Mapping, characterizing and assessing the composition, health and resilience of Galápagos coral reefs

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Field Report

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Front cover: Large colony of *Porites lobata* off Wolf Island. Photo by Joshua Feingold.

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All research was performed under Permiso de Investigación Cientifica PC-07-12 (No. 0059922) issued by the Parque Nacional Galápagos, Ecuador on 28/05/2012. No animals were killed or injured during the execution of the project, and no injured or dead marine mammals or turtles were observed. No oil spills occurred from the M/Y Golden Shadow or any of the support vessels, and oil slicks were not observed.

The information in this Field Report is submitted to fulfill the requirements of the *Reporte Inicial*, as identified in the *Permiso de Investigación Cientifica*. Information presented in the report summarizes the activities conducted during the Galapagos research mission and general trends and observations. Data sets have not been fully analyzed or finalized as of the writing of this report. The Living Oceans Foundation cannot accept any legal responsibility or liability for any errors.

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SUMMARY

Between June 1-16, 2012, a multidisciplinary research team from the Khaled bin Sultan Living Oceans Foundation (KSLOF), University of Miami, University of the Virgin Islands, Pennsylvania State University, Nova Southeastern University National Coral Reef Institute, the National Oceanic and Atmospherics' AOML, Instituto NAZCA de Investigaciones Marinas, and the Galápagos National Park conducted groundtruthing, detailed SCUBA assessments, physio-chemical sampling, and biological sampling of corals and their symbionts within coral reefs and coral communities located in the Galápagos. All research was staged from the M/Y Golden Shadow, a 67 m research vessel, with use of small catamarans and tenders to access the sites. The main targets were Darwin and Wolf Island coral reefs, with additional assessments and research on coral communities surrounding Marchena, Floreana, Santa Cruz/Baltra, San Cristóbal, Isabela and Urvina (Fig. 1). The research provides information on: a) the spatial distribution and extent of different shallow marine communities and detailed coral zonation patterns within these communities; b) population dynamics of corals and reef fishes within these communities; c) the current status, health and resilience of coral ecosystems; d) patterns of recovery from past ENSO disturbances; and e) specific factors and processes contributing to the stability, resilience and expansion of these communities.

The research team conducted work within 23 sites, spending a total of 411 hours under water and conducted groundtruthing over a total area of 750 km^2. The groundtruthing team surveyed shallow marine habitats off seven islands, collecting 295 drop camera videos and 1,258,413 bathymetric readings. SCUBA assessments and underwater research was conducted off eight islands in 23 different locations.

Coral assessments included 54 quantitative belt transects completed off 5 islands, population surveys using quadrats in six locations, multiple phototransects, and additional roving coral surveys within coral communities off seven islands. Recorded measurements for corals included species, size (width and height), extent of partial mortality and cause of mortality, if it could be determined. Twenty two species of corals were observed, although many species were identified from a single location. Massive colonies of *Porites lobata*, *Pavona clavus* and branching *Pocillopora damicornis* were the dominant taxa, although *Pocillopora* colonies in general have declined substantially since the 1980s and were absent or extremely rare in many locations where they once formed large build-ups. Large aggregations of *Pavona varians*, *P. gigantea*, *Psammocora stellata* and *Diaseris distorta* were also identified in one or two locations. Concurrently, point intercept surveys were completed in each location to measure living cover of corals, other invertebrates and algae, and to quantify the type and amount of each substrate (sand, coral, hardground, rubble). Fish size (total length) and abundance for ecologically and commercially-important species was characterized within 146 belt transects and were conducted in 23 locations. A total of 154 species of reef fish were recorded during roving surveys.

Clonal plots (each 15 m radius) were completed in 5 locations to determine the genetic structure of *Porites lobata* (Marchena, Wolf, Darwin, Urvina) and *Pocillopora damicornis* (Concha y Perla). In total, 253 *Porites lobata* and 144 *Pocillopora damicornis* samples were collected for genetic characterization. Small tissue samples were also collected from *P. damicornis* in seven locations (n=103 colonies) to assess the symbiont diversity; an additional 65 *Pavona clavus*, 53 *Pavona gigantea* and 30 *Psammocora stellata* samples were also collected for symbiont characterization. An unusually high prevalence of pink spots, blotches and lesions were documented among massive *Porites lobata* colonies on both Darwin and Wolf. Samples of six colonies with different types of pink lesions were taken in each location for histological examination of tissue changes and to identify the possible cause.

Rates of carbonate accretion will be estimated using reef cores (n=26) taken at various depths and from different sections of the reef (top, middle and base) at Darwin. Coral rubble (n=24) was also collected at Darwin to characterize rates of cementation and dissolution of calcium carbonate. In addition, coral growth rates will be estimated for *Pavona gigantea, Porites lobata*, and *Pavona clavus* from cores of living colonies (n=30 cores per site for each species) collected at Darwin, Wolf, Marchena, Floreana (*Pavona* only), Urvina (*Porites* only), Isabela (*Pavona* only), Champion, and Devil's Crown. Invertebrates were also collected using scavenger traps (21) deployed for one night at Concha y Perla Lagoon.

Numerous oceanographic measurements and sensors were deployed within coral communities and in surrounding deep water habitats to collect data on water temperatures, salinity, pH, light levels and current patterns. This included long-term monitoring of water temperature using Hobo temperature meters, and short term (24-96 hour) deployments of current meters, light meters, thermister strings and a pH sensor, as well as multiple CTD casts and CO_2 measurements.

In addition to the research program, video footage was obtained of the research and associated fauna, flora and geomorphology at various sites five days prior to the research mission and during Marchena, Wolf and Darwin (see separate report); a hard drive containing all video imagery was provided to the GNP on June 15, 2012. Education and outreach activities included a live presentation for elementary and high school audiences from Wolf Island and a World Ocean Day broadcast from Darwin Island in conjunction with Dr. Sylvia Earle at the Smithsonian Institution in Washington DC. These presentations are available on line at www.livingoceansfoundation.org.

Background and justification

The Galápagos is an isolated archipelago of volcanic islands that straddle the equator, about 1000 km (620 miles) off the coast of Ecuador, in the Eastern Pacific Ocean. There are 14 main islands and over 100 small islets that sit on a deep platform and are surrounded by deep (2000-4000 m) water. Shallow waters adjacent to the islands support large populations of marine mammals, turtles, cartilaginous fishes and bony fishes, as well as hundreds of species of invertebrates and diverse algal communities. One of the key groups of invertebrates present throughout much of the archipelago is the stony (scleractinian) corals.

Scleractinian corals in the Galápagos are represented by characteristic eastern Pacific species, with no known endemics. They consist of many fewer species than found in the Caribbean and IndoPacific (22 in total) and form true coral reefs in only a single location, off Darwin Island Hoeksema 1989, Veron 1992,1993, Glynn and Alt 2000). In other locations, the coral communities typically occur as scattered colonies, and rarely form carbonate build-ups. One of the reasons that coral reefs are less developed here is because the water temperatures at certain times of year are too cold to support coral growth. Water currents are responsible for the upwelling of cold water rich in nutrients and plankton, which provides the energy needed to support growth of plankton and algae, providing food for higher levels of the food chain, but it also affects the water chemistry. Upwelled water contains unusually high levels of carbon dioxide which can alter the pH and aragonite concentrations in shallow water, reducing the potential for calcification by corals and other organisms. Furthermore, the species and ecosystems undergo cyclical shifts that occur every 2-8 years in accordance with the strength of the El Niño Southern Oscillation (ENSO). During an ENSO event normal oceanic and atmospheric systems are disrupted, causing winds to shift to the east and changes in water currents, pushing warm water toward South America, increasing rainfall, and cutting off the supply of cold, nutrient rich water. The extreme variations in temperature and CO_2 both play a critical role in the survival and growth of corals.

In recent times, two ENSO events (1982-1983 and 1997-1998) have been particularly devastating for the marine environments in the Galápagos and around the globe. In the Galápagos, mass mortality of corals during 1982-1983 was followed by population explosions of sea urchins. Most of the corals died and the reef framework was bioeroded by urchins to rubble and sand (Glynn 1994, Reaka-Kudla et al 1996). Remarkably, the reef systems have shown unusually high resilience, progressively rebounding from this catastrophe. The 1997-1998 bleaching event was also associated with mass bleaching, but mortality was much more patchy, and some taxon (e.g. *Pocillopora*) that bleached and died during the 1982-1983 event showed only minimal bleaching during 1997-1998 (Feingold 1995).

Research conducted over the last decade suggests that Galápagos corals have now recovered to varying degrees. In the northern islands of Darwin and Wolf, coral cover has increased (Glynn et al. 2009). Coral communities in the central and southern archipelago have experienced some

recovery and some relapse (Feingold 2001, Feingold and Glynn 2008). Coral communities in the Galápagos Islands are now primarily formed by aggregations of the massive corals *Pavona* spp. and *Porites lobata.* Scattered colonies of the branching *Pocillopora* species occur in most locations, but *Pocillopora* build-ups that once were common now appear to be restricted to a single location (Bruckner, pers. obs). Unique assemblage of free-living fungiid corals and *Psammocora* sp. are also found at Devil's Crown (Feingold 1996) and a few other locations.

The Galápagos Archipelago is one of the best coral reef regions to understand the natural processes of resilience to climate perturbations, especially thermal stress and ocean acidification. High variability in marine climate, from tropical to temperate within kilometers, and the equatorial location in the Eastern Tropical Pacific (ETP) makes the Galápagos one of the most susceptible regions to the direct effects of the El Niño-Southern Oscillation (ENSO). Reefs and coral communities are affected frequently by cool conditions at the lower end of their tolerance limit, and by infrequent, periodic warm events that exceed their upper tolerance range. These events, combined with ocean warming associated with climate change, are predicted to worsen in the future. As a direct consequence of warming, coral bleaching and mortality may become more frequent and severe.

The diversity of corals and their symbionts, as well as the reproductive strategies of these corals are two key factors affecting their resilience to climate change. Corals are known to differ in their susceptibility to bleaching and temperature stress. Higher diversity of symbionts is believed to confer higher resistance and resilience of communities to temperature stress. By using newly-developed highly-sensitive methods to detect and quantify Symbiodinium in clade D (a clade which contains several thermotolerant types such as D1 and D1a), and comparing these results with collections made at different sites around the Galápagos in the past, it will be possible to assess whether differences in the abundance of these symbionts has contributed to the resilience and persistence of the reefs at Darwin Island (Banks et al. 2009). In addition, the contributions of asexual reproduction to population structure is known to vary across the range of the species (Baums et al. 2006) and populations in marginal habitats can have low clonal (genotypic) diversity. A comparison of the diversity of coral species and symbionts among sites with population structure and coral condition (e.g. partial and whole colony mortality) provides valuable information on the resistance and resilience of these communities to environmental stressors. By quantifying the clonal structure of *Porites* and *Pocillopora* sp. in the Galápagos Islands, it will be possible to determine the importance of asexual vs. sexual reproduction in maintenance of these populations and also the potential sources of sexual recruits.

Another factor that may enhance coral resilience is the occurrence of deep water refuges. One of the most promising habitats for a coral refuge are deeper coral communities (Glynn 1996; Bongaerts et al. 2010), where dimly lit, cool waters can mitigate the largest potential sources of stress leading to coral bleaching. Also, plankton rich depth zones, such as those associated with a chlorophyll max layer, could provide heterotrophic subsidies to bleached or stressed corals (e.g., Grottoli et al. 2006). In the ETP and Galápagos even moderately deep areas are dim,

influenced by a shallow and dynamic thermocline (Glynn and Wellington 1983), and are rich in plankton (Smith unpub. data). Such refuges have been shown to be important for maintaining susceptible species in the ETP (Glynn 2011), and facilitating resilience of these species between disturbances (Smith et al. 2011). An investigation of environmental gradients, particularly depth, in the distribution of these symbionts will also help identify potential refugia (e.g. deep water) that might help these symbionts persist at this site.

Recent work has shown that the Galápagos are bathed in seawater with abnormally high concentrations of dissolved carbon dioxide (CO_2) (Manzello et al. 2008, 2010b). Unusually high levels of CO_2 are known to suppress aragonite saturation states, which can affect the ability for corals to build skeletons and grow. This archipelago is located downstream from the Peruvian upwelling current, which brings deeper waters to the surface that have been enriched in CO_2 from the microbial breakdown of organic matter in the deep sea. Seawater in the Galápagos mimics what is expected for the entire tropics with an excess of double the pre-industrial levels of atmospheric CO2, the greenhouse gas responsible for global warming (Manzello et al. 2008), providing a window by which to view coral reef structure and function of the future. To better understand linkages between coral calcification and CO_2 levels, chemical, oceanographic and physical processes were evaluated through the use of deployed sensors, coring of massive corals, examination of carbonate matrices, and analysis of water chemistry.

Linkages between associated species and their biology and symbiotic associates, as well as a host of ecological processes (e.g. bioerosion, herbivory), natural stressors (disease, predation and bioerosion) and chemical, physical and environmental parameters further contribute to the overall resilience of coral reefs and coral communities. These topics were examined through detailed quantitative assessments of fish communities, coral population dynamics and health, invertebrate assessments and characterization of benthic community structure.

The overall goals of this project are to understand how well these environments are recovering, what factors enhance their recovery and what we can do make them more resilient to future disturbances. The research 1) contributes to long term monitoring of coral communities whose populations are known to be fluctuating; 2) identifies threats affecting these populations and resilience to cold-water upwelling, El Niño and climate-related disturbances; 3) provides new information on the spatial extent and zonation of these coral communities; and 4) expands the knowledge base for newly discovered coral communities.

Objectives

1) Create high resolution habitat maps of the coral reefs and coral communities in shallow water (0-25 m depth) throughout the archipelago;
2) Determine the distribution, abundance, cover, demographics and health the dominant coral species around Darwin and Wolf Islands;
3) Map the abundance and clustering of shallow water coral species in deeper habitats;
4) Assess the distribution, extent, diversity, population structure, and health of coral communities around the central and southern islands;
5) Determine the clonal structure of *Porites* spp. and *Pocillopora* spp. and the relative contribution of asexual reproduction to population maintenance;
6) Characterize of biological, physical and chemical properties of the water column;
7) Evaluate the effects of high-CO_2 seawater on coral growth rates and the fragility of these reefs to thermal stress;
8) Assess the age, growth and carbonate thickness of coral reefs;
9) Determine symbiont diversity and variation across hosts within a location, across similar host species in different geographic locations, and under different environmental conditions;
10) Evaluate relationships between photosynthetic efficiency and symbiont diversity;
11) Characterize the role of scavengers in bioerosion, nutrient cycling;
12) Evaluate biological and ecological resilience indicators including fish population dynamics, algal community structure, and patterns of herbivory.

