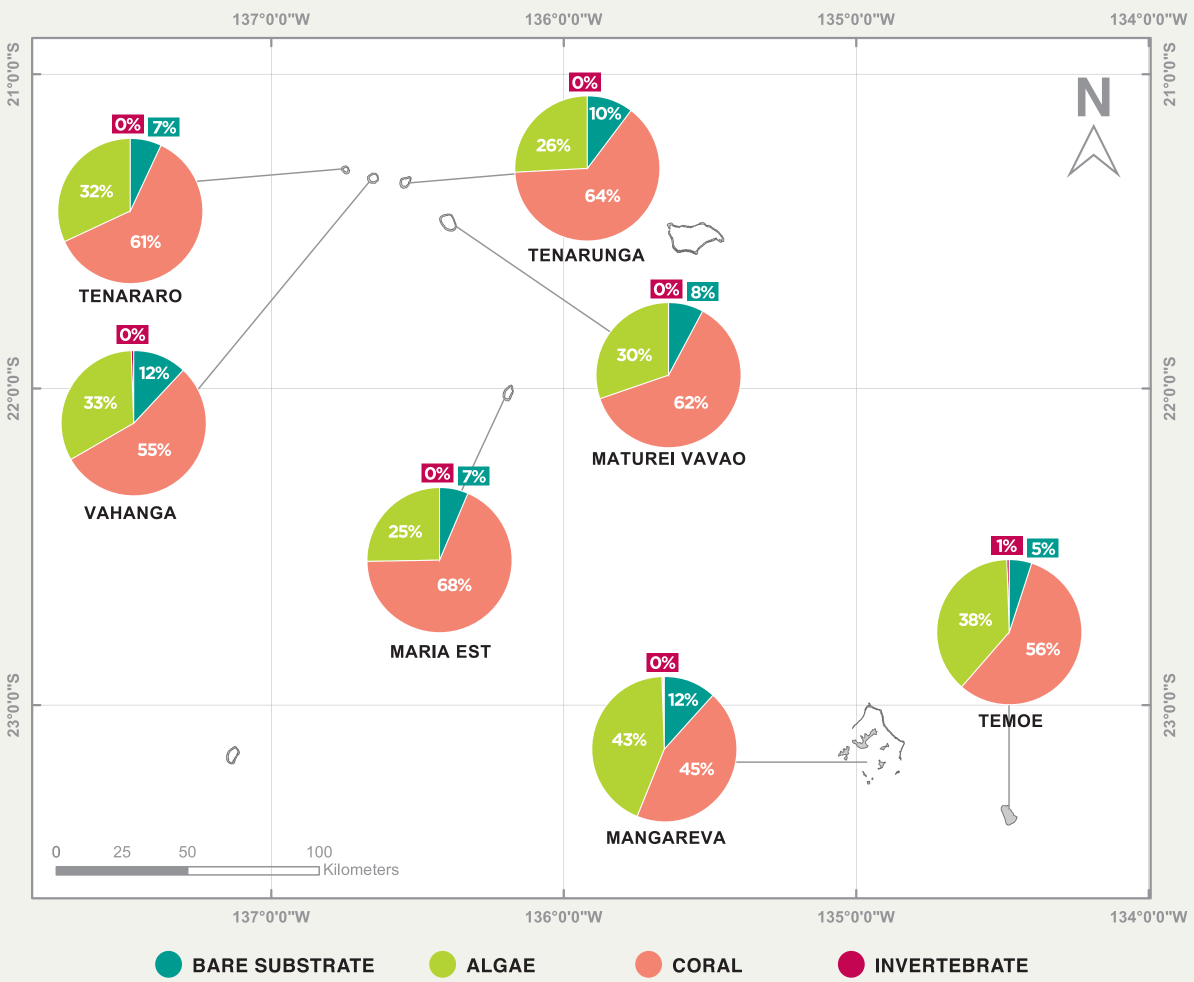
The Gambier Archipelago had the highest overall percent coral cover of all of the archipelagoes visited on the GRE. Shown in Figure 23, live coral was the dominant substrate type, followed by pavement for all atolls visited. Figure 24 shows the percentage of each algae type found at each atoll.

The Acteon group, which includes Maria Est, Maturei Vavao, Tenarunga, Tenararo, and Vahanga, had exceptionally high coral cover ranging from 61-68% overall live coral. Vahanga had slightly lower coral cover with 55% (±13% S.D.) (Figure 23), but is still considered a high coral cover percentage. Mangareva and Temoe had lower coral cover than those found in the Acteon group, with 45% (±14% S.D.) and 56% (±9% S.D.) respectively (Figure 23), again, still considered high cover. The overall coral cover in the Gambier Archipelago is the highest of all of the island groups visited on the GRE mission to French Polynesia. There was no evidence of a recent major disturbance in the Gambier Archipelago which is likely the reason for such very high coral cover.

The dominant coral genus across all of the islands was *Acropora,* with the highest number of table forming *Acroporiids* in French Polynesia observed. *Acropora* accounted for between 30-38% of the total coral on each atoll in the Acteon group, and 43-52% of the total coral recorded in Mangareva and Temoe. The next dominant

Figure 23

BBENTHIC COVER (%) OF THE ISLANDS SURVEYED IN THE GAMBIER ARCHIPELAGO. THE SUBSTRATE TYPES ARE BARE SUBSTRATE, ALGAE, LIVE CORAL, AND INVERTEBRATES.



The Gambier Archipelago had the **highest overall percent live coral cover** of all of the archipelagoes visited on the GRE mission to French Polynesia.

coral genus varied by location, typically being either *Pocillopora, Pavona,* or *Porites.*

The dominant algae species was CCA at all of the locations visited in the Gambier Archipelago except for Mangareva which was dominated by macroalgae **(Figure 24)**. The islands of Mangareva and Temoe had the highest percentage of dead coral (8-15%) recorded in the Gambier Archipelago.

The coral diversity in the archipelago was slightly higher than the Society and Tuamotu island groups, ranging from 1.6-2.0 on the Shannon-Weiner index **(Table 4)**. The islands with the highest diversity was Temoe (2.0) and Mangareva had the lowest recorded diversity (1.6) of all the atolls. The Acteon Group had coral species diversity ranging from 1.8-1.9.

Figure 24 RELATIVE COMPOSITION OF ALGAE (%) AT EACH ISLAND IN THE GAMBIER ARCHIPELAGO.

3.3 c FISH COMMUNITY ASSESSMENT

The reefs of the Gambier Archipelago had some of the highest richness, density and biomass of fish in French Polynesia. Commercially important fish were diverse and plentiful, and reef health indicators and ecologically important fish species were well represented.

SPECIES RICHNESS OF THE FISH ASSEMBLAGE

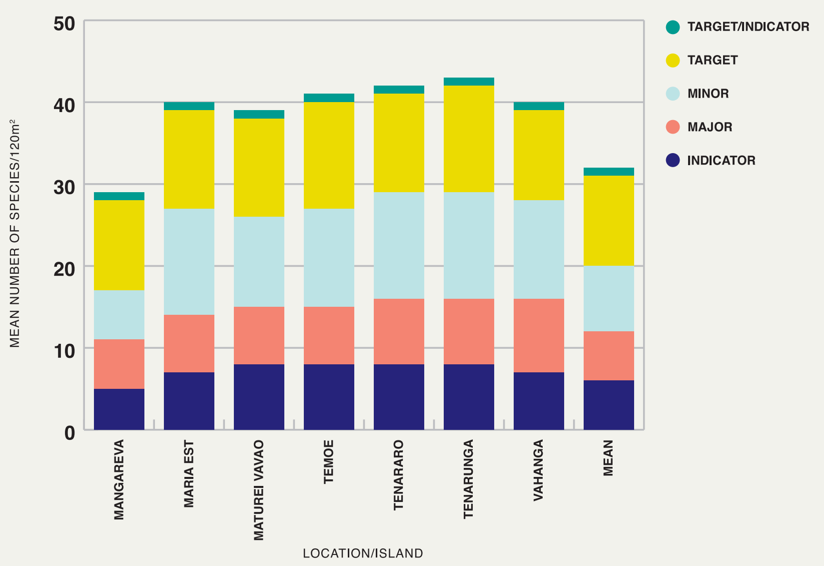
Surveys conducted on the GRE in January and February of 2013 documented 272 fish species in Gambier Archipelago (Table 10). Fish species richness ranged from 106 species at Vahanga to 239 species at Mangareva (Table 10). The majority of the fish identified belonged to the target fish category, with wrasses, damselfish, butterflyfish, and surgeonfish also accounting for much of the fish species listed.

The mean total estimated fish species richness from the seven islands visited was 32 (±12 S.D.) species/120 m^2 (Table 10). The fish at all the islands were dominated by target and minor species (Figure 25). Target fish

> The reefs of the Gambier Archipelago had some of the **highest richness, density and biomass of fish in French Polynesia.** Commercially important fish were diverse and plentiful, and reef health indicators and ecologically important fish species were well represented.

comprised between 11 to 13 species of the mean species richness at each island, while minor species made up about 6 to 13 species. Major and indicator species were also relatively diverse and they comprised about 6 to 9 species and 5 to 8 species of the mean estimated species richness among all islands.

Figure 25 MEAN ESTIMATED SPECIES RICHNESS OF FISH (SPECIES/120 M^2) BY CATEGORY IN THE GAMBIER ARCHIPELAGO.



FISH DENSITY

The mean total estimated density of fish in the Gambier Archipelago was 162 (±94 S.D.) individuals/100 m^2 (Table 10). The highest fish density surveyed in the Gambier Archipelago was observed at Temoe with 279 (±89 S.D.) individuals/100 m^2.

In general, minor species were the dominant fish group across all of the Gambier Archipelago except at Mangareva where target species where relatively more abundant (Figure 26). Minor species only had an estimated density of 34 (±38 S.D.) individuals/100m^2 at Mangareva, while at the other six locations, minor

Table 10 MEAN FISH SPECIES RICHNESS (# SPECIES/120 M² ±S.D.), MEAN FISH DENSITY (# INDIVIDUALS/100 M² ±S.D.), MEAN FISH BIOMASS (KG/100 M² ±S.D.) IN THE GAMBIER ARCHIPELAGO.

LOCATION/ISLAND	# of Survey Stations	# of Replicate Transects	Total Families	Total Species	Mean # of Species	Mean Density	Mean Biomass
Mangareva	33	198	36	239	28 (±11)	119 (±73)	16.3 (±24.4)
Maria Est	3	18	27	127	40 (±8)	233 (±55)	32.4 (±36.8)
Maturei Vavao	3	15	21	117	38 (±10)	215 (±45)	11.2 (±15.7)
Temoe	6	35	29	156	41 (±9)	279 (±89)	25.3 (±42.1)
Tenararo	3	12	22	125	41 (±7)	194 (±54)	11.2 (±10.5)
Tenarunga	3	12	22	112	44 (±4)	264 (±70)	9.4 (±10.5)
Vahanga	3	12	21	106	39 (±5)	223 (±38)	6.1 (±4.1)
TOTAL/MEAN	**104**	**486**	**44**	**299**	**34 (±15)**	**283 (±227)**	**52.5 (±81.9)**

fish densities ranged between 114 (±48 S.D.) individuals/100 m² at Tenararo and 165 (±58 S.D.) individuals/100 m² at Tenarunga. Target fish had slightly higher relative abundances over major fish species across islands, with densities between 27 (±7 S.D.) individuals/100 m² at Vahanga and 49 (±49 S.D.) individuals/100 m² at Mangareva. Other than indicator and target/indicator species, major species were the least abundant with only about 22 (±20 S.D.) individuals/100 m² mean total density.

FISH BIOMASS

The Gambier Archipelago had the second highest mean total biomass of the four island groups visited in French Polynesia at 17.1 (±26.8 S.D.) kg/100 m² (Table 6, Table 10). Mean fish biomass varied across sites with the highest estimate at Maria Est with 32.4 (±36.8 S.D.) kg/100 m² and the poorest at Vahanga with only 6.1 (±4.1 S.D.) kg/100 m².

Target fish species contributed a mean total biomass of about 12.8 (±22.7 S.D.) kg/100 m²and as much as 25.2 (±32.1 S.D.) kg/100 m² at Maria Est (Figure 27). The blacktip reef shark (Carcharhinidae) had the highest total accumulated biomass among the target

Figure 26 MEAN DENSITY OF FISH (# INDIVIDUALS/100 M²) OF FISH BY CATEGORY IN THE GAMBIER ARCHIPELAGO.

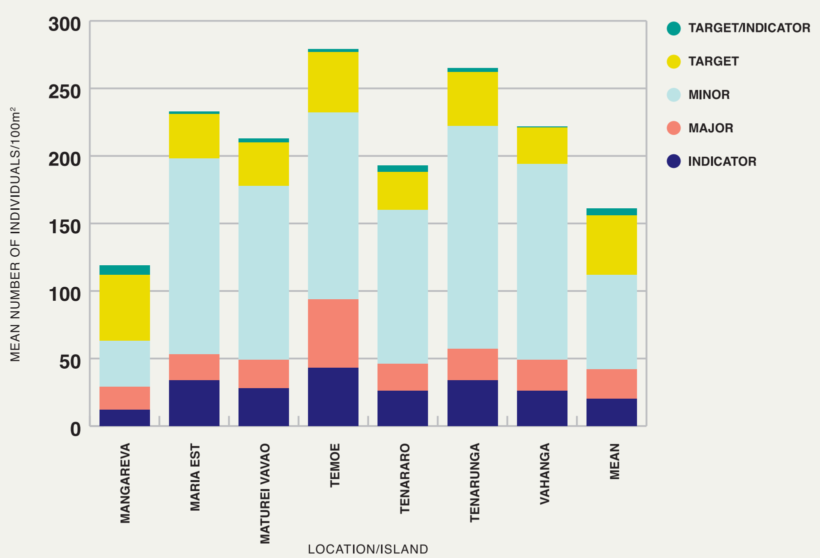


Figure 27 MEAN FISH BIOMASS (KG/100 M²) BY CATEGORY IN THE GAMBIER ARCHIPELAGO.

