Bertarelli Programme in Marine Science Coral Reef Expedition to the British Indian Ocean Territory, April 2019

Figure 1: Early signs of coral reef recovery in BIOT, Takamaka, Salomon

Executive Summary

The Bertarelli Programme in Marine Science Coral Reef Expedition to the British Indian Ocean Territory on Coral Reef Condition took place in April 2019, and involved Bangor University, Oxford University, University College of London, and Woods Hole Oceanographic Institution, USA. The team joined the British Patrol Vessel Grampian Frontier in Male, Maldives on 6th April and travelled south, arriving Diego Garcia on 27th April 2019. Exceptionally calm seas were experienced until 17th April, and then rough conditions which progressively worsened until 27th April. Thirteen experienced scientific divers including a Medical Officer conducted a total of 113 dives, equating to 301 person dives and 318 hours underwater over the period. The team undertook 7 scientific tasks to investigate the current condition of the coral reefs at 34 sites across the archipelago as follows:

Tasks 1 & 2: Coral condition, cover, juveniles, and water temperatures (C. Sheppard, A. Sheppard).

Task 3: Extend video archive for long term assessment of coral reef benthic community structure (J. Turner, R. Roche)

Task 4: Three-dimensional determination of reef structural complexity and spatial analysis of coral recruitment (D. Bayley, A. Mogg).

Tasks 5 & 6: Spatiotemporal variations in internal wave driven upwelling and resilience potential across the Chagos Archipelago (G. Williams, M. Fox, A. Heenan, R. Roche)

Task 7: Coral reef recovery and resilience (B. Wilson and A. Rose).

The coral reefs of the Archipelago are still in an erosional state with very low coral cover 3 years after the back to back bleaching events of 2015/2016. Little improvement can be expected until dead material is either washed off the reef or consolidates into a substrate suitable for longer term recolonization. Surviving corals are recovering, and coral larvae have settled though in lower numbers than previously. Recruits that survived the warming events do appear to have grown into small colonies in shallow waters on some reef rims. Structural loss is apparent, and this will be affecting both available habitat and food resources for reef fish and other organisms. There seems little, additional, local management action that can improve the reefs at this time; they need time to recover without any further warming events, as was observed after the 1997/98 event. However, the severity of impact of recent back-to-back warming events on BIOT reefs and modest signs of recovery in the absence of synergistic and cumulative impacts from local anthropogenic activity convey an important message - to strengthen the global response to climate change by reaching and sustaining net zero global CO_2 emissions. Coral reefs are projected to decline by a further 70–90% at 1.5°C with even greater losses (>99%) at 2°C, and therefore current global policies are unlikely to be sufficient to protect coral reefs from climate change.

New investigations have focussed on whether internal waves can provide cooling on some seaward reefs and whether nutrients are being delivered to these areas, conferring resilience on some corals and reef communities. Current and future genetic studies are also attempting

to reveal whether some corals and their algal symbionts are more resistant to warming, bleaching and disease. Again, there may be limited direct management action, but a greater understanding of the connectivity and resilience of reef systems should become apparent.

Recommendations made concern embarkation in Male vs Diego Garcia, team size, grey water, limits on diving and small boat operations at Force 6 and above, and equipment provision.

Figure 2: Science boats deploy from the BPV Grampian Frontier

Introduction

The expedition undertook further in-depth assessment of reef condition across the Archipelago following impacts caused by the 2015-2016 warming events resulting in coral reef bleaching and mortality. The techniques so far developed by the collaborative team were refined and tasks linked to assess what has been lost, what is resilient or resistant, and what determines the recovery potential of the reefs. The expedition aimed to revisit many of the sites previously assessed, while increasing statistical rigour by focusing on replicated surveys across groups of 6 sites within each of the atoll localities of Peros Banhos, Salomon, the western Great Chagos Bank and Egmont, with additional sites in northern Diego Garcia. The team joined the British Patrol Vessel *Grampian Frontier* in Male, Maldives on 6th April and travelled south, arriving Diego Garcia on 27th April 2019. We experienced very calm seas until 17th April, and rough conditions which progressively worsened until 27th April.

The major tasks for this expedition were:

1. Extend existing long-term coral reef datasets, including coral cover, coral recruitment, and potentially functionally extinct corals
2. Integrate Sea Surface Temperature trends into coral reef resilience.
3. Extend the video archive for long term assessment of coral reef benthic community structural change.
4. Repeat three-dimensional determination of reef structural complexity and spatial analysis of coral recruitment to assess structural loss.
5. Investigate spatiotemporal variations in internal wave driven upwelling and resilience potential in corals across the Chagos Archipelago.
6. Investigate the Interaction between upwelling and planktivorous fish.
7. Examination of why some corals are more resilient than others – an investigation of the innate immune response.

Figure 3. Reef 2 Team 2019: Back row –L-R: Dr Michael Fox, Dr Andy Mogg, Dr Gareth Williams, Prof John Turner, Anne Sheppard, Dr Dan Bayley, Dr Bry Wilson, Prof Charles Sheppard, Dr Adel Heenan. Front-row L-R: Dr Katie Sellens, Amelia Rose, Dr Ronan Roche

Expedition Personnel

Table 1: Expedition Personnel			
	Name	**Institution**	**Role**
1	Professor John Turner	Bangor	PI – Expedition lead Benthic video, Task 3
2	Dr Ronan Roche	Bangor	Post Doctoral Researcher & Deputy lead Benthic video & fish, Tasks 3 & 6
3	Dr Andrew Mogg	UCL	Diving Officer -Underwater stereo-photogrammetry, Task 4
4	Professor Charles Sheppard	Bangor	Emeritus Researcher Measurements of coral cover, relict corals, temperature recording loggers collection, download & replacement, Tasks 1 & 2
5	Anne Sheppard	Bangor	Research Assistant - Measurements of coral cover, relict corals, temperature recording loggers collection, download & replacement, Tasks 1 & 2
6	Dr Kate Sellens		Medical Officer and Diving Assistant
7	Dr Daniel Bayley	UCL	Postgraduate Researcher - Reef structural analysis Task 4
8	Dr Michael Fox	Woods Hole, USA	Post Doctoral Researcher - Reef heterotrophy & nutrients Task 5
9			
10	Dr Gareth Williams	Bangor	Reader Researcher -Reef heterotrophy and nutrients Task 5
11	Dr Adel Heenan	Bangor	Lecturer Researcher –Benthic fish interaction Task 6
12	Dr Bryan Wilson	Oxford	Postdoctoral Researcher -Coral diseases resilience Seminar Organiser Task 7
13	Amelia Rose	Oxford	Graduate Research Assistant -Coral diseases resilience Task 7

Expedition Schedule

Table 2: Expedition Schedule 5th – 30th April, 2019

The daily schedule involved two dives per day, one dive am, and second dive pm with a no-dive day every 10 dives. Dive sites were selected daily, based on wind and wave direction, and transit to dive site. The team used five 4.2m inflatable boats launched from deck and occasionally the BPV Daughter Craft/ Fast Response Craft when weather conditions prevented the launch of the small vessels.

Date	Site	Activity	Comments
5th April (Fri)	UK to Maldives		In transit
6th April	Male	Arrive early am. Transfer directly from airport to BPV Grampian Frontier via agent's boat.	Off Male Leave Male for Chagos Northern atolls 1800 hrs
7Th April	Transit to Peros Banhos	Prepare expedition diving and scientific equipment Re-floor container laboratory. Install new air conditioning unit	In transit at sea
8th April	Transit to Peros Banhos	Prepare expedition diving and scientific equipment Re-floor container laboratory. Install new air conditioning unit	In transit at sea
9th April	Transit to Peros Banhos	Prepare personal diving and scientific equipment	In transit at sea
10.04.19 Thurs	Peros Banhos	AM Arrive Peros Banhos dive briefing & prepare dive kit PM Dive 1: Ile du Coin (lagoon)	Ile du Coin Anchorage, South West
11.04.19	Peros Banhos	AM Dive 2: Ile Poule 1 PM Dive 3: Ile Gabrielle	Ile du Coin Anchorage

12.04.19	Peros Banhos	AM Dive 4: Ile Petite Soeur (seaward) or Dive 4a Bernard's Shoal (lagoon) + Temperature logger PM Dive 5: Ile de la Passe	Ile du Coin Anchorage Transit to Ile Diamont anchorage (2 hrs from Petite Souer) Ile Diamont anchorage
13.04.19	Peros Banhos	AM Dive 6: Ile Diamant PM Dive 7: Moresby	Ile Diamont anchorage
14.04.19	Peros Banhos	AM Dive 8: Grande Ile Mapou or Dive 8a: Ile Diamont (lagoon + temp logger) PM Dive 9: Ile Ye Ye	Ile Diamont anchorage Transit to Ye Ye locality (2 hrs) Overnight Isle Coquillage anchorage
15.04.19	Peros Banhos	AM Dive 10: Ile Coquillage PM No dive: equipment, sample maintenance etc	Transit to Salomon (18nm, 3 hrs) Safety: >24 hrs off diving
16.04.19	Salomon	AM No dive: equipment maintenance etc PM Dive 11: Ile Anglaise (tip) - Temp logger	Safety: >24 hrs off diving Drift off Isle Anglaise (south west)
17.04.19	Salomon	AM Dive 12: Ile de la Passe PM Dive 13: Ile Takamaka	Drift off Salomon (north east)
18.04.19	Salomon atoll	AM Dive 14: Ile du Sel PM Dive 15: Ile Boddam	Drift off Salomon (south east) Drift off Salomon (north)
19.04.19	Salomon atoll	AM Dive 16: Ile Anglaise Mid or Dive 16a: T-logger knoll (lagoon) PM Dive 17: Ile Anglaise North Or Dive 17a: Courts knoll (lagoon)	Off of Salomon (north) Transit to Brothers 71 nm (12 hrs)

20.04.19 Spring tide (large) expect current	Great Chagos Bank	AM Dive 18: Middle Brother PM Dive 19: South Brother	Middle Brother anchorage
21.04.19 (Easter Sunday)	Great Chagos Bank 3	AM Dive 20: North Brother PM No dive, samples, equipment, maintenance etc	Middle Brother anchorage Transit to Eagle anchorage (15nm, 2.5 hrs) >24 hrs of no diving
22.04.19	Great Chagos Bank 4	AM No dive PM Dive 21: Eagle North	Eagle anchorage Transit to Danger Island overnight
23.04.19	Great Chagos Bank 5 -6	AM Dive 22: Danger island (aborted due to no visibility) PM No dive due to poor weather conditions	Transit to Egmont (20nm, 3.3hrs), Banks anchorage
24.04.19	Egmont	AM Dive 23: Ile de Rats PM Dive 24: Ile Lubine	North West Egmont Banks anchorage
25.04.19	Egmont 3-4	AM Dive 25: Mid Egmont PM Dive 26: North Egmont	East Egmont Banks anchorage
26.04.19	Egmont 5-6	AM Dive 27: Ile Sudest SouthWest (Tattumuca) PM: Dive 28: Ile Sudest SouthEast (Task 3 & 6 only)	South Egmont Transit to Diego Garcia (75nm 12.5 hrs)
27.04.19	Diego Garcia	AM Dive 29: Barton Point PM Dive 30: Middle Island or Dive 30a: Cannon Point	Diego Garcia Into harbour late afternoon
28.04.19	Diego Garcia harbour	Demobilise, clean and store gear, pack samples	Small boat harbour, Diego Garcia
29.04.19 Mon	Diego Garcia Moody Brook	Complete demobilization by 1200hrs, move all kit to Moody Brook	Move to NGIS Accommodation, Diego Garcia Meeting with Brit Rep
30.04.19 Tues	Diego Garcia	flight to Bahrain Tuesday B757 0950 arr 1215	Onward flights from 2100 hrs for some
01.05 19 Weds	Bahrain	onward flights to UK	Arrive UK

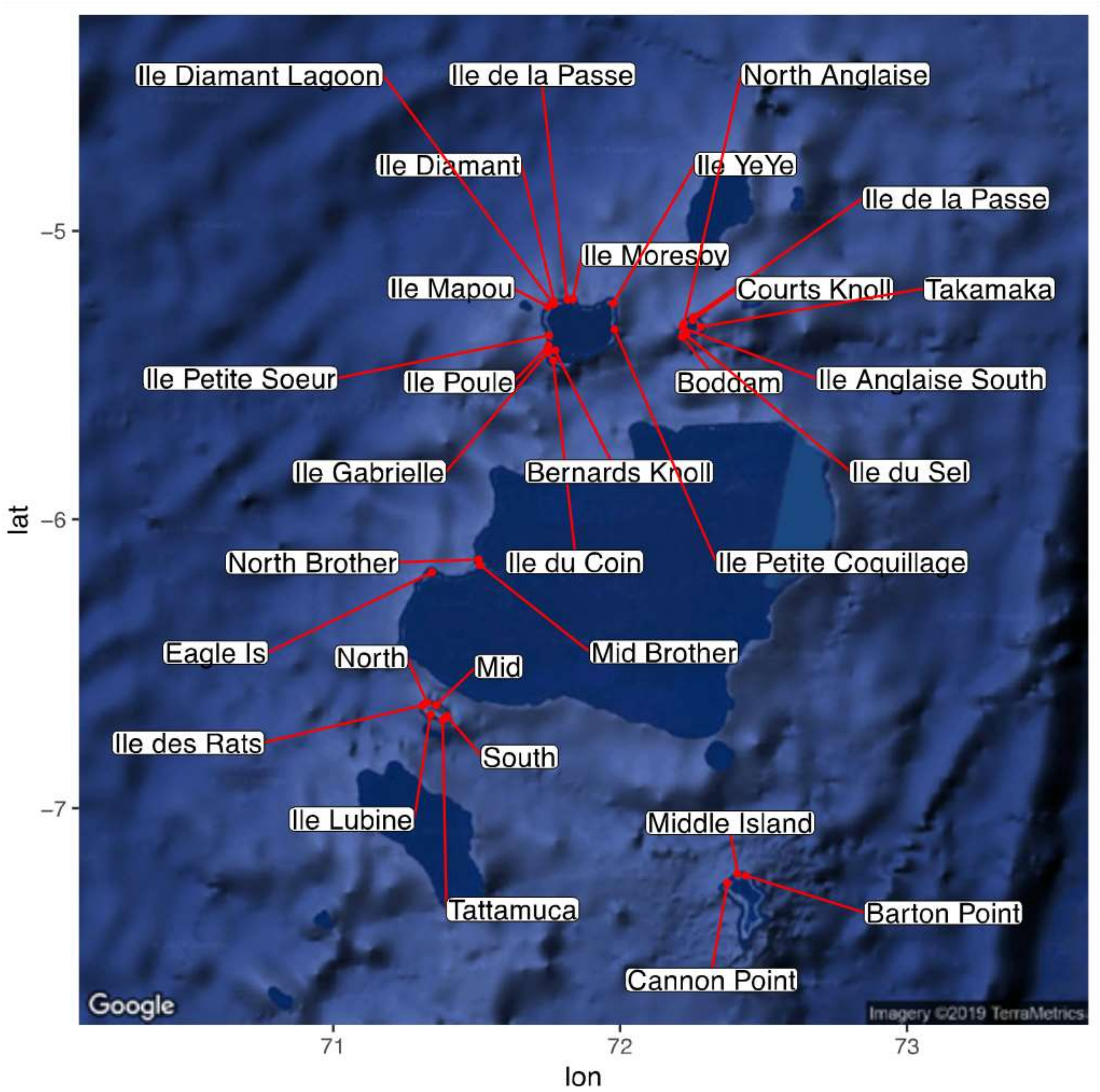

Figure 4. Names and distribution of sites of scientific investigation visited during the 2019 expedition