The mapping program involved habitat characterization and mapping of the full extent of shallow marine habitats using WorldView2 multispectral satellite imagery as a platform. Detailed biological inventories, ecological characterizations, threat assessments, and physiochemical sampling were undertaken to determine the overall extent of recovery from past ENSO bleaching events, and identify biological, ecological and physiochemical factors that affect resilience of these ecosystems to future temperature stress. Through assessment of coral growth rates and amount of carbonate deposition, a more thorough understanding of the age and growth history of the reefs and extent of bioerosion will be determined for Darwin and Wolf Islands. Characterization of symbiont diversity, patterns of connectivity between deep water and shallow populations, and the contribution of asexual reproduction to population maintenance will allow predictions of future trends in reef health, as reefs continue to face increasingly adverse conditions as a result of climate change. This project will also allow further characterization of the status of unique coral assemblages found around the central and southern archipelago and patterns of recovery and decline, while contributing to long term monitoring of population fluctuations in these areas. Unique tools developed during this research, directly applicant to management, include detailed high resolution habitat maps that illustrate the spatial extent and distribution of different habitat types and provide detailed information on coral reef zonation (0-25 m depth). All data are being incorporated into a GIS database containing georeferenced satellite imagery, bathymetric maps, and habitat mapping and photographs.

Methods

1. Mapping and groundtruthing

Using multispectral satellite imagery obtained from DigitalGlobe WorldView2 satellite, high resolution bathymetric maps and habitat maps are being developed for shallow coral communities. Groundtruthing efforts necessary to develop these maps focused on continuous bathymetry measures, drop camera analysis, characterization of sediment and hard substrates and habitat features using two acoustic sub-bottom profiling equipment (Stratabox and Hydrobox) and fine scale photo-transect surveys.

An underwater video camera attached to a cable (referred to as a "drop-cam") was used to collect video footage on the benthic composition at each survey site. At each point, the drop-cam was deployed from the survey boat enabling it to 'fly' along the sea floor as it recorded video for 15 to 60 seconds. The video was recorded to hard-disk on a laptop aboard the survey vessel in real-time, and the geographic position, time, date, boat heading, and boat speed were also recorded and burned into the video. The geopositional data were acquired by a Garmin handheld GPS device with a horizontal accuracy of approximately ±5 m. Drop-cam deployment was limited to depths above 40 m due to the limited length of the tether cable (50 m). The acquired videos will be used in the creation of the benthic habitat maps by providing the necessary information for developing the habitat classification scheme and training of classification models.

Depth soundings were gathered along transects between survey sites using Hydrobox, a single-beam acoustic transducer, developed by Syqwest. The instrument emits 3 pings per second. Depths were estimated based on the time the return-pulse's reaches the sounder's head. The depth estimates were recorded by the Hydrobox software on a field laptop aboard the survey vessel. Geopositional data were simultaneously acquired by a dGPS unit and recorded in the bathymetric file. The soundings will be used to train a water-depth derivation model, which is based on the spectral attenuation of light in the water column, that will be applied to the satellite imagery. The final topographic map will have the same spatial resolution as the satellite imagery.

Profiles of the seafloor's sub-bottom were also gathered along transects using the Stratabox acoustic sounder, also developed by Syqwest. Similar to the bathymetric soundings, the sub-bottom profile emits an acoustic ping which reflects off the seafloor. However, the pulse has a lower frequency (3.5 Khz) enabling it to penetrate the seafloor. The instrument provides observations on stratal geometry beneath the seafloor along the transect lines, allowing estimates of Holocene reef-growth and sediment accumulation to be made. Geopositional data for each ping was simultaneously acquired by dGPS unit; it was recorded in the SEGY file. Profiles are typically run shore-perpendicular to capture the geometry of the bank flanks and span a depth range of 300 m to 5 m. Total transect length varies with the slope's angle; steeper slopes resulted in shorter transect lines.

2. Quantitative coral assessments

A combination of quantitative methods, including belt transects, radial plots and quadrats were used to assess corals, fish and other benthic organisms. Five measures were recorded for corals: 1) benthic cover; 2) coral diversity and abundance (by species); 3) coral size class distributions (by species); 4) recruitment; and 5) coral condition. Additional information was collected on causes of recent mortality, including

signs of coral disease and predation. For fish, data on abundance and size structure were collected along 2 m X 30 m belt transects for about 100 species of fishes, targeting species that have a major functional role on reefs or are major fisheries targets. Other indicators recorded along belt transects included large motile invertebrates (urchins, octopus, lobster, large crabs, sea cucumbers); cover and biomass of algae (fleshy macroalgae, turf algae and crustose coralline algae); and prevalence of nuisance species. Surveys of coral species composition, live cover, coral recruits (sexual and asexual), regeneration, and abundances of bioeroders conducted in 1992, 2000, 2002, 2006 and 2007 were repeated and new previously unexamined areas were characterized.

Sampling for corals smaller than 4 cm was done using a minimum of five 0.25 m^2 quadrats per transect, with each quadrat located at fixed, predetermined intervals (e.g. 2, 4, 6, 8, 10 m), alternating between right and left side of the transect. Recruits were identified in both point intercept surveys and belt transects. Recruits were divided into two categories: corals up to 2 cm diameter and larger corals, 2-3.9 cm diameter.

Visual estimates of tissue loss was recorded for each colony over 4 cm in diameter using a 1 m bar marked in 1 cm increments for scale,. If the coral exhibited tissue loss, estimates of the amount of remaining tissue, percent that recently died and percent that died long ago were made based on the entire colony surface. Tissue loss was categorized as recent mortality (occurring within the last 1-5 days), transitional mortality (filamentous green algae and diatom colonization, 6-30 days) and old mortality (>30 days). For each coral with partial or whole colony mortality, the cause of mortality was identified if possible. The diagnosis included an assessment of the type of disease, extent of bleaching, predation, competition, overgrowth or other cause of mortality. Each coral was first carefully examined to identify cryptic predators. Lesions were initially diagnosed into four categories: recent tissue loss, skeletal damage, color change, and unusual growth patterns; an individual colony could have multiple characteristics (e.g. color change and recent tissue loss). The location (apical, basal, medial) and pattern of tissue loss (linear, annular, focal, multifocal, and coalescing) was recorded and when possible a field name was assigned.

Cover of benthic organisms (plants and animals) was estimated using a point intercept method. At each site, a minimum of six 10 meter long transects were deployed. The organism and substrate type was recorded every ten cm for a total of 100 points per transect. Substrates included hardground, rubble, sand/silt, and dead coral. All corals were identified to species and recorded as live, bleached, recently dead or long dead. Invertebrates were identified to the lowest taxonomic level possible. Sponges, if present are differentiated into crustose, rope, massive, tube and barrel sponges, unless identification is possible. Algae were divided into five functional groups (fleshy macroalgae, erect coralline algae, crustose coralline algae, turf algae, cyanobacteria). Additional measurements of algal height were recorded for macroalgae.

Detailed species-specific surveys were conducted for *Pocillopora* colonies located off San Cristóbal, within the crater of Devil's Crown, and in Concha y Perla lagoon. All colonies were counted, photographed and assessed for tissue condition (live vs. dead, and normal, pale and bleached). Underwater photographs of each colony were taken with a scale bar placed adjacent to each colony for size. Surface area of live tissue will be calculated as a 2-dimensional projection of the digital photographic image using the program CPCe. Additional assessments of *Diaseris, Cycloseris* and

Psammocora populations were made at Devil's Crown using a combination of randomly located ½ x ½ m quadrats, phototransects, and/or visual observations. Because of the low abundance, all living *Cycloseris* individuals at Devil's Crown were counted and measured (length and width) with a plastic 25cm ruler to the nearest 0.5cm. These measurements will be converted to surface area using the formula for half an ellipsoid. Polyps will be assessed for tissue condition (live vs. dead, and normal/pale/bleached), and the presence or absence of any symbiotic organism.

A series of benthic surveys using digital video were conducted to assess the density, clustering and, extent of shallow water coral species at depths greater than 12 m, to a maximum depth of 30 m. At each station, surveys involved either circular plots, 15m in diameter, or belt transects. Analysis of the video will include measurements of each coral colony's species and size, and levels of partial mortality.

3. Fish assessments

On each reef two divers completed a minimum of six 30 X 2 m belt transects to assess the community structure of the dominant reef fish assemblages. All species were identified and their size was estimated to the nearest 5 cm using a T-bar marked in 5 cm increments for scale. The assessment focused on species that are ecologically relevant to the health of reefs and also important for commercial or recreational fisheries. The emphasis was on herbivores, invertebrate feeders and larger piscivores. Additional roving surveys were undertaken to characterize species diversity.

4. Oceanographic Measurements

A series of sensor deployments to assess temperature, light, and chlorophyll were undertaken around Darwin and Wolf Islands and off Isabela. Each deployment involved two vertical thermistor strings that record temperatures every 1 minute at 5 m depth intervals from 5 – 30 m. Each thermistor has 6 Star Oddi Data Storage Tags designed to be fast equilibrating to ambient temperature (<1 min.). In addition, one tag is capable of recording pressure (depth), important for capturing the influence of tidal dynamics on thermocline fluctuations. Strings were surface deployed and placed in areas of potentially contrasting thermal conditions (e.g., windward and lee). A systematic series of CTD casts using a calibrated Seabird 25 Conductivity-Temperature-Depth (CTD) probe was also conducted around Darwin, Wolf, Floreana and Isabela to examine the horizontal and vertical variability of the water column. The CTD measured temperature, salinity, dissolved oxygen, pH, turbidity, and chlorophyll (fluorometrically) profiles from 0-100 m depth. Onset Instruments Hobo Water Temp Pro v2 submersible temperature recorders deployed at the Devil's Crown study site in 2011 were retrieved and replaced with similar instruments. Two recorders were located outside the crater (15m depth) and two others are within the crater in shallow water (2m depth). Each recorder recorded temperature measurements every hour.

5. Coring of reef framework

The carbonate framework thickness of the reef at Darwin as estimated using a sub-bottom profiler and small-diameter (2 cm) push cores. Carbonate material was collected at the reef base/basalt interface and aged using C14 to determine vertical accretion rates.

6. Collection of invertebrates

Baited scavenger traps were deployed (60 traps total) to identify scavengers that facilitate the degradation of dead organisms and nutrient cycling. The original plan was to deploy these at Darwin reef on three separate occasions, but strong currents prevented deployment. Instead, a single deployment was undertaken at Concha y Perla lagoon.

7. Coral clonal structure

Coral surveys were paired with coral genetic sampling to assess levels of clonality, and possible connectivity between shallow and deep populations. The analysis of the clonal structure and symbiont diversity was conducted on *Porites* and *Pocillopora* corals located within the plots at Darwin, Wolf, Floreana and Isabela. A maximum of 30 individuals per taxon per plot, for a total of 90 individuals per taxon per island were sampled. Using a compass and a measuring tape secured to the center point of the circle, coordinates were located by a team of SCUBA divers. The colony underneath each coordinate was sampled using snippers to break off a small fragment of coral tissue (three to four polyps). An underwater photograph was taken of each colony sampled for future reference, and colony size was measured in three dimensions using maximum length, width, and height to the nearest 10 cm. All colonies within each 15 m radius circle were counted to determine density and maps were created by identifying the location of each colony sampled in relation to the center point. One 15m radius plot was completed by two divers per dive. Each sample consists of a very small fragment (3-4 polyps) of no more than 1 cm diameter. Fragments were placed in individual zip-lock bags underwater and then transferred to vials containing 95% ethanol on shore (making refrigeration in the field unnecessary).

DNA from coral tissue will be extracted for each sample following the manufacturer instructions in the DNeasy 96 Blood and Tissue Kit (Qiagen). *Porites* species identification will be achieved via six nuclear single copy sequencing markers (Hellberg et al. unpublished) including primers to ATPase-B (intron, 471 bp), MM32 (ORF - 391 bp), MM100 (ORF - 138 bp), MM271 (intron - 322 bp), Anon1 (non-coding - 337 bp). *Pocillopora* species identification will follow Pinzon and LaJeunesse (2010). Multilocus genotypes will be established for each *Porites* colony sampled using published microsatellite loci (Polato et al. 2010). Four multiplex and one singleplex 10µl polymerase chain reactions (PCR) will be performed for each Porites sample using fourteen primers. Each *Pocillopora* sample will also be genotyped using ten fluorescently labeled primers (Pinzon et al. in revision). Samples that have the same two alleles at all loci will be considered clone mates belonging to the same genet. Once individual genotypes are established, clonal diversity measures such as genotypic richness, genotypic diversity, and genotypic evenness will be calculated using the program GenClone (Arnaud-Haond & Belkhir 2007, Arnaud-Haond et al. 2007). Clone mapping and estimation of maximum clone size will also be performed with GenClone. Genotypic richness is directly proportional to frequency of sexual recruitment.

8. Characterization of symbiont diversity

DNA biopsies of reef corals were taken at select sites in the Galápagos (including at sites that were sampled in 1997, 1998 and 2006). Typical biopsies were $<0.5 cm^2$ in total surface area, and were removed from host colonies using pincers (branching colonies such as *Pocillopora*) or hollow steel punches (massive colonies such as *Porites*). While past efforts have successfully identified the dominant clades present in a host, the goal of this work is to identify all Symbiodinium clades, as some of the background

communities may play a key role in adaptation of these corals to thermal stress. New qPCR assays will be completed on these samples to detect and quantify Symbiodinium in clade D. The use of high-sensitivity molecular techniques allows the analysis of mixed symbiont communities and the detection of background symbiont communities. Quantitative PCR (qPCR) is a high-resolution technique used to detect background Symbiodinium populations at abundances 100-1,000 times lower than conventional techniques, and these tests have revealed the presence of background Symbiodinium within particular coral species. The application of quantitative methods will also be standardized to coral host DNA to allow, for the first time, an assessment of cell-specific densities of different symbiont taxa.

9. Ocean Acidification (OA)

Three to four seawater bottle samples (500 ml) were collected from each site visited to determine the carbonate chemistry of the water. A total of 24, 500 ml seawater samples were collected, totaling 12 liters. Seawater samples were preserved with 2 µl of saturated HgCl2 and sealed with large rubber bands to prevent any changes to the carbonate system before analysis. Total CO_2 (TCO_2) will be measured coulometrically and total alkalinity (TA) will be measured utilizing a gran titration. Measurement of TCO_2, TA and temperature allows calculation of the carbonate system of seawater (i.e., partial pressure of CO_2 (pCO_2), pH and Ω). During collection of each water sample, temperature was also measured using a hand-held temperature probe and an autonomous pH sensor was deployed off Wolf, Darwin, Floreana and Isabela for the duration of the visit to each site to determine the diel variability in seawater CO_2.

A total of 12 non-living, dead fragments of coral rubble (3-4 cm in maximum length and 2 cm in diameter) were collected from Darwin and Wolf Islands to assess levels of cementation and understand the CO_2 threshold where inorganic cement precipitation ceases. Cementation is the precipitation of secondary $CaCO_3$ that acts to bind framework components and occlude porosity (Perry and Hepburn 2008). These coral rubble pieces will be analyzed for determination of 1) carbonate cement types and abundances; 2) community composition and abundance of infaunal organisms; and 3) bulk skeletal density. The impetus for this work is to determine the Ωarag values where cement precipitation ceases and to test the working model that we have developed to explain the lack of cement at Ωarag values < 3. This will help determine levels of OA that may cause the breakdown of reef framework structures.

