BERTARELLI PROGRAMME IN MARINE SCIENCE

Science and Conservation Expedition to the Northern Atolls of the Chagos Archipelago, British Indian Ocean Territory

5th- 22nd April 2017

Figure 1. Ile Anglaise reef slope, Salomon atoll in April 2006 (top) and in April 2017 (bottom), to illustrate the impact of repeat warming events causing coral bleaching and due to climate change

Introduction

Background

The opportunity for a 2017 Expedition within the window of 5th - 26th April was mooted on 8th March, because a filming visit had been scheduled by BIOT to visit the northern atolls. It was suggested that this might provide an opportunity for a small team to assess the impact of the 2016 warming event on the northern atoll coral reefs, given that it was unclear when the BIOT patrol vessel (BPV) would next be available for such an assessment. The expedition was originally planned to deploy from Male, Maldives because the BPV was scheduled for a crew change there, and would focus on the northern atolls before returning to Male on 24th April. 2 further projects involving small teams were planned for April (the first to assess effectiveness of the Darwin Initiative rat eradication on Ile Vache Marine with support from Chagos Conservation Trust, and the second a BIOT/ZSL initiative to test hydrophones for Illegal, unidentified and unreported (IUU) fishing at Salomon and Peros Banhos) and therefore, given their focus on the northern atolls, could combine with reef assessment and filming objectives. The Bertarelli Foundation generously agreed to fund this interim expedition, and the feasibility was assessed, and potential participants approached. It quickly became clear that key personnel had limited availability, or were not available (reef calcification budget & fish survey teams), and that an alternative operation using BRUVs for fish surveys would not be compatible with the schedule of 10 days diving. A further plan to incorporate a member of the Stanford team to visit Speakers and other banks over 3 days to change batteries in acoustic receivers was considered unfeasible given the tight schedule. The film crew work was eventually postponed, and exit was later moved to Diego Garcia, but the availability of flights required an end of expedition arrival in Diego Garcia on 18th April to give sufficient time for cleaning and storing equipment. This expedition was therefore organised at very short notice and on a very tight timeframe, and therefore very specific objectives were identified.

Aims & Objectives

The April 2017 scientific and conservation expedition to the northern atolls aimed to undertake three separate, but logistically complementary projects:

1) *An assessment of reef condition post the 2016 bleaching event*
2) *Check of the rat status of Ile Vache Marine post eradication*
3) *Field test of hydrophone equipment for IUU enforcement application.*

The objectives of the three projects were:

Project 1: Coral Reef Assessment

Sustained high sea temperatures between March and June of 2015 and 2016 (Figure 2) led to reports of wide scale bleaching on many reefs, including those of the Chagos Archipelago. Results from the April 2016 expedition (pre that year's bleaching episode) had already indicated significant and widespread mortality resulting from the 2015 warming event resulting in a reduction of live coral cover to less than 20%. However, what was needed was a further assessment of the impact of the more sustained warming event in 2016 to assess bleaching induced mortality after two consecutive years of warming events (Figure 3 & 4, 5 & 6), and with the knowledge of White Syndrome coral disease from observations in 2014 and 2015. 5 complimentary methodological approaches were used:

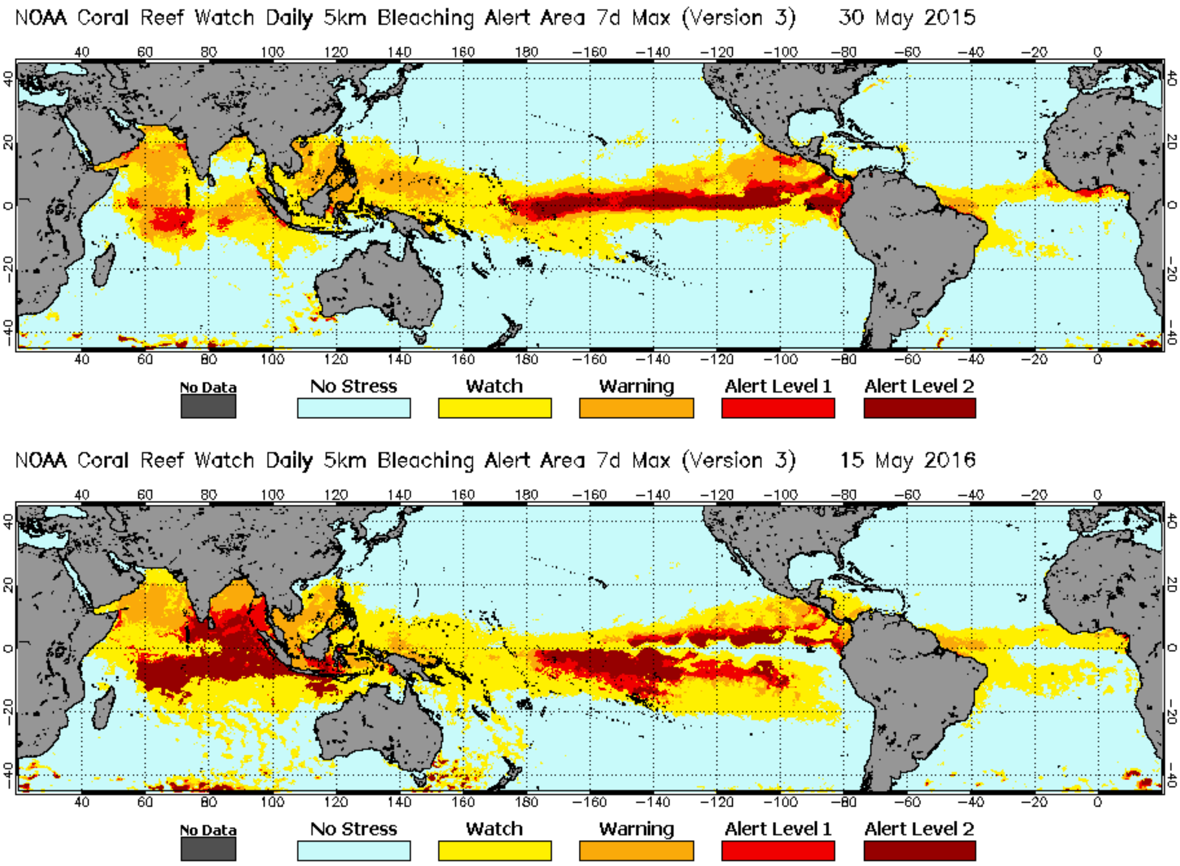


Figure 2. Global coral bleaching alerts derived from 5km resolution satellite imagery for May 2015 and 2016. [*https://coralreefwatch.noaa.gov/satellite/bleaching5km/images_archive/*](https://coralreefwatch.noaa.gov/satellite/bleaching5km/images_archive/)

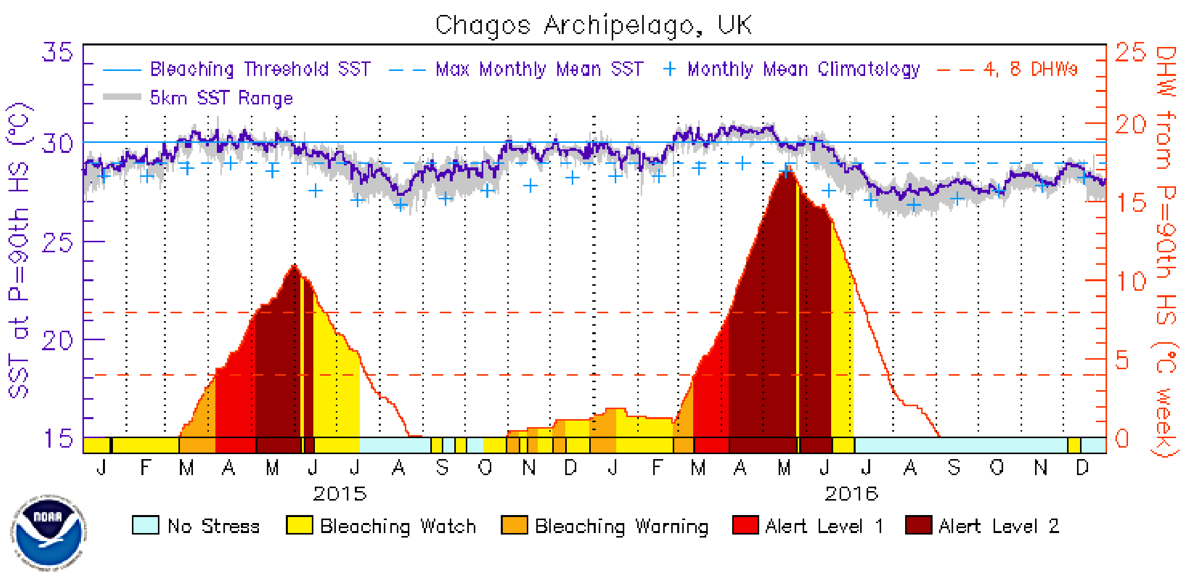


Figure 3. Sea Surface Temperature (purple line) and stress level due to warming for the Chagos Archipelago from January 2015 to December 2016 illustrating two consecutive annual periods of warming causing bleaching. [*https://coralreefwatch.noaa.gov/vs/gauges/chagos_archipelago.php*](https://coralreefwatch.noaa.gov/vs/gauges/chagos_archipelago.php)

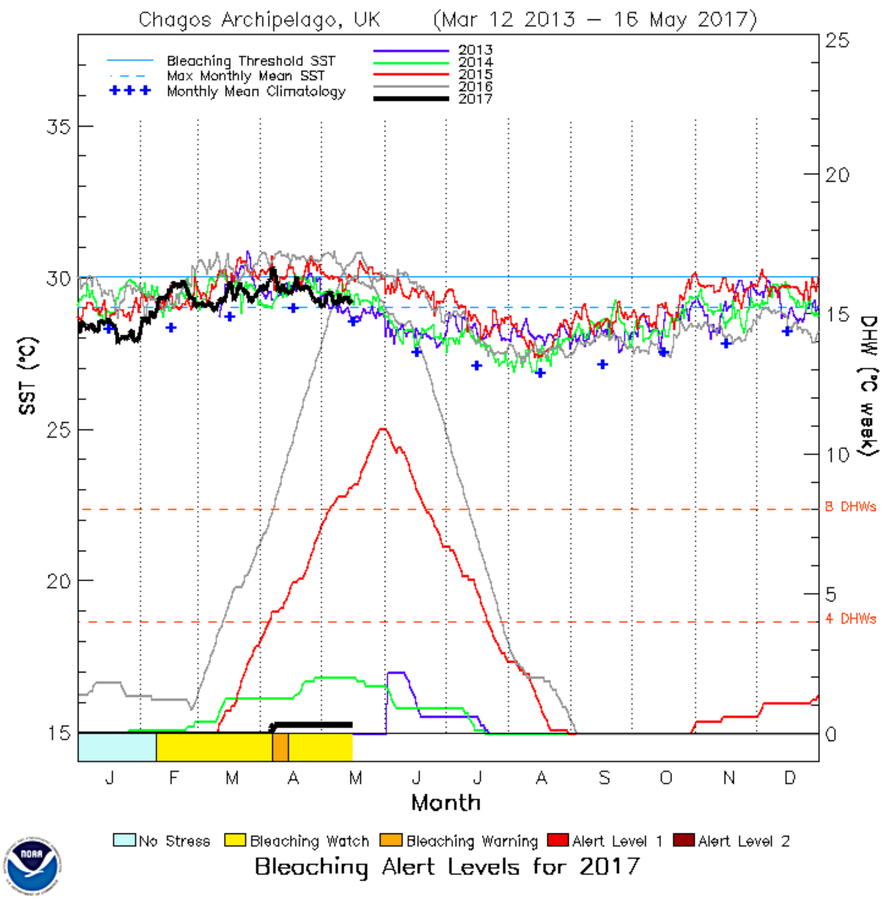


Figure 4. Sea surface temperature March 2013 to May 2017 showing that 2015 and 2016 temperatures exceeded the bleaching threshold for the Chagos Archipelago in 2015 and 2016. https://coralreefwatch.noaa.gov/vs/gauges/chagos_archipelago.php

Figure 5 & 6. Bleached corals in the Chagos Archipelago, May 2015 (Living Ocean Expedition 2015) and May 2016 (David Tickler, Pangaea expedition 2016)

(i) Extending existing long-term coral reef datasets

Coral cover was measured at the same sites and depths around the three northern atolls as measured since 1996 to extend the longest time series that has been recorded for Indian Ocean reefs. Visual assessments of benthic cover at 5m depth intervals around the three northern atolls provide a broad overview of (1) the net effect of stressors (disease, predation, and bleaching mortality) on the coral community, and (2) capture and explain the effects of individual events such as warming events and storms.

(ii) Integrating Sea Surface Temperature trends into coral reef resilience

Water temperature recorded since 2006 at two hourly intervals at 5, 15 and 25 m depth intervals from sites in both lagoons and ocean slopes around all the atoll were continued. Temperature data loggers were collected from the northern atolls, downloaded and replaced to relate temperature peaks to coral mortality.

(iii) Measuring future resilience via juvenile coral abundance

Juvenile corals were counted on a variety of substrates (dead standing coral, reef pavement, on calcareous algae) at long term monitoring sites to assess recruitment to the reefs. Those counted were newly settled adults of less than 5 mm diameter, reflecting 'potential' recovery. The stability of the substrate is important since juvenile corals can be lost from reefs on unstable substrates.

(iv) A Video Archive for Long Term Monitoring of Coral Reef Benthic Communities

A video archive of coral reef benthic community structure, recorded since 2006 and annually since 2013 was continued to assess change in coral reef community structure over time. The data enable analysis of all components of the coral reef benthos, including sponge and soft coral cover, macroalgal cover, crustose coralline algal cover, and turf algae over a relatively large tract of reef and depth without the constraints imposed on an observer underwater.

(v) Three-dimensional determination of reef structural complexity

Rapid capture of the 3D coral reef environment was undertaken using in-water photogrammetry for direct comparison with a survey of the same technique conducted in April 2016, in order to quantify the effects of bleaching induced coral mortality on the reef physical structure and composition. In addition, branching corals were tagged and photographed to assess their fate or growth.

Project 2: Rats and Islands

(i) Rat eradication

The outcome of the Darwin funded rat eradication operation conducted on Ile Vache Marine in August 2014 was tested, since the internationally recognised minimum period of two years before a failed eradication can be detected with certainty has passed. This check involved setting rat tunnels, gnaw sticks, snap-traps and crucially, night-time spot-light searches on the island.

(ii) Rat reinvasion

In August 2014 a rat eradication operation was conducted on Iles Jacobin and Sel on Salomon atoll to test the reinvasion time for islands that have rat-infested islands extremely close by.

(iii) Status of rats on other islands

Whether rats are present on Ile de la Passe and Diablo (Salomons) and Iles Finon, Verte, and Manon (Peros Banhos) was investigated since their status was unclear and is required for future management.

(iv) Experiment to determine whether 15kg/ha of rat poison is sufficient loading to successfully deliver bait to all rats on an island in BIOT

Bait acceptance trials were conducted on Yeye and Manoel in Peros Banhos to assess the density and abundance of rats present, especially on islands where land crabs prevail, to support future rat eradication initiatives in BIOT.

(v) Breeding Sulidae populations in BIOT

Over 40 years of breeding seabird data for Chagos has been accumulated. At least two species of breeding seabird (Red-footed and Brown Booby) are increasing in numbers and widening their distribution in BIOT, and this is likely to be the only site in the world where this is occurring. A standard breeding seabird census involving counting Apparently Occupied Nests (AON) was employed on the IUCN designated or proposed Important Bird Areas (Parasol, Longue, both Bois Mangues, and both Coquillages) of Peros Banhos.

Project 3: Hydrophone testing

The British Indian Ocean Territory Administration (BIOTA) and the Zoological Society of London (ZSL) have collaborated to add underwater acoustic sensors to ZSL's Instant detect multi-sensor alarm system, designed to provide real-time intelligence on illegal activity to monitor and protect the UK Overseas Territories' Marine Protected Areas (MPAs) in Peros Banhos and Salomon. ZSL has recommended an underwater acoustic vessel detection system (VDS) developed by JASCO Applied Sciences (hereinafter referred to as JASCO), which uses underwater hydrophones to detect vessels and send real time alerts to ZSL.

(i) **Field testing in situ in Peros Banhos and Salomon to rigorously test the performance of the VDS.**

The VDS was tested in situ within the Peros Banhos and Salomon atolls, confirming the range, sensitivity and other key performance indicators. Long-term baseline acoustic data was established within Peros Banhos to optimize vessel detection algorithms. The proof of concept was validated to identify a recommended solution and design for full implementation in each atoll.

(ii) Land and shore based site reconnaissance within Peros Banhos and Salomon lagoons to identify permanent locations for fixed hydrophones and to recommend cable deployment of the final system

1 km data cable routes to shore were reviewed and the feasibility of recommended cabled deployment methods were considered. Specific locations for full deployment were identified, and development costs assessed.

Figure 7. The BIOT Patrol Vessel Grampian Frontier *in Peros Banhos atoll*

Itinerary & Programme

Date	Activity and location
2nd April	P Carr arrives Male.
3d April	P Carr contacts agents and purchases stores. Most team members fly to Male.
4th April	London, New Zealand and Australia parties arrive Male. Manchester party fly to Male.
5th April	Manchester party arrive Male airport & proceed directly to *Grampian Frontier* by agent's boat. Rest of party boards *Grampian Frontier* from Male island. Crew change activity. Induction.
6th April	At anchor Male awaiting freight. Safety procedures. Delayed depart for BIOT at 1830.
7th April	In transit to BIOT. Unpack and prepare equipment.
8th April	In transit to BIOT. Unpack and prepare equipment.