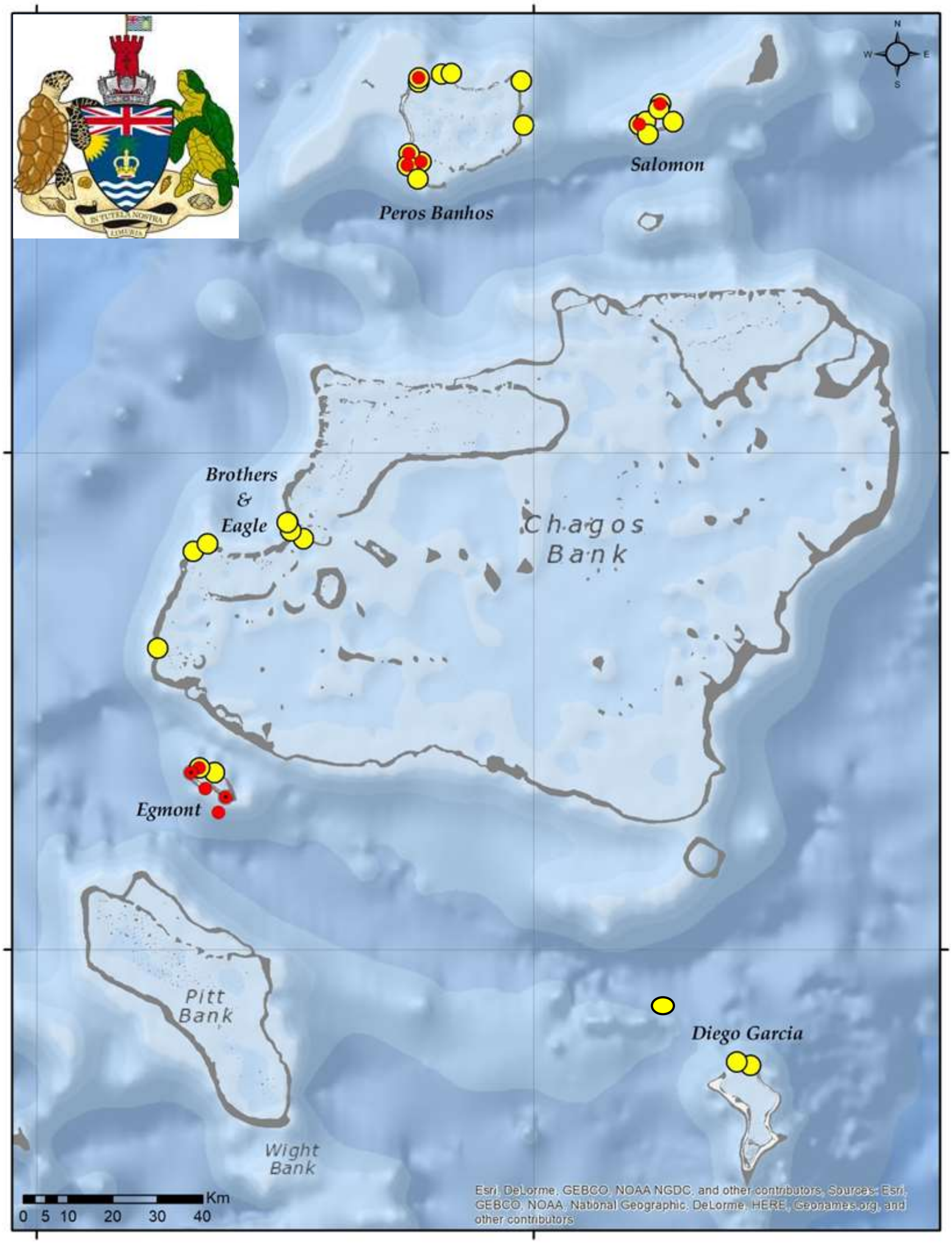

Figure 5. Sites of scientific investigation visited during the 2019 scientific expedition

Yellow dots indicate diving survey sites and red dots indicate sites where a small ROV was deployed

Report on Activities, Preliminary Scientific Findings and the Value of Research to BIOT

Tasks 1 & 2: Coral condition, cover, juveniles, and water temperatures (C. Sheppard, A. Sheppard)

Introduction

The team visited sites that have been visited over many years in order to continue to build the time series that commenced over 40 years ago. At every site, estimates were made, using quadrats (over 600 this year), across the entire archipelago to gain the widest possible indication of condition. This monitoring provides a knowledge base for management and assists other projects in selecting sites. Estimates were obtained of (a) coral cover, (b) juvenile corals with maximum dimension 15 mm (recent spat fall), and young corals (1-3 years old) for the survivorship of older corals might be as important a mechanism for recovery of grossly damaged reefs as is new recruitment, and (c) water temperature. Tasks (a) and (b) were conducted at intervals of 5 m depth to 25 m deep on ocean facing reefs slopes, facing all points of the compass. Seventeen ocean facing and three lagoonal reefs were visited and each was examined at 5 depths: a combination of 85 stations. Temperature measurements were mostly recorded on ocean facing reefs and in the northern lagoons of Peros Banhos and Salomon (Table 3).

Coral cover

The general appearance of Chagos reefs was of low live cover, and varied little from the past two years (Figure 6). Mostly, cover on ocean facing reefs was 10-12%, though sites with more live coral existed throughout, and on average cover was 10 to 12% only at each depth. The presence of over 20% coral cover at any depth was found only at five island/depth combinations (out of 85) while less than 5% coral cover was found at ten sites. Overall cover has increased marginally since last year though in a non-significant manner, and shows a similar pattern and lag as was seen following the 1998 mortality. Following the marine heatwave which ended in 2016, the >90% mortality of corals and soft corals on all ocean slopes extended down to at least 25 m depth (Figure 7).

Figure 6. Examples of (left) shallow reef terrace and (right) reef slope, both Ile Gabrielle in Peros Banhos in 2019. Live coral cover in both scenes is close to zero. In the shallow location, wave energy has removed much of the rubble leaving only stumps of corals and larger eroding fragments. On the deeper terrace, rubble from the dead corals remains.

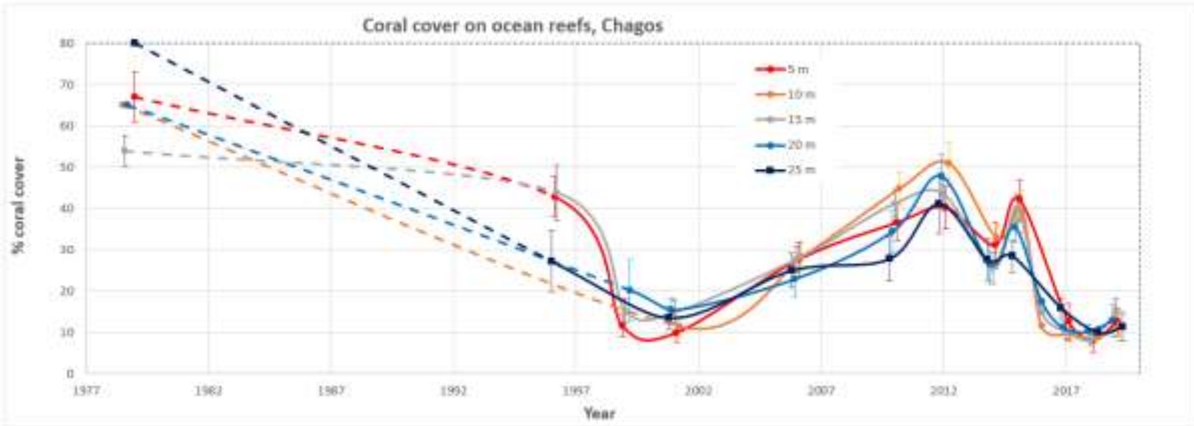

Figure 7. Coral cover at five depths on ocean facing slopes of all Chagos atolls (+/- s.e.) including data from 2019.

There is no trend with latitude, or distance from Diego Garcia which had reefs with cover over 20% (Barton Point) as well as the most depauperate (Cannon Point). The nearest atoll to Diego Garcia is Egmont, which contained the next highest cover of 33%, while the poorest sites were in the northern atolls. This suggests a correlation with latitude with greater cover occurring in more southerly locations, but no correlations existed. Suggestions have been made about some atolls being somehow more 'resilient', but based on the fact that one atoll can exhibit both the greater and least values of cover, local oceanographic features are likely to be responsible; for example sites near major passes showed greatest cover. Many sites exhibited increased crumbling of the matrix of dead coral skeletons (Figure 8), while in more shallow, wave exposed locations most coral rubble had been removed, leaving a more solid but bare substrate. Southeast facing reefs exposed to the full force of the SE Trade winds previously had populations of soft corals, but these have now disappeared as they leave no skeleton.

Figure 8. Considerable erosion continues on reef slopes, undercutting old dead colonies and increasing the friable nature of the substrate.

Whether recovery continues as it did after 1998's event will depend on the frequency and severity of further warming events (Figure 9). The correlation between El Niño and coral decline is clear. The El Niño, being primarily a Pacific index, is not a perfect indication of the Indian Ocean situation but is nevertheless a good proxy. The severity of temperature rise and its duration are both important and, while 2019 does not look like being a severe El Niño year, water temperature was usually over 30° C throughout the archipelago down to 25 m depth or more during April 2019.

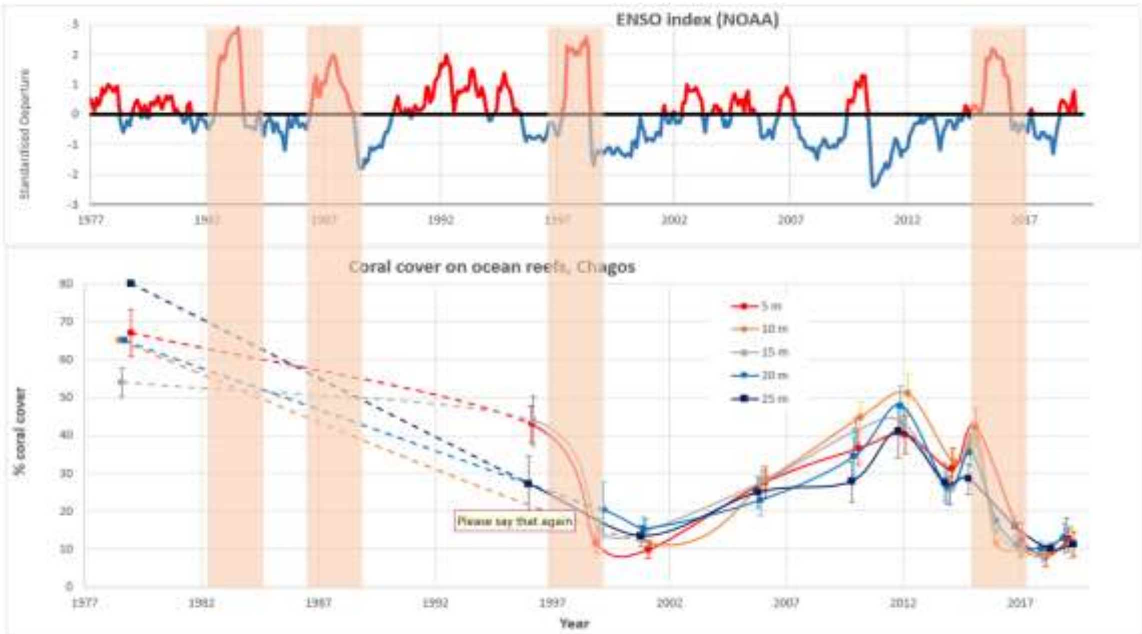

Figure 9. Coral cover with the El Niño Southern oscillation index. The pink bars indicate periods of major positive indices only.

Ocean temperature
Data series for ocean temperatures at different depths are now extensive for many locations across the archipelago, where in some places they have been recorded every two hours since 2006 (Table 3). A few temperature recorders have been lost but in many cases the gaps in Table 2 indicate changed locations based on various logistical considerations and according to need. All show a rising mean trend (straight line regressions) over the period they have been deployed, but most important are periodic rises to 29.5 or 30.3°C for several months; these are the extended periods of high temperatures that cause the mass mortality of corals on these reefs. In addition, especially between 2000 and 2012 there were several episodes of warming that led to bleaching but only in some places to widespread mortality as well, as in the case of Salomon lagoon (Figure 10).

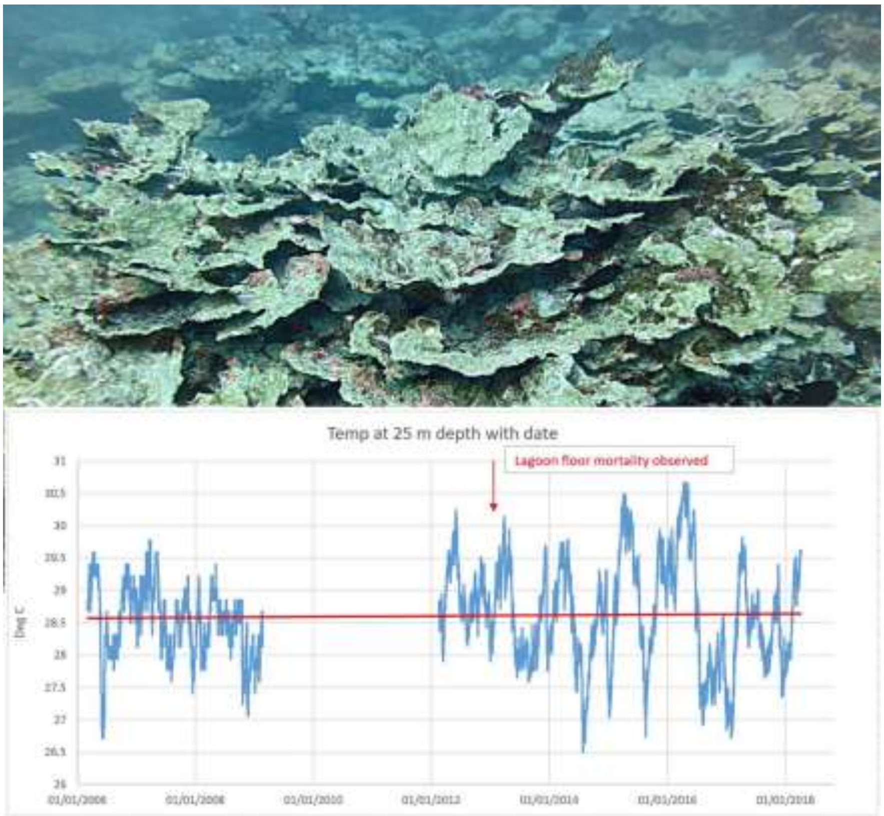

Figure 10. Salomon lagoon. Example of temperature trace 2006 to present, with a temperature data loss between 2009-2012, located at 25 m on the floor of Salomon lagoon. This is an extensive area of several square km, with near total cover of deep foliaceous corals, now almost 100% dead. Annual observations were made since 2010. Mortality occurred shortly before point marked by red arrow, in 2013. Note that the peak temperatures of later years in 2015 and 2016 are greater still – the lagoon remains covered with dead coral whose skeletons are now crumbling

Juvenile corals

Juveniles of less than 15mm in any dimension were simply counted using a magnifying glass in each quadrat. These counts do not include those colonies which are clearly young but are probably 1 to 3 years old – these were studied in a separate project. Prior to the recent mortality numbers ranged from about 20 to 80 per square metre which were values amongst the highest known in the world. In 2019, many sites have averaged about five per square metre (Figure 11). It is not known what densities of juveniles are needed to sustain a viable population of corals, let alone separated by species but the current paucity of mature adults for production of juveniles is not encouraging. One project still to be worked up with Dr Andy Mogg involved taking high-resolution images of each quadrat under UV light after the initial, 'traditional' counting method was finished. If this method shows comparable numbers, its use in future will greatly shorten the time needed for this time consuming element of the work.