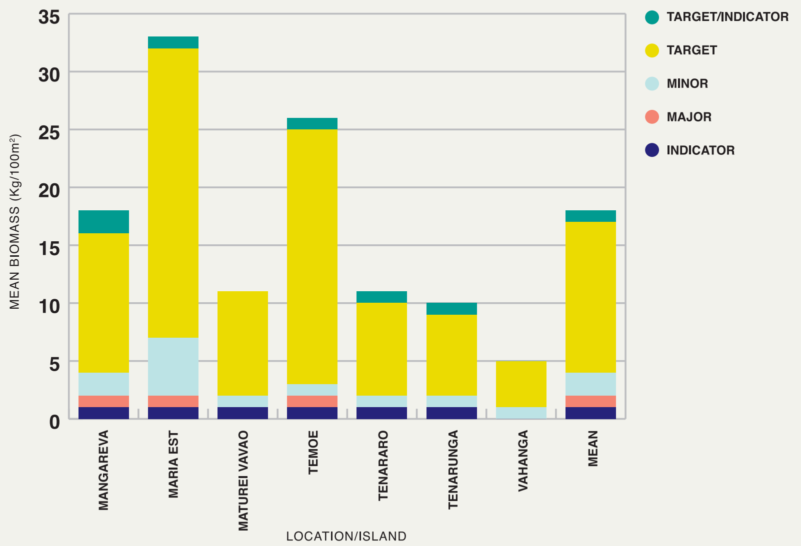
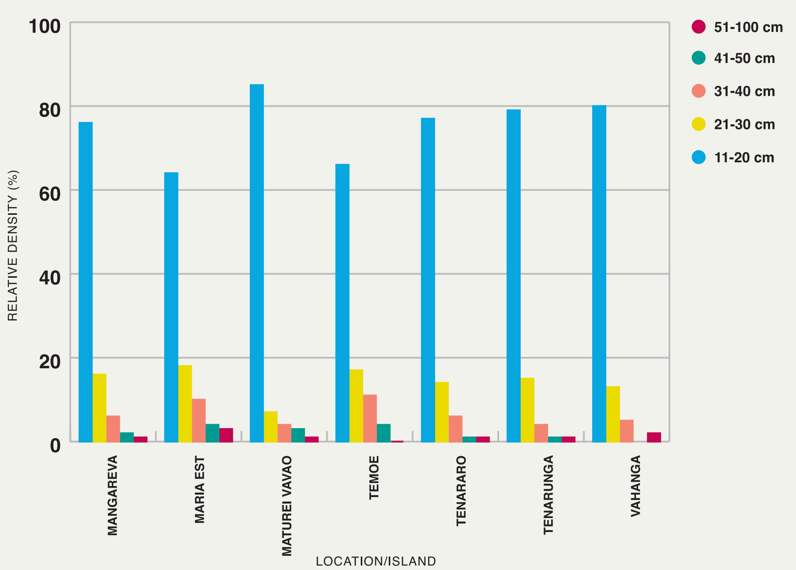


Figure 28 RELATIVE SIZE CLASS DISTRIBUTION (%) BASED ON TOTAL DENSITIES OF SELECTED IMPORTANT SPECIES IN THE GAMBIER ARCHIPELAGO.



species. This shark species was present across all locations but had especially high biomass at Temoe, Maria Est and Mangareva. Curiously, it was not recorded in Vahanga. Despite accounting for a larger portion of the overall biomass, large fish such as sharks with total lengths from 51 to 100 cm were few and comprised less than 5% of the fish abundance across locations **(Figure 28)**. Nevertheless, it is these large predators that contributed considerably to the high biomass in the Gambier Archipelago. As with the other island locations in French Polynesia, fish between 11 and 20 cm in length were the most abundant. These fish were mostly of the Acanthuridae, Carangidae, Labridae, Lethrinidae, Lutjanidae Scaridae, and Serranidae families.

The Gambier Archipelago fish communities exhibited some of the highest species richness, abundance and biomass of fish in all of French Polynesia. There was a dominance of large predatory species which accounted for impressive biomass estimates. Small ecologically important species as well as coral indicator species were diverse and likewise numerous.

The coral communities of the Gambier Archipelago reached nearly **70% live coral cover** in some locations. For the South Pacific, these numbers are **unprecedented and were the highest seen** in all of French Polynesia.

3.4 AUSTRAL ARCHIPELAGO

The Austral Archipelago is the southernmost island group in French Polynesia, primarily made up of high volcanic islands. The archipelago can be separated into two different island groups, of which, the GRE focused on the Tupua'i Islands. The GRE surveyed the islands of Maria Oeste, Raivavae, Rimatara, Rurutu, and Tubuai in April 2013. Among 30 dive sites around these five islands, 264 benthic habitat surveys, and 177 fish surveys were completed.

The Austral Archipelago experiences a cooler climate on average than the rest of the French Polynesian island groups, which is also reflected in the cooler average water temperature. The majority of the population of the Austral Archipelago can be found on the islands of Tubuai and Rurutu. There are local communities found on the islands of Rimatara and Raivavae as well, although smaller. Maria Oeste (located at the farthest northwest of the Austral Archipelago) is the smallest island and cannot sustain a permanent human population.

In recent years, natural disturbances have affected the reefs around some of the islands in the Austral Archipelago. The most detrimental being a COTS outbreak that began in 2006 shortly following the elevated starfish populations observed in the Society Archipelago. This corallivorous pest caused severe coral mortality at the islands of Rimatara and Rurutu, and at the time of sampling meaningful recovery was not observed[2].

3.4 a HABITAT MAPPING

A total of 578 km^2 of satellite imagery, along with 341 drop-cam videos and over 1.5 million depth soundings were used to create high resolution benthic habitat and bathymetric maps around the Austral Islands visited during the GRE.

On average, the Austral islands were relatively small in size compared to the other island groups. The total reef habitat covered 68 km^2 with the dominant reef type being shallow fore reef community. Tubuai and Raivavae had the largest reef areas **(Table 11)**. Rimatara and Rurutu have no lagoon surrounding the islands, so there were no lagoonal habitats mapped. Maria Oeste has a unique shallow sediment filled lagoon, with no lagoonal pinnacle reefs and less than 1 km^2 of reef habitat (including backreef coral) found at the island. Lagoonal coral was the second most dominant reef type at Maria Oeste, and the most dominant habitat type found within the lagoons of Raivavae and Tubuai. Lagoonal macroalgae was most dominant in the Austral Archipelago, primarily at Raivavae and Tubuai, measuring 4 and 8 km^2 at each island respectively. Raivavae had the largest deep fore reef slope found in any of the archipelagoes, covering over 45 km^2.

Detailed maps of the islands visited, along with a detailed description of the habitat classifications, can be found on the KSLOF interactive map portal. GIS data is available upon request.

Table 11 TOTAL AREA (KM^2) MAPPED OF HABITAT TYPES FOUND ON EACH ISLAND SURVEYED IN THE AUSTRAL ARCHIPELAGO.

THE AUSTRAL ARCHIPELAGO	TOTAL AREA SQUARE KM				
HABITAT CLASSIFICATION	Maria Oeste	Raivavae	Rimatara	Rurutu	Tubuai
Back reef coral bommies	0.018	0.386	--	0.046	0.442
Back reef coral framework	0.619	0.732	0.671	0.857	3.657
Back reef pavement	1.144	4.201	0.572	0.857	8.51
Back reef rubble dominated	0.152	2.56	0.096	0.032	6.097
Back reef sediment dominated	0.093	14.453	0.252	0.551	12.532
Beach sand	0.724	0.154	0.126	0.184	0.225
Carbonate blocks	0.947	0.15	0.03	0.41	0.023
Coral rubble	0.372	0.047	--	0.042	0.019
Coralline algal ridge	0.406	1.734	0.161	0.74	1.7
Deep fore reef slope	1.912	46.912	2.108	4.222	7.277
Deep lagoonal water	--	--	--	--	--
Fore reef sand flats	0.044	1.068	0.214	0.431	0.477
Inland waters	--	--	--	--	--
Mud	--	--	--	--	--
Lagoonal Acropora framework	--	--	--	--	--
Lagoonal coral framework	0.047	--	--	--	--
Lagoonal floor barren	2.398	23.421	--	--	36.143
Lagoonal floor coral bommies	0.022	1.389	--	--	1.041
Lagoonal fringing reefs	--	2.482	--	--	3.144
Lagoonal floor macroalgae on sediment	0.716	4.28	--	--	8.114
Lagoonal patch reefs	0.017	1.216	--	--	1.933
Lagoonal pavement	0.94	--	--	--	--
Lagoonal pinnacle reefs branching coral dominated	--	0.175	--	--	0.255
Lagoonal pinnacle reefs massive coral dominated	--	1.657	--	--	6.096
Lagoonal sediment apron macroalgae on sediment	--	--	--	--	--
Lagoonal sediment apron sediment dominated	--	--	--	--	--
Reef-top algal mats	--	--	--	--	--
Rock	--	--	--	--	--
Shallow fore reef slope	0.878	7.413	1.461	3.07	19.148
Shallow fore reef terrace	0.519	3.947	0.57	1.374	3.266
Soil	--	0.279	0.454	0.032	0.904
Terrestrial vegetation	1.389	16.518	7.439	31.916	42.93
Urban	--	0.305	0.312	0.986	1.102

3.4 b BENTHIC COVER ASSESSMENT

Three of the five islands of the Austral Archipelago had moderate to high overall coral cover, but because of the COTS outbreak the islands of Rurutu and Rimatara had the lowest coral cover seen in all of French Polynesia[2]. The remainder of the islands had moderate to high coral cover with Raivavae having 35% (±16% S.D.) live coral, followed by Tubuai with 42% (±3% S.D.) coral, and Maria Oeste with the highest of the group with 52% (±12% S.D.) coral cover (see Figure 29). The dominant coral genera varied by island. On Maria Oeste, the dominant coral genera were *Acropora* and *Pocillopora* with nearly equal dominance accounting for over half of total overall coral observed. Raivavae and Tubuai were dominated by *Acropora* and *Astreopora,* together accounting for 48-50% of the overall coral cover at each island. *Pocillopora* was the dominant coral genera at Rurutu and Rimatara, measuring 14%

> The Austral Archipelago has the **overall highest diversity of corals** seen in these four French Polynesian archipelagoes.

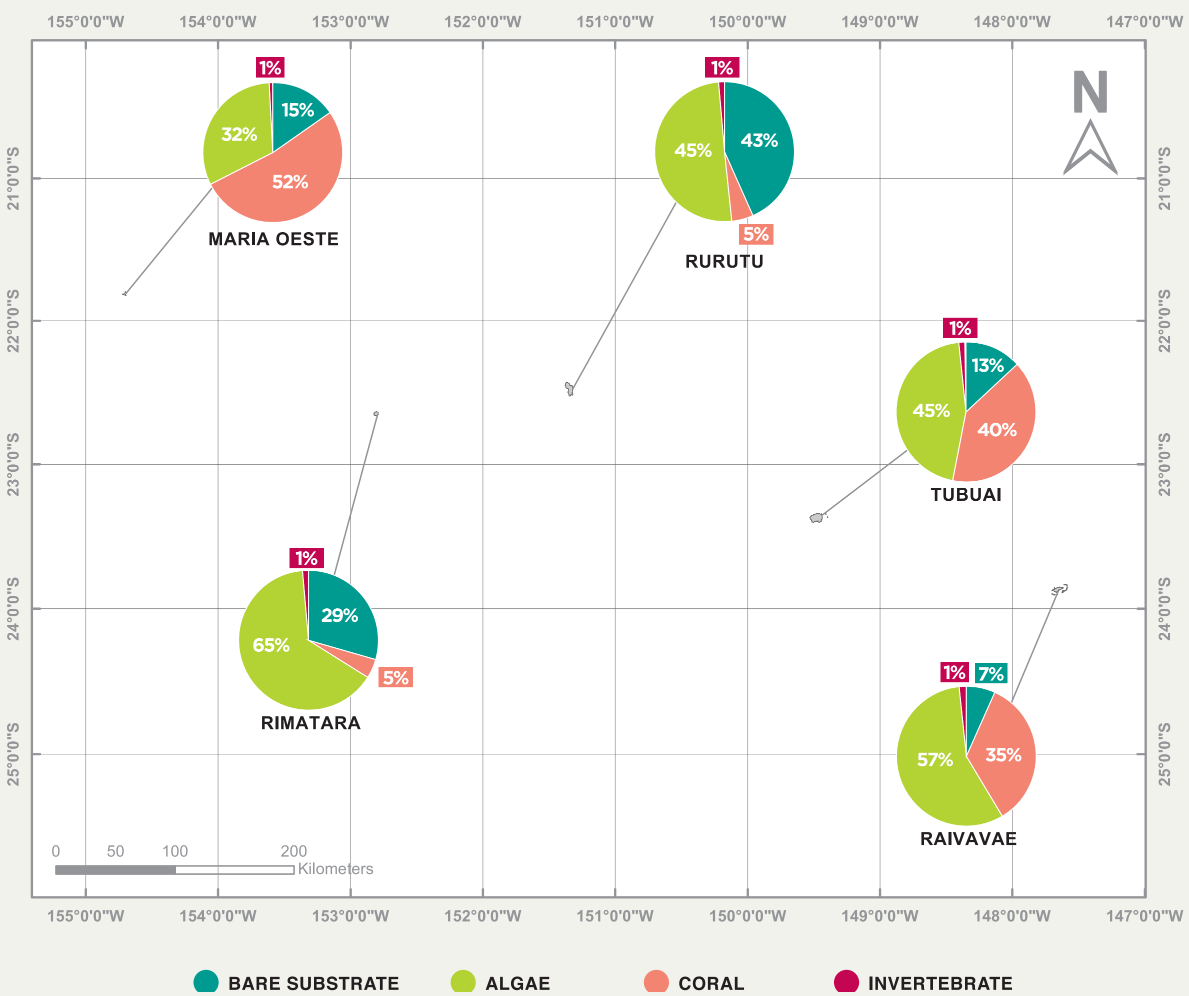


Figure 29

BENTHIC COVER (%) OF THE ISLANDS SURVEYED IN THE AUSTRAL ARCHIPELAGO. THE SUBSTRATE TYPES ARE BARE SUBSTRATE, ALGAE, LIVE CORAL, AND INVERTEBRATES.

