Chagos Archipelago Pelagic Expedition, February 5-24, 2016

Expedition Report

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Scientific Report: Pacific Marlin Expedition
February 2016

1. Executive summary

The British Indian Ocean Territory (BIOT) was declared a fully no-take marine reserve in April 2010 by the United Kingdom government, closing the international longline and purse seine fisheries that were operating in the area. The closure of the BIOT fisheries has the potential to afford protection to large migratory predators like pelagic tunas and sharks, which include a number of species considered under threat internationally. The recovery of pelagic populations within large marine reserves like BIOT remains a controversial issue within the scientific community. This and other priority research questions were defined in a science plan developed by a consortium of research and conservation organisations in October 2013 (Gollock and Koldewey 2013) well as forming an important priority within the BIOT Interim Conservation Management Framework (Compston 2014).

In February 2016, we conducted a pelagic expedition on board the BIOT patrol vessel the Pacific Marlin (BPV), designed to understand the physical and biological characteristics supporting the distribution, diversity, abundance, and potential recovery of pelagic predators in the BIOT marine reserve. The expedition was funded by the Bertarelli Foundation and was the second expedition under the umbrella of the Chagos Archipelago Science Consortium, following previous pelagic trips onboard the BPV in 2012 and 2015 (Letessier *et al.* 2015b). The expedition explored the pelagic realm using mid-water baited remote underwater video systems (BRUVS), hydroacoustics, oceanographic measurements, undertook manta ray tagging, bird and other wildlife observations. Unfavorable weather including a tropical cyclone rendered it a challenging expedition, although superior seamanship enabled scientifically robust levels of spatial coverage and survey effort. Equipment loss was limited to a single oceanographic sensor string, as the adverse weather displaced the kit to deeper and unreachable waters.

One hundred and sixty mid-water BRUVS deployments with concurrently run acoustics surveys will allow the quantification and characterisation of fish populations (including sharks) and mid-water prey fields at six locations around the Chagos Archipelago, providing baselines of abundance again which change can be assessed, to assess the role of the reserve in protecting mobile species. Deployment of a towed acoustic body allowed acoustic data to be collected at steaming speed, enabling a first ever collection of cross-Archipelago transects. The use of a novel multibeam sonar enabled 3D mapping of focal habitats and associated fauna at Egmont atoll and Sandes seamount. Six manta rays were tagged with acoustics and miniPAT tags. Deployments of oceanographic instruments and moorings throughout the archipelago will further enable the characterisation of water masses, and the description of interactions between tidal regimes, stratification, and topography on coral islands and seamounts. These characteristics are important in identifying productive habitats for higher trophic levels such as birds, mantas, pelagic sharks, and tunas, and for interpreting the mid-water BRUVS and acoustics observations.

Key achievements

1. First integrated analysis of mid-water BRUVS with cross archipelago acoustics transects.
2. First integrated analysis of 3D multibeam documenting fish distribution (particularly sharks) and characterising seamount habitat with mid-water BRUVS.
3. First mapping of the unique 'manta alley' habitat and first acoustic observation of manta ray using a 3D multibeam in Egmont atoll.
4. 5178 birds of 17 seabird species were recorded. One species of seabird that had not been previously documented in BIOT was identified and photographed in the Small Boat's Basin of Diego Garcia, a Lesser Black-backed Gull *Larus fuscus*.
5. Deployment and recovery of oceanographic mooring on Swart seamount, and in Egmont Atoll.
6. Tagging of 6 reef mantas using acoustic and miniPAT tags

1.1 Table of Content

2. Objectives, strategies and participants

The following expedition objectives were identified as top priorities following guidance from the BIOTA (Compston 2014) and the Chagos Archipelago consortium science plan (Gollock and Koldewey 2013):

1) Documentation of spatial and temporal variability in pelagic (open water) fish populations, using mid-water BRUVS. This involved revisiting a subset of November 2012 and 2015 sampling locations, thus continuing a time series to assess change in mid-water fish abundance, as well as increasing overall spatial coverage of surveys.

2) Characterisation of vertical and horizontal distributions of mid-water fish and their potential fish and zooplankton prey using hydroacoustics to investigate their interaction with seabed topography, and to explore their variability across different habitats.

3) Assessment of vertical and horizontal differences in water mass characteristics and exploration of regional and geographical influences in tidal regimes, using a score of oceanographic indices. This information is critical to interpret the distribution of top predators and their prey.

4) Scientific tagging of reef manta rays (*Manta alfredi*). This will enable the description of their residency and site fidelity inside the reserve, and thus enable the assessment of the efficiency of the reserve in affording them protection.

6) Observations of pelagic bird species, and other megafauna e.g. cetaceans. This information can be used to identify areas of high species richness, abundance and can be used for management.

The following personnel participated in the expedition

Name	Institution	Role
Tom B Letessier	Zoological Society of London	Expedition leader
Pete Carr	Zoological Society of London	Logistic manager/Ornithologist
Marjory C Fernandes	University of Western Australia	Mid-water BRUVS
Jemma Turner	University of Western Australia	Mid-water BRUVS
Andrew S Brierley	University of St-Andrews	Acoustics
Lilian Lieber	University of St-Andrews	Acoustics
Roland Proud	University of St-Andrews	Acoustics
Phil Hosegood	Plymouth University	Oceanography
Alex Nimmo Smith	Plymouth University	Oceanography
Zosia Bellamy	Independent	Medic
Niv Froman	Manta Trust	Manta tagging
Robbie Schallert	Stanford University	Manta tagging
Sian Addison	Zoological Society of London	Documentarist
Pamela Clement	Zoological Society of London	Chagos Community Research Intern

3. Mid-water fish assemblages

3.1. Introduction

Understanding the distribution patterns of pelagic fish, including sharks, is fundamental to the effective conservation of the pelagic realm, the largest marine environment on Earth (Angel 1993). The species are distributed either as solitary foragers or forming large schools the shape of which is a trade-off between access to oxygen and predator avoidance (Brierley and Cox 2010). In addition, many pelagic species, whether solitary or schooling, aggregate around physical features such as atolls and seamounts (Morato *et al.* 2010) and around persistent oceanographic features such as fronts and upwellings (Worm *et al.* 2005). In fact, the proximity to seamounts increases the chances of finding ecologically and economically characteristics pelagic species such as the short-finned mako shark (*Isurus oxyrinchus*), silky shark (*Carcharhinus falciformis*), yellowfin tuna (*Thunnus albacares*), blue marlin (*Makaira nigricans*) and swordfish (*Xiphias gladius*).

Pelagic predators are threatened by the increasing global demand of fish for consumption, bait, fish meal, oil and highly valued shark fins. Catches have been poorly reported in fisheries records and shark are rarely identified to the species level, which increases the challenge of quantifying the real impact of pelagic predator exploitation (Dulvy *et al.* 2014). Overall, our understanding of pelagic fish and shark assemblages is relatively limited due to challenges in sampling low overall densities and heterogeneously distributed species (Letessier *et al.* 2015a). Therefore, the use of non-destructive sampling techniques for monitoring pelagic fish assemblages is paramount to conservation and adequate management strategies of Marine Protected Areas (MPAs).

The Chagos Archipelago (British Indian Ocean Territory) is a large group of atolls containing approximately 50% of the healthy reefs remaining in the Indian Ocean. Fisheries records in the archipelago have shown pelagic fishing targeted tuna species with annual catches rising from 1 ton to 379 tonnes between the 1950s and 2010 (Zeller and Pauly 2014). In order to assess and monitor targeted pelagic species after 2010 we conducted the third expedition in the reserve. Our aim was to evaluate the importance of large no-take MPAs in monitoring pelagic fish assemblages' structure after the implementation of the reserve.

<u>Objectives</u>

The BIOT Marine Reserve enables the study pelagic fish assemblages across large spatial scale in the Indian Ocean under varying environmental conditions. Further, it enables exploration of the structure of pelagic assemblages in a no-take reserve where all forms of exploitation are prohibited and human activity is very limited. The study site is important to global biodiversity as it is considered to be one of the healthiest remaining marine systems. Studying these areas will help us to identify the components of the pelagic assemblage and evaluate their response to different management approaches according to their spatial distribution patterns.

3.2. Method

BRUVS have been widely used on seabeds, but the need to study the pelagic environment in the BIOT Marine Reserve prompted their adaption to pelagic environments (Letessier *et al.* 2013; Bouchet and Meeuwig 2015) providing robust and repeatable measures of the assemblage that allow assessments of the impacts of anthropogenic activity and management and conservation strategies (Mclean *et al.* 2011).

Mid-water BRUVS are deployed in drifting "longline" configuration based on stratified sampling designs. They consist of stabilisation, floating, fish bait and video recording systems altogether. The stabilisation is provided by individual surface floats attached independently to the rig and weights on the base end of the uprights. These keep the rigs stable at 10m depth dependent of the water speed current. Three sets of 3 buoys keep the rigs afloat, and are attached to the rigs and to the 200m longline ropes. The bait canister with fish is suspended from the bait arm at a standardised distance of 1.9 m from the cameras. The bait arm also functions as a sea-anchor and stabilises the rig within the water column. The video system consists of a pair of GoPro video cameras in stereo configuration on a stainless steel frame (Fig. 1).