Date	Anchorage	Dive Team	Terrestrial Team	Hydrophone Team
9th April	Arrive Peros Banhos SW 0830	Ile du Coin Bernards Shoal	Ile Vache Marine (overnight)	Vicinity of Ile Vache Marine
10th April	Peros Banhos SW Overnight to NW	Ile Poule ile Fouquet	Ile Vache Marine	Vicinity of Gabrielle
11th April	Peros Banhos NW	Ile Diamant Seaward, Ile de la Passe	Yeye, Manoel (overnight)	North Peros Banhos lagoon
12th April	Peros Banhos NW Move to NE	Ile Diamant Lagoon Moresby	Yeye, Manoel	North Peros Banhos lagoon
13th April	Peros Banhos NE	Ile YeYe Petite Coquillage	Yeye, Manoel	North Peros Banhos lagoon
14th April	Peros Banhos North Overnight to Salomon	No Dive	Yeye, Manoel	Deploy Hydrophone
15th April	Salomon Atoll	Ile Anglaise South Tip Sams Knoll	Jacobin & Sel	Salomon pass bathymetry
16th April	Salomon Atol Overnight to Blenheim	Ile de la Passe Ile Takamaka	Ile de Diablo	Salomon

17th April	Blenheim Reef Overnight to Diego Garcia	Blenheim SW Blenheim SE		
18th April	Arrive Diego Garcia 0830. Wash, dry & pack equipment and move to science store at Moody Brook			
19th April	Flight delay 24 hrs			
20th April	1300 Flight to Bahrain. Overnight in Bahrain			
21st April	Onward flights to UK, New Zealand			

Participants

Name/Institution	Role	Nationality
Professor John Turner Bangor University	PI Expedition lead Project 1: Video archive for long term monitoring	British
Dr Ronan Roche Bangor University	Project 1: Video archive for long term monitoring	Republic of Ireland
Professor Charles Sheppard University of Warwick (Emeritus)	Project 1: Integrating Sea Surface Temperature trends into coral reef resilience; Extending existing long-term coral reef datasets; Integrating Sea Surface Temperature trends into coral reef resilience	British
Anne Sheppard	Project 1: Integrating Sea Surface Temperature trends into coral reef resilience; Extending existing long-term coral reef datasets; Integrating Sea Surface Temperature trends into coral reef resilience	British
Dr Andrew Mogg NFSD Dive Technician & PDRA Scottish Association of Marine Science	Dive Officer Project 1: Three-dimensional determination of reef structural complexity; Dive support	British
Daniel Bayley PhD candidate UCL/ZSL	Project 1: Three-dimensional determination of reef structural complexity	British
Dr Dominic Andradi Brown Research Assistant, University of Oxford	Expedition communications & dive support Project 1: Three-dimensional determination of reef structural complexity,	British
Dr Grant Harper Biodiversity Restoration Specialist	Project 2: Rat eradication and Islands	New Zealand
Peter Carr PhD candidate ZSL & University of Exeter	Project 2: Rat eradication and Islands	British

Emily Smith Project Manager, ZSL	Project 3: Hydrophone testing	British
Dr Tom Letessier Field Specialist ZSL	Project 3: Hydrophone testing	Norwegian
Robin Burns Technician JASCO	Project 3: Hydrophone testing	British
Stephen Hipsey Technician JASCO	Project 3: Hydrophone testing	British
Simon Watton	Coxswain and field medical specialist	British

Figure. 8. Expedition team, 2017. Back row: Prof Charles Sheppard, Prof John Turner, Emily Smith, Dan Bayley, Anne Sheppard, Robin Burns, Dr Tom Letessier, Dr Dominic Andradi Brown, Dr Ronan Roche; Middle row: Dr Andrew Mogg, Dr Grant Harper, Peter Carr, Stephen Hipsey, Foreground: Simon Watton

Project 1: Coral Reef Assessment

Site locations

During the 2017 expedition, coral reef sites on seaward and within lagoons in the northern atolls of Peros Banhos, Salomon and Blenheim reef (a submerged atoll) (Figure 9) were assessed.

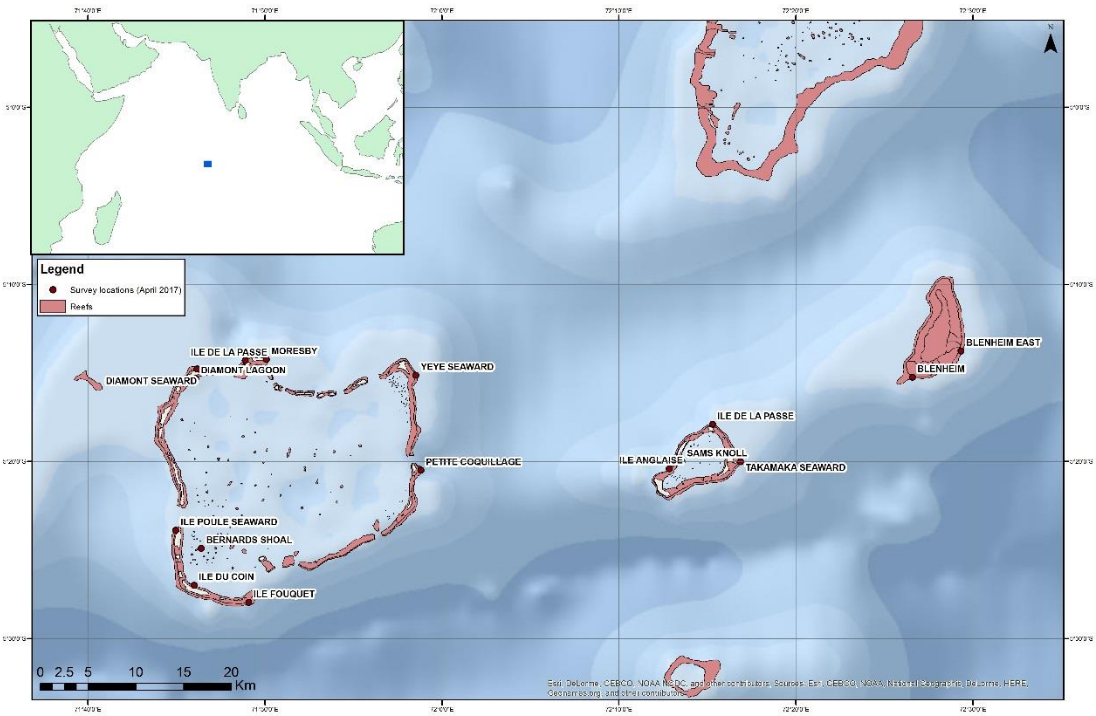


Figure 9. Map of northern atolls, Chagos Archipelago, displaying sites surveyed left to right, Peros Banhos atoll, Salomon atoll and Blenheim reef.

The specific locations of the 16 sites surveyed are indicated below:

Date	Atoll	Site	Latitude	Longitude
9th April	Peros Banhos	Ile du Coin	S5 26.979	E71 46.012
9th April	Peros Banhos	Bernard’s Knoll	S5 24.890	E71 46.419
10th April	Peros Banhos	Ile Poule	S5 23.882	E71 44.963
10th April	Peros Banhos	Ile Fouquet	S5 27.900	E71 49.100
11th April	Peros Banhos	Ile Diamant Seaward	S5 14.780	E71 46.170
11th April	Peros Banhos	Ile de la Passe	S5 14.240	E71 48.899
12th April	Peros Banhos	Ile Diamant Lagoon	S5 15.309	E71 46.093
12th April	Peros Banhos	Moresby Island	S5 14.241	E71 50.090

13th April	Peros Banhos	Ile YeYe	S5 15.151	E71 58.533
13th April	Peros Banhos	Petite Coquillage	S5 20.510	E71 58.800
14th April	No Dive	No Dive		
14th April	No Dive	No Dive		
15th April	Salomon Atoll	Ile Anglaise South Tip	S5 20.370	E72 12.750
15th April	Salomon Atoll	Sams Knoll	S5 20.000	E72 13.545
16th April	Salomon Atoll	Ile de la Passe	S5 17.930	E72 15.310
16th April	Salomon Atoll	Ile Takamaka	S5 20.050	E72 16.890
17th April	Blenheim	Blenheim SE	S5 15.229	E72 26.582
17th April	Blenheim	Blenheim SW	S5 13.755	E72 29.345

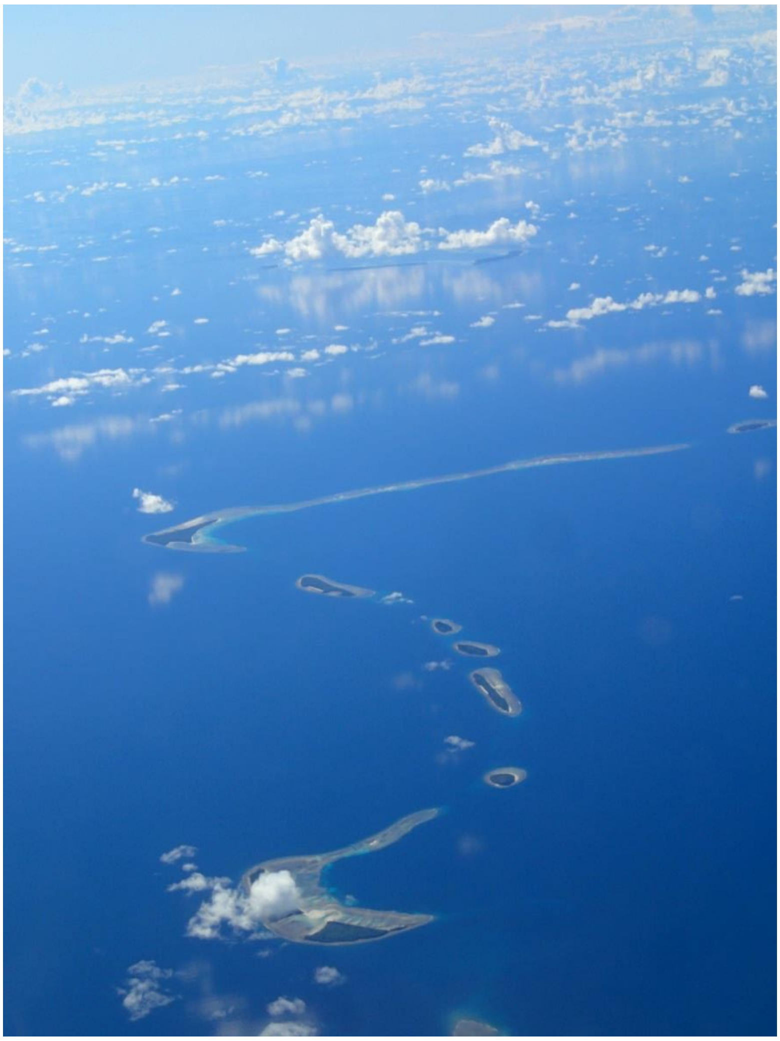


Figure 10. Northern islands of Peros Banhos atoll from Ile de la Passe and Moresby in foreground under cloud to Parasol, Longue, the two Bois Mangues, Monoel and Yeye, and then across to Petite Coquillage, with Salomon atoll in background

Project Report 1 Objectives i-iii: Extending existing long-term coral reef datasets; Integrating Sea Surface Temperature trends into coral reef resilience; Measuring future resilience via juvenile coral abundance

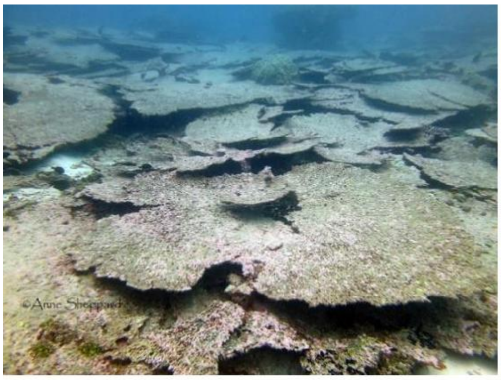
Charles Sheppard and Anne Sheppard

Summary
Across the three northern atolls of Chagos (Peros Banhos, Salomon, Blenheim) reef condition was assessed for mortality following the warming event that occurred in 2015-2016. Methods used were similar to those used in the preceding 20 years and, for comparison, were at the same locations. Cover of the major substrate forms was measured in over 600 quadrats with side of 0.5 metre, a size previously chosen for its optimal ability in such a broad and rapid survey. At the same time, juvenile corals were counted in the same quadrats. Also, eight temperature recorders across the two islanded atolls were recovered and replaced with new ones. It is clear that the coral reef ecosystem has essentially collapsed to about 15 m depth, and the reefs are currently probably in an erosional state.

Cover of corals and other key species groups
Several incremental plots of coral cover data over the years have shown, firstly, the initial good state of coral cover in the 1970s and 1996, followed by the near-collapse after the warming episode of 1998, then a pause of at least three years followed by a rapid recovery of several benthic forms including corals over the following decade. [1] [2] In rough terms, the 1998 warming event reduced the cover of corals to below that needed to maintain the reefs (and islands), and the values gathered in 2017 look similar, or even worse, than the pattern that was seen in 1998.

Broad eye estimates were also made of benthic cover, at each site and depth over areas each greater than 200-300 m^2. Some broad conclusions follow:

1. Corals have declined markedly to at least 15 m depth, and in this depth span the coral ecosystem has essentially collapsed. The reefs are variously covered mainly by dead table corals, or by jumbles of mixed, dead coral skeletons. (Figures 11-12)



Figures 11-12. Dead table corals over 1 m across in a lagoon (left), and a mixed jumble of dead corals on an ocean-facing reef.

[1] Sheppard CRC and 20 others. 2013. British Indian Ocean Territory (the Chagos Archipelago): Setting, Connections and the Marine Protected Area. In: Sheppard (ed) *Coral Reefs of the British Indian Ocean Territories*. Springer. Chapter 17 pp 223-240.
[2] Sheppard CRC and 17 others. 2013, Coral Reefs of the Chagos Archipelago, Indian Ocean. In: Sheppard (ed) *Coral Reefs of the British Indian Ocean Territories*. Springer. Chapter 18 pp 241-252

Notable also are two areas that previously were dominated by soft corals on the southeast aspects of the two islanded atolls that were visited. Here, the soft corals have likewise vanished, but as these leave no skeletal traces, these huge, gently sloping reef surfaces were strangely featureless and devoid of relief or much living benthic forms (Figure 13).

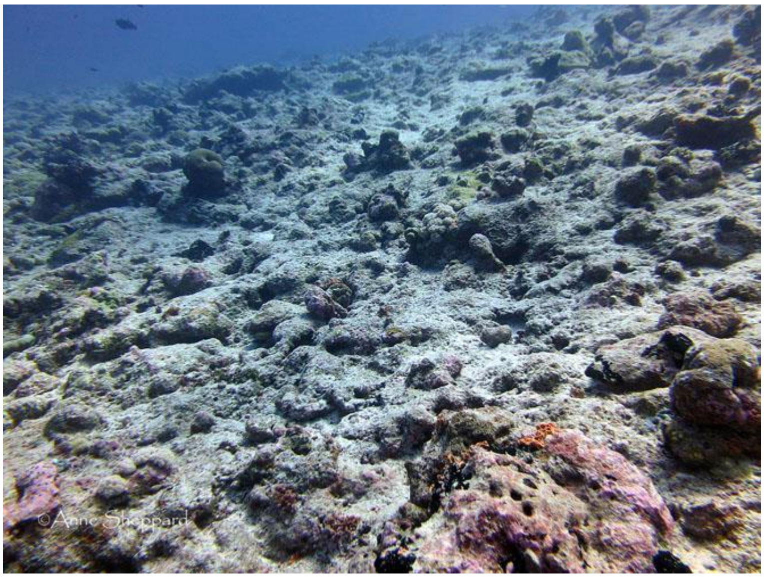


Figure 13. Expanse of southeastern facing reef previously dominated by soft corals, which have disappeared leaving no skeletons.

In all such areas, coral cover is extremely low, being less than one or two percent over large expanses.

2. In 2017 a much increased area was covered by the calcareous algae *Halimeda*, and sometimes by a small but significant percentage of the fleshy green *Caulerpa* (Figure 14-15). Fleshy red seaweeds were common too.

Figures 14-15. Substantially increased growths of green algae were present, most commonly Halimeda *and* Caulerpa*, with several other more fleshy species. Left: lagoon, right: ocean slope. (The table-shaped fauna in these photos are a leafy sponge in the left case and a* Porites *coral which is possibly the species most resistant to temperature rise in the right photo.)*

3. While data collected is inadequate to perform proper calculations, it is clear that these reefs have most likely flipped from being growing into an erosion phase. Sheets of boring sponge that substantially erode the reef rock (mostly *Cliona* spp.) occupy shallow bare areas. Their presence, often in abundance in some areas, has always been the case here, but when corals are absent and the proportion of bare substrate is hugely increased, they have a far greater area on which to settle and burrow (Figure 16).