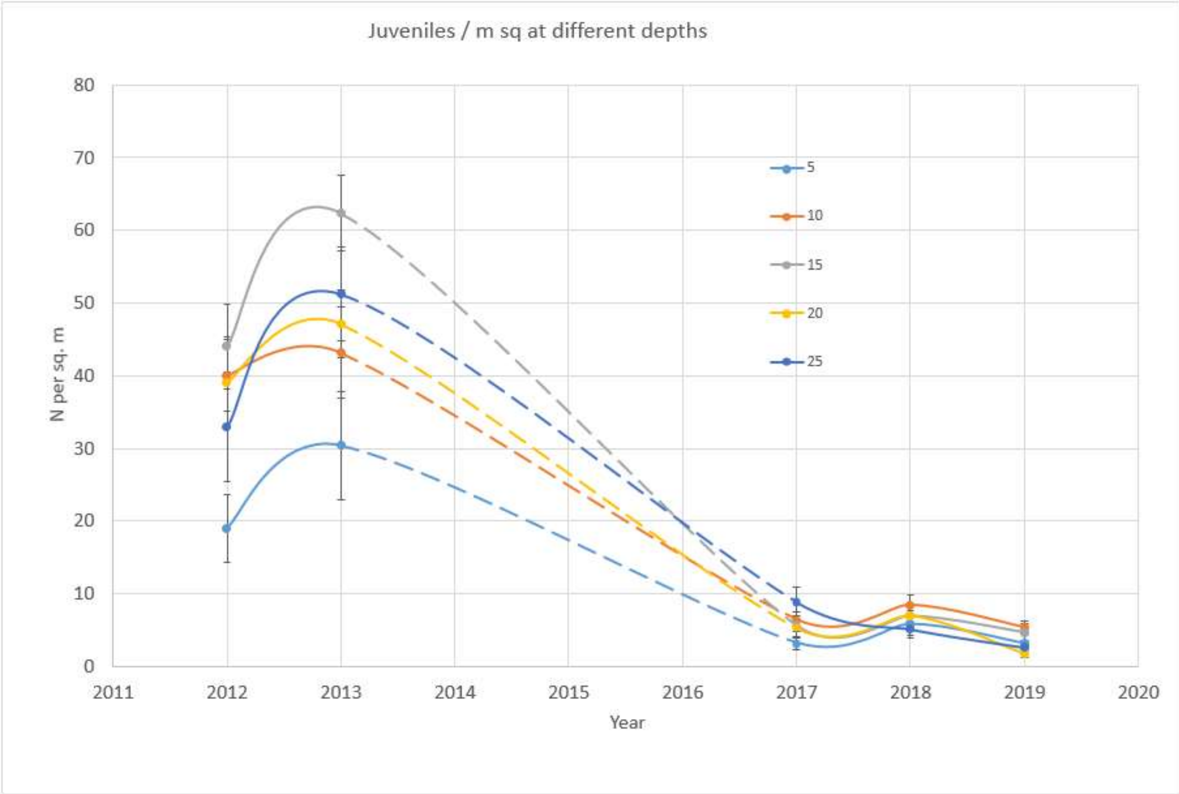

Figure 11. Juvenile corals (defined as less than 15 mm in any dimension) per square metre on Chagos seaward reefs. Note: this excludes young colonies which are more than about one year old.

Phoenix corals, Survivors and Recruits.

Dead *Acropora* tables are a site of concentrated numbers of juvenile coral recruitment, especially juvenile *Acropora*. The possibility has been suggested that the juvenile corals frequently found on dead *Acropora* tables are the result of some of the table *Acropora* polyps surviving the mortality that killed the table and re-grow a new individual. These corals have been termed 'Phoenix corals'. The importance of this compared with new recruits was investigated. Those easily observed are not new recruits ('juveniles' as defined earlier) but are 1-3 years old. Originally it was planned to take samples from each recruit for genetic analysis, had they all looked similar. It would not be possible to obtain coral genetic material from the dead table substrate. However, it was clear from gross morphological analysis of recruits on the table that they are not only genetically different but are, in most cases, clearly from a different variety of *Acropora* species and often a different genera. Of approximately 50 tables photographed, all had recruits growing on them. The numbers of different species on each table are still to be examined. Examples are shown in Figures 12, 13, 14. Clearly these are not Phoenix corals but were new 'recruits'. Some partly surviving specimens of massive coral forms in which most but not all tissue had been bleached, had resulted in the death of much of the coral colony apart from corallites around the sides out of direct sunlight. These colonies are indeed 'survivors' and are may be important for recolonisation as, after some time, they may be able to reproduce again. This includes the few discovered specimens of *Ctenella*, all of which were seen as patches of surviving tissue on mostly dead skeletons (Figure 15). Determining the quantitative importance of this is planned for next year.

Figure 12. A Porites *sp recruit growing on a dead* Acropora *table.*

Figure 13. At least 5 different Acropora *species are growing on this table along with two other genera.*

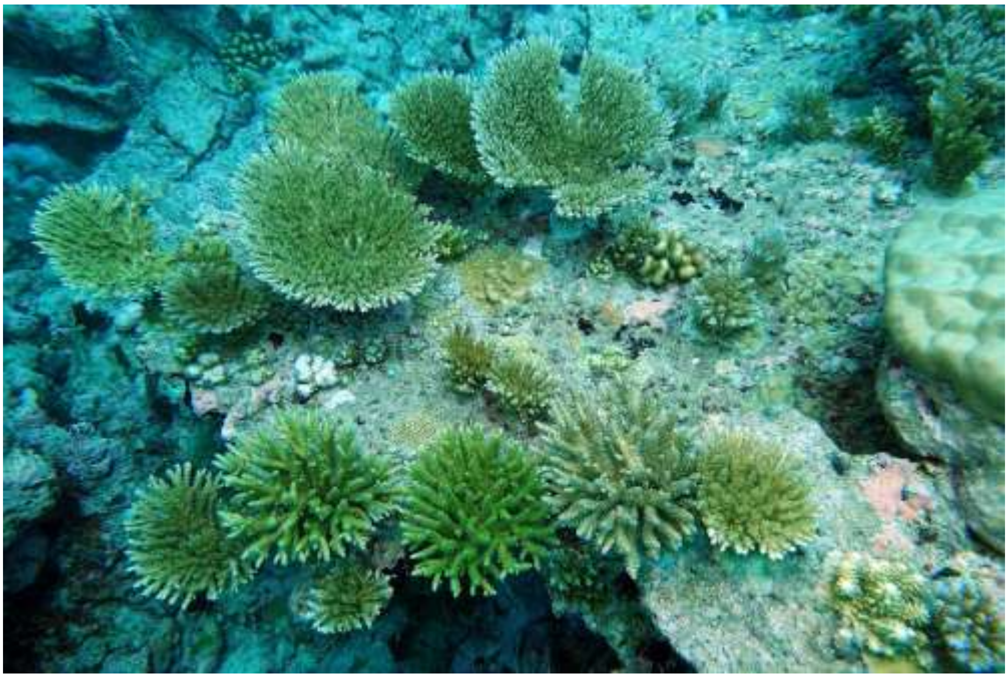

Figure 14. At least seven different Acropora *species are growing on this large table along with specimens of three other genera.*

Figure 15. A survivor specimen of Ctenella*. The areas of the colony receiving greater light intensity were killed and the surviving, more shaded, area has started to grow over the dead areas*.

Details of loggers	lat	long	2006	2007	2007	2008	2008	2009	2009	2010	2010	2011	2011	2012	2012	2013	2013	2014	2014	2015	2015	2016	2016	2017	2017	2018	2018	2019	2019
dark green is currently placed	light green is date codes sorted by CS so far																												
DG cannon Pt 5 m	-7.25738	72.372567	y	y	y	y																							
DG cannon Pt 15 m	-7.25738	72.372567	y	y	y	y					y	y	y	y	y	y	y	y	y	y	y	y	y				y	y	
DG cannon pt 25 m	-7.25738	72.372567	y	y	y	y					y	y	y	y	y	y	y	y	y	y	y	y	y				y	y	
DG North Pass 5m	7 13.78	72 24.74	y	y	y	y																							
DG North Pass 15m	7 13.621	72 24.425	y	y	y	y																							
DG North Pass 25	7 13.78	72 24.74	y	y	y	y																							
DG Mid island seaward 15 m															y	y	y	y	y	y									
Egmont Seaward 6 m	6 38.597	71 21.486	y	y	y	y	y	y	y	y	y	y	y	y	y	y	y	y	y	y	y	y	y	y	y	y	y	y	
Egmont Seaward 15	6 38.597	71 21.486																	y	y	y	y	y	y	y	y	y	y	
Egmont Seaward 25 m	6 38.597	71 21.486							y	y	y	y	y	y															
Egmont lagoon 6 m									y	y																			
Egmont lagoon 9 m			y	y	y	y	y	y																					
PB Diamant Seaward 5m			y	y	y	y	y	y																					
PB Diamant Seaward 15m	S5 14.769	E71 46.168	y	y	y	y	y	y																			y	y	
PB Diamant Seaward 25m	S5 14.769	E71 46.168	y	y	y	y	y	y																			y	y	
PB Diamant Lagoon 6m	S05 15.484	E71 45.952													y	y	y	y			y	y	y	y	y	y	y	y	
PB Diamant Lagoon 25m	S05 15.484	E71 45.952																	y	y	y	y	y	y	y	y	y	y	
PB logger knoll 5m	S5 24.888	E71 46.418	y	y	y	y	y	y	y	y	y	y																	
PB logger knoll 15m	S5 24.888	E71 46.418	y	y	y	y	y	y	y	y	y	y	y	y	y	y	y	y	y	y	y	y	y	y	y	y	y	y	
PB logger knoll 25m	S5 24.888	E71 46.418	y	y	y	y	y	y																					
PB Coin lagoon 15m	S05 26.979	E71 46.012																	y	y	y	y	y	y	y	y	y	y	
PB Coin lagoon 25m	S05 26.979	E71 46.012																	y	y	y	y	y	y	y	y	y	y	
GCB E Eagle 15m	S06 11.242	E71 20.328																	y	y	y	y	y	y	y	y	y	y	
Sal Anglais central 5m			y	y	y	y	y	y																					
Sal Anglais central 15m			y	y	y	y	y	y																					
Sal Anglais central 25m			y	y	y	y	y	y																					
Sal Anglais South 10m	S05 20.414	E72 12.804																	y	y	y	y	y	y	y	y	y	y	
Sal Anglais South 25m	S05 20.414	E72 12.804																	y	y	y	y	y	y	y	y	y	y	
Sal logger knoll 6m	S5 20.346	E72 13.905							y	y	y	y	y	y	y	y	y	y			y	y	y	y	y	y	y	y	
Sal logger knoll 15m	S5 20.346	E72 13.905	y	y	y	y	y	y																					
Sal logger knoll 25m	S5 20.346	E72 13.905															y	y	y	y									
Sal logger knoll 25	S5 20.346	E72 13.905	y	y	y	y	y	y							y	y	y	y	y	y	y	y	y	y	y	y	y	y	

Table 3. Details of Temperature Logger deployment 2006-2019

Task 3: Extend video archive for long term assessment of coral reef benthic community structure (J. Turner, R. Roche)

Introduction

A video archive of coral reef benthic community structure has been developed across depths at permanent monitoring sites (the same sites as the long term visual assessments described above) throughout the atolls and allows for detailed analysis of the changes in communities to extend the broad scale assessments described previously. The aim of the study is to produce a record that can be analysed to assess change when compared with video records first made at sites in 2006, and annually since 2013. A video archive provides the opportunity to revisit sites in time to assess factors that have more recently become of note (e.g. disease, functional extinction) and provides a visual baseline allowing newly engaged scientists to compare coral reef community structure in time. The rationale is that the videos provide a permanent reference and 'bench mark' for observing the effects of changing conditions in the absence of direct human impact, and one that can be repeatedly revisited in future. Video recording (Figure 16) enables a relatively large tract of reef to be recorded that can be then be analysed without the constraints imposed on an observer underwater. The data collected enables analysis of all components of the coral reef benthos, including sponge, hard and soft coral cover, macroalgal cover, crustose coralline algal cover, and turf algae (Figure 17) and will permit some of the calcification parameters collected by others to be applied more widely across the Archipelago. Bayley and Mogg are using the video to create digital 3D models of the reefs in past years.

Figure 16: Recording video at Moresby and isle du Sel

Methodology

Sites were revisited across the Chagos Archipelago in 2019 (Table 4), and to increase the statistical robustness of the study, additional sites were added to provide 6 sites per locality at Peros Banhos, Salomon, western Great Chagos Bank and Egmont. 4 video transect replicates of 2 minutes were recorded within each 5 m depth interval from 25 m to 5 m depth by two divers using identical high definition video cameras in housings equipped with a wide angle port lens, LED video lights for deeper depths and red filter for mid depths, with scale being provided by two lasers mounted below the camera to project dots 10 cm apart on the video image. In addition, high definition wide angle digital still images were recorded at 10 second intervals by Go-Pro cameras mounted on the housings in a horizontal plane to provide context of the reef habitat in the vicinity of each video transect, such that the video archive can be used in conjunction with the structural complexity determination described below.

Video sequences from four 5 m depth intervals (5-10 m, 10-15 m, 15-20m and 20-2 5m) are being compared between years. Frame grabs are being extracted randomly from each depth interval at each site and imported into an image processing package - Coral Point with Excel Extensions (CPCe, NCRI Florida), and overlaid by 16 randomly generated points. The substrate, benthic life form, and where appropriate genus and species underlying each point are imported into statistical software for analysis. The analysis team is reworking data from 2006 to the present year using a consistent approach utilising 3 analysts each working on 10 images per depth per site per year, with a moderator checking identifications. Tissue loss, discolouration and diseases are recorded by playing each video through and recording frequency. Sustained high sea temperatures between April and May of 2015, 2016 led to wide scale bleaching, and survey results from April 2017 and 2018 indicate significant and widespread mortality of similar severity to that resulting from mass mortality after 1997/98. The resulting mortality and subsequent restructuring of the coral canopy will continue to be assessed as the reef recovers.

Results

Video data from 2019 is currently being analysed, but data from 2018 compared to 2014 (Figure 17) shows a reduction in hard coral cover, being greatest in the 5-10m depth band from just under 50% cover to just under 25% cover, with progressively less change in deeper depths to no significant change at 20-25m. An increase in algae (mostly *Halimeda*) and sponges with depth is apparent, and an increase in Crustose Coralline Algae (CCA) in shallow waters. Soft corals have been lost from most sites, and much of the dead coral material has been removed from the reefs. We anticipate these trends to have continued in 2019, with hard cover lost from all depths, in line with the visual observations of Sheppard (above).