The rapid growth and calcification of scleractinian corals is responsible for the persistence of coral reefs through time. Alarmingly, the main reef-building coral species of the ETP, *Pocillopora damicornis*, has exhibited a 30 year decline in growth rate at the Uva Island Reef in Panamá, the Great Barrier Reef and Thailand (Manzello, 2010a). Research in the Galápagos will help determine whether or not the synchronous, inter-specific decline in coral calcification across the Indo-Pacific is the 'smoking gun' of ocean acidification. To do so, massive coral species (*P. lobata, P. clavus*, and *P. gigantea*) were cored to assess linear extension, bulk-density, and calcification using a micro-CT machine. Up to ten cores (approx. 3 cm in diameter and 7 cm in maximum length) per location of each species were obtained at Darwin and Wolf Islands, Baltra, Floreana and Urvina, to contrast growth rates in areas exposed to different environmental conditions. All core holes were filled with cement plugs and epoxy to aid tissue recovery of the parent colony. The rates of growth obtained herein will be compared to the rich history of growth studies across the ETP (see Manzello 2010a) and any trends will be verified from the coral cores of massive species.

Research Completed

The Expedition focused on coral reefs and coral communities surrounding 8 islands (Fig. 1) with 5 days devoted to work around Darwin Island, 2 days at Wolf Island, Floreana and Devil's Crown, and Isabela, and 1 day each at Marchena, Baltra, San Cristóbal and Urvina. A total of 23 sites were evaluated using SCUBA, with multiple dives conducted in most locations (Table 3). Coral reef-related research was conducted simultaneously at the same sites. Groundtruthing efforts were also conducted simultaneously over the surrounding areas from 0-30 m depth.

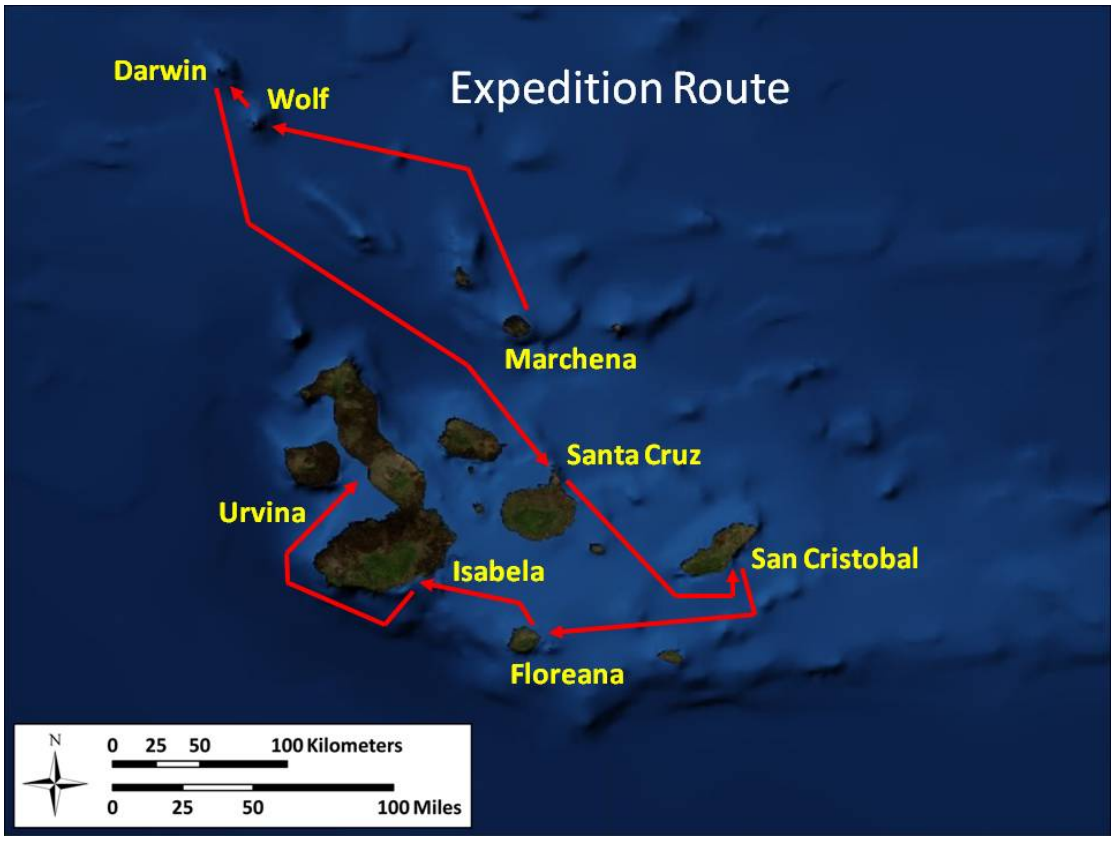

Fig. 1. Route taken by the Golden Shadow during the research mission.

Schedule

The research team departed on May 31 from Baltra for Marchena. The Shadow anchored off the north coast, with small boats deployed for research conducted at Marchena on June 1. At Wolf, the Shadow was unable to anchor; one day of diving operations and groundtruthing were conducted off small boats while the Shadow drifted. The Shadow relocated off Darwin on June 3-4 and then returned to Wolf on June 5 for a second day of work. An unsuccessful attempt was made to land the seaplane off Wolf Island. After completing work at Wolf, the Shadow returned to Darwin (June 6 -8). A single day of dive operations was completed in the Canal de Itabaca on June 9. Concurrently several team members departed and additional researchers joined the mission. A single dive was conducted off San Cristóbal on June 10. The groundtruthing team

was unable to complete their research at San Cristóbal and additional dive surveys were aborted due to rough seas. The Shadow relocated to Floreana on June 11 for 3 days of work around Devil's Crown, Floreana, and Champions. The Shadow relocated off Isabela on June 14. The team conducted multiple dives within Concha y Perla lagoon. Extensive snorkel surveys were made along the coastline to the north and south in attempt to locate former *Pocillopora* stands, but no live coral was found. Two dives were also made off Tortuga to verify the presence of *Pavona* stands. A few (n=3) isolated colonies were found in one location, with no coral was seen on the opposite side. The final day was used to survey coral areas off Urvina. All former *Pocillopora* stands were gone, with no recovery of this species. In shallow water close to shore, small aggregates of *Porites lobata* and isolated *Psammocora* colonies were identified and assessed. A single deeper dive on a hardground was conducted in search of coral; no scleractinian corals were found.

1. Aerial Overflight

The aerial overflight using the Golden Eye originally planned for 31, May, 2012 was not completed due to lack of permissions. A second attempt was made on 5-June, 2012 from Wolf Island. This was not completed because the plane was unable to land off Wolf due to rough sea conditions. A portion of the original proposed route was successfully evaluated on 9 June 2012. The seaplane flew from Baltra to San Cristóbal to obtain fuel, and then the coastal zone was examined off San Cristóbal, Floreana, Isabela and Urvina (Fig. 2). The remainder of the proposed route was not completed because of time limitations associated with airport closure.

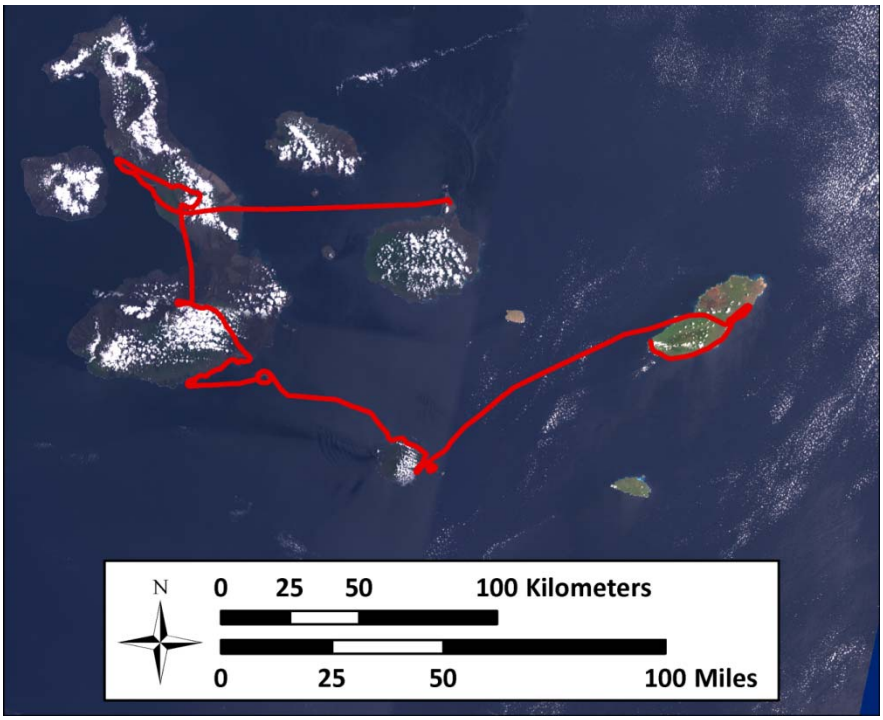

Fig. 2. Track of the Cessna 208 Caravan during our aerial overflight on June 9, 2012.

2. Groundtruthing and habitat mapping

A total of 750 sq. km WorldView 2 satellite imagery was acquired for 8 locations in the Galápagos Islands (Fig. 3; Table 1). Ground-truthing was conducted in 7 locations (Fig. 4-5). A total of 1,258,413 bathymetric reading were taken and 295 drop camera deployments were completed to characterize the habitats (Table 2). No groundtruthing data were collected off San Cristóbal due to high seas.

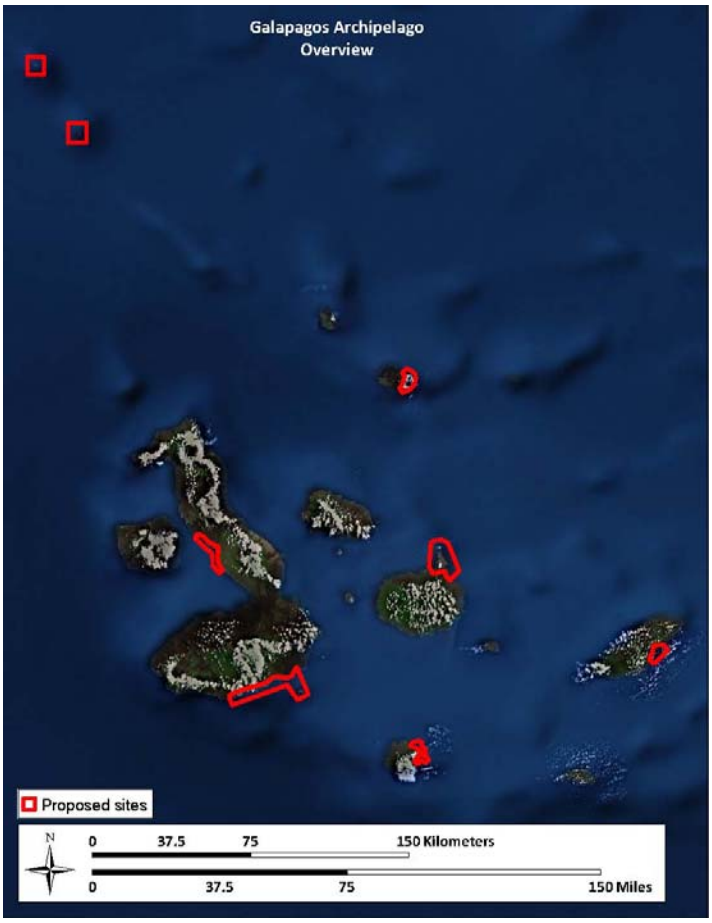

Fig. 3. Schematic illustration depicting polygons that were included in the acquisition of WorldView 2 multispectral satellite imagery.

Location	Site	Polygon area (sq km)
Galápagos	Isabela	220.50
	Floreana	40.82
	Marchena	52.97
	Santa Cruz	175.81
	Darwin	66.04
	Wolf	83.57
	Urvina	66.40
	San Cristóbal	44.67

Table. 1. Total area of imagery acquired for each location within the Galápagos.

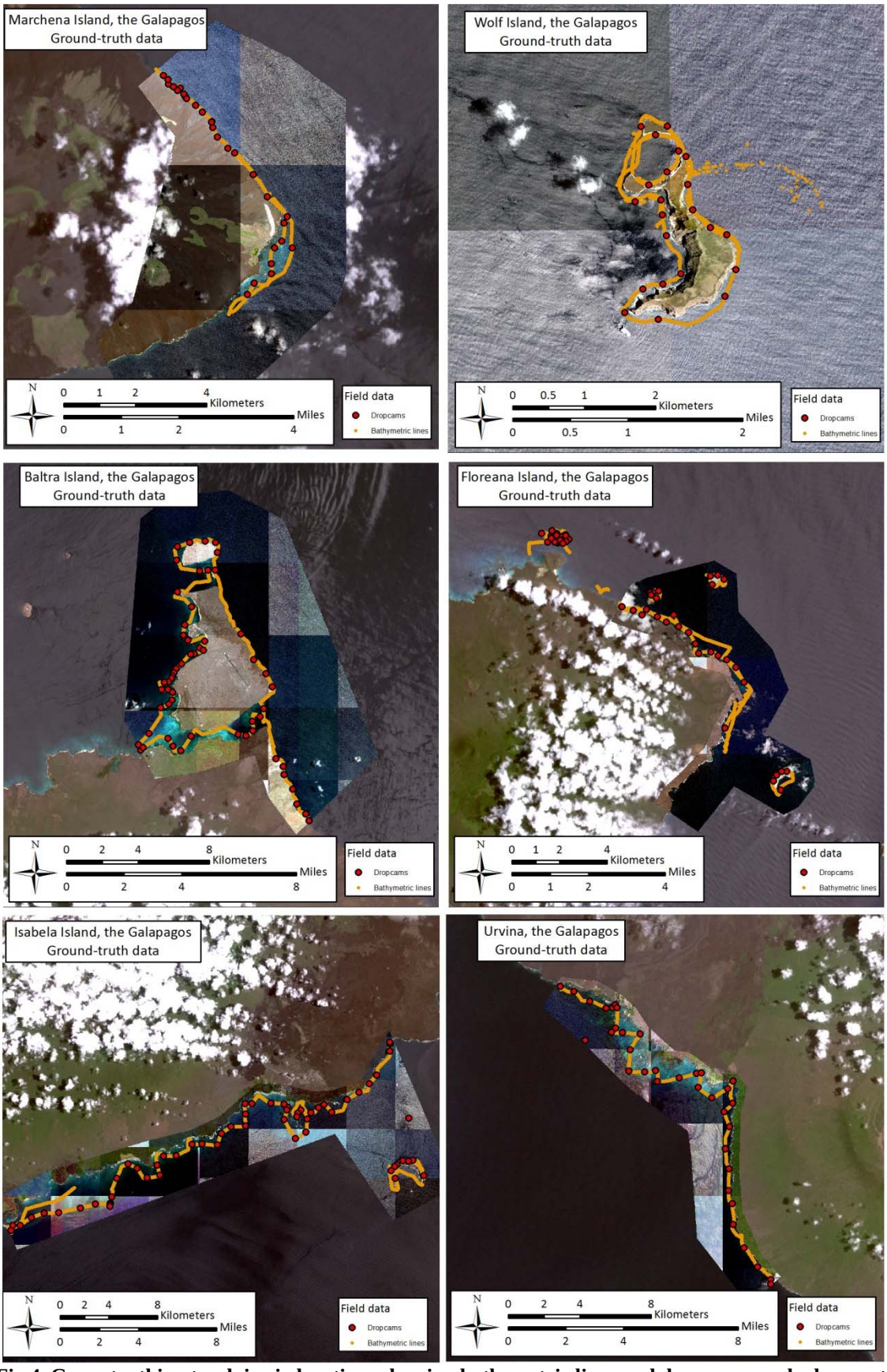

Fig.4. Grountruthing track in six locations showing bathymetric lines and drop camera deployments.