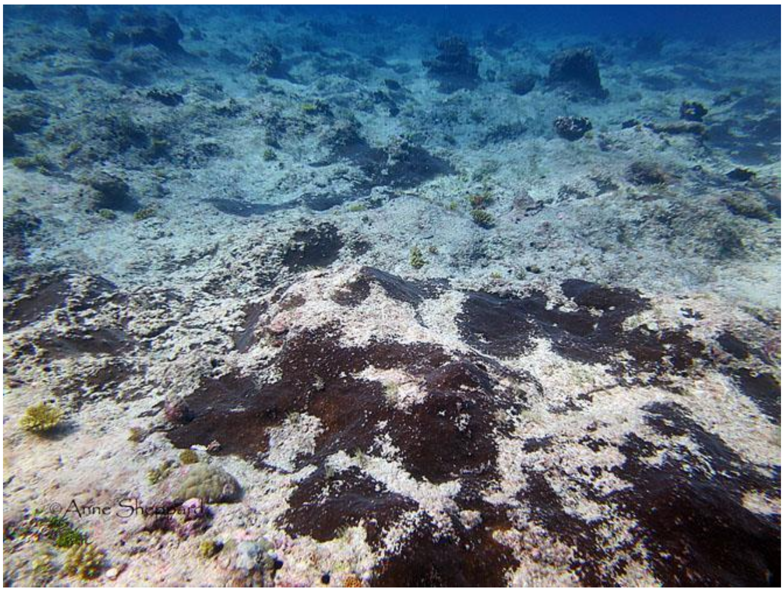


Figure 16. Shallow reefs on ocean-facing slopes are devoid of coral, providing greatly increased substrate to the burrowing and eroding sponge Cliona *and its relatives.*

The Great Chagos Bank and southern atolls were not examined on this expedition, and in the last mass mortality event at least, they were affected more than these northern atolls. At that time, in the north the dead zone extended to about 15 m deep, with cover improving by about 20 m deep, whereas the more southern atolls showed equally severe mortality to much greater depth, 40 m or more in the case of Diego Garcia. This is an important difference given that corals have an optimum depth span: where mortality extends 'only' to the peak diversity zone of about 20 m there is a good chance that survivors of that species might occur deeper and be able to repopulate the shallow zones. But where the mortality is severe to 40 m then there is a likelihood of much less survival of shallow or mid depth species and thus a more limited possibility of any swift recovery. No reef fish estimates were undertaken. Our broad observations suggest that while there were some large schools, the reef fish were considerably depleted at the time of our visit.

Juvenile Corals

Juveniles (defined here as coral colonies less than 15 mm across) are present at most sites, though not usually very abundant. They were measured in 2001 three years after the 1998 event when juveniles were common [3] (especially on dead *Acropora* tables (Figures 17-18), a phenomenon that seems to be universal). Recruit number was next measured in 2006 [4] after total coral cover had

[3] Sheppard C.R.C., Spalding M, Bradshaw C, Wilson S. 2002. Erosion vs. recovery of coral reefs after 1998 El Niño: Chagos reefs, Indian Ocean. *Ambio*. 31:40-48.

[4] Francis B, Sheppard ALS, Sheppard CRC. 2013. Coral juveniles in Chagos: The Next Generation. *Poster given at 2013 conferences of UK Coral Reef Conservation Society*.

returned, at which time the numbers of similarly sized recruits seen on bare substrate were the highest recorded anywhere. Mean numbers at that time ranged from 30-60 m^2 depending on depth. In 2017, results indicate lower numbers (still awaiting detailed analysis), but they were at least present on all reefs.

Corals that were clearly very young but over a year old were also common in 2017, but the intention was to focus on the very young cohort, this being the most indicative of reproductive success (or otherwise) of corals that survived the 2016 warming. Numbers in 2017 are clearly less, unsurprisingly, but they are certainly present, which does suggest that recovery to some degree will occur. The identity of the juveniles did seem to be rather limited to a few species – only a later survey can determine these.

Figures 17-18. Juvenile corals from the previous year and this year. The fragile substrate in these cases (a dead table coral) will probably not allow them to grow into adult corals. Most coral juveniles here are older than 1 year – those of less than a year are too small to see here.

Surviving corals

As has been the case previously in many places in the Indo-Pacific Ocean, boulder corals of the genus *Porites* are the best survivors. On several shallow reefs these form the main, almost only coral component in 2017, and are relatively strongly present to about 3 m depth, surrounded by dead colonies of other shallow water dwelling genera such as *Stylophora, Pocillopo*ra and of course stubby branching forms of *Acropora*.

Common also were examples where adults had small surviving patches, possibly single polyps that were more deeply embedded in their colony, which survived and have started to regrow over their old skeleton (Figures 19). Also present, though less commonly, were examples where only the tops were killed and most of the shaded part survived (because the tops of colonies receive greater illumination and light as well as temperature is involved in the mortality process - Figures 20). From both of these phenomena as well as from juveniles, recovery can occur.

Figures 19-20. Examples of surviving patches. Left, example of surviving single polyps or patches on a Goniastrea *species that have started to grow again. Right, An* Astrea *or* Phymastrea *colony whose shaded parts survived more completely.*

Temperature recorders

Eight temperature loggers, recording at two hour intervals, had been placed in the Northern atolls two and three years ago. Some are parts of a series first started in 2006. All were recovered and replaced with new ones (Figure 21).

Figure 21. New temperature logger in protective pipe attached to the stake at 15 m depth in Peros Banhos lagoon. The surrounding corals are all dead at this location (the live plate in foreground is a sponge).

Because no swapping was carried out in 2016 some considerable luck was present in this recovery as some had been in place for three years. Several were on dangerously low battery level and about to expire, one has been returned to the manufacturers to see if data can be recovered from it, while two had detached from their posts in the very recent past and were found under sand or in a crevice near their stakes! At the time of writing, seven which could be downloaded by the user all showed recoverable temperature data. The data show that in about June last year (uncharacteristically late) the ocean temperatures started to fall to levels more compatible with coral life. Analysis will involve changes in mean seawater temperature over 11 years, changes in number of times temperature exceeded fixed levels (governed by defined, lethal values for corals previously determined for Chagos), and will explore changes, if any, in the extent and frequency of cooling pulses resulting from rising thermoclines of cool water, thought to be an important reason for good coral recovery in this archipelago. [5]

The two temperature loggers in Diego Garcia from 15 and 25 m depth were collected in December 2016, which was very helpful, but they were not replaced and there was no opportunity to do so during our transit through on this expedition. There are some also at these depths on the Great Chagos Bank and Egmont atolls that were not visited, and which will most likely expire or become lost during 2017. It has always been the long time series of data that are of value, and hopefully an opportunity to attend to these might be possible before they or their data are lost.

This is a suitable time, after 11 years of records to make available this very detailed temperature set for the wider community, and this is being done.

Apparent losses of some species

It has been noted before that the large massive coral *Diploastrea heliopora* (Figure 22) which used to be common in lagoons especially in 1996 and before, has never been recorded since the 1998 warming.[6]

Figure 22. The massive coral Diploastrea heliopora *museum specimen from before 1998.*

[5] Sheppard CRC 2009. Large temperature plunges recorded by data loggers at different depths on an Indian Ocean atoll: comparison with satellite data and relevance to coral refuges. *Coral reefs* 28:399-403.
[6] We collected a sample before this which is in the Natural History Museum (Accession number nhm2001.1010)

All species of the genus *Seriatopora* (Figure 23) likewise vanished after 1998 but then began to recover in recent years; however, it has now disappeared again. (This genus also disappeared from the Maldives and has still not recovered since 1998.)

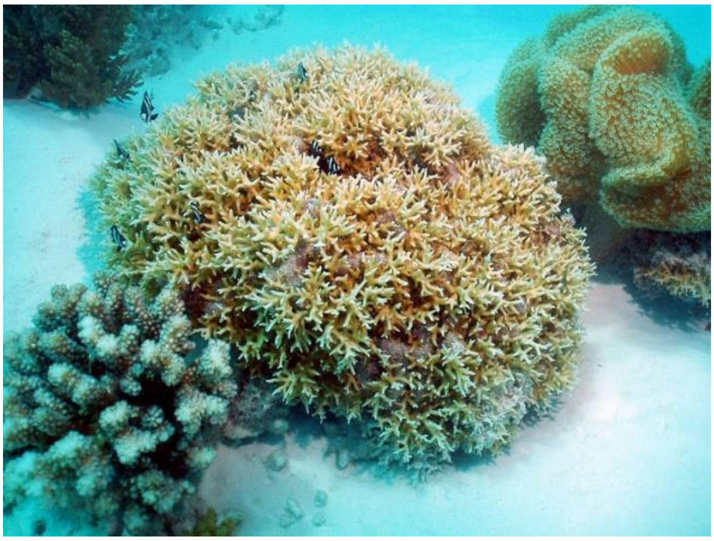


Figure 23. Seriatopora hystrix*, formerly a common lagoon and sheltered water coral.*

The coral *Ctenella chagius* (Figure 24) which used to be common in 1996 and before was severely reduced by the 1998 event but was seen in lower numbers subsequently, but in 2017 no live colonies were seen at all, by any diver at any depth or site. This, commonly known as the 'Chagos brain coral' is a near-endemic species (one colony was photographed by Dr David Obura from St Brandon banks to the west – photo dated 2012). The depth range of this coral is mainly 5-25 metres depth on both ocean reefs and lagoons. Thus its present demise is alarming.

Figure 24. Colonies of the 'Chagos Brain coral' Ctenella chagius*. This was not seen alive at any site in 2017.*

Prognosis

Considerable work today is being given to the declining condition of coral reefs around the world, and also of the effect this is already having on coral islands. [7] Numerous studies document demise of reefs in different areas and a few have predicted dates of the demise of reefs in various areas. The recent massive mortality on the Great Barrier Reef, for example, has gained considerable publicity [8] where it was shown that recent warming has essentially swamped all other local conservation measures as well as any ability of corals to acclimate to the gradually warming seas, leading to overwhelming demise.

Recovery of reefs, even where this leads to different dominant species, is only possible when that recovery is not interrupted too soon by further warming events. Predictions have been derived for Chagos reefs on two occasions: firstly in 2003 it was predicted using Hadley Centre data together with the fact that corals need to be an average of five years old to reproduce, that the mid-2020s would see mass coral mortality in the Chagos reefs about every five years, i.e. repeat killing would recur before they could properly re-establish after the previous one. [9] Secondly and, more recently in 2016, it was predicted that severe bleaching temperatures in the Chagos would become *annual* around 2041.[10] Since it is clear that a terminal state for corals will occur at frequencies less than annual (since corals need to be a few years old before they reproduce) these results roughly support the earlier predictions.

It is clear enough that local management can do little about this on a local (Territory) level, since these warming events swamp any local management effects, [8] and also swamp any ability of corals to acclimate to warmer conditions. In a Territory like BIOT, where the islands' maintenance is entirely dependent on reef growth, this is critical. However, it is also clear that *recovery* from any one mortality event is determined by different factors from the one that caused the mortality in the first place. Recovery of a killed reef, when it occurs at all, takes place when the higher temperature has abated. Impediments to reproduction and recovery do include a range of local stressors which can be managed in Chagos atolls – sedimentation, sewage, fishing, industrial pollution, shoreline disturbance etc. Continuing these controls will be essential to prolonging the chances of successful reef recovery after this and future mortalities.

[7] For brief summary of islands: Hubbard D and 17 others. 2014. Island outlook: Warm and swampy. *Science*, 345: 1461.

[8] Hughes and 35 others. 2017. Global warming and recurrent mass bleaching of corals. *Nature* 543:373-377.

[9] Sheppard, C.R.C. 2003. Predicted recurrences of mass coral mortality in the Indian Ocean. *Nature* 425:294-297.

[10] Van Hooidonk and 8 others. Local-scale projections of coral reef futures and implications of the Paris Agreement. *Scientific Reports*. 6:39666 | DOI: 10.1038/srep39666

Project Report 1 Objective iv: Video Archive for Long Term Monitoring of Coral Reef Benthic Communities

John Turner and Ronan Roche, School of Ocean Sciences, Bangor University

Introduction

During the 2017 Expedition, John Turner and Ronan Roche continued to develop a video archive of coral reef benthic community structure across depths at permanent monitoring sites (Figure 25) throughout the northern atolls, building upon previous work. The aim of the study is to produce a record that can be analysed to assess change when compared with video records made at sites first recorded in 2006, and again in 2013, 2014, 2015 and 2016. A video archive provides the opportunity to revisit sites in time to assess factors that perhaps have only recently become of note (eg. disease), and provides a visual baseline allowing newly engaged scientists to compare coral reef community structure in time.

Figure 25. Video survey of coral reef community structure

The reefs provide a 'bench mark' for observing the effect of changing conditions in the absence of direct human impact, and indicate how functional reef communities respond to these conditions. Previous studies have shown that benthic cover, especially of hard corals, reduced following bleaching related mortality after warming events in 1997, 2003 and 2005 but that *Acropora* corals especially re-established across the shallow reef slopes and terraces. Although benthic cover measurements were made on the earliest scientific expeditions, photography and then film techniques were limited, and it is difficult to compare the state of today's reef communities with those before because little imagery exists. However recent investigations have shown that visual surveys and video surveys provide comparable measures of cover, and therefore a video archive can provide important data for assessing change. Video recording has a number of advantages over traditional survey techniques; the main advantage being that a relatively large tract of reef (up to 500 m^2) can be recorded during one dive. Around 200 randomly grabbed frames (equivalent to sampling from quadrats) can be assessed from the video record of homogeneous reef tracts which promotes representative sampling. Imagery can be then be analysed in the laboratory with access to play back, identification books and guides, and without the constraints imposed on an observer underwater.

Methodology

Figure 26. High Definition camera in housing with wide angle port, LED lights, laser scale and Go-Pro camera recording digital images every 30 seconds.

16 Sites on 3 atolls (Peros Banhos, Salomon, Blenheim) were surveyed during this expedition as described above, covering approximately 8000 m^2 in total. Ten minute sequences of video were recorded across 5 m depth intervals from 25 m depth to 5 m depth using a Sony HDR 550 video camera and/or a Canon GS30 camera in a Light and Motion Blue Fin housing equipped with a Fathom 90 wide angle port lens and Sola LED video lights for deeper depths and red filter for mid depths. Scale was provided by two 638 nm (red) wavelength lasers mounted below the camera to project dots 10 cm apart on the video image. Approximately 80 wide angle habitat images were recorded randomly on each dive by a Go Pro Hero camera with red filter and set to record high definition images at 30 second intervals (Figure 26). This year, two cameras were used over slightly different tracts, allowing us to compare reproducibility and test sampling rates.

Analysis

Video sequences from the four 5 m depth intervals (5-10 m, 10-15m, 15-20m and 20-25m) are being compared between years over the next few months. Fifty frame grabs are extracted randomly from each depth interval at each site (using Pinnacle Studio 10 software), and these are imported into Coral Point Count with Excel Extensions (CPCe, NCRI Florida) and overlaid by 16 randomly generated points (Figure 27). The substrate, benthic life form, and where appropriate genus and species underlying each point are automatically collated in an Excel spreadsheet using tab keys in CPCe and the spreadsheet data is then imported into statistical software for analysis. Frame grabs can be moved frame by frame to assist in identification, and the 'truthing' images are used to identify species where video image resolution is insufficient. The Go-Pro images provide context and allow reef descriptions. Tissue loss, discolouration, disease and mortality are recorded by playing each video through and recording frequency.

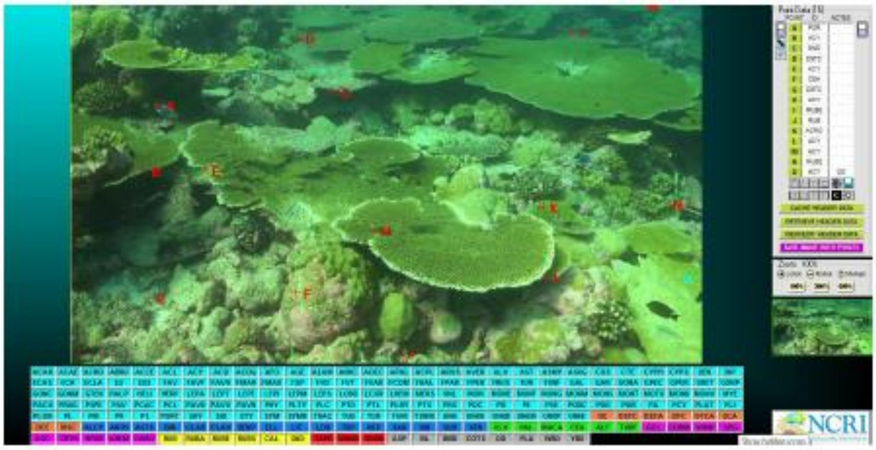


Figure 27. Images analysis using CPCe software. Substrate or life form under each point are recorded by entering the relevant category via the tabs at the bottom of the screen to construct an Excel spreadsheet displaying frequency (%).