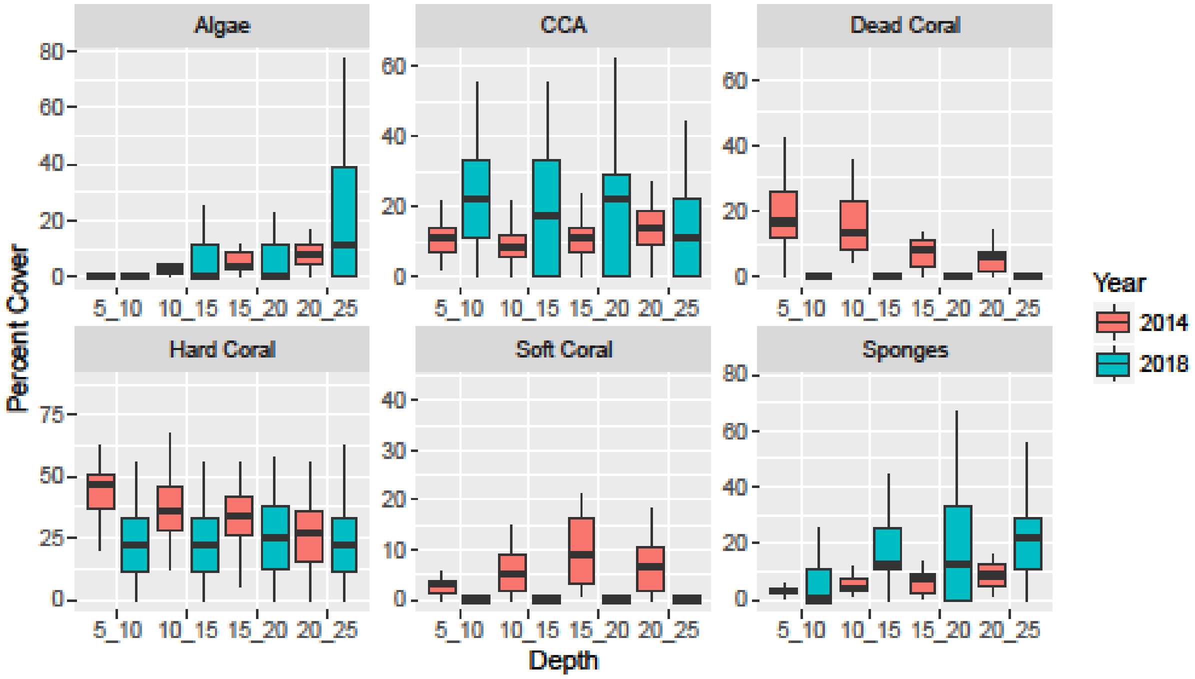

Figure 17. Example of video archive analysis: The increase in algae, Crustose Coralline Algae (CCA), Soft corals and Sponges and decrease in Hard coral, and Dead coral with depth between 2014 (pre coral bleaching) and 2018 (post coral bleaching) from video assessments at sites across Chagos Archipelago.

Significance of current condition

The study provides important information on how the reefs are changing, allowing the reef community structure at different depths at sites to be compared between years (Figure 18) showing which zones of the reef are being affected and how well they are recovering when compared to their former state. Further, the archival information allows us to compare newly recognised features and phenomena with what previously existed.

The current condition of the reefs is one in which dead coral material is either consolidating on the reef (Figure 19) or being removed by water movement (Figure 20) and therefore the reefs are probably looking at their worst at present, barring further repeat warming events. Dead standing corals are bio-eroded by a variety of marine organisms including sponges and algae (Figure 21) and become brittle, often undercut, and eventually topple. However, some of these also provide an elevated well-illuminated surface on which new corals settle (Figure 22). Those on reef slopes often fall down the reef slope or wash off in storms, creating further piles of debris. Pockets of rubble do occur (Figure 23) and where there is movement due to wave swell, and then abrasion occurs as the rubble disintegrates, and little life can exist here. Larger coral colonies such as sections of coral tables and lumps of coral colony that are not washed away by water movement, begin to lock together in a matrix that gets cemented together by calcium carbonate producing organisms. Once stable, these calcium carbonate pavements provide a good surface for marine larvae to settle and a succession develops. A biofilm and turf algae often cover these surfaces, but coral larvae will attach in grooves and pits and begin to establish themselves. Many larvae will be grazed away by echinoderms, molluscs and fish, and other will be outcompeted by algal growth. In some places, a colonial growth form such as a sponge, soft coral (Figure 23), zoanthid anemone or calcareous macroalgae (Figure 24) may reproduce asexually/grow to rapidly colonise available space. Such lifeforms may later reduce in cover as slower growing, but more aggressive species such as corals begin to establish themselves.

Some coral colonies may have mostly died off, but remnants of the colony, may survive and with time, the colony may re-establish itself again by a process of asexual reproduction producing new corallites mostly from budding. Upturned corals may produce new growth from the previously shaded surface. New corals can only be produced if surviving corals produce larvae through sexual reproduction, and these larvae settle in habitats that allow for viable growth into coral colonies that themselves can reproduce. Bleached corals are stressed through physiological damage and due to starvation, and lack the resources to invest in producing gametes. If these corals survive, then it is unlikely that they can reproduce in the years immediately following bleaching events, even if conditions return to normal. This suggests that recruits are being produced by corals in deeper water – perhaps on 20m + parts of the reefs or reefs out on banks and mounts, and being swept in and up onto the shallower parts of the reefs. However, corals on deeper reefs than these may be different species and unlikely to establish on shallow reefs. There is also a possibility that some corals may survive in shallow parts of the reef where nutrients (possibly from shallow lagoons) and cool waters (from stationery waves or upwelling) or turbid conditions (reducing solar bleaching) mitigate the effect of bleaching, and these corals are still capable of sexual reproduction after warming events. However, these corals appear to be small digitate *Acropora* species and lack the variety of the corals lost from the reefs.

There are no specific additional local management recommendations that are relevant here at the current time. We can expect succession and reef development although what develops may be different from what existed before the back-to-back warming event, due to species being lost, resilient surviving species (Figure 25), resettlement and recruitment before the next major warming event. Reef recovery after the 1997/98 warming event produced reefs which were different in community structure to those that existed before, with a predominance of *Acropora* tables (*A. clathrata*, *A. cytherea)* at shallow depths. By 2006, these corals were beginning to form a new reef canopy (Figure 26) as corals and other life forms began to compete for space and light, although the dead standing consolidated material was still evident, comparable with some observations in 2019 (Figure 27). By 2012/ 2013, it is believed that these reefs had reached their best structural state, after which white band syndrome initiated a rapid decline in the tabular *Acropora* colonies in shallow waters, Crown of Thorns starfish plagued some shallow corals in the vicinity of the west Great Chagos Bank (Eagle, Danger island) and temperature inversions in some lagoons (eg. Salomon) caused the loss of deeper coral communities as discussed above.

On the last dive of the expedition at Middle Island, Diego Garcia, we were rewarded with the sight of a large Bull shark that came up the reef to inspect us (Figure 28).

Figure 18: Isle Anglaise Salomon reef terrace in 2006 (left) and 2019 (right) exemplifies the loss of tabular Acropora *colonies on many seaward reefs*

Figure 19. Digitate and table Acropora *colonies growing on consolidated substrate (Egmont North)*

Figure 20. Unstable table Acropora *brought down the reef slope (Egmont North)*

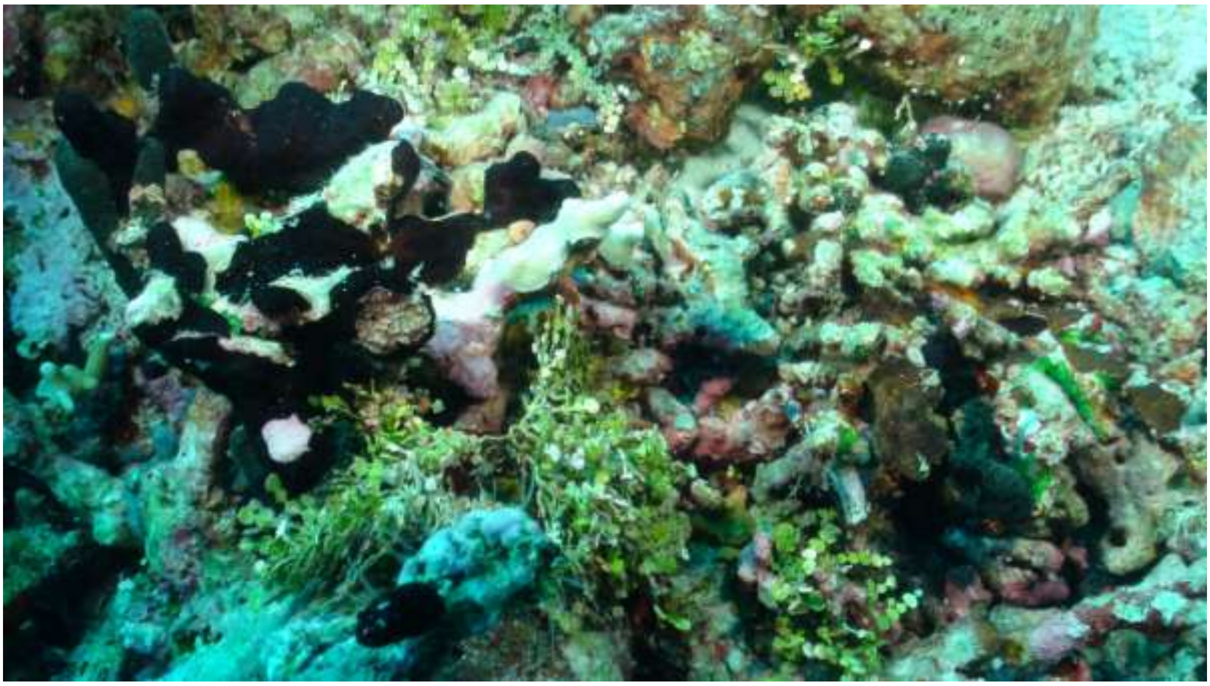

Figure 21. Sponges and algae bioerode dead coral, and Halimeda *and CCA are frequent (isle de la Passe, Salomon)*

Figure 22. Dead standing tables provide a temporary elevated well-illuminated surface on which new corals settle

Figure 23 Coral rubble (Egmont, left) and soft coral growing on rubble at Middle Island (right)

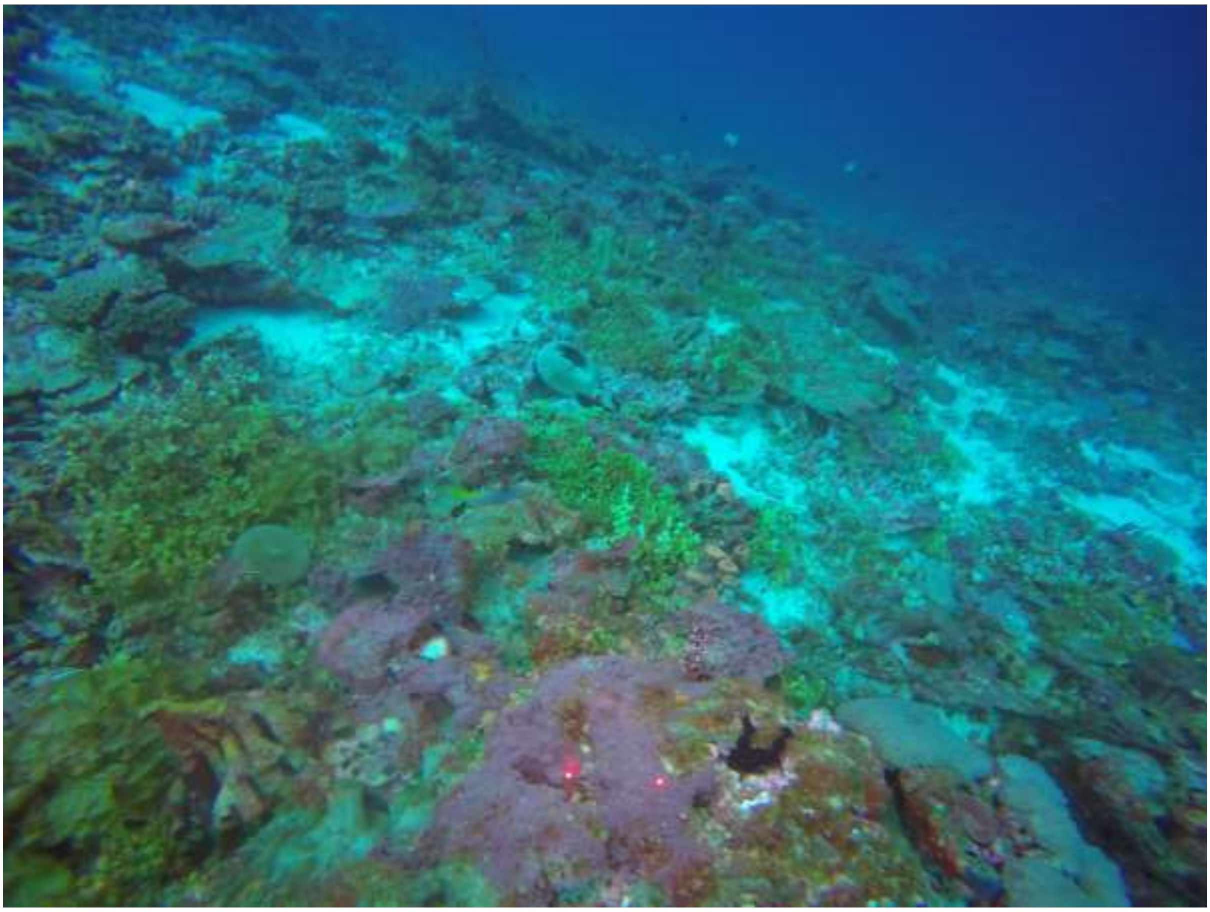

Figure 24: extensive growth of Halimeda *on deep reef slope, Bernard's Shoal, Peros Banhos*

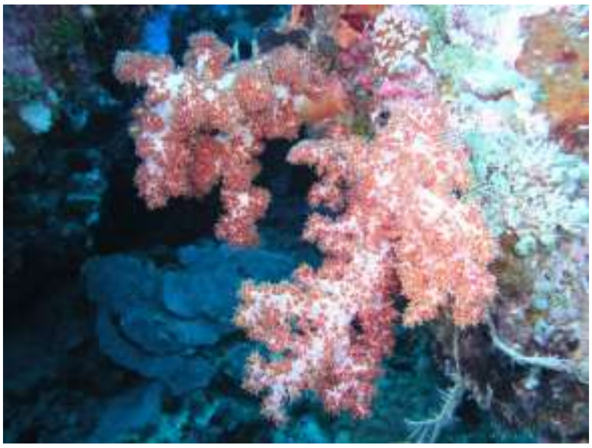

Figure 25. Many Nepthiid soft corals have been lost (left) and large Ctenella chagius *colonies (right) like this are now rare and incomplete (images from 2006).*

Figure 26. Acropora *tables dominating reef slope and forming a new canopy in 2006 (Isle Anglaise Salomon)*

Figure 27. In 2006, 8 years after the 1997/98 bleaching event, corals at Isle Anglaise, Salomon were as in image on left – not unlike those at the same site in 2019, 3 years after the 2015/26 bleaching event.