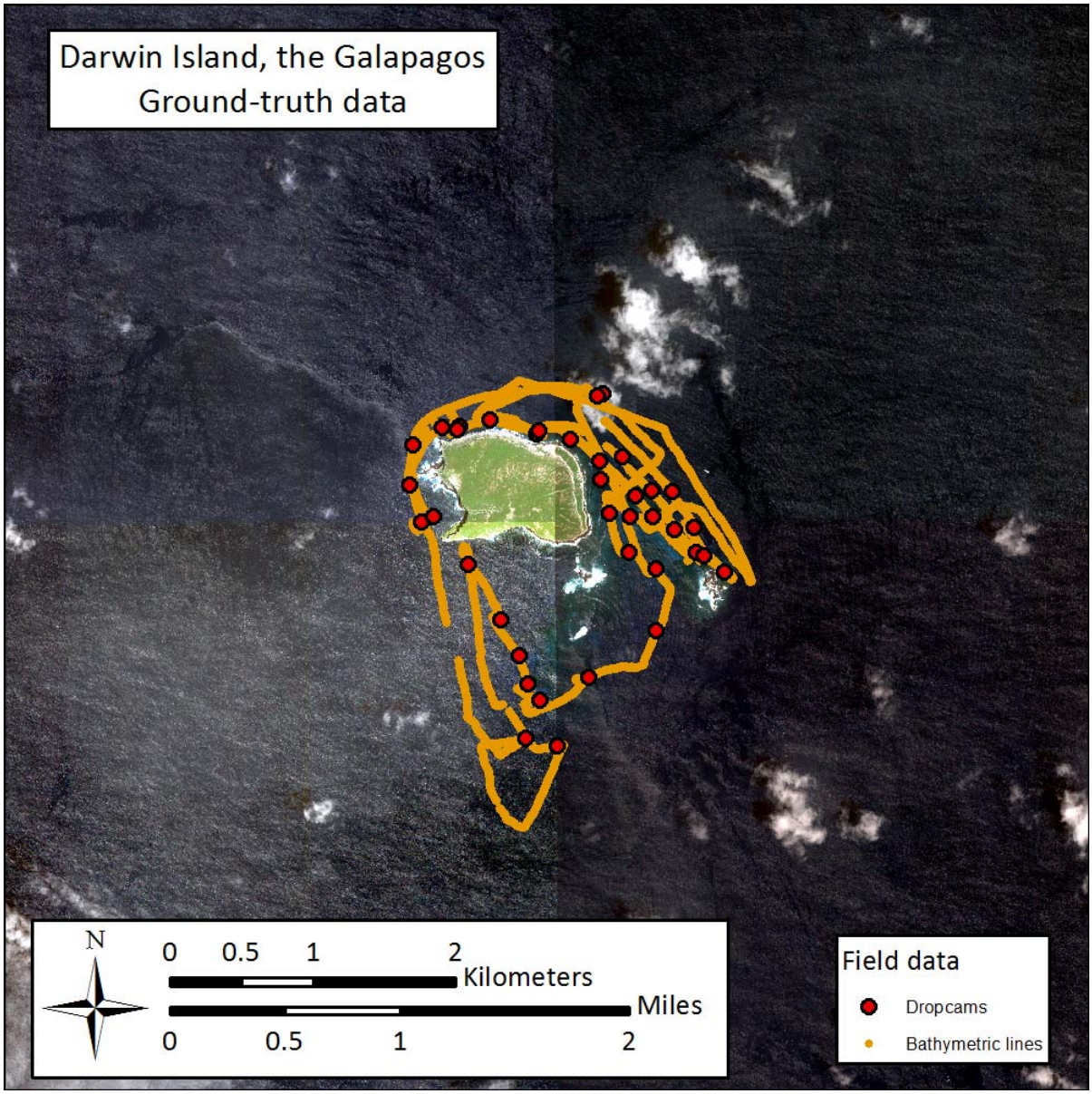

Fig.5. Grountruthing track for Darwin Island showing bathymetric lines and drop camera deployments.

Location	Dropcams	Bathy points
Marchena	27	99151
Wolf	22	78104
Darwin	37	137964
Baltra	57	222736
Floreana	54	234397
Isabela	61	339496
Urvina	37	146565
Total	**295**	**1258413**

Table 2. Summary of ground-truth data collected in seven locations in the Galápagos.

3. SCUBA Assessments

General site descriptions

Marchena: The site is a shallow rocky plateau that rises gently from the deep and is covered by strewn boulders with shallow sand in between the boulders. Sediment is primarily siliciclastic. At 8-10 m is a series of small ridges, extending approximately 0.5 m above the surrounding substrate. Around the sampling sites are many *Porites lobata* colonies, some large (~1m diameter) and many small. On the ridge, most (80%) of the small colonies are unattached and are true coralliths with living undersides. The ridges were colonized by *Pavona clavus*, dozens of *Pocillopora* colonies, small *Porites* colonies and large numbers of *Tubastraea coccinea*. Several of the ridges also had dense patches of *Psammocora*. In deeper (seaward) water, sand and rubble bottom alternates with larger ridges, hard bottom and boulder fields. Many areas are densely colonized by aggregates of *Porites* and *Pavona*, with small patches of *Psammocora* and isolated *Pocillopora* colonies. Several large coral communities consisting of 100s of colonies were observed at 10-15 m depth.

Wolf: All sides of Wolf are steep, about 45 degree slopes, consisting of large basaltic boulders shed off the subaerial cliff. Coral communities were concentrated on the eastern end of Wolf, extending for several hundred meters. Coral growth is variable, with the biggest colonies at around 40ft depth, smaller above and smaller below. The dominant coral in shallow water and at mid depths is *Porites lobata*; in some areas colonies are up to 5 m in height and 5-10 m diameter. Intermixed with *Porites* are patches of *Pavona*, with *Pavona* increasing in abundance in deeper water. *Pavona* colonies form thin crusts over basaltic boulders (primarily *Pavona varians*) with aggregates of large mounding and lobate colonies of *Pavona clavus* and *Pavona gigantea*. Isolated colonies of *Pocillopora* occur throughout the reef. Coral cover exceeds 50% along most of this reef system. Coral growth terminates between 80-100 feet in sand.

Darwin: An elongate reef system extends from the island to Darwin's arch. Constructed predominantly of massive *Porites lobata* colonies, the reef extends from about 4 m depth to 25 m depth, terminating in a sandflat littered with dead *Diaseris* skeletons. The reef contains areas with high cover (50-70%) at the eastern end (in shallow water), and slightly lower cover and taller corals (1-2 m) surrounding small to medium-sized sand patches in the central part of the reef. The reef slope consists of mixed *Pavona* and *Porites* colonies of moderate to high cover (20-50%). Isolated colonies of *Pocillopora* (multiple species) have colonized hardground areas and dead coral colonies, however this taxon did not form any build-ups but rather occurred as scattered colonies. Sand patches between the coral framework was littered with rubble, predominantly *Pocillopora***.** Massive corals were generally in good shape, although *Peysonnelia* algae had colonized and killed portions of numerous *Porites* colonies. Damselfish algal lawns were causing substantial mortality to some colonies. Fish bites and pink spots were prevalent.

Baltra: A gently sloping sandy seafloor with small boulder fields that are settled by corals. Dominant corals were *Pavona clavus* and *gigantea*, isolated *Porites lobata* and a few *Pocillopora* sp. From the shore is a steep drop-off in pillar basalt; the rocky shore slopes as a boulder-field to about 5m depth terminating in sand. On these boulders are individual *Pocillopora*.

The opposite side is also a steep shoreline. The canal may be caused by a fault line that cuts Baltra from Santa Cruz. The sea-cliffs are the same pillar basalt, with overlying massive and pillar basalts. The shoreline consists of big boulders. At Punta Carrion itself, there is a drop-off consisting of big boulders in the shallower part, then a drop-off into the deep. In the shallow, there are many isolated coral colonies, often >1m in diameter, but most are encrusting. At the base of the reef, *Pavona clavus* formed small aggregations of colonies, 25-50 cm in diameter.

San Cristóbal: Snorkeled on a rocky ledge just outside Punta Pitt. The Punta is an ash volcano with strongly eroded surface that forms a bay between two coastal cinder cones. At the southern end of the rocky ridge there used to be several very large Porites colonies which are no longer present. On top of the rocky ridge are isolated patches of coral, mostly *Pocillopora* colonizing cracks and fissures in the ridge with some massive *Porites* at the edge and base of the ridge.

Dove off a small island outside of the cone, at the end of the rocky ledge. The seafloor consists of pillow lavas that are eroded into small pillars and are densely settled by Eucidaris and other urchins. The base contains isolated corals, including some *Pavona clavus*. Closer to the island, on the eastern side (facing the open ocean, 5-9 m depth), small aggregates of *Pocillopora* colonized rock outcrops, the ridge surrounding the island and a flattened ledge. These generally occur as individual colonies or 3-4 colonies of the same genet formed from fragments of the largest (up to 50 cm diameter). A flattened rock ridge also contained a dense thicket of *Psammocora stellata*.

Devil's Crown Outside: Between 15-30 m depth is a flat sandy seafloor, with low rocky outcrops. The flat sandy areas consist of a fine, purely carbonate sediment that is produced by millions of *Diaseris distorta* that carpet the seafloor. Their distribution is patchy. In dense patches, the corals are several layers deep without any indication of stress or aggression among the individuals. These dense patches are several meters in diameter (up to 10m diameter); in between are areas of thinner *Diaseris*. In these thinner areas, smaller colonies are more frequent. The biggest colonies seem to be in the densest areas.

At 15 m depth, slightly closer to the Crown is an area similar to the deeper *Diaseris* patch. A dense *Diaseris* carpet occurs on white, fine, carbonate sand. Other fauna inside the patch are garden eels, and many jawfish. Towards the periphery of the *Diaseris* patch, the sediment becomes more coarse and is composed by nodules constructed predominantly of broken *Psammocora* colonies. In the *Diaseris* patch, a few dozen *Cycloseris* are mixed-in. In total, approximately 30 *Diaseris* colonies were observed. The entire patch then ends in a small rocky

outcrop, after which the seafloor is a mixture of sand and *Psammocora* corallith beds. These are unusually dense corallith beds that occur around and among rocky outcrops.

Devil's Crown, Inside of the Corona: 3m depth. Inside the crown, sediments were very coarse and consisted of urchin spines and basalt particles. In some areas, the sediment is mixed basalt/carbonate sand of finer texture. Isolated *Pocillopora* colonies occur at the northeastern end, with a single small patch in the center consisting of about 15 colonies. At the northwestern end is a dense aggregation of *Pavona clavus* and *Porites lobata* colonies, some several meters in diameter. On the landward side, in an area of rapid water movement and tidal flushing is a dense thicket of *Psammocora stellata*; all colonies are unattached. A second small patch of *Pavona clavus* colonies occur at the southern end of the crown. Very few stony corals are found on the outside of the crown, with exception of encrusting corals on the wall on the southeastern end.

Champion: A beautiful island consisting of layered lava flows and ash cones. A relatively steep slope consisting almost exclusively of big igneous blocks on which there are many black corals and many echinoids. The sediment is carbonaceaous in places. Best coral colonization is at the edge of the terrace, adjacent to a ledge and steep (1-3 m) drop-off, and also on the top of the terrace in 5-8 m water depth. On the terrace is a large aggregation (100+ corals) of larger massive *Porites* and *Pavona* colonies, including many 50-75 cm diameter. Corals included *Pavona gigantea, Pavona clavus, Porites lobata,* and *Psammocora stellata.*

Floreana Caldera, opposite Champion island: A steep slope consisting mainly of big basalt blocks, with numerous large corals. *Pavona* colonies of up to 1m diameter form a dense band, but many are severely bioeroded by sea urchins. The sediments are also mainly carbonaceaous and have many echinoid spines. *Pavona gigantea* aggressively overgrew many *Pavona clavus*. *Pavona* colonies form a band running parallel to shore at about 4-5 m depth and also form a series of mounds extending down the slope from about 5-190 m depth. In one area, *Pavona* colonies end abruptly at a large patch of *Psammocora stellata*. Very clearly, skeletons are apparently more brittle and easier to erode than in other places. Many live corals were just being hollowed out by echinoids. Species observed include *Pavona gigantea, Pavona clavus, Porites lobata* and *Psammocora stellata.*

Concha y Perla: Concha y Perla is a tidepool on the outskirts of Puerto Villamil, a short distance from the general boat dock. It is a lagoon in a ropy pahoehoe lava flow. Tidal difference between the high and low tide is about 1.5m and much of the lagoon's rim is dry at low tide. In the central part of the lagoon there are four thickets of *Pocillopora verrucosa* and *damicornis.* Isolated *Porites lobata* (two colonies 100x80x20, 120x100x50) occur at the seaward edge of the lagoon. A single, dense *Psammocora stellata* corallith bed is located at the eastern end of the lagoon. Species observed are: *Psammocora stellata, Pocillopora inflata, Pocillopora damicornis, Pocillopora elegans, Porites lobata.*

Tortuga Island: Tortuga Island is a cinder-cone caldera off Puerto Villamil. Only half of the caldera still exists. Interestingly, the crescent opens into the dominant wind and wave direction. Therefore the inside of the crater is not protected. The crater is made up mainly of ash-layers throughout, making it a cinder-cone. The dives were on the leeward side, but a strong current was present. Underwater, the same morphology as above water persists; volcanic rock consists of a bedding plane of the ash layers. Rocks are covered in urchins (*Eucidaris* and *Lytechinus*), and are sparsely colonized by gorgonians and black corals; a small number of *Tubastraea* and a single *Porites* were seen in each location.

Urvina: Coral communities were restricted to a single nearshore area in 1-2 m depth. The dominant taxa was *Porites lobata*, which formed small mounding, boulder and encrusting colonies (5-50 cm diameter) that were frequently attached to the sides of larger boulders. Scattered throughout the community were isolated free living *Psammocora* colonies. Although dense assemblages of *Pocillopora* once occurred here, this species was not located. Extensive searchers for corals were conducted along the coast and slightly seaward to depths of 5 m. No other coral aggregations were identified.

A single deeper dive on a rocky ridge was conducted to search for the presence of other scleractinian corals. The community was dominated by small sponges and branching gorgonians, with a complete absence of stony corals. Water temperatures were notably colder in slightly deeper water, with a thermocline at about 8 m depth.

