VOL 13

CHAGOS

ARCHIPELAGO

GLOBAL REEF EXPEDITION FINAL REPORT

Khaled bin Sultan Living Oceans Foundation

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Khaled bin Sultan Living Oceans Foundation

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Khaled bin Sultan
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Foundation

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The Khaled bin Sultan Living Oceans Foundation (KSLOF) is a nonprofit organization dedicated to providing science-based solutions to protect and restore ocean health. KSLOF was incorporated in California as a 501(c)(3), public benefit, Private Operating Foundation in September 2000. Since then, the Living Oceans Foundation has worked to conserve the world's oceans through research, outreach, and education.
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EXECUTIVE SUMMARY

The Khaled Bin Sultan Living Oceans Foundation (KSLOF) embarked on the Global Reef Expedition (GRE) to assess the state of coral reefs around the world. This ambitious five-year scientific mission was designed to evaluate the status of the benthic and reef fish communities, assess the impact of anthropogenic and natural disturbances on coral reef ecosystems, and provide communities with the findings so they can inform marine conservation and management plans.

The Global Reef Expedition mission to the Chagos Archipelago in 2015 allowed an international team of scientists to study some of the most remote and undisturbed coral reefs in the world. When the expedition began, the coral reefs in the Chagos Archipelago were stunning, with high live coral cover and an astounding abundance of fish. However, towards the end of the research mission, KSLOF scientists witnessed the beginning of what would become a catastrophic mass global bleaching event, illustrating that negative human impacts reach even the most isolated and well-protected coral reefs on Earth.

THE GLOBAL REEF EXPEDITION

The Khaled bin Sultan Living Oceans Foundation was founded by His Royal Highness Prince Khaled bin Sultan to protect, preserve, and restore coral reefs and other marine ecosystems around the world. Prince Khaled envisioned a foundation that utilizes science, education, and outreach, all working together, to expand conservation efforts on a global scale. After witnessing the decline of coral reefs himself, Prince Khaled funded a research mission that would circumnavigate the globe to assess the status of coral reefs: the Global Reef Expedition. This expedition is an embodiment of the Foundation's motto, *Science Without Borders®*. The GRE brought together an international team of scientists to conduct a comprehensive global survey of coral reefs, used standardized methods to assess the status of coral reefs, and identified threats to their health and resiliency. The goal of the GRE was to provide decision-makers with valuable baseline data on the state of coral reefs as well as the tools and science-based solutions needed to address the coral reef crisis.

CORAL REEFS IN THE CHAGOS ARCHIPELAGO

The Chagos Archipelago in the British Indian Ocean Territory (BIOT) is home to some of the most remote coral reefs in the world. Found in the central Indian Ocean, the archipelago is comprised of five main atolls and numerous submerged coral banks that have been largely undisturbed by humans for the last 50 years. The reefs of the Chagos Archipelago are home to at least 784 species of fish and 300 species of reef building corals. In 2015, it was estimated that 50% of the remaining healthy reefs in the Indian Ocean were found in Chagos. The ecological importance of this area was recognized by the British government in 2010 as they designated the region a Marine Protected Area (MPA). This is the largest no-take MPA in the Indian Ocean, protecting all 640,000 km^2 of the uninhabited islands of the Chagos Archipelago and the surrounding waters. Despite these protections, the reefs of the Chagos Archipelago have still experienced major disturbances such as multiple coral bleaching events which have had severe detrimental impacts on the coral communities.

One priority of the Global Reef Expedition was to study reefs that experienced minimal anthropogenic disturbance, and there was no better place on Earth to do that than the Chagos Archipelago. In March through May of 2015, KSLOF scientists and partners surveyed the reefs of the Chagos Archipelago in order to map and characterize the shallow marine habitats, and assess the status of the coral reefs and reef species.

The GRE surveyed coral reefs around the atolls of Great Chagos Bank, Peros Banhos, Salomon Islands, and Egmont as well as the submerged atolls of Blenheim Reef, Victory Bank, and Speakers Bank. Across the archipelago, a total of 106 stations were surveyed, within which 1,554 benthic habitat surveys and 1,222 fish surveys were conducted.

BENTHIC COVER ASSESSMENTS

The benthic communities of the Chagos Archipelago were impressive. Across all locations surveyed, all of the smaller northern atolls had higher live coral cover than observed around Great Chagos Bank. Although the average live coral cover ranged from 31-52%, some individual survey sites, such as Site 72 at Peros Banhos and Site 96 at Speakers Bank, had exceptionally high live coral cover reaching 72% and 86% respectively. Large table *Acroporids* and massive *Porites* spp. were common throughout all locations, but some of the most interesting findings were the monospecific stands of *Lobophyllia* spp. and *Heliopora* spp. observed at some sites. Compared to other countries surveyed, the reefs of the Chagos Archipelago had some of the highest live coral cover observed on the GRE.

FISH COMMUNITY ASSESSMENT

The Chagos Archipelago had the highest fish density and the second-highest fish biomass of all countries surveyed on the GRE. Fish populations were uniformly diverse across all locations surveyed in the Chagos Archipelago, and a high percentage of the fish species known to occur in the archipelago were recorded. However, fish density, biomass, and size-frequency distributions differed across locations despite uniform levels of protection across all of the sites surveyed. Differences in the fish communities between sites do not appear to be directly related to benthic and coral cover.

> This report provides a comprehensive **assessment** of the **coral reef** communities in the **Chagos Archipelago.**

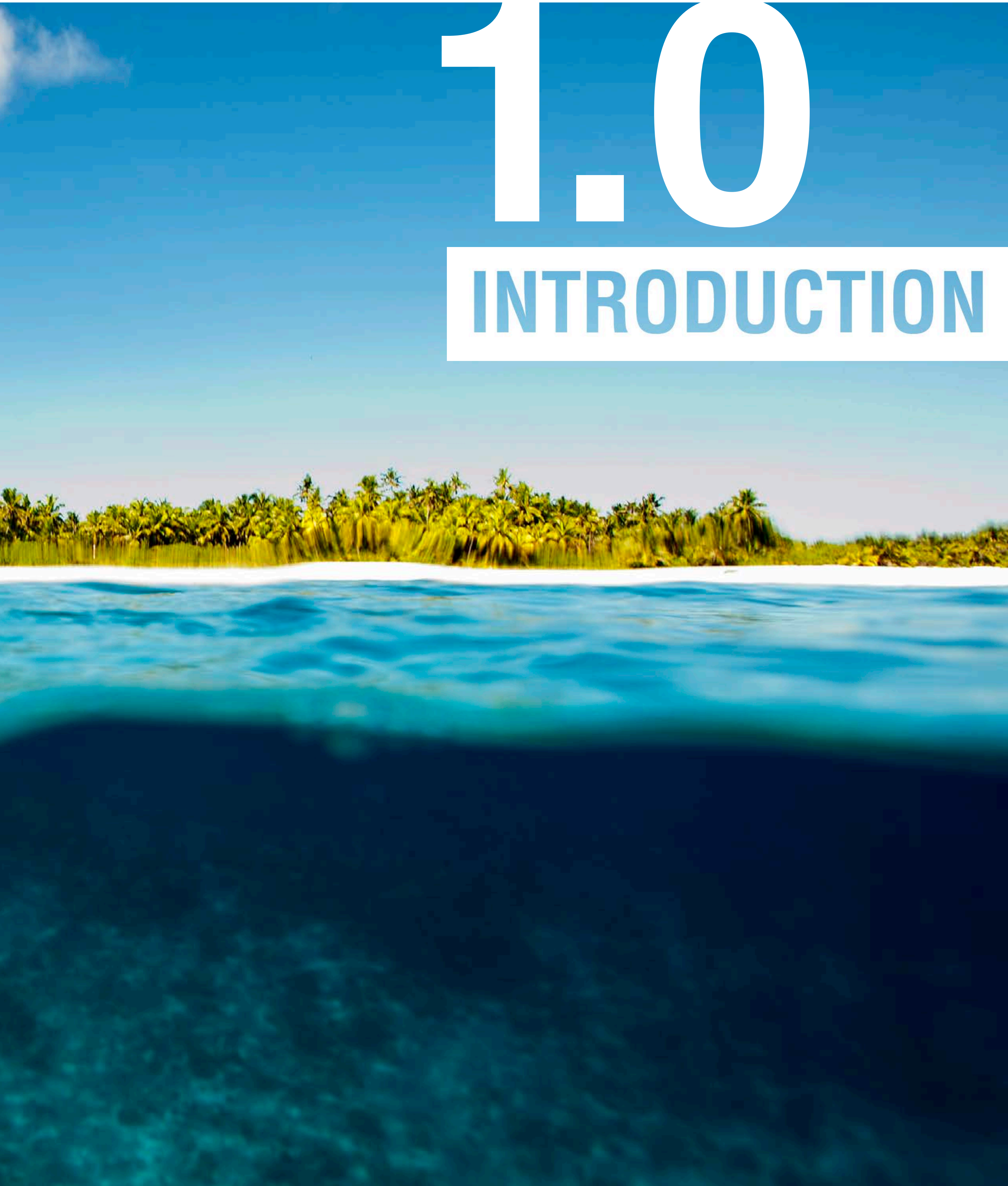
CONSERVATION CONCLUSIONS

The reefs of the Chagos Archipelago were remarkable. At the time of surveying, these reefs had some of the most impressive benthic and fish communities seen on the Global Reef Expedition. Many of the differences in the fish and benthic communities can be attributed to local oceanographic influences, such as localized upwelling. It is also possible sea bird presence may be contributing to nearshore productivity, influencing the fish and benthic communities as well. However, major disturbances such as bleaching events and crown-of-thorn starfish outbreaks may help explain some of the differences in the benthic communities among the different locations.

One of the most significant discoveries KSLOF made was the beginning of a massive bleaching event that started during our research mission. While conducting our surveys in April of 2015, KSLOF witnessed the beginning of one of the most damaging bleaching events ever recorded. Studies that took place immediately following our research mission showed live coral cover was reduced to only 5-10%, a drastic difference from the 31-52% that was observed by KSLOF. The research described herein should be considered an important baseline study for what the reefs of the Chagos Archipelago were like immediately prior to the 2015-2016 bleaching event.

Continued conservation and long-term studies of the reefs of the Chagos Archipelago is imperative. These reefs may be some of the last in the world to be largely undisturbed by humans. Despite their remoteness, they are not protected from human-induced climate change. These reefs may play a critical role in understanding the ways shallow marine habitats adapt to ongoing disturbance events and may shed light on their resilience.

1.0 INTRODUCTION



INTRODUCTION

1.0

The Chagos Archipelago, located in the central Indian Ocean, is home to some of the least disturbed coral reefs found in the world. The archipelago spans approximately 60,000 sq. km and is comprised of five atolls and numerous submerged coral banks **(Figure 1)**[1,2]. With the exception of Diego Garcia, the reefs in the Chagos Archipelago have been undisturbed for nearly the last 50 years[1,3].

One of the priorities of the Khaled bin Sultan Living Oceans Foundation (KSLOF) Global Reef Expedition (GRE) was to study reefs that experience minimal anthropogenic disturbance, making the Chagos Archipelago an optimal research site. This remote location allowed KSLOF to collect important baseline data for studying the effects of anthropogenic activities on reef condition globally. In March through May 2015, KSLOF scientists and partners studied the reefs of the Chagos Archipelago with the following objectives:

1. **Map and characterize the shallow marine habitats, and**
2. **Assess the status of the benthic and reef fish communities.**

> This **remote location** allowed KSLOF to collect **important baseline data** for studying the effects of **anthropogenic activities** on **reef condition** globally.

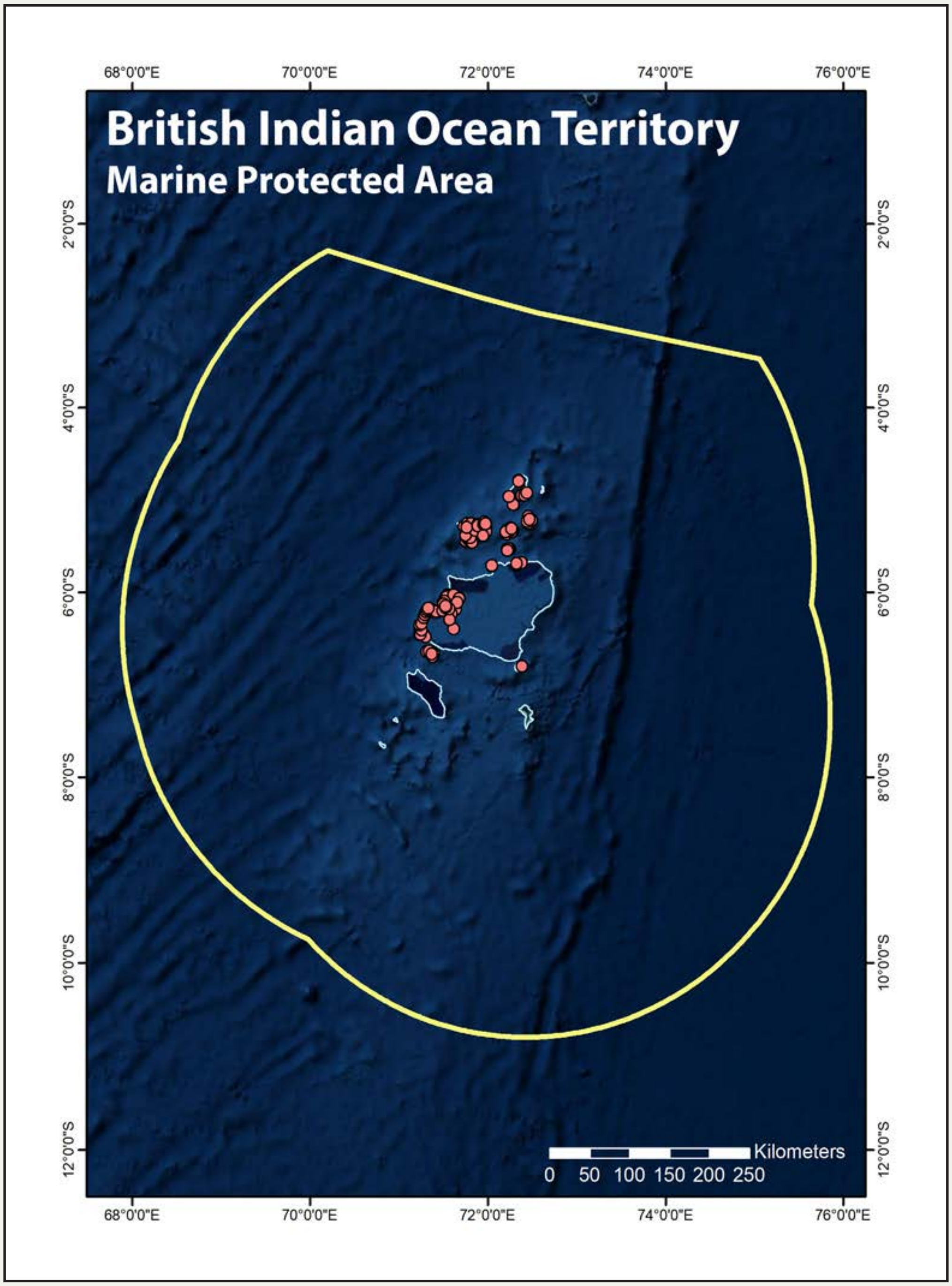
During this mission, KSLOF surveyed the reefs around the atolls of Great Chagos Bank, Peros Banhos, Salomon Islands, and Egmont, as well as the submerged atolls of Blenheim Reef, Victory Bank, and Speakers Bank **(Figure 2)**. The largest atoll surveyed was Great Chagos Bank, which is the largest atoll in the world and covers approximately 18,000 sq. km[2].

The reefs of the Chagos Archipelago are home to at least 784 species of fish[4] and 300 species of reef building corals[5]. In 2015, it was estimated that 50% of the remaining healthy reefs of the Indian Ocean were found in Chagos[6,7]. Furthermore, it is speculated that the centralized location within the Indian Ocean allows the Chagos Archipelago to play a crucial role in linking the reefs of the Indo-Pacific, western, and northern Indian Ocean[3,6,8,9]. The connectivity of the reefs in the Chagos Archipelago to the rest of the ocean, and possibly into the Pacific as well, emphasizes the importance of its conservation. Studies have shown that multiple species of fish, corals, and invertebrates, among other marine organisms, have spread and settled to the reefs of the Chagos Archipelago[3].

The ecological importance of this area was recognized by the British government as they designated the region a no-take Marine Protected Area (MPA) in 2010[3,10,11]. Because coral reefs are being negatively impacted by humans on a global scale, large conservation efforts such as the designation of the British Indian Ocean Territory (BIOT) MPA will contribute to the preservation of this vulnerable ecosystem. Many reefs in other parts of the Indian Ocean have been heavily exploited by local communities where evidence of overfishing and damage to the reefs have been observed[12–15]. These damaged reefs are more susceptible to disturbances such as climate change-induced coral bleaching[11]. Because the reefs of the Chagos Archipelago are isolated from most human influences, climate change is currently the greatest threat. By establishing this area as a no-take MPA, the reefs—while still experiencing some disturbance such as through coral bleaching—have a better chance of recovery since they are buffered from the compounding impacts of local disturbances.