Table 4. Video Archive monitoring sites in Chagos Archipelago from 2006 to 2019

Atoll	Island	Site Name	Position	Year (no of sites)								Latitude (Degrees and Minutes, South)	Longitude (Degrees Minutes, East)
				2006 (19)	2013 (19)	2014 (23)	2015 (33)	2016 (10)	2017 (16)	2018 (28)	2019 (27)		
Diego Garcia	Middle Is	MIDDLE IS	Seaward		■	■	■			■	■	7:13:570	72:24:500
	East Is	EAST IS	Seaward	■			■					7 13.700	72 24.700
	Diego Garcia	CANNON POINT	Seaward				■			■		7:15:443	72:22:354
	Diego Garcia	BARTON POINT	Seaward	■			■			■	■	7:14:365	72:27:000
	Diego Garcia	BARTON SOUTH	Seaward	■		■							
	Diego Garcia	HORS BAY	Seaward				■			■			
Great Chagos Bank	Nelson Is	NELSON IS	Seaward	■	■		■			■		5:40:769	72:18:906
	Nelson Is	NELSON LAGOON	Lagoon		■		■					5:41:279	72:18:847
	Eagle Is	EAGLE IS LAG	Lagoon		■	■	■			■	■	6:11:015	71:20:630
	Eagle Is	EAGLE SOUTH	Seaward		■	■	■					6:11:950	71:18:942
	Middle Brother	MID BRO DROP	Seaward	■		■	■			■	■	6:08:950	71:31:015
	Middle Brother	MID BRO CHANNEL	Seaward		■	■	■					6:09.429	71:30.652
	South Brother	SOUTH BRO SEAWARD	Seaward			■	■	■		■	■	6:10:384	71:32:241
	North Brother	NORTH BRO	Seaward	■			■			■	■	6:08:329	71:30:426
	Danger Is	DANGER SEAWARD	Seward			■	■			■			
	Danger Is	DANGER LAGOON	Lagoon				■			■			
Egmont	Egmont	NORTH	Seaward		■	■	■	■		■	■	6:38:096	71:19:645
	Egmont	MIDDLE	Seaward		■		■			■	■		
	Egmont	SOUTH	Seaward		■	■		■				6:40:812	71:23.730
	Egmont	ILE DES RATS	Seaward								■		
	Egmont	ILE LUBINE	Seaward								■		
	Egmont	ILE SUD EST	Seaward								■		
Peros Banhos	Ile Diamant	DIAMANT SEAWARD	Seaward	■		■	■		■	■	■	5:14:780	71:46:170
	Ile Diamant	DIAMANT LAO	Lagoon	■	■		■		■	■	■	5:15:309	71:46:093
	Ile du Passe	PASSE	Seaward	■		■			■	■	■	5:14:240	71:48:899
	Moresby	MORESBY	Seaward			■	■	■	■	■	■	5:14:241	71:50:090
	Petite Ile Coquillage	PETITE COQ	Seaward		■	■	■	■	■	■	■	5:20:510	71:58:800
	Knoll	BERNARD KNOLL/SHOAL	Lagoon	■	■	■	■	■	■	■	■	5:24:890	71:46:419
	Ile du Coin	COIN LAGOON	Lagoon			■	■		■	■	■	5:26:979	71:46:012
	Ile Poule	POULE	Seaward	■		■	■		■	■	■		
	Ile Fouquet	FOUQUET	Seaward	■	■		■		■	■			
	Ile YeYe	YEYE	Seaward			■			■	■	■		
	Ile Gabriel	GABRIEL SEAWARD	Seaward								■		
Salomon	Ile du Passe	PASSE	Seaward	■		■	■	■	■	■	■	5:17:930	72:15:310
	Ile Anglaise	ANG SOUTH	Seaward		■		■						
	Ile Anglaise	ANGS TIP	Seaward		■	■	■		■	■	■	5:20:370	72:12:750
	Ile Anglaise	ANGS PASS	Seaward	■	■	■							
	Ile Anglaise	ANG MID	Seaward	■	■		■	■				5:19:900	72:13:150
	Ile du Sel	SEL	Seaward	■							■		
	Ile du Sel	SEL	Lagoon	■									
	Knoll	SAMS KNOLL	Lagoon		■		■	■	■	■		5:20:000	72:13:545
	Knoll	COURTS KNOLL	Lagoon					■		■	■		
	Knoll	LAGOON KNOLL	Lagoon	■									
	Ile Takamaka	TAKAMAKA	Seaward	■	■		■		■		■		
	Ile Boddam	BODDAM SEAWARD	Seaward								■		
Blenheim	Blenheim	BLENHEIM SE	Seaward			■	■		■			5:15:229	72:26:582
	Blenheim	BLENHEIM SW	Seaward			■	■		■	■		5:13:755	72:29:545

Figure 28. Bull shark observed at Middle Island in 12-15m water depth on last dive of expedition

Task 4: Three-dimensional determination of reef structural complexity and spatial analysis of coral recruitment (D. Bayley, A Mogg)

Introduction

The aim of this task was to use emerging underwater imaging technologies to assess and monitor the health of the reefs of BIOT, quantitatively recording and visualising change.

A detailed and comprehensive measure of the physical characteristics of both individual coral colony growth traits and coral reef structure (which incorporates a number of 3D metrics such as rugosity, roughness and granularity), is critical to understand how a reef functions and whether it is in a state of historic decline or regrowth. Further to this, accurate and repeatable indicators of habitat availability, productivity and composition are needed to understand how disturbance alters reefs. A permanent and detailed quantitative digital record of the 3D structure of the reef using 'structure from motion' (SfM) records the associated biodiversity (richness and composition) of reef and demersal organisms. Using marked plots in multiple locations and across reef types, changes associated with the recent El Niño bleaching episode are being measured. Rapid capture of the 3D environment (using in-water SfM photogrammetry) has already been carried out at each of the atoll sites in April 2016, 2017 and 2018 and will be recorded again this year to quantify the reef flattening and erosion which is becoming apparent. These data are processed and calibrated to create a digital model covering 200 square metres of reef Images are recorded using a mixture of digital camera stills and HD video footage.

The specific objectives were:

- To assess changes in multiple metrics of reef physical structure and volume through the period 2018-2019, in order to monitor recovery trajectories of the reef of BIOT following widespread mortality in 2015 and 2016.
- To directly compare the use of Structure from Motion (SfM) photogrammetry with the *ReefBudget* method of carbonate budget assessment for multiple sites *in situ*, across gradients of wave exposure.
- To trial the utility of fluorescent photogrammetry for the assessment of coral recruit abundance relative to traditional visual methods.
- To conduct a rapid health assessment of the upper mesophotic reefs of Peros Banhos, Salomon and Egmont atolls within BIOT using a mini Remotely Operated vehicle (ROV).
- To record 360 VR video of sites above and below the water for outreach and science communication.

Methodology

31 sites were visited (7 lagoon, 24 seaward) over the course of the expedition (Figure 4 & 5, Table 5) Permanent markers for Structure from Motion multi-year comparison were placed at 25 sites (imaging approximately 7000 m^2 of reef), with direct in-situ carbonate budget comparison at three sites. Direct recruit comparison was conducted at two sites and the ROV was deployed at 10 site locations (totalling 25 dives).

Reef structure and volume change

The primary objective was to continue the annual 3D monitoring of reef structural changes in the reefs of the Chagos Archipelago started in 2015. Surveys were conducted at a depth of 10 metres, on the seaward reef flat / crest and lagoon slope using SfM photogrammetry techniques. Sites are grouped spatially into: 1) Peros Banhos, 2) Salomon and Blenheim atoll, 3) Western Great Chagos Bank, and 4) Diego Garcia atoll. Camera imagery was captured using a Nikon D750 DSLR camera (with 20 mm wide angle fixed lens and dome port) under ambient lighting at ~1-2 m from the substrate with in-situ reference scales positioned across the survey area. Surveys covered a planar area of approximately 200 m^2 consisting of ~1000 images per site. Images will be stitched together as above, with the resulting dense xyz pointcloud (accurate to < 5 mm) clipped to 20 x 2 m sections and exported to Gwyddion (Figure 29). Using this software, changes in four specific reef structural metrics were investigated: 1) 3D rugosity ratio, 2) surface Z-axis maximum and minimum height difference, 3) surface skew, and 4) fractal dimension through the 'cube-counting' method.

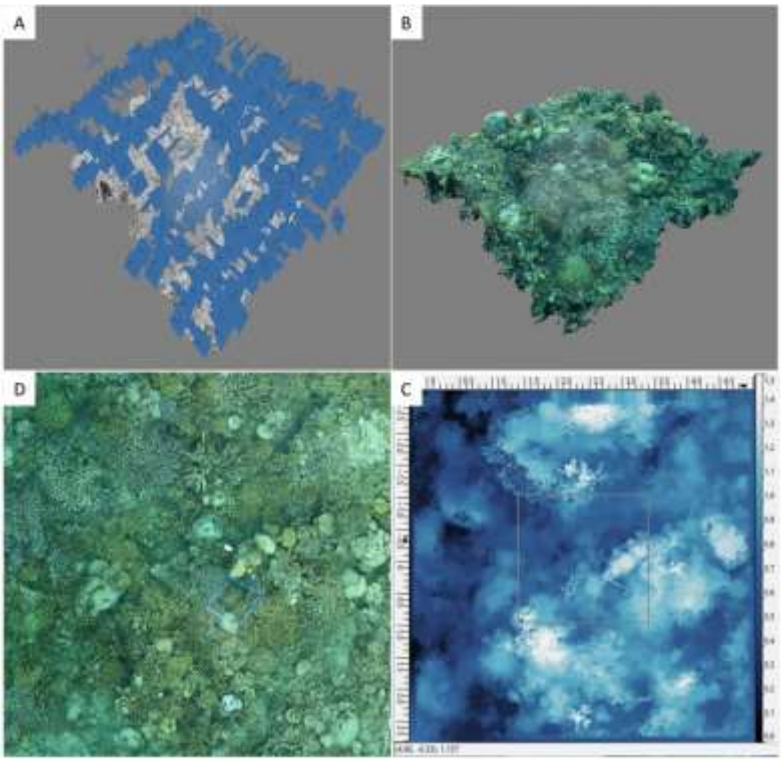

Figure 29. Typical SfM process and 3D outputs from a site. Illustrating A) the initial dense point-cloud, with individual camera locations shown; B) mesh with draped colour imagery; C) calibrated XYZ point-cloud with a virtual 2 x 2 metre quadrat illustrated in the centre; and D) a high definition ortho-rectified image mosaic of a 5 x 5 metre reef area, with in-situ blue quadrat (0.5 x 0.5 m) shown centre.

Carbonate budget assessment

At the northern sites, two blocks of 10 x 10 m size models were imaged annually (2017-2019) following the same point-cloud creation and calibration technique previously described. At each site block, models were orientated to an in-situ compass and spirit-level, and calibrated to a scaling accuracy of < 5 mm. The corresponding years' point-cloud layers for each site block were cropped to broadly overlapping 50 m^2 reef sections based on in situ markers and exported as dense point-clouds to the open-source software 'CloudCompare' (Girardeau-Montaut, 2018) for direct point-cloud to point-cloud surface comparison (Figure 30). This allows detailed estimation of annual volumetric change and therefore overall carbonate budget loss or gain through time.

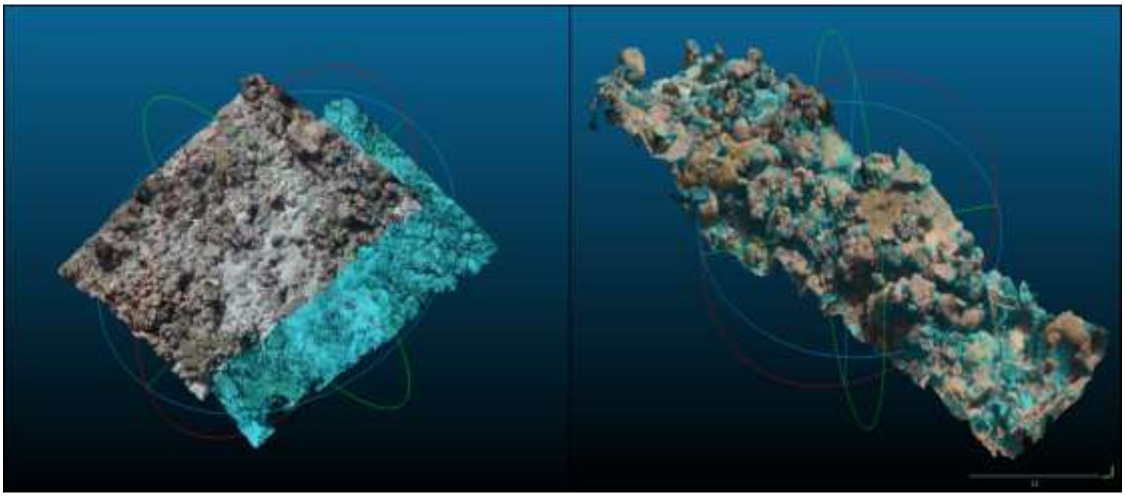

Figure 30. Illustrating the process of aligning two dense point-cloud sections from SfM outputs of repeat annual surveys along the Chagos archipelago reef during 2017 and 2018 (left), and a fully aligned (composite point-cloud) 10 m^2 clipped section (right).

Coral recruit assessment

The use of a novel 'fluorescent photogrammetry' technique was trialled at a number of sites, as a means to rapidly assess coral recruitment to the reef. This new method was directly compared with previous the traditionally used visual in-situ technique (Task 2) in order to validate its effectiveness (Figure 31). The same SfM technique described above was used assessing volume change to compare growth rates of new established colonies.

Figure 31. Comparing traditional and modern in-situ methods for assessing new recruits to the reef (left), and established juvenile recruits (~1-2 years old) settling on a dead reef matrix of tabular growth forms.

Mesophotic reefs
A mini US-built 'Trident' ROV with a maximum depth of 100 m and an integrated HD camera and lighting system was used to survey depths of between ~ 10 - 70 m to investigate both shallow and previously unexplored mesophotic benthic communities and their 3D structure. The ROV was deployed during dive surface intervals at 10 sites around Peros Banhos, Salomon atoll and Egmont atoll. Survey dives were typically around 20 mins, with video recorded via the integrated HD camera.

VR visualisation
A Theta V 360 and GoPro Fusion camera was employed to record panoramic video footage of both the marine and terrestrial life found in the Chagos Archipelago. This footage can be integrated with the Oculus Rift virtual reality headset to give an immersive experience for people wanting to know more about this region.

Initial results and observations
In total, nearly 30,000 images were captured over the 25 multi-year comparison sites, with upward of 1,800 images at some complex locations. Such a volume of data necessitates the use of a massively parallel processing distributed network to achieve measurable outputs in an effective timescale. A four node, 5CPU, 7GPU network with a third of a petabyte of solid state RAM is currently being used to process the SfM models needed to compare structure, volume and recruitment, after which we will be able to analyse the changes which have occurred through the period April 2018 to April 2019. We are similarly still in the process of analysing the outputs from the ROV and fluorescent photogrammetry. The 360VR videos are being further processed alongside existing models displayed in an immersive display to the public at the World Conference of Science Journalists, Switzerland.