(±24% S.D.) and 23% (±27% S.D.) of the overall coral recorded respectively.

Given the low coral cover, it was interesting how dramatically different the dominant algae types were between Rimatara and Rurutu (Figure 30). Rurutu was dominated by macroalgae comprising 42% (± 32% S.D.) of the total algae present, while Rimatara was dominated by 35% (±24% S.D.) CCA. Rimatara had the highest number of *Diadema* urchins observed that feed on fleshy macroalgae (Figure 31), while Rurutu had very few urchins present. The high population of *Diadema* is the likely reason for dramatic difference in dominant algae type.

Crustose coralline algae was the most dominant algae type at Maria Oeste, comprising nearly 60% (±13% S.D.) of the total algae present. Raivavae, was dominated by fleshy macroalgae. The dominant algae on Tubuai was CCA, measuring 26% (±10% S.D.) of the total algae, followed closely by macroalgae, erect coralline algae, and turf sediment.

Curiously, despite its lower latitude and moderate coral cover, the Austral Archipelago has the overall highest diversity of corals seen in these four French Polynesian archipelagoes. On the Shannon-Weiner index, the coral diversity (by genus) in the Austral Archipelago ranged from 2.0-2.2 (Table 4). Maria Oeste had the lowest diversity found in the Austral Islands falling at 2.0, with the highest diversity found at Tubuai with an index of 2.2.

Figure 30 RELATIVE COMPOSITION OF ALGAE (%) AT EACH ISLAND IN THE AUSTRAL ARCHIPELAGO.

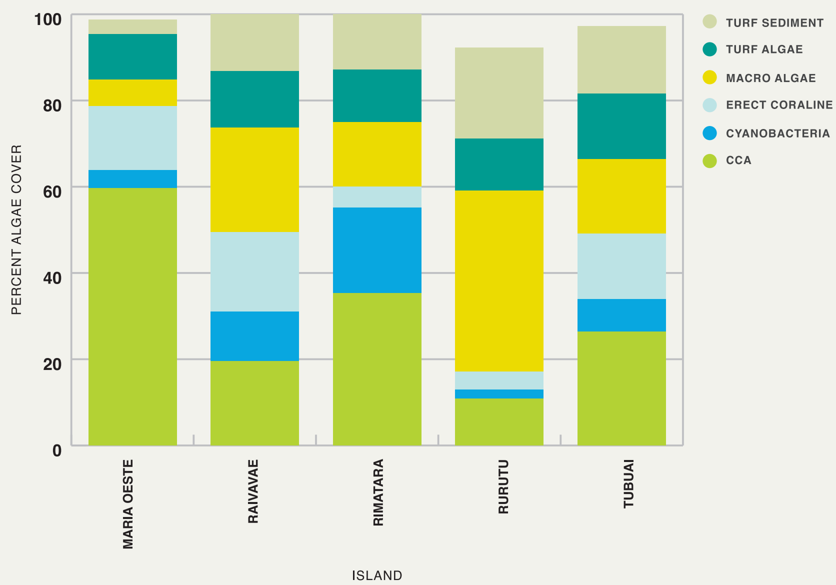
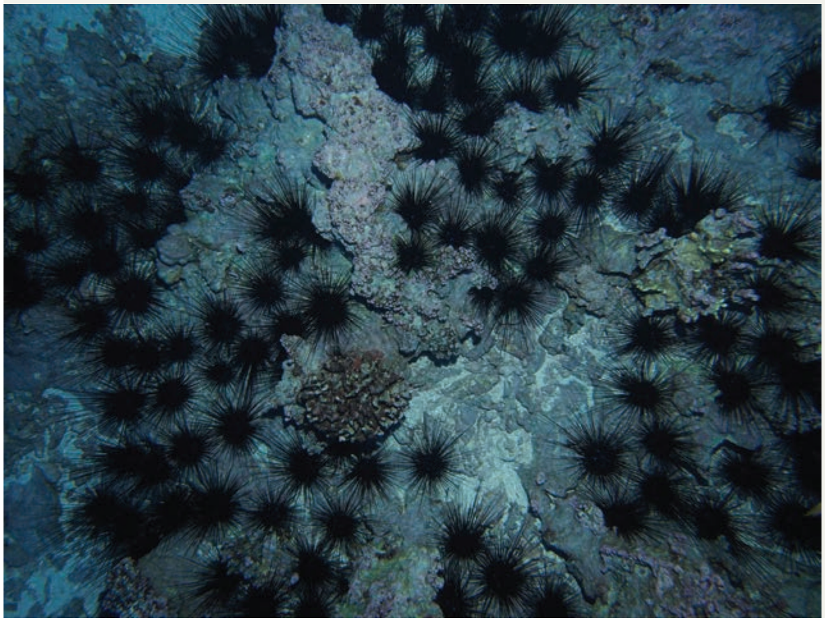


Figure 31 PHOTO OF A LARGE POPULATION OF DIADEMA SP. SEA URCHINS OBSERVED AT RIMATARA.



3.4 c FISH COMMUNITY ASSESSMENT

The reefs of the Austral Archipelago had the lowest total fish species numbers, mean species richness and mean density relative to the Society, Tuamotu and Gambier Archipelagoes **(Table 6)**. Compared to high diversities of target species at other locations, the fish communities in the Austral Islands were virtually evenly represented by major, minor and target species. Large predatory fish were few in numbers. Nevertheless, the fish communities of the Austral Archipelago were still relatively diverse and abundant, making them potentially important contributors to the stability of fish structures in adjacent areas.

The fish identified included 82 target species, 62 minor species, 45 majors, 31 indicators and only 3 target/indicator species. There was a relatively even distribution of species between targets, majors and minor fish species across islands **(Figure 32)**. The mean total richness of target and major fish species were similar at 8 (±5 S.D.) species and 8 (±3 S.D.) species/100 m^2, respectively. Minor species had a mean total richness of 7 (±3 S.D.) species/120 m^2.

> Reefs of the Austral Archipelago had the **lowest mean species richness, mean fish density, and relatively low mean fish biomass** when compared to the other four archipelagoes.

SPECIES RICHNESS OF THE FISH ASSEMBLAGE

Surveys of the five islands in the Austral Archipelago identified a total of 223 species of reef fish from 37 families **(Table 12)**. Total species richness ranged between 104 and 154 species across islands. The Austral Archipelago had the lowest total species counts and mean total species richness among the four mission locations in French Polynesia **(Table 6)**.

Table 12 MEAN FISH SPECIES RICHNESS (# SPECIES/120 M^2 ±S.D.), MEAN FISH DENSITY (# INDIVIDUALS/100 M^2 ±S.D.), MEAN FISH BIOMASS (KG/100 M^2 ±S.D.) IN THE AUSTRAL ARCHIPELAGO.

LOCATION/ISLAND	# of Survey Stations	# of Replicate Transects	Total Families	Total Species	Mean # of Species	Mean Density	Mean Biomass
Mangareva	33	198	36	239	28 (±11)	119 (±73)	16.3 (±24.4)
Maria Est	3	18	27	127	40 (±8)	233 (±55)	32.4 (±36.8)
Maturei Vavao	3	15	21	117	38 (±10)	215 (±45)	11.2 (±15.7)
Temoe	6	35	29	156	41 (±9)	279 (±89)	25.3 (±42.1)
Tenararo	3	12	22	125	41 (±7)	194 (±54)	11.2 (±10.5)
Tenarunga	3	12	22	112	44 (±4)	264 (±70)	9.4 (±10.5)
Vahanga	3	12	21	106	39 (±5)	223 (±38)	6.1 (±4.1)
TOTAL/MEAN	**104**	**486**	**44**	**299**	**34 (±15)**	**283 (±227)**	**52.5 (±81.9)**

FISH DENSITY

The average density of fish in the Austral Archipelago was 110 (±55 S.D.) individuals/100 m^2 (Table 12). Relative to the other three mission locations in French Polynesia, this was the lowest mean total density (Table 6).

Minor species of fish were the most abundant fish at four of the five islands where their densities ranged from 44 (±31 S.D.) individuals/100 m^2 at Tubuai to 80 (±50 S.D.) individuals/100 m^2 at Maria Oeste (Figure 33). At Raivavae, target species were relatively more abundant than minor species, and the surgeonfish *Acanthurus nigrofuscus* and *Ctenochaetus striatus* (Acanthuridae) were present in high numbers. These same species were also especially abundant at Tubuai which contributed to the relatively high density of target species at this location (Figure 33). The estimated densities of indicator species were high at Maria Oeste, Raivavae and Tubuai, ranging between 9 (±6 S.D.) and 13 (±6 S.D.) individuals. At Rimatara and Rurutu, only 4 (±2 S.D.) to 3 (±3 S.D.) individuals of the fish observed were indicator species which is to be expected given the severely damaged reefs (Figure 33).

FISH BIOMASS

The average fish biomass in the Austral Archipelago was estimated to be 8.8 (±17.8) kg/100 m^2 (Table 12). This was relatively poor compared to the estimates from the Tuamotu and Gambier island groups and was only about 1 kg greater than the estimate at the Society Archipelago (Table 6). Target species contributed the majority of the fish biomass across the Austral Archipelago. The biomass of target species ranged between 2.9 (±3.5 S.D.) kg and 15.5

Figure 32 MEAN ESTIMATED SPECIES RICHNESS OF FISH (SPECIES/120 M^2) BY CATEGORY IN THE AUSTRAL ARCHIPELAGO.

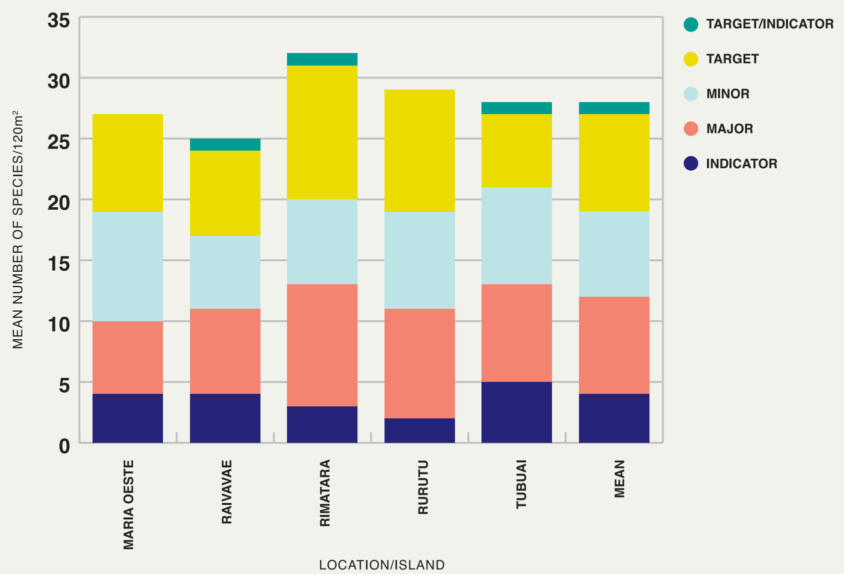


Figure 33 MEAN DENSITY OF FISH (# INDIVIDUALS/100 M^2) OF FISH BY CATEGORY IN THE AUSTRAL ARCHIPELAGO.

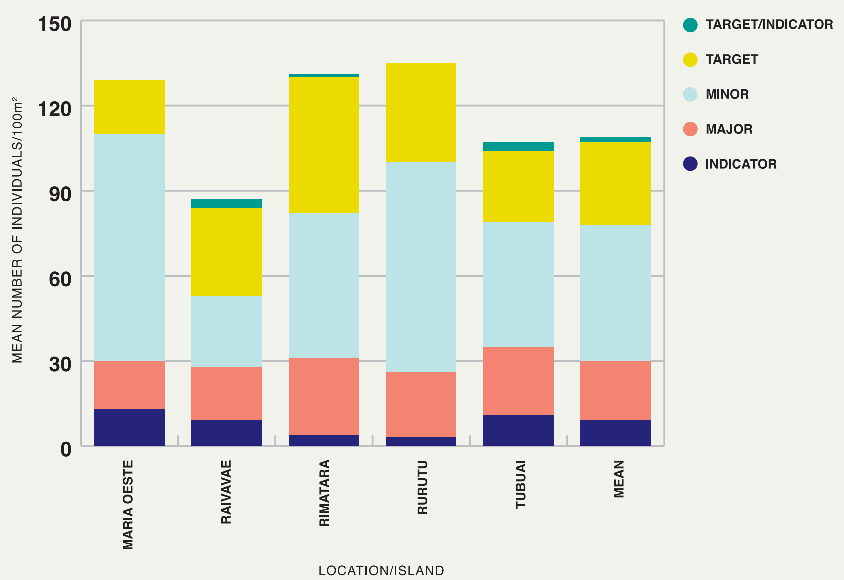


Figure 34 MEAN FISH BIOMASS (KG/100 M²) BY CATEGORY IN THE AUSTRAL ARCHIPELAGO.