Figure 1

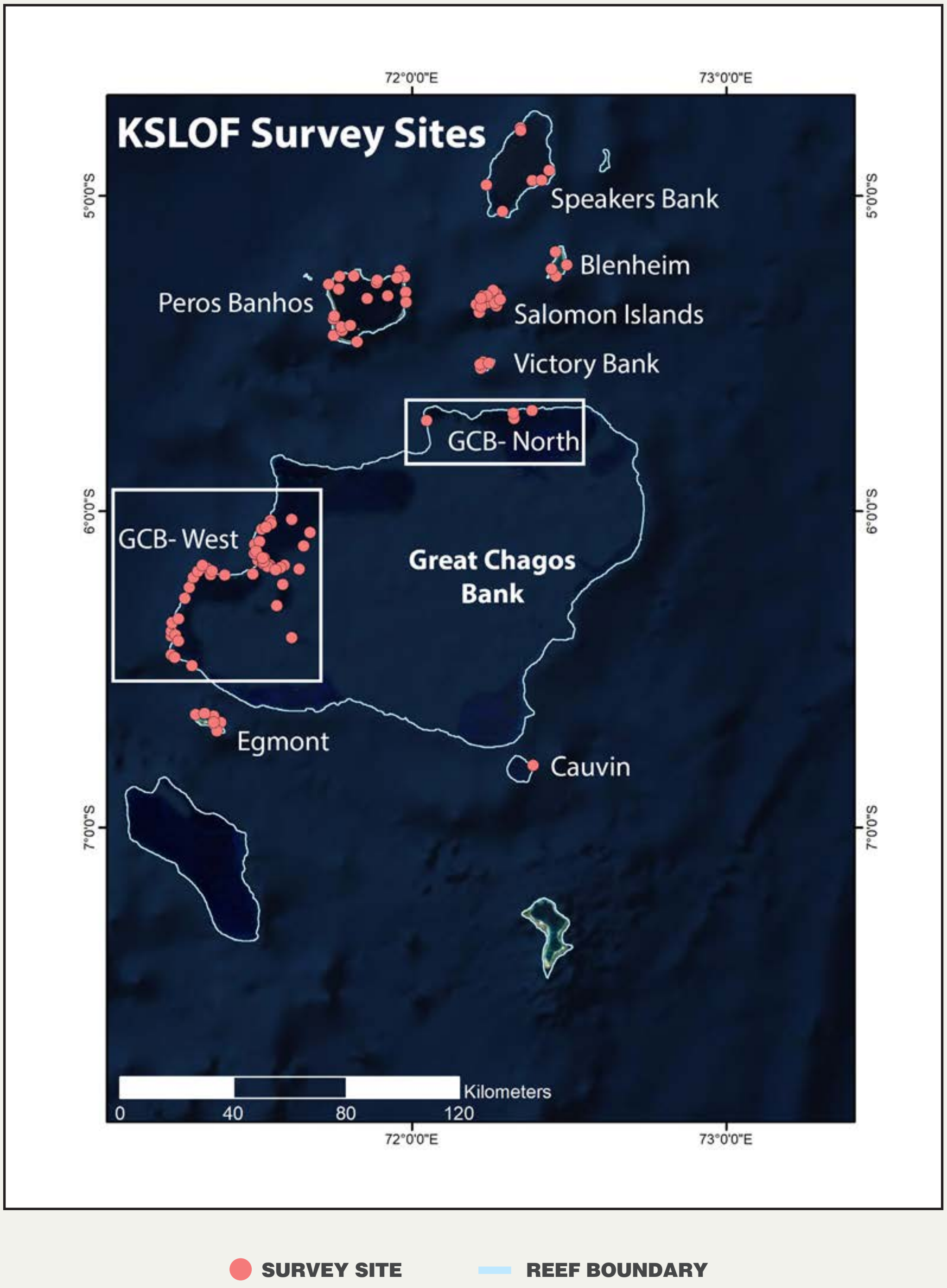
THE BOUNDARY OF THE BIOT MARINE PROTECTED AREA (MPA) IS OUTLINED IN YELLOW. THE TOTAL AREA OF THE MPA IS 550,000 SQ. KM. THE SITES SURVEYED BY KSLOF ARE INDICATED BY PINK DOTS.



EXCLUSIVE ECONOMIC ZONE AND MPA BOUNDARY

SURVEY SITES

Figure 2 MAP OF GRE SURVEY SITES THROUGHOUT THE CHAGOS ARCHIPELAGO WITH LOCATIONS LABELED.

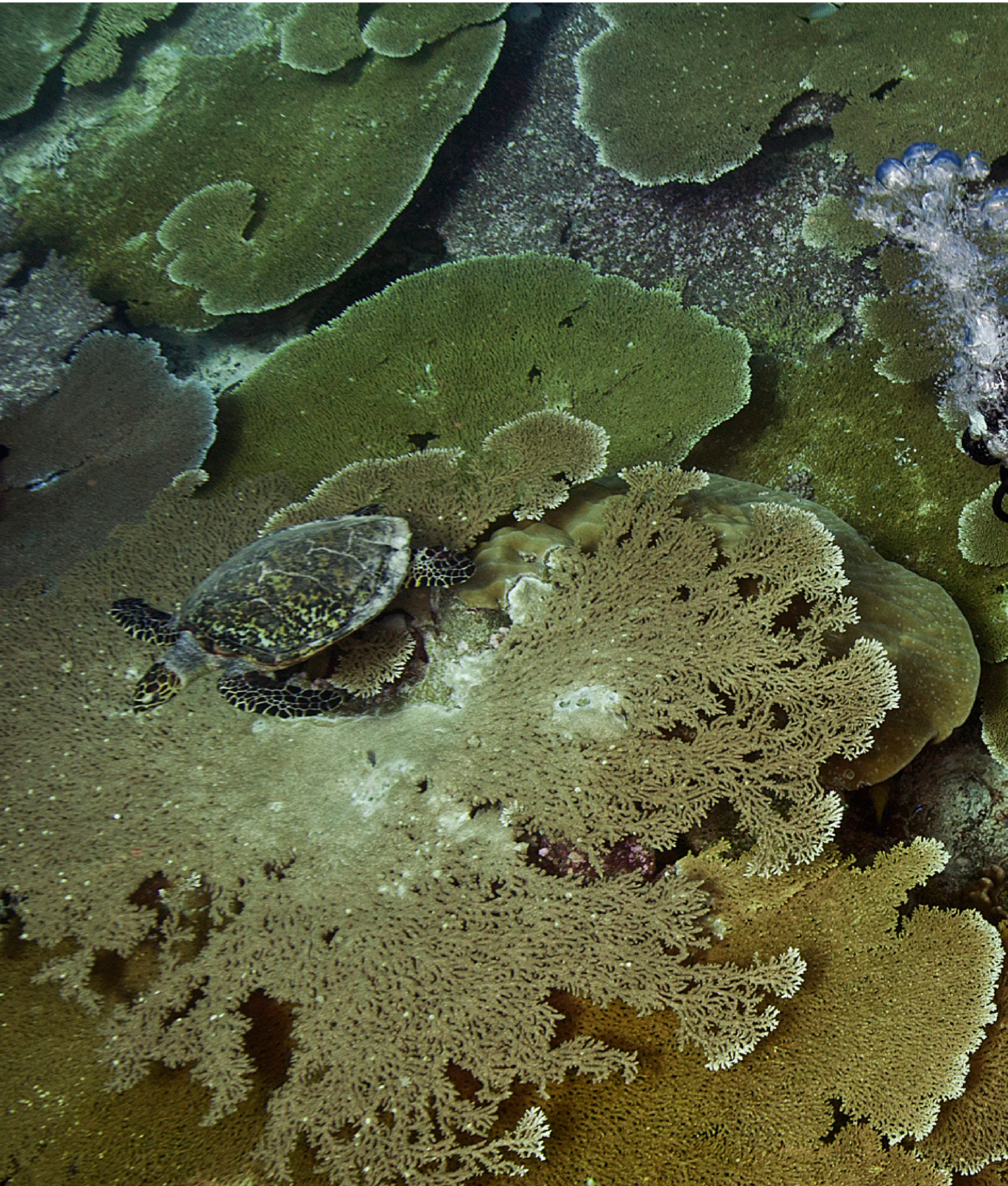


Unfortunately, over the last 50 years, the reefs of the Chagos Archipelago have experienced multiple bleaching events. Research on these reefs began in the late 1970s[16] with only the second scientific survey occurring 18 years later in 1993[17,18]. These surveys showed an overall decline in the coral cover and the authors of these studies attribute the decline to multiple warming events during the elapsed time. Since then, two severe warming events have occurred. Once in 1998 and again in 2015, when KSLOF was surveying the reefs. The 2015 warming event became the longest ever recorded warming episode in the Chagos Archipelago. The bleaching event lasted well into 2016 and resulted in mass coral mortality, with only 5-10% live coral cover remaining[1]. With the increase in frequency and severity of bleaching events globally, KSLOF's research will be critical in understanding the impacts of climate change on the reefs of the Chagos Archipelago. The extensive dataset presented in this report should be used to aid scientists in tracking the temporal changes of the reefs following future events. Having extensive baseline data of the coral cover of these reefs immediately prior to the latest bleaching event will be important in understanding the recovery of both the coral cover and diversity of the coral communities. Following the 1998 bleaching event that was observed throughout the Archipelago, there was a nearly total loss of coral on the ocean-facing reefs[19]. However, after about 7-10 years, studies showed the reefs had recovered nearly all large framework *Acropora* species but there were also widespread changes in the coral cover as a result of the bleaching that is still seen to the present day[1].

Despite these bleaching events and changes in the coral communities, the reef fish communities have been relatively stable and may be aiding in the resiliency of these reefs by helping maintain a more balanced benthic community. While most other reefs in the world experience some type of fishing pressure, since the United Kingdom established control over the area, fishing pressure on reef fish in the Chagos Archipelago has been limited. However, from the 1970s to 2006, there were substantial declines in the shark populations due to illegal fishing activities. It is estimated that the shark populations declined by up to 90% during this time[20]. This decline in top predatory fish may have impacted the trophic structure of the reef fish in this area. Despite this impact, compared to other reef fish assemblages in the Indian Ocean, recent studies suggest the reef fish communities of the Chagos Archipelago are relatively stable and resilient to disturbance[4,21].

KSLOF hopes the findings and analyses outlined in this report will be useful for both scientists and managers who may be using the BIOT MPA as an example for conservation. Because the reefs of the Chagos Archipelago have been largely undisturbed and protected since 2010, this reef system may provide insight into the changes reef habitats may experience in the face of climate change, particularly when other external pressures have been removed.

This report provides **marine managers** with relevant information they can use to **prioritize management efforts** and **make informed conservation decisions.**



2.0 METHODS

METHODS

2.1

SITE DESCRIPTIONS

The GRE surveyed coral reefs around the atolls: Great Chagos Bank, Peros Banhos, Salomon Islands, Egmont; and submerged atolls: Blenheim, Victory Bank, and Speakers Bank. For the purposes of this report, and due to the extensive size of the bank, we have grouped survey locations at Great Chagos Bank into Great Chagos Bank- North, and Great Chagos Bank- West **(Figure 2)**. Across the archipelago, a total of 106 stations were surveyed, within which 1,554 benthic habitat surveys and 1,222 fish surveys were conducted. **Table 1** shows the total number of surveys conducted at each location. The sampling intensity varied between sites, with some sites, such as Victory Bank, having only 4 survey stations compared to Great Chagos Bank-West with 48 survey stations. The M/Y *Golden Shadow* and its support vessels were graciously donated for use on this expedition to allow KSLOF to easily gather data in these remote locations.

Table 1 NUMBER OF FISH AND BENTHIC TRANSECT SURVEYS COMPLETED AT EACH LOCATION IN CHAGOS.

LOCATION	NUMBER OF SURVEY STATIONS	NUMBER OF FISH TRANSECTS	NUMBER OF BENTHIC TRANSECTS
EGMONT	6	70	90
GREAT CHAGOS BANK- WEST	48	575	699
GREAT CHAGOS BANK- NORTH	4	46	50
VICTORY BANK	4	47	55
PEROS BANHOS	20	233	307
SALOMON ISLANDS	13	139	189
BLENHEIM	4	50	66
SPEAKERS BANK	7	62	98
TOTAL	**106**	**1,222**	**1,554**

2.2

CORAL REEF COMMUNITY SURVEYS

KSLOF scientists and fellows on 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 the Chagos Archipelago. This standardized collection methodology provides robust data that can be compared regionally and globally. This report provides a broad discussion of trends and patterns as a prelude to more in-depth analyses.

2.2 a

BENTHIC COVER ASSESSMENTS

Cover of major functional groups and substrate type (Box 1) were assessed along 10 m transects using recorded observations and/or photographic assessments. The major functional groups assessed included: corals identified to genus, other sessile invertebrates such as giant clams, anemones, and others identified to phylum or class, and six functional groups of algae: crustose coralline algae (CCA), erect calcareous algae, cyanobacteria, fleshy macroalgae, turf algae, and turf mixed with sediment. At least two KSLOF surveyors used SCUBA-recorded observations to quantify benthic cover 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 among the five depth strata were completed at each survey station (Figure 3), and when possible, surveys were completed at 25, 20, 15, 10, and 5 m water depths.

At some locations, we additionally conducted a photographic assessment to supplement the point-intercept surveys. On occasion, we were not able to complete these surveys at every depth due to SCUBA time limitations, so we supplemented this dataset with photographic

Box 1 CLASSIFICATION OF SUBSTRATE TYPES RECORDED DURING BENTHIC TRANSECT SCUBA SURVEYS.

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

METHODS

Figure 3

A DIVER CONDUCTING A BENTHIC SURVEY. DIVER USES A 10 M TRANSECT LINE AND RECORDS BENTHIC SUBSTRATE TYPE AND COVER EVERY 10 CM. PHOTO BY KEN MARKS.

Figure 4

A DIVER TAKES A PHOTO OF A 1 M X 1 M SQUARE QUADRAT. TRANSECTS OF TEN PHOTOS ARE COMPLETED AT MULTIPLE DEPTHS TO SUPPLEMENT BELT TRANSECTS. PHOTO BY PHILIP RENAUD.

assessments. In this sampling technique, a scientific diver used a 1 m × 1 m quadrat, flipping it over a total of 10 times per transect to photograph a full 1 × 10 m photo transect **(Figure 4)** at each depth. As before, when possible, the diver completed at least one survey at 20, 15, 10, and 5 m depth at each site. To measure the benthic community, the digital photographs were downloaded and analyzed using *Coral Point Count with Excel Extensions* (CPCe), a software developed by Nova Southeastern University's National Coral Reef Institute (NCRI)[22]. The 1 × 1 m images were imported into the software where 50 random points were overlaid on each photograph. A KSLOF scientist then defined the organism and substrate type directly underneath the point **(Figure 5)**. These data were then exported into a Microsoft Excel (2013) spreadsheet and added to the benthic survey database for further analysis.

The benthic substrate cover percentages were calculated for each reef zone at each island as the average percentage of all transects collected in that zone, 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 each location 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 genera recorded on each transect was divided by the total number of algae or coral observed per transect.

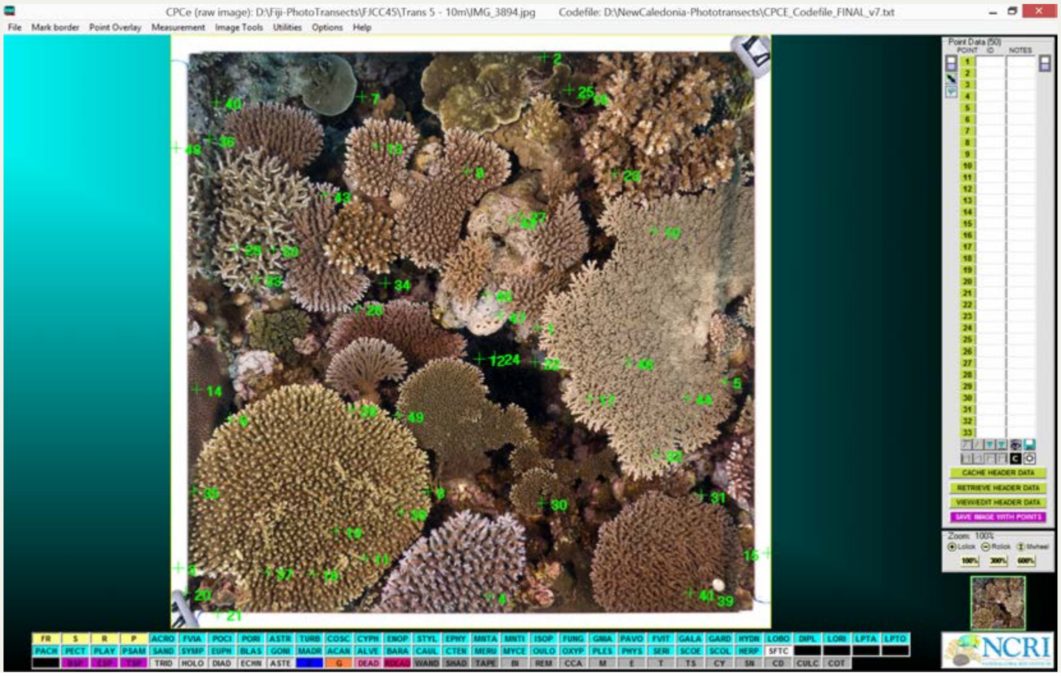
To measure overall coral diversity by genus, we used the Simpson Index of Diversity which is commonly used to characterize species diversity in a community[23]. This index uses the total number of individual coral colonies of a specific genus observed per island and location either inside or outside of the lagoon, and the total number of genera, to provide a number to represent the total diversity of the island community. Using this index, the diversity will fall within a range of 0-1 with 0 being low diversity, and 1 being the most diverse.