In addition, an unusual Napoleon wrasse (*Cheilinus undulatus*) aggregation of 8 adults on the seaward slope of Ile Boddam, was observed the day before full moon (Figure 32). This could potentially be a transient spawning aggregation, given the number of fish, timing and behavioural gesturing observed (although no mating was directly observed). It is therefore recommended given the fish's commercial value and endangered status that further investigations are made of this site to ensure its correct management for this species.

Figure 31: Possible beginning of a spawning aggregation of Napoleon Wrasse at Boddam, Salomon

Site locations and activities

Table 5. Locations of all surveys conducted in the Chagos Archipelago (April 2019), including atoll group, aspect, GPS coordinates, and survey type. All ROV surveys ranged from the surface to a maximum of 70 metres, all SfM-based surveys were conducted at 10 metres, and recruit surveys ranged from 10-25 m.

Site	Atoll	Aspect	Latitude	Longitude	ROV	SfM	Recruit
Middle Island	Diego Garcia	Seaward	-7.226208	72.408867	No	Yes	No
Barton Point	Diego Garcia	Seaward	-7.232669	72.436675	No	Yes	No
Egmont North	Egmont	Seaward	-6.634576	71.327326	Yes	Yes	No
Egmont Mid	Egmont	Seaward	-6.643535	71.358270	No	Yes	No
Ile Lubine	Egmont	Seaward	-6.675948	71.339959	Yes	No	No
Ile Du Rattes	Egmont	Seaward	-6.644167	71.310667	Yes	No	Yes
Ile Sud Est	Egmont	Seaward	-6.693918	71.380611	Yes	No	Yes
Diamont Lagoon	Peros Banhos	Lagoon	-5.254751	71.768042	No	Yes	No
Bernards Shoal	Peros Banhos	Lagoon	-5.414941	71.773411	Yes	Yes	No
Ile Poule	Peros Banhos	Seaward	-5.398063	71.749385	Yes	Yes	No
Diamont Seaward	Peros Banhos	Seaward	-5.246148	71.769464	Yes	Yes	No
Ile De La Passe	Peros Banhos	Seaward	-5.238323	71.814839	No	Yes	No
Moresby	Peros Banhos	Seaward	-5.237186	71.834747	No	Yes	No
Ile Yeye Seaward	Peros Banhos	Seaward	-5.252142	71.975504	No	Yes	No
Petite Coquillage	Peros Banhos	Seaward	-5.341558	71.980222	No	Yes	No
Ile Du Coin	Peros Banhos	Seaward	-5.449826	71.767034	No	Yes	No
Ile Gabrielle	Peros Banhos	Seaward	-5.422004	71.746644	Yes	Yes	No
Sams Knoll	Salomon	Lagoon	-5.333686	72.225794	No	Yes	No
Courts Knoll	Salomon	Lagoon	-5.308833	72.252367	No	Yes	No
Ile Boddam	Salomon	Lagoon	-5.367770	72.215080	No	No	No
Ile Anglaise South	Salomon	Seaward	-5.339867	72.213395	Yes	Yes	No
Isle De La Passe	Salomon	Seaward	-5.298367	72.254967	Yes	Yes	No
Takamaka	Salomon	Seaward	-5.333429	72.281125	No	Yes	No
Ile Du Sel	Salomon	Seaward	-5.359447	72.229765	No	Yes	No
Nth Brother 2019	Western GCB	Seaward	-6.140310	71.504334	No	Yes	No
Mid Brother	Western GCB	Seaward	-6.156646	71.511175	No	Yes	No
Sth Brother	Western GCB	Seaward	-6.172903	71.537219	No	Yes	No
Eagle West	Western GCB	Seaward	-6.198828	71.315124	No	Yes	No
Eagle East	Western GCB	Seaward	-6.183550	71.343608	No	Yes	No
Mid Brother	Western GCB	Seaward	-6.156760	71.511162	No	Yes	No
Nth Brother	Western GCB	Seaward	-6.140498	71.504918	No	Yes	No
Danger West	Western GCB	Seaward	-6.385297	71.234832	No	No	No
Danger East	Western GCB	Seaward	-6.394054	71.243883	No	Yes	No
Egmont Sanbbank	Western GCB	Seaward	0.000000	0.000000	Yes	No	No

Tasks 5 & 6: Spatiotemporal variations in internal wave driven upwelling and resilience potential across the Chagos Archipelago (G. Williams, M. Fox, A. Heenan, R. Roche)

Introduction

The aim was to quantify spatiotemporal patterns in upwelling to shallow (< 25 m depth) reefs around Chagos and link to coral reef ecosystem community condition and resilience.

Internal waves are a core delivery mechanism of deep water derived nutrients and heterotrophic subsidies on reefs . These subsidies delivered by internal waves fuel coral growth and spatial dominance around island coastlines and could help buffer resistance and resilience to disturbance at Chagos. High-resolution subsurface temperature recorders (SBE-56) will be deployed at deep (20-25 m) and shallow (0-10 m) sites to complement previous deployments by Dunbar (Project 9). Variations in internal wave driven upwelling drives resource utilisation, and thus resilience potential, in reef corals and algae will be assessed by collecting thumbnail sized coral nubbin samples from digitate *Acropora* colonies and from the alga *Halimeda opuntia* for stable isotope analyses, specifically to quantify degree of heterotrophy and/or lipid/chlorophyll content as appropriate. Tissue will be removed for transport to the USA for isotopic analysis. To determine how variations in internal wave driven upwelling and heterotrophic feeding in corals relates to long-term benthic community response to acute disturbance (ocean warming event), statistical modelling will relate the various data sources to each other.

The external influx of energy from deep water derived nutrients not only influences the growth and feeding strategy of corals, but over large spatial (pan-ocean) gradients, reefs in areas of greater oceanic productivity have an increased capacity to support coral reef fishes, in particular planktivores and piscivores). The purpose of this investigation is to understand how external energy subsidies relates to the condition, growth and nutritional composition of coral reef fishes. Fish collected uses clove oil and dip nets around the core sampling sites where the oceanographic loggers are deployed. Fishes sampled are ubiquitous on coral reefs in the Indo Pacific, none are CITES listed and all have a low vulnerability and high resilience (minimum population doubling time is < 15 months) (FishBase). Collected fish will be used for otolith extraction (to estimate growth curves) and to estimate length (fork and total) and body weight (for condition) parameters. Fish will be measured and otoliths extracted onboard the vessel, and a tissue sample will also be taken and fish will be frozen. Once on land fish will be dried in a dehydrator for a set time prior to weighing.

Methodology

Quantifying upwelling – oceanographic instrument deployment

To quantify patterns of upwelling, depth arrays were deployed (n = 18, three depths: 25 m, 17.5 m, 10 m) of high-resolution subsurface temperature recorders (Sea Bird Electronics 56). The loggers were attached to the reef using rebar and cable ties (Figure 32). These loggers have an accuracy of 0.002 °C and were set to record temperature every 10 seconds. This temporal resolution allows the tracking of directional movement of cold-water pulses between the loggers and hence separate upwelling from surface downwelling from the lagoons and shallow reef flats. The arrays were spread across sites at Peros Banhos, Salomon, and Egmont and were haphazardly located to ensure (as best as possible) coverage of all major cardinal points around the circumference of the forereef habitat at each atoll (Table 6).

Table 6. Location of subsurface temperature recorder (STR) depth arrays across the Chagos Archipelago.

Atoll	Area/Quadrant	Site	Reef habitat	LAT	LONG
Peros Banhos	South West PB	Ile Poule	Forereef	5.39803	71.74931
Peros Banhos	West PB	Ile Petite Soeur	Forereef	5.36318	71.75191
Peros Banhos	North PB	Ile Diamant	Forereef	5.24626	71.76952
Peros Banhos	North PB	Ile Moresby	Forereef	5.25224	71.97541
Peros Banhos	North East PB	Ile Mapou	Forereef	5.26326	71.77059
Peros Banhos	North East PB	Ile YeYe	Forereef	5.25224	71.97541
Peros Banhos	East PB	Ile Petite Coquillage	Forereef	5.34153	71.98020
Salomon	West SA	Ile Anglaise South	Forereef	5.33458	72.21618
Salomon	North SA	Ile de la Passe	Forereef	5.29837	72.25506
Salomon	East SA	Takamaka	Forereef	5.33326	72.28100
Salomon	South SA	Boddam	Forereef	5.36777	72.21508
Salomon	South SA	Ile du Sel	Forereef	5.35935	72.22974
Salomon	West SA	North Anglaise	Forereef	5.32197	72.22128
Egmont	North West Egmont	Ile des Rats	Forereef	6.64416	71.31067
Egmont	North	Mid	Forereef	6.64320	71.35827
Egmont	North	North	Forereef	6.63462	71.32764
Egmont	North	South	Forereef	6.68080	71.39653
Egmont	South East	Tattamuca	Forereef	6.69415	71.38060

Biological sample collections

Hard corals and macroalgae: the aim was to collect 10 samples of the hard coral *Pocillopora meandrina/verrucosa* (Figure 33) and 10 samples of the macroalga *Halimeda opuntia* (Figure 34) at each site/depth location. In reality, the number of coral samples sometimes fell short of the target due to the lack of species abundance in some locations, particularly at the deepest depth strata. Samples were collected from replicate colonies/individuals at least 5 m apart. For the coral, a nubbin (2 cm^2) was collected from the centre-top of each colony. For the macroalgae, parts were chosen that were as epiphyte-free as possible. All samples were placed in to light-proof ziplock bags, stored in a cooler on the small boats, and subsequently frozen at -20 °C on the Grampian Frontier within an hour of collection.

Fish: The sampling target was changed from 4 species identified in the original permit to one other, in consultation with the SFPO John Caddle. The planktivorous bicolor damselfish *Chromis dimidiata* (Figure 35) was found to be abundant and ubiquitous at all depths on all seaward reef sites, and fulfils the original criteria of being of Least Concern status. A minimum of 5 and a maximum of 15 fish at each site/depth location were targeted for collection. In all instances, this minimum target was reached (total number of samples = 351), with the exception of Egmont South where there was a low abundance of the *Chromis* in the surge conditions. Fishes were collected using clove oil (10% clove oil mix) and dip nets along the same depth contour as the sea surface temperature logger that were being deployed (Fig 36). Anaesthesised fishes were zip lock bagged, taken to the surface and killed via exsanguination. All samples were measured by total length and fork length, their otoliths removed and a muscle tissue sample taken and frozen at -20 °C on the Grampian Frontier.

Surface plankton and particulate organic matter (POM): The aim was to obtain surface plankton samples for stable isotope analysis. These plankton provide an estimate of isotopic signatures of a key heterotrophic resource to reef corals . Samples were collected by towing a 200 µm plankton net (30 cm diameter opening leading to a cod end) (Figure 37) ~1m below the surface, at idle speed, ~8m behind one of the small boats. The plan was to travel 100 m back and forth from the dive site. Back on the small boat, copepods and larger plankton that had accumulated on the net but had not travelled down to the cod end were rinsed through and the cod ends were subsequently stored in a cooler until returning to the Grampian Frontier. There, the samples were filtered on to pre-combusted glass fibre filters and frozen at -20 °C. Particulate organic matter samples (POM) were collected by filling a 10 L collapsible bottle underwater in the shallows (8-10 m depth) at the end of a dive. Again, the water was stored in a cooler until returning to the Grampian Frontier, and also filtered using a hand pump on to pre-combusted 0.7µm glass fibre filters and frozen at -20 °C. Effort for surface plankton and POM was comprehensive across the sites (Table 7).

Estimates of reef slope

A key determinant of whether physical processes such as deep-water internal waves result in shallow water upwelling of cold nutrient-rich water is reef slope. Rough estimates of reef slope across sites were made by taking depth soundings and co-recording GPS positions to estimate the distances between depth changes and reconstruct the reef profiles. Recordings were started in ~4m depth at each site and moved straight out from the atoll until exceeding the maximum depth of the depth sounder (~75m), keeping to a linear transect as best as possible (Table 8).

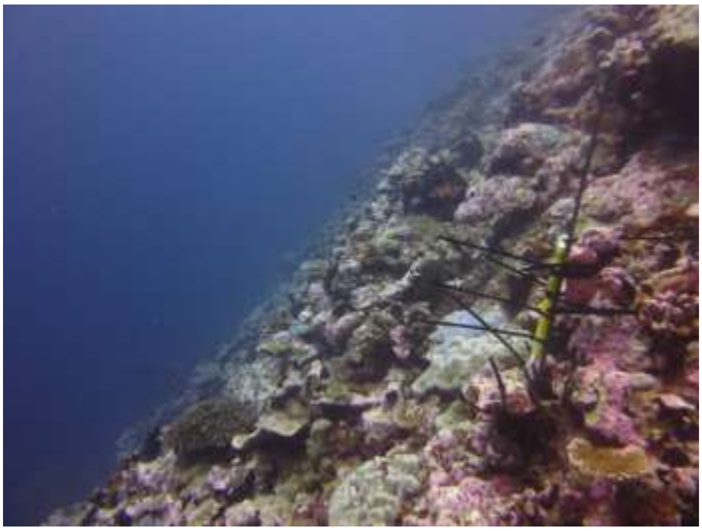

Figure 32. A subsurface temperature recorder (STR) secured to the reef at 17.5 m on Salomon Atoll.

Table 7. Location of surface plankton and particulate organic matter (POM) collections across the Chagos Archipelago.

Atoll	Area/Quadrant	Site	Reef habitat	LAT	LONG	Surface Plankton	POM
Peros Banhos	South West PB	Ile du Coin	Backreef	5.44965	71.76687		
Peros Banhos	South West PB	Ile Gabrielle	Forereef	5.42229	71.74681		
Peros Banhos	South West PB	Ile Poule	Forereef	5.39803	71.74931		
Peros Banhos	West PB	Ile Petite Soeur	Forereef	5.36318	71.75191		
Peros Banhos	North PB	Ile de la Passe	Forereef	5.23794	71.81558		
Peros Banhos	North PB	Ile Diamant	Forereef	5.24626	71.76952		
Peros Banhos	North PB	Ile Moresby	Forereef	5.25224	71.97541		
Peros Banhos	North East PB	Ile Mapou	Forereef	5.26326	71.77059		
Peros Banhos	North East PB	Ile YeYe	Forereef	5.25224	71.97541		
Peros Banhos	East PB	Ile Petite Coquillage	Forereef	5.34153	71.98020		
Salomon	West SA	Ile Anglaise South	Forereef	5.33458	72.21618		
Salomon	North SA	Ile de la Passe	Forereef	5.29837	72.25506		
Salomon	East SA	Takamaka	Forereef	5.33326	72.28100		
Salomon	South SA	Boddam	Forereef	5.36777	72.21508		
Salomon	South SA	Ile du Sel	Forereef	5.35935	72.22974		
Salomon	West SA	North Anglaise	Forereef	5.32197	72.22128		
Egmont	North West Egmont	Ile des Rats	Forereef	6.64416	71.31067		
Egmont	South West	Ile Lubine	Forereef	6.67597	71.33964		
Egmont	North	Mid	Forereef	6.64320	71.35827		
Egmont	North	North	Forereef	6.63462	71.32764		
Egmont	North	South	Forereef	6.68080	71.39653		
Egmont	South East	Tattamuca	Forereef	6.69415	71.38060		

Table 8. Estimates of reef slope profiles across the Chagos Archipelago.