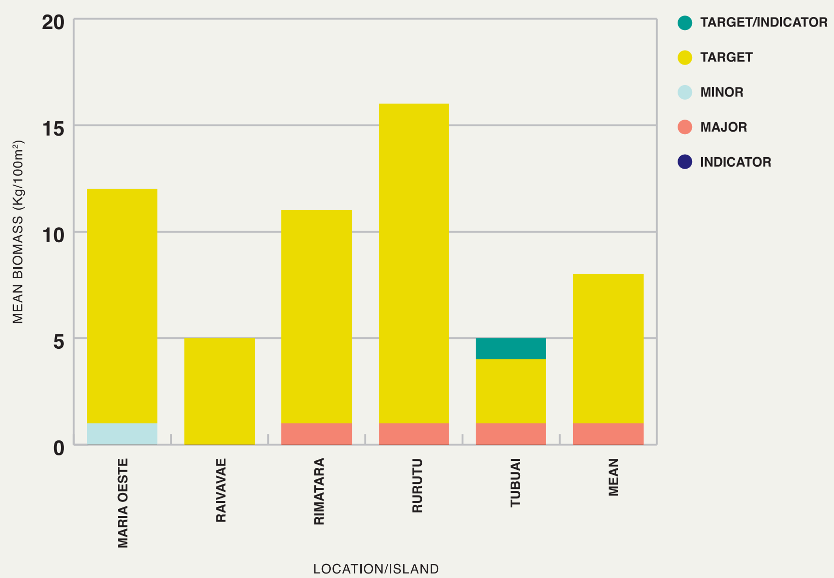
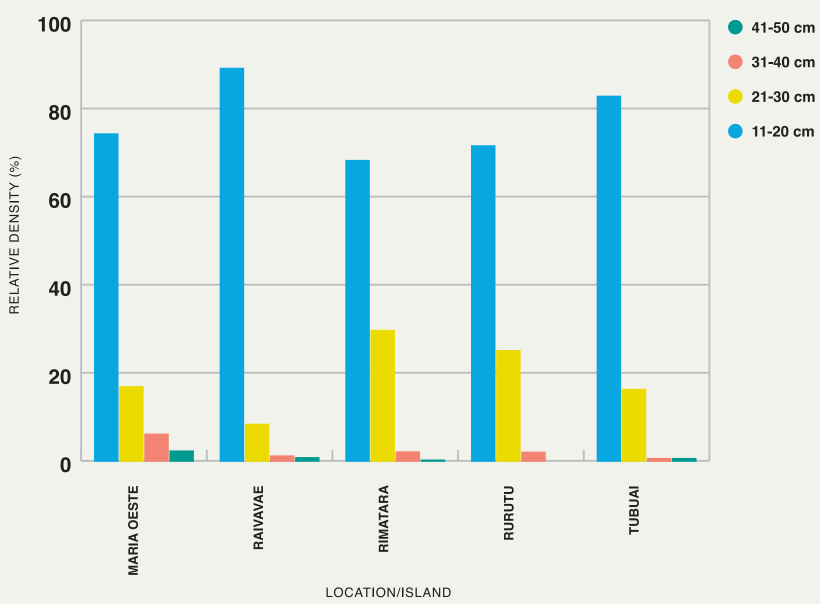


Figure 35 RELATIVE SIZE CLASS DISTRIBUTION (%) BASED ON TOTAL DENSITIES OF SELECTED IMPORTANT SPECIES IN THE AUSTRAL ARCHIPELAGO.



(±12.7 S.D.) kg/100 m² **(Figure 34)**. The biomass of the other fish categories hardly exceeded 1 kg at any of the locations with the exception of major species at Rimatara and Rurutu. The size frequency distribution of selected important fish families showed that large fish were scarce **(Figure 35)**. Fish between 11 and 20 cm and 21 to 30 cm in total length were predominant, while fish in excess of 31 cm were very few.

The species richness, abundance and biomass of fish communities at the Austral Archipelago were poor relative to the communities found at the Society, Tuamotu and Gambier Archipelagoes. Despite this, the Austral islands still harbor an imposing array of fish species and assemblages.

The Austral Archipelago had the **highest coral diversity** seen in French Polynesia. There were also several islands with high live coral cover reaching just over 50%, while others were severely impacted by **Crown-of-Thorn Starfish outbreaks, devastating the reefs** and reducing live coral to only 5%.

4.0 DISCUSSION

DISCUSSION

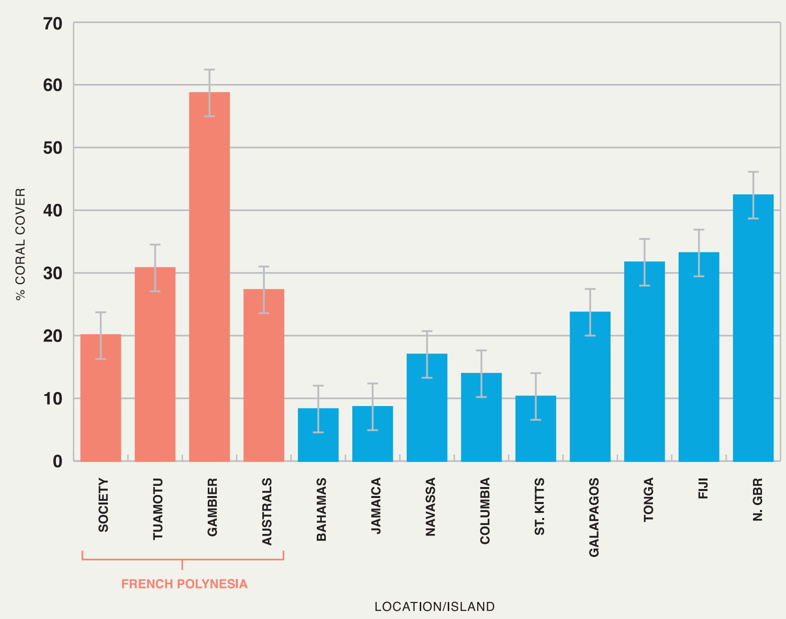
4.0 The ability to survey four of the five major archipelagos in French Polynesia was a critical component of the Khaled bin Sultan Living Oceans Foundation's GRE. It provided us with valuable information on the reefs of the South Pacific that will contribute greatly to our global assessment of coral reef health. Many of the islands visited in French Polynesia were examples of healthy thriving reef communities.

> The Gambier Archipelago exhibited **extraordinary coral and fish communities,** with coral cover being nearly **20% higher than other locations** surveyed throughout the world.

In general, the Gambier Archipelago exhibited extraordinary coral and fish communities. The percent coral cover was not only the highest observed by KSLOF in French Polynesia, but when compared to other locations surveyed on the GRE, the average cover proved to be exceptionally high globally **(Figure 36)**[44–46], being nearly 20% higher than other locations surveyed throughout the world. Fish communities in the Gambier Archipelago had some of the highest richness, abundance, and biomass recorded. Economically important fish species were diverse and plentiful, as were reef health indicator species. The lack of both anthropogenic and natural disturbances allowed for healthy coral communities to persist. Coral diversity in the Gambier Archipelago was lower than the Austral Archipelago, likely due to very large monospecific stands, particularly within the lagoon at Mangareva. When there is minimal localized disturbance, such as a cyclone, space becomes available for new coral species to settle, thus driving up the overall diversity. Because there was no recently recorded disturbance at the time of sampling, little open space and recruitment was observed when compared to the other island groups, possibly driving down the coral diversity.

The atolls of the Tuamotu Archipelago exhibited the second highest overall coral cover of all of the groups visited, and the fish communities were the healthiest recorded. The reef fish species richness, density, and biomass of Tuamotu were the highest measured in French Polynesia, with a high abundance of large target species and top predatory fish such as sharks, groupers, and barracuda. When compared on a global scale, the fish densities were notably higher than many other countries researched on the GRE **(Figure 37)**[44,46].

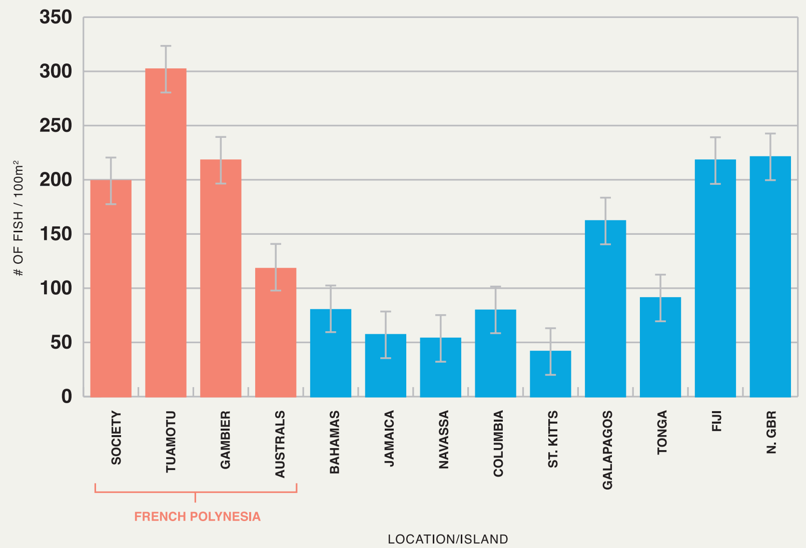
Figure 36 GLOBAL COMPARISON OF CORAL COVER (% WITH STANDARD ERROR).



The Society and Austral Archipelagoes provided some of the most intriguing findings from the GRE in French Polynesia. These two island groups were most severely impacted by COTS and cyclone disturbance in the 10 years prior to surveying, and this was evident in our findings[2,41,47]. In both archipelagoes, the un-populated, outlying islands had some of the highest coral and fish communities observed **(Figures 36 and 37)**. The elevated numbers of COTS were first observed in the Society Archipelago in 2002, with numbers increasing throughout the subsequent years until about 2009. The rapid COTS population growth caused significant damage to the islands of Huahine, Raiatea, Taha'a, Bora Bora, Maupiti, Tahiti, and Moorea in the Society Archipelago, then moved south to the islands of Rurutu and Rimatara in the Austral Archipelago[2]. Recovery from this detrimental disturbance was observed in the Society Archipelago where there were notably more coral recruits, although this parameter was not quantitatively collected. There are numerous factors that likely contributed to the higher number of recruits noted in the Society Archipelago, one possibility being the dominance of CCA which is used as an ideal settlement site for new coral polyps[48,49]. The lack of fleshy macroalgae and turf algae in the Society Archipelago supports the evidence of relatively stable herbivorous fish communities as well, although the coral populations were less abundant and diverse as compared to the Tuamotu and Gambier Archipelagoes to the north and east. In the Austral Archipelago, there was much lower coral recruitment observed at the islands severely impacted by COTS, with higher overall macroalgae present at Rurutu. There was also a lack of indicator fish species at these specific islands which coincides with the damaged reefs. It is possible that the absence of new coral recruits could be due to the more southern location of the archipelago, although we suggest this be investigated further. There may be higher recruitment seen as more time has passed since the COTS outbreak and this sampling effort.

Figure 37

GLOBAL COMPARISON OF MEAN FISH DENSITIES (# INDIVIDUALS/100M²) WITH STANDARD ERROR).



The Society and Austral archipelagoes were most severely impacted by COTS and cyclone disturbance in the 10 years prior to surveying.

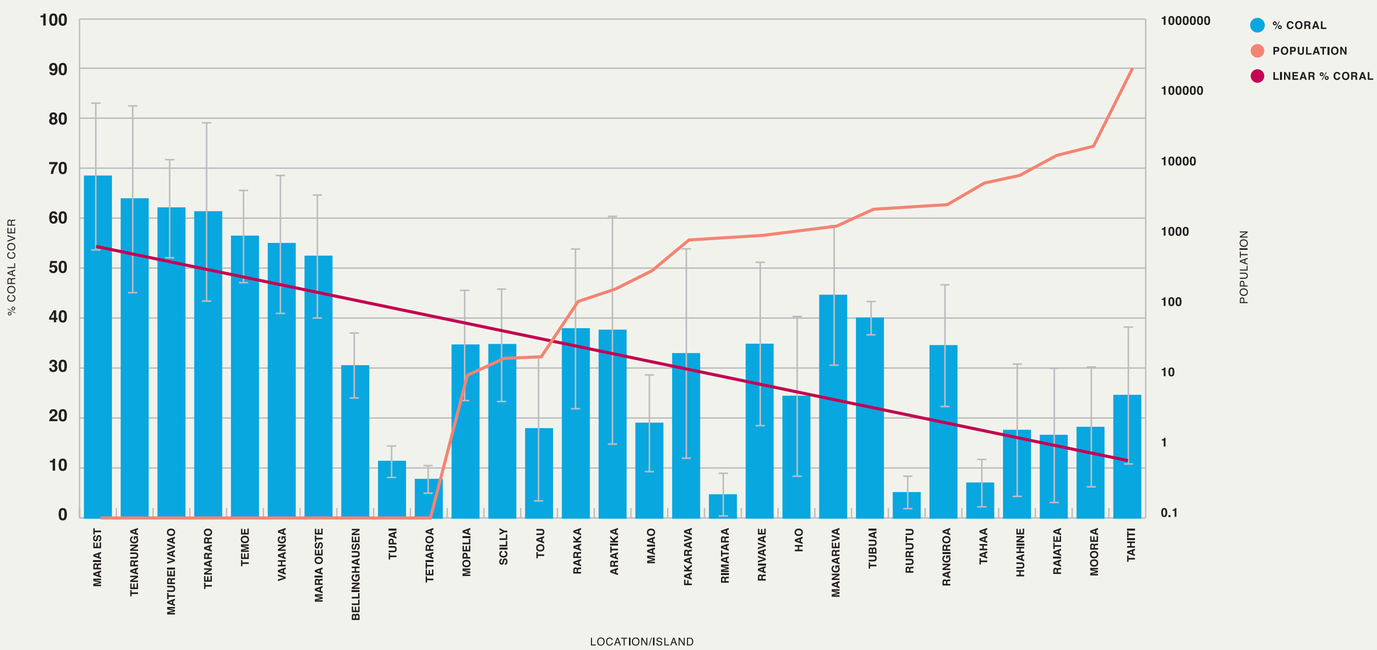
An increase in nearshore nutrient runoff is frequently related to islands with higher elevation, larger land mass, and consequently larger human population centers. This high nutrient runoff can often times have a negative impact on the surrounding coral reefs[50,51]. Although there have been numerous natural disturbances that have impacted