2.2 b FISH ASSESSMENTS

Reef fish surveys were conducted by the scientific team at selected locations. The survey transects covered depths between 1 to 22 m, but most of the surveys were between 5 and 20 m depth (Figure 6). Transects were deployed at deep (>11 m) and shallow (<10 m) sections of the reefs, as allowed by the morphology of the survey stations. At least two deep and two shallow transects were conducted by divers at each site. The fish assemblages at each survey station were surveyed following a fish visual census technique modified from the survey principles described by English et al. (1994)[24]. The diver identified and counted fish along a 30 × 4 m transect over a period of 10 to 15 minutes.

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] and their body lengths were visually estimated to the nearest centimeter. The abundance of each species of a particular size was estimated by actual counts or by cluster in the case of a school of fish. The biomass of each species was then computed using the formula $\mathbf{W=aL^b}$ where **W** is the weight in grams, **L** is the length of the fish in centimeters, and **a** and **b** are the species-specific growth constants derived from the 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.

Figure 5 EXAMPLE OF A PHOTOGRAPHED QUADRAT IMPORTED INTO CPCE SOFTWARE, WITH RANDOMLY PLACED POINTS FOR IDENTIFICATION. FIFTY RANDOM POINTS ARE OVERLAID ON EACH PHOTO QUADRAT AND SUBSTRATE TYPE AND LIVE COVER CLASSIFICATION ARE IDENTIFIED FOR EACH POINT.



METHODS

The counted fish were also attributed to trophic-level categories based on diet by species[32]. The correspondence between trophic levels and feeding habits is not strictly straightforward, or well-defined, because of wide overlaps in the food items consumed by different species[34]. Hence, the trophic levels under which a specific species is classified may be considered elastic and representative of the mean of its diet items. Trophic levels were expressed numerically and broadly represented herbivores (2.0 – 2.5), corallivores (2.6 – 3.0), planktivores (3.1 – 3.5), benthic carnivores (3.6 - 4.0), and piscivores (4.1 – 4.5)[35].

By analyzing the fish communities using trophic levels, we strived to understand the community structures and determine how fishing pressures might be affecting the fish communities. Fish in trophic levels 2.0-2.5 and 2.5-3.0 are typically small in size and are not considered important to local fisheries[36]. Fish that are classified in trophic levels 2.0-3.0 are usually important indicator species that contribute to the health of the reef by providing such services as cropping algal growth which otherwise would impede the settlement of juvenile corals[37,38]. These fish include damselfish, tangs, surgeonfish, butterflyfish, and a few small-bodied parrotfish. Fish in trophic level 3.0-3.5 and 3.5-4.0 include larger-bodied herbivores, planktivores, omnivores, or carnivores that feed on small benthic invertebrates. Fish classified in these ranges include wrasses, some species of butterflyfish, damselfish, hogfish, goatfish, snappers, and triggerfish. Fish in trophic level 4.0-4.5 are typically considered top predators and prey on finfish of the lower trophic levels. These predatory fish include large wrasse, grouper, hawkfish, snapper, goatfish, and sharks. The majority of the fish important to local fisheries are found in trophic levels 3.5-4.0 and 4.0-4.5[36,39].

Figure 6

A SCIENTIFIC SCUBA DIVER RECORDS FISH ALONG A TRANSECT LINE. SCIENTIST RECORDS FISH OBSERVED ALONG A 30 M × 4 M TRANSECT OVER A 10-15 MINUTE PERIOD. PHOTO BY KEN MARKS.

The **Khaled bin Sultan Living Oceans Foundation** used standarized methods to quantitatively **assess benthic** and **fish** communities in the **Chagos Archipelago**.

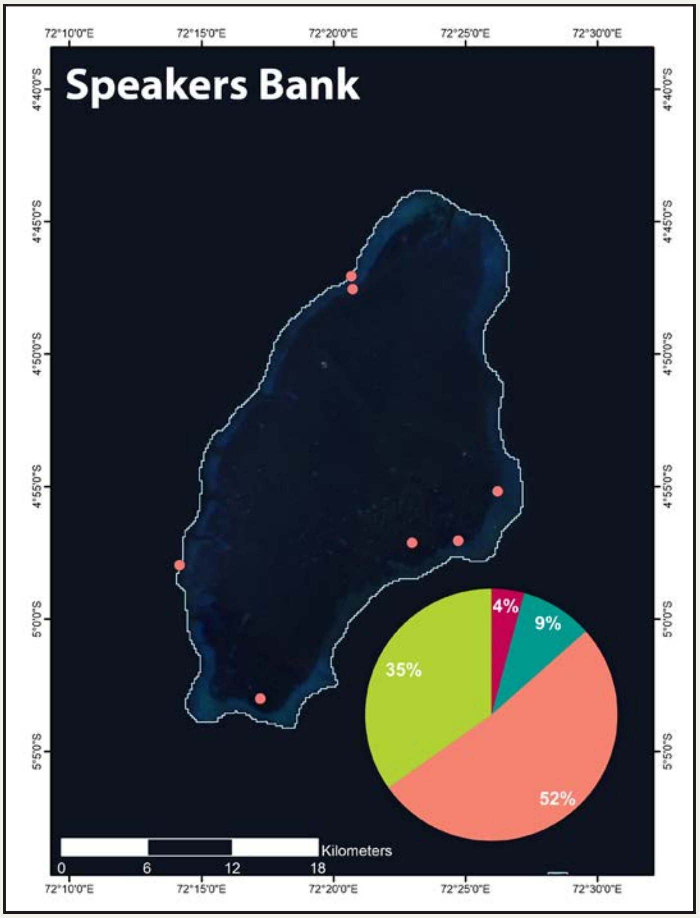
3.0 RESULTS

RESULTS

3.1 BENTHIC COMMUNITY ASSESSMENT

The reefs of the Chagos Archipelago were some of the most diverse and had some of the highest coral cover seen on the Global Reef Expedition. Overall, live coral cover ranged between 31-52%, with the overall average being 42% across the archipelago. Crustose coralline algae (CCA) and turf algae were the dominant algae types across all locations with cyanobacteria being nearly absent from all sites. Across all locations, a total of 58 genera of coral were recorded on transects completed in the Chagos Archipelago.

Figure 7 AVERAGE BENTHIC COVER (%) OF SPEAKERS BANK. THE SUBSTRATE TYPES ARE BARE SUBSTRATE, ALGAE, LIVE CORAL, AND SESSILE INVERTEBRATES. THESE VALUES WERE CALCULATED FROM THE BENTHIC SURVEYS, AVERAGING ACROSS DEPTH, THEN SITE. NUMBER OF SITES = 7; NUMBER OF TRANSECTS TOTAL = 98.



3.1 a

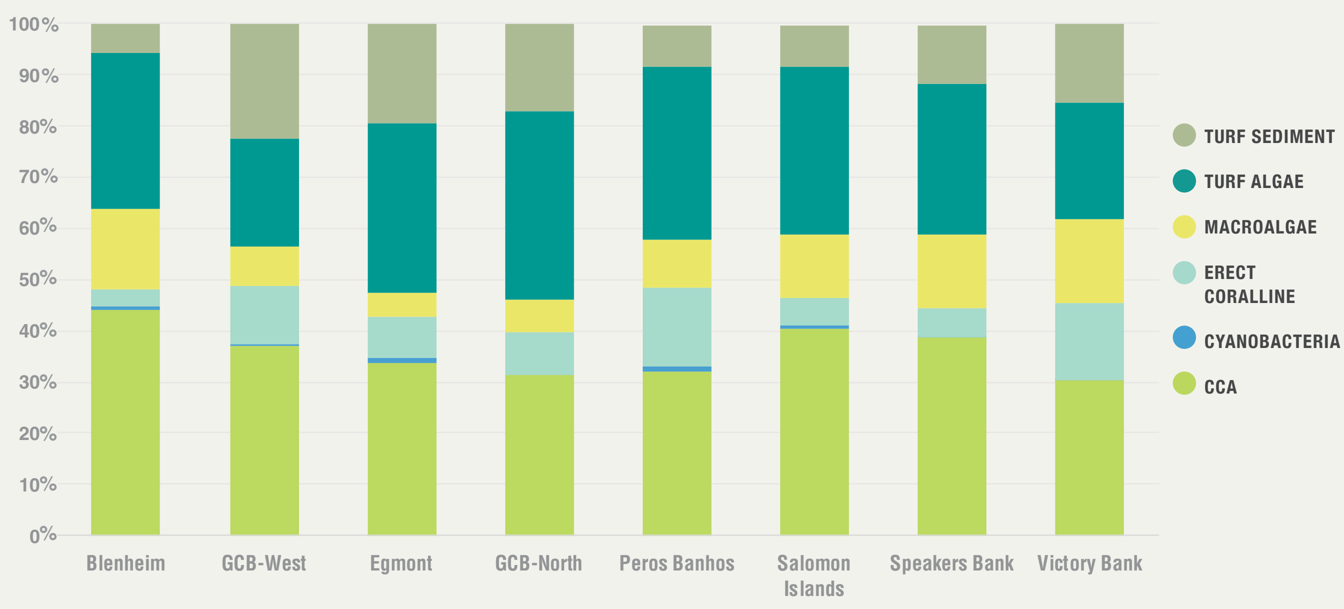
SPEAKERS BANK

Speakers Bank is the farthest north submerged atoll surveyed in the Chagos Archipelago and has a total area of 680 sq. km[3]. Not all depth gradients were able to be surveyed at this location with nearly all the benthic habitat surveys falling between 15-30 m and only four transects at Site 89 reaching 10-15 m. The average live coral cover was 52% (±17% S.D.; *n*-site=7; *n*-transects=98) and was the highest observed in the Chagos Archipelago **(Figure 7)**. Site 96 had an impressive 86% (±8% S.D.; *n*-transects=15) live coral cover. All of the surveys completed at Speakers Bank were dominated by the genus *Acropora*, where it accounted for 56% (±28% S.D.; *n*-site=7; *n*-transects=98) of the total coral observed. The coral diversity at Speakers Bank was 0.60. This lower diversity is likely due to the large number of *Acropora* spp. tables found throughout the reef system, as well as the exceptionally high coral cover at site 96 where this genus accounted for 81% (±7% S.D.; *n*-transects=15) of the coral found at this site.

The algae at Speakers Bank was mostly comprised of CCA, turf, and macroalgae **(Figure 8)**. Overall, algae accounted for 35% (±28% S.D.; *n*-site=7; *n*-transects=98) of the total substrate. CCA was the most abundant algal group, accounting for 39% (±12% S.D.; *n*-site=7; *n*-transects=98) of the total algae observed, followed by turf measuring 29% (±12% S.D.; *n*-site=7; *n*-transects=98), and macroalgae measuring 14 (±9% S.D.; *n*-site=7; *n*-transects=98) of the total algae **(Figure 8)**.

Figure 8

RELATIVE COMPOSITION OF ALGAE (%) AT EACH SITE SURVEYED IN CHAGOS. THE DATA PRESENTED ARE AVERAGED ACROSS DEPTH FROM DATA COLLECTED ON THE BENTHIC TRANSECTS AT EACH SITE. ALGAE CATEGORIES ARE: CRUSTOSE CORALLINE ALGAE, CYANOBACTERIA, ERECT CALCAREOUS ALGAE, MACROALGAE, TURF ALGAE, AND TURF MIXED WITH SEDIMENT.



RESULTS

3.1

b BLENHEIM

Blenheim is a small submerged atoll measuring 40 sq. km, found just to the south of Speakers Bank[3]. This atoll had live coral cover of 40% (±6% S.D.; *n*-site=4; *n*-transects=66) and algae accounted for 45% (±6% S.D.; *n*-site=4; *n*-transects=66) of the total substrate **(Figure 9)**.

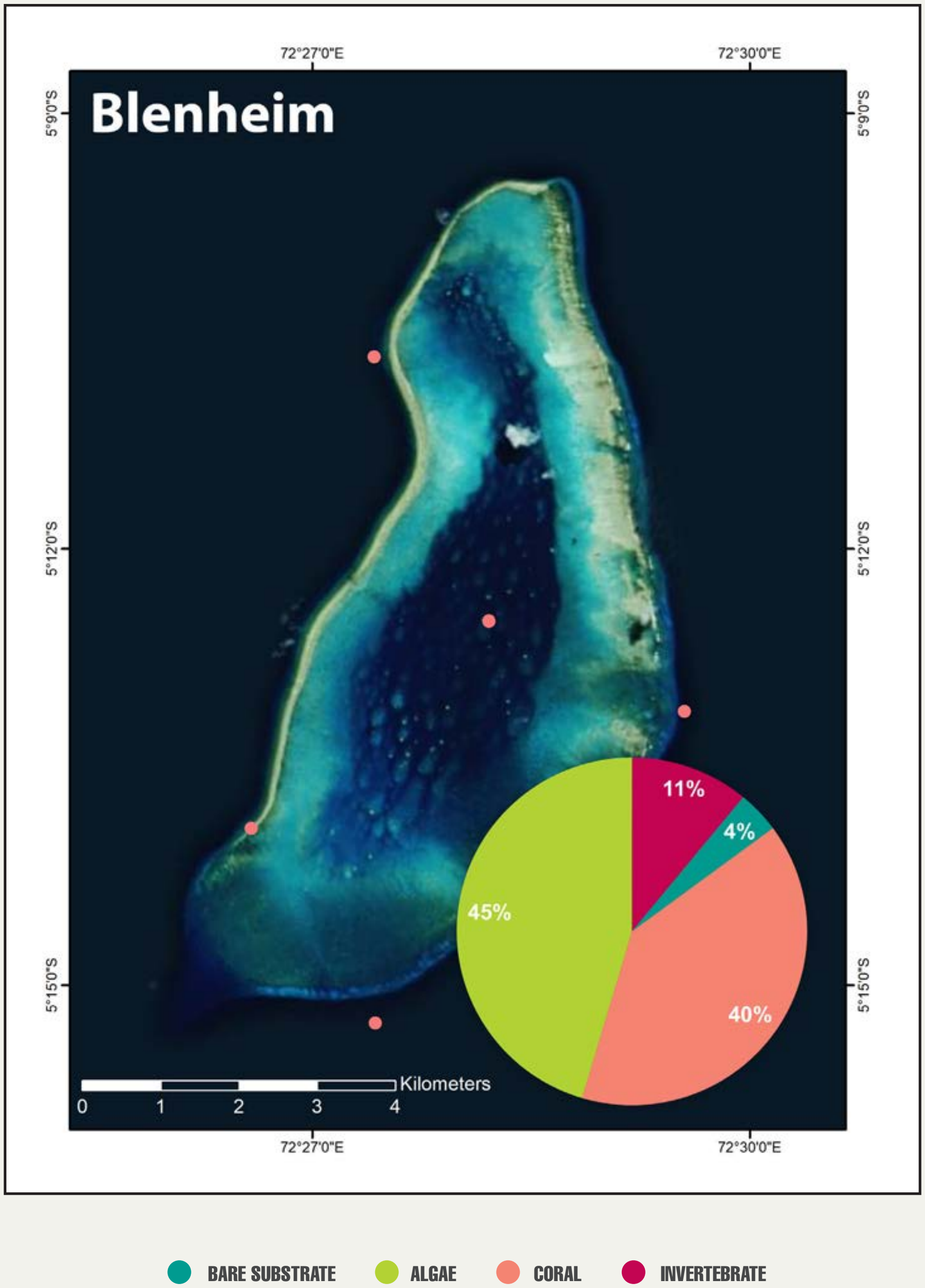
CCA and turf algae were the two most common algal groups recorded with CCA accounting for 44% (±14% S.D.; *n*-site=4; *n*-transects=66) and turf algae accounting for 31% (±17% S.D.; *n*-site=4; *n*-transects=66) of the total algae observed **(Figure 8)**. This site had some of the highest fleshy macroalgae observed with 15% (±10% S.D.; *n*-site=4; *n*-transects=66) of the total algae falling in this group. Sessile invertebrates accounted for 11% (±9% S.D.; *n*-site=4; *n*-transects=66) of the substrate with most invertebrates recorded being octocoral or sponges.

This site had the lowest percentage of bare substrate, meaning no live organisms were occupying the substrate, totaling only 4% (±3% S.D.; *n*-site=4; *n*-transects=66) of the recorded benthos.

The coral diversity at Blenheim was 0.924 which was exceptionally high. While the major reef-building corals such as *Acropora* spp. and *Porites* spp. were present, combined they only accounted for 25% of the total coal recorded at this location. The remaining coral cover was mostly evenly distributed among the remaining 40 genera of coral observed at this atoll. This site had the highest percentage of *Millepora* spp. observed in the Chagos Archipelago, accounting for 7% (±10% S.D.; *n*-site=4; *n*-transects=66) of the coral recorded. At all other sites except Victory Bank, *Millepora* spp. accounted for less than 1% of the coral recorded.

Coral diversity at **Blenheim** was **exceptionally high.** Over **40 genera** of **coral** were observed at this atoll.

Figure 9 AVERAGE BENTHIC COVER (%) OF BLENHEIM. THE SUBSTRATE TYPES ARE BARE SUBSTRATE, ALGAE, LIVE CORAL, AND SESSILE INVERTEBRATES. THESE VALUES WERE CALCULATED FROM THE BENTHIC SURVEYS, AVERAGING ACROSS DEPTH, THEN SITE. NUMBER OF SITES = 4; NUMBER OF TRANSECTS TOTAL = 66.