Location	Site #	Date	Lat	Long	Depth (M)	Site
Marchena	GAMA-01	1-Jun-12	0.3122	-90.4015	8	Punta Espejo
Wolf	GAWO-02	2-Jun-12	1.3873	-91.8168	30	
Wolf	GAWO-03	2-Jun-12	1.3856	-91.8146	27	
Darwin	GADA-04	3-Jun-12	1.67603	-91.99481	13	Darwin Reef
Darwin	GADA-05	4-Jun-12	1.676	-91.9937	14	Darwin Reef
Wolf	GAWO-06	5-Jun-12	1.385	-91.8133	12	
Wolf	GAWO-06	5-Jun-12	1.3853	-91.8134	31	
Darwin	GADA-07	6-Jun-12	1.6758	-91.9952	13	Darwin Reef
Darwin	GADA-08	6-Jun-12	1.6772	-91.9938	23	Darwin Reef
Darwin	GADA-09	6-Jun-12	1.6751	-91.9925	16	Darwin Reef
Darwin	GADA- 10	7-Jun-12	1.6761	-92.008	24	Darwin Cove
Darwin	GADA-11	8-Jun-12	1.6772	-91.9947	16	Darwin Reef
Darwin	GADA- 04	8-Jun-12	1.67603	-91.99481	13	Darwin Reef
Darwin	GADA-12	multiple	1.673	-91.989	30	Darwin Arch
Baltra	GABA-13	9-Jun-12	-0.471	-90.2549	11	
Baltra	GABA-14	9-Jun-12	-0.4819	-90.2527	13	
San Cristóbal	GASC-15	10-Jun-12	-0.7003	-89.2462	13	Punta Pitt
Floreana	GAFL-16	11-Jun-12	-1.217	-90.4183	34	Devil's Crown
Floreana	GAFL-16a	11-Jun-12	-1.2171	-90.4213	17	Devil's Crown
Floreana	GAFL-17	11-Jun-12	-1.216	-90.4235	2	Devil's Crown
Floreana	GAFL-18	12-Jun-12	-1.2382	-90.3879	24	Champions
Floreana	GAFL-19	12-Jun-12	-1.2368	-90.4063	22	Punta Cormorant
Isabela	GAIS-20	13-Jun-12	-0.96243	-90.95677	2	Concha y Perla lagoon
Isabela	GAIS-21	14-Jun-12	-1.0217	-90.8611	34	Tortuga 1
Isabela	GAIS-22	14-Jun-12	-1.0069	-90.8754	19	Tortuga 2
Urvina	GAUR-23	15-Jun-12	-0.3927	-91.2665	16	Urvina

Table 3. Locations of SCUBA assessments and coral-related research.

Fig. 6. Location of sites examined using SCUBA.

Coral assessments

Coral assessments focused on recorded measurements of species diversity, abundance, size structure and health. A variety of methods were employed due to the vast differences in the coral community dynamics. At Marchena, all corals within a permanent 25 x 25m quadrat were counted and the size structure of corals within certain belt transects were measured. This quadrat is a permanent plot that has been sampled over time. Additional random belt transects (1m X 10 m) were completed in the surrounding area. At Wolf, a combination of belt transects and phototransects were run parallel to depth contours. At Darwin, belt transects were conducted in different parts of the reef ("leeward and windward" sides, near the island, centrally and close to the arch, along depth gradients). Around the arch and in a cove on the opposite side of the island, roving surveys were completed because colonies were not dense enough to use transects. Roving surveys were also employed at Baltra, San Cristóbal, Floreana, and Urvina. Within Devil's Crown, quadrats were used to assess populations of free living fungiids and *Psammocora*. In other areas (San Cristóbal, Concha y Perla, Urvina) all corals observed were photographed using a scale bar.

Fish assessments

Fish visual censuses were surveyed in a total of 24 stations at Baltra, Wolf Island, Darwin Island, Isabela, San Cristóbal, Sta. Cruz, and Urvina. Fish diversity listings were also conducted at these 24 stations and in additional areas within these sites. Up to three fish surveys were conducted by 2 observers each day. Each survey involved four replicate 50x2m transects. Transects were laid at depths ranging from 1 to 30m depending on the extent of the reef and the area of interest of the coral reef survey teams. Fish were identified to the species level and fish sizes were estimated according to size categories of 0-5cm, 6-10, 11-20, 21-30, 31-40 and greater than 40cm. Fish abundance was estimated by actual counts whenever possible.

After completing replicate transects, roving fish surveys were conducted to record all species of fish observed within the general survey area. An estimated 10-20 minutes were spent for these roving surveys. A total of 154 species of fish were recorded during the roving surveys (Appendix I). A total of 146 belt transects were completed off 8 islands (Table 4). Belt transects will be analyzed for abundance and biomass, with emphasis on key functional groups.

Site	No. belt transects
Marchena	12
Wolf	24
Darwin	48
Baltra	8
San Cristóbal	4
Floreana	22
Isabela	16
Urvina	12

Table 4. Number of fish transects conducted at each research site.

4. **Evaluation of coral symbionts and photosynthetic efficiency, and coral genetic structure**

This component was lead by Dr. Joao Monteiro and Dr. Iliana Baums. It included the sampling and collection of corals for both symbiont work and genetic composition, direct measurements of light using data loggers, and measurements of coral fluorescence using a PAM fluoremeter. The main objectives of Dr. Monteiro's work were: 1) to collect coral fragments to assess the diversity of endosymbiotic algae (from the genus *Symbiodinium*) associating with *Pocillopora spp.;* and 2) to assess the photosynthetic efficiency and/or condition of photosystem II of the symbiotic algae assemblages in these coral taxa. The integration of both approaches aimed to check for a relation between light regimes, *Symbiodinium* assemblage diversity and photosynthetic efficiency and/or condition status of photosystem II. Dr Monteiro collected 192 samples from 103 colonies (Table 5). Additional samples of other species (*Pavona gigantea*, *Pavona clavus* and *Psammocora stellata*) were collected simultaneously for symbiont characterization by Dr. Andrew Baker, who was unable to participate in this mission.

Dr. Monteiro also included the assessment of photosynthetic efficiency and/or condition of photosystem II of the symbiotic algae assemblages of targeted coral taxa, relying on the use of a Dive-PAM Fluorometer, a submersible Pulse Amplitude Modulated Fluorometer. The principle requires one to measure fluorescence immediately prior and after a pulse of light in "normal", light adapted conditions and in dark acclimated conditions. Fieldwork planning required multiple dives per site and the use of the Dive-PAM at night (to assure dark acclimated conditions). The impossibility of doing night dives (for lack of specific permit) compromised the significance of the overall assessment of photosynthetic efficiency of *Symbiodinium sp.* assemblages in *Pocillopora.* Nevertheless, it was possible to get some light and dark acclimated fluorescence readings using special clips and waiting 15 minutes between them (Fig. 7). This approach has major drawbacks, including: i) the clips are designed for leaves and do not cover adequately the coral branches, thus not assuring true dark acclimated condition, and; ii) the 15 minute wait required among readings limits the number of readings per colony and total colonies included in the assessment. Future missions will preferably resort to night dives for dark acclimated readings, however, it is necessary to develop an alternative method of collecting dark acclimated data (e.g. use of leaf clips with rubber or plastic casings to fully cover the branches).

The initial plan also included light monitoring on each location using Onset HOBO Pendant Light/Temperature Loggers on the full, yellow, green and blue spectrums. After testing the loggers in Marchena, a logger set was successfully deployed and retrieved from Darwin (Fig. 8), collecting data over a 4-day period. Addition data were collected over a single day from Devil's Crown and Concha y Perla. A set of four loggers was also deployed in Baltra, but these could not be relocated. Galápagos National Park observers volunteered to try and retrieve them at a later time using the GPS coordinates taken on the day of deployment.

Fig 7. Underwater field work. *Pocillopora* sampling (left) and Pulse Amplitude Modulated fluorometry readings (right). *Photos by Joshua Feingold*

Fig. 8. Onset HOBO-Pendant light /temperature data logger set deployment with four data loggers to monitor yellow, green, blue and full visible spectrum intensity (lux).

Island	Sum of Colonies sampled	Sum of Vial Samples
Baltra	1	1
Darwin	27	46
Devil's crown	13	20
Isabela	27	33
Marchena	11	33
S. Cristóbal	3	5
Wolf	21	54
Total	**103**	**192**

Table 5. Overall *Pocillopora* sample record, including: island of collection, sum and total *Pocillopora* colonies samples and sum and total fragment/vial samples.

Clonal plots, each 15 m radius were established for *Porites lobata* at Marchena (2), Wolf (3), Darwin (4), Devil's Crown (1), Floreana (1) and Urvina (1) and for *Pocillopora damicornis* at Concha y Perla (2). All colonies within these circles were mapped and measured, and small tissue samples were collected from up to 30 colonies per plot. Examples of the measurements taken using the light meter are shown in Fig. 9-10 for Darwin Reef. Data include the average light intensity and relative light intensity overall, and for the yellow, green and blue spectrums. The sampling design for the *Pocillopora* samples, PAM readings and clonal plot assessments are summarized in Table 6.

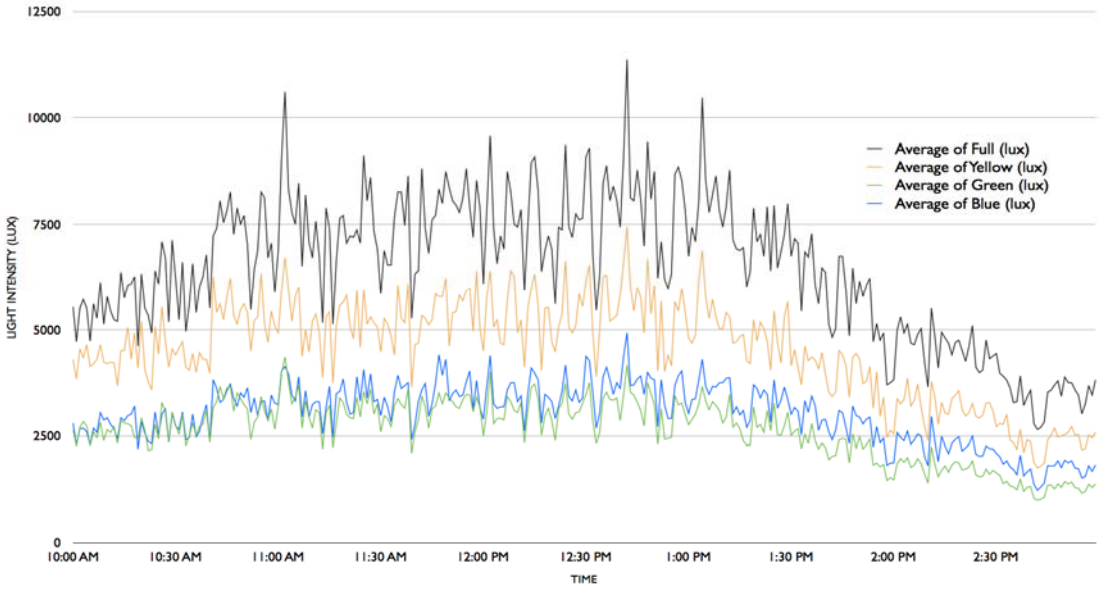

Fig. 9. Average light intensity between 10:00 AM and 02:59 PM on full visible, yellow, green and blue spectrums in Darwin (between 3rd and 7th of June 2012, at -10 m).

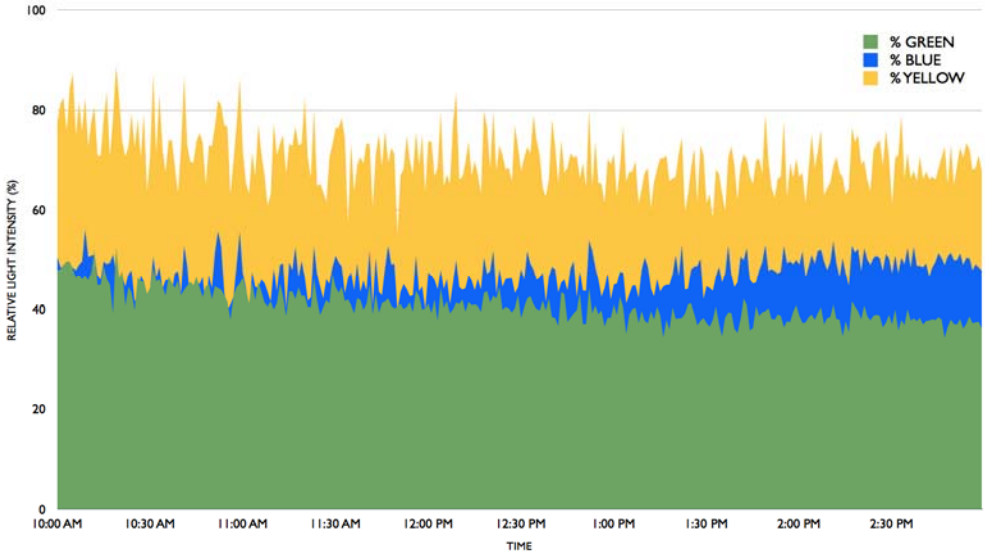

Fig. 10. Relative light intensity of yellow, green and blue spectrums between 10:00 AM and 14:59 PM in Darwin (3- 7 June, 2012) at -10 m. Percent values in relation to the full visible spectrum.

Dive	Date	Island	Site	Activity
1	20120601	Marchena	1	Random plot sampling
2	20120601	Marchena	1	Random plot sampling and *Pocillopora sampling*
3	20120601	Marchena	1	*Pocillopora sampling*
4	20120602	Wolf	2	15 m Circle mapping of *Porites* colonies
5	20120602	Wolf	3	15 m Circle mapping of *Porites* colonies and *Pocillopora sampling*
6	20120602	Wolf	3	*Pocillopora sampling*
7	20120603	Darwin	4	Random plot sampling
8	20120603	Darwin	4	Random plot sampling and *Pocillopora sampling*
9	20120603	Darwin	4	*Pocillopora sampling*
10	20120604	Darwin	4	Random plot sampling and *Pocillopora sampling*
11	20120604	Darwin	4	Random plot sampling
12	20120604	Darwin	12	Scout survey and *Pocillopora* sampling
13	20120605	Wolf	6	Scout survey and *Pocillopora* sampling
14	20120605	Wolf	6	Random plot sampling
15	20120605	Wolf	6	Random plot sampling
16	20120606	Darwin	5	Random plot sampling
17	20120606	Darwin	5	Random plot sampling
18	20120606	Darwin	9	Scout survey and *Pocillopora* sampling
19	20120607	Darwin	10	Scout survey and *Pocillopora* sampling
20	20120607	Darwin	?	Scout survey and *Pocillopora* sampling
21	20120607	Darwin	8	Scout survey and *Pocillopora* sampling
22	20120608	Darwin	5	PAM test readings and *Pocillopora* sampling
23	20120609	Baltra	i	ONSET Light/temperature loggers Deployment
24	20120609	Baltra	ii	Scout survey and Pocillopora sampling
25	20120609	Daphne Menor	i	Scout dive
26	20120610	Baltra	i	ONSET Light/temperature loggers Retrieval
27	20120610	S. Cristóbal	i	PAM readings and *Pocillopora* sampling
28	20120611	Devil's Crown	i	Scout survey and *Porites* sampling
29	20120611	Devil's Crown	ii	Random plot sampling
30	20120611	Devil's Crown	i	PAM readings and *Pocillopora* sampling
31	20120612	Floreana	i	Scout survey and *Porites* sampling
32	20120612	Floreana	ii	Scout survey and *Porites* sampling (no *Pocillopora*)
33	20120612	Devil's Crown	i	PAM readings and *Pocillopora* sampling and ONSET Loggers Retrieval
34	20120613	Concha y Perla	i	PAM readings and *Pocillopora* sampling
35	20120613	Concha y Perla	ii	PAM readings and *Pocillopora* sampling and ONSET Loggers Deployment
36	20120614	Concha y Perla	ii	PAM readings and *Pocillopora* sampling
37	20120616	Urvina	i	Random plot sampling
38	20120616	Urvina	ii	Scout survey dive

Table 6. Summary of sampling design for clonal analysis and symbiont characterization.