In BIOT, BRUVS were deployed with five rigs per longline with 200m between each rig. Four sets of longlines were deployed per site, a day when possible in order to cover the biggest area within the site possible. The rigs were deployed from the back deck of the British Patrol Vessel R/V Pacific Marlin (57.7 m) for a minimum of 2 hours. The sampling design was stratified by spatial features typical of the marine reserve in order to evaluate these sites as hotspots of biodiversity. The mid-water BRUVS were deployed at two shallow seamounts (Sandes and Swart), one open water site in the vicinity of an atoll (Salomon), one seamount west of Peros Banhos, one site on the Great Chagos Bank (Fig. 1).

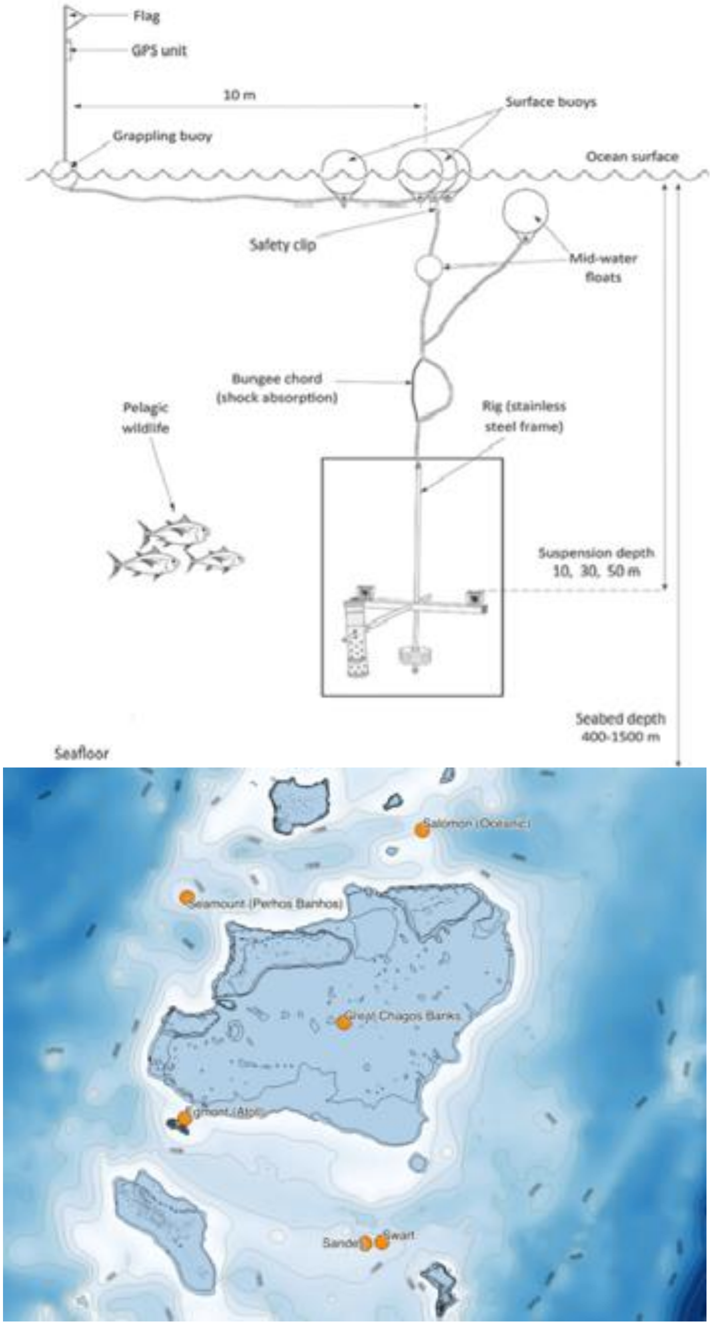

Fig. 1. Mid-water BRUV rig suspended in the open water (top pane), and sampling locations in the Chagos Archipelago (bottom pane).

3.3. Preliminary results

A total of 160 mid-water BRUV deployments were completed during the expedition (Table 1). Partial replacement of the sampling stations of the November 2012 and January 2015 expeditions will enable the continuous of a time series to assess the recovery of population of sharks and tuna previously targeted by commercial operations in the BIOT Marine Reserve.

Preliminary viewing of mid-water BRUVS video footage have revealed records of pelagic megafauna and predators previously fishing targeted species observed on footage in the BIOT reserve, such a silky sharks (*Carcharhinus falciformis*), wahoo (*Acanthocybium solandri*) and a range of juveniles of trevallies and scads.

Table 1. Mid-water BRUV efforts during the BIOT pelagic expedition 2016.

Location	LAT	LONG	SEABED DEPTH (m)	#LONGLINES	#BRUVS
Swart	-7.13795	72.18907	73	2	10
Salomon	-5.40708	72.3934	585	8	40
Oceanic seamount (PB)	-5.68246	71.38373	1201	6	30
Egmont	-5.4188	72.35	410	8	40
Great Chagos Bank	-6.2962	72.13746	73	4	20
Sandes	-7.15357	72.13698	171	4	20

Further analysis

All video imagery derived from the mid-water BRUVS will be processed using standard image analysis software (EventMeasure) to (i) generate estimates of species richness, relative abundance per species and length for each sample, and to (ii) estimate demographic metrics using the individual body length and to (iii) evaluate behaviour (e.g., time of first arrival and individual behavioural responses). Species richness is estimated as the sum of unique species observed on a BRUVS. The relative abundance is quantified as MaxN, the maximum number of animals of a given species observed in a given frame of video (Bailey *et al.* 2007). This measure avoids double counts and has been shown to be robust through space and time (Langlois *et al.* 2012). We will also develop predictive models for spatial structure of pelagic assemblages in relation to environmental and topographic features.

4. Multi-frequency single beam echosounders

4.1. Introduction

Light does not penetrate far into the ocean and reaches an intensity of 1% of its surface value between 50 and 200m (photic depth) - dependent upon sea-state and water clarity. Echosounders, active acoustics instruments that produce sound waves and record backscatter, are used to make observations of mid-water communities found within the mesopelagic region (200 – 1500m) of the water-column. Echosounders are normally hull-mounted to ships, but can also be mounted to poles or housed by towed bodies, and commonly operate and record at frequencies between 18 and 200 kHz. The most common frequency is 38 kHz, which has an observational range of between 0 and 1200 metres; this is subject to the signal-to-noise ratio of the sounder, which decreases with depth. These instruments were developed for scientific use from existing SONAR technology after WWII. Advancements in the field of marine acoustics has enabled important biological metrics to be estimated, such as biomass and abundance aiding in both fisheries and conservation management (Fernandes *et al.* 2002; Chu 2011; Handegard *et al.* 2012). A ubiquitous feature of echograms (data output by echosounders: backscattering strength by depth over time) are sound scattering layers (SSLs), acoustic representations of mid-water communities, which consist of mid-trophic level species such as zooplankton and small fish (Proud *et al.* 2015). Notably, deep SSLs (DSLs) take part in the largest migration by biomass on the planet (Brierley 2014), diel vertical migration (DVM), where organisms swim vertically upwards towards the surface at dusk to feed before returning to depth at dawn (reforming vertically discrete layers), remaining in complete darkness and therefore out of sight of visual predators, during the entire event.

Objectives

To make observations of mid-water organisms across the Chagos Archipelago and map the bathymetry of shallow features such as banks, atolls and seamounts using scientific echosounders. More specifically, we aim to collect information on fish and shark distributions, and that of their prey.

4.2. Method

Vertical echosounders were deployed via a pole mount and towed body (Fig. 2). Pole mounted echosounders were used to survey site locations and the towed body was deployed to survey on-transect between sites (Fig. 3).

Fig. 2. Vertical echosounding: a.) & b.) Towed body, housing 38, 120 and 200 kHz transducers; c.) & d.) Pole mounted 38 and 120 kHz transducers

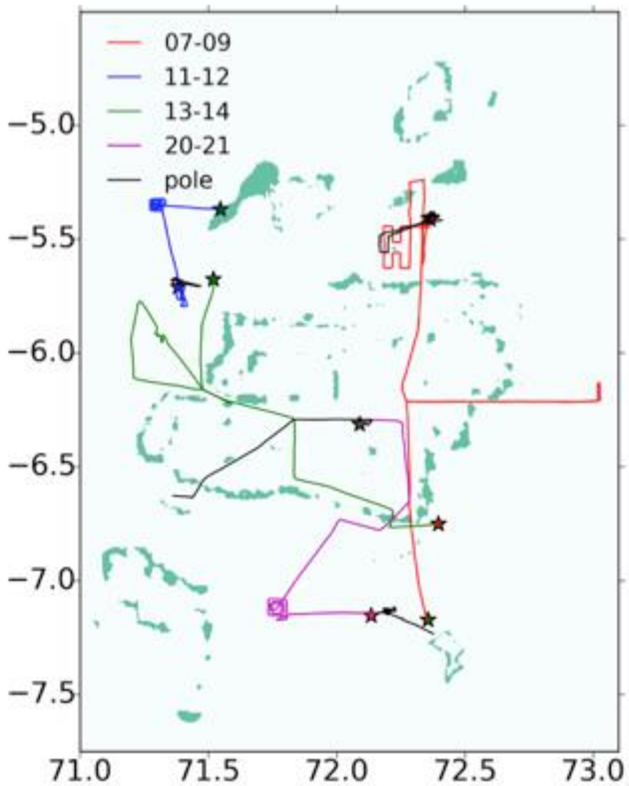

Fig. 3. Acoustic transects for both the towed body (TB) and pole mounted echosounders. For each towed body (TB) transect the time period (days in February) is given in the legend. Green and red stars mark start and stop locations of TB transects respectively.