3.1 c PEROS BANHOS

Peros Banhos is one of the larger atolls north of Great Chagos Bank with a total area of 463 sq. km^3. This is one of two locations within the Chagos Archipelago where permitted mooring is allowed, however, there are restrictions on mooring locations. The reefs of Peros Banhos had 47% (±15% S.D.; *n*-site=20; *n*-transect=307) live coral cover and 34% (±9% S.D.; *n*-site=20; *n*-transect=307) algae covering the benthos **(Figure 10)**.

CCA accounted for 32% (±13% S.D.; *n*-site=20; *n*-transect=307) of the total algae recorded **(Figure 8)**. This site had the highest recorded value for erect calcareous algae recorded in the Chagos Archipelago, specifically *Halimeda*, where this group accounted for 15% (±11% S.D.; *n*-site=20; *n*-transect=307) of the total algae recorded. There was 10% bare substrate (±5% S.D.; *n*-site=20; *n*-transect=307) which was mostly sandy substrate found in the lagoon sites **(Figure 10)**.

The live coral cover at Peros Banhos was dominated by *Acropora* spp. and *Porites* spp. which together accounted for over 65% of the live coral recorded. Large table *Acroporids* intermixed with massive *Porites* spp. were frequently recorded at this location. The coral diversity at this location was 0.66.

Figure 10

AVERAGE BENTHIC COVER (%) OF PEROS BANHOS. THE SUBSTRATE TYPES ARE BARE SUBSTRATE, ALGAE, LIVE CORAL, AND SESSILE INVERTEBRATES. THESE VALUES WERE CALCULATED FROM THE BENTHIC SURVEYS, AVERAGING ACROSS DEPTH, THEN SITE. NUMBER OF SITES = 20; NUMBER OF TRANSECTS TOTAL = 307.

- BARE SUBSTRATE
- ALGAE
- CORAL
- INVERTEBRATE

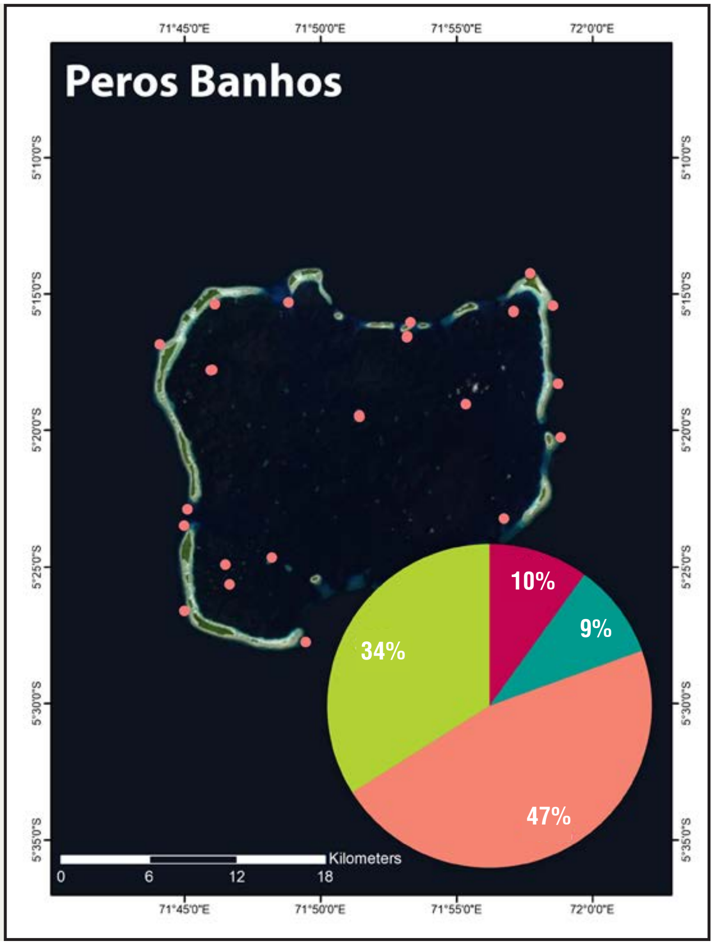
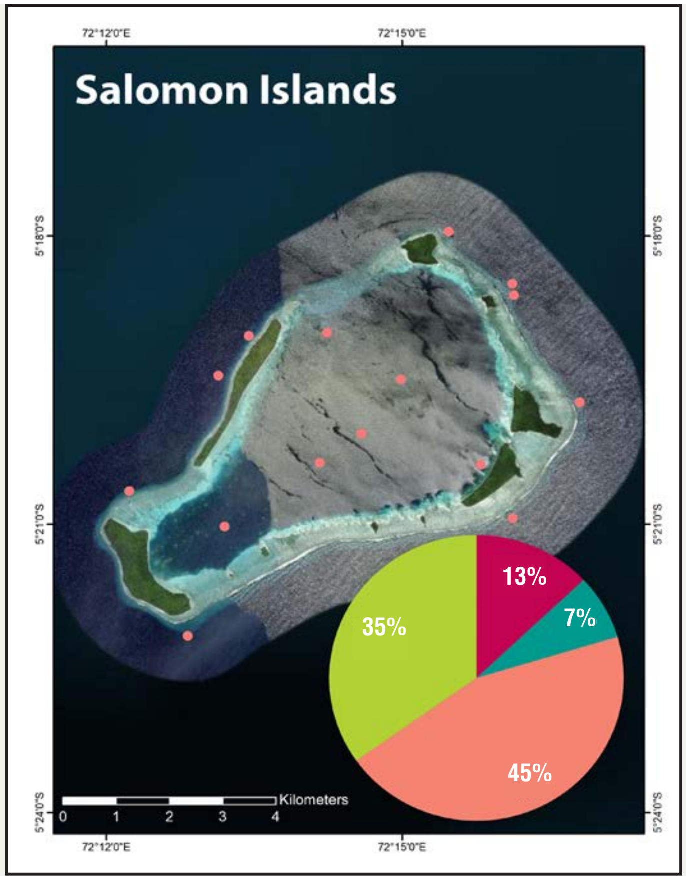


Figure 11

AVERAGE BENTHIC COVER (%) OF SALOMON ISLANDS. THE SUBSTRATE TYPES ARE BARE SUBSTRATE, ALGAE, LIVE CORAL, AND SESSILE INVERTEBRATES. THESE VALUES WERE CALCULATED FROM THE BENTHIC SURVEYS, AVERAGING ACROSS DEPTH, THEN SITE. NUMBER OF SITES = 13; NUMBER OF TRANSECTS TOTAL = 183.

- BARE SUBSTRATE
- ALGAE
- CORAL
- INVERTEBRATE



3.1 d SALOMON ISLANDS

Salomon Islands is one of the smaller atolls surveyed on the GRE mission to the Chagos Archipelago, only measuring 38 sq. km[3]. This location is the second permitted anchorage area where designated mooring sites are identified. The reefs of Salomon Islands had an overall live coral cover of 45 % (±12% S.D.; *n*-site=13; *n*-transects=114) **(Figure 11)**.

The coral diversity at this site was 0.85 with 54 genera of coral recorded. This was the only location where *Plerogyra* spp. and *Merulina* spp. were observed. *Goniastrea* accounted for 6% (±10% S.D.; *n*-site=13; *n*-transects=114) of the total coral recorded which was the highest amount recorded in the Archipelago and nearly three times that observed at Egmont, the only other site with a notable amount recorded. There were also extensive *Lobophyllia* spp. colonies found at sites inside of the lagoon and accounting for 6% (±7% S.D.; *n*-site=13; *n*-transects=114) of the total coral recorded in this location. This was the most *Lobophyllia* spp. recorded in the Chagos Archipelago.

The remaining benthic substrate was covered with 35% (±8% S.D.; *n*-site=13; *n*-transects=114) algae and 13% (±10% S.D.; *n*-site=13; *n*-transects=114) sessile invertebrates. The algal community was dominated by CCA and turf algae where 40% (±9% S.D.; *n*-site=13; *n*-transects=114) of the algae recorded was CCA and 32% (±8% S.D.; *n*-site=13; *n*-transects=114) was turf **(Figure 8)**. The fleshy macroalgae at this site accounted for 13% (±9% S.D.; *n*-site=13; *n*-transects=114) of the total algae recorded.

3.1 e VICTORY BANK

Victory Bank is the smallest submerged atoll surveyed on the mission to the Chagos Archipelago with a total area of 16 sq. km^3. This was an interesting site as it had small stands of seagrass intermixed within the reef. The top of the reef was 12 m deep, which is where the seagrass was found. Seagrass accounted for less than 1% of the recorded substrate.

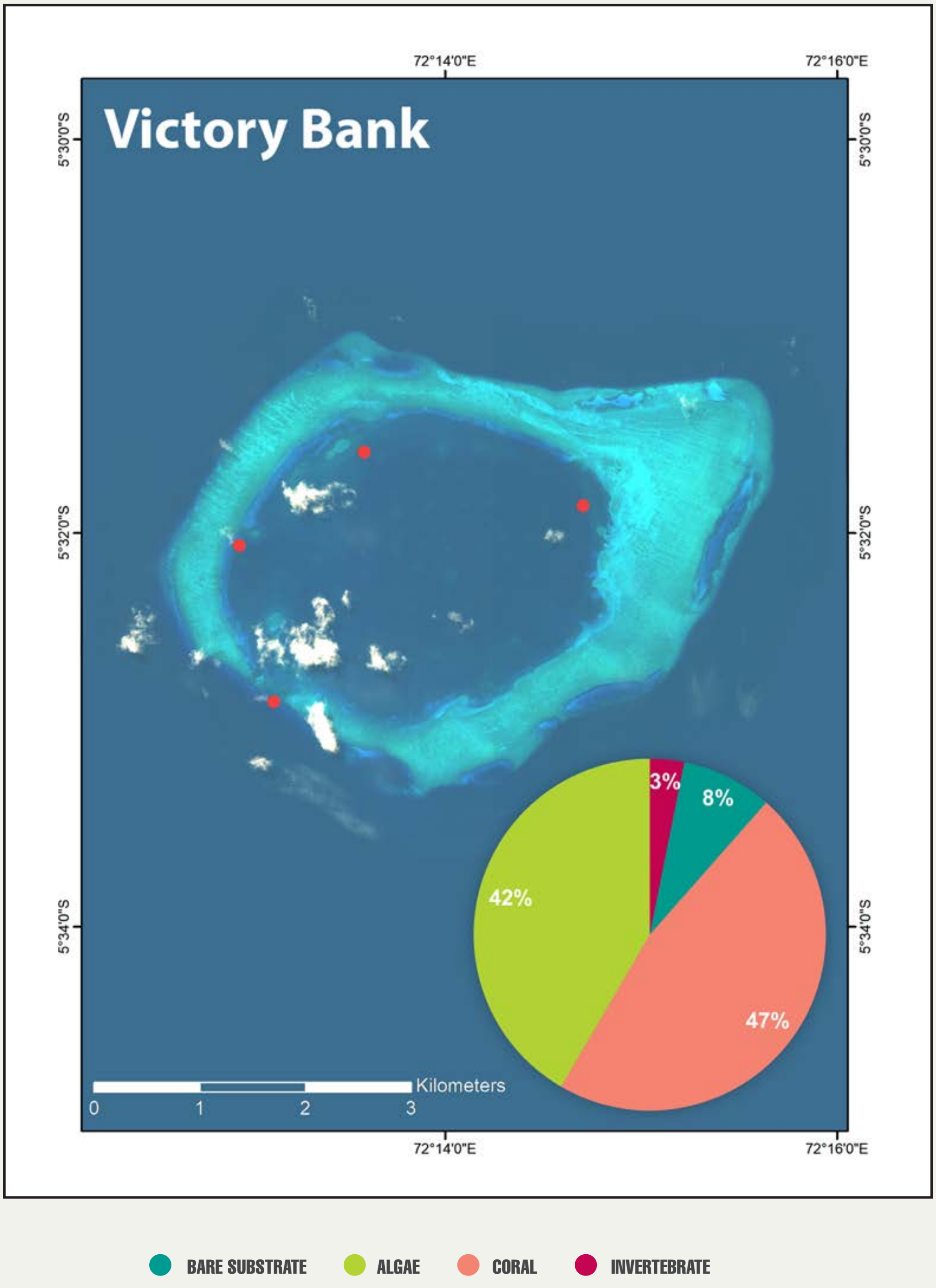
This submerged atoll had an average live coral cover of 47% (±9% S.D.; *n*-sites=4; *n*-transects=55) **(Figure 12)**. The reefs had 42% (±3% S.D.; *n*-sites=4; *n*-transects=55) algae and 3% (±3% S.D.; *n*-sites=4; *n*-transects=55) sessile invertebrates covering the substrate. Similar to the other nearby reefs, the algal communities were dominated by CCA which accounted for 30% (±9% S.D.; *n*-sites=4; *n*-transects=55) of the total algae recorded; however, this was the lowest percentage observed in the Chagos Archipelago **(Figure 12)**. Victory Bank had 15% (±11% S.D.; *n*-sites=4; *n*-transects=55) of erect calcareous algae, specifically *Halimeda* spp., which was the same as observed in Peros Banhos. These two locations had the highest observed value of erect calcareous algae in the Chagos Archipelago.

Victory Bank had a high coral diversity of 0.83. *Acropora* spp. accounted for 30% (±19% S.D.; *n*-sites=4; *n*-transects=55) of the coral observed and was the most common coral genus recorded. This location also had a notable amount of *Heliopora* spp. and *Millepora* spp. which accounted for 19% (±38% S.D.; *n*-sites=4; *n*-transects=55) and 7% (±6% S.D.; *n*-sites=4; *n*-transects=55) of the coral recorded, respectively. The *Heliopora* spp. grew in large stands, particularly at Site 99 where it accounted for 77% (±8% S.D.; *n*-transects=16) of the total coral observed and was commonly intermixed with other smaller branching corals such as *Pocilloporids* and *Acroporids*. Victory Bank also had the second-highest amount of *Millepora* spp. recorded in all of the Chagos Archipelago and was primarily found on the forereef.

Victory Bank had **high coral diversity** and small stands of **seagrass** intermixed within the **coral reefs.**

Figure 12

AVERAGE BENTHIC COVER (%) OF VICTORY BANK. THE SUBSTRATE TYPES ARE BARE SUBSTRATE, ALGAE, LIVE CORAL, AND SESSILE INVERTEBRATES. THESE VALUES WERE CALCULATED FROM THE BENTHIC SURVEYS, AVERAGING ACROSS DEPTH, THEN SITE. NUMBER OF SITES = 4; NUMBER OF TRANSECTS TOTAL = 55.



3.1 f GREAT CHAGOS BANK-NORTH

Due to the expanse of the Great Chagos Bank, analysis of the data collected here was divided into two regions: Great Chagos Bank-North (GCB-N) and Great Chagos Bank-West (GCB-W). The reefs of GCB-N had an average live coral cover of 34% (±11% S.D.; *n*-site=4; *n*-transect=50) **(Figure 13)**. Algae accounted for 42% (±5% S.D.; *n*-site=4; *n*-transect=50) of the substrate and was dominated by CCA and turf algae which, combined, accounted for 68% of the algae recorded **(Figure 8)**. This location had 13% (±4% S.D.; *n*-site=4; *n*-transect=50) bare substrate which, very similar to what was observed in Great Chagos Bank-West, was some of the highest percentage of bare substrate observed in the Chagos Archipelago. The bare substrate was mostly comprised of unconsolidated sand. This location had 18% (±9% S.D.; *n*-site=4; *n*-transect=50) dead coral recorded as the substrate type which was more than double the amount seen at the other locations in the Archipelago. There were large *Acropora* spp., *Porites* spp., *Pocillopora* spp., and *Stylophora* spp. colonies that appear to have been impacted by a recent crown-of-thorns starfish (COTS) outbreak, however this should be investigated further to rule out other mortality causes.

The coral diversity of GCB-N was 0.64. The coral diversity of this location was mostly comprised of *Acropora* spp. and *Porites* spp. when combined accounted for 64% of the coral recorded here. This location had the highest percentage of *Stylophora* spp. which accounted for 9% (±10% S.D.; *n*-site=4; *n*-transect=50) of the coral recorded.