The results can be used to show comparisons of coral cover between atolls (Figure 28), and to drill down into the data, for example to show coral genera cover by atoll (Figure 29) or soft coral by reef type (Figure 30) or macoalgae cover with depth (Figure 31) (here for 2015 before the warming event)

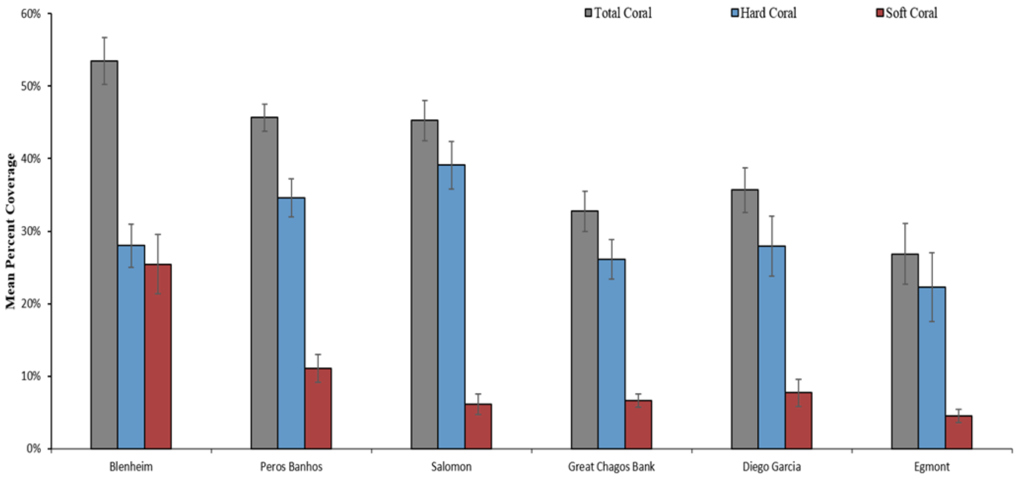


Figure 28.Total cover, hard coral cover and soft coral on atolls in 2015 before the warming event

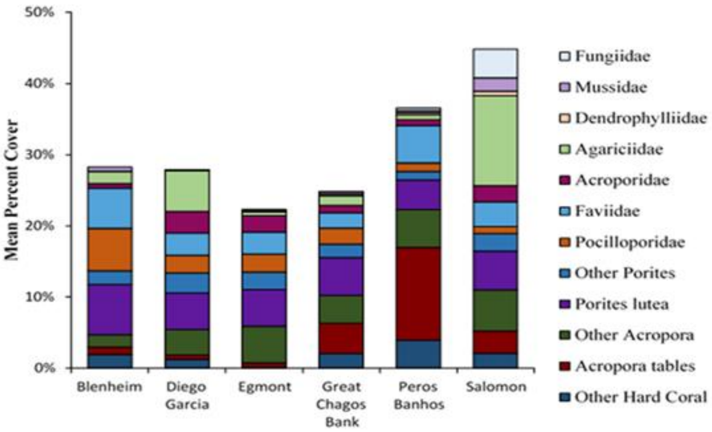


Figure 29. Coral genera cover by atoll in 2015 pre bleaching

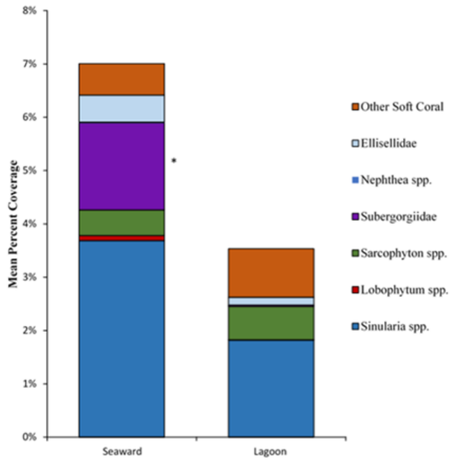


Figure 30. Soft coral by reef type in 2015

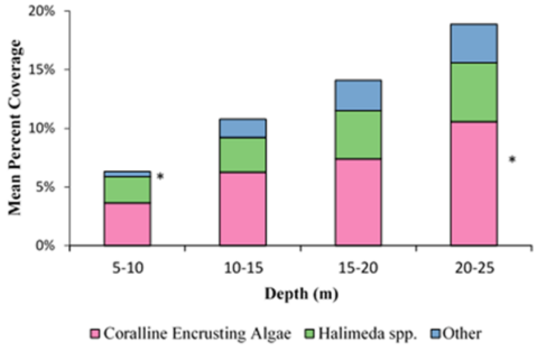


Figure 31. Macroalgae by depth in 2015

Results from surveys conducted in 2016 following the 2015 warming event (but before the 2016 bleaching event) identified the severe loss of coral cover (Figure 32), and a comparison with long term data of coral cover shows that the coral reefs were already 'set back' to levels of coral cover seen in 2001 after the 1997/98 warming event (Figure 33).

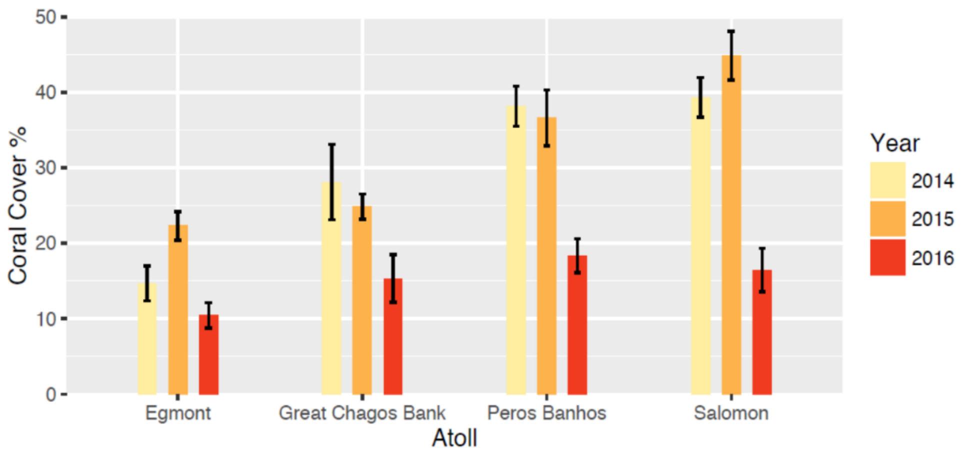


Figure 32. Coral cover by atoll in 2014, 2015 and 2016

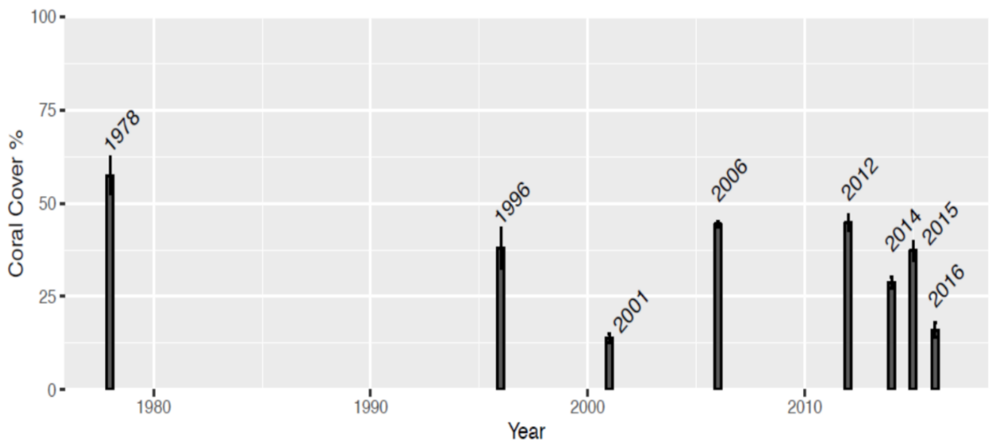


Figure 33. Coral cover by year from visual assessment (1978, 1996, 2001, 2012) and from video archive (2006, 2014, 2015, 2016)

A clear pattern emerged in 2017 after assessing 16 sites across 3 atolls, including a mixture of exposed and more protected seaward reefs, lagoon reefs and lagoon patch reefs to a depth of 25 m. Branching and tabular corals, such as *Pocillopora* and *Acropora* were mostly dead in shallow water above about 15 m (Figure 34). Diseased corals were rarely seen. The smaller branching colonies were still standing, but many of the table corals had collapsed, potentially forming new calcareous substrate which will eventually become cemented together, and form a suitable surface for coral recruits. The calcified green macroalga *Halimeda* had colonised spaces between corals (Figure 35). In more exposed locations, the tables had fallen down the reef sleep (Figure 36), often being overturned, and in very exposed sites, they had been swept off the reef entirely, taking the newly settled recruits with them. Corals surviving in the shallows were most frequently colonies of *Porites* (Figure 37) including the extremely large (>5m diameter) colonies that could be many hundreds of years old, but many of these showed paling due to bleaching and in some, partial mortality of parts of the colony (Figure 38). A different picture emerges at deeper depths, where coral communities were generally in good health (Figure 39). Below 15 m on seaward reef slopes and lagoon (leeward) reefs, most corals are surviving, although some instances of partial bleaching and mortality were evident. Noticeable on exposed seaward reefs were colder water upsurges at depth that may be helping to cool the corals. These are mostly the same species as those found at shallow depths, and may be an important continued source of larvae for future recruitment. Detailed analysis of the video material will elaborate these observations

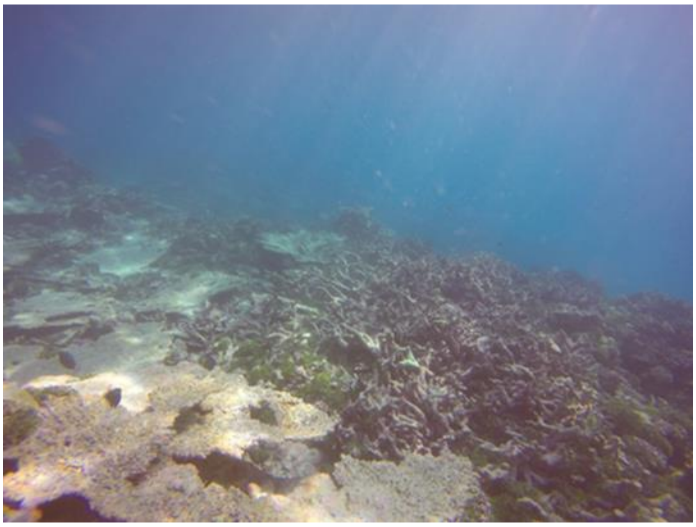


Figure 34. Dead branching and tabular corals in shallow water, Ile Diamont, Peros Banhos

Figure 35. Green calcareous Halimeda *growing amongst dead standing coral, Ile Diamont, Peros Banhos*

Figure 36. Exposed reef with low living coral cover at Blenheim Reef East.This reef previously had high cover of soft corals.

*Figure 37.*Acropor*a table fallen down reef slope harbouring new recruits, Ile de la Passe, Salomon*

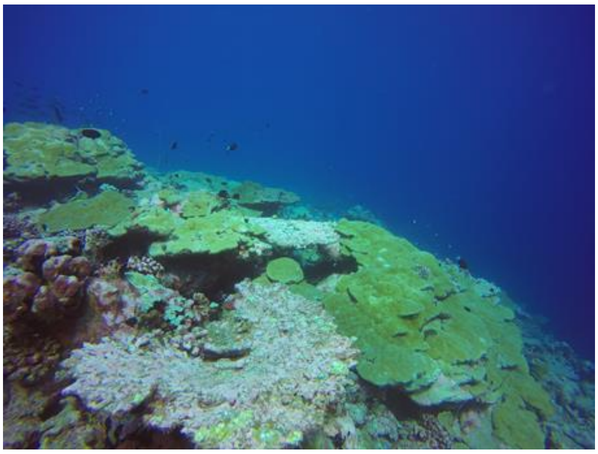


Figure 38. Porite*s colonies survive in shallow waters, ile de la Passe, Salomon*

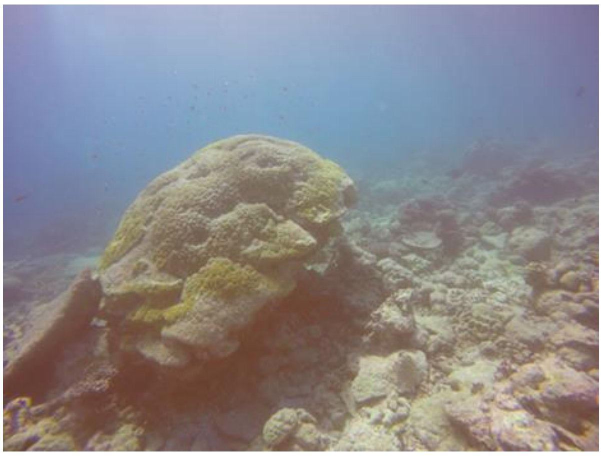


Figure 39. Large Porites *with paling and partial mortality, Ile Diamont, Peros Banhos*

Figure 40. Corals below 15m depth generally in good health and potentially providing a source of recruitment, ile de la Passe, Peros Banhos

Project Report 1 Objective v: Three-dimensional determination of reef structural complexity

Daniel Bayley (UCL/ZSL), Andrew Mogg (SAMS) & Dominic Andradi Brown (University of Oxford)

Introduction

The physical structure of coral reef habitats is known to be a strong driver of the abundance and diversity of associated organisms (Graham & Nash 2013; Darling *et al.* 2017), and furthermore gives a clear indication of a reef's health and resilience to disturbance (Alvarez-Filip *et al.* 2009; Graham *et al.* 2015). Alongside the morphological structure of the reef, the composition of reef organisms gives an indication of the level of carbonate accretion or erosion occurring. This balance is an important metric for reef health and ecosystem functioning (Perry *et al.* 2015). 'Structure from Motion' (SfM) photogrammetry (Westoby *et al.* 2012) has recently begun to be applied to marine systems in an attempt to better quantify and measure reef forms for such analyses (Burns *et al.* 2015). The SfM methodology creates a photogrammetrically derived digital surface model of the reef from imagery collected in-situ which can then be analysed quantitatively in a number of ways. Rapid capture of the 3D environment (using in-water SfM photogrammetry) was carried out at in the Northern atolls of the Chagos archipelago immediately following the 2016 El Niño event and then one year following this heating episode (in April 2017), to quantify the resulting disturbance effects on the reef physical structure, composition and net level of carbonate production.

Methods

Photogrammetric surveys were performed at sixteen sites in three atolls to the north of the Grand Chagos Bank, constituting approximately 9000 m^2 of high resolution modelled reef, and approximately 18000 m^2 of lower resolution context imagery. Two 10 m x 10 m (100 m^2) quadrats were surveyed at each site with the exception of Ile du Coin and Petite Coquillage, where only one quadrat was obtained. The quadrats were oriented broadly along cardinal points, from a central fluorescently marked rebar on reef flat / crest areas at 5 – 10 m depth within both lagoon and seaward sites. The two survey quadrats at each site were diametrically opposed to maximise independence whilst also maximising the possibility of successful re-discovery and survey upon successive visits. The corners of both quadrats within each site were marked by brightly coloured y-form aluminium tent pegs to further aid future repeat surveys (Figure 41).

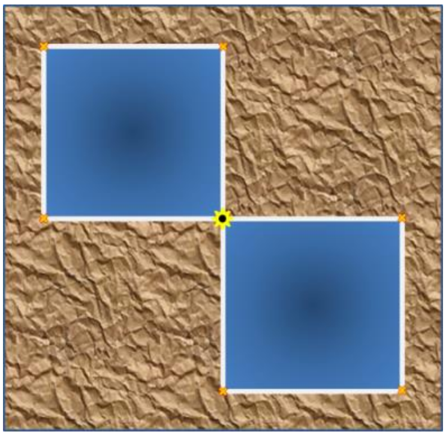


Figure 41 . Detailing the typical arrangement of survey quadrats across the reef within each site surveyed in 2017. Each blue box represents a 10 x 10 m quadrat, with markers on each corner shown in yellow. Photo shows underwater layout.

High -resolution (sub-cm) photogrammetric surveys of each quadrat were performed using a Nikon D750 camera with 20 mm wide-angle Nikor lens, within a domed Subal housing, under ambient light conditions. Camera settings were unique to each site and required adjustment by the photographer throughout the dive. Broader scale, > 1 cm resolution surveys were performed using a GoPro Hero 3+ on timelapse setting to give context at every site except Petite Coquillage and Blenheim. The context surveys varied in planar area depending on substrate and dive conditions, but were generally 250-400 m^2. Both high-resolution and context surveys were performed using a 'boustrophedonic' or lawn-mower pattern, to facilitate the maximum linear and lateral overlap between images of individual areas of substrate within the most efficient time. All surveys were given scale and orientation by the use of a 60 cm tripod-mounted spirit level with a compass placed at a known depth (measured using a dive computer) and a number of scale markers of known length (Figure 42). The spirit level enabled the extrapolation of depth throughout the resultant photogrammetric models as well as the determination of slope angle and positioning within future bathymetric maps. The inclusion of scale markers throughout the measured area reduces the risk of errors in measurements due to photogrammetric extrapolation.

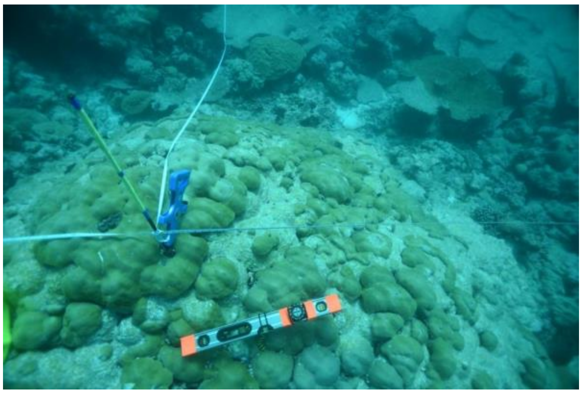


Figure 42. Illustrating the scale and xyz orientation marker for a typical survey. The 1 m rebar marker placed at the centre of each survey area is also shown.

Survey images (between 400-600 per 100 m^2 high-resolution quadrat, and around 1000 per 400 m^2 context survey) were initially processed aboard the *Grampian Frontier* on a pair of mobile workstations (Dell, Latitude E6540 and XPS15 9550; Intel(R) Core(TM) i7-4810MQ CPU @ 2.80GHz, 2801 Mhz, 4 Core(s), 8 Logical Processor(s); 32 Gb RAM) before being prepared for further processing to the highest tolerances on a lab-based cluster. Initial high resolution results are shown in Figure 43.