The islands with the **lowest elevations and population size** appear to be able to sustain much **healthier reefs** overall, including **healthier fish communities.**

the reefs in the Society and Austral Archipelagoes, the islands with the lowest elevations and population size appear to be able to sustain much healthier reefs overall, including healthier fish communities. It was generally observed that of the islands visited in French Polynesia, the lower the human population size on the island, the healthier the surrounding coral reef ecosystem (Figure 38). Besides lowering the water quality near coral reefs, higher nutrient runoff has been linked to an increase in COTS populations[40]. This appears to be the case in French Polynesia. Moorea and Tahiti have the highest concentrations of people in the territory, the highest elevation, and largest land masses. The elevated COTS numbers were first observed surrounding these two large, highly populated islands. We theorize that these COTS populations were able to spread and populate nearby islands, eventually decimating numerous reefs in the Society Archipelago. We also believe the increased nutrient runoff due to construction and dredging around

Figure 38a

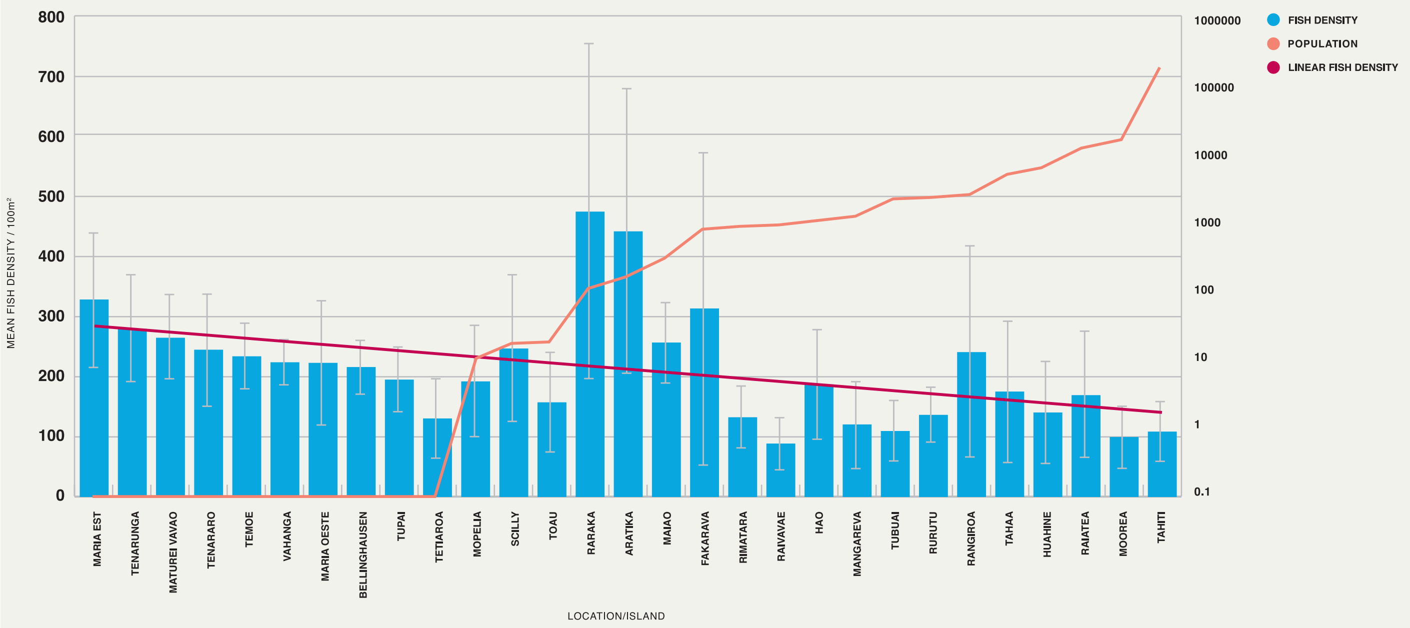
COMPARISON OF CORAL COVER VERSUS LOGARITHMIC CONVERSION OF ISLAND POPULATION. ERROR BARS ARE STANDARD DEVIATION.



Tetiaroa, at the time we surveyed, contributed to the secondary outbreak in COTS that was observed. In the Austral Archipelago, Rurutu (the most highly populated island in the Austral Archipelago) and nearby Rimatara were the two islands most severely impacted by COTS, suggesting higher human populations and nutrient runoff were likely contributors to the increase in densities of this corallivore.

Generally, the reef and fish communities of French Polynesia are healthy and, based on recovery from previous natural disturbances, there is strong evidence to support that they are resilient reefs. Just like other coral reefs around the world, these reefs are susceptible to damage from increased nutrients and natural disturbances, but we are hopeful that with successful management practices, these impacts can be reduced.

Figure 38b MEAN FISH DENSITY VERSUS LOGARITHMIC ISLAND POPULATION. ERROR BARS ARE STANDARD DEVIATIONS.

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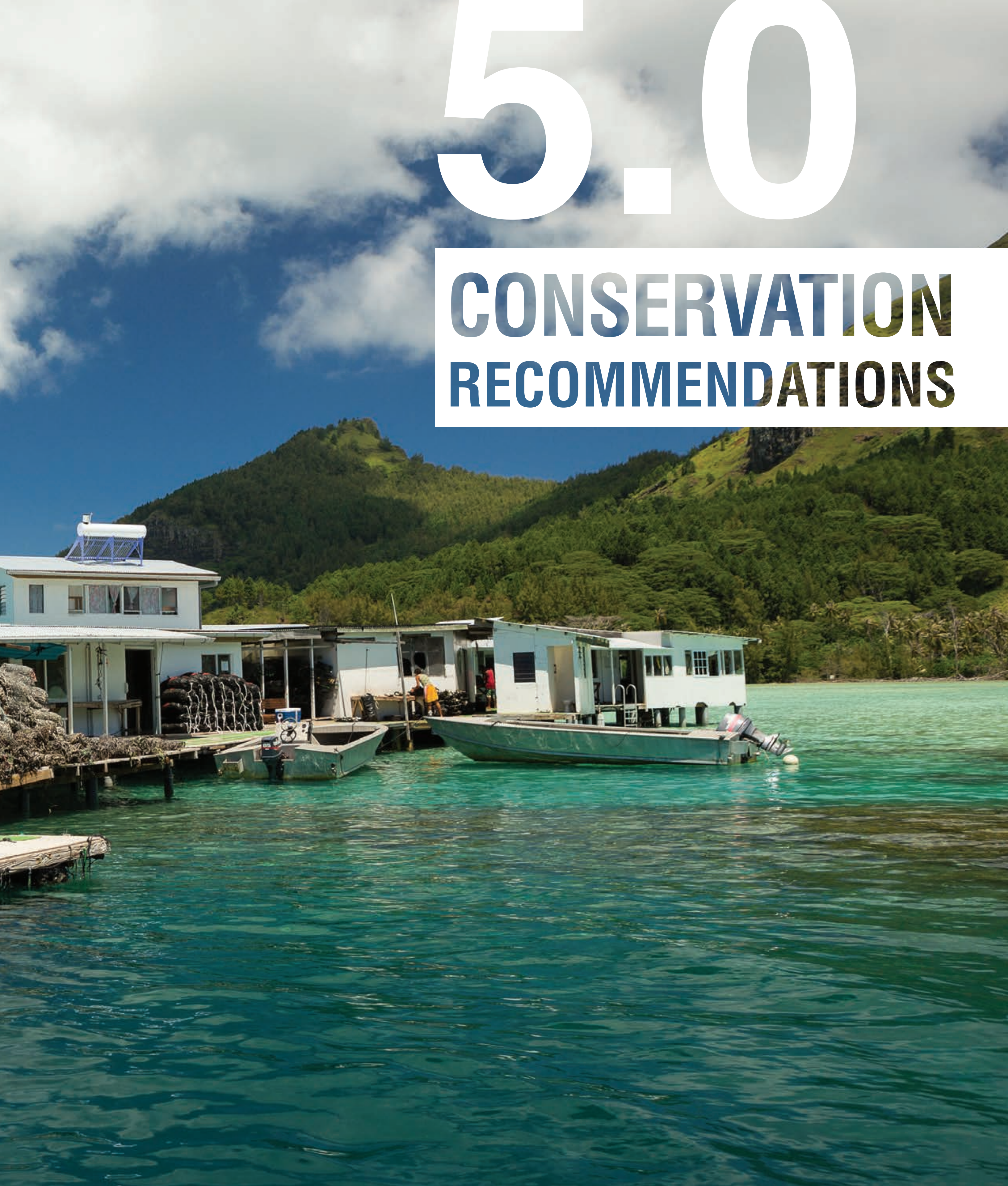
5.0 CONSERVATION RECOMMENDATIONS



CONSERVATION RECOMMENDATIONS

5.0

Based on the benthic communities, coral diversity, fish populations, and connectivity of these coral reef communities within the island groups, we are able to provide scientifically supported recommendations for areas of protection within the four archipelagoes visited.

HOW TO CONSERVE FRENCH POLYNESIA'S CORAL REEFS

There is considerable evidence showing high connectivity among and within the reefs of the French Polynesian Archipelagoes[16,52]. Numerous coral and fish species are reliant on a pelagic larval stage that allows them to have a wider dispersal and settle in locations farther from the parent organism[16,53]. These organisms are dependent on ocean currents, and determining where healthy reef communities are found is only one part in choosing sites that should be protected. Understanding the connectivity within the islands is also a critical component in establishing protected areas[16]. *Martinez et al* (2007) shows during El Niño Southern Oscillation events the major currents within the archipelagoes tend to shift and strengthen, as well as change annually on a seasonal basis (wet vs. dry seasons), but overall is largely driven by the strength of the South Equatorial Current to the north of French Polynesia, and South Pacific Current to the south. There are also major eddies that form within the island groups that have a strong influence on the retention of larvae within the archipelagoes. Both Treml et al (2008) and *Martinez et al* (2007) show that there is a strong persistent current, flowing from the Marquesas toward and through the Tuamotu Archipelago, continuing southwest to the Society and eventually the Austral Archipelagoes. There is also strong evidence showing an eastward water flow (largely driven by the Southern Pacific Current) from the Austral Archipelago toward the Gambier Archipelago. During certain years, there can be a northward and eastward current traveling from the Society Archipelago toward the Tuamotu and Gambier Archipelagoes, and a northward current traveling from the Austral Archipelago toward the Society and Tuamotu Archipelagoes.

Encouragingly, the benthic habitats of the Society Archipelago are showing signs of resilience and recovery. The moderate coral cover and higher recruits observed suggests the reefs may show signs of recovery following the cyclone and devastating COTS outbreaks that recently impacted this island group. The fish assemblages of the Society Archipelago show community differences likely related to human population on the islands, and this trend is found throughout all of the other regions as well. There is a decline in the fish biomass as the population increases (Figure 37). The fish communities around the populated islands of Huahine, Raiatea-Taha'a, Tahiti and Tūpai had poor mean biomass estimates and the relative size distribution at these islands was lower than those found at the uninhabited outer islands of Mopelia, Scilly, and Bellinghausen. The outer islands had generally larger fish and a higher overall biomass. The large human population concentrations appear to be putting pressure on the fish communities and it is recommended more rigorous management efforts be implemented particularly focusing on the larger, economically important fish species.

It is recommended more **rigorous management efforts** be implemented, particularly **focusing on the larger, economically important fish species** throughout all of French Polynesia.

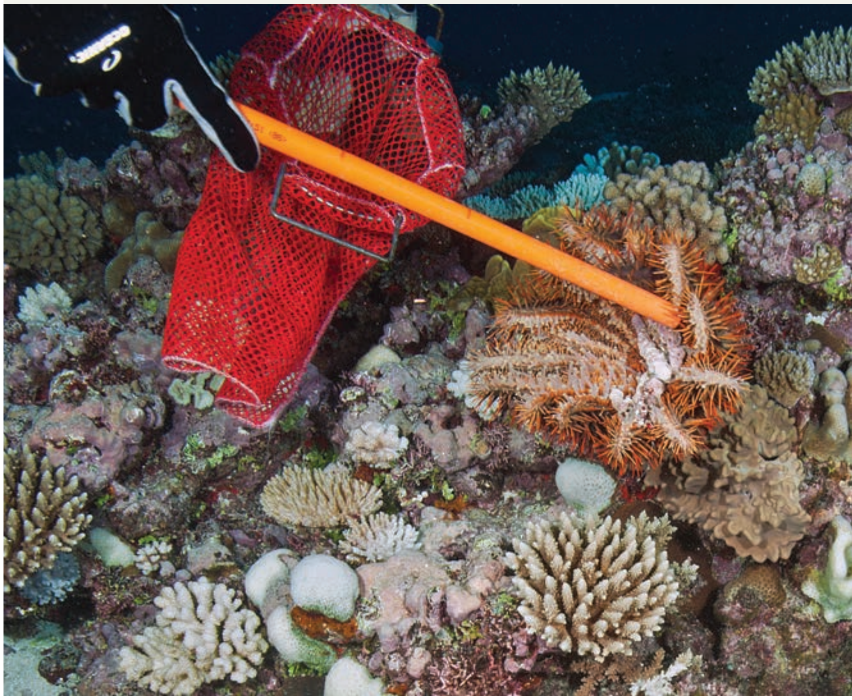
We also recommend continued management around the islands of Bellinghausen and Scilly, and establishment of a MPA around the island of Mopelia as these three islands had the healthiest reef and fish communities in the Society Archipelago. Additionally, because the Society Archipelago is likely facilitating the seeding of reefs in the other three archipelagoes[16–18], it is important to protect these healthy reef communities so they can support neighboring reefs should another major disturbance occur.