4.2.1. Pole mount

Two narrow split-beam single frequency EK60 (Simrad, www.simrad.com) echosounders, operating at 38 kHz and 120 kHz, were mounted onto a plate, fixed to a pole and welded to the port side of the ship (Fig. 1c/d). The pole mount was used to record on site, as opposed to between site transects, recording data at a maximum vessel speed of 4 knots. The pulse duration was set to 1.024 ms and the ping rate set to maximum (dependent upon recording depth and therefore seabed depth) for both echosounders. Data quality recorded at the time of the BRUV deployment and recovery was poor, due to increased ship noise (mechanical) and movement (pitch and role).

4.2.2. Towed body

Three echosounders, operating at 38 kHz, 120 kHz and 200 kHz, were housed by the towed body (TB – Fig. 1) which was deployed off the starboard bow, via a 25m Kevlar cable that extended from a 3m (approx.) boom welded in an athwartship direction. The TB was used between sites, weather permitting, traveling at a nominal speed of 8 knots, which suspended the TB approximately 3 meters below the sea surface. Transects were conducted on/off the Great Chagos bank (Fig. 3) ranging in seabed depth from 15m to beyond 2000m.

4.2.3. Calibration of echosounders

On the 11th February a calibration was conducted for both the pole mounted and towed body housed transducers. A tungsten carbide sphere (38.1 mm in diameter) was used as a standard target and the standard calibration procedure outlined by Foote (1983) was carried out. Calibration parameters for the 3 echosounders housed by the towed body were derived in-situ (see Appendix #1 for results). Data collected for the pole mounted echosounders coincided with many fish echoes which caused erroneous target strength measurements to be made. These data will be cleaned and calibration parameters determined in post-processing at a later date.

4.3 Preliminary results

We conducted 4 towed-body transects across the archipelago during the expedition (Fig 2), recording data at 3 frequencies, 38, 120 and 200 kHz. Data collected at 38 kHz usually has a range of around 1200m, allowing observations of the mesopelagic community (200 – 1500m) to be made (Fig. 4).

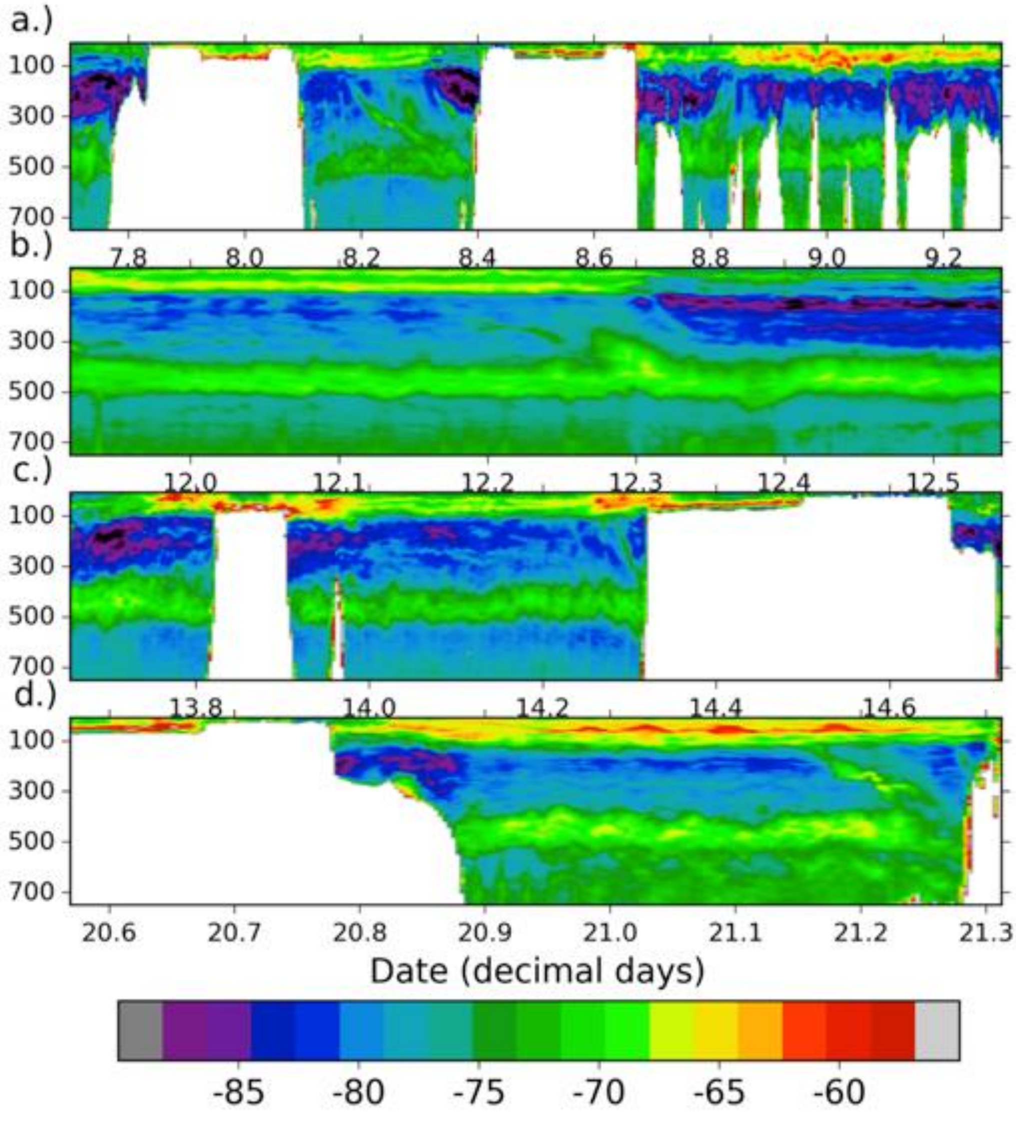

Fig. 4. Echograms (depth in meters by time) for towed body transects in February 2016. a.) 7th – 9th; b.) 11th- 12th; c.) 13th -14th; d.) 20th – 21st.

We observed an archipelago wide DSL at around 450m and increased surface scattering intensity (that could signify an increase in biomass) close to and over shallow topography, such as that which is found at seamounts and during night-time (Fig. 4).

5. WASSP multibeam sonar trials

5.1. Introduction

The spatio-temporal distribution of large, mobile marine predators (e.g. fish) and their prey (e.g. zooplankton) can be highly heterogeneous in the pelagic environment. Habitat features, such as seamounts, can generate distinctive bio-physical conditions. This results in patchiness in resource distribution, which in turn often leads to the aggregation of marine predators in time and space. In order to further our understanding of the habitat use and spatial scale of bony fish, shark and ray aggregations in the Chagos Archipelago, we mapped the bathymetry and spatial distribution of these marine predators around two distinct habitats, an atoll and a seamount, using state-of-the-art hydroacoustic instruments.

Recent advances in the application of hydroacoustic tools to study fish and other marine predators (elasmobranchs, marine mammals or diving seabirds) has provided high resolution, real-time spatial data for a more detailed understanding of school characteristics, biomass estimations, distribution patterns, water column use, or predator-prey dynamics.

Specifically, multibeam sonar allows these dynamics to be captured at broader spatial scales and at a higher temporal resolution. Although developed for seabed mapping, multibeam sonars can simultaneously provide high-resolution bathymetry data and 3D spatial information on midwater targets over time (individual fish/fish schools); providing means to investigate marine predator spatial distribution in relation to their environment. Compared to conventional single-beam echosounders, the application of multibeam sonar significantly increases the sampling volume as well as the resolution of water column targets and seafloor profiles during hydroacoustic surveys. Here, the suitability of a 80kHz WASSP multibeam sonar (WMB-5230) was tested to provide spatio-temporal snapshots of marine predators and their environment within the Chagos Archipelago.

The WASSP multibeam generates over 112 beams spread over a 120° port/starboard swath (112 beams x 1.07° lateral diameter), and a fore/aft beam width of 4°. Typically, using the full 120° swath, the seafloor coverage achieved by the WASSP multibeam is 3.4 times the depth (max. depth: 800m). As an example, in order to map a 1km^2 area at a 100m depth, the wide coverage of the WASSP multibeam (120° swath = 340m coverage) compared to that of a single beam echosounder (13° beamwidth = 23m coverage) would require less than a tenth of the tracks and significantly less time (13 minutes versus 3 hours at 7knots) to map the specified area.

Spatial resolution is a function of range and beam width. With increasing range, sampling volume becomes quite wide with conventional echosounders, with beam angles typically ranging between 5-13°. With the WASSP system, the narrow angle of each beam (1.07°) means that even at long ranges, the sampling volume per beam remains relatively small, allowing for higher resolution. The smallest detectable target height at nadir by the WASSP is 15cm, where one beam covers a target size of 19cm at 10m range and thus a target size of 190cm at a 100m. Therefore, larger water column targets (such as fish, shark and manta species) will be covered by multiple beams (depending on their orientation) even at relatively long ranges, allowing for increased resolution during target identification.