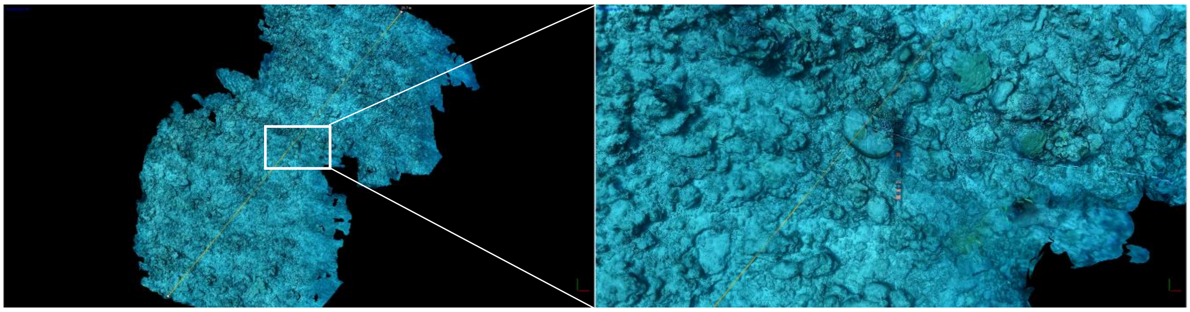


Figure 43. Photogrammetric models of 10 x 10 replicate survey quadrats. Total three dimensional area in excess of 600 m²

Planned analysis

The survey data collected will be used in conjunction with data collected at 19 sites across the same area in April 2016 (preceding the warming episode experienced last year) to reconstruct detailed 3D models of each monitoring site. Metrics of reef 3D structural complexity, growth-form and volume will be compared across sites and between years to quantify changes and differences within the surveyed areas as a result of environment disturbance. Additionally, reef carbonate budget analysis will be conducted on each high-resolution quadrat to assess the rate at which the reef is growing its hard carbonate structure relative to the rate of biological or physical erosion.

Coral Tagging

Following the widespread loss of coral cover in the Chagos Archipelago it is important to understand recovery patterns. While the long-term benthic monitoring captures broader trends across the reef scape level, it is hard to assess recovery at an individual coral colony level. To enable patterns at an individual coral colony scale to be assessed we tagged individual coral colonies on the reefs of Chagos, allowing their survival and growth rates to be tracked in future expeditions. *Acropora* or *Pocillopora* colonies were identified close to the rebar marker stakes (established for the larger 3D modelling areas) to aid in future identification. A photo was taken from above of the coral colony alongside a scale within the image, allowing planar area to be calculated (Figure 44). The colony surface was then filmed from multiple sides/angles using a GoPro Hero 4 Black, allowing a 3D model to be constructed using structure-from-motion 3D modelling techniques. Planar images will allow changes in the 2D area occupied by the coral colony to be compared through time, while the 3D structure-from-motion model will allow fine scale measurements of changes in volume. A numbered plastic cattle tag was then cable tied to the reef either through an existing hole or around a suitable piece of reef structure, taking care that the cable tie and tag would only have contact with bare dead reef substrate and not affect any live coral. In total 99 coral colonies were tagged across the northern atolls. This represents a large dataset allowing patterns in recovery of *Acropora* or *Pocillopora* corals to be tracked. All data has been backed up, and is ready to be analysed and compared to future assessments of these colonies from surveys taken over the coming years.

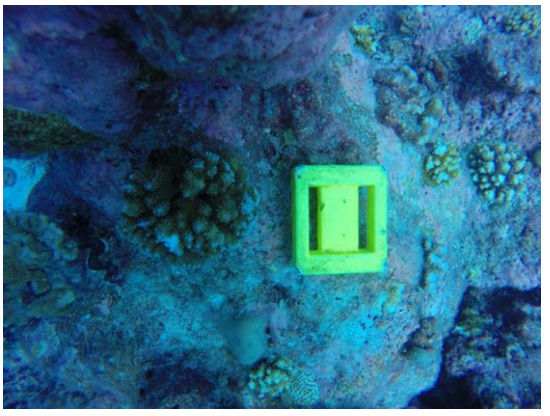


Figure 44. Planar assessment of Acropora *colonies on the reef. These colonies were then tagged to allow growth rates to be assessed on future expeditions*.

Fluorescence photogrammetry

In addition to the large scale photogrammetric surveys detailed above, a small scale pilot study was undertaken at Ile du Coin (Peros Banhos) to investigate the use of fluorescence photogrammetry for determining the abundance of macro-scale coral recruits on complex substrates. Five areas of substrate, each of roughly 600-700 cm^2, were photographed using a Canon G9X camera fitted with a 450 nm wavelength pass filter (Nightsea) and illuminated with a Sea and Sea YS-02 strobe with a 450 nm wavelength excitation filter (Nightsea). Camera settings were f/6.3, 1/250 and ISO 640. Around 20 photos were taken per area, and scaled using a slate tile (2.2 cm x 2.2 cm) wrapped in auto-fluorescent tape. Images were processed as for the larger scale surveys, above. Initial results revealed the potential to record and measure fluorescent coral juveniles at a millimetre scale (Figure 45).

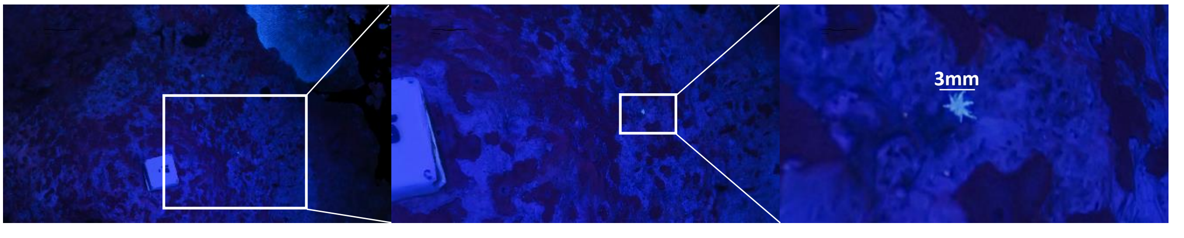


Figure 45. Multiple juvenile coral colonies imaged using a blue light and fluorescent filter. 2.2 cm scale tile shown.

Coral micro-CT

Twenty samples of (~ 15 cm diameter) dead massive growth-form coral samples were collected across six sites. Micro-CT, a non-destructive X-ray technique, will be used to extract historical coral growth and bioerosion rates from each sample in order to build up a comprehensive baseline of coral health across periods of environmental change. In addition to growth measurements, characterisation of internal bio-eroder communities and measurement of species-specific tissue thickness will be used as proxies for colony and reef health and added to existing specimens held at the Natural History Museum in London, collected at various periods from 1880 to 1978.

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Project 2: Rats and Islands

Dr Grant Harper, Biodiversity Restoration Ltd and Peter Carr, ZSL and University of Exeter

Introduction

Figure 46. Ile Vache Marine, Peros Banhos has been successfully cleared of rats

The terrestrial element was in part funded by a grant from CCT and tasked to assess the 2014 Darwin Plus funded rat eradication operation conducted on Ile Vache Marine, Peros Banhos. Secondary tasks were to: (1). Assess the 2014 rat eradication experiment conducted on Iles Sel and Jacobin in the Solomon Islands. (2) If time permitted to assess six islands that Carr and Harper (2015)[1] assessed as "uncertain" as to the presence of rats. (3) Conduct a bait application trial to be carried out on either Ile Yéyé or Manoel, Peros Banhos. In addition Carr would collect breeding booby (*Sulidae* spp.) data as additional material for a seabird project being administered by the Zoological Society of London (ZSL). The primary mission was achieved. Secondary task (1) was successfully completed. These were of the highest importance. Secondary tasks (2) and (3) were only partially completed due to the necessary movements of the ship in order to maximise the overall expedition outputs. Some breeding seabird data was collected and was an additional unexpected bonus considering the time constraints.

(i) Rat eradication – Ile Vache Marine (Peros Banhos)

Dr. Grant Harper, contracted by CCT as a recognised international expert in invasive mammal eradication operations concluded that the Darwin Plus funded rat eradication operation on Ile Vache Marine had been a success. Ship rats *Rattus rattus* were no longer present on the island.

This conclusion was drawn on witnessing the following cumulative evidence:

- A ground nesting seabird, greater-crested tern, was in a continuous breeding cycle on the island. Distributed throughout the sandy beach areas of the island were eggs, small (3 – 7 day old) and large (4 – 6 week old) chicks. There were 25 – 30 pairs in total breeding. This evidence by itself is not conclusive, this species is robust and can breed on rat-infested islands.
- There had been an increase in the number of arboreal breeding seabird species on the island. Four pairs of brown noddy were recorded with a chick each. At least two pairs of common white tern (possibly up to eight) were breeding on the island and had a single chick each. This is an increase in number from any of the numerous previous surveys. Again this is not conclusive, both of these species are known to nest on rat-infested islands.
- There were a proliferation of seeds germinating throughout the island. Rats have a devastating impact upon seed germination, often completely preventing any rejuvenation of plants for numbers of years, especially on small islands where food is limited. This was a strong indicator that no rats were present.
- There were uneaten fruits and flowers on the ground and on bushes and trees. Again, rats have a massive impact upon both fruit and flowers. Ship rats, known to be accomplished climbers are particularly effective at suppressing fruit dispersal, often eating both fruit and flowers direct from bushes and trees. This was another strong indicator of success.
- No rats were witnessed at baited stations. Rats will come to baited stations, particularly at dawn, dusk and through the night. Two extensive (fruit and peanut butter) baited stations were established and watched extensively over a 24 hour period. No rats were seen in their vicinity and this was seen as a very strong indicator that rats were not present. (This is

[1] Carr, P. and Harper, G.A., 2015. The Distribution of Ship Rat *Rattus rattus* in the Chagos Archipelago. Chagos News 47. The Periodical Newsletter of the Chagos Conservation Trust and Chagos Conservation Trust US.

especially so on a small tropical island where they would be expected in the campsite searching for food, let alone at bait stations).

- No rats were trapped in 50 rat traps set overnight. This is self-explanatory. Whilst there is an expected impact upon baited snap-traps by land crabs, the population level of rats, had the eradication operation failed, would have expected to be at a sufficient level that a few rats would have been caught in traps overnight.
- No evidence of rats chewing on wax “gnaw sticks” was witnessed. Gnaw sticks are a standard weapon in a rat eradicators arsenal. These are sited on likely rat food foraging routes and have a waxen end that rats chew on. The denture of rats is such that they leave a distinctive gnaw mark.
- No rats were recorded in lamplight searches of the island. This was deemed the conclusive piece of evidence. Using a high-powered torch the island was inspected in the dark. The glow from a rat’s eyes is very distinctive and easily detectable. None were noted from throughout the interior of the island.

(ii) Rat reinvasion -Islets Sel and Jacobin (Salomon)

These two tiny Islets in the Solomon Island atoll had a rat eradication experiment conducted on them in August 2014. The essence of the experiment was to measure how long it would take for rats to reinvade these Islets following an eradication. The aim of the experiment was to demonstrate that CCT had the expertise to manage rat eradication projects in the Chagos and, that in the Solomon Islands (and elsewhere in the Chagos) groups of islands would need to have eradication operations conducted near-simultaneously due to the high probability of reinvasion from nearby islands.

The conclusion drawn by Dr. Harper for similar cumulative observations as for Ile Vache Marine is that both islands remained rat-free.

(iii) Bait Application Rates in the British Indian Ocean Territory &
(iv) Status of rats on other islands

Bait acceptance trials are deemed essential to eradication efforts on tropical islands, particularly where land crabs prevail. These trials provide an indication of the amount of bait required for successful eradication. Bait should be available for four nights to ensure rats have maximum access to poison bait during an eradication operation. They also give an indication of the abundance of rats present. This is essential background information to enhance the probability of success of future rat eradication operations in BIOT. Harper and Carr (2015)[2] have conducted bait application trials on

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[2] Harper, G.A. and Carr, P. 2015. An initial trial to determine an effective rat bait application rate at Diego Garcia, British Indian Ocean Territory. Chagos News 47. The Periodical Newsletter of the Chagos Conservation Trust and Chagos Conservation Trust US.

[3] Carr, P. and Harper, G.A., 2015. The Distribution of Ship Rat *Rattus rattus* in the Chagos Archipelago. Chagos News 47. The Periodical Newsletter of the Chagos Conservation Trust and Chagos Conservation Trust US.

Diego Garcia for the NAVFAC Environmental Department as part of feasibility studies in to eradicating rats from Chagos islands, but trials at the islands of interest are more relevant.

If only a single or pair of islands are to have rats eradicated (probably the most likely next step in the Chagos) then Yéyé and Manoel in northeastern Peros Banhos are the obvious choices as they are the only islands with rats in a series of rat-free atolls. Therefore, these islands were chosen for the bait application experiment. A trial grid was laid on Ile Yéyé on 12 April. It consisted of a 100m x 100m (1ha) plot with throwing points on a 25m x 25m grid in an area of 'coconut chaos'. Non-toxic bait (Pestoff 20R) was spread at a rate of 22kg/ha respectively on the plot. The numbers of baits in each subplot were counted at the start of the trial and each day. It was intended that this be continued for at least four nights but was truncated due to conflicting demands for the use of the support vessel.

The bait trial proved to be useful but not conclusive. About half the bait was gone after two nights which suggests that there will still be bait available on the forth night. If possible a second trial should be conducted during the CAREX expedition to confirm this assumption.

The status of rats on Ile Manoel was unclear so 20 rats traps were deployed along with 12 wax tags within the coconut chaos. These were run for two nights. No rats were trapped and few traps were sprung. No wax tags were chewed by rats. This information, along with the lack of rats trapped by Carr in 2010 (Carr & Harper 2015)[3] suggests there are no rats present on Ile Manoel but should be confirmed with more extensive trapping where possible. It may be useful to conduct more rat trapping during the CAREX expedition when more time is likely to be available.

(v) Census of Breeding Booby (Sulidae) Populations

As part of the Chagos Seabird Project, Carr for his PhD has been looking at over 40 years of breeding seabird data from BIOT. There appear to be exceptional circumstances occurring there with two species, Red-footed and Brown Booby increasing in both breeding numbers and breeding distribution. This is likely to be the only site in the world where this is occurring. It was hoped that where time, ship location and expedition programme allowed, further, current information on the breeding distribution and status of these two seabirds could be gathered.

Four IUCN designated or proposed Important Bird Areas (IBAs) were visited during the expedition had their breeding seabirds counted: Iles Parasol, Longue, Grand Bois Mangue and Grand Coquillage and one further island known to be a prime breeding island for Red-footed Booby, Moresby Island.

From this snapshot it could not be confirmed that either booby had increased in abundance or range. The data gathered on these islands is to be used in Carr's PhD thesis.

Project 3: Hydrophone testing

Emily Smith & Tom Letessier (ZSL) and Robin Burns and Stephen Hipsey (JASCO ltd)

Summary

ZSL and JASCO Applied Sciences trialled underwater acoustic sensors to detect vessels within the northern atolls of the BIOT MPA. This research supports BIOTAs involvement to trial different technologies to help monitor and enforce Illegal, Unreported and Unregulated (IUU) fishing in the overseas territories. Vessel detection algorithms detected low frequency engine tones against the background environment, and extensive surveys identified that an autonomous buoy based system is the optimum deployment that can be scaled across the atolls in the MPA. An autonomous multi-channel acoustic recorder was deployed in Peros Banhos to collect baseline acoustic data for a period of 5 months (2017-04 to 2017-09). This dataset will characterise the ambient noise spectrum to inform the development of vessel detection software. The acoustic dataset will also extract marine mammal vocalisations and clicks, supporting the study of taxonomic groups, distribution and density within the MPA. The results validate ZSL's research to date, and a proposal will be submitted to collaborate with BIOTA to monitor the use of low cost technologies to help enforce the BIOT MPA.

Introduction

The British Indian Ocean Territory (BIOT) administration and the Zoological Society of London are collaborating to implement Instant Detect (ID) to monitor and protect the UK Overseas Territories' Marine Protected Areas (MPAs). ZSL's Instant Detect multi-sensor alarm system is designed to provide real-time intelligence on illegal activity. Already deployed across eight sites internationally, the system connects to a range of low power sensors that detect human presence and send instant alerts to an enforcement team. The system communicates via the Iridium Satellite network at a discounted conservation rate from anywhere in the world.

In 2016, ZSL completed an initial three month proof of concept study to research fixed underwater acoustic sensors (or hydrophones) as a method to detect illegal fishing vessels in BIOT. The illegal fishing vessels reported within the BIOT MPA are predominately 10-15 meters in length, multi-purpose vessels with wooden hulls. These vessels are unlikely to adopt AIS (Automatic Identification System) and have weak radar detection signatures, often making them difficult to detect by the British Patrol Vessel. The underwater noise generated by engines and the hull offers a reliable detection signature.

Peros Banhos and Salomon Atoll were selected by BIOTA as initial test locations, with the aim to roll out to illegal fishing hotspots across the archipelago and other overseas territories. This project is part of a BIOTA wider programme to trial different technologies to help monitor and enforce overseas protected areas from illegal undocumented unregulated (IUU) fishing.

Following this research phase, ZSL is recommending a solution jointly developed by ZSL and JASCO Applied Sciences (hereinafter referred to as JASCO). The solution consists of a Vessel Engine Detection System (Figure 47), where sophisticated in-situ algorithms distinguish vessel patterns and send real-time alerts to an enforcement team. This innovative technology boosts BIOTA's capacity to detect threats, gather evidence and deploy a response team to protect the rich marine life in the MPA. The Proof of Concept study report and Letters of Agreement can be made available on request.