Atoll	Area/Quadrant	Site	Reef habitat	LAT	LONG
Peros Banhos	South West PB	Ile Poule	Forereef	5.39803	71.74931
Peros Banhos	West PB	Ile Petite Soeur	Forereef	5.36318	71.75191
Peros Banhos	North PB	Ile Diamant	Forereef	5.24626	71.76952
Peros Banhos	North PB	Ile Moresby	Forereef	5.25224	71.97541
Peros Banhos	North East PB	Ile Mapou	Forereef	5.26326	71.77059
Peros Banhos	North East PB	Ile YeYe	Forereef	5.25224	71.97541
Peros Banhos	East PB	Ile Petite Coquillage	Forereef	5.34153	71.98020
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Salomon	North SA	Ile de la Passe	Forereef	5.29837	72.25506
Salomon	East SA	Takamaka	Forereef	5.33326	72.28100
Salomon	South SA	Boddam	Forereef	5.36777	72.21508
Salomon	South SA	Ile du Sel	Forereef	5.35935	72.22974
Salomon	West SA	North Anglaise	Forereef	5.32197	72.22128
Egmont	North	Mid	Forereef	6.64320	71.35827
Egmont	North	North	Forereef	6.63462	71.32764
Egmont	South East	Tattamuca	Forereef	6.69415	71.38060

Follow-up laboratory analyses

Benthic and planktonic isotopic sample processing: Hard coral, macroalgae, surface plankton, and POM samples will be analysed for bulk tissue stable isotope values ($\delta^{13}C$ $\delta^{15}N$) using massspectrometry facilities at the Woods Hole Oceanographic Institution. The sample processing is laborious and estimated to take up to 6-8 months.

Fish otoliths: Otoliths will be used to construct growth curves for *Chromis dimidiata*. Otoliths will be read by the Australian Institute of Marine Science.

Fish isotopic sample processing: Similar to the benthic and planktonic samples, the fish tissue will be analysed for bulk tissue stable isotope values ($\delta^{13}C$ $\delta^{15}N$).

Figure 33. A typical colony of Pocillopora meandrina/verrucosa *at 25 m depth on Salomon atoll.*

Figure 34. Halimeda opuntia *specimen (bright green, centre) from 17.5 m depth on Peros Banhos Atoll.*

Figure 35. Chromis dimidiata *specimens illustrating range of size classes present prior to processing for otolith and tissue samples. Samples taken from Ile Anglaise, Salomon Atoll.*

Figure 36. Fishes were collected using clove oil (10% clove oil mix) and dip nets along the same depth contours as the sea surface temperature loggers

Figure 37. Swimming the plankton net at 25 m on Peros Banhos during an exploratory dive to collect a sample of the deep reef plankton communities.

Task 7: Coral reef recovery and resilience (B. Wilson and A. Rose)

Introduction

The aim was to investigate the mechanisms of resilience and recovery in the coral host and its symbionts.

Some corals are more resilient or resistant than others to disease and warming events. This study aims to identify coral genes associated with resilience factors such as immune receptors, heat-shock proteins, and transcription. A profile of the microbiome of corals - the pre-existing bacterial community which may affect resistance to disease and/or bleaching will be identified. A pilot study using the digitate Acroporid *Acropora digitifera* has investigated Toll-Like Receptors (TLRs). TLRs are a family of transmembrane pattern recognition receptors that sense invading pathogens or endogenous damage signals and initiate the innate and adaptive immune response in most animals. They interact with ligands of microbial components (e.g. bacterial cell wall components, viral nucleic acids) and cause a change in Dimeric transmembrane proteins and these polymorphisms are associated with disease susceptibility. TLRs are therefore important innate immune receptors and variants may be associated with resilience in corals. Field studies will collect thumb-nail sized nubbins of coral from diseased and non diseased colonies, and resilient corals from the sites being surveyed during the expedition. The following tasks were undertaken this year:

Time series comparison of *A. tenuis/A. vermiculata* colonies pre- (2014) and post-(2019) bleaching: Triplicate tissue samples were collected in 2014 from three independent putatively healthy *A. tenuis/A. vermiculata* colonies at Isle du Coin (Peros Banhos Atoll), serendipitously prior to the back-to-back bleaching episodes of 2015 and 2016; this same sampling regime was repeated in 2019. For each sample, an approximately 2 cm^3 coral fragment was removed from a colony and stored in a pre-labelled ziplock bag. At the surface (< 1h after sampling), fragments were transferred into 5 mL tubes and fully immersed in RNALater, to be stored at -20°C upon return to the ship. These samples (along with those from 2014) will be genotyped to confirm species identification, and host microbiome and endosymbiont communities analysed (using short-read sequencing of 16S rRNA and ITS2 genes, respectively), to assess the relative contribution of these members of the holobiont to resilience and recovery of corals in the intervening years.

Genomics of *Ctenella chagius*

Historically, the endemic *C. chagius* coral (see image below) was abundant on Chagos' reefs, but the coral has all but disappeared from the archipelago in the last decade. However, a few scattered colonies were reported on the previous expedition, and therefore surviving colonies were searched for at each dive site. Unfortunately, in our twenty-five dives across the archipelago, the coral was only observed at two sites at between five and fifteen metres' depth: Moresby (Peros Banhos Atoll) and Isle de la Passe (Salomon Islands). Four *C. chagius* corals sampled at Moresby. The tissues were collected and processed as described above, except that a single replicate tissue sample was taken from each colony, so as not to unduly damage it, and the corals were tagged to monitor their progress over subsequent years; only two corals were discovered, sampled and tagged at Isle de la Passe.

The *Ctenella chagius* genome will be hybrid sequenced (using both short- and long-read sequencing technologies) and the genome assembled and annotated. Host microbiome and endosymbiont communities will be analysed (as detailed above) to better describe the coral's holobiont (for the first time). It is hoped that the holobiont genomics may reveal key aspects of the coral's biology (such as its endosymbiont diversity and its breeding strategy) that are currently unknown, and this knowledge may allow for future directed husbandry and restoration efforts for this endangered coral.

Biogeographical comparison of corals along a bleaching impact gradient

Coral bleaching across the archipelago has been variable and whilst bleaching occurrence is seemingly determined by site, the factors affecting this are not known. In collaboration with Dr Catherine Head (University of Oxford and ZSL) who participated in the March 2019 expedition, the intention was to collect samples from three keystone coral species (*A. tenuis/A. vermiculata*, *A. cytherea* and *Porites lutea*) in BIOT at sites showing a range of bleaching impacts. Samples collected will be processed (genomic DNA extracted from tissues) in an identical manner, and the material shared for genomic analyses. Analyses will focus on genotyping each coral to confirm identification and analysis of various host immune-related genes, microbiome and endosymbiont communities.

It is hoped that these various analyses (which study different components of the coral holobiont) might reveal biological mechanisms for the degree of resilience and recovery in these coral species across the archipelago. However, a major limitation to this study is that the reefs were in much poorer condition than previously expected and so a gradient of bleaching impact (from non- to heavily-impacted) was difficult to ascertain, with historically non-impacted high-cover reefs found to be in a severely degraded state. However, samples of colonies of the three coral species were taken across the archipelago in each of the atolls and numerous colonies concurrently tagged to monitor their health status in upcoming expeditions.

Diving Report (A. Mogg and J. Turner)

Thirteen experienced divers conducted a total of 113 dives, equating to 301 person dives and 318 hours underwater between 10th and 27th of April, 2019. Tidal conditions were generally satisfactory for all diving operations (using estimates based on diving within 2 hours of High or Low water at Spring Tides), though poor weather made launching and recovery of small boats problematic at Salomon, Great Chagos Bank and Egmont, and on these occasions, a reduced team utilised the Grampian Frontier's Daughter Craft.

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 and 25 m depth, with 24 hrs off diving every 10 dives. Diving air was provided by a new Bauer Mariner 320B compressor, which allowed four cylinders to be filled at once, with an average of 25 minutes run time per batch of 4. A large filter block and digital management indicated that no filter cartridge changes were necessary during the expedition. A combination of 15L and 12L steel high pressure cylinders (Faber) were used for the primary air supply and divers carried independent breathing devices (primarily 3L pony cylinders) when diving below 10m. Dives were conducted in pairs or threes and divers carried delayed surface marker buoys and submersible Nautilus Lifeline GPS systems, in addition to operating directly under moored boats. Bottom times were kept to >2minutes within no stop, with a maximum planned time of 60 minutes and a maximum depth of 25 metres. A mandatory 3 minutes stop at 5 metres depth was required. Dives were supervised by a nominated, competent person, with at least one other individual present as tender. First aid kits and at least one Oxygen resuscitation kit were present at each dive site, and an oxygen generator and full medical kit were 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. Five 4.2 m inflatable boats equipped with 25 hp four stroke outboard motors, oars, anchors, handheld GPS, and waterproof peli-cases containing flares and essential spares supported dive operations, and wherever possible (sea conditions permitting), two boats anchored and three tied off. Dives were logged on personnel dive computers and on a white board in the reception area of the BPV.

Poor weather caused one dive at Danger Island to be aborted due to large waves, surge and no visibility. On all other occasions, the decision to select a more sheltered site, utilise the Daughter Craft with a reduced diving team or not to dive was made prior to launching the small craft. Many of the dive sites south of the Northern atolls, in particular Egmont, are exposed to oceanic weather with no suitable shelter. This made both launch and recovery of diving vessels problematic, whilst additionally causing a number of divers to drop out of rotation with sea sickness.

One incident occurred on 26th April on the south east coast of Egmont from which lessons were learned. Due to strong wind and waves, only the Daughter Craft (DC) could be launched with a team of 4 divers, a Dive Marshal and 2 crew. The DC sat at anchor over the dive site, but unknown to the crew, was dragging its anchor and moving south. The Marshal reported that the divers were over time after 60 minutes, causing the Master of the BPV and Dive Supervisor – both of whom were monitoring the dive from the bridge – to undertake a visual survey for the orange surface marker buoys indicating the diver's position. The BPV AIS was turned on in the event of the divers using their Nautilus Lifelines GPS to indicate their position, and the Fast Response Craft (FRC) was launched, and the Medic was called to the bridge, and others asked to leave the bridge. The marker buoys were located visually within a few minutes and several hundred metres north west along the reef, and the FRC was contacted to move in their direction, since neither DC or FRC had a visual contact. The divers were recovered safely and both vessels returned to the BPV. The divers had been unable to see the DC because it was too far away, or the approaching FRC because of the height of the waves, but were able to see the BPV. A debriefing was held once the crews and divers were back on board.

It was originally thought that the divers had drifted, but they had stayed on site as indicated by a rebar stake to which an instrument was attached and their GPS position on collection. The problem was that the DC had dragged anchor unknown to the crew and Marshal. Large waves prevented visual contact. The featureless backdrop meant that neither the BPV or DC crew identified that they had drifted, and therefore they had not checked or monitored the DC position. The 4 divers put up two surface marker buoys (I per pair) and therefore close visual contact was required to confirm that all 4 divers had surfaced.

Lessons learned from the incident were: (1) While launching and recovery of the DC is possible in conditions where the inflatables cannot be launched, conditions can deteriorate quickly, especially during squalls, and one of the greatest risks is loss of visual contact between tenders and the diving team. Despite tight schedules, decisions to dive should always air on the side of caution, especially if squalls are likely. In this case, one more survey site was needed to complete data collection, and in water conditions at the site looked acceptable, and hence just a small team of 4 was deployed, but conditions worsened. There will always be situations where the decision to proceed is marginal, and these should default to one of 'no dive'. One consideration is a defined upper wind speed at which diving operations do not go ahead (eg. where gusts at 10 m above sea level are Force 6 or greater). Force 5 is generally accepted as the limit for diving even though boats are capable of operating at greater wind speeds. The HSE requires further risk assessment for operations where wind speeds exceed 20-25 knots – in line with Force 6. The limit for launching the DC/FRC is usually considered a wave height of 3.5 m, which is a height experienced at Force 6. It should also be noted that a wave period of 10 seconds or more will create significant surge at 25 m and prove unworkable for scientific divers. The most dangerous part of diving/boating operations in rough sea conditions is loading equipment into the small boats and embarking and disembarking at the Rescue Zone, because ship and boat move unpredictably. **It is therefore recommended that the limit of no boat/dive operations at Force 6 or greater be employed**, bearing in mind that at Force 5, conditions can worsen. (2) Divers should utilise the Nautilus lifelines/GPS radios on surfacing immediately in the event of losing visual contact with the tender or within 2 minutes of surfacing overtime if tenders have not responded in that time. The Lifelines depend on the ship turning on the AIS. The older Nautilus GPS radios (no longer made – we only have 3 now) are more valuable because they allow the divers to speak to the marshal on the tender and to the bridge of the ship, and therefore one member of the team should at the least carry one of these. (3) The response on the bridge of the BPV was excellent, ensuring that the situation was immediately managed, with key personnel in place and FRC launched. (4) The DC crew need to be aware that even their large anchor can drag in such conditions, and they should therefore monitor the GPS regularly, especially if their relative position to land features change or cannot be determined due to poor visibility. The BPV was moving and hence the position relative to the ship was not constant. (5) the dive team should consider whether a position marker buoy can be deployed securely at the site – although if this should drag, be pulled underwater or lost, then this is a false security.

Medical Report (K. Sellens)

Diving in a location as extremely remote as BIOT has inherent risks, but from a medical perspective this was a very successful expedition with only minimal medical events. There were no diving related medical incidents and only minor medical illnesses consisting of minor skin lacerations or infections, some musculoskeletal aches and pains and a viral upper respiratory tract infection which affected at least 6 of the party; this caused significant sinus congestion in one person resulting in 4 lost dives.

The MedAire kit is extremely comprehensive; I have completed an inventory of both this and an extra large white box which has an assortment of other medical items which have accumulated over expeditions. The oxygen concentrator was not used but it is vital to have on these expeditions in case of decompression illness. The 3 DAN oxygen green boxes are an excellent addition to our equipment which we took on every dive in case of emergency.

Medical Conditions Arising:

Viral Upper Respiratory Tract Infection and sinus congestion – affected 6 of the expedition members.

- Treated with paracetamol, Cold and Flu tablets.
- At least 4 scientific dives lost to sinus congestion.

Migraine – in expedition member prone to these.

- Treated with own medication – Naproxen, Tryptophan.
- 2 Dives lost.

Vomit with haematemesis (blood in vomitus) – 1 x episode, no other associated symptoms, after eating rich food. Small amount of blood seen by me, likely from mucosal trauma whilst vomiting.

- Treated with observation, no further episodes.

Hypoglycaemic episode in a person with Insulin Dependent Diabetes – self treated but high risk of potentially life threatening situation recognised and therefore withdrew from diving until recovered.

Corneal Foreign Body – Fluorescein strips used, doctor's own local anaesthetic drops, plastic foreign body removed with cotton bud.

- treated with ciprofloxacin (antibiotic) drops and lubricating drops.

Minor skin lacerations and mild localised infection from coral.

- topical application of polyfax (antibiotic) ointment.

Minor sunburn.
– aloe vera gel.

Motion/sea sickness – affected several expedition members.
– treated with antiemetics from Medaire kit.

Strained muscles – hand pain, rib pain, back pain, mainly from lifting heavy cylinders and equipment.

- treated with diclofenac and paracetamol.

Insomnia
– from noisy environment, affecting dive performance.