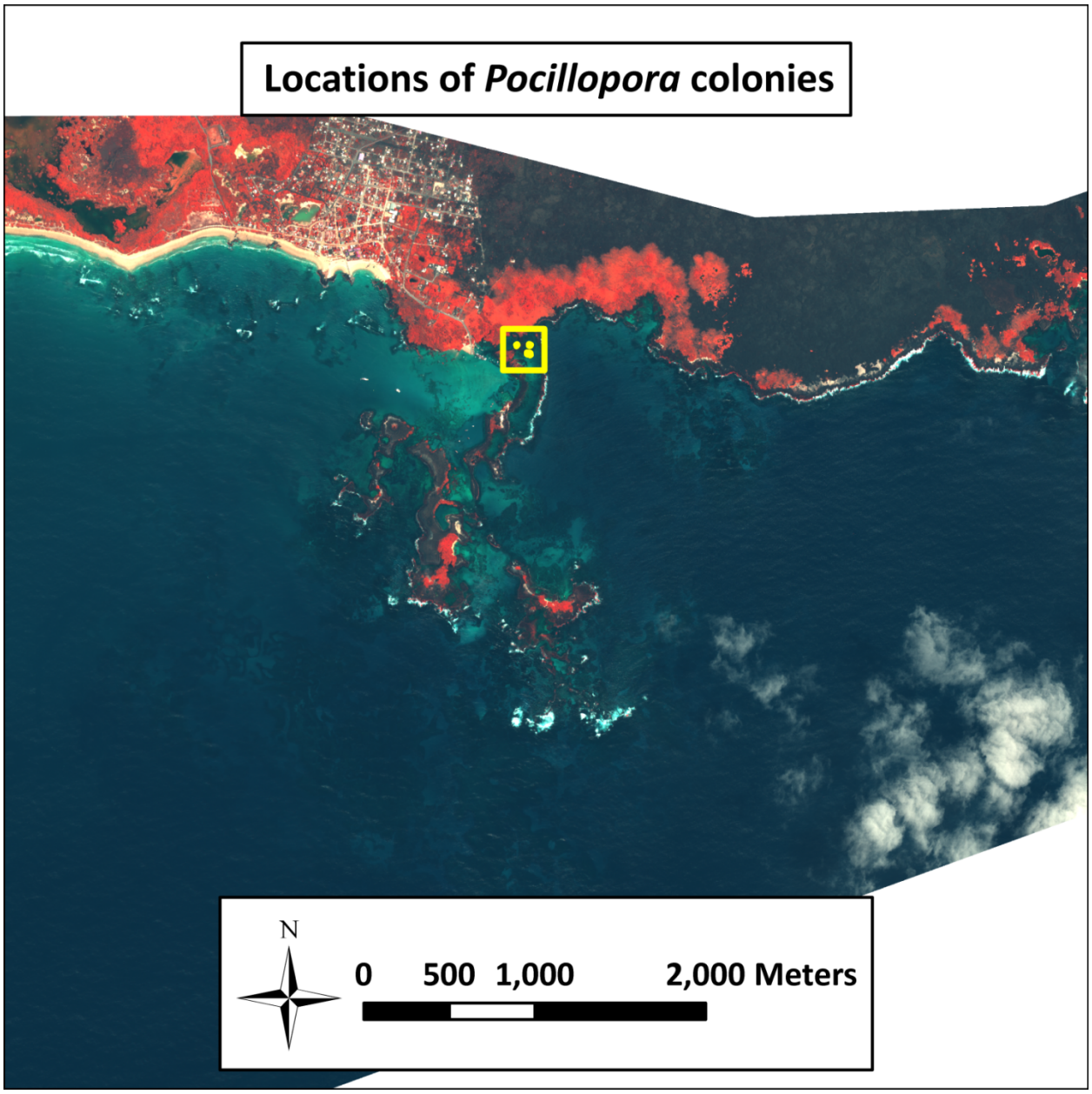

Fig. 11. The location of *Pocillopora damicornis* populations within Concha y Perla Lagoon.

In Concha y Perla Lagoon, *Pocillopora* samples were collected for both symbiont characterization and determination of genetic structure and the importance of sexual vs. asexual reproduction in population maintenance. Clonal plots were established within three populations (Fig. 11). In addition, every colony was photographed with a scale bar. The size structure and condition of these colonies will be assessed from photographs.

5. Oceanographic measurements

To better characterize environmental parameters affecting the research sites, a variety of oceanographic measurements were collected as follows:

- Deployment of deep water CTD were conducted off offshore, seaward of the dive sites at Marchena, Darwin, Wolf, and Devil's Crown. This provided profiles of temperature, salinity, dissolved oxygen, and chlorophyll from the surface to a maximum of 50 m depth. An example is shown in Figure 12.
- CTD casts were done at each of the dive sites to obtain temperature and salinity data from the surface to up to 30 m depth.
- Long term temperature records were collected from HOBO temperature meters deployed off Marchena and Devil's Crown. Temperature records for one year are shown for deep (30 m) and shallow water. See Figure 13.
- A current meter was deployed for 24-48 hours off Darwin, Floreana (Devil's Crown) and Baltra. An example of the data is provided in Figure 14.
- Water samples were collected at each dive site to determine alkalinity and $C0_2$.
- Light intensity was measured off Darwin Reef. See Figures 9-10.
- A pH logger was deployed off Marchena, Darwin, Devil's Crown, and Concha y Perla Lagoon. This provided data on pH and temperature (Fig. 16).

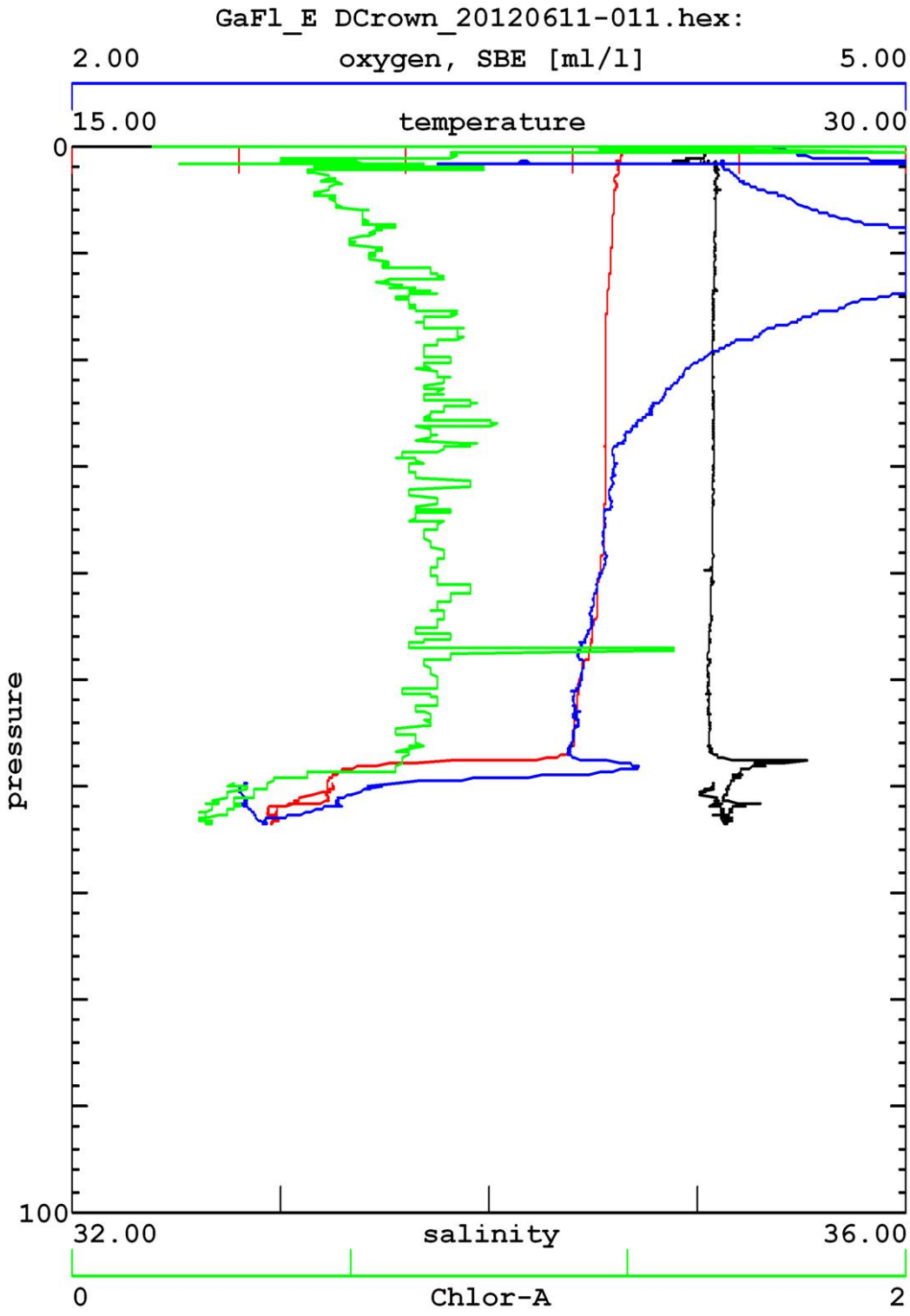

Fig. 12. CTD cast off Devil's Crown. Temperature, salinity and chlorophyll profiles are shown.

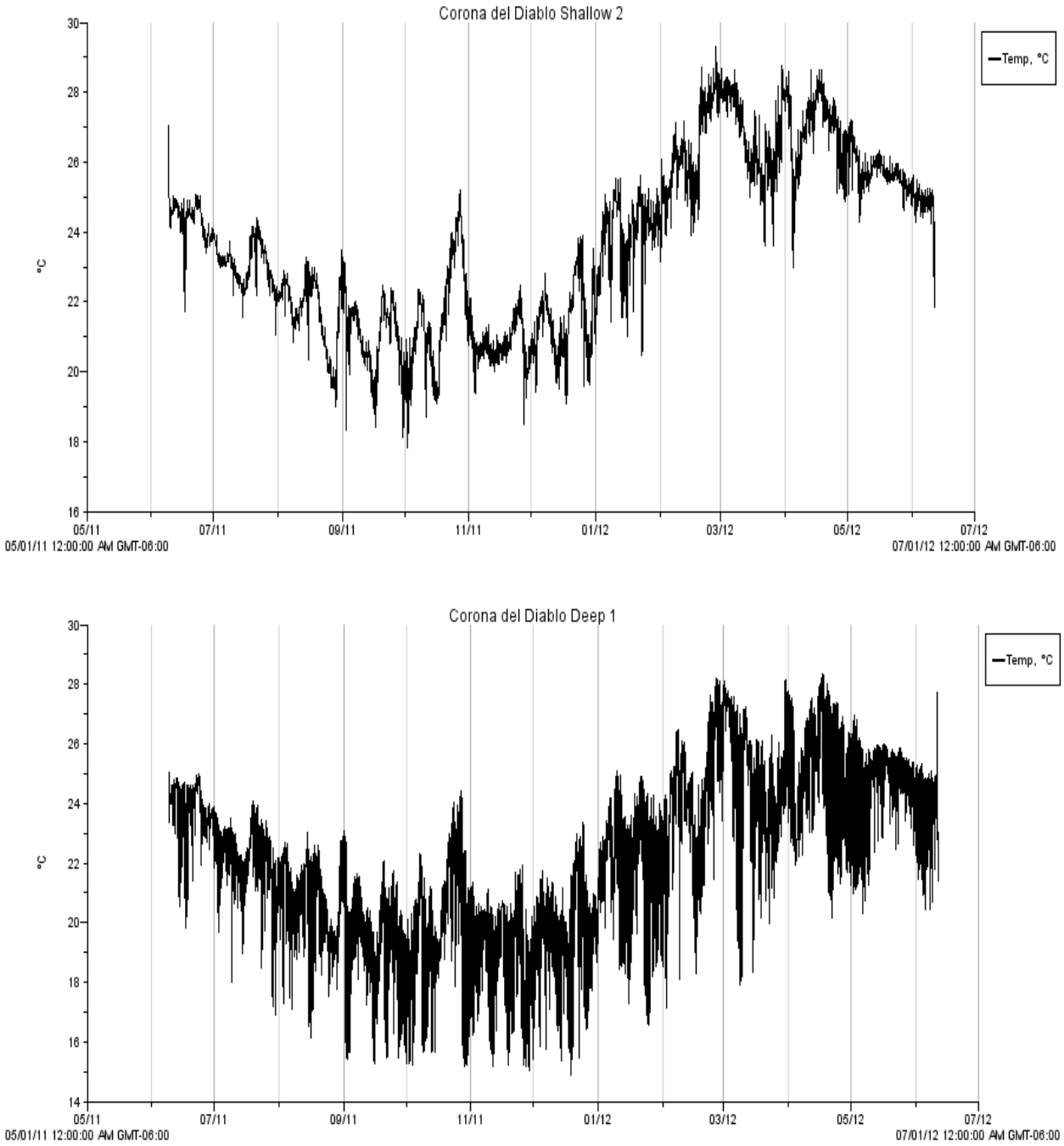

Fig. 13. Variation in temperature at Devil's Crown between June 2011-June 2012.Top figure is from 5 m depth and bottom figure is 30 m depth.