> **The healthiest coral and fish communities** must be protected to maintain the coral and fish population **connectivity within the island groups.**

With the Austral Archipelago having the highest coral diversity of all of the island groups visited, KSLOF strongly recommends establishing MPAs, particularly focusing efforts around the islands of Tubuai and Maria Oeste. These islands had some of the healthiest fish and coral communities in this Archipelago. These islands are the farthest west and provide new fish and coral recruits to the rest of the reef communities in the Archipelago as the dominant current travels in an eastward direction. Due to the severe damage observed at Rimatara and Rurutu, we recommend reef restoration efforts be made, such as through ecological restoration and managing local stressors[54–56], to both help regenerate the coral communities, as well as protect the present fish communities. Throughout all of French Polynesia, to prevent further damage to the reefs, we recommend continued monitoring of COTS populations and immediate removal efforts should be implemented when elevated numbers are reported **(Figure 39)**. Based on an outbreak in the Cook Islands in 2013, KSLOF has developed a removal protocol that can be found on our website (www.lof.org/science/crown-of-thorns-starfish/managing-cots-outbreak/) to aid in removal and management of COTS outbreaks **(Figure 39)**.

We recommend mitigating efforts continue to be focused on the islands of Fakarava, Aratika, and Rangiroa in the Tuamotu Archipelago, and throughout all of the Gambier Archipelago. These locations have some of the healthiest coral and fish communities that must be protected to maintain the coral and fish population connectivity within the island groups. The islands in the Tuamotu Archipelago are primarily sharing coral and fish recruits to the Society Archipelago. Considering the Society Archipelago has been affected by natural disturbances in recent years, protection of these parent reefs is critical. The Gambier Archipelago likely contains some of the healthiest reefs seen in the whole South Pacific Ocean, therefore it is imperative that protection be implemented. The reefs of the world are already declining, saving this precious ecosystem is not only critical for the people of French Polynesia, but the downstream reefs of nearby countries in the whole South Pacific.

Figure 39 COTS REMOVAL FROM AN INFESTED REEF. PHOTO BY KEN MARKS.



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The research mission to French Polynesia would not have been possible without the leadership, vision, and generosity of His Royal Highness Prince Khaled bin Sultan. The Foundation is deeply appreciative of his financial support and for the generous use of his research vessel, the *M/Y Golden Shadow*. His vision of *Science Without Borders®* was materialized in the research mission to French Polynesia through the involvement and partnerships by scientists from the following countries: French Polynesia, New Caledonia, France, United States of America, New Zealand, Australia, Portugal, the Philippines, and Taiwan.

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The research mission to French Polynesia benefited from Captain Steve Breen, Captain Patrick Walsh and the officers and crew of the *M/Y Golden Shadow*. They were responsible for getting us safely to our research sites and conducting all logistical operations of the dive and research vessels. They ensured that each researcher had access to the study sites and proper working tools and equipment needed to complete the work, and had highly capable engineers and electricians that repaired and fabricated gear when we ran into complications. Behind the scenes, the crew worked at all hours to support the scientists on the Global Reef Expedition, and for that, the Foundation is immensely grateful.

As deliverables from this research project are completed, we look forward to continuing these partnerships to ensure the information and data from this project are applied toward the conservation needs and goals of the French Polynesian people.

Society

Tuamotu

Rangiroa

Austral

Gambier*

*NOT PICTURED

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APPENDIX 1 | DIVE SITES & SITE DESCRIPTIONS

Appendix 1 | Society

GROUP	Island	Site	Date	Latitude	Longitude	Reef Location	Exposure
Society	Mopelia	FPMO01	17-Sep-12	-16.7856	-153.9803	Fore Reef	Intermediate
	Mopelia	FPMO02	17-Sep-12	-16.7733	-153.9703	Fore Reef	Intermediate
	Mopelia	FPMO03	18-Sep-12	-16.8031	-153.9937	Fore Reef	Intermediate
	Mopelia	FPMO04	18-Sep-12	-16.7721	-153.9689	Fore Reef	Intermediate
	Mopelia	FPMO05	18-Sep-12	-16.7862	-153.9697	Lagoon	Protected
	Mopelia	FPMO06	19-Sep-12	-16.8154	-153.9952	Fore Reef	Intermediate
	Mopelia	FPMO07	19-Sep-12	-16.7811	-153.9768	Fore Reef	Intermediate
	Mopelia	FPMO08	19-Sep-12	-16.8205	-153.953	Lagoon	Protected
	Scilly	FPSC09	20-Sep-12	-16.5683	-154.7337	Fore Reef	Exposed
	Scilly	FPSC10	20-Sep-12	-16.5362	-154.7325	Fore Reef	Exposed
	Scilly	FPSC11	20-Sep-12	-16.4885	-154.7123	Fore Reef	Exposed
	Scilly	FPSC12	21-Sep-12	-16.494	-154.6603	Fore Reef	Intermediate
	Scilly	FPSC13	21-Sep-12	-16.4789	-154.6907	Fore Reef	Intermediate
	Scilly	FPSC14	21-Sep-12	-16.5081	-154.7291	Fore Reef	Exposed
	Bellingshausen	FPBE15	22-Sep-12	-15.7968	-154.5277	Fore Reef	Intermediate
	Bellingshausen	FPBE16	22-Sep-12	-15.7986	-154.5135	Fore Reef	Intermediate
	Bellingshausen	FPBE17	22-Sep-12	-15.8171	-154.5463	Fore Reef	Intermediate
	Tupai	FPTU18	23-Sep-12	-16.2588	-151.7954	Fore Reef	Intermediate
	Tupai	FPTU19	23-Sep-12	-16.2836	-151.8361	Fore Reef	Exposed
	Tupai	FPTU20	23-Sep-12	-16.2285	-151.83	Fore Reef	Exposed
	Huahine	FPHU21	24-Sep-12	-16.6904	-150.9835	Fore Reef	Intermediate
	Huahine	FPHU22	24-Sep-12	-16.7173	-151.049	Fore Reef	Exposed
	Huahine	FPHU23	24-Sep-12	-16.7692	-151.0458	Lagoon	Protected
	Huahine	FPHU24	25-Sep-12	-16.7682	-150.9596	Lagoon	Protected
	Huahine	FPHU25	25-Sep-12	-16.7976	-151.0136	Lagoon	Protected
	Huahine	FPHU26	26-Sep-12	-16.7363	-151.0572	Fore Reef	Exposed
	Huahine	FPHU27	26-Sep-12	-16.7476	-151.0484	Lagoon	Protected
	Tahaa	FPTA28	26-Sep-12	-16.7036	-151.4828	Lagoon	Protected
	Tahaa	FPTA29	27-Sep-12	-16.625	-151.5799	Fore Reef	Intermediate
	Tahaa	FPTA30	27-Sep-12	-16.5717	-151.552	Fore Reef	Intermediate
	Tahaa	FPTA31	28-Sep-12	-16.6814	-151.5255	Fore Reef	Intermediate
	Tahaa	FPTA32	28-Sep-12	-16.6607	-151.4403	Lagoon	Protected
	Tahaa	FPTA56	9-Oct-12	-16.5627	-151.4461	Fore Reef	Intermediate
	Tahaa	FPTA57	9-Oct-12	-16.5527	-151.4982	Fore Reef	Intermediate
	Raiatea	FPRA33	29-Sep-12	-16.8329	-151.4962	Fore Reef	Intermediate

GROUP	Island	Site	Date	Latitude	Longitude	Reef Location	Exposure
Society	Raiatea	FPRA34	29-Sep-12	-16.8986	-151.4718	Lagoon	Protected
	Raiatea	FPRA35	30-Sep-12	-16.8746	-151.4938	Fore Reef	Intermediate
	Raiatea	FPRA36	30-Sep-12	-16.89502	-151.49214	Fore Reef	Intermediate
	Raiatea	FPRA37	30-Sep-12	-16.91732	-151.46751	Lagoon	Protected
	Raiatea	FPRA38	1-Oct-12	-16.80644	-151.49919	Fore Reef	Intermediate
	Raiatea	FPRA39	1-Oct-12	-16.8479	-151.4952	Fore Reef	Intermediate
	Raiatea	FPRA40	1-Oct-12	-16.9035	-151.4738	Lagoon	Protected
	Raiatea	FPRA41	2-Oct-12	-16.9198	-151.4602	Lagoon	Protected
	Raiatea	FPRA42	2-Oct-12	-16.8794	-151.4759	Lagoon	Protected
	Raiatea	FPRA43	2-Oct-12	-16.9095	-151.4196	Lagoon	Protected
	Raiatea	FPRA44	3-Oct-12	-16.922	-151.4817	Fore Reef	Intermediate
	Raiatea	FPRA45	4-Oct-12	-16.8251	-151.3479	Fore Reef	Exposed
	Raiatea	FPRA46	4-Oct-12	-16.9027	-151.4282	Lagoon	Protected
	Raiatea	FPRA47	4-Oct-12	-16.922	-151.4817	Fore Reef	Protected
	Raiatea	FPRA48	5-Oct-12	-16.934	-151.4582	Fore Reef	Intermediate
	Raiatea	FPRA49	5-Oct-12	-16.9313	-151.4761	Fore Reef	Intermediate
	Raiatea	FPRA50	7-Oct-12	-16.8502	-151.3328	Fore Reef	Exposed
	Raiatea	FPRA51	7-Oct-12	-16.7901	-151.3765	Fore Reef	Exposed
	Raiatea	FPRA52	7-Oct-12	-16.8066	-151.3638	Fore Reef	Exposed
	Raiatea	FPRA53	8-Oct-12	-16.7032	-151.4385	Fore Reef	Exposed
	Raiatea	FPRA54	8-Oct-12	-16.765	-151.4004	Fore Reef	Exposed
	Raiatea	FPRA55	8-Oct-12	-16.8135	-151.3778	Lagoon	Protected
	Raiatea	FPRA58	9-Oct-12	-16.8011	-151.3847	Lagoon	Protected
	Maiao	FPMA59	10-Oct-12	-17.6489	-150.6498	Fore Reef	Intermediate
	Maiao	FPMA60	10-Oct-12	-17.6315	-150.6356	Fore Reef	Intermediate
	Maiao	FPMA61	10-Oct-12	-17.6361	-150.6252	Fore Reef	Intermediate
	Tetiaroa	FPTE62	11-Oct-12	-16.9852	-149.5829	Fore Reef	Intermediate
	Tetiaroa	FPTE63	11-Oct-12	-17.0042	-149.5931	Fore Reef	Intermediate
	Tetiaroa	FPTE64	11-Oct-12	-16.9816	-149.5671	Fore Reef	Intermediate
	Tahiti	SOTH01	15-Nov-12	-17.4988	-149.5041	Fore Reef	Intermediate
	Tahiti	SOTH02	15-Nov-12	-17.7887	-149.4195	Fore Reef	Exposed
	Tahiti	SOTH03	15-Nov-12	-17.7786	-149.4332	Lagoon	Protected
	Tahiti	SOTH05	15-Nov-12	-17.6924	-149.5912	Fore Reef	Exposed
	Tahiti	SOTH04	15-Nov-12	-17.7808	-149.4228	Lagoon	Protected
	Moorea	MMMO32	21-Mar-13	-17.4828	-149.902	Fore Reef	Intermediate
	Moorea	MMMO33	21-Mar-13	-17.4848	-149.8672	Fore Reef	Intermediate
	Moorea	MMMO34	22-Mar-13	-17.4986	-149.9278	Fore Reef	Intermediate

Appendix 1 | Tuamotu

GROUP	Island	Site	Date	Latitude	Longitude	Reef Location	Exposure
Tuamotu	Rangiroa	TURA-06	18-Nov-12	-14.9723	-147.6221	Fore Reef	Exposed
	Rangiroa	TURA-07	18-Nov-12	-14.9554	-147.7099	Lagoon	Protected
	Rangiroa	TURA-08	18-Nov-12	-15.0192	-147.7572	Lagoon	Protected
	Rangiroa	TURA-09	19-Nov-12	-14.9321	-147.8594	Fore Reef	Intermediate
	Rangiroa	TURA-10	19-Nov-12	-14.9567	-147.867	Fore Reef	Intermediate
	Rangiroa	TURA-11	19-Nov-12	-14.9562	-147.788	Lagoon	Protected
	Rangiroa	TURA-12	20-Nov-12	-15.1409	-147.8095	Lagoon	Protected
	Rangiroa	TURA-13	20-Nov-12	-15.1987	-147.7607	Lagoon	Protected
	Rangiroa	TURA-14	20-Nov-12	-14.9351	-147.706	Fore Reef	Exposed
	Rangiroa	MMRA-01	9-Mar-13	-15.127	-147.9418	Fore Reef	Intermediate
	Rangiroa	MMRA-02	9-Mar-13	-15.0886	-147.9428	Fore Reef	Intermediate
	Rangiroa	MMRA-03	9-Mar-13	-14.9792	-147.616	Fore Reef	Exposed
	Rangiroa	MMRA-04	10-Mar-13	-15.1656	-147.9089	Fore Reef	Intermediate
	Rangiroa	MMRA-05	10-Mar-13	-15.0561	-147.9392	Fore Reef	Intermediate
	Rangiroa	MMRA-06	10-Mar-13	-15.0113	-147.9093	Fore Reef	Intermediate
	Rangiroa	MMRA-07	11-Mar-13	-14.9762	-147.8772	Fore Reef	Intermediate
	Rangiroa	MMRA-08	11-Mar-13	-14.9151	-147.8344	Fore Reef	Exposed
	Rangiroa	MMRA-09	11-Mar-13	-14.9555	-147.6449	Fore Reef	Exposed
	Rangiroa	MMRA-10	12-Mar-13	-15.2359	-147.6532	Fore Reef	Intermediate
	Rangiroa	MMRA-11	12-Mar-13	-15.2556	-147.5754	Fore Reef	Intermediate
	Rangiroa	MMRA-12	12-Mar-13	-15.2362	-147.7561	Fore Reef	Intermediate
	Rangiroa	MMRA-13	13-Mar-13	-14.9481	-147.6703	Fore Reef	Exposed
	Rangiroa	MMRA-14	13-Mar-13	-14.9898	-147.597	Fore Reef	Exposed
	Rangiroa	MMRA-15	13-Mar-13	-14.9695	-147.6272	Fore Reef	Exposed
	Rangiroa	MMRA-16	14-Mar-13	-14.9295	-147.764	Fore Reef	Exposed
	Rangiroa	MMRA-17	14-Mar-13	-14.9826	-147.6346	Lagoon	Protected
	Rangiroa	MMRA-18	15-Mar-13	-15.0137	-147.573	Fore Reef	Exposed
	Rangiroa	MMRA-19	15-Mar-13	-14.9721	-147.6221	Fore Reef	Exposed
	Rangiroa	MMRA-20	16-Mar-13	-15.0048	-147.5792	Fore Reef	Exposed
	Rangiroa	MMRA-21	16-Mar-13	-15.0262	-147.565	Fore Reef	Exposed
	Rangiroa	MMRA-22	17-Mar-13	-15.0015	-147.8808	Lagoon	Protected
	Rangiroa	MMRA-23	17-Mar-13	-14.9344	-147.709	Fore Reef	Exposed
	Rangiroa	MMRA-24	17-Mar-13	-14.9615	-147.6318	Fore Reef	Exposed
	Rangiroa	MMRA-25	18-Mar-13	-15.0467	-147.5406	Fore Reef	Exposed
	Rangiroa	MMRA-26	18-Mar-13	-14.9417	-147.6896	Fore Reef	Exposed