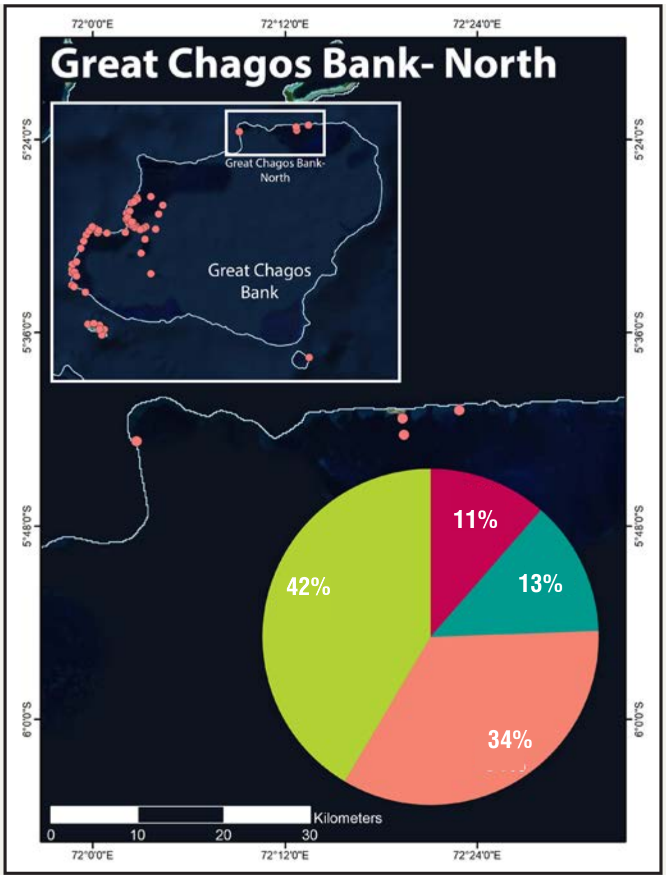


Figure 13

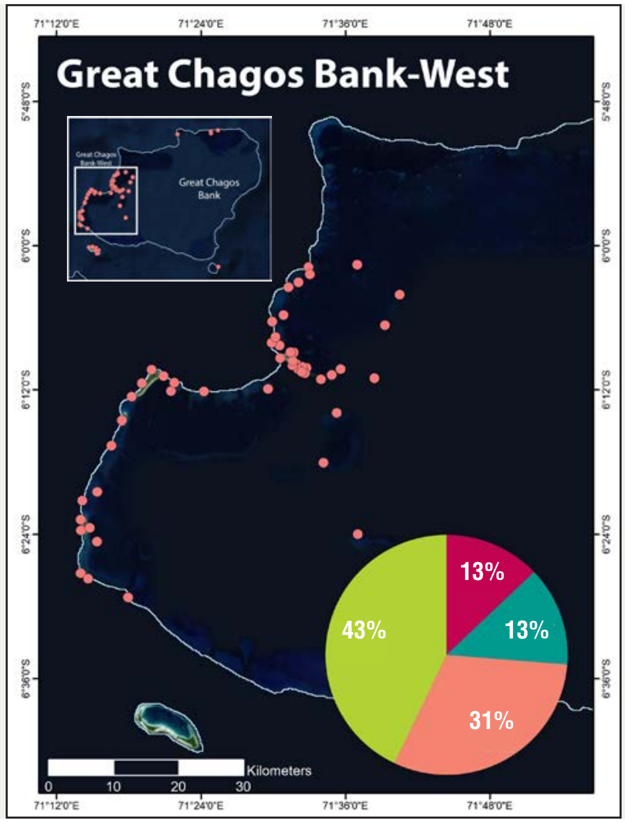
AVERAGE BENTHIC COVER (%) OF GCB-NORTH. MOST SURVEY SITES WERE NEAR NELSON ISLAND. THE SUBSTRATE TYPES ARE BARE SUBSTRATE, ALGAE, LIVE CORAL, AND SESSILE INVERTEBRATES. THESE VALUES WERE CALCULATED FROM THE BENTHIC SURVEYS, AVERAGING ACROSS DEPTH, THEN SITE. NUMBER OF SITES= 4; NUMBER OF TRANSECTS TOTAL = 50

- BARE SUBSTRATE
- ALGAE
- CORAL
- INVERTEBRATE

Figure 14

AVERAGE BENTHIC COVER (%) OF GCB-WEST. THE SUBSTRATE TYPES ARE BARE SUBSTRATE, ALGAE, LIVE CORAL, AND SESSILE INVERTEBRATES. THESE VALUES WERE CALCULATED FROM THE BENTHIC SURVEYS, AVERAGING ACROSS DEPTH, THEN SITE. NUMBER OF SITES= 49; NUMBER OF TRANSECTS TOTAL= 700.

- BARE SUBSTRATE
- ALGAE
- CORAL
- INVERTEBRATE



3.1 g GREAT CHAGOS BANK-WEST

KSLOF made a substantial effort surveying the reefs along the western bank of the Great Chagos Bank. The majority of the sites surveyed at this location were concentrated around Danger Island, Eagle Island, and Three Brothers with a few falling closer to the center of the atoll. The reefs of Great Chagos Bank- West (GCB-W) had the lowest overall live coral cover of 31% (±15% S.D.; *n*-site=49; *n*-transect=699) **(Figure 14)** when compared to all other locations surveyed in the Chagos Archipelago.

The sites closest to Three Brothers, on average, had a higher live coral cover, while the reefs closer to the center of the bank had much lower live coral cover. Algae accounted for 43% (±12% S.D.; *n*-site=49; *n*-transect=699) of the total substrate and bare substrate totaled 13% (±6% S.D.; *n*-site=49; *n*-transect=699), the highest percentage seen in all of the Archipelago. The bare substrate was mostly comprised of sand and rubble. The algal community was dominated by CCA which accounted for 37% (±12% S.D.; *n*-site=49; *n*-transect=699) of the total algae recorded. This site had the most turf mixed with sediment recorded in the Chagos Archipelago which accounted for 22% (±15% S.D.; *n*-site=49; *n*-transect=699) of the total algae **(Figure 8)**.

The coral diversity of GCB-West was 0.84, and 48 of the 58 genera of coral recorded in the Chagos Archipelago were found here. This was the only location where *Pectinia* spp. and *Madracis* spp. were observed. *Porites* was the most common genus recorded, totaling 30% (±15% S.D.; *n*-site=49; *n*-transect=699) of the coral recorded. This location also had the highest percentage of *Pocillopora* spp., which accounted for 12% (±7% S.D.; *n*-site=49; *n*-transect=699) of the total coral recorded.

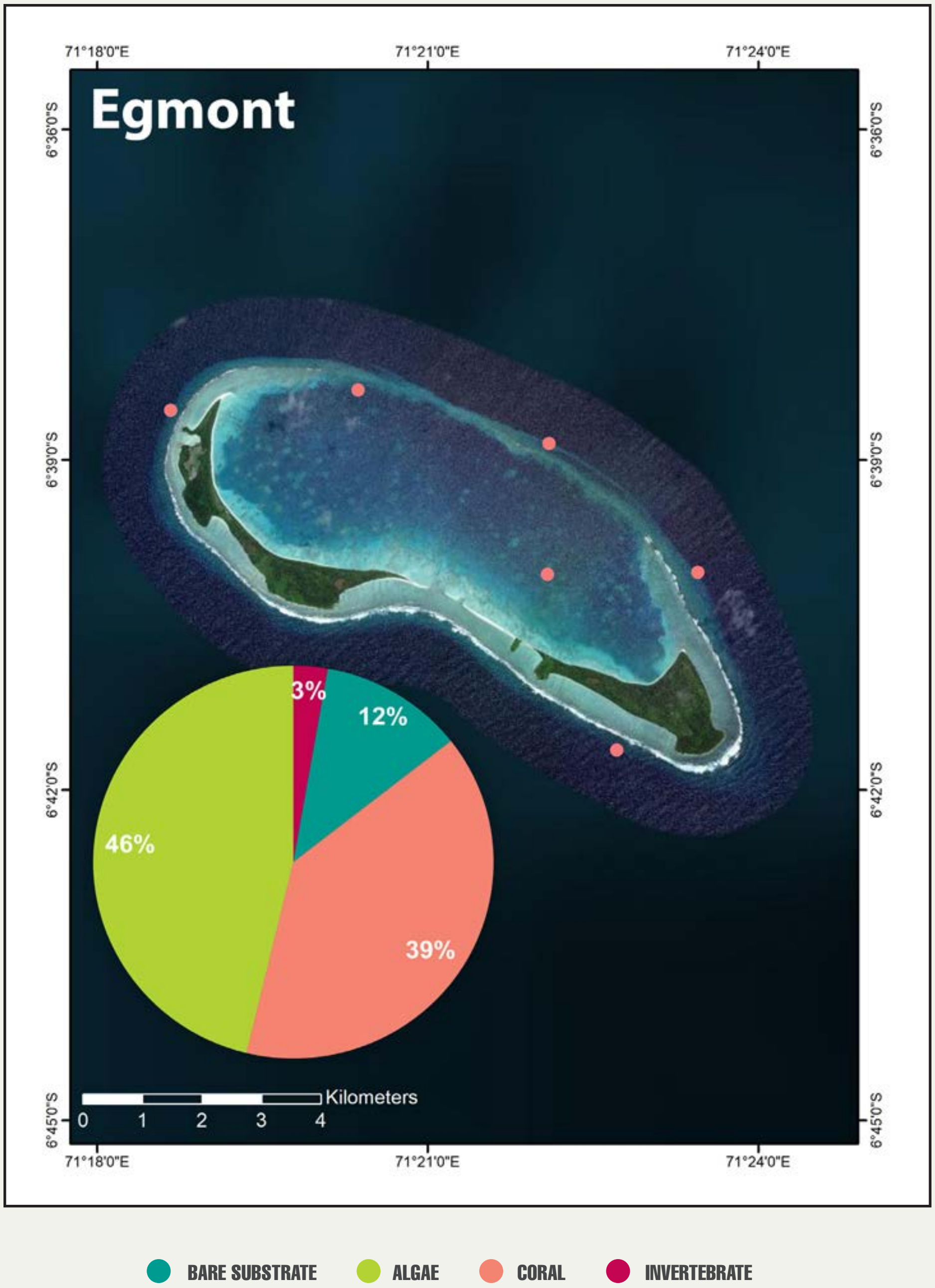
3.1 h EGMONT

Egmont is the southernmost atoll surveyed on the GRE. This atoll is located to the southwest of the Great Chagos Bank and has a total area of 40 sq. km[3]. This atoll had an average live coral cover of 39% (±8% S.D.; *n*-site=6; *n*-transect=90). The algal cover accounted for 46% (±8% S.D.; *n*-site=6; *n*-transect=90) of the total substrate, and sessile invertebrates accounted for 3% (±2% S.D.; *n*-site=6; *n*-transect=90) of the substrate, the lowest invertebrate cover observed in the Chagos Archipelago **(Figure 15)**. The bare substrate in Egmont accounted for 12% (±3% S.D.; *n*-site=6; *n*-transect=90) of the recorded substrate and was mostly due to unconsolidated sand. The algal community was dominated by CCA and turf algae, when combined totaled 67% of the total algae recorded **(Figure 8)**.

The coral community was dominated by *Acropora* spp. which accounted for 42% (±21% S.D.; *n*-site=6; *n*-transect=90) of the live coral recorded here. This site was the only location where *Euphyllia* spp. was observed, although it accounted for less than 1% of the coral recorded here. The coral diversity of Egmont was 0.75 and a total of 36 genera of species were recorded here. Similar to what was observed at Salomon Islands, sites inside of the lagoon had expansive *Lobophyllia* spp. colonies. At Site 7, 70% of the total coral recorded was *Lobophyllia* spp. and an average of 4% (±10% S.D.; *n*-site=6; *n*-transect=90) of the total coral recorded in Egmont.

One of the **most interesting** findings was **large monospecific stands** of different **coral species** observed in some locations.

Figure 15 AVERAGE BENTHIC COVER (%) OF EGMONT. THE SUBSTRATE TYPES ARE BARE SUBSTRATE, ALGAE, LIVE CORAL, AND SESSILE INVERTEBRATES. THESE VALUES WERE CALCULATED FROM THE BENTHIC SURVEYS, AVERAGING ACROSS DEPTH, THEN SITE. NUMBER OF SITES= 6; NUMBER OF TRANSECTS TOTAL= 90.



3.2

FISH COMMUNITY ASSESSMENT

The results from the present survey support previous findings that the northern atolls of the Chagos Archipelago support abundant and diverse fish communities with high biomass[4]. Of the estimated 784 species of fishes found in the Chagos Archipelago, 559 were noted at the sites surveyed. While Victory Bank had the lowest diversity of the locations surveyed, it stood out as the location with the highest fish density, biomass, and percentage of large fish. Different regions of the Great Chagos Bank (GCB) showed opposite patterns, with larger, more diverse, and more abundant fish populations at GCB-West than GCB-North.

3.2 a

FISH SPECIES RICHNESS

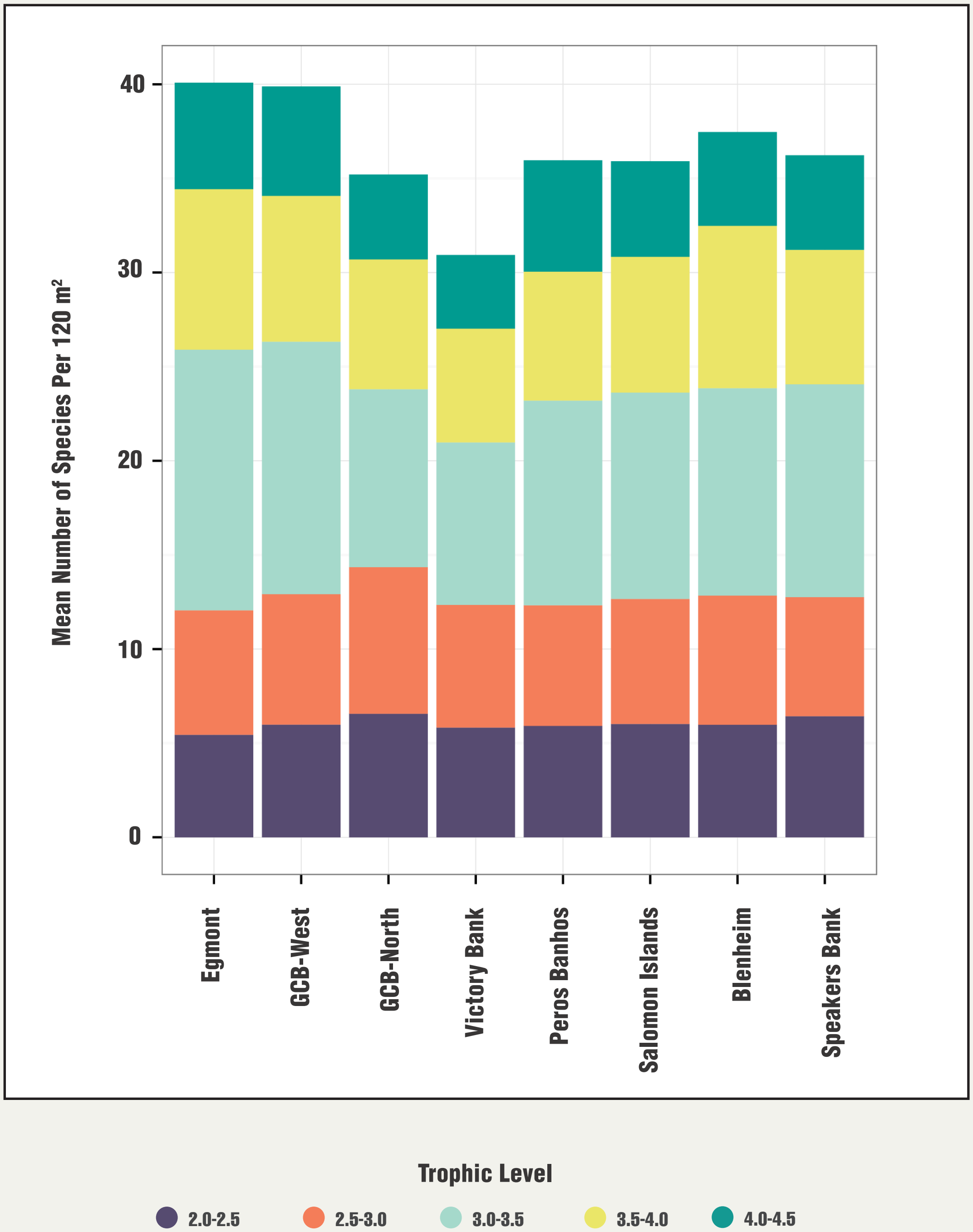
Species richness was fairly uniform across the archipelago, with the overall mean number of species surveyed varying only from 24.4 species/ 120 m^2 at Victory Bank to 34.2 species/ 120 m^2 at Blenheim (Table 2). Similarly, the distribution of species across different trophic groups was similar at all locations, with only slight differences in proportion at each location (Figure 16). In particular, species richness in the lower trophic categories were very even across all locations (only ranging, for example, from 5.8 species/ 120 m^2 +/- 2.2 at Victory Bank to 6.6 species/ 120 m^2 +/- 3.1 at GCB-West in the 2.0-2.4 trophic category) while more variation was evident in the middle and higher trophic categories. The 3.0-3.4 trophic category was the most variable, ranging from 8.6 species/ 120 m^2 (+/- 3.8) at Victory Bank to 13.8 species/ 120 m^2 (+/- 5.4) at Egmont.

Table 2 SAMPLING INTENSITY, DIVERSITY, AND MEAN SPECIES RICHNESS (NUMBER OF SPECIES/120 M^2), MEAN DENSITY (INDIVIDUALS/100 M^2), AND MEAN BIOMASS (KG/100 M^2) OF FISH AT SITES SURVEYED IN CHAGOS.

LOCATION	NUMBER OF SURVEY STATIONS	NUMBER OF TRANSECTS	NUMBER OF FAMILIES	NUMBER OF SPECIES	MEAN SPECIES RICHNESS	MEAN DENSITY	MEAN BIOMASS
Egmont	6	70	47	332	32	205	29
GCB-West	48	575	62	471	31	232	39
GCB-North	4	46	34	215	29	126	22
Victory Bank	4	47	33	208	24	421	98
Peros Banhos	20	233	46	342	28	256	25
Salomon Islands	13	139	44	321	29	289	20
Blenheim	4	50	32	220	34	212	26
Speakers Bank	7	62	36	237	26	158	23
TOTAL	**106**	**1222**	**69**	**559**			
MEAN	**13**	**153**	**42**	**293**	**29**	**238**	**35**

Figure 16

MEAN FISH SPECIES RICHNESS (NUMBER OF SPECIES/120 M²) BY TROPHIC CATEGORY OF LOCATIONS SURVEYED IN CHAGOS. TROPHIC CATEGORIES ARE BASED ON DIET BY SPECIES. SMALLER TROPHIC CATEGORIES TYPICALLY INCLUDE SMALLER HERBIVOROUS FISH SUCH AS BUTTERFLY FISH AND WRASSES WHILE LARGER CATEGORIES INCLUDE PREDATORY OMNIVORES SUCH AS SHARKS AND GROUPERS.