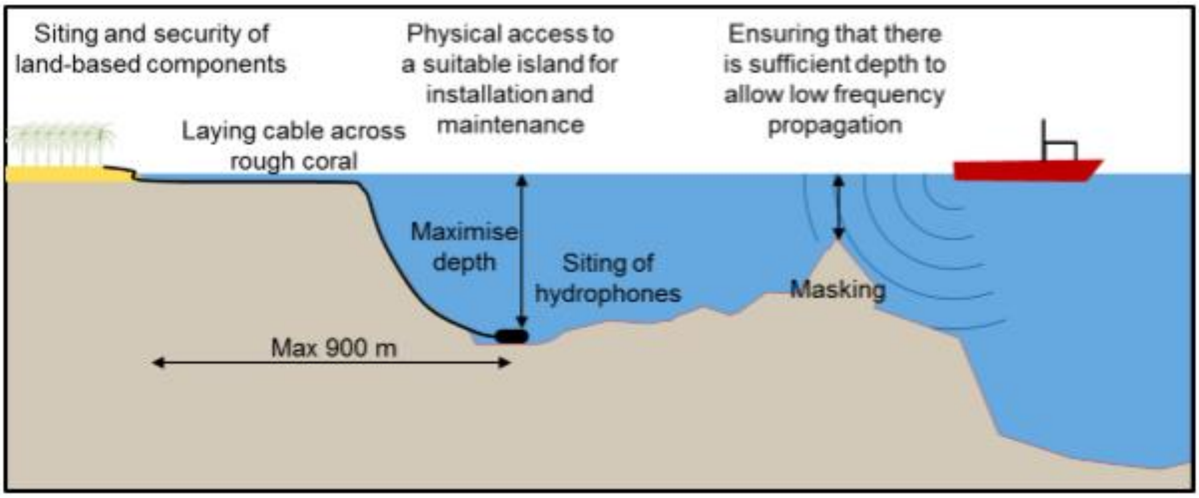

Figure 47. Proposed Vessel Engine Detection System

Methodology

Vessel detection algorithm testing

Vessel engine tones were recorded in Peros Banhos lagoons from 9th to 14th using the JASCO Ocean Sound Meter and a GTI M3 hydrophone (Figure 48). The hydrophone was deployed from the side of the BPV daughter craft using an anchored line and subsurface float to reduce mooring noise. BPV anchorage depth was limited to 30m. The BIOT Patrol vessel, *Grampian Frontier*, was used as a source vessel. The vessel has a conventional shaft driven main propulsion plant comprised of two main engines, gearbox and shaft drive. Only one engine at 1-2 knots was used during the testing to replicate the tones and intensity expected in 10-15m fishing vessel. The recording location, duration and distance to the BPV was limited to the daughter craft availability, crew rest regulations and safety limitations. The recordings were post processed in PAMLab software using JASCO vessel detection algorithms to detect the BPV engine tones.

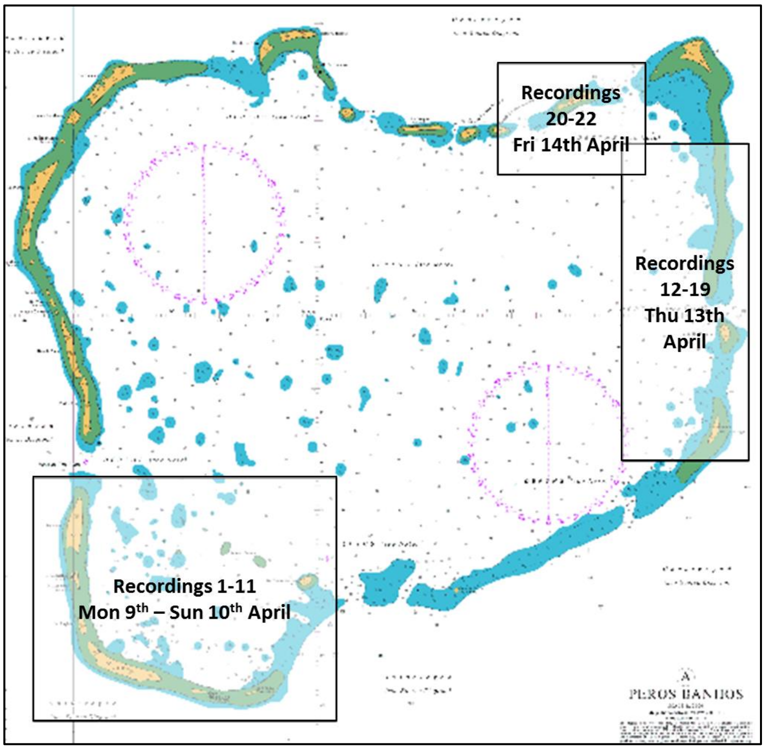

Figure 48. Recording locations within Peros Banhos

Assessment of the viability of cabled or buoyed vessel detection infrastructure

A cabled solution has a lower Bill of Materials (BoM) cost compared to a buoyed system, however the complexity and feasibility to install and maintain a cabled system in the lagoons is unknown. Detailed site-surveys were therefore undertaken at seven of the most preferable locations, five in Peros Banhos and two in Salomon (Figures 49 and 50).

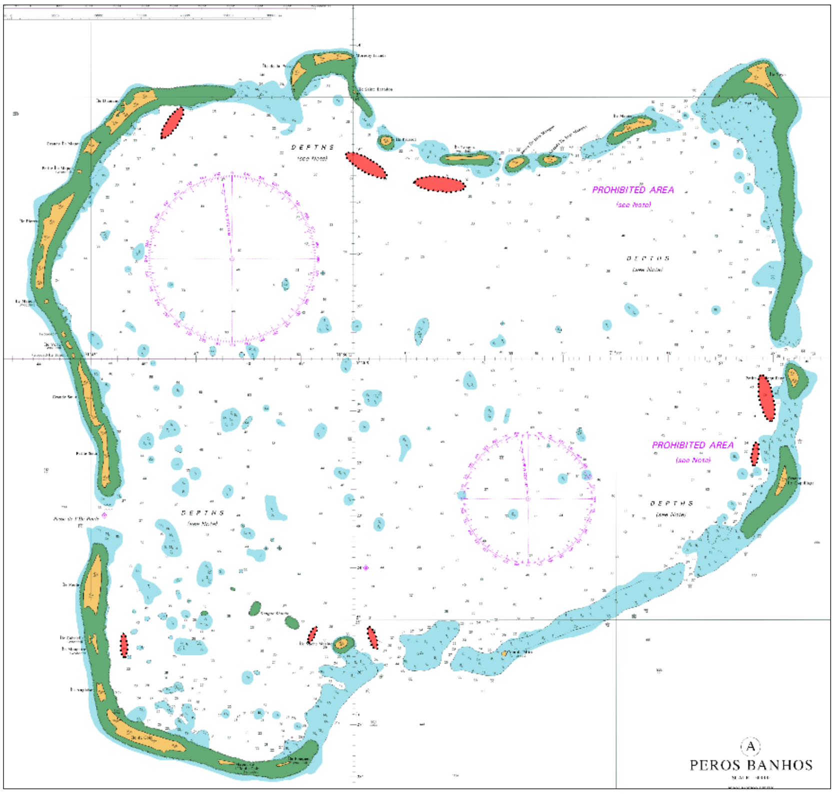

Figure 49. Shortlisted VEDs locations within Peros Banhos

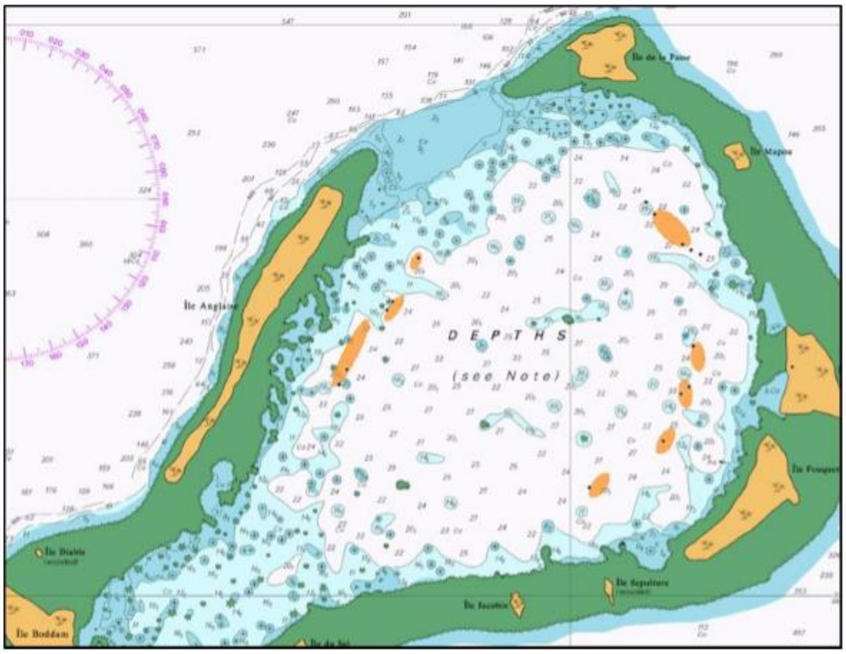

Figure 50. Shortlisted VEDS locations in Salomon Atoll

Initial desk-based acoustic modelling was used to shortlist locations where the hydrophone performance will be most effective, and Figures 51 and 52 demonstrate the predicted range and signal excess from a single hydrophone in different locations across the atolls. A copy of the modelling report can be made available on request. The site survey process consisted of a review of the offshore bathymetry, to confirm there was sufficient depth of water (>30m) within 900m of the nearest island. The coral shelf around each island was assessed to evaluate the width, profile and density of coral for a 1km cable route, and finally the topography, soil structure and vegetation was assessed on each island for the land-based equipment (solar, antennas and vessel detection system).

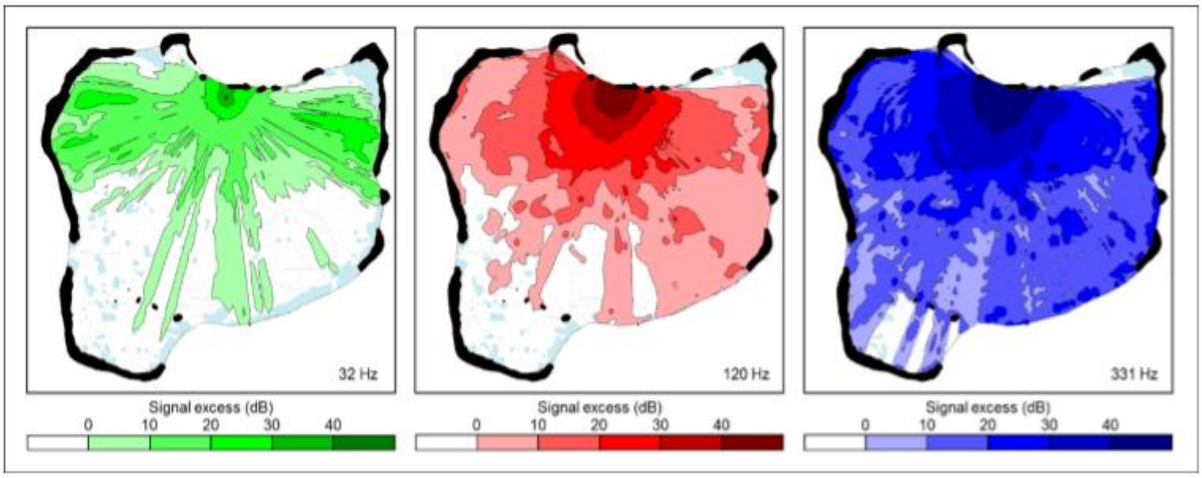

Figure 51. Predicted signal excess levels for the optimum hydrophone off Île Longue in Peros Banhos Area A from propagation loss modelling. Green =32Hz, red 120Hz and blue 331 Hz

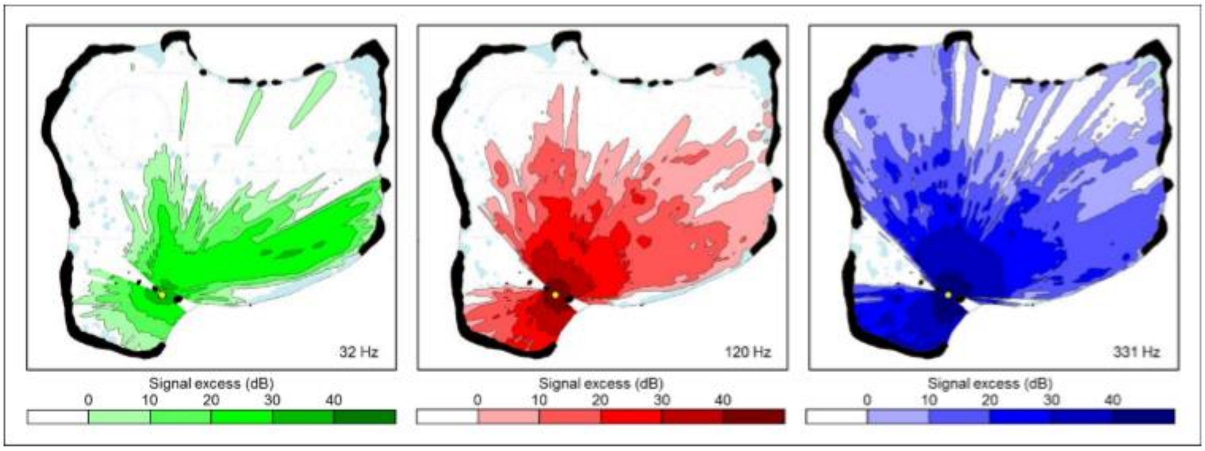

Figure 52. Predicted signal excess levels for the optimum hydrophone northwest of Île Vache marine in Peros Banhos Area C from propagation loss modelling. Green =32Hz, red 120Hz and blue 331 Hz

Autonomous Multichannel Acoustic Recorder (AMAR)

A single AMAR instrument was deployed in the Peros Banhos lagoon at 04:38:00 UTC in position 05° 22.207' S 071° 56.662' E within 25m water depth (Figures 53 and 54). It is configured to record for a period of approximately 163 days at following duty-cycled configuration:

1. 670 seconds at 16 kSps (recorded bandwidth ~7 Hz to 8 kHz)
2. 84 seconds at 128 kSps (recorded bandwidth ~7 Hz to 64 kHz)
3. 746 seconds sleep (recorder dormant)

This configuration meets the primary aim of recording the lower end of the acoustic spectrum, which is relevant to the detection of vessel engine noise. However, the short period of higher sampling will provide sufficient data to characterise the full acoustic spectrum up to 187.5 kHz. This will offer a much more valuable dataset for further scientific research. The instruments can be retrieved at any stage before or after the anticipated 163-day recording period, to fit in with the schedule of the BPV or the ZSL Science Programme.

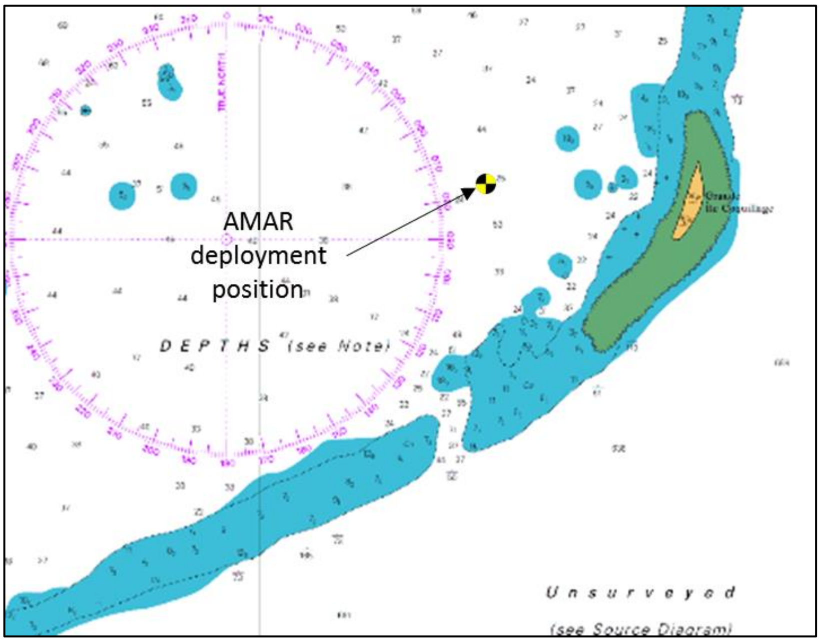

Figure 53. AMAR location

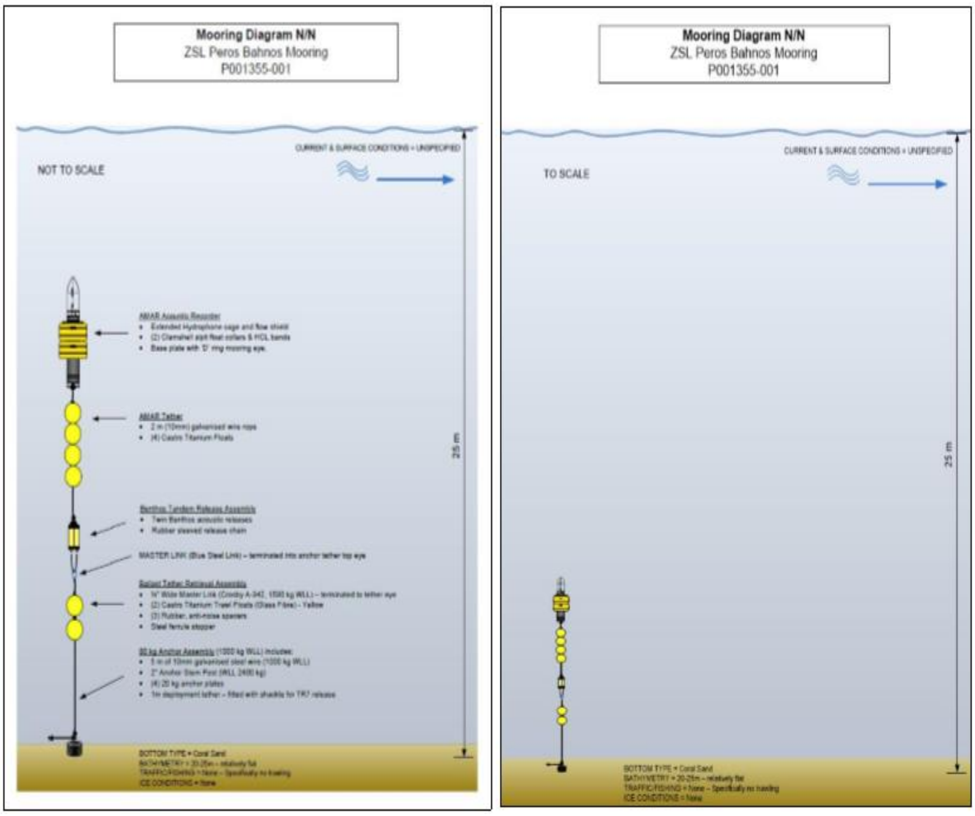

Figure 54. AMAR mooring design

Initial Results

Vessel Detection Algorithm testing

A total of 23 recordings of idle and moving engine tones were taken in Peros Banhos lagoon. The recordings were post analysed in JASCO's PAMlab software with the vessel detection algorithms applied. For the purpose of this trial the detection algorithm paints a marker line over each detected tonal (Figure 55). (Note the permanent system will be programmed to produce an alert in the Instant Detect Alert Management Tool).