- Diazepam 5mg x 2 tablets over 3 weeks to enable diving.

Items used from MedAire kit:
Paracetamol 500mg tablets x 8
Ibuprofen 200mg tablets x 16
Cold and flu tablets x 10
Liquifilm tears x 1
Ciprofloxacin 0.3% drops x 1
Diclofenac tablets 75mg x 4
Polyfax x 1 tube
Fluorescein strips
Prochlorperazine 3mg tablets x 16
Diazepam 5mg x 2

Equipment Report (J. Turner)

Compressors
This year, a new Bauer Mariner 320b diving compressor (Figure 38) was purchased to improve the efficiency of dive cylinder filling because the 4 Bauer Oceanus compressors (purchased between 2006 and 2014 on previous projects) are becoming unreliable, expensive to repair, and are insufficient to fill 28 dive cylinders daily. The new compressor is trolley mounted, and has an auto-condensate drain (eliminating oil emulsion discharge onto the deck), an upgraded P41 filtration system and a B timer which displays operating hours and current level of filter saturation to indicate when the filter should be replaced. The compressor has 4 whips to fill

4 cylinders simultaneously at a 320 l/min charge rate – effectively filling 4 cylinders in 25 minutes. **It automatically cuts out when the cylinders are full**, allowing safe exchange. The motor is a Honda petrol engine (because an electric compressor would require permanent installation on the vessel). The unit weighs 138 kg and therefore requires 4 persons/crane to lift it. The compressor and maintenance kit cost Project 6 £15,669. **Careful handling, use and storage is essential to protect this investment**. The correct oils must be used, and the unit must not be overfilled with oil, and fuel spills must be avoided by using funnels. **The filling valves must not be submerged in the filling tank, and the knurled knobs on the filling whips must be tightened to avoid them vibrating off and being lost**. The compressor must be cleaned regularly using a damp cloth and covered when cool after use. Particular care is required in moving the compressor to avoid damage. The wheels can be removed when sited on the deck but split pins, washers and bearings must be stored with care. Filter changes must only be made when indicated by the B-Timer because the P42 Triplex filter cartridges are very expensive (~£150 each).

Figure 38. New Bauer Mariner 320B compressor capable of filling 4 cylinders simultaneously in under 30 minutes. The compressor stops automatically when the cylinders are full, and filters are drained automatically into an integral disposal tank.

The old Bauer Oceanus compressors have deteriorated significantly since last year, with most plastic parts cracked and filling whips in poor state. We still have spares and Triplex cartridges for these compressors and they are **due an overhaul prior to the next expedition**. Compressors 1 and 3 are in running order, and compressors 2 and 4 have been combined to make a serviceable unit. These units should be used by small teams/ teams operating in Diego Garcia, and as a temporary backup to the main compressor.

Diving Cylinders

We currently have 47 diving cylinders in two sets: 4 x 12l and 16 x 15l purchased in 2017 by BPMS and 15 x tall 12 l, 3 x dumpy 12l and 9 x 15l from the Darwin project. All are currently in test**. 5 cylinders require attention to valve handles prior to the next expedition.** There are 26 pony cylinders: 10 Faber steel (black) bought 2019, 4 steel Faber steel cylinders (white/black) 2018, and 11 3l Aluminium cylinders 2012 (yellow) . There are 15 Apex ATX40 DS4 pony regulators with first stage pressure gauges and 6 Spare Air systems.

Boats

Last year, Project 6 purchased 3 Mercury 415 HDXS inflatable boats at a cost of £6150 and 3 Yamaha F25GMHS engines at £9,537. This year, we bought 2 further boats, upgrading to the Zodiac Bombard Commando C4 model, and 2 further Yamaha F25GMHS engines at £13,210 (Figure 39). The Yamaha engines are lightweight, replacing the 3 Tohatsu 4 stroke engines purchased by the Darwin project which will be kept as backups, and the 4 Tohatsu 2 stroke engines bought with OTEP funds in 2006 which have now been donated to the Grampian Frontier. The Mercury boats are heavier duty models than the previous SeaSearch boats (which had a flaw in their transom design), but do tend to fold at the bow board in large waves (potentially trapping toes and causing the boat to pitch). The Zodiac Bombard boats are better constructed and significantly more expensive (£3500 vs £1500) and have a composite keel which gives them greater manoeuvrability. Next year, the final SeaSearch boat will be replaced by a Zodiac Bombard and Yamaha engine from central funds. The aim is to standardise equipment and spares carried, providing 6 boats with the same Yamaha engine model.

6 large red tarpaulins have been purchased to cover the boats when on deck to protect them from UV. **One new peli-case boat box will be required for next year, and it is recommended that a GPS, set up with all survey locations, be purchased and allocated to each boat box.**

The April 2019 expedition only had 2 lifting strops available; the two spares could not be found in the store on return**. 2 new 6m webbing boat lift strops are required for the next expedition.**

It was disappointing to discover that the SeaSearch boats purchased in 2017 and last used by the May 2018 expedition had been stored in a container at Moody Brook along with an older boat, and had consequently and unsurprisingly melted in the extreme heat. The one remaining SeaSearch boat is from 2015 – all others have now been scrapped due to irreparable transom failures.

The current storage racks at Moody Brook constructed last year are not fit for purpose (being made of coconut wood nailed together) and risk damaging boats (some nails protrude). It is planned that these will be replaced by a stronger structure made from a Uni-strut system.

Emergency equipment

There are 3 Dan O2 kits purchased in 2018 and 1 Marinox unit purchased in 2017 in serviceable condition. **These must be checked and dried if wet at the end of each day**.

Medical oxygen is a challenge to get to Diego Garcia and therefore cylinders **must not be opened except when checked at the beginning and end of an expedition**. The Oxygen generator kept on board the Grampian Frontier was found damaged (assembled incorrectly) and has been sent away for repair, with a hired one in its place. 16 new lifejackets were purchased centrally this year. 2 of 5 the Nautilus Lifeline GPS radio units were damaged beyond repair in 2019 – one on each expedition - one flooded probably because it was not checked after every dive (being left wet in a BCD), and the other with components destroyed by sunscreen. 5 orange Nautilus Lifelines GPS (non radio) are in working order**. It is recommended that 4 more units are purchased centrally so that every diver is equipped with a Lifeline**. **In addition, every diver must carry a large (2m length) brightly coloured delayed surface marker buoy** – this has not been the case. An incident this year identified the importance of this personal kit.

Figure 39. 5 x 4.2m inflatable boats are used to support diving operations and are launched from the deck of the BPV Grampian Frontier. The ship's Daughter craft (right) is used when conditions do not allow the launch of the inflatable boats using the deck crane.

Deck Container laboratory

The deck container was repaired with a new plywood floor and new AC unit, and replaced sink drain. However, previous damage resulting from it being left unlevelled quayside by a previous expedition and it subsequently being commandeered by contract workers, has resulted in rust, leakage and rot to the floor beams. The aluminium shelf unit, 2 tall machine chairs and fridge freezer were stolen in 2016/17. The container must come off the ship in autumn 2019 during the audit, and new mountings will be required when replaced. **A new container conversion is planned**, and the old unit may be used as a laboratory behind the Moody Brook equipment store. The container will need some repairs to the roof rust holes (welding at best, or expanding foam at worst) and will need an electrical connection.

 

Figure 40. Deck container lab (left) provides an air conditioned dry work space on deck (right)

Equipment Store
The Moody Brook store has inadequate air conditioning and is now overfull. Superfluous equipment must be discarded appropriately to make space for new equipment. Unfortunately, items are still going missing from the stores, such as tarpaulins and boat lifting strops. **It is most important that scientific groups replace any equipment used.**

Final Note
To date, the previous Darwin Project and Project 6 has borne the cost of much of the equipment in use and yet all teams benefit from the use of the equipment. Further, freight last year cost Project 6 £3,675. **Given the wear, tear and shipping costs, there does need to be a greater contribution to maintenance and sharing of costs across projects**.

It is also essential that each expedition using the equipment **allocates sufficient time to work through the inventory and accurately record what has been used, because items need replacing ahead of the next expedition**, **and it is the duty of the last expedition to replace these.** Important items such as tarpaulin, 2 boat lifting strops, 2 boats, 3 boat anchor boxes, anchors, LP and HP hoses and a radio were missing this year, and other items damaged but uneported (eg. Nautilus Lifeline, Oxygen generator). **The implications of not reporting missing or damaged items is that the next expedition is inconvenienced or worse, safety is compromised.**

In addition, expeditions must appropriately discard waste. The April expedition identified several unlabelled plastic bottles containing an unknown acid and a box of large lithium batteries left in the Reception area of the BPV by the previous team.

Seminars at Sea

Evening seminars were presented in the mess of the BPV and all aboard were invited to attend:

Bryan Wilson: *A year in the life of the minutiae in a changing Arctic Ocean.*

Charles Sheppard: *A Very Brief History of Chagos.*

John Caddle (SFPO): *Fisheries Protection.*

John Turner: *Darwin Initiative to enhance an established Marine Protected Area system in the Cayman Islands.*

Ronan Roche: *The Evolution of Conservation- Concepts: Coral Reefs and People.*

Dan Bayley: *Empirical and mechanistic approaches to understanding and projecting change in coastal marine communities.*

Gareth Williams: *The fear of sharks: where does it stem from?*

Michael Fox: *Are all corals vegan?*

Adel Heenan: *A jazz band view of ecosystem monitoring.*

Media engagement

5 blogs were posted through the National Geographic Open Explorer platform. 28 Instagram posts were made using #BIOTscience, and 15 Twitter posts with #BIOTscience (Twitter engagement metrics below):

Date	Impressions	Total engagements
28-01-19	3743	91
08-02-19	4282	69
14-03-19	2252	118
08-04-19	6434	214
15-04-19	5102	189
16-04-19	6336	323
20-04-19	5920	177
26-04-19	3551	162
03-05-19	5687	230
04-05-19	2528	71
Total	**45835**	**1644**

Final Recommendations

Scientific Considerations

The coral reefs of the Archipelago are in an erosional state with very low coral cover 3 years after the back to back bleaching events of 2015/2016. Little improvement can be expected until dead material is either washed off of the reef or consolidates into a substrate suitable for recolonization. Early colonisation will be in the form of biofilms and calcareous algae, and in places overgrowths of fast replicating soft coral, macroalgae and sponges. Surviving corals may recover, and coral larvae have settled though in lower numbers than previously. Recruits that survived the warming events do appear to have grown into small colonies in shallow waters on some reef rims. Structural loss is apparent, and this will be affecting both available habitat and food resources for fish and other reef organisms. We anticipate major changes in populations of large carnivorous fish and corallivores. There seems little local additional management action that can improve the reefs – they will need time to recover, as observed after the 1997/98 event, and recovery will depend on the severity and frequency of future warming events. However it is important to continue to monitor their state, and continue policies of no anchoring and no fishing and clearing waste materials where possible such as plastics. Monitoring is essential to identify the geographical extent and causes of changes to reef community structure, and to assess recovery. The severity of impact of recent back-to-back warming events on BIOT reefs and modest signs of recovery in the absence of synergistic and cumulative impacts from local anthropogenic activity convey an important message - to strengthen the global response to climate change by reaching and sustaining net zero global CO_2 emissions. Coral reefs are projected to decline by *a further* 70–90% at 1.5°C with even greater losses (>99%) at 2°C. Therefore, an important outcome of the scientific observations so far is for the assessment of BIOT coral reefs to be used as a case study, warning of the severity of threat to coral reefs globally.

While continuing to monitor reefs, our teams have turned their attention to why some corals are able to recolonise, and why some species are resistant or resilient. Future collaboration with the mesophotic reef team from Plymouth is being initiated to investigate the current sites to deeper depths, and to investigate coral reefs on banks and sea mounts, for these may be the sources of coral larvae. This work naturally links with studies of turbulence in the vicinity of reefs and mounts undertaken by the Plymouth oceanography team. Similarly, our teams new investigations have focussed on whether internal waves can provide cooling on some seaward reefs and whether nutrients are being delivered to these areas, conferring resilience on some corals and reef communities. Current and future genetic studies are also attempting to reveal whether some corals and their algal symbionts are more resistant to warming, bleaching and disease. Again, there may be limited direct management action, but a greater understanding of the connectivity of the systems resulting from these studies.

Logistical Considerations

The April 2019 expedition embarked in Male, Maldives and disembarked in Diego Garcia, largely due to the timing of the BPV crew change. The advantages of joining the ship in Male are cheaper scheduled flights, no need for overnight layover for most team members, and time to acclimatise to climate and living aboard ship, with time for equipment preparation and set up. The disadvantages are being reliant on shipping agents for smooth transfer of personal and equipment, being reliant on the previous expedition team having loaded everything required from stores in Diego Garcia and leaving this in good state, and 4 days passage to the northern atolls for all personal. The latter is balanced against 2 days of checking and loading equipment in Diego Garcia, and nearly 2 days passage to the northern atolls.

Team members arrived in Male on different flights, and the reception service provided by the shipping agents, Antrac, was poor for several of the groups, who ended up making their own arrangements. Immigration arrangements were complicated because officials needed to understand that we were boarding a ship in Male and then disembarking in Diego Garcia. **Proof of intention to join the Grampian Frontier and evidence of flights from Diego Garcia is essential to avoid complications boarding flights to Male and to pass through Immigration on arrival in Male.**

It is most efficient if the expedition team is focussed on similar tasks and operates in one location, with a relatively standard daily plan. Briefings with the bridge each evening ensure that the team's plans and needs are well understood, and crew prepared. Additional am and pm briefings before setting out to site accommodate contingency plans due to weather, personal and equipment. A maximum team size of 14 is recommended, with 5 small boats in operation, and one in reserve. Working at multiple locations complicates the tasks, and different launch times divert the crew from their daily tasks. It also requires clear communication to allow the Bridge to monitor operations.

Expeditions need to be aware of the need to offload grey water beyond the 12nm limit at frequent intervals. The BPV crew alone have to offload grey water every 5 days, and therefore with an additional 14 scientific crew, this must be undertaken every 2.5 days. Any excess use of water that drains to the greywater tanks will increase the frequency of grey water disposal, and excursions and fuel required must therefore be planned for.

It is preferred to manage diving operations ourselves utilising our small boats. One of the Daughter craft or FRC are available when our boats cannot be launched, or if necessary in addition, but in which case the crews require careful briefing of diving operations and at least one Dive Marshal should be onboard the craft to monitor diving.

It is proposed that no dive or boat operations should be undertaken if wind speed at 10 m above sea level are Force 6 or greater. It should also be noted that a wave period of 10 seconds or more will create significant surge at 25 m depth and prove unworkable for scientific divers. At Spring tides, strong currents can be expected outside of 2 hrs of High or Low water.

It is also recommended that every diver is equipped with a Nautilus Lifeline and 2m orange delayed surface marker buoy. The buoy must be deployed whenever divers leave an moored site or as soon as they are over the dive time. The Nautilus Lifeline must be turned on if divers surface beyond the agreed dive time and if the tender has not responded (they may be lifting anchor etc.).

Instructions for use of the Bauer 320B compressor (noted above) must be followed to avoid damage.

Each diving expedition must update the inventory and account for all equipment and consumables used. In addition, arrangements must be made for the disposal of all waste including hazardous items such as chemicals and lithium batteries. **These must not be left on the BPV or in the science store**.

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Edited by Professor John Turner, 2019.