GROUP	Island	Site	Date	Latitude	Longitude	Reef Location	Exposure
Tuamotu	Rangiroa	MMRA-27	19-Mar-13	-15.1447	-147.4247	Fore Reef	Exposed
	Rangiroa	MMRA-28	19-Mar-13	-15.104	-147.4769	Fore Reef	Exposed
	Rangiroa	MMRA-29	19-Mar-13	-14.92	-147.8015	Fore Reef	Exposed
	Rangiroa	MMRA-30	20-Mar-13	-14.9684	-147.6247	Fore Reef	Exposed
	Rangiroa	MMRA-31	20-Mar-13	-15.2364	-147.2797	Fore Reef	Exposed
	Aratika	TUAR-15	21-Nov-12	-15.4902	-145.5865	Fore Reef	Intermediate
	Aratika	TUAR-16	21-Nov-12	-15.4633	-145.5712	Fore Reef	Intermediate
	Aratika	TUAR-17	21-Nov-12	-15.5934	-145.561	Fore Reef	Intermediate
	Aratika	TUAR-18	22-Nov-12	-15.6273	-145.5187	Fore Reef	Intermediate
	Aratika	TUAR-19	22-Nov-12	-15.623	-145.4911	Fore Reef	Exposed
	Aratika	TUAR-20	22-Nov-12	-15.5096	-145.5186	Lagoon	Protected
	Raraka	TURK-21	23-Nov-12	-16.2701	-144.9073	Fore Reef	Intermediate
	Raraka	TURK-22	23-Nov-12	-16.2871	-144.8584	Fore Reef	Intermediate
	Raraka	TURK-23	23-Nov-12	-16.0889	-144.9563	Fore Reef	Intermediate
	Raraka	TURK-24	24-Nov-12	-16.0956	-144.9539	Lagoon	Protected
	Raraka	TURK-25	24-Nov-12	-16.1171	-145.0056	Fore Reef	Intermediate
	Raraka	TURK-26	24-Nov-12	-16.0944	-144.9525	Lagoon	Protected
	Raraka	TURK-27	25-Nov-12	-16.1117	-144.8296	Fore Reef	Exposed
	Raraka	TURK-28	25-Nov-12	-16.097	-144.864	Fore Reef	Exposed
	Raraka	TURK-29	25-Nov-12	-16.0884	-144.9393	Lagoon	Protected
	Raraka	TURK-30	26-Nov-12	-16.2518	-144.8106	Fore Reef	Intermediate
	Raraka	TURK-31	26-Nov-12	-16.202	-144.7741	Fore Reef	Exposed
	Raraka	TURK-PI	26-Nov-12	-16.0963	-144.9452	Lagoon	Protected
	Fakarava	TUFK-32	2xc7-Nov-12	-16.0741	-145.7056	Fore Reef	Intermediate
	Fakarava	TUFK-33	27-Nov-12	-16.0514	-145.6568	Fore Reef	Intermediate
	Fakarava	TUFK-34	27-Nov-12	-16.1877	-145.8216	Fore Reef	Intermediate
	Fakarava	TUFK-35	29-Nov-12	-16.1523	-145.8247	Fore Reef	Intermediate
	Fakarava	TUFK-36	29-Nov-12	-16.124	-145.815	Fore Reef	Intermediate
	Fakarava	TUFK-37	29-Nov-12	-16.1484	-145.703	Lagoon	Protected
	Fakarava	TUFK-38	30-Nov-12	-16.0469	-145.6355	Fore Reef	Intermediate
	Fakarava	TUFK-39	30-Nov-12	-16.1037	-145.7856	Fore Reef	Intermediate
	Fakarava	TUFK-40	30-Nov-12	-16.0834	-145.6942	Lagoon	Protected
	Fakarava	TUFK-41	1-Dec-12	-16.2338	-145.6738	Lagoon	Protected
	Fakarava	TUFK-42	1-Dec-12	-16.2438	-145.6423	Lagoon	Protected
	Fakarava	TUFK-43	1-Dec-12	-16.2415	-145.6284	Lagoon	Protected
	Fakarava	TUFK-44	2-Dec-12	-16.2895	-145.7363	Lagoon	Protected
	Fakarava	TUFK-45	2-Dec-12	-16.2845	-145.7037	Lagoon	Protected

APPENDIX 1 | DIVE SITES & SITE DESCRIPTIONS

Appendix 1 | Tuamoto

GROUP	Island	Site	Date	Latitude	Longitude	Reef Location	Exposure
Tuamotu	Fakarava	TUFK-46	2-Dec-12	-16.3018	-145.62	Lagoon	Protected
	Fakarava	TUFK-47	3-Dec-12	-16.4456	-145.5296	Lagoon	Protected
	Fakarava	TUFK-48	3-Dec-12	-16.5035	-145.4627	Lagoon	Protected
	Fakarava	TUFK-49	3-Dec-12	-16.532	-145.465	Fore Reef	Intermediate
	Fakarava	TUFK-50	4-Dec-12	-16.441	-145.3622	Fore Reef	Exposed
	Fakarava	TUFK-51	4-Dec-12	-16.5167	-145.4553	Fore Reef	Intermediate
	Fakarava	TUFK-52	4-Dec-12	-16.5162	-145.4629	Fore Reef	Intermediate
	Fakarava	TUFK-53	5-Dec-12	-16.367	-145.6734	Lagoon	Protected
	Fakarava	TUFK-54	5-Dec-12	-16.2817	-145.5584	Lagoon	Protected
	Fakarava	TUFK-55	5-Dec-12	-16.0785	-145.7152	Fore Reef	Intermediate
	Toau	TUTO-56	6-Dec-12	-15.9293	-145.9535	Lagoon	Protected
	Toau	TUTO-57	6-Dec-12	-15.9289	-145.9903	Lagoon	Protected
	Toau	TUTO-58	6-Dec-12	-15.9065	-145.8987	Lagoon	Protected
	Toau	TUTO-59	7-Dec-12	-15.9135	-145.8888	Fore Reef	Exposed
	Toau	TUTO-60	7-Dec-12	-15.912	-145.8955	Lagoon	Protected
	Toau	TUTO-61	8-Dec-12	-15.8982	-145.9108	Lagoon	Protected
	Toau	TUTO-62	9-Dec-12	-15.8907	-146.0718	Lagoon	Protected
	Toau	TUTO-63	9-Dec-12	-15.8859	-146.0357	Lagoon	Protected
	Hao	TUHA-01	16-Jan-13	-18.0653	-140.9966	Fore Reef	Exposed
	Hao	TUHA-02	16-Jan-13	-18.0695	-141.0102	Fore Reef	Exposed
	Hao	TUHA-03	16-Jan-13	-18.0759	-141.0055	Lagoon	Protected
	Hao	TUHA-04	17-Jan-13	-18.173	-141.048	Fore Reef	Intermediate
	Hao	TUHA-05	17-Jan-13	-18.0826	-141.068	Fore Reef	Intermediate
	Hao	TUHA-06	17-Jan-13	-18.0632	-140.9876	Fore Reef	Exposed
	Hao	TUHA-07	18-Jan-13	-18.3069	-140.9068	Fore Reef	Intermediate
	Hao	TUHA-08	18-Jan-13	-18.0729	-141.0197	Fore Reef	Exposed
	Hao	TUHA-09	18-Jan-13	-18.1157	-141.049	Lagoon	Protected
	Hao	TUHA-10	19-Jan-13	-18.3901	-140.7982	Lagoon	Protected
	Hao	TUHA-11	19-Jan-13	-18.3806	-140.7674	Lagoon	Protected
	Hao	TUHA-12	19-Jan-13	-18.304	-140.8639	Lagoon	Protected
	Hao	TUHA-13	20-Jan-13	-18.3503	-140.8144	Lagoon	Protected
	Hao	TUHA-14	20-Jan-13	-18.3418	-140.8414	Lagoon	Protected
	Hao	TUHA-15	20-Jan-13	-18.3452	-140.8609	Lagoon	Protected
	Hao	TUHA-16	21-Jan-13	-18.0642	-140.9526	Fore Reef	Exposed
	Hao	TUHA-17	21-Jan-13	-18.0958	-140.9095	Fore Reef	Exposed

Appendix 1 | Gambier

GROUP	Island	Site	Date	Latitude	Longitude	Reef Location	Exposure
Gambier	Tenararo	GATR-18	23-Jan-13	-21.3079	-136.7322	Fore Reef	Exposed
	Tenararo	GATR-19	23-Jan-13	-21.3135	-136.7548	Fore Reef	Intermediate
	Tenararo	GATR-20	23-Jan-13	-21.2967	-136.7591	Fore Reef	Intermediate
	Vahanga	GAVA21	24-Jan-13	-21.315	-136.6555	Fore Reef	Intermediate
	Vahanga	GAVA-22	24-Jan-13	-21.3375	-136.6714	Fore Reef	Exposed
	Vahanga	GAVA23	24-Jan-13	-21.334	-136.6328	Fore Reef	Intermediate
	Tenarunga	GATG-24	25-Jan-13	-21.3562	-136.531	Fore Reef	Intermediate
	Tenarunga	GATG-25	25-Jan-13	-21.3518	-136.561	Fore Reef	Exposed
	Tenarunga	GATG-26	25-Jan-13	-21.3276	-136.5391	Fore Reef	Intermediate
	Maturei Vavao	GAMV-27	26-Jan-13	-21.4817	-136.3659	Fore Reef	Intermediate
	Maturei Vavao	GAMV-28	26-Jan-13	-21.4445	-136.4037	Fore Reef	Intermediate
	Maturei Vavao	GAMV-29	26-Jan-13	-21.4841	-136.4157	Fore Reef	Exposed
	Maria Est	GAME-30	27-Jan-13	-22.0175	-136.2081	Fore Reef	Exposed
	Maria Est	GAME-31	27-Jan-13	-22.0228	-136.1779	Fore Reef	Exposed
	Maria Est	GAME-32	27-Jan-13	-21.9928	-136.1895	Fore Reef	Intermediate
	Mangareva	GAMG-33	28-Jan-13	-23.0977	-135.0399	Fore Reef	Intermediate
	Mangareva	GAMG-34	28-Jan-13	-23.0975	-135.0346	Fore Reef	Intermediate
	Mangareva	GAMG-35	28-Jan-13	-23.1589	-134.9639	Lagoon	Protected
	Mangareva	GAMG-36	30-Jan-13	-23.0144	-134.9723	Fore Reef	Intermediate
	Mangareva	GAMG-37	30-Jan-13	-23.0566	-134.9989	Fore Reef	Intermediate
	Mangareva	GAMG-38	30-Jan-13	-23.144	-135.0968	Fore Reef	Intermediate
	Mangareva	GAMG-39	31-Jan-13	-23.1911	-135.0927	Fore Reef	Intermediate
	Mangareva	GAMG-40	31-Jan-13	-23.178	-135.0923	Lagoon	Protected
	Mangareva	GAMG-41	31-Jan-13	-23.1697	-135.0608	Lagoon	Protected
	Mangareva	GAMG-42	1-Feb-13	-23.1489	-134.846	Fore Reef	Exposed
	Mangareva	GAMG-43	1-Feb-13	-23.1374	-134.9014	Lagoon	Protected
	Mangareva	GAMG-44	1-Feb-13	-23.189	-134.903	Lagoon	Protected
	Mangareva	GAMG-45	2-Feb-13	-23.2164	-134.8582	Fore Reef	Intermediate
	Mangareva	GAMG-46	2-Feb-13	-23.2241	-134.9646	Lagoon	Protected
	Mangareva	GAMG-47	2-Feb-13	-23.1548	-135.0189	Lagoon	Protected
	Mangareva	GAMG-48	3-Feb-13	-23.1675	-134.9306	Lagoon	Protected
	Mangareva	GAMG-49	3-Feb-13	-23.1763	-134.9023	Lagoon	Protected
	Mangareva	GAMG-50	3-Feb-13	-23.2017	-134.9234	Lagoon	Protected
	Mangareva	GAMG-51	4-Feb-13	-23.236	-134.9014	Fore Reef	Intermediate
	Mangareva	GAMG-52	4-Feb-13	-23.0791	-135.0039	Lagoon	Protected