Positive detections of the *Grampian Frontier* were made in 19 recordings. Multiple low frequency engine tones were visible below 1 KHz, reflecting the different sounds produced by the ships engine and machinery. The algorithms distinguished engine tones at 9.5km with only one engine engaged (Figure 56), proving the algorithm performed against the expected modelling results. The maximum range test was limited to 9.5km due to BPV safety restrictions.

Recordings taken in the Southwest corner of Peros Banhos proved to have shorter range detection in comparison to the North East. This verified modelling results, as this part of the lagoon presented the worst propagation conditions due to the shallow bathymetry and large coral bommies impeding the transmission of sound. Thus supporting the need to install the system in deeper water with a clear field of view.

Recordings were effected by mooring noise (particularly strum and flow noise), with some cases noted at 120 – 155 dB re 1 µPa which exceeds typical source levels for most engine and drive train tonals. This was true in the four recordings where no detections were present. In the remaining recordings, successful detections were made by tuning / and or increasing the sensitivity of the algorithm. This is an important consideration for the permanent system as the algorithm can be remotely optimised if local conditions change. The mooring design for the permanent system will be bottom mounted to remove excess noise interference, which is a critical factor in the success of the system. The AMAR results will further provide true background ambient noise to validate the modelling, and to support algorithm development during the project development phase.

Full results will be interpreted and presented in the ZSL proof of concept study.

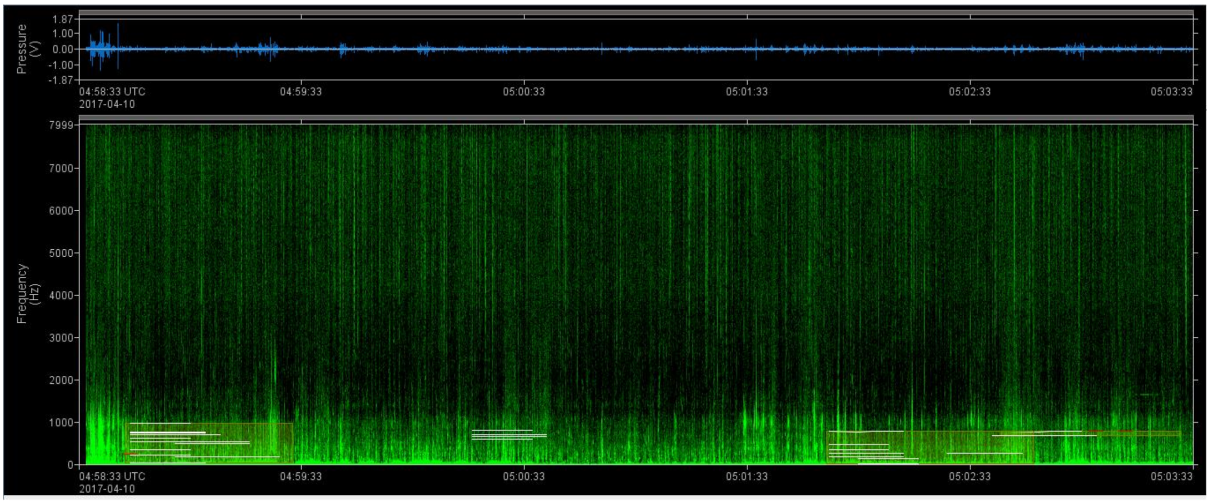

Figure 55. Low frequency engine tones with painted white lines to show the detection

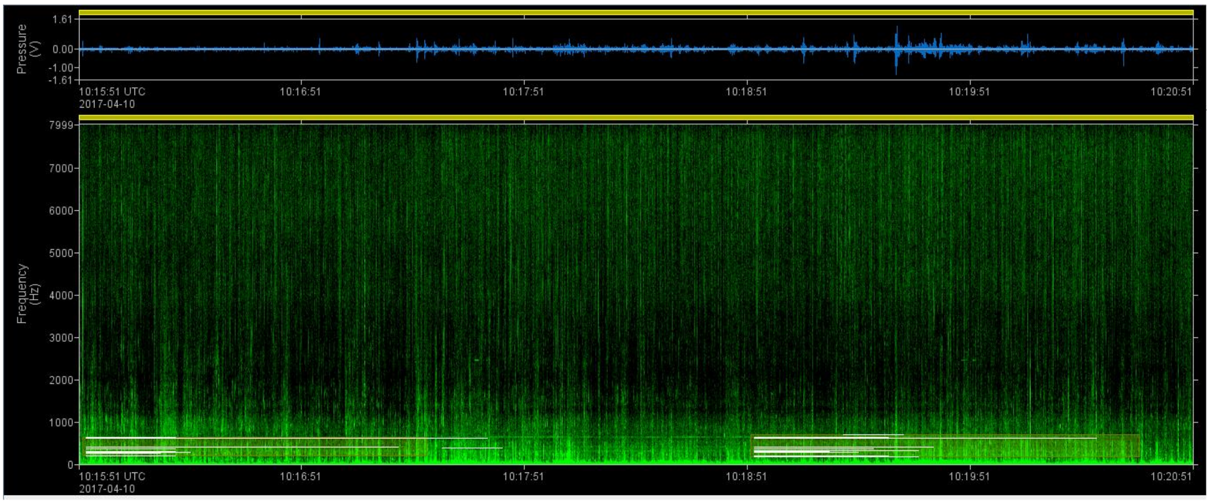

Figure 56. Detections recorded at 9.5km from the GF

Assessment of the viability of cabled or buoyed vessel detection infrastructure

A review of the viability of deploying an autonomous, shore-based, cabled vessel detection system was undertaken by the team. Ile Parasol presented the most suitable deployment location for Peros Banhos with Ile Vache Marine the most suitable for a second system. The coral margin was relatively short and the beach was relatively steep and narrow. A clearing in the centre of Ile Parasol provides an ideal location to deploy the shore equipment, solar panels and aerial which would remain hidden from view from passing vessels. Two systems would be required in Peros Banhos if lagoon-wide coverage is required.

Ile Anglaise presented the most viable site in Salomon lagoon. This position is close to the principle access channel to the lagoon and would be an ideal location for a detection system as all vessels entering the lagoon via the channel would have to pass close to the hydrophone. The coral margin was regularly interrupted by deeper sand channels through which a cable could be run, the beach was relatively narrow but a clearing would need to be cut in the coconut trees to create a clearing for the shore equipment.

The site reconnaissance highlighted important considerations for the deployment of a cabled system(s). Whilst it is ultimately possible, the technical challenges to install a cabled solution will be significant and costly. The cable will need to be heavily armoured and pinned so it is protected against wave and reef action. A specialist vessel or landing craft would be required to move equipment and personnel to shore and support the weight (~1.0t) of the cable. Installation would require a small (10 x 10m patch) of de-vegetation for the solar panels, and a deep trench dug along the beach to bury the cable, which would require an erosion modelling study. The 'footprint' of the cabled system, compared to a buoyed solution (50m^2) is also significant. The cable would run ~900m over coral formations on the lagoon floor and environmental impact should be considered.

A buoy-based system offers the easiest and simplest solution to a fixed detection system but is likely to have a higher capital and BoM cost. The comparative advantages of this approach are listed, but not limited to:

- Ease of deployment. The buoy and ballast structure could be deployed from the Grampian Frontier without having to approach any of the islands.

- The 'footprint' of the system would be limited to the ballast structure which would sit on the sea floor in the deeper part of the lagoon. And damage to coral structures by the ballast structure would be limited to an area equivalent to the size of the ballast structure itself.
- There would be no impact, equipment or need for personnel to land on any of the islands.
- The acoustic detection performance of the buoy-based system would be enhanced due to its position in the deeper water.
- Deployment of a buoy-based system could be completed in less than a day.
- Servicing of the system could be conducted entirely from the Grampian Frontier.

The current BIOT Patrol vessel, the *Grampian Frontier*, is well-equipped for either infrastructure. It has a large deck area, two hydraulic arm cranes and an experienced crew. The vessel is understandably and sensibly cautious about approaching close to any of the islands, and an additional support vessel would be needed for a cabled solution. A bathymetric survey of the vessel channel in to Salomon is essential to confirm if the *Grampian Frontier* can access the lagoon, potentially meaning that any deployment in Salomon would require a different method, vessel, or discounted if becomes cost ineffective.

The recommendation from the survey work is that a cabled system is viable but presents more risks and potential long-term costs than a buoy-based system for both Peros Banhos and Salomon lagoons.

AMAR

The retrieved AMAR Q4 2017 will be shipped to the UK and the data uploaded. Auto-processing of the data will extract the relevant noise metrics, including vessel detections and search for marine mammal vocalisations and clicks. A summary report on the measured ambient spectrum will be provided and made available two months after retrieval (scheduled Jan 18). This information will further be utilised to guide future Marine Monitoring Surveys (MMOs), to target seasons and periods when mammals are known to be active in Peros Banhos. MMO survey can take the form of vessel based shore surveys, aerial surveys, using either manned or un-manned vehicles]. Proposal regarding the use of unmanned vehicles (drones) to study megafauna detectible at the surface (turtles, sharks, and manta ray) are already being considered as part of the Chagos Science Plan, and the work could be incorporated as part of this. We envisage that this work could offer species habitats maps, and therefore help guide vessel lanes within the reserves in order to minimise potential harmful impact on mammals.

Conclusion and Recommendation

The recommendation from the survey work is the vessel detection algorithms are capable of detecting engine tones in-situ, and the tuneable functionality provided by JASCOs software is essential for best performance. The AMAR data will provide the peak ambient threshold noise to support future development of the algorithms and guide future MMO surveys. A cabled system is viable but presents greater risk and long-term costs compared to an autonomous buoy installation. Furthermore a buoy can be moved across hotspots within the MPA. A full assessment of the needs, requirements and impact of the proposed solution is discussed in the ZSL proof of concept report. ZSL recommends evaluation workshops, investment needs and road mapping to be completed in collaboration with BIOTA.

Diving Report & Recommendations

Andrew Mogg and John Turner

-

Figure 57. Diving operation with BPV in support *Figure 58. Diving in Chagos 2017*

Introduction

Sixteen sites in the northern Chagos atolls were surveyed during the period 9-17th April 2017, with a no-diving day on the 14th of April. Dive teams assessed: broad scale coral coverage over a 25-5m depth gradient using extended video transects; quadrat-based adult and juvenile coral coverage over a similar depth range; and large-scale 3D coral coverage and 4D structural complexity at 10-5m. Additionally, divers recovered and replaced long-term temperature loggers at key sites, and tagged and photogrammetrically modelled individual colonies of fast growing coral for extension estimates. A pilot study investigating fluorogrammetric quantification of coral juveniles was performed on one dive.

Eight experienced divers conducted a total of 53 dives, equating to 115 person dives and just over 112 total hours underwater for all divers combined. Strong currents were experienced at Petite Coquillage on the afternoon of the 13th April (on spring tide, but surprisingly at high water) resulting in the dive being curtailed, but generally conditions were satisfactory for operations. Diving operations were conducted under the HSE Approved Code of Practice for Scientific and Archaeological Diving 2017 (ACoPs) and Bangor University Diving Rules and Diving Policy. Dives were limited to 2 no decompression dives per day of 60 minutes duration to no more than 25 m depth, with 24 hrs off diving every 10 dives. Diving air was provided by 4 air quality tested Bauer Oceanus portable petrol compressors, with filter changes every 12-15 hours operation. New Faber steel 12 l and 15 l diving cylinders were used, with 3 l ponies in addition. Divers operated in pairs or threes, carried independent breathing devices, GPS Life-line radios (per pair) and delayed surface marker buoys, and operated directly below the moored dive boats. Bottom times were kept to >2 minutes within no stop times, and a mandatory 3 minute stop at 5/6m depth was required. Dives were supervised from the surface by boat cover, with first aid kits and Marinox on site, and an oxygen generator and full medical kit available on the BIOT Patrol Vessel (BPV), which was usually within a kilometre or two of operations. Radio communications were maintained between dive boats and bridge of the BPV. Three 4.2m Sea Searcher boats equipped with 25 hp four stroke outboard motors, oars, and waterproof peli-cases containing flares and essential spares supported dive operations, and wherever possible (sea conditions permitting), only one boat anchored and two tied off. All dives were logged electronically and a central record kept. One anchor was lost (cut loose) at Petite Coquillage during the strong current event, and its position marked for retrieval. The Seasearch boats have a weakness in the attachment of the transom, which fails when the glue dries out in extreme heat, and need repair/replacement. There are also issues with incompatibility of replacement tube valves.

Recommendations

No decompression incidents or injuries directly related to diving were reported, although one diver was bruised after losing balance while descending from the BPV to the dive boat, and another may have fractured 2 ribs when entering the boat from the water. Accessing dive boats from the deck is a high risk operation due to the movement of the vessels, and is not possible in rough weather (Figure 61 later). The transfer of equipment between boats also risks losing equipment into deep water. The Captain was able to move the vessel to create calm water, *but a fixed ladder would provide safe access in the future. A further recommendation is to reconsider the opportunity to utilise the containerised hyperbaric chamber from NERC NFSD, to provide the level of safety support usually expected for diving operations in the UK.* There is room on the deck of the *Grampian Frontier* for this facility, and a major advantage is that the container provides two electric diving compressors and medical oxygen, and both Andrew Mogg and Simon Watton are qualified hyperbaric operators. *There is also a need to replace the Sea Search boats with models with a stronger transom fixing, and to furnish every diver with a Life Line EPIRB device (currently one per dive pair).*

Medical Report & Recommendations

Simon Watton, Expedition Medic

Only minor incidents were recorded in the medical log:

- **Various minor lacerations and abrasions due to coral and vegetation:** treated and monitored with no complications using tropical antiseptic preparations and dressings held.
- **Minor stomach upset and diarrhea:** Easily settled with Loperamide and oral rehydration salts.
- **Motion sickness:** Treated and monitored with no complications. Care plan included input from DG Medical Direction to allow administration of prescription medication and consideration of IV access for fluids.
- **Gout (acute discomfort affecting mobility):** Care plan included input from DG Medical Direction to allow administration of prescription medication. Medication held aboard easily dealt with symptoms and they did not return.
- **Blunt trauma (thrown backwards onto engine cover during launching of inflatables):** Not severe but patient was experiencing some discomfort and had visible bruising from impact. Administered paracetamol and ibuprofen for the pain and swelling.
- **Spider bite whilst ashore:** Initial call came whilst divers were just about to surface and timing worked well with getting everyone back aboard in time to meet patient when brought back from the island. Patient was in good spirits and observably well other than the bite, cold compress applied for immediate relief and followed up with antihistamines. Care plan included input from DG Medical Direction to allow administration of prescription medication including hydrocortisone given via IM.
- **Localised pain and swelling due to displaced rib/fractured rib/sprain/strain:** Patient originally thought this was just a previous injury flaring up after getting in/out of dive boats. Examined and discovered localised inflammation which was causing discomfort and being exacerbated by getting in/out of the inflatable boats. Care plan included input from DG

Medical Direction to allow administration of prescription medication. Medical doctor on Diego Garcia offered his own examination whilst team was on Diego Garcia and advised follow up in the UK. Follow up in the UK revealed that patient had fractured two ribs.

- **Sinus congestion:** Treated and monitored with no complications.

Recommendations

Condition of medical equipment and stores: There was sufficient medical equipment to adequately support the expedition.

MARINOX kits: All old MARINOX require inspection, service and filling. Lines and regulators are rusty with some missing o-rings, masks and tubing require replacement (the heat, humidity and exposure to salty air are destroying them), the green decanting line and fittings looked in good order. The oxygen generator has been left locked in the BPV sick bay.

Expired medications: Some controlled medicines requiring appropriate disposal. Need to follow through to disposal to complete chain of custody. *It is illegal to destroy unwanted Category A and B drugs. They can be disposed of only by giving them to a person who may lawfully supply them, such as qualified pharmacist or qualified doctor. It is also possible to dispose of drugs via the police. A receipt should be obtained from the recipient, and kept with, or affixed to, the controlled drugs register* (from MCA (UK) MSN 1768, Annex 7, Storage and Security of Medicines, Security of controlled drugs). Recommend keep controlled drugs out of the team kit and use stock from the *Grampian Frontier*/research platform as required. For reference, VAVA II and GF are scaled differently (A and B respectively) but the amount of strong analgesics (Morphine and Codeine) required to be held is the same for both vessels.

Medical direction from Diego Garcia: Civilian call in +246 370, Sick Bay ext 4211/4212 and ask for on-call doctor. The doctor may not be on site and will need to be called in which may take some time but usually no more than 15min. Follow up all calls with an email for clarity of advice (shipboard comms could be quite difficult at times) and accurate record keeping necessary.

MedAire assisted in getting the medical kit together and resupplies should now be a very simple operation via an account manager (details below) and a managed system. I will emphasise though, that for the system to work as it should, all usage should be accurately recorded as and when, otherwise the system will fail and make it harder to keep track of kit/meds to be replaced.