Objectives

1) To test the efficacy of the WASSP multibeam sonar for water column target detection (presence/absence) and quantification. The aim is to map the distribution patterns of individual, large mobile marine predators (e.g. sharks and rays) and their prey (e.g. fish schools and zooplankton) in the Chagos Archipelago.
2) To collect high resolution bathymetry data within two distinct habitat features, Egmont Islands and Sandes seamount, and link this information to marine predator/prey spatio-temporal distribution.
3) In-situ calibrations tests using a a) sphere and b) mid-water baited remote underwater video camera systems (BRUVS) to assess individual marine predator target strength and sizes during post-processing.

5.2. Method

5.2.1. Deployment

The WASSP (WMB-5230) multibeam sonar was mounted to a 2.8m custom-made pole mounting (Fig 5 a,b) on the port side of a 6.4m rigid inflatable boat (RIB). The transducer (sonar head) was submerged approximately 0.75m and directed downward with the 120° swath in the athwartship (across track) plane and the 4° vertical opening along the track, rendering a 3D volumetric image of fish distribution over time.

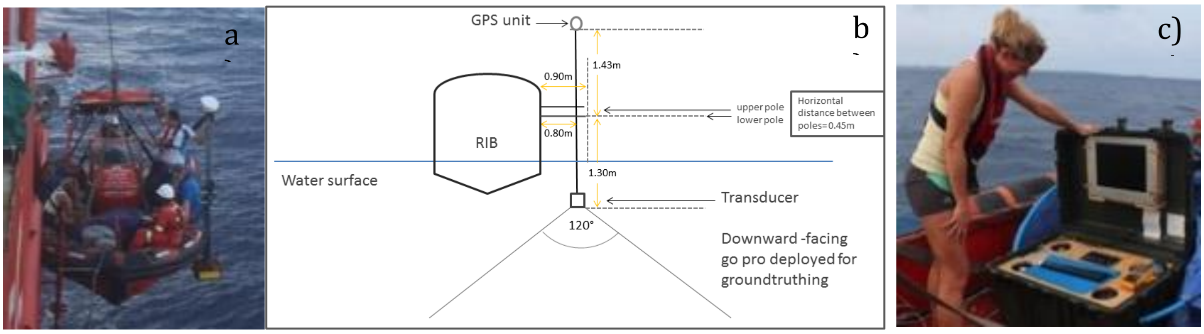

Fig. 5. a) Pole-mounting on the RIB, with the GPS unit (white) on top of the pole, b) Front view of pole-mounting measurements and direction of 120° multibeam swath c) Dry end displaying real-time multibeam sonar data.

The GPS and motion sensor unit was mounted on the top of the pole. The dry end (WASSP processor, BTx transceiver, battery converters, fans and monitor) displayed real-time recordings to a monitor. The dry end was built into a pelican case with the transducer cable and power cables (connecting to a 12V battery onboard the RIB) feeding through a hole on its side, making the unit watertight when required (Fig.1c). Raw sonar data (ping information; such as sound speed, sampling frequency, samples per beam; motion; heading; latitude; longitude; depth; date; time) was recorded in numbered data files (.001-file format) with an individual file size of 637Mb collected every 5-10m, depending on the power settings. Output files can later be converted to *.nwsf files which can be read by Echoview. The operation range was set automatically and the gain adjusted occasionally, but mostly kept at 45.

5.2.2. Groundtruthing and calibration

A downward-facing, wide-angle, high-definition subsurface camera (GoPro) was time-

stamped and mounted on the upper bracket above the transducer; angled to register targets before entering the sonar view. The rational to use underwater video is based on a) visual groundtruthing of targets during target identification, discrimination and quantification and b) on the restricted ensonified region immediate to the sonar head. Another wide-angle, high-definition surface camera was mounted on the pole midway between the GPS unit and the water surface, facing ahead of the boat's track to register sea state and bird activity in the absence of qualified bird observers on-board the RIB.

5.3. Preliminary results

Initial sea trials of the WASSP multibeam sonar system were performed on Feb 16th at Egmont Islands during calm sea conditions in water depths ranging between 10 and 265m. Offsets were set in the system configuration according to commissioning steps outlined in the WASSP installation manual (x,y,z offsets of GPS unit and transducer to a reference point, Fig. 5). Sea surface salinity (34.2psu) and temperature (29°C) readings were taken from a CTD (conductivity, temperature, depth) reading from the 15th February 2016 for sound speed calculation. Multibeam survey days included the 16th, 18th, 19th February 2016 at Egmont Islands and the 21st and 22nd February 2016 at Sandes seamount. When conditions allowed, surveys were generally run between 8.00 and 11.30am and 2.00 and 17.30pm.

5.3.1. Egmont Islands

On the 16th, reef manta rays were sighted at the sea surface within the Egmont Atoll during the morning survey. Mantas were predominantly visually detected between shallow waters (5m-15m) and the 60m depth contour, hereafter referred to as the 'manta alley'. Mantas were detected on the sonar display and will be groundtruthed using the downward-facing camera during post-processing (Fig. 6). Mantas were not detected in the afternoon and a change in sea conditions did not allow for highly controlled vessel movement and consequently, seabed mapping along the 60m depth contour was performed.

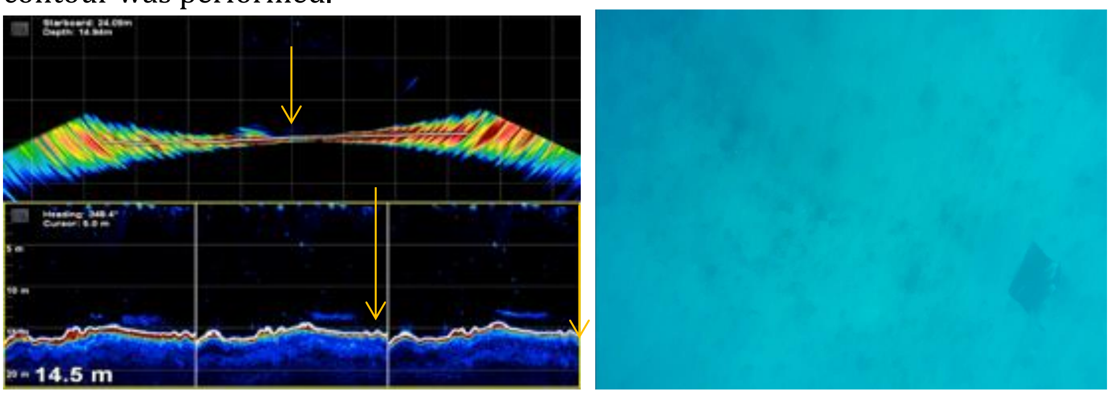

Fig. 6. Left: Multibeam sonar display showing a single target near the seabed, 16th Feb, Egmont Islands. Right: Downward-facing subsurface camera showing a manta as part of groundtruthing sonar data during post-processing.

On the 18th, the additional deployment of an echosounder (38kHz frequency) was attempted during the morning survey (Fig. 7), however the two sounders were not synchronised in advance and interference was detected on the multibeam sonar display.

Fig. 7. Mounting of the 38kHz echosounder transducer and the 80kHz multibeam transducer, 18th Feb, Egmont Islands

Calibration tests using a sphere on a rod were performed during the afternoon survey in relatively shallow waters (20m). Power levels were adjusted manually (from 1 to 4) during calibration, but set to 'automatic' during survey time (seabed mapping and mid-water target detection). The beam width of each of the three beams was set to 40°. Individual blue trevally fish approached the sphere and were visible on the sonar display (see Appendix #2, Fig. 1).
Seabed mapping towards the northern end of Egmont Island was continued on the 19th, however no mantas were detected during either the morning or afternoon survey. From the northern tip of Egmont Islands (Île des Rats) towards the south-east (Île Sudest), an area of 6x1 nautical miles was mapped, including the shallow waters of 5-10m depth, across the 60m dip and towards the channel entrance at the northeast side of the atoll where water depth ranged between 200-260m (Fig. 8).

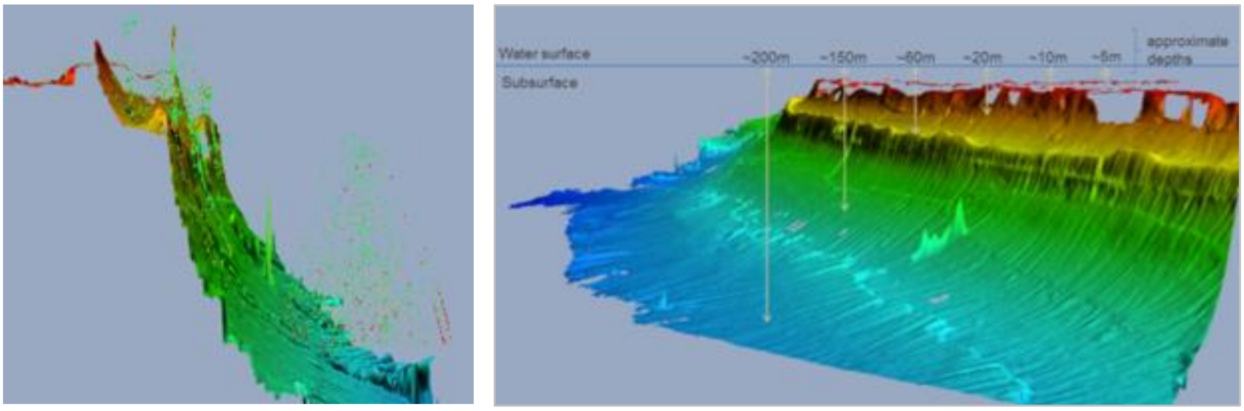

Fig. 8. Seabed 3D representation (scale=4:1) off Egmont Islands, Chagos Archipelago. Manta Alley refers to the yellow depth contour embedded between the very shallow waters (10m depth) and the 60m dip. Left: Seabed with display of mid-water targets. Right: Seabed only; approximate depths given.