Appendix 1 | Gambier

GROUP	Island	Site	Date	Latitude	Longitude	Reef Location	Exposure
Gambier	Mangareva	GAMG-53	5-Feb-13	-23.1694	-135.0322	Lagoon	Protected
	Mangareva	GAMG-54	5-Feb-13	-23.1418	-134.9174	Lagoon	Protected
	Mangareva	GAMG-55	5-Feb-13	-23.2607	-134.9958	Fore Reef	Intermediate
	Mangareva	GAMG-56	6-Feb-13	-23.0776	-134.8884004	Fore Reef	Exposed
	Mangareva	GAMG-57	6-Feb-13	-23.1104	-134.8464	Fore Reef	Exposed
	Mangareva	GAMG-58	6-Feb-13	-23.1772	-134.8436	Fore Reef	Exposed
	Mangareva	GAMG-59	7-Feb-13	-23.1691	-134.8591	Lagoon	Protected
	Mangareva	GAMG-60	7-Feb-13	-23.0711	-134.9108	Lagoon	Protected
	Mangareva	GAMG-61	8-Feb-13	-23.1984	-134.8733	Lagoon	Protected
	Mangareva	GAMG-62	8-Feb-13	-23.1271	-134.9097	Lagoon	Protected
	Mangareva	GAMG-63	8-Feb-13	-23.1451	-134.8559	Lagoon	Protected
	Mangareva	GAMG-70	11-Feb-13	-23.1973	-135.0646	Fore Reef	Intermediate
	Mangareva	GAMG-71	11-Feb-13	-23.169	-135.1252	Fore Reef	Intermediate
	Temoe	GATE-64	9-Feb-13	-23.3158	-134.4848	Fore Reef	Intermediate
	Temoe	GATE-65	9-Feb-13	-23.3574	-134.4934	Fore Reef	Intermediate
	Temoe	GATE-66	9-Feb-13	-23.329	-134.506	Fore Reef	Intermediate
	Temoe	GATE-67	10-Feb-13	-23.3436	-134.462	Fore Reef	Exposed
	Temoe	GATE-68	10-Feb-13	-23.3248	-134.4751	Fore Reef	Exposed
	Temoe	GATE-69	10-Feb-13	-23.3152	-134.4956	Fore Reef	Intermediate

Appendix 1 | Austral

GROUP	Island	Site	Date	Latitude	Longitude	Reef Location	Exposure
Austral	Raivavae	AURV-01	11-Apr-13	-23.8605	-147.7151	Fore Reef	Exposed
	Raivavae	AURV-02	11-Apr-13	-23.8902	-147.7208	Fore Reef	Exposed
	Raivavae	AURV-03	11-Apr-13	-23.8318	-147.6574	Fore Reef	Intermediate
	Raivavae	AURV-04	12-Apr-13	-23.8281827	-147.5901199	Fore Reef	Intermediate
	Raivavae	AURV-05	12-Apr-13	-23.8339	-147.6291	Fore Reef	Intermediate
	Raivavae	AURV-06	12-Apr-13	-23.8962	-147.7123	Fore Reef	Exposed
	Raivavae	AURV-07	13-Apr-13	-23.9123	-147.6609	Fore Reef	Exposed
	Raivavae	AURV-08	13-Apr-13	-23.9108	-147.6843	Fore Reef	Exposed
	Tubuai	AUTB-09	14-Apr-13	-23.4213	-149.4402	Fore Reef	Exposed
	Tubuai	AUTB-10	14-Apr-13	-23.3827	-149.5493	Fore Reef	Exposed
	Tubuai	AUTB-11	14-Apr-13	-23.4253	-149.5184	Fore Reef	Exposed
	Tubuai	AUTB-12	15-Apr-13	-23.4251	-149.4057	Fore Reef	Exposed
	Tubuai	AUTB-13	15-Apr-13	-23.3786	-149.3853	Fore Reef	Intermediate
	Tubuai	AUTB-14	15-Apr-13	-23.3339	-149.4361	Lagoon	Protected
	Tubuai	AUTB-15	16-Apr-13	-23.3485	-149.5313	Fore Reef	Intermediate
	Tubuai	AUTB-16	16-Apr-13	-23.3561	-149.5518	Fore Reef	Intermediate
	Tubuai	AUTB-17	16-Apr-13	-23.4242	-149.4837	Fore Reef	Exposed
	Rurutu	AURR-18	17-Apr-13	-22.4522	-151.3235	Fore Reef	Intermediate
	Rurutu	AURR-19	17-Apr-13	-22.4323	-151.376	Fore Reef	Exposed
	Rurutu	AURR-20	17-Apr-13	-22.5204	-151.3327	Fore Reef	Exposed
	Rimatara	AURM-21	18-Apr-13	-22.6406	-152.8223	Fore Reef	Intermediate
	Rimatara	AURM-22	18-Apr-13	-22.6665	-152.7958	Fore Reef	Exposed
	Rimatara	AURM-23	18-Apr-13	-22.644	-152.7882	Fore Reef	Exposed
	Rimatara	AURM-24	19-Apr-13	-22.6648	-152.8163	Fore Reef	Exposed
	Rimatara	AURM-25	19-Apr-13	-22.6592	-152.7891	Fore Reef	Exposed
	Maria	AUMA-26	20-Apr-13	-21.813	-154.6891	Fore Reef	Exposed
	Maria	AUMA-27	20-Apr-13	-21.7901	-154.7037	Fore Reef	Intermediate
	Maria	AUMA-28	20-Apr-13	-21.82	-154.7239	Fore Reef	Exposed
	Maria	AUMA-29	21-Apr-13	-21.7972	-154.6917	Fore Reef	Intermediate
	Maria	AUMA-30	21-Apr-13	-21.8008	-154.718	Fore Reef	Intermediate

Appendix 2 | Habitat Classifications

HABITAT CLASSIFICATION GROUP	
Backreef Coral	Back reef coral bommies Back reef coral framework
Deep Forereef Slope	
Deep Lagoonal Water	
Lagoonal Coral	Lagoonal Acropora framework Lagoonal coral framework Lagoonal floor coral bommies Lagoonal fringing reefs Lagoonal patch reefs
Lagoonal Pinnacle Reefs	Lagoonal pinnacle reefs branching coral dominated Lagoonal pinnacle reefs massive coral dominated
Lagoonal Substrate	Back reef pavement Back reef rubble dominated Back reef sediment dominated Lagoonal floor barren Lagoonal pavement Lagoonal sediment apron sediment dominated
Lagoonal Macroalgae Dominated Substrate	Lagoonal floor macroalgae on sediment Lagoonal sediment apron macroalgae on sediment
Nearshore Algal Communities	Coralline algal ridge Reef-top algal mats
Shallow Forereef Community	Shallow fore reef slope Shallow fore reef terrace
Fore Reef Sand Flats	
Terrestrial	Beach sand Carbonate blocks Coral rubble Inland waters Mud Rock Soil Terrestrial vegetation
Urban	

Appendix 3 | Participants

PARTICIPANT	Mission	Institution	Function
Phil Renaud	Society, Tuamotu, Gambier	Khaled bin Sultan Living Oceans Foundation, USA	Executive Director
Alexandra Dempsey	Society, Tuamotu, Gambier, Austral	Khaled Bin Sultan Living Oceans Foundation, USA	Coral Reef Ecologist
Andy Bruckner	Society, Tuamotu, Gambier, Austral	Khaled bin Sultan Living Oceans Foundation, USA	Former Chief Scientist
Sam Purkis	Society, Tuamotu	Nova Southeastern University, USA	NCRI Lead Scientist
Renée Carlton	Society, Austral	Khaled Bin Sultan Living Oceans Foundation, University of Miami, NOAA, USA	Ocean Acidification
Jeremy Kerr	Society, Tuamotu, Gambier, Austral	Nova Southeastern University, USA	Groundtruthing/Habitat Mapping
Sonia Bejarano	Society, Tuamotu	University of Queensland, Living Oceans Foundation Fellow	Fish Herbivory
Badi Samaniego	Society, Tuamotu, Gambier, Austral	University of the Phillippines, Living Oceans Foundation Fellow	Fish Surveyor
Joao Monteiro	Society, Tuamotu, Gambier, Austral	University of Azores, Living Oceans Foundation Fellow	Coral Flourescence
Nick Cautin	Society, Tuamotu, Gambier, Austral	Dive Safety Officer	Diving Operations
Serge Andrefouet	Society, Tuamotu, Gambier	Institut de Recherche pour le Développement	Investigator
David Grenda	Society, Tuamotu	Florida Aquarium, REEF, USA	Fish Surveyor
Anastasios Stathakopoulos	Society, Tuamotu, Austral	Nova Southeastern University, USA	Groundtruthing/Habitat Mapping
Laureline Chabran-Poete	Society, Tuamotu	Institut de Recherche pour le Développement	Benthic Assessment
Eva McClure	Society, Gambier	University of Tasmania	Fish Surveyor
Katherine Hillyer	Society, Tuamotu	Victoria University, Wellington, NZ	Benthic Surveyor
Sylvain Petek	Society	Institut de Recherche pour le Développement	Sponge Sampling
Eve Perrin	Society	Direction de l'environnement	Turtle Surveyor
Joseph Campazzoni	Society	Direction des Ressources Marines et Minières	Invertebrate Surveyor
Claire Dolphin	Society	Nova Southeastern University, USA	Photo Transects
Gerard Mou-Tham	Society	Institut de Recherche pour le Développement	Invertebrate Surveyor
Candice Jwaszko	Society	Ecole Paul Kane High School	C.R.E.W. Teacher
Matti Kiupel	Society	Michigan State University, College of Vetrenary Medicine, USA	Coral Disease
Brian Beck	Tuamotu, Gambier, Austral	Khaled bin Sultan Living Oceans Foundation, USA	Coral Reef Ecologist
Kenneth Marks	Austral	Atlantic and Gulf Rapid Reef Assessment Program (AGGRA)	Photo Transects

Appendix 3 | Participants

PARTICIPANT	Mission	Institution	Function
Marine Couraudon-Reale	Tuamotu, Gambier, Austral	Independent Contractor	Photo Transects
Gabriel Haumani	Tuamotu, Gambier	Direction des Ressources Marines et Minières	Invertebrate Surveyor
Pierre Sasal	Tuamotu, Austral	French National Centre for Scientific Research	Fish Sampling
Kate Fraser	Tuamotu, Austral	Independent Contractor	Fish Surveyor
Derek Manzello	Tuamotu	University of Miami, NOAA, USA	Ocean Acidification
Bertrand Make	Tuamotu	Direction de l'environnement	Turtle Surveyor
Valentina Piveteau	Tuamotu	Direction de l'environnement	Turtle Surveyor
John Ruthven	Tuamotu	Independent Contractor	Film producer
Ernie Kovacs	Tuamotu	Independent Contractor	Cameraman
Scott Cutmore	Tuamotu	University of Queensland	Fish Sampling
Peter Mumby	Tuamotu	University of Queensland	UQ Lead Scientist
Robert Steneck	Tuamotu	University of Maine, USA	Benthic Ecology
George Roff	Tuamotu	University of Queensland	Coral Recruitment
Yves-Marie Bozec	Tuamotu	University of Queensland	Marine Ecology
Maggy Nugues	Tuamotu	Le Centre de Researches Insularies et Observatoire de l'Environnment de Polynésie Francaise (CRIOBE)	Benthic Surveyor
Gaelle Quere	Tuamotu	University of Queensland	Benthic Surveyor
Jim Evans	Tuamotu	Schools without Walls, Washington D.C.	C.R.E.W. Teacher
Jeremy Sofonia	Tuamotu	University of Queensland	Groundtruthing
William Robbins	Tuamotu	Wildlife Marine	Shark Biology
Alexa Elliot	Tuamotu	West Palm Beach Television PBS "Changing Seas"	Film producer
Sean Hickey	Tuamotu	West Palm Beach Television PBS "Changing Seas"	Cameraman
Fabian Tertre	Tuamotu	Direction des Ressources Marines et Minières	Invertebrate Surveyor
Doug Allen	Tuamotu	Independent Contractor	Cameraman
Edward Gonzalez	Gambier	Khaled bin Sultan Living Oceans Foundation, USA	Education

Appendix 3 | Participants

PARTICIPANT	Mission	Institution	Function
Megan Berkle	Gambier	Linda Esperanza Marquez High School, California	C.R.E.W. Teacher
Jenna Moore	Gambier	Florida Museum of Natural History, Scripps Institute of Oceanography	Invertebrate Taxonomy
Andrew Calhoun	Gambier	Nova Southeastern University, USA	Groundtruthing/Habitat Mapping
Ian Enochs	Gambier	University of Miami, NOAA, USA	Ocean Acidification
Simon Van Wynsberge	Gambier	Universitéde la Polynésie Francaise and Institut de Recherche pour le Développemen	Invertebrate Surveyor
Mireille Chinain	Gambier	Institut Louis Malardé	Ciguatera Research
Claude Payri	Gambier	Institut de Recherche pour le Développement	Algae Sample
Marie Kospartov	Gambier	Independent Contractor	Coral Surveyor
Michele Westmorland	Gambier	Westmorland Images, LLC	Photographer
Megan Cook	Gambier	Rolex Scholar	Assistant Photographer
Melanie Roue	Gambier	Institut de Recherche pour le Développement	Ciguatera Research
Andre Ung	Gambier	Institut Louis Malardé	Ciguatera Research
John Butscher	Gambier	Institut de Recherche pour le Développement	Ciguatera Research
Anderson Mayfield	Austral	National Museum of Marine Biology and Aquarium, Living Oceans Foundation Fellow	Coral Genetics
Serge Planes	Austral	Le Centre de Researches Insularies et Observatoire de l'Environnment de Polynésie Francaise (CRIOBE)	Fish Sampling
Tom Cribb	Austral	University of Queensland	Fish Sampling
Jeff Williams	Austral	Smithsonian Museum of Natural History	Fish Taxonomy
Erwan Delriue-Trotin	Austral	Pierre and Marie Curie University (Paris 6)	Fish Sampling
Laetitia Hedouin	Austral	Le Centre de Researches Insularies et Observatoire de l'Environnment de Polynésie Francaise (CRIOBE)	Coral Surveyor
Pauline Boserelle	Austral	Le Centre de Researches Insularies et Observatoire de l'Environnment de Polynésie Francaise (CRIOBE)	Benthic Surveyor
Gilles Siu	Austral	Le Centre de Researches Insularies et Observatoire de l'Environnment de Polynésie Francaise (CRIOBE)	Benthic Surveyor
Agnes Benet	Austral	Consultancy PROGEM	MPA Monitoring
Gabriel Haumani	Austral	Direction des Ressources Marines et Minières	Invertebrate Surveyor
Simon Van Wynsberge	Austral	Universitéde la Polynésie Francaise	Giant Clam Genetics

NOTES

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