Account Manager: Amanda Thompson; Email amanda.thompson2@medaire.com; Tel +34630 675004

Medical direction from Diego Garcia was excellent but there is always the risk that there may be a time-critical patient and unable to reach the doctor. Recommend speaking with Account Manager to arrange a charge-per-case arrangement with MedLink as a backup, unless of course this already exists within insurance plans. The main difference with MedLink is that the call centre is staffed 24/7 within a trauma hospital in the US.

Recommend for future expeditions an up-to-date PDF of the current medical kit to be sent to the Diego Garcia Sick Bay so that the medical staff can very quickly see what stores are held by expedition (this would already be instantly available to MedLink through their arrangement).

The MedAire kit can also be managed through a desktop/laptop based Medical Management System (MMS) or through the Sea to Shore app. Recommend discussing with Account Manager to see how this could be implemented for future trips.

Additional kit/equipment to consider/replace: MedAireTender Oxykits. Purpose made waterproof kits for using on tenders/inflatables and do not require assembly before administration. Humidifier (and spare) for O2 concentrator to helps prevent dryness associated with longer term use of oxygen through a mask. Haemostatic gauze, chest seals, ACS units expired, would advise considering a better replacement, Skin glue (other units had set in the heat).

Seminar Series

Expedition briefings were held each evening, including those focused on general safety, first aid response, and diving. In addition, a series of seminars for scientists and crew were presented on topics as diverse as tidal energy, fisheries patrols, seabirds, invasive lionfish in the Caribbean, and 3 D coral reef mapping. Charles Sheppard made two presentations about Chagos coral reefs to the crew, and we even held a quiz evening constructed by resident quiz master, Steven Hipsey.

BPV *Grampian Frontier*

John Turner

The new BIOT patrol vessel (BPV) *Grampian Frontier* operated by North Star Shipping/Craig Group, Aberdeen, is a 69 m 2064 tonnes Tanker Assist Offshore Support Vessel built for operations in the North Sea (Figure 59). She has a draft of 6.5 m, a 300 m^2 wooden sheathed aft deck with 2 cranes. The ship has 2 engines and dynamic positioning, and operates at up to 12 knots. There are davit launched 9.5 m covered daughter craft (DC) and an open 6.4 m Fast Rescue Craft (FRC). The steep superstructure comprises Reception level, Boat level, Crew deck, Forecastle level and Bridge with some 10 flights of stairs. Facilities include a mess room and lounge, gym and sauna, WiFi internet (somewhat patchy and slow), reception/assembly area and sick bay. There are four 2 bunk cabins with toilet/shower for visiting scientists, with 2 on Boat deck (same level as mess), and 2 on the Reception deck, accommodating 8 persons. A further 6 persons were accommodated in bunks (actually room for 12) in the Recovery room with 2 showers and 2 toilets on the Reception deck level. This area, known as the '*sweat box'* lacked air conditioning integrated into the ship's systems, and was serviced by an independent AC unit. The Reception/assembly area directly off the aft deck was occupied by a desk and seating for about 20 persons, and conveniently had a large showering area and toilets adjacent. This area was used to log dives and charge radios, and to store dry items. The team had access to a storage locker on deck, and the deck container laboratory was fixed to the aft deck to store equipment (Figure 60 & 62). The dive boats were kept on the aft deck and launched by the crew operating a crane using slings under the boats (Figure 63). These boats were operated by the dive team and medic/coxswain. Fuel cells were refueled by the BPV crew. The Island and Hydrophone test teams used the BPV daughter craft or FRC with BPV crew.

Figure 59. The BIOT Patrol Vessel Grampian Frontier

We express our gratitude to Captain John Muir, and his officers and crew of the *Grampian Frontier* for their expert support in our operations. They were extremely helpful and friendly, and did everything possible to make us feel welcome and to support our operations. Excellent communication through regular briefings working through each day's operations ensured that the work was completed safely with complete understanding of what was required by all involved. David Hughes, FPO, was also most helpful, supportive and interested in our work.

The BPV changes crew in Male, and is part provisioned in Male and part provisioned at Diego Garcia. The vessel sits offshore in Male, and provisions and personnel are transported out by the shipping agents on small boats. The BPV was 2 crew short and due to a failed delivery of lube oil, was compromised in speed and use of the dynamic positioning system. The 6.5 m draft meant that the vessel could not enter Salomon atoll (it may be able to in the future if more detailed bathymetric data is made available – our team used a sounder to map the pass into Salomon and provided data to the BPV Captain). Permission is required from the Bridge before going on deck at any time, and parts of the aft deck can be awash in heavy seas. The vessel has 900 m^3 of freshwater but this is not all available due to the need for ballast, and there were no water limitations during our short visit. The ship must dump' grey water' approximately every 5 days beyond the 12 nm limit, and this is generally undertaken at night. It is understood that should the vessel encounter illegal fishing boats, or there be operational issues, then the priority is to return to Diego Garcia, which can interrupt the scientific expedition. No encounters were made during the expedition.

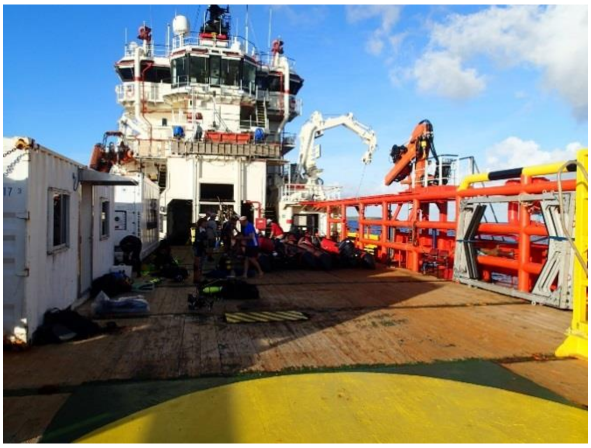

Figure 60. Aft deck with container lab on left

Figure 61. Boarding access, difficult in rough seas

Figure 62. Aft deck area and cranes with freezer and lab containers and fuel stores at stern

Figure 63. Lifting dive boats with crane & strops

Communications

Dominic Andradi Brown and John Turner

There has been considerable interest in the news and social media arising from the observations of the expedition, especially due to an article in the *Washington Post*.

Items featuring the 2017 expedition to date are:

https://www.fondation-bertarelli.org/expedition-to-survey-corals-in-the-british-indian-ocean-territory/

https://www.zsl.org/blogs/conservation/assessing-two-years-of-back-to-back-reef-changes-in-the-chagos-archipelago

https://www.zsl.org/blogs/conservation/a-first-glimpse-of-corals-the-story-so-far

https://www.bangor.ac.uk/reo/news/urgency-scientific-expedition-to-assess-climate-induced-death-of-coral-reefs-32202

https://www.facebook.com/SAMS.Marine/posts/1523297624356531

http://chagos-trust.org/news/emergency-expedition-to-the-chagos-archipelago

http://chagos-trust.org/blog/the-story-so-far.....2017-expedition

http://chagos-trust.org/blog/a-first-glimpse-at-corals-after-two-years-of-extreme-sea-temperature

http://chagos-trust.org/blog/assessing-two-years-of-back-to-back-reef-changes-in-the-chagos-archipelago

http://chagos-trust.org/news/news-first-successful-invasive-rat-eradication-in-the-chagos-archipelago

https://www.islandconservation.org/celebration-chagos/

https://www.washingtonpost.com/news/energy-environment/wp/2017/05/16/scientists-just-discovered-yet-another-coral-reef-thats-been-devastated-by-global-warming/?utm_term=.58e8c9a5373c

http://e360.yale.edu/digest/a-second-major-coral-reef-system-is-hit-by-large-scale-bleaching

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http://fairfaxmedia.newspaperdirect.com/epaper/showarticle.aspx?article=29f65599-6ca1-4621-bfba-712f99282db7&viewmode=2

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https://twitter.com/savingoceans?ref_src=twsrc^tfw&ref_url=http%3A%2F%2Fnewsclips.marine-conservation.org%2F%23%2F

http://theconversation.com/does-a-new-era-of-bleaching-beckon-for-indian-ocean-coral-reefs-73938

Final General Recommendations

Professor John Turner, Expedition Lead

Introduction

Working in the Chagos Archipelago is challenging, but over the years, we have established good working practices and equipment to ensure that we can be flexible and have the back-up resources to maintain our programme while out on the water. As a result, the 2017 Science and Conservation Expedition was a great success, but did encounter some issues that compromised the expedition in several ways, and could have impacted the outcomes. I have identified these to ensure lessons can be learned for going forwards:

Preparation

The opportunity to use the BIOT Patrol vessel was at short notice. Past expeditions have required at least a 6 month lead time, and this expedition was organized in less than one month. We are immensely grateful to Rachel Jones Bertarelli Foundation Programme Manager at ZSL, and Helen Stevens, Environmental Officer of BIOT, for their assistance in making the 2017 expedition take place. However, the unavailability or limited available of team members was an issue, and it was not possible to include a reef calcification budget or fish survey dive team. It quickly became evident that there would not be time during the programme to run a BRUV fish survey or service acoustic instruments, and that we would have to limit the reach of the expedition to the northern atolls, which meant some important monitoring sites could not be accessed this year, and some temperature loggers could not be serviced. Some equipment was purchased in advance and freighted to Male, but a paperwork error by the shippers resulted in freight missing its flight, causing the loss of one day while awaiting late arrival with the consequence of losing 2 dive surveys and trimming the Yeye/Manoel rat assessment by one day. *Adequate time for preparation (recommend 6 months), including contingency for arrival of freight is therefore essential*.

Arrival through Male.

Although scheduled flights to Male are reliable, convenient and relatively cheap, a lot of downtime (14 persons x 4 days) ensued in travel down to the Chagos Archipelago from the Maldives, and the ship was slightly compromised in speed due to failed provision of lube oil. Little preparation could be achieved during transit due to restricted space and safe access to the deck while underway. We were also reliant on the correct equipment having been loaded onto the ship in Diego Garcia, and this requires knowledge of the kit and stores. It has been suggested that we should consider moving stores to Male, but this is a non-starter because storage space in Male is at a premium. *Recommend access via Diego Garcia.*

Equipment preparation in Diego Garcia.

Although we were aware that of the short lead time into this expedition, and we appreciated the assistance given in loading equipment, it would of course be preferable for all parties for an advance team travel to Diego Garcia to make ready the appropriate equipment to ensure all the correct equipment is loaded, and anything missing or deteriorated can be replaced by the incoming team. Several items that were not located for loading were found in the store at the end of the expedition. These included tents, electrical extension blocks, and diving log sheets. Most importantly, we were missing the diving compressor air intake hoses, without which we were unable to fill diving cylinders. Fortunately, the Engineer on the *Grampian Frontier* was able to fabricate intake hoses from stock material on board. Equipment security at Moody Brook remains a concern: one radio and charger (valued at £175), and one Lifeline Underwater GPS/Radio/EPIRB (valued at £425) remain missing, although these taken prior to locks being fitted. *Recommend permission for advance party to ready equipment on Diego Garcia before future expeditions.*

Equipment lending to other teams

One compressor failed. This compressor had been used since our last expedition and had evidently been left with a part-used filter and an emulsion of undrained condensate, causing backpressure preventing the compressor from starting and damage to the safety valve. The unit could not be repaired or recovered during the expedition. One 4 stroke boat engine failed. This had been used by another team in 2016. The engine had clearly not been flushed with freshwater, and failed to start, reducing our expedition to 2 engines for 3 days. We were grateful for the skilled assistance of the BPV Engineer once again, who was able to repair this engine between his work shifts. We have always tried to be independent in terms of equipment maintenance, including provision of our own tools, but the damage was beyond our skills and equipment. **Had another engine failed, then we would have been unable to continue the diving aspects of the project because our risk assessment requires at least 2 boats to operate providing safety support for one another.** 8 missing lead weights (2 belts worth); this would have created a problem had our team been larger, and is expensive to procure and ship to Diego Garcia. *Equipment should not be used by others without permission and then only with the technical competence to do so.*

Deck Container Laboratory

The deck container was left by the last pelagic expedition of 2016 in the vicinity of the finger pier, under agreement that it would be moved to the Moody Brook compound. This never happened, and it was adopted by Philippine contract workers as their 'tea shack', complete with large screen TV. This was widely known on island, but no one intervened. Unfortunately, contents including shelving (£161), 2 stools (£334.80), fridge freezer (£297.60) (all costing a further $750 in shipping and handling) had been stolen from the deck laboratory, and water ingress had destroyed the floor, and ants nested in the rotten wood. This was most disappointing, especially when we were assured that the store and container would be checked fortnightly. Because of missing contents, we were unable to use the container as a workplace as intended, and only as a deck store, **which compromised our ability to efficiently prepare equipment prior to each dive, and to charge equipment at various locations throughout the ship**. *The air conditioned container is now aboard the Grampian Frontier, secured to the deck, cleaned and supplied with electricity. The Captain has agreed to keep it aboard because it provides a much needed covered space for equipment brought aboard by visiting parties and operations space, and the crew will attend to the rust on the roof and repaint*.

Scientific Stores Issues

We had a brief meeting with the outgoing and incoming Brit Reps, and were able, briefly, to inform them of our expedition findings. The matter of support and the scientific store was discussed, and we were genuinely surprised to hear complaints from the outgoing Brit Rep regarding previous expedition teams and their use of the scientific store and the state in which they left a vehicle. *It is important* *that all teams are considerate of equipment belonging to others, and ensure that equipment is left in a clean and tidy state.*

Much of the diving, boat, medical and laboratory equipment in the store belongs to the OTEP/Darwin Science and Conservation projects (although new equipment is owned by the Bertarelli Foundation Marine Programme). This essentially means that the primary universities and institutions who purchased the equipment under those grants are responsible for it. Most of the reef survey equipment (with exception of the new dive cylinders) is indicated by Darwin Initiative Chagos Science and Conservation stickers, and these will be replaced as the inventory is updated. The Brit Rep himself indicated that no equipment should be lent to other users to ensure security and condition. Given these issues, we are at the current time not prepared to lend equipment to third parties, because we cannot ensure its presence or condition for our own work. We have spent years building up a depository so that we can help BIOT fulfil its monitoring obligations, and while we regret such restrictions, we cannot be assured that the equipment will be available for its purpose otherwise, and we do not want to regress to the situation where equipment is transported to and fro between UK and Diego Garcia. *The equipment should not be used by others without permission and the technical competence to do so.*

Scientific and Conservation Recommendations

The coral reefs of the Chagos Archipelago are in a precarious state, with further loss of live and dead standing corals expected this year, due to weakened colonies suffering partial mortality and bioerosion from sponges and algae which will cause them to collapse further. The reefs are therefore now in an erosional state. The resilience of these reefs indicates that they are capable of recovery since corals lower down the reefs do survive and will produce recruits, but it is unknown whether recruitment can be maintained if warming events become more frequent, and especially if they occur in consecutive years preventing the establishment of corals. Soft corals may recover more quickly on some reefs, and macroalgae may increase in cover, but succession may depend on the period taken for substrates to stabilize and for loose material to be washed off the reefs. Disease was barely evident, probably because diseased corals have been killed off, but it is unknown whether the vectors of disease remain within the system, and at what point disease may become prevalent again (previous results suggest ~15 years). The effects on fish and other reef biodiversity will increase as the structure collapses, and there may be effects on island topography and ecology. Rat eradication will improve the resilience of island flora and fauna. With this in mind, key priorities are:

1. Continued protection of coral reefs from impacts such as fishing, island development, and effluents. The IUU detection system has potential to assist if appropriately located. (Note also that Ciguatera poisoning can be an issue post bleaching due to toxic dinoflagellates living in the increased cover of macroalgae, and localized recreational fishing of apex predators may require restriction through management intervention).
2. Monitoring of reef state across the depth range, especially in relation to changes in reef structure, benthic cover and coral recruitment, and in understanding the recovery potential of species. Surveys are necessary across the whole Archipelago for southern reefs were already in a more degraded state than those of the north in 2015 and 2016. Compare observations with Seychelles (including Aldabra atoll), Maldives, and other regions.
3. Continued monitoring of temperature, and urgent retrieval and replacement of loggers from the Great Chagos Bank reefs.
4. Reassessment of reef carbonate budgets, since many reefs that were positive in 2015 will now be negative.
5. Assessment of impact of reef collapse on fish diversity, abundance and biomass.
6. Monitoring of island erosion and changes in sedimentation.
7. Monitoring of rat eradication and extended initiatives to achieve this.
8. Continued assessment of change in seabird populations.

Acknowledgements

The success of any expedition is due to the support and assistance of those who help make it happen. The Expedition teams are therefore grateful to **Captain John Muir and his crew of the Grampian Frontier** for implementing our often complicated movements with expertise and good humour and with our safety in mind, and to S**FPO David Hughes** for his interest in our work. We thank **BIOT HQ Brit Rep Cdr Edward Lees** for his encouraging support of our expedition at a busy change over time, and especially **XO Major Andy Coventry** for his considerable assistance and understanding, and **BIOT Environmental Officer Helen Stevens** for making so many arrangements in London and Diego Garcia. We are grateful to **LO Lt Ben Samuel** for answering our questions during preparations, **Cpl David Kemp** for assisting at Moody Brook Stores, **CPO David Wilton of BIOT Customs**, and also for the assistance of the **BIOT Police**. **Mary Grace Dumlao** arranged flights home and made changes at late notice, and **Marine Malik Oud** gave up several days to help transport van loads of kit. In London, we thank **Murielle Benjamin** and **Zoe Townsley** of **BIOT Section Administration of the FCO** for assisting with permits and plans, and **Dr Mark Spalding, BIOT Science Advisor** for his suggestions. **Rachel Jones, Bertarelli Marine Programme Manager at ZSL** magically made the short lead time work, and without whom the expedition would never have got off the ground, and we thank **Dr Heather Koldewey**, **ZSL Marine and Freshwater Programmes**, for expediting the expedition opportunity.

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