5.3.2. Sandes Seamount

On the 21st, the morning survey included a straight line transect (~2.5 nautical miles) from west (07°08.8065, 072°06.7164) to east (07°09.1411, 072°08.4794) across Sandes seamount. Bathymetry ranged from around 400m at the edge of the seamount to around 60m on the summit of the seamount (Fig. 9). The cross-sectional multibeam transect helped determine the extent of the seamount and allowed for seven equally spaced CTD deployments. The surface and subsurface cameras were recording and sharks encountered (visually groundtruthed) during all CTD stations, except station 1 and 5. Most of the sharks were identified as silvertip sharks, but occasionally, grey reef sharks or silky sharks were sighted underwater. Two separate, large seabird feeding frenzies were observed during the survey, one of which constituted over a hundred birds. The frenzy started at the north-western side of the mapped seamount at the 140m depth contour (07°08.7882, 072°07.0727) and was still observed 10min later (07°08.8954, 072°07.6481).

During the afternoon survey, a mid-water baited remote underwater video camera system (BRUVS) was deployed between 20-30m depth underneath the transducer to groundtruth shark numbers and individual sizes (using the stereo camera system of the BRUV) for target strengths calculations during post-processing.

On the 22nd, a large tuna school and bird feeding frenzy was observed in the morning midway between Swart and Sandes seamount (07°08.6033, 072°10.8001). 20min later, a strong scattering layer was detected between the surface and 80m depth (07°08.777, 072°09.035) near the eastern side of Sandes seamount (seabed at 280m), resulting in unsuccessful seabed detection and mapping during this time (see Appendix, Fig. 9).

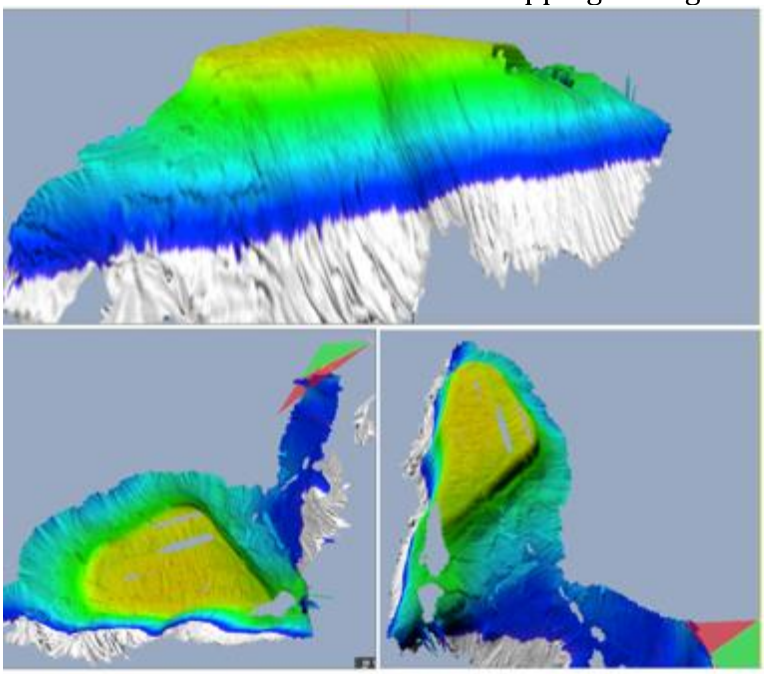

Fig. 9. Seabed 3D representation (scale=4:1) of Sandes seamount, Chagos Archipelago.

A circular multibeam survey around the 140m depth contour was performed to map the temporal occurrence of marine predators (sharks, fish and seabirds) around Sandes seamount. Although the surface camera served as a groundtruthing element during the 21st, a trained bird observer noted bird numbers, species and locations during the circular survey. Multiple bird feeding frenzies were observed, and large fish schools and silvertip shark (20+) aggregations were detected. It became evident that the waters between 140 and 160m depth just off the seamount summit showed a higher abundance of fish and shark aggregations (see Appendix, Fig. 10). The BRUV was deployed again towards the end of the survey, resulting in silvertip sharks, silky sharks, barracudas and rainbow runners to aggregate next to the device.

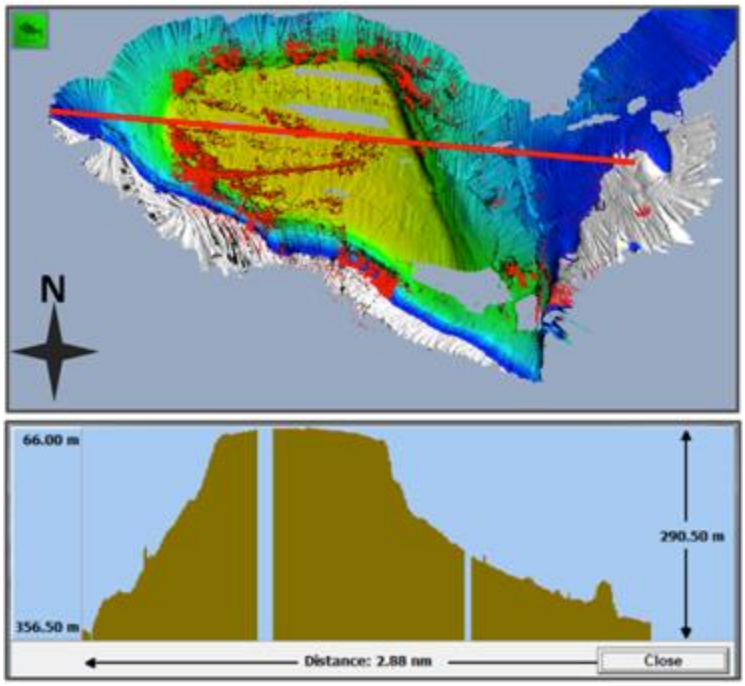

Fig 10. Depth profile across Sandes seamount where profile corresponds to red line cross section. The red dots represent mid-water targets (fish distribution) during the circular survey.

Future deployment considerations

We have demonstrated the successful deployment of a multibeam sonar to map the occurrence (presence/absence) of mobile, marine predators around Egmont atoll and Sandes seamount. In order to investigate temporal variability in spatial (horizontal and vertical) distribution patterns, we suggest (near-) continuous mapping of mid-water targets over time (day/night; tidal cycle; seasonal cycle) and link this information with simultaneously collected oceanographic data. The continuous collection of distribution patterns over time can help characterise the scale and spacing of aggregations and aid towards a better understanding of the drivers and mechanisms of dynamic, marine predator aggregations in the Chagos Archipelago.
Until calibrated responses (i.e. target strength information) of the multibeam sonar are validated, we further suggest the additional use of a synchronised, multi-frequency echosounder in order to assess the performance of the multibeam through quantitative comparisons with the echosounders.
This would also have the benefits of obtaining prey field information at the same, fine spatio-temporal scale. With the addition of the echosounder, the multibeam sonar could also be applied to investigate predator-prey dynamics through individual, fine-scale tracking (focal follows). Prolonged tracking of large, mobile predators such as sharks and mantas, could be used to determine how they forage on fish schools/use the scattering layer and to investigate potential responses of prey fields to predators. Predators modify their foraging behaviour in response to (spatially and temporally variable) prey patch characteristics and the combined use of multibeam and echosounders would allow a quantitative assessment of prey resources at various scales relative to the foraging animal. As an alternative survey method, a flexible pan/tilt mechanism could be added to the multibeam pole mounting. The sonar head could be directed at 45° downside, with the outermost beam directed vertically downward, and the remaining beams directed towards the water column (horizontal plane on the side

of the vessel) to circumvent potential fish avoidance behaviour to the boat or the multibeam.

Finally, survey time has been limited by sea conditions and battery power. In order to significantly increase survey time in the future, 12V lithium battery packs should be considered for long-endurance operations. Further, although the current set up of the dry end protected it from minor splashes and rain, a canopy-style cover fitted to the RIB would allow survey time even during moderate-rough conditions.

6. Indian Ocean Standard Net

6.1. Introduction

Plankton are small organisms (plant and/or animal) that drift or float in remarkably large numbers in the world's oceans. Plankton is the basis of the marine food web and the primary source of the manta ray's diet. Since most plankton are barely visible to the unaided eye, scientists use a special net to gather these small creatures. The plankton net is a funnel-shaped, fine-meshed net that is towed through the water. The net concentrates the plankton from hundreds of gallons of water that pass through it (Fig. 11). The net is towed using a key ring and three strands of string which are tied onto a wire hoop. The hoop itself holds open a cylinder of fine mesh netting, shaped like a wind sock (Fig. 12). After the net is pulled through seawater, the particles which do not pass through the net will be concentrated and trapped within the collection cylinder or cod-end (Fig. 13).