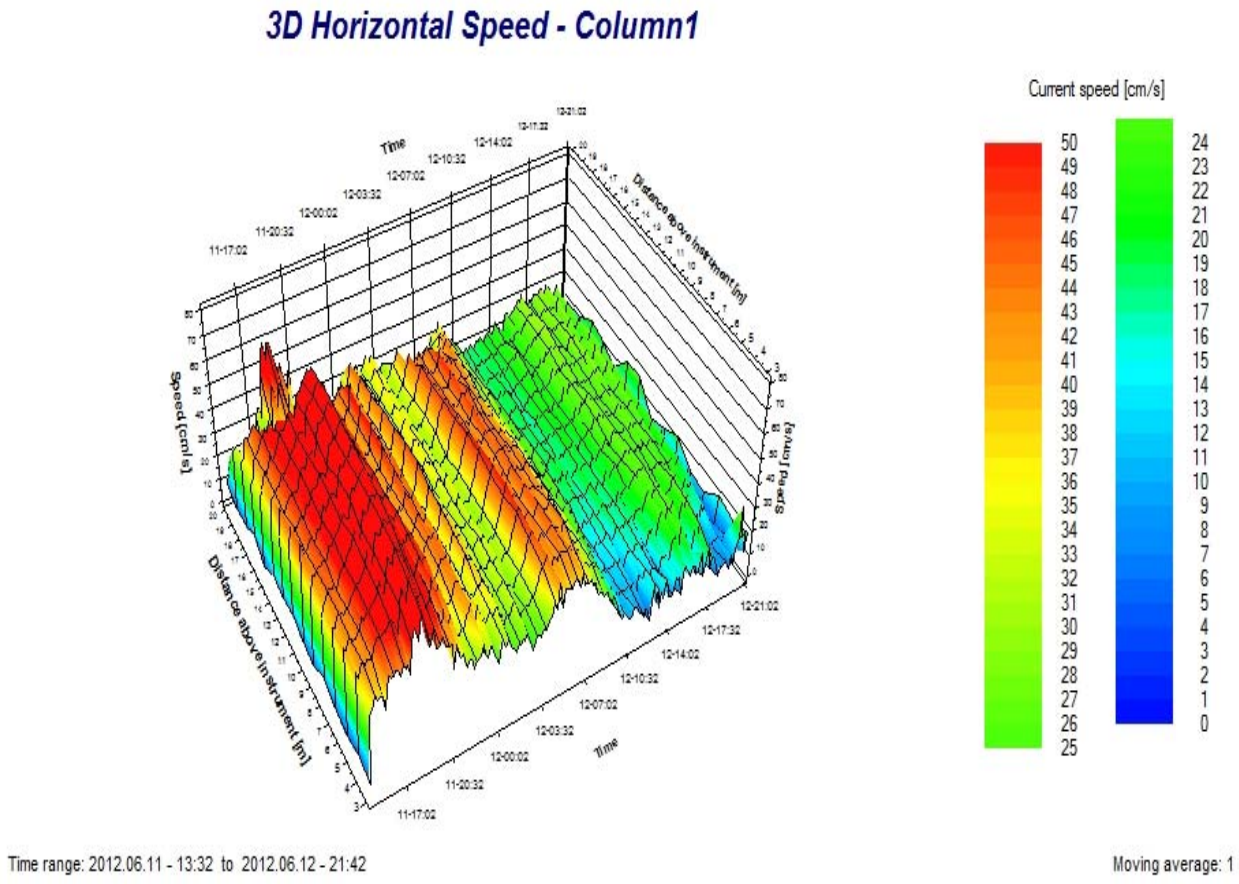

Fig. 14. Current profile off Devil's Crown during June 11 and 12, 2012.

6. Ocean acidification

Efforts to characterize the effects of water chemistry on coral growth and reef accretion focused on 1) the collection of coral cores to assess growth rates over the last decade; 2) measurements of pH at the seafloor bottom, within reef or coral communities; 3) collection of seawater samples from the water's surface and from the reef to assess alkalinity and TCO_2; 4) flow-thru measurements of CO_2; and 5) collection of pieces of reef substrate and coral rubble. Coral cores were collected from massive corals at Marchena, Wolf, Darwin, Baltra, Floreana, Devil's Crown, and Urvina. The numbers of each species collected per location are summarized in Table 7. The pH meter was deployed at Marchena, Darwin, Devil's Crown, and Concha y Perla. A total of 12 liters of water was collected at Marchena, Wolf, Darwin, Punta Pitt, Devil's Crown, and Concha y Perla. pCO2 measurements were taken at Wolf, Darwin, Devil's Crown, Baltra and Villamil (Table 7).

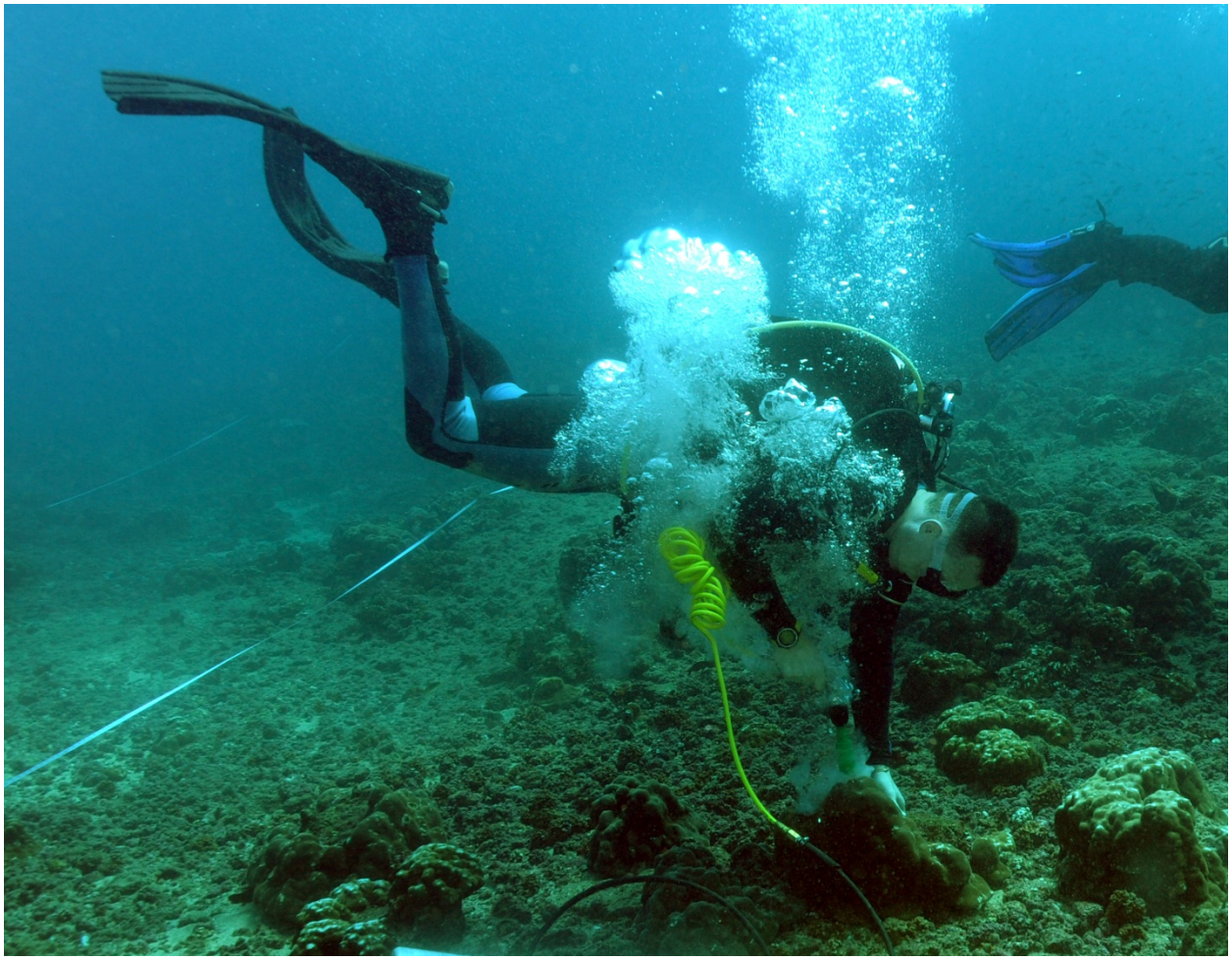

Fig. 15. Use of a pneumatic drill to collect small (2 cm X 7 cm) cores from massive *Pavona* and *Porites* colonies.

	Marchena	Wolf	Darwin	Baltra	San Cristobal	Devil's Crown	Floreana	Champion	Concha y Perla	Urvina
Pavona clavus cores	**0**	**7**	**14**	**0**	**3**	**7**	**0**	**1**	**0**	**0**
Pavona gigantea cores	**0**	**5**	**0**	**0**	**2**	**0**	**5**	**5**	**0**	**0**
Porites lobata cores	**8**	**5**	**7**	**0**	**0**	**5**	**0**	**0**	**0**	**5**
pH	**X**		**X**			**X**			**X**	
Water samples	**X**	**X**	**X**		**X**	**X**			**X**	
pCO_2		**X**	**X**	**X**		**X**			**X**	

Table 7. Summary of sampling design for ocean acidification studies.

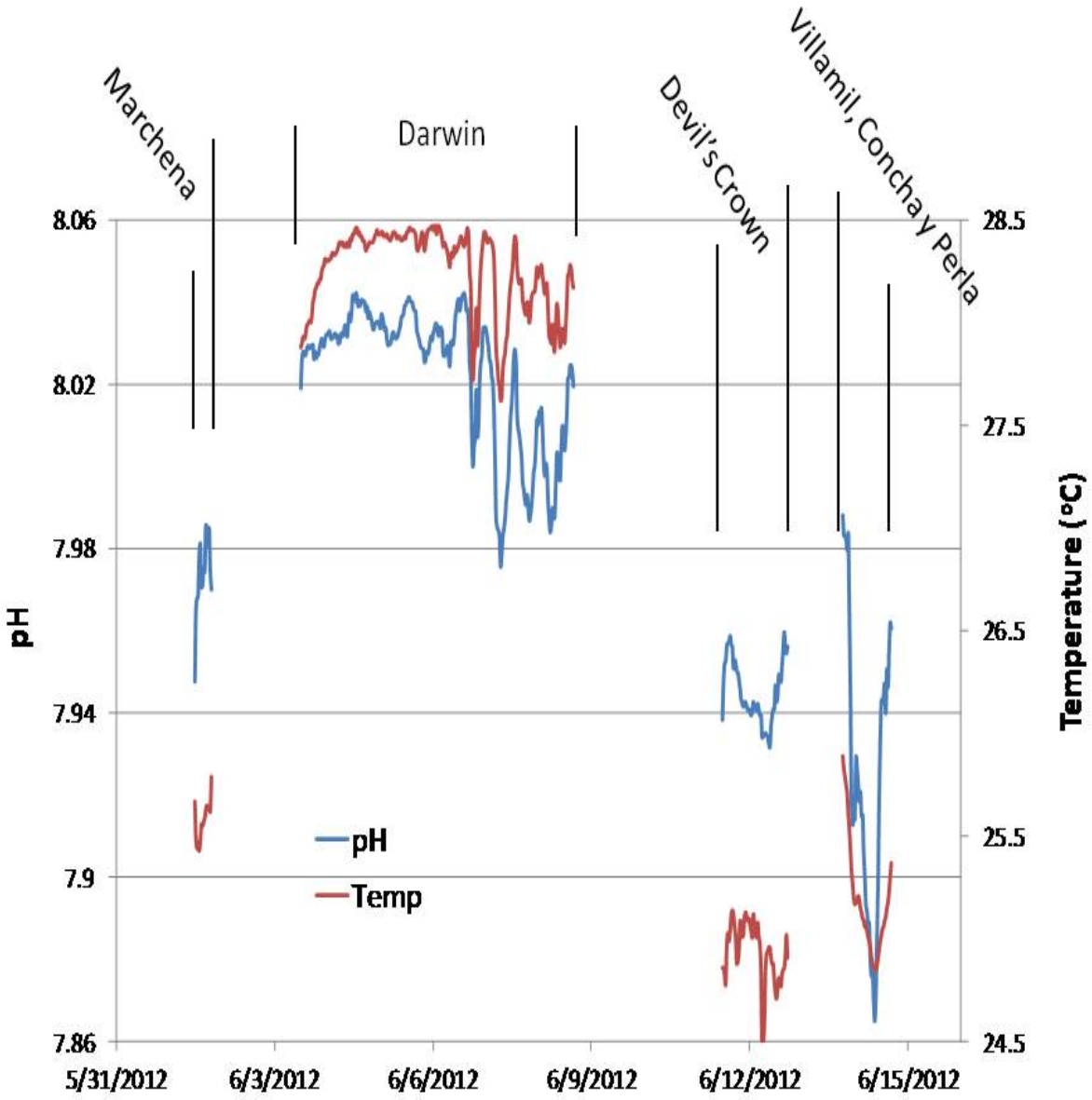

Fig. 16. pH and temperature readings at the bottom (adjacent to coral communities) at Marchena, Darwin, Devil's Crown and Concha y Perla Lagoon, Isabela.

Discussion

The research mission conducted by the Khaled bin Sultan Living Oceans Foundation represents a multidisciplinary collaboration that allowed collection of diverse data sets and samples that will assist in characterizing patterns of recovery of coral reefs and coral communities from past disturbances and help determine future conditions. Several of the researchers have long term study sites in the Galapagos, and this Expedition allowed them to revisit sites and explore new areas. Threats affecting these coral communities were better characterized, including impacts from predation and disease. Unusually high prevalence of "pink spots" were recorded on massive corals (*Porites*) in two locations; sampling of these syndromes will help determine the potential causes and impacts at a cellular and tissue level. The samples collected for symbiont characterization will supplement existing data, and answer new questions regarding the ability of corals to alter their clade of *Symbiodinium* in response to temperature stress, and the tendency to retain these stress tolerant symbionts. Samples collected for genetic analysis will provide additional information on the geographic distribution of certain clones, importance of different life history traits (e.g reproductive mode) in population maintenance, and the potential distance of dispersal of reproductive propagules. The cores obtained from massive corals will allow determination of rates of growth of these corals over the last decade, interannual variation in growth rates and linkages with environmental perturbations (e.g. temperature stress) and relationship between growth rates and variations in water chemistry (e.g. pH and CO_2). These data will help us determine the likely future impacts from climate change and ocean acidification.

Oceanographic and water quality measurements will help tie the biological data together, and help elucidate mechanisms controlling the distribution, abundance and persistence of corals and coral communities. In many cases, however, these represent baseline or single measurements, and more detailed long-term and larger spatial scale assessments are necessary. One particular constraint of this research had to do with the reduced sampling of PAM readings, because the dive team was not allowed to conduct research at night. The limited data collected during daylight will not allow a comprehensive analysis and will not provide significant results in the assessment of overall photosynthetic efficiency. It does, however provide some preliminary data and it has provided important information regarding operational restraints of the Dive-PAM and this method.