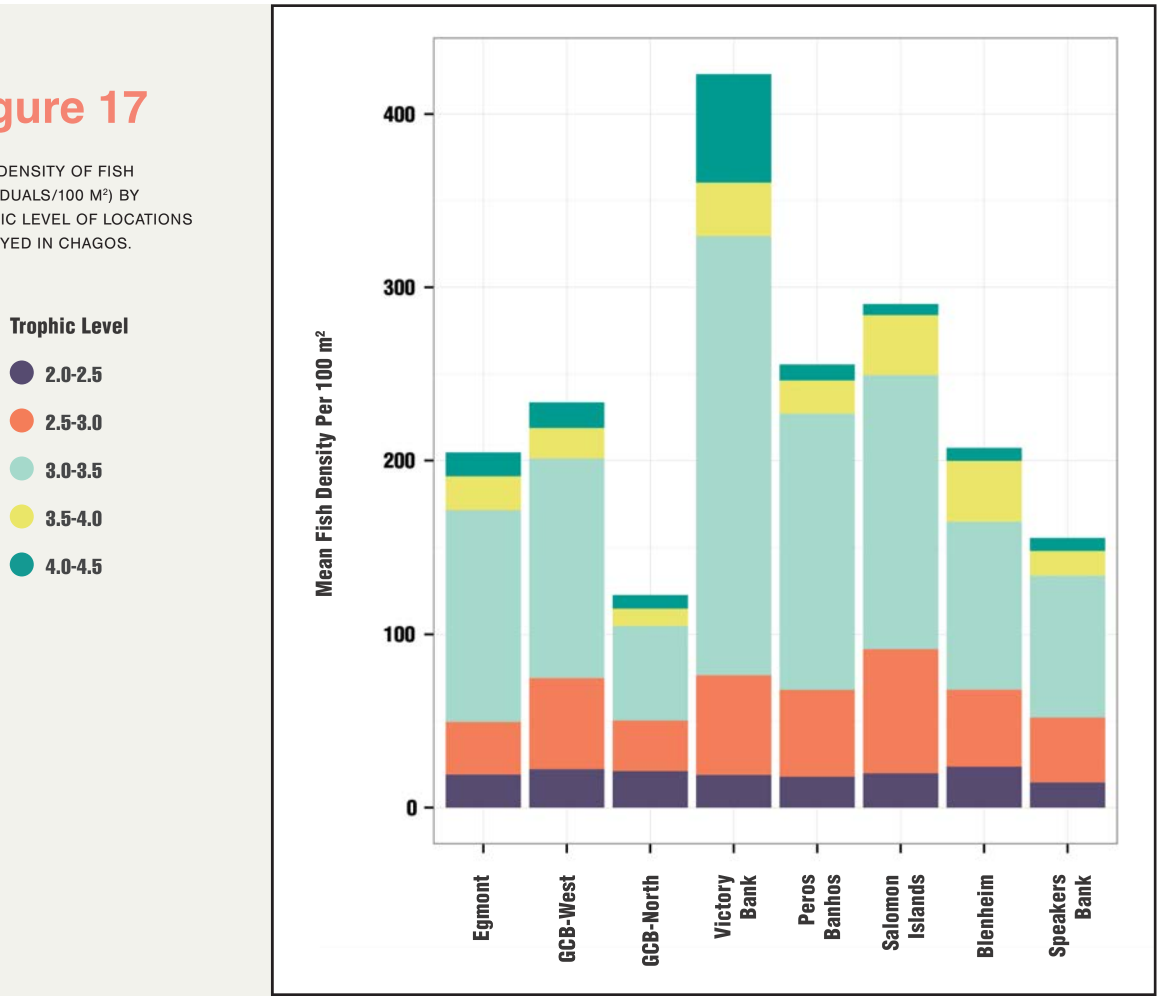
3.3 b FISH DENSITY

In contrast to species richness, fish density varied substantially between locations (Figure 17). Overall mean fish density at Victory Bank (421.3 individuals/100 m²) was about 3.5 times greater than at GCB-North, where mean density was 125.7 individuals/100 m². The 3.0-3.4 trophic category was particularly variable, ranging from 54.6 individuals/100 m² (+/- 101.2) at GCB-North to 253.1 individuals/100 m²(+/- 517.0) at Victory Bank. Victory Bank also had substantially more fish in the 4.0-4.5 trophic category on average (62.6 individuals/100 m² +/- 160.7) than the remaining seven locations. By contrast, the second-highest mean value in this trophic group was fourfold lower (14.8 individuals/100 m² +/- 26.0 at GCB-West).

Fish in the 2.0-2.4 trophic category made up a relatively small proportion of the overall density at all locations, and this was also the least variable trophic category, ranging from 14.6 individuals/100 m² +/- 11.3 at Speakers Bank to 23.7 individuals/100 m² +/- 15.4 at Blenheim. Fish in the lower two trophic categories made up ≤1/3 of the fish density at all sites except at GCB-North, where they accounted for 41.0% of the total fish density.

Figure 17

MEAN DENSITY OF FISH (INDIVIDUALS/100 M²) BY TROPHIC LEVEL OF LOCATIONS SURVEYED IN CHAGOS.



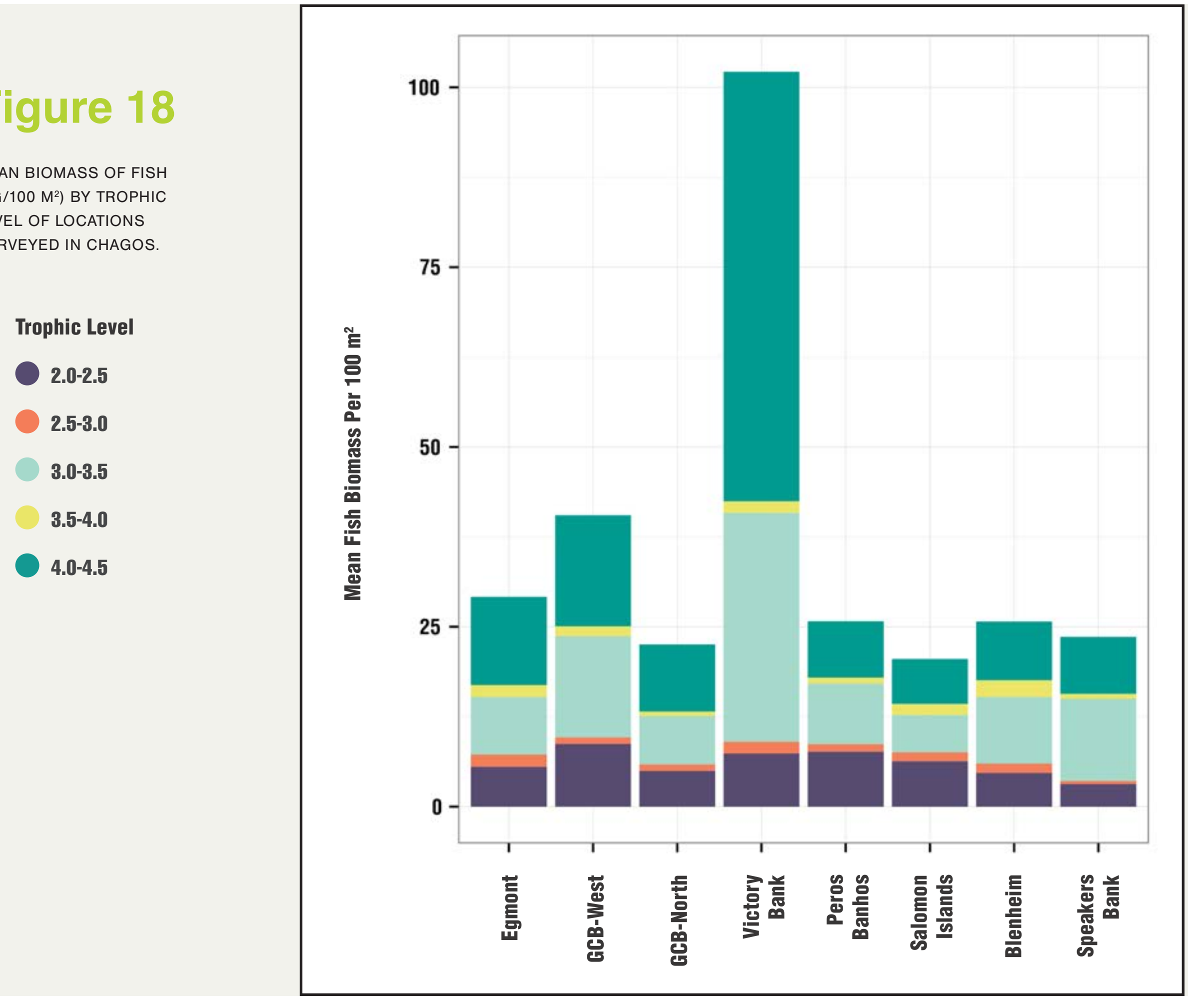
3.3 c FISH BIOMASS

Fish biomass was similar across most of the locations surveyed, particularly from Peros Banhos northward; however, mean biomass at Victory Bank dwarfed biomass at all other locations. Total mean biomass at Victory Bank was 97.5 kg/100 m^2, more than twice as high as the next highest site (GCB-West; 39.4 kg/100 m^2) Figure 18). Biomass at Victory Bank was dominated by fish in the 4.0-4.5 trophic category, with a mean value of 59.7 kg/100 m^2 (+/- 95.4). Mean biomass in the 3.0-3.4 trophic category was also quite high at this location, averaging 31.8 kg/100 m^2 (+/- 56.2).

Biomass in the 2.5-2.9 and 3.5-3.9 trophic categories was low across the archipelago. Biomass in the 2.5-2.9 category ranged from 0.5 kg/100 m^2 (+/-0.4) at Speakers Bank to 1.7 kg/100 m^2 (+/- 3.4) at Egmont, and biomass in the 3.5-3.9 category ranged from 0.6 kg/100 m^2 (+/- 1.2) at GCB-North to 2.3 kg/100 m^2 (+/- 2.3) at Blenheim. Despite representing a relatively low proportion of the total fish density, fish in the 2.0-2.4 trophic category made up a substantial portion of the total biomass at most locations, indicating the presence of relatively large herbivores across the archipelago.

Figure 18

MEAN BIOMASS OF FISH (KG/100 M^2) BY TROPHIC LEVEL OF LOCATIONS SURVEYED IN CHAGOS.

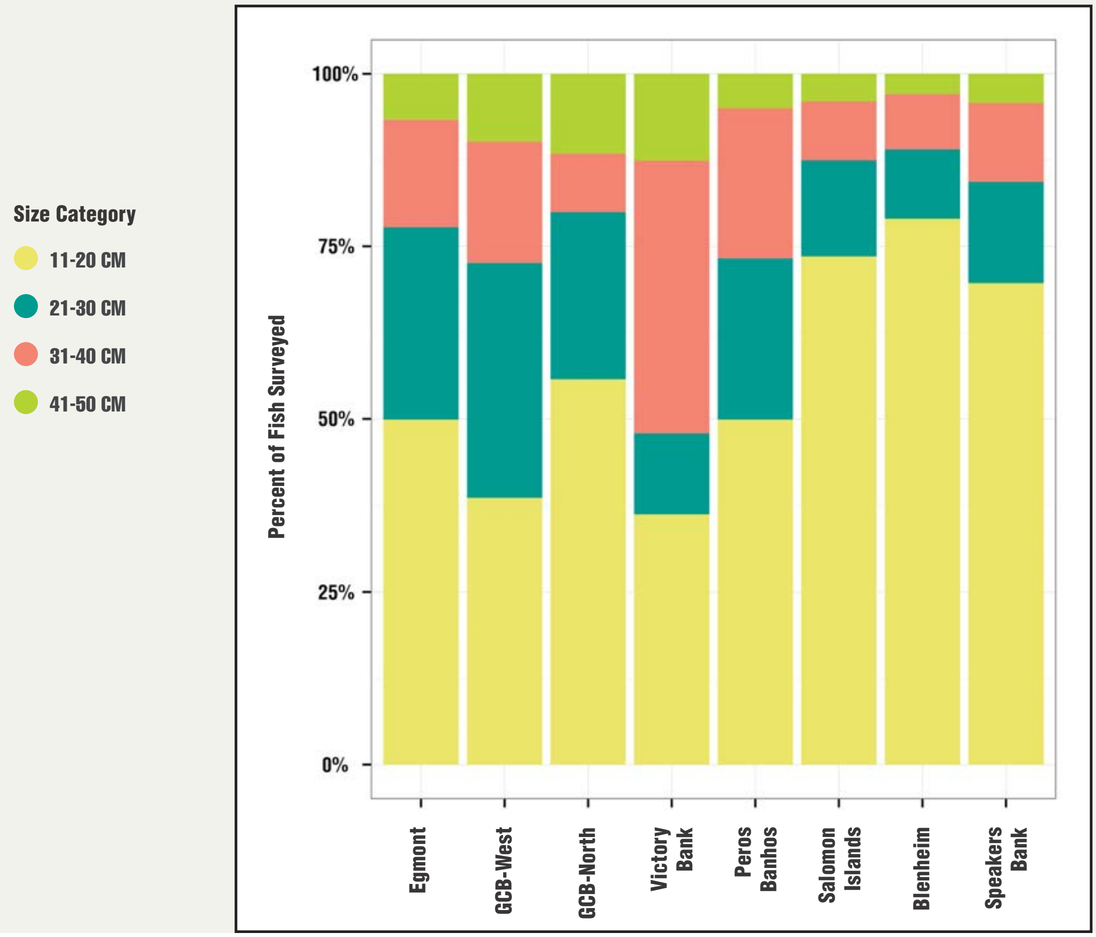


3.3 d SIZE DISTRIBUTION OF FISH

Small fish in the 11-20 cm size category made up the largest proportion of fish surveyed at all locations except for Victory Bank, which had the most fish in the 31-40 cm size category **(Figure 19)**. While fish >31 cm made up a relatively small proportion of fish at most locations (from 11.0% at Blenheim to 27.4% at GCB-West), fish in the higher two size categories made up greater than half of the fish surveyed at Victory Bank (52.1%).

The three northernmost atolls (Salomon Islands, Blenheim, and Speakers Bank) had the highest proportions of small fish and the lowest proportions of large fish. Mid-size fish (21-40 cm) were generally more abundant from Peros Banhos southward, and large (41-50 cm) fish were more abundant from Victory Bank southward.

Figure 19 THE RELATIVE SIZE DISTRIBUTION (%) OF SELECTED IMPORTANT FISH FAMILIES OF LOCATIONS SURVEYED IN CHAGOS. FAMILIES INCLUDED WERE: ACANTHURIDAE, CARANGIDAE, HAEMULIDAE, LETHRINIDAE, LUTJANIDAE, NEMIPTERIDAE, SCARIDAE, SERRANIDAE, AND SIGANIDAE. FISH WITH TOTAL LENGTHS BELOW 10 CM AND GREATER THAN 50 CM WERE EXCLUDED.



The **reefs** of the **Chagos Archipelago** were some of the **most diverse** and had some of the **highest coral cover** and **fish biomass** seen on the **Global Reef Expedition.**

4.0 DISCUSSION

DISCUSSION

4.0

The benthic and fish communities of the Chagos Archipelago were impressive. Across all locations surveyed, all of the smaller northern atolls had higher live coral cover than observed around Great Chagos Bank. Although the average live coral cover ranged from 31-52%, some individual survey sites, such as Site 72 at Peros Banhos and Site 96 at Speakers Bank, had impressive live coral cover reaching 72% and 86% respectively. Large table *Acroporids* and massive *Porites* were common throughout all locations, but some of the most interesting findings were the monospecific stands of *Lobophyllia* spp. and *Heliopora* spp. observed at some sites. Compared to other countries surveyed on the GRE, the reefs of the Chagos Archipelago had, on average, some of the highest live coral cover **(Figure 20)**.

Globally, the Chagos Archipelago had the highest fish density and the second-highest fish biomass compared to reefs in other countries surveyed on the GRE **(Figures 21-22)**. Considering the shark population—one of the biggest contributors to fish biomass—and the fact that the Chagos Archipelago is recovering from years of decline due to illegal fishing[20], this number is impressive and indicates the fish community here is thriving.

Fish populations were uniformly diverse across all locations surveyed in the Chagos Archipelago and a high percentage of the fish species known to occur in the archipelago were recorded. However, despite uniform levels of protection across all of the sites surveyed, fish density, biomass, and size-frequency distributions differed across locations. The differences in the fish communities don't appear to be directly related to benthic and coral cover. For example, Victory Bank did not have the highest overall live coral cover, although it was the second-highest and above the overall average, but did have the highest fish biomass observed in Chagos. Furthermore, Great Chagos Bank-West, which had the lowest live coral cover observed, had the second-highest mean fish biomass, although it was half of what was observed at Victory Bank. The variations observed might instead be driven by local oceanographic influences. One study from 2013 showed higher levels of chlorophyll-*a*, likely due to localized upwelling, occurred around areas of

Figure 20 GLOBAL COMPARISON OF PERCENT LIVE CORAL COVER AMONG COUNTRIES VISITED ON THE GRE.

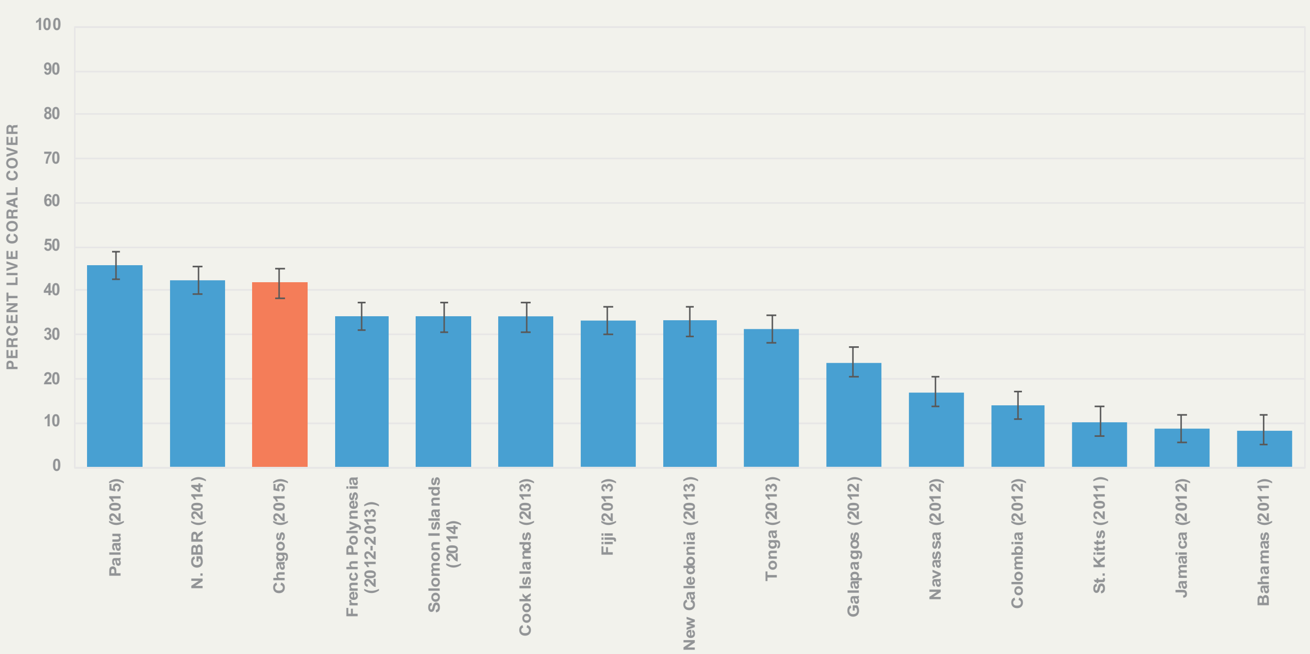


Figure 21

GLOBAL COMPARISON OF FISH BIOMASS AMONG COUNTRIES VISITED ON THE GRE.

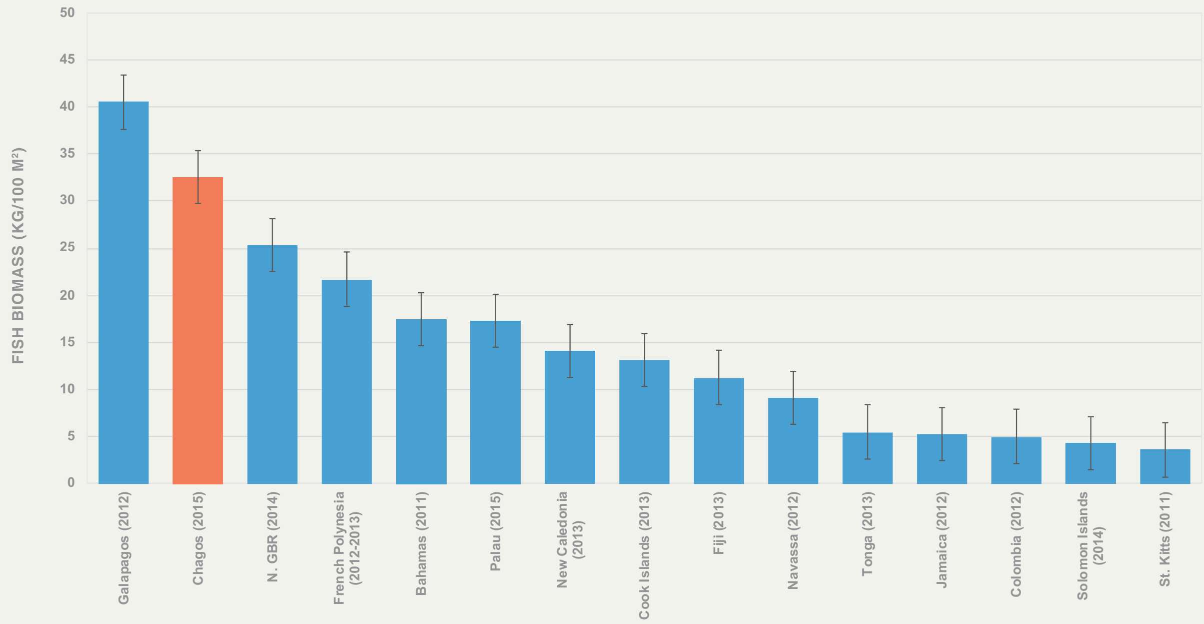
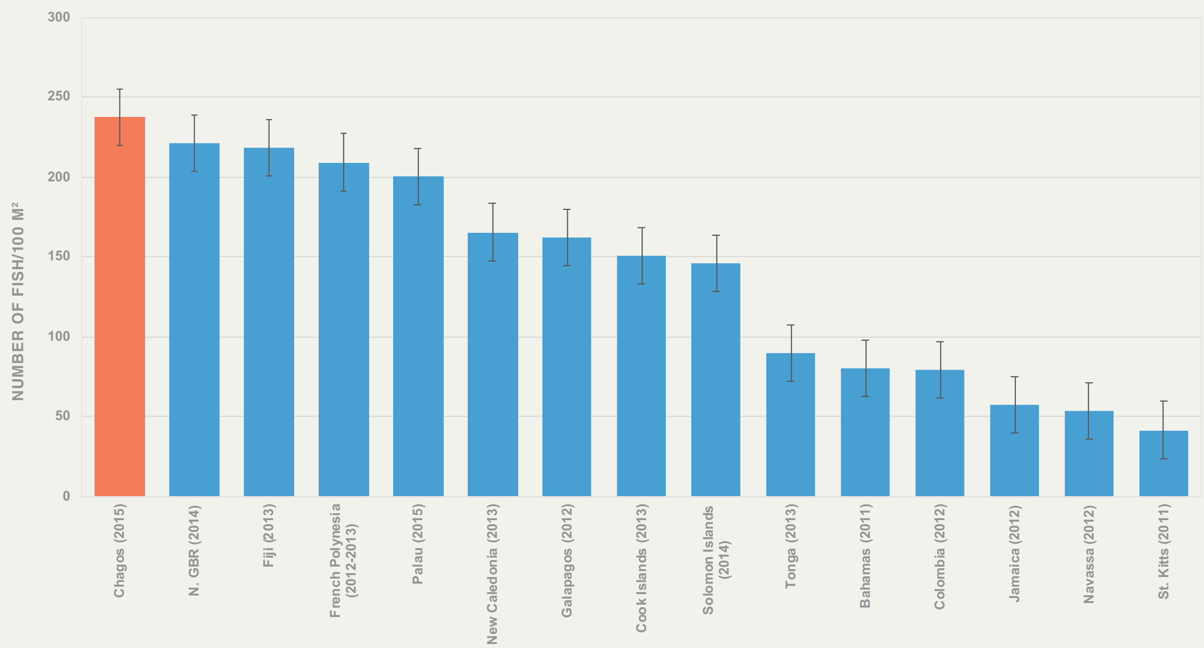


Figure 22

GLOBAL COMPARISON OF FISH DENSITY (NUMBER. OF FISH/100 M²) AMONG COUNTRIES VISITED ON THE GRE.



DISCUSSION

topographic shallowing, particularly around Victory Bank, Salomon Island, and Great Chagos Bank[40]. High chlorophyll-*a* levels indicate an area with high productivity and can lead to fish aggregations such as what was observed at Victory Bank[6,41].

Based on both the benthic and fish surveys, Victory Bank was one of the most interesting locations studied. The most striking pattern at Victory Bank was that on average, there were larger, more abundant fish populations with a much higher overall biomass, especially of fish in the higher trophic categories. This difference compared to other locations of the Chagos Archipelago could be due in part to large schools of fish, particularly snappers, crossing within the belt transects at this location. At Victory Bank, large schools of *Lutjanus gibbus* and *Macolor niger* were particularly common and contributed heavily to the high fish density and biomass in the 4.0-4.5 trophic category. As many of these schools contained individuals >50 cm in total length, the size-frequency of larger fish in the analyses presented here are likely an underestimate at this location.

The benthic community of Victory Bank was also noteworthy. There was one lagoon site where *Heliopora* spp. accounted for 77% of the total coral recorded and was the most concentrated stand of this coral genus observed in the Chagos Archipelago. A recent study showed that *Heliopora* spp. may be better adapted to warmer water and will allocate energy to promote rapid growth and spatial extension[42]. With more frequent bleaching events observed in Chagos, the *Heliopora* spp. at this site may be better adapted for growth and surviving these bleaching disturbances. There was also higher *Millepora* spp. cover at Victory Bank, particularly on the forereef which was unlike any other locations surveyed. *Millepora* spp. is considered a weedy coral that can quickly grow and out-compete other coral species, particularly after a disturbance[43]. It is possible that previous unrecorded bleaching or crown-of-thorns starfish outbreak disturbances, in combination with the higher productivity, may have allowed this coral to dominate the reef. It is worth noting that *Heliopora* and *Millepora* are not true Scleractinian corals; however, they both deposit aragonite skeletons adding to the overall reef accretion.

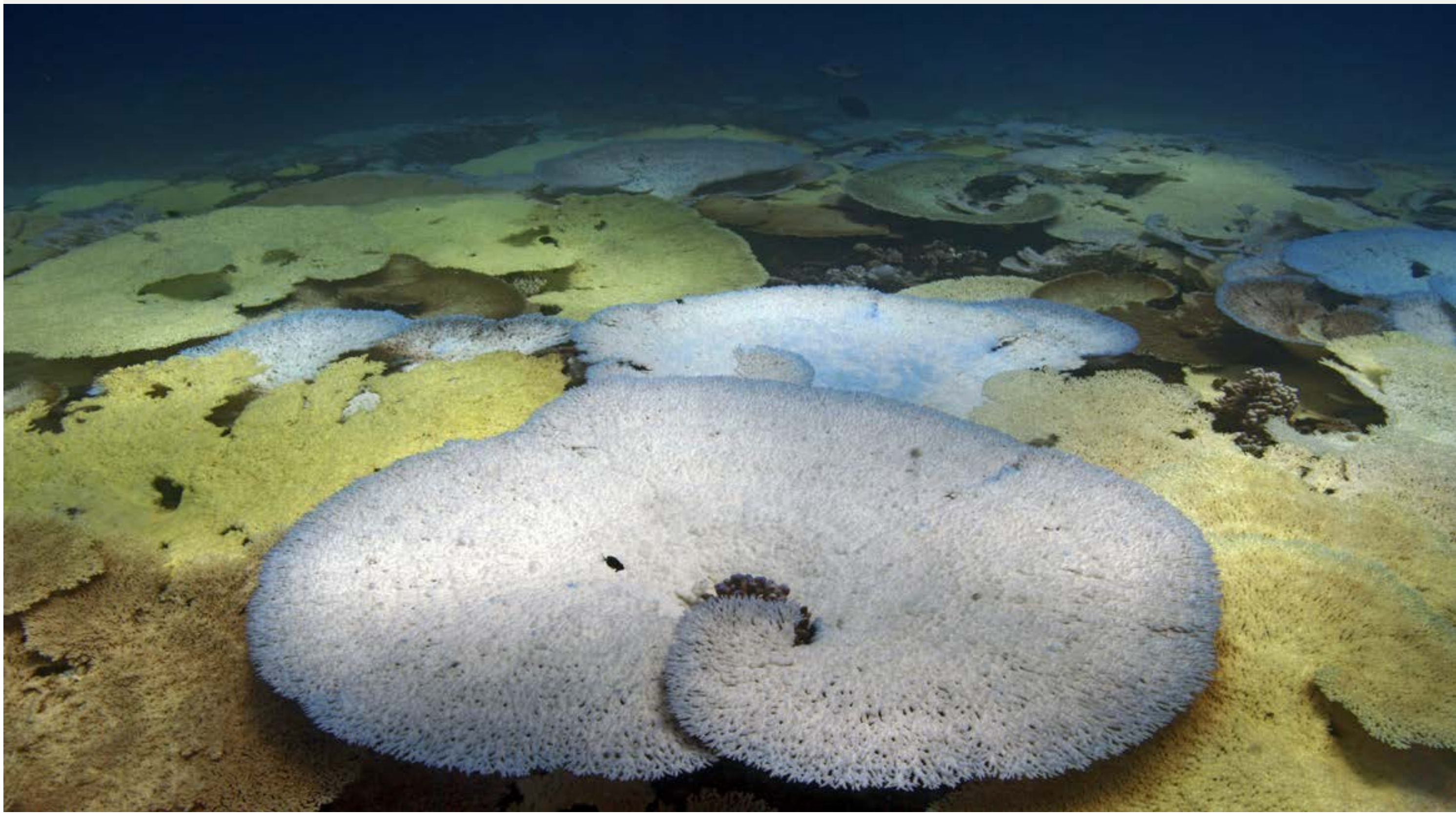
The **Chagos Archipelago** had the **highest fish density** and the **second highest fish biomass** of all reefs surveyed on the **Global Reef Expedition**.

Despite equivalent protection across the entire archipelago (except for Diego Garcia, which was not surveyed for this study), differences in the benthic and fish populations existed between locations. Besides localized upwelling, it is possible patterns of productivity may be linked to the presence of sea birds. For example, Graham et al.[44] found that islands in the Chagos Archipelago with invasive rat populations had smaller seabird populations. The lack of seabirds at rat-infested islands led to less productivity near these islands, as fewer nutrients from bird droppings were leached into the surrounding seawater. The fish populations at rat-free islands had 48% greater biomass than those at rat-infested islands, and fish were shown to grow faster, indicating that productivity can be a strong driver of fish population structure. In nearly all locations, our findings support the hypothesis presented by Graham et al. For example, Great Chagos Bank-West had the second-highest fish biomass and is also the location where some of the most sea birds were observed in the study. This indicates that the connection between bird presence and fish biomass is likely supported at this location. Additionally, in areas where bird presence was low, there was a lower fish biomass, such as what was observed at Salomon Islands. While the current study did not specifically analyze productivity at the locations surveyed, a combination of bird presence and oceanographic conditions may explain the variability of the benthic and reef fish communities recorded between survey locations.

Large-scale disturbances like coral bleaching have negatively impacted the coral communities of the Chagos Archipelago. Previous studies have shown that after the 1998 mass coral bleaching event, which caused widespread coral mortality across the Indian Ocean, fish populations in Chagos remained remarkably healthy when compared to even the best performing marine protected areas elsewhere in the Indian Ocean[4,7]. The locations surveyed during the second leg of the expedition (Peros Banhos, Blenheim, Salomon Islands, GCB-North, Victory Bank, and Speakers Bank) were surveyed in April 2015, which corresponded with the onset of a thermal stress event across the archipelago, leading to widespread coral mortality[45]. In 2017, coral cover was re-surveyed by Sheppard et al. and found only 5-15% live coral cover remained following this thermal stress event[1]. While the data from the KSLOF mission does not indicate that fish populations were affected at the time of the survey, coral mortality due to bleaching has been shown to affect species richness, abundance, and size structure of reef fish populations[21]. Therefore, comparing these results with more contemporary data from the same locations would give insight into whether fish populations in Chagos remain resilient to disturbances such as coral bleaching.

Continued conservation and long-term studies of the reefs of the Chagos Archipelago is imperative. These reefs may be some of the last in the world to be largely undisturbed by humans. Despite their remoteness, they are not protected from human-induced climate change. These reefs may play a critical role in understanding the ways shallow marine habitats adapt to ongoing disturbance events and may shed light on their resilience.

Figure 23 WHILE SURVEYING THE REEFS IN THE CHAGOS ARCHIPELAGO, KSLOF WITNESSED THE FIRST SIGNS OF THE MOST DAMAGING BLEACHING EVENT EVER RECORDED. THIS IMAGE TAKEN DURING THE EXPEDITION DEPICTS THE EXPANSE OF THE BLEACHING, AS NEARLY EVERY CORAL IN THE IMAGE SHOWS SIGNS OF BLEACHING. STUDIES AFTER THE BLEACHING EVENT SHOWED LIVE CORAL COVER FELL FROM 31-52% TO ONLY 5-15%[1].



ACKNOWLEDGMENTS

The Global Reef Expedition research mission to the Chagos Archipelago would not have been possible without the leadership, vision, and generosity of His Royal Highness Prince Khaled bin Sultan. We are deeply appreciative of his financial support and for the generous use of his research vessel, the M/Y *Golden Shadow*.

The Khaled bin Sultan Living Oceans Foundation would like to express our thanks to Mr. Tom Moody of the British Indian Ocean Territory (BIOT) Administration for granting us permission to sample and study the reefs of the Chagos Archipelago. KSLOF would like to especially thank Dr. Charles Sheppard for his invaluable knowledge and for reviewing this report.

The research mission to the Chagos Archipelago would not have been possible without the leadership, vision, and generosity of His Royal Highness Prince Khaled bin Sultan. We are 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 the Chagos Archipelago through the involvement and partnerships by scientists from the following countries: the United States of America, Australia, Germany, the United Kingdom, Portugal, the Philippines, and Taiwan.

The Khaled bin Sultan Living Oceans Foundation appreciates the skill and dedication of the scientific divers who aided in the collection of vital data for the Foundation, especially our international partners from Nova Southeastern University, University of the Philippines, University of the Azores, University of Miami, the National Oceanic and Atmospheric Administration (NOAA), University of Wellington, Florida Museum of Natural History, the Atlantic and Gulf Rapid Reef Assessment (AGRRA) Program, and the National Museum of Marine Biology and Aquarium, Taiwan. The Foundation is particularly grateful for the dedicated efforts of each scientist and would like to thank each of you for your contributions, especially the detailed data you gathered.

The research mission to the Chagos Archipelago benefited from the hard work of the Captain, 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, we are immensely grateful.

We look forward to continuing these partnerships to ensure the information and data from this project are applied toward the conservation needs for the BIOT Marine Protected Area.

Thank you to Prince Khaled bin Sultan, esteemed scientists, and crew of the M/Y *Golden Shadow* for making this research mission a success.

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APPENDIX 1 | DIVE SITES AND SITE DESCRIPTIONS

Location	Exposure	Latitude	Longitude	Reef Type	Reef Location	Lagoon	Emergent/ Submerged	Site
Blenheim	Intermediate	-5.25432	72.45724	Fringing Reef	Fore Reef	Outside	Submerged	BIBL82
Blenheim	Exposed	-5.21858	72.49256	Fringing Reef	Fore Reef	Outside	Submerged	BIBL83
Blenheim	Intermediate	-5.17795	72.45708	Fringing Reef	Fore Reef	Outside	Submerged	BIBL86
Blenheim	Intermediate	-5.23198	72.44305	Fringing Reef	Fore Reef	Outside	Submerged	BIBL87
Egmont	Exposed	-6.66706	71.39087	Fringing Reef	Fore Reef	Outside	Submerged	BIEG02
Egmont	Protected	-6.69394	71.37862	Fringing Reef	Fore Reef	Outside	Submerged	BIEG03
Egmont	Exposed	-6.64751	71.36836	Fringing Reef	Fore Reef	Outside	Submerged	BIEG04
Egmont	Intermediate	-6.64248	71.31116	Fringing Reef	Fore Reef	Outside	Submerged	BIEG05
Egmont	Protected	-6.63941	71.33949	Patch Reef	Lagoonal	Inside	Submerged	BIEG06
Egmont	Protected	-6.66732	71.36813	Patch Reef	Lagoonal	Inside	Submerged	BIEG07
GCB- North	Protected	-5.7059	72.32407	Patch Reef	Lagoonal	Inside	Submerged	BINI77
GCB- North	Protected	-5.68049	72.38146	Back Reef	Lagoonal	Inside	Submerged	BINI78
GCB- North	Protected	-5.68903	72.32247	Back Reef	Lagoonal	Inside	Emergent	BINI79
GCB- North	Protected	-5.71253	72.04568	Back Reef	Fore Reef	Outside	Submerged	BINI80
GCB- West	Intermediate	-6.18385	71.64028	Back Reef	Fore Reef	Outside	Submerged	BICC35
GCB- West	Intermediate	-6.23205	71.58827	Back Reef	Fore Reef	Outside	Submerged	BICC36
GCB- West	Intermediate	-6.39945	71.61726	Patch Reef	Lagoonal	Inside	Submerged	BICC50
GCB- West	Intermediate	-6.30018	71.56963	Patch Reef	Lagoonal	Inside	Submerged	BICC51
GCB- West	Protected	-6.39417	71.23412	Fringing Reef	Fore Reef	Outside	Submerged	BIDI08
GCB- West	Protected	-6.37934	71.23359	Fringing Reef	Fore Reef	Outside	Submerged	BIDI09
GCB- West	Exposed	-6.39078	71.24618	Back Reef	Lagoonal	Inside	Submerged	BIDI10
GCB- West	Intermediate	-6.48727	71.29902	Back Reef	Fore Reef	Outside	Submerged	BIDI11
GCB- West	Protected	-6.4534	71.2337	Back Reef	Fore Reef	Outside	Submerged	BIDI12
GCB- West	Protected	-6.46106	71.24386	Back Reef	Fore Reef	Outside	Submerged	BIDI13
GCB- West	Protected	-6.40987	71.25622	Patch Reef	Lagoonal	Inside	Submerged	BIDI14
GCB- West	Protected	-6.3531	71.2358	Back Reef	Fore Reef	Outside	Submerged	BIDI15
GCB- West	Protected	-6.34088	71.25667	Back Reef	Lagoonal	Inside	Submerged	BIDI16
GCB- West	Protected	-6.18099	71.34828	Fringing Reef	Lagoonal	Inside	Emergent	BIEA17
GCB- West	Exposed	-6.2024	71.4042	Back Reef	Fore Reef	Outside	Submerged	BIEA18

Location	Exposure	Latitude	Longitude	Reef Type	Reef Location	Lagoon	Emergent/ Submerged	Site
GCB- West	Protected	-6.202	71.3588	Back Reef	Lagoonal	Inside	Submerged	BIEA19
GCB- West	Exposed	-6.1899	71.3633	Back Reef	Fore Reef	Outside	Submerged	BIEA20
GCB- West	Intermediate	-6.27659	71.27627	Back Reef	Fore Reef	Outside	Submerged	BIEA22
GCB- West	Intermediate	-6.24221	71.29063	Fringing Reef	Fore Reef	Outside	Emergent	BIEA23
GCB- West	Intermediate	-6.20961	71.30426	Fringing Reef	Fore Reef	Outside	Emergent	BIEA24
GCB- West	Intermediate	-6.19072	71.31839	Fringing Reef	Fore Reef	Outside	Emergent	BIEA25
GCB- West	Intermediate	-6.17221	71.33191	Fringing Reef	Fore Reef	Outside	Emergent	BIEA26
GCB- West	Protected	-6.19878	71.4931	Back Reef	Lagoonal	Inside	Submerged	BIEA52
GCB- West	Intermediate	-6.15622	71.50993	Fringing Reef	Fore Reef	Outside	Emergent	BITB27
GCB- West	Intermediate	-6.1384	71.5091	Channel Reef	Fore Reef	Channel	Emergent	BITB28
GCB- West	Intermediate	-6.13459	71.49796	Fringing Reef	Fore Reef	Outside	Emergent	BITB29
GCB- West	Protected	-6.16396	71.53207	Fringing Reef	Lagoonal	Inside	Emergent	BITB30
GCB- West	Protected	-6.17152	71.5934	Back Reef	Lagoonal	Inside	Submerged	BITB32
GCB- West	Protected	-6.1793	71.58126	Back Reef	Lagoonal	Inside	Submerged	BITB33
GCB- West	Protected	-6.16935	71.54637	Fringing Reef	Lagoonal	Inside	Emergent	BITB34
GCB- West	Exposed	-6.17699	71.54402	Fringing Reef	Fore Reef	Outside	Emergent	BITB37
GCB- West	Protected	-6.16828	71.54042	Back Reef	Lagoonal	Inside	Emergent	BITB38
GCB- West	Intermediate	-6.17145	71.53494	Fringing Reef	Fore Reef	Outside	Emergent	BITB39
GCB- West	Intermediate	-6.14811	71.52852	Channel Reef	Lagoonal	Channel	Emergent	BITB40
GCB- West	Intermediate	-6.02997	71.549	Back Reef	Fore Reef	Outside	Submerged	BITB41
GCB- West	Intermediate	-6.05761	71.52129	Back Reef	Fore Reef	Outside	Submerged	BITB42
GCB- West	Intermediate	-6.10527	71.49875	Back Reef	Fore Reef	Outside	Submerged	BITB43
GCB- West	Protected	-6.03978	71.55077	Back Reef	Lagoonal	Inside	Submerged	BITB44
GCB- West	Protected	-6.05076	71.53503	Back Reef	Lagoonal	Inside	Submerged	BITB45
GCB- West	Protected	-6.0961	71.5143	Back Reef	Lagoonal	Inside	Submerged	BITB46
GCB- West	Protected	-6.02659	71.61644	Patch Reef	Lagoonal	Inside	Submerged	BITB47
GCB- West	Intermediate	-6.06785	71.67516	Patch Reef	Lagoonal	Inside	Submerged	BITB48
GCB- West	Intermediate	-6.1103	71.6547	Patch Reef	Lagoonal	Inside	Submerged	BITB49
GCB- West	Intermediate	-6.12684	71.50318	Fringing Reef	Lagoonal	Inside	Submerged	BITB53

APPENDIX 1 | DIVE SITES AND SITE DESCRIPTIONS

Location	Exposure	Latitude	Longitude	Reef Type	Reef Location	Lagoon	Emergent/ Submerged	Site
GCB- West	Intermediate	-6.16601	71.52676	Channel Reef	Fore Reef	Outside	Submerged	BITB54
GCB- West	Intermediate	-6.17526	71.53974	Fringing Reef	Fore Reef	Outside	Emergent	BITB55
GCB- West	Protected	-6.18566	71.56613	Back Reef	Lagoonal	Inside	Submerged	BITB56
GCB- West	Protected	-6.15979	71.5271	Channel Reef	Lagoonal	Channel	Submerged	BITB57
GCB- West	Protected	-6.1479	71.52411	Channel Reef	Lagoonal	Channel	Submerged	BITB58
Peros Banhos	Protected	-5.31748	71.9224	Patch Reef	Lagoonal	Inside	Submerged	BIPB110
Peros Banhos	Exposed	-5.2373	71.962	Fringing Reef	Fore Reef	Outside	Emergent	BIPB112
Peros Banhos	Exposed	-5.25724	71.97576	Fringing Reef	Fore Reef	Outside	Emergent	BIPB114
Peros Banhos	Intermediate	-5.44336	71.74987	Fringing Reef	Fore Reef	Outside	Emergent	BIPB60
Peros Banhos	Intermediate	-5.39123	71.74974	Channel Reef	Fore Reef	Channel	Emergent	BIPB61
Peros Banhos	Protected	-5.42721	71.77779	Patch Reef	Lagoonal	Inside	Submerged	BIPB62
Peros Banhos	Protected	-5.41518	71.77499	Patch Reef	Lagoonal	Inside	Submerged	BIPB63
Peros Banhos	Intermediate	-5.46244	71.82438	Fringing Reef	Fore Reef	Outside	Emergent	BIPB64
Peros Banhos	Protected	-5.41077	71.80349	Patch Reef	Lagoonal	Inside	Submerged	BIPB65
Peros Banhos	Intermediate	-5.3813	71.7518	Channel Reef	Fore Reef	Channel	Emergent	BIPB66
Peros Banhos	Intermediate	-5.28098	71.73499	Fringing Reef	Fore Reef	Outside	Emergent	BIPB67
Peros Banhos	Protected	-5.2563	71.76861	Fringing Reef	Lagoonal	Inside	Emergent	BIPB68
Peros Banhos	Protected	-5.29642	71.76703	Patch Reef	Lagoonal	Inside	Submerged	BIPB69
Peros Banhos	Protected	-5.32515	71.85739	Patch Reef	Lagoonal	Inside	Submerged	BIPB70
Peros Banhos	Protected	-5.25511	71.81393	Channel Reef	Lagoonal	Channel	Emergent	BIPB71
Peros Banhos	Protected	-5.27607	71.88663	Pinnacle Reef	Lagoonal	Inside	Emergent	BIPB72
Peros Banhos	Exposed	-5.26732	71.88862	Fringing Reef	Fore Reef	Outside	Emergent	BIPB73
Peros Banhos	Protected	-5.26106	71.95179	Patch Reef	Lagoonal	Inside	Submerged	BIPB74
Peros Banhos	Exposed	-5.305	71.97903	Fringing Reef	Fore Reef	Outside	Emergent	BIPB75
Peros Banhos	Exposed	-5.33774	71.98058	Fringing Reef	Fore Reef	Outside	Emergent	BIPB76
Salomons Island	Exposed	-5.36938	72.21379	Fringing Reef	Fore Reef	Outside	Emergent	BISA102
Salomons Island	Exposed	-5.34896	72.26869	Fringing Reef	Fore Reef	Outside	Emergent	BISA103
Salomons Island	Exposed	-5.30829	72.26865	Fringing Reef	Fore Reef	Outside	Emergent	BISA104

Location	Exposure	Latitude	Longitude	Reef Type	Reef Location	Lagoon	Emergent/ Submerged	Site
Salomons Island	Protected	-5.33426	72.24311	Patch Reef	Lagoonal	Inside	Submerged	BISA105
Salomons Island	Protected	-5.34425	72.2039	Fringing Reef	Fore Reef	Outside	Submerged	BISA106
Salomons Island	Exposed	-5.31024	72.26888	Fringing Reef	Fore Reef	Outside	Emergent	BISA107
Salomons Island	Intermediate	-5.3173	72.22408	Fringing Reef	Fore Reef	Outside	Emergent	BISA84
Salomons Island	Protected	-5.33932	72.23605	Patch Reef	Lagoonal	Inside	Submerged	BISA88
Salomons Island	Protected	-5.33965	72.26332	Back Reef	Lagoonal	Inside	Emergent	BISA91
Salomons Island	Exposed	-5.32886	72.28001	Fringing Reef	Fore Reef	Outside	Emergent	BISA92
Salomons Island	Exposed	-5.29926	72.25788	Fringing Reef	Fore Reef	Outside	Emergent	BISA93
Salomons Island	Protected	-5.35038	72.22001	Patch Reef	Lagoonal	Inside	Submerged	BISA94
Salomons Island	Protected	-5.31676	72.23729	Channel Reef	Lagoonal	Channel	Submerged	BISA97
Salomons Island	Intermediate	-5.32422	72.21898	Fringing Reef	Fore Reef	Outside	Emergent	BISA98
Speakers Back	Intermediate	-4.78432	72.34454	Back Reef	Fore Reef	Outside	Submerged	BISP100
Speakers Back	Protected	-4.7925	72.34557	Back Reef	Lagoonal	Inside	Submerged	BISP101
Speakers Back	Protected	-4.91949	72.43696	Back Reef	Lagoonal	Inside	Submerged	BISP115
Speakers Back	Protected	-4.95175	72.38296	Patch Reef	Lagoonal	Inside	Submerged	BISP89
Speakers Back	Protected	-4.95045	72.41215	Back Reef	Lagoonal	Inside	Submerged	BISP90
Speakers Back	Protected	-5.04994	72.28725	Patch Reef	Lagoonal	Inside	Submerged	BISP95
Speakers Back	Intermediate	-4.96593	72.23623	Back Reef	Fore Reef	Outside	Submerged	BISP96
Victory Back	Protected	-5.52648	72.22646	Back Reef	Lagoonal	Inside	Submerged	BIVB108
Victory Back	Protected	-5.54759	72.21877	Back Reef	Fore Reef	Outside	Submerged	BIVB109
Victory Back	Protected	-5.53439	72.21585	Back Reef	Lagoonal	Inside	Submerged	BIVB81
Victory Back	Protected	-5.53102	72.24508	Patch Reef	Lagoonal	Inside	Submerged	BIVB99

APPENDIX 2 | PARTICIPANT LIST

Participant	Institution	Function
Alex Dempsey, M.S.	Khaled bin Sultan Living Oceans Foundation	Director of Science Management
Renee Carlton, M.P.S.	University of Miami/NOAA	Marine Ecologist, Benthic assessments
Sam Purkis, Ph.D.	Nova Southeastern University (NCRI)	Coral Reef geologist
Bernhard Riegl, Ph.D.	Nova Southeastern University (NCRI)	Coral Reef biologist
Steve Saul, Ph.D.	Nova Southeastern University (NCRI)	KSLOF Fellow, Habitat mapping
Luis Ramirez	Nova Southeastern University (NCRI)	Ph.D. Candidate, Habitat mapping
Samantha Clements	Scripps Institution of Oceanography	Benthic assessments
Ken Marks	Atlantic and Gulf Rapid Reef Assessment	Coral reef photo-transects
Badi Samaniego	University of Philippines	KSLOF Fellow, Fish surveys
Anderson Mayfield, Ph.D.	National Museum of Marine Biology and Aquarium, Taiwan	KSLOF Fellow, Post Doc, Coral health
Kristin Stolberg, M.S.	University of Queensland	Coral assessments
Derek Manzello, Ph.D.	University of Miami/NOAA	Ocean acidification
Lauren Valentino	University of Miami/NOAA	Ocean acidification
Stefan Andrews	Rolex Fellow	Reef fish surveys
Gideon Butler	Scripps Institution of Oceanography	Benthic assessments
Katie Lubarsky	University of Hawaii	Fish assessments
Kate Fraser, M.S.	Independent Contractor	Fish assessments
Chris Mirbach, Ph.D.	James Cook University	Fish assessments
Carly Reeves. M.S.	Independent Contractor	Coral surveys
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NOTES

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