Plankton nets have been utilized throughout the world's oceans in order to quantify zooplankton. The net used for sampling is based on the *Discovery* N 100 net described in the *Discovery* Investigations, Objects, Equipment and Methods by Kemp, Hardy and Mackintosh (*Discovery Rep.* I, 141-232, 1929.) In August of 1961, the Special Committee on Oceanic Research and UNESCO held a meeting of zooplankton scientists and decided to standardize a modify version of the *Discovery* N 100 net for the Indian Ocean. The Indian Ocean Standard Net (Deep-Sea Research, 1963 Vol. 10, pp. 27-32) was used on the Pacific Marlin for the study of the quantitative and qualitative distribution of planktonic organisms across the Chagos Archipelago. Typically the net was deployed once or twice a day at stations along the cruise track. The net was hauled "vertically" from 200 m to the surface at a speed of 1m/s. Since vertical net hauls are rarely absolutely vertical, the use of a flowmeter was used. The speed of the haul was limited by the speed at which the Pacific Marlin's capstone could pull the net, where as the standard speed should be 1 m/s.

Objectives

The plankton net was done in conjunction with a CTD, acoustic sampling and BRUV sampling in order to get a clearer understanding of what may impact biological abundance throughout the Archipelago.

6.2. Preliminary Results

The following plankton net deployment were conducted as part of the expedition (Table 2). The samples were preserved on borax buffered formaldehyde and are presently stored in St Andrews to be processed (identified and quantified) at a later stage.

Table 2. Location and timing of Indian Ocean Standart Net deployment on the 2016 Pelagic Expedition to the

ID	DATE	TIME_IN	TIME_BOTTOM	TIME_OUT	LAT_in	LONG_in	LAT_out	LONG_out	STATION
IOSN1	07/02/16	9:00	9:06	9:18	07.14347	072.15543	07.14224	072.15909	Swartz
IOSN2	09/02/16	8:59	9:03	9:18	05.38944	072.36562	05.38697	072.36823	Salomon Oceanic
IOSN3	09/02/16	13:18	13:22	13:35	05.39251	072.38251	05.39426	072.38733	Salomon Oceanic
IOSN4	10/02/16	8:38	8:42	8:55	05.40129	072.35834	05.40057	072.36362	Salomon Oceanic
IOSN5	12/02/16	16:29	16:36	16:50	05.68458	071.38186	05.68253	071.38718	Pero banhos 'Seamount'
IOSN6	12/02/16	20:58	21:03	21:17	05.70257	071.43794	05.70483	071.44794	Pero banhos 'Seamount'
IOSN7	13/02/16	8:18	8:23	8:36	05.67023	071.36926	05.67310	071.37503	Pero banhos 'Seamount'
IOSN8	16/02/16	13:38	13:40	13:56	06.64131	071.39793	NA	NA	Egmont
IOSN9	18/02/16	13:00	13:05	13:23	06.64684	071.40576	06.65164	071.41594	Egmont
IOSN10	20/02/16	8:17	8:19	8:26	06.31254	072.10995	06.31148	072.10906	Great Chagos Bank
IOSN11	21/02/16	12:40	12:44	12:53	NA	NA	07.16479	072.14419	Sandes Seamount
IOSN12	21/02/16	20:57	21:02	21:14	07.15630	072.13963	071.15895	0721.14553	Sandes Seamount

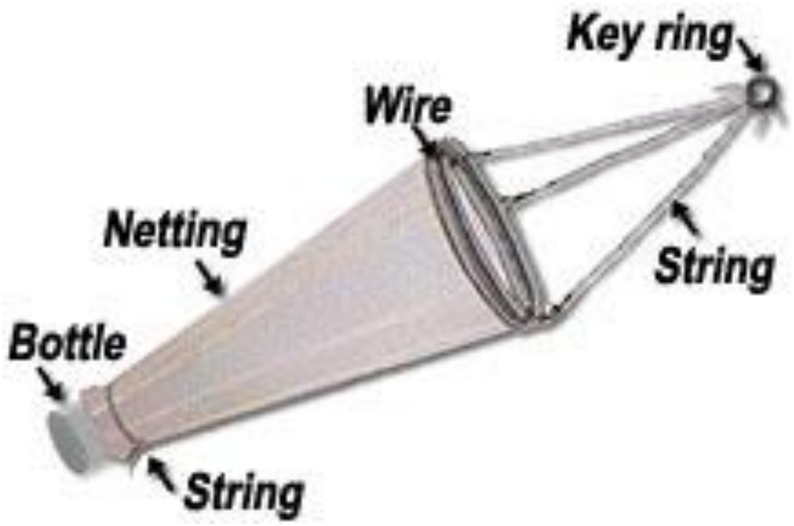

Fig. 11. Schematics of the Indian Ocean Plankton Net

Fig. 12. Scientists deploying plankton net

Fig. 13. Scientist pouring the sample from the cod-end into a mesh strainer to retrieve sample

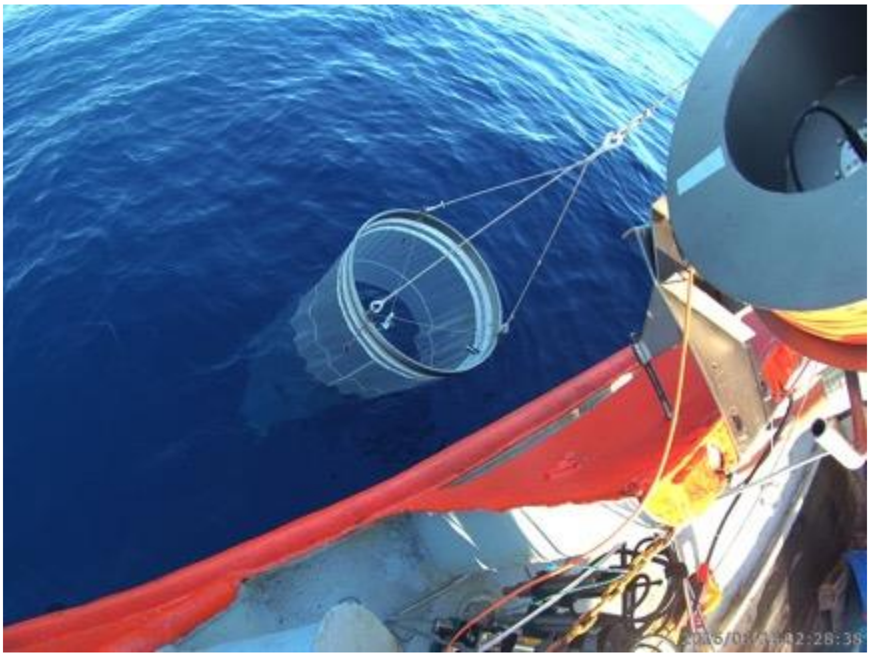

Fig. 14. Plankton net is deployed vertically 200m and recovered at 1 m/s

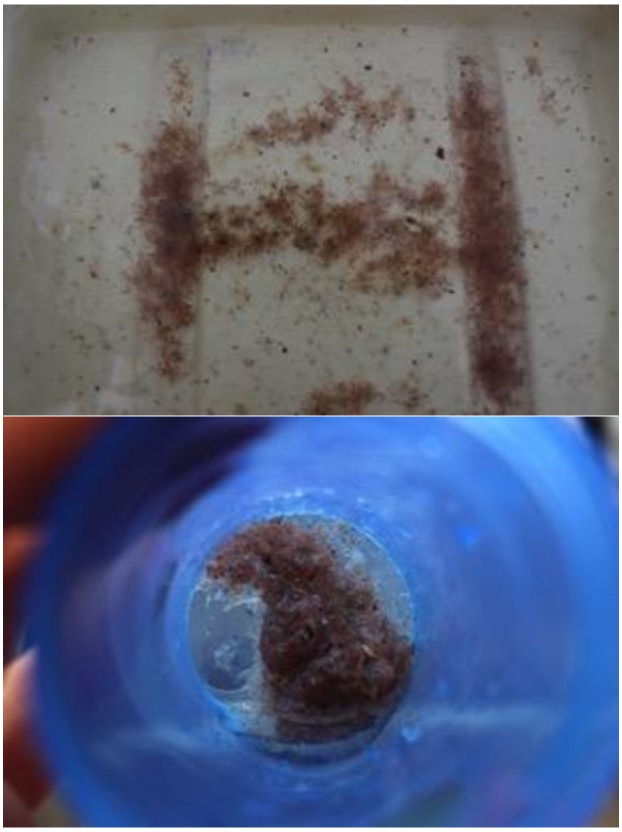

Fig. 15. Plankton sample (left) preserved in formalin (right).

7. Oceanography

7.1. Introduction

Following last year's successful acquisition of the first extensive oceanographic dataset within BIOT to date by Drs. Phil Hosegood and Kate Adams, the team returned to further extend our understanding of the processes driving the regional circulation. The team was composed of Drs. Phil Hosegood and Alex Nimmo Smith and extended the previous year's measurements by adding sensors measuring nutrients and particles to the long-term mooring, this time deployed over Swart Seamount, and by deploying instrumented drifters at multiple sites. We also deployed short term moorings over 'Manta Alley' in Egmont throughout the storm during which the weather was the worst experienced over recent years.

Our goal during was to further broaden our understanding of the oceanography of BIOT with particular interest being given to the impact of El Nino and other basin–scale perturbations on the conditions observed throughout the archipelago. During the expedition last year conditions were particularly calm; this year conditions were somewhat unsettled due in part to El Nino but at a more immediate level due to a tropical cyclone that passed just to the south of the study area during the latter half of the expedition. Weather was overcast for the majority of the cruise and we were subject to heavy and persistent rainfall accompanied by strong winds.

Objectives

The overall aim of the physical oceanography team was to broaden our understanding of the prevalent oceanographic processes that drive spatiotemporal variability in currents and water properties. This was to be achieved through achieving the following objectives:

1) Characterise the circulation over Sandes Seamount through the deployment of a heavily instrumented mooring for 15 days.
2) Identify episodic upwelling events over the seamount and quantify nutrient fluxes arising as a result of the injection of cold water into the euphotic zone.
3) Identify any flow perturbations arising downstream of Discovery Bank and other shallow water features.
4) Resolve the vertical distribution of nutrients and associated water properties at a range of locations throughout the archipelago.

7.2. Method

7.2.1. Swart Seamount mooring

Following on from the successful 2 week deployment of a fully instrumented oceanographic mooring over the flank of Sandes Seamount during the 2015 Pelagic Expedition, we deployed during this expedition a more heavily instrumented mooring over the summit of Swart Seamount (Fig 16). The full details of the instrumentation deployed on the mooring are listed and illustrated in the Appendix #3 but, briefly, they enabled measurements to be made of currents and temperature over the full water column. Additionally, a frame mounted 8 m above the bed contained instruments measuring chlorophyll, nitrate, and particle size and distribution. The mooring was deployed over the flat seamount summit in a water depth of 70 m at -7 º 8.373N, 72 º 11.362E.

The specific aim of the mooring was to reveal the extent to which cold, nutrient rich water from depths beneath the euphotic zone are able to reach the flat summit of the seamount. Prior to the cruise and on the basis of results from last year, we considered it likely that the tides periodically flush the summit with cold water, creating a dynamic and variable environment that, due to the magnitude and abruptness of the associated changes in temperature and biogeochemical regime, will have important consequences for the benthic ecosystem.

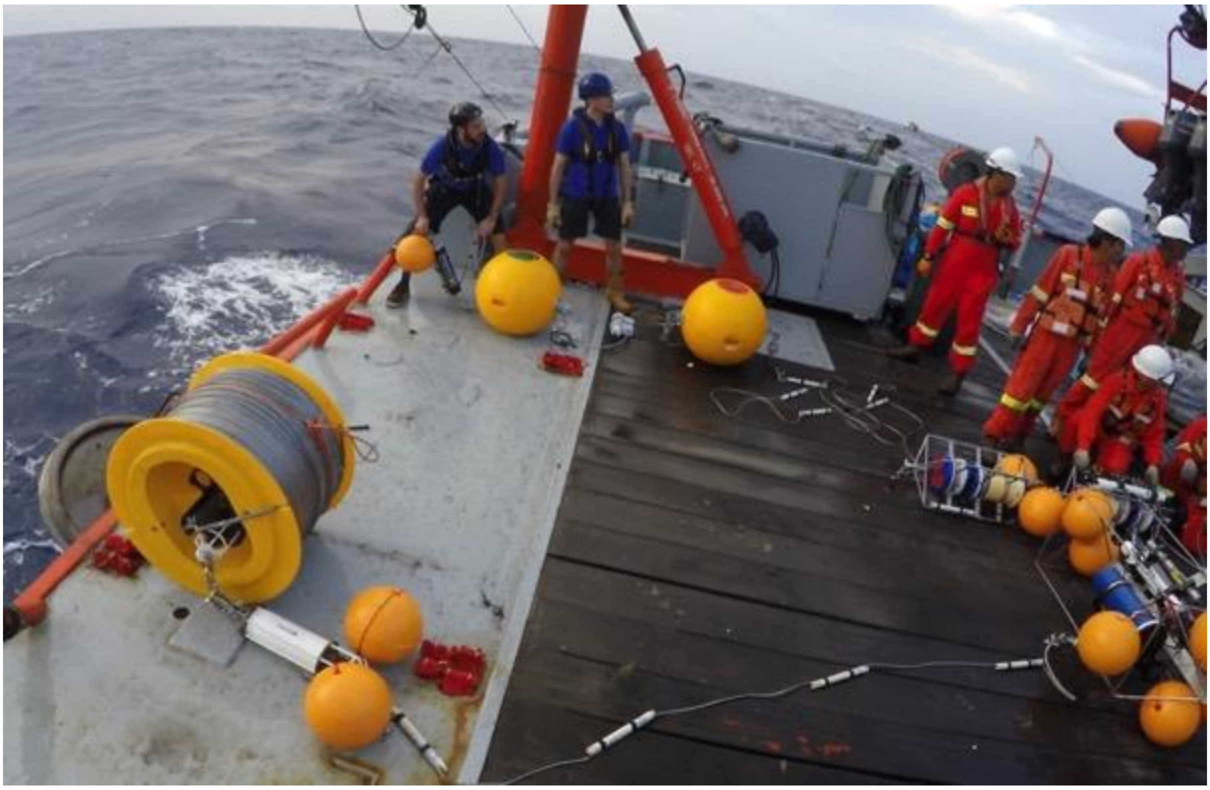

Fig. 16. Deployment of the Swart Seamount mooring. Note the CROM anchor recovery system on the stern rail nearest the camera. The CROM enabled the successful recovery of the 750 kg train wheel that acted as the anchor for the mooring, thereby minimising the impact the mooring had on the environment by removing any material associated with its deployment.

7.2.2. CTD Profiling

At each main sampling station, the Plymouth University team deployed their compact multi-parameter CTD system (Fig. 17). This was lowered from the port quarter of the Pacific Marlin using a Kevlar-reinforced hydro-cable and electric winch. The system was configured with an RBR Maestro CTD to measure Conductivity, Temperature and Depth (used to measure the vertical distribution of salinity and density in the water column) to which were also attached a Seapoint Chlorophyll-a fluorometer (to estimate the abundance and distribution of phytoplankton in the water column) and a RINKO dissolved oxygen sensor. The system was also configured with a TrIOS OPUS ultra-violet absorption sensor for measuring nitrate (NO_3, one of the nutrients required for phytoplankton growth), and a fast-sampling prototype digital holographic camera (holocam) to record high-magnification images of suspended particles (phytoplankton, zooplankton, detritus). The clocks of the CTD and OPUS sensors were synchronised prior to each deployment, while the holocam output a synchronisation signal to the CTD datastream. The CTD system was deployed at the locations given in Table 3.

Table 3. Multi-parameter CTD system deployment details

Profile Number	Date/Time (UTC)	Position	Parameters	Max Depth (m)
01	2016-02-09 03:55	05°22.80S 72°22.52E	CTD, Chl-a, O_2	320
02	2016-02-09 09:51	05°23.68S 72°23.47E	CTD, Chl-a, O_2, NO_3	300
03	2016-02-10 02:58	05°24.08S 72°21.65E	CTD, Chl-a, O_2, NO_3	300
04	2016-02-12 13:32	05°41.93S 71°22.90E	CTD, Chl-a, O_2, NO_3	300 (multiple profiles over migration period)
05	2016-02-13 02:46	05°40.44S 71°22.68E	CTD, Chl-a, O_2, NO_3	300
06	2016-02-16 03:55	06°40.39S 71°25.42E	CTD, Chl-a, O_2, NO_3, HOLO	300
07	2016-02-18 03:34	06°39.86S 71°25.88E	CTD, Chl-a, O_2, NO_3, HOLO	200 (winch failed, so deployed on plankton net line)
08	2016-02-20 02:33	06°18.65S 72°06.52E	CTD, Chl-a, O_2, NO_3	70
09	2016-02-21 07:21	07°10.09S 72°08.98E	CTD, Chl-a, O_2, NO_3, Go-Pro	110

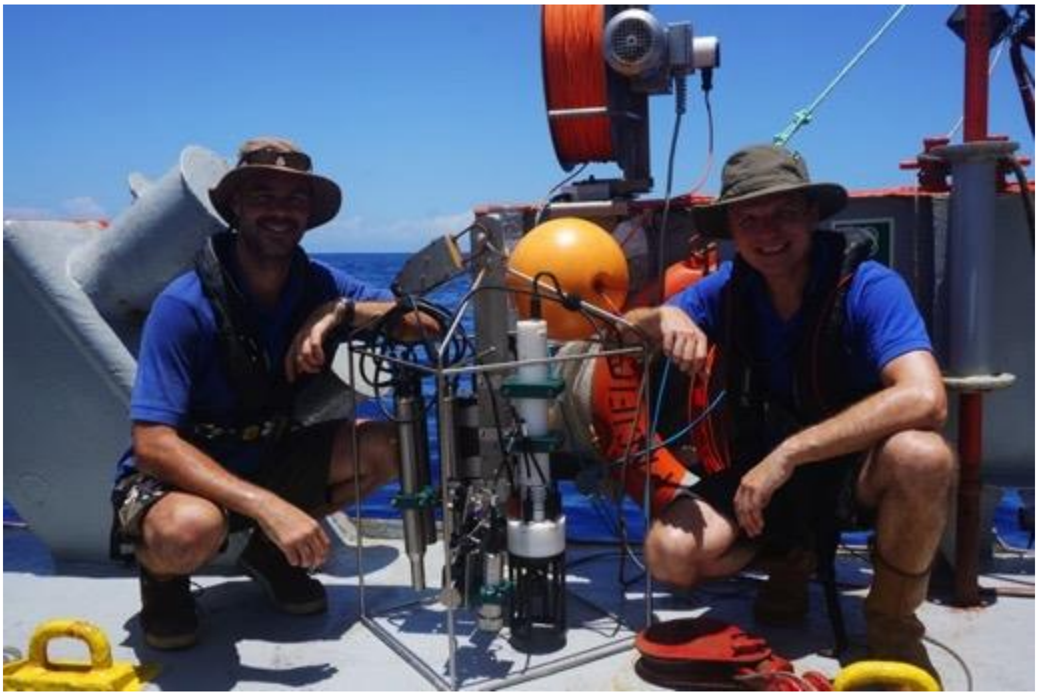

Fig. 17. The Plymouth University team and their compact multi-parameter CTD system.

7.2.3. Instrumented drifters

We successfully trialled an innovative technique during this expedition whereby we attached a Nortek 400 kHz ADCP, RBR Concerto CTD and 10 Seabird temperature sensors to a 20 m line attached to the bottom of a drogued drifter (Fig. 18). The drifters are adapted from those used by Dr. Hosegood in a recent Southern Ocean cruise and permitted high resolution measurements of currents and temperature to be made between depths of 20-70 m.

Drifters were deployed at 3 locations (Table 4); at Discovery Bank 2 pairs of drifters, of which one in each pair was instrumented, were deployed to the north and south of the western flank of the Bank. To the west of the archipelago, a single drifter was deployed in the deep water and later in the cruise, a further brief deployment took place in the shallower water of the central Grand Chagos Bank

Table 4. Drifter deployment details

Location	Deployment Date/Time	Recovery Date/Time	Deployment Lat/Lon
Discovery Bank	C4: 9/2/2016, 19:39 C5: 9/2/2016, 21:10	C4: 10/2/2016, 16:43 C5: 10/2/2016, 17:49	C4: 5° 29.43 S, 72° 12.08 E C5: 5° 33.35 S, 72° 12.04 E
West Chagos Bank (C5)	12/2/2016, 15:51	13/2/2016, 14:44	5° 40.83 S, 71° 21.39 E
Central Chagos Bank (C4)	15/2/2016, 07:13	15/2/2016, 12:44	6° 17.27 S, 71° 50.38 E

Fig. 18. Instrumented drogued drifter on deck following recovery. At the bottom of the photograph lies the Nortek 400kHz current meter that measured currents between depths of 20 – 70 m; above it the CTD measured the temperature, salinity and depth, confirming that the instrumentation beneath the drogue remained at a stable depth. To the left of the drogue are the 10 SBE56 temperature sensors mounted on the 20 m line at 2m vertical spacing. At the top of the photograph is the orange buoy within which the satellite communication and GPS electronics are mounted.

7.2.4. Egmont atoll moorings

To supplement the Manta tagging and multibeam surveys over 'Manta Alley', we deployed two short term moorings over the Alley ridge. The moorings essentially comprised the instrumentation mounted on the drifters but here configured such that the Nortek current meters were mounted at the bottom of the mooring looking upwards and the Seabird temperature sensors and Concerto CTD evenly spaced on a line extending to 10 m from the surface. The moorings were deployed in 55m of water at the following positions:

-Egmont eastern mooring: 6° 38.692 S, 71° 21.928 E

-Egmont western mooring: 6° 38.413 S, 71° 21.237 E

The deployment occurred immediately before the storm passed and on recovery we were unable to locate the southerly mooring. The multibeam detected what we believe to be the 12 inch trawl float located 10 m above the bed; efforts will be made in a later cruise to effect a recovery of the mooring. We consider that the uppermost float at a depth of 10 m failed during the storm and that as such the entire mooring is still located in Manta Alley at a known position.

7.3. Preliminary results

7.3.1. Swart Mooring

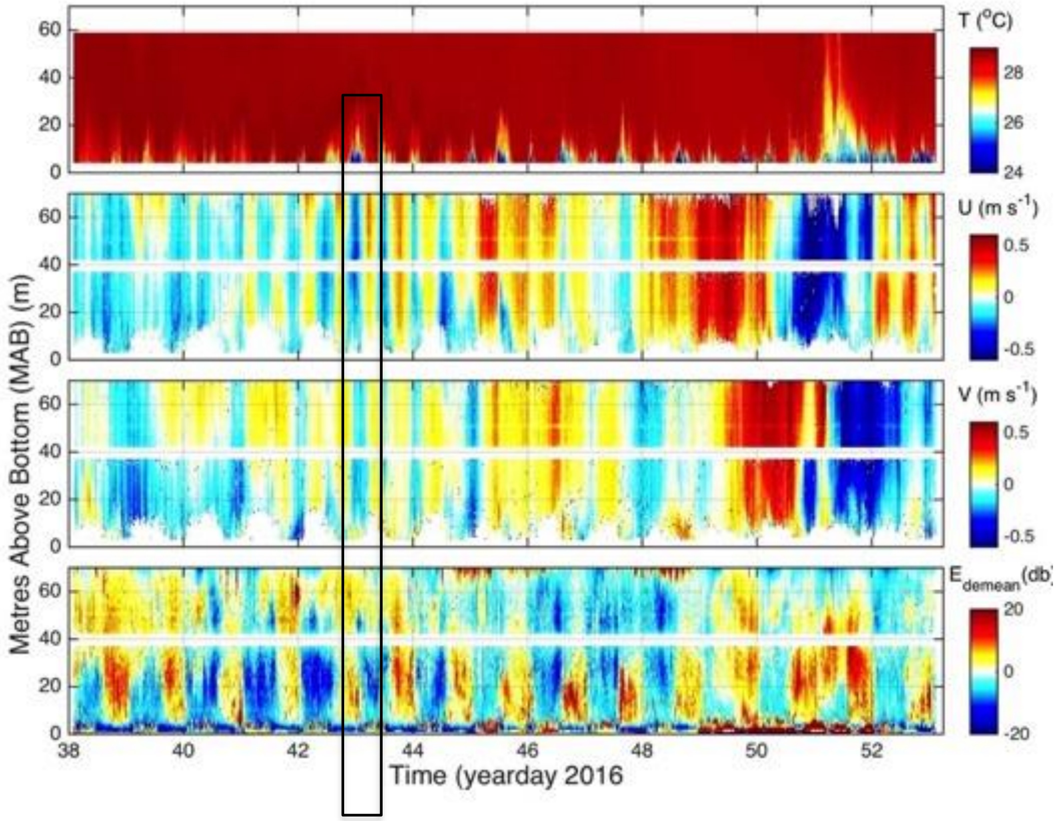

Fig. 19. (from top) Temperature, eastward, northward velocities and echo intensity observed by the instrumented mooring on Swart Seamount throughout the entire cruise. Temperature was measured by 30 Seabird 56 sensors and the currents and echo intensity (the latter of which the time mean has been removed from each depth) by the two ADCPs mounted at mid-depth. The black rectangle indicates the period that is depicted in greater detail in Figure 5. Note the diurnal migration of zooplankton apparent in the bottom panel, the echo intensity; red shading indicates higher than average backscatter, and therefore the presence of zooplankton.

The summit of Swart Seamount is a dynamic environment, being vigorously flushed with cold water on every tide (Fig. 19). The cold, and likely nutrient rich, water immerses the bottom 10-20 m typically but following the storm experienced towards the end of the cruise extended as far as 40 m above the bed. Throughout the upper 50 m, the water column exhibits a relatively weak vertical temperature gradient; however a particularly interesting feature is the layer of warmest water observed immediately above the cold water events. In this 10 m thick layer, temperature exceeds 29 °C whilst underlying water of only 28 °C.

Similar to the previous year's observations (2015) over the edge of Sandes Seamount, currents display a weak tidal dependence despite the clearly tidal periodicity associated with the cold water incursions. No clear persistent background current is apparent in contrast to the predominant westward current experienced at the similar time of year during 2015. The storm on day 48 clearly accelerated currents to 0.6 m s^{-1}; the reversal in the eastward current (U) throughout days 48-51 strongly suggests the generation of a near inertial wave with 5 day periodicity that was also observed to result from wind forcing during 2015.

Echo intensity from the ADCP reveals the expected diurnal migration of zooplankton. Backscatter increases during night-time before dropping with sunrise (corresponding to the end of each day in Figure due to the time expressed in UTC, 6 hours later than local time). The high backscatter occurring immediately adjacent to the bed during day time is suggestive of trophic focussing whereby the zooplankton are trapped at the sea bed over the summit as they try to escape to greater depths.

A detailed look at one of the cold water inundations (Fig. 20) reveals the complex character of the events. The cold water takes the form of an intense bore trapped against the seabed. The currents are strongly baroclinic as evidenced by the northward velocity component (V). Specifically, the current above the cold water is directed to the south with a velocity of >0.2 m s^{-1}, but the cold water itself is directed to the north with a similar velocity, in completely the opposite direction. High levels of backscatter during the inundation suggest that the cold water is accompanied by high concentrations of suspended particulate matter. Furthermore, individual waves within the bore exhibit strong vertical velocities consistent with nonlinear internal waves. Currents are directed upwards towards the surface at the leading edge of the waves and downwards on the trailing edge.