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Appendix 1. Fish diversity

Species	common name	Marchena 1	Wolf 2	Wolf 3	Darwin 4	Darwin 5	Wolf 6	Darwin 7	Darwin 8	Darwin 9	Darwin 10	Darwin 11	Darwin (Arch) 12	Baltra west 13	Baltra east 14	San Cristobal 15	Devil's Crown deep 16	Devil's Crown 17	Champion 18	Floreana 19	Concha y Perla 20	Tortuga, Isabela 21	Tortuga, Isabela 22	Urvina, shallow 23	Urvina, deep 24
Alectis ciliaris	African Pompano			x			x			x															
Seriola rivoliana	Almaco Jack	x	x	x	x		x	x		x	x	x			x	x									
Lutjanus argentiventris	Amarillo (Yellow) Snapper		x	x	x		x	x					x		x	x	x	x			x				
Decapterus muroadsi	Amberstripe Scad																x		x	x					
Canthigaster amboinensis	Ambon Sharpnose-puffer													x											
	Anchovies																	x	x	x					
Scarus compressus	Azure Parrotfish	x													x	x	x					x	x		
Mycteroperca olfax	Bacalao (Golden Grouper)				x		x				x				x	x	x	x	x	x				x	x
Diodon holocanthus	Balloonfish													x		x				x					
Elacatinus nesiotes	Banded Cleaner Goby													x	x				x	x				x	x
Johnrandallia nigrirostris	Barberfish	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x		x	x		x
Hypsoblennius brevipinnis	Barnaclebill Blenny															x								x	
Cantherhines dumerilii	Barred (Vagabond) Filefish				x		x		x																
	Barred Pargo																								
Serranus psittacinus	Barred Serrano	x												x	x	x	x	x	x	x	x	x	x	x	x
Haplopargus guentheri	Barred Snapper																				x				
Scarus rubroviolaceus	Bicolor Parrotfish	x	x	x	x	x	x	x	x	x	x	x			x										
Selar crumenophthalmus	Bigeye Scad	x																							
Caranx sexfasciatus	Bigeye Trevally				x		x		x				x												
Myripristis berndti	Bigscale Soldierfish				x																				
Melichthys niger	Black Durgon		x	x	x	x	x	x	x	x	x	x	x												
Caranx lugubris	Black Jack		x		x		x	x	x				x												
Euthynnus lineatus	Black Skipjack		x	x	x	x	x	x	x	x	x								x	x					
Apogon atrodorsatus	Blacktip Cardinalfish	x												x	x	x	x	x	x	x		x	x		x

Species	common name	Marchena 1	Wolf 2	Wolf 3	Darwin 4	Darwin 5	Wolf 6	Darwin 7	Darwin 8	Darwin 9	Darwin 10	Darwin 11	Darwin (Arch) 12	Baltra west 13	Baltra east 14	San Cristobal 15	Devil's Crown deep 16	Devil's Crown 17	Champion 18	Floreana 19	Concha y Perla 20	Tortuga, Isabela 21	Tortuga, Isabela 22	Urvina, shallow 23	Urvina, deep 24
Carcharhinus limbatus	Blacktip Shark				x							x													
Lutjanus viridis	Blue-and-Gold Snapper		x		x	x		x	x	x	x	x			x	x	x	x	x	x		x			
Kyphosus analogus	Blue-Bronze Chub		x	x	x		x	x	x																
Scarus ghobban	Bluechin Parrotfish	x				x								x	x	x	x	x	x	x	x	x	x	x	x
Caranx melampygus	Bluefin Trevally				x		x	x			x		x												
Sectator ocyurus	Bluestriped Chub		x		x	x	x		x				x				x	x					x		
Pseudobalistes naufragium	Blunthead Triggerfish					x	x										x								
Labrisomus dendriticus	Bravo Clinid				x					x			x	x	x	x	x	x	x	x	x	x	x	x	x
Odontoscion eurymesops	Bronze Croaker													x											x
Sphoeroides annulatus	Bullseye Puffer	x												x	x	x	x				x			x	x
Microspathodon bairdii	Bumphead Damselfish		x	x	x		x								x	x		x							
Scarus perrico	Bumphead Parrotfish													x	x	x	x	x				x			
Anisotremus interruptus	Burrito Grunt		x							x						x	x	x	x						
Synodus lacertinus	Calico Lizardfish	x												x	x		x	x		x			x		
Paralabrax albomaculatus	Camotillo																								x
Halichoeres dispilus	Chameleon Wrasse	x			x			x			x			x	x	x	x	x	x	x	x	x	x	x	x
Cirrhitichthys oxycephalus	Coral Hawkfish	x	x	x	x	x	x	x	x	x	x	x	x	x		x	x	x	x	x		x	x		
Thalassoma lucasanum	Cortez Rainbow Wrasse	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Kyphosus elegans	Cortez Sea Chub	x	x	x	x	x	x	x		x	x	x	x			x	x	x					x		
Uraspis helvola	Cottonmouth Jack						x																		
Dasyatis dipterura	Diamond Stingray																			x					x
Girella freminvilli	Dusky Chub																	x					x		
Balistes polylepis	Finescale Triggerfish	x			x	x	x		x		x					x	x	x							
Gymnothorax dovii	Finespotted Moray	x	x	x	x	x	x	x	x	x	x	x	x			x	x		x						
Epinephelus labriformis	Flag Cabrilla	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x		x
Acanthemblemaria castroi	Galapagos Barnacle Blenny														x										

Species	common name	Marchena 1	Wolf 2	Wolf 3	Darwin 4	Darwin 5	Wolf 6	Darwin 7	Darwin 8	Darwin 9	Darwin 10	Darwin 11	Darwin (Arch) 12	Baltra west 13	Baltra east 14	San Cristobal 15	Devil's Crown deep 16	Devil's Crown 17	Champion 18	Floreana 19	Concha y Perla 20	Tortuga, Isabela 21	Tortuga, Isabela 22	Urvina, shallow 23	Urvina, deep 24
	Galapagos Blue Banded Goby																								
	Galapagos Drum															X									
Taenioconger klausewitzi	Galapagos Garden Eel																X	X		X					
Orthopristis forbesi	Galapagos Grunt													X	X		X		X				X		
Mugil galapagensis	Galapagos Mullet		X				X																		
	Galapagos Porgy																X	X		X			X		X
	Galapagos Puffer																X								
Stegastes beebei	Galapagos Ringtail Damselfish	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Archosargus pourtalesii	Galapagos Seabream																				X				
Carcharhinus galapagensis	Galapagos Shark			X	X	X		X	X																
Orthopristis cantharinus	Galapagos Sheephead													X	X			X					X		
Lepidonectes corallicola	Galapagos Triplefin Blenny															X		X				X	X	X	X
	Giant Damselfish adult						X				X						X	X				X		X	X
Cirrhitus rivulatus	Giant Hawkfish		X	X	X		X			X	X		X			X	X	X	X			X	X		
	Glasseye Snapper		X	X	X		X	X	X	X	X		X												
Rhinoptera steindachneri	Golden Cowray															X									
	Goldrim Surgeonfish		X	X	X	X	X	X	X	X	X		X												
Semicossyphus darwini	Goldspot Sheephead				X																				X
	Grape Eye																X								
	Green Jack	X	X												X										
	Green Sea Turtle	X	X	X	X	X	X		X		X		X				X	X			X	X		X	
	Guineafowl Puffer	X	X	X	X	X	X	X	X	X		X	X				X	X			X				
Bodianus eclancheri	Harlequin Wrasse																X		X						X
	Indo-Pacific Bonito		X	X	X	X	X	X					X							X					
	Jack Mackerel																		X						
Muraena lentiginosa	Jewel Moray	X														X			X	X	X		X		X
	King Angelfish	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X	X		X
	Leather Bass	X	X	X	X	X	X	X	X	X	X	X	X				X	X							

Species	common name	1 Marchena	2 Wolf	3 Wolf	4 Darwin	5 Darwin	6 Wolf	7 Darwin	8 Darwin	9 Darwin	10 Darwin	11 Darwin	12 Darwin (Arch)	13 Baltra west	14 Baltra east	15 San Cristobal	16 Devil's Crown deep	17 Devil's Crown	18 Champion	19 Floreana	20 Concha y Perla	21 Tortuga, Isabela	22 Tortuga, Isabela	23 Urvina, shallow	24 Urvina, deep
Hemiramphus saltator	Longfin Halfbeak				x			x										x							
Oxycirrhites typus	Longnose Hawkfish																		x	x					
Nicholsina denticulata	Loosetooth Parrotfish																		x		x			x	x
	Mackerel Scad																	x							
	Manta Ray						x																		
Taeniura meyeri	Marbled Ray													x		x		x							
	Mexican Goatfish	x	x	x	x		x	x	x	x	x	x	x			x		x		x			x		
	Mexican Hogfish	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
	Milkfish		x	x																					
Haemulon scudderii	Mojarra Grunt													x	x	x	x	x							
	Moorish Idol	x	x	x	x	x	x	x	x	x	x	x	x		x	x	x	x							
Rypticus bicolor	Mottled Soapfish	x	x		x		x										x	x	x	x		x	x		
	Needlefish (sp)												x												
	Notchfin Blenny				x																				
	Orangeside Triggerfish	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x		x	x		
Ostracion meleagris	Pacific Boxfish	x	x												x	x									
Paranthias colonus	Pacific Creole Fish	x	x	x	x	x	x	x	x	x	x		x	x	x	x	x	x	x	x		x	x		x
Lutjanus novemfasciatus	Pacific Dog Snapper		x	x	x		x							x		x					x				
	Pacific Seahorse													x	x										
Alphestes immaculatus	Pacific Mutton Hamlet						x							x		x			x	x			x		
Abudefduf concolor	Pacific Night-sergeant																				x				
Calamus brachysomus	Pacific Porgy													x				x							
Scomberomorus sierra	Pacific Sierra												x					x				x	x		
	Panama Graysby		x		x		x	x		x				x	x	x	x		x	x		x			
	Panamic Fanged Blenny	x	x	x	x	x	x	x	x	x	x		x	x	x	x	x	x	x	x	x	x	x	x	x
	Panamic Green Moray	x	x		x																				
Abudefduf troscheli	Panamic Sergeant Major			x			x							x	x	x	x	x			x	x	x	x	x
	Panamic Soldierfish			x	x					x						x	x	x	x			x	x		
Iniistius pavo	Peacock Razorfish																x								

Species	common name	Marchena 1	Wolf 2	Wolf 3	Darwin 4	Darwin 5	Wolf 6	Darwin 7	Darwin 8	Darwin 9	Darwin 10	Darwin 11	Darwin (Arch) 12	Baltra west 13	Baltra east 14	San Cristobal 15	Devil's Crown deep 16	Devil's Crown 17	Champion 18	Floreana 19	Concha y Perla 20	Tortuga, Isabela 21	Tortuga, Isabela 22	Urvina, shallow 23	Urvina, deep 24
Sphyraena idiastes	Pelican Barracuda	X			X												X	X	X						
Anisotremus scapularis	Peruvian Grunt																								X
	Pilot Fish		X																						
	Pinktail Triggerfish						X																		
	Porcupinefish																X	X							
	Rainbow Runner			X	X	X	X	X	X		X		X												
Prionurus laticlavius	Razor Surgeonfish	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X	X		
Ogcocephalus darwinii	Red-Lipped Batfish																X								
	Red-shouldered Wrasse					X																			
	Redlight Goby													X	X										
	Redtail Triggerfish																			X					
Fistularia commersonii	Reef Cornetfish	X			X	X	X	X	X	X				X	X	X	X	X	X	X	X	X	X		
	Remora		X			X																			
	Rockmover Wrasse				X			X	X	X		X					X	X							
	Rough Triggerfish				X		X	X				X													
	Sabertooth Blenny	X												X	X	X	X	X	X	X		X	X	X	X
	Scalloped Hammerhead		X	X	X	X	X	X	X	X		X										X			
Chromis atrilobata	Scissortail Damselfish													X	X	X	X	X	X	X		X	X	X	X
	Scrawled Filefish							X																	
Prognathodes carlhubbsi	Scythe Butterflyfish (southern)																X		X						X
	Silky Shark					X																			
Chromis alta	Silverstripe Chromis																								X
	Spinster Wrasse	X			X				X					X	X	X	X	X	X	X	X	X		X	X
Chilomycterus reticulatus	Spotfin Burrfish													X			X	X				X	X		
	Spotted Cabrilla													X	X						X				X
Aetobatus ocellatus/narinari	Spotted Eagle Ray	X			X			X									X	X	X						
	Spotted Sharpnose Puffer	X					X	X								X									

Species	common name	1 Marchena	2 Wolf	3 Wolf	4 Darwin	5 Darwin	6 Wolf	7 Darwin	8 Darwin	9 Darwin	10 Darwin	11 Darwin	12 Darwin (Arch)	13 Baltra west	14 Baltra east	15 San Cristobal	16 Devil's Crown deep	17 Devil's Crown	18 Champion	19 Floreana	20 Concha y Perla	21 Tortuga, Isabela	22 Tortuga, Isabela	23 Urvina, shallow	24 Urvina, deep
	Spotted Unicornfish				X			X																	
	Steel Pompano	X	X	X	X		X	X					X												
Scorpaena plumieri mystes	Stone Scorpionfish	X			X										X	X		X		X			X		
Arothron hispidus	Stripebelly Puffer																				X				
Mugil cephalus	Striped Mullet																				X				
	Sunset Wrasse	X	X		X	X		X			X		X												
	Threadfin Jack		X																						
	Threebanded Butterflyfish	X												X	X	X	X				X				X
	Throatspotted Blenny																					X		X	
	Tiger Shark																								
	Tinsel Squirrelfish				X	X		X								X						X			
Bothus mancus	Tropical Flounder				X												X	X							
	Trumpetfish	X	X	X	X	X	X	X	X	X	X	X	X		X	X	X	X					X		
Rypticus nigripinnis	Twice-spotted soapfish		X											X			X	X	X	X	X		X		
Acanthocybium solandri	Wahoo																X		X						
	Whale Shark		X																						
	White-Tipped Reef Shark				X												X	X							
	Yellowfin Tuna		X	X			X																		
	Yellowtail Damselfish	X	X	X	X	X	X	X	X	X				X	X	X	X		X		X			X	
Acanthurus xanthopterus	Yellowtail Surgeonfish		X													X						X			

Appendix II. Coral Species Checklist

	Location	MA	WO	WO	Da	Da	WO	Da	Da	Da	DC	Da	DA	BA	BA	SC	DC	DC	CH	FL	CP	TO1	TO2	UR
	SITE	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**
Genus	**species**																							
Cycloseris	*curvata*																X							
Diaseris	*distorta*																X							
Gardineroseris	*planulata*										X													
Leptoseris	*scabra*							X			X													
Pavona	*clavus*	X	X	X	X	X	X	X	X	X	X	X	X	X	X			X	X	X	X			
Pavona	*chiriquiensis*		X	X				X			X													
Pavona	*gigantea*	X	X	X			X				X	X	X	X				X	X	X	X		X	
Pavona	*maldivensis*																							
Pavona	*varians*	X	X	X		X	X	X	X			X												
Porites	*lobata*	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X	X	X	X	X		X
Porites	*evermanni*				X		X			X		X												
Psammocora	*stellata*	X	X		X	X		X	X	X	X				X	X	X	X	X	X	X			X
Psammocora	*superficialis*																							
Pocillopora	*damicornis*	X			X	X		X	X	X	X	X				X		X						
Pocillopora	*verrucosa*	X	X	X	X	X	X				X					X								
Pocillopora	*lingulata*																							
Pocillopora	*meandrina*																							
Pocillopora	*capitata*		X	X																				
Pocillopora	*woodjonesi*						X																	
Pocillopora	*eydouxi*		X	X	X	X	X	X	X	X		X				X								
Pocillopora	*effusus*		X	X			X					X												
Pocillopora	*inflata*		X		X		X									X								

Appendix III. Science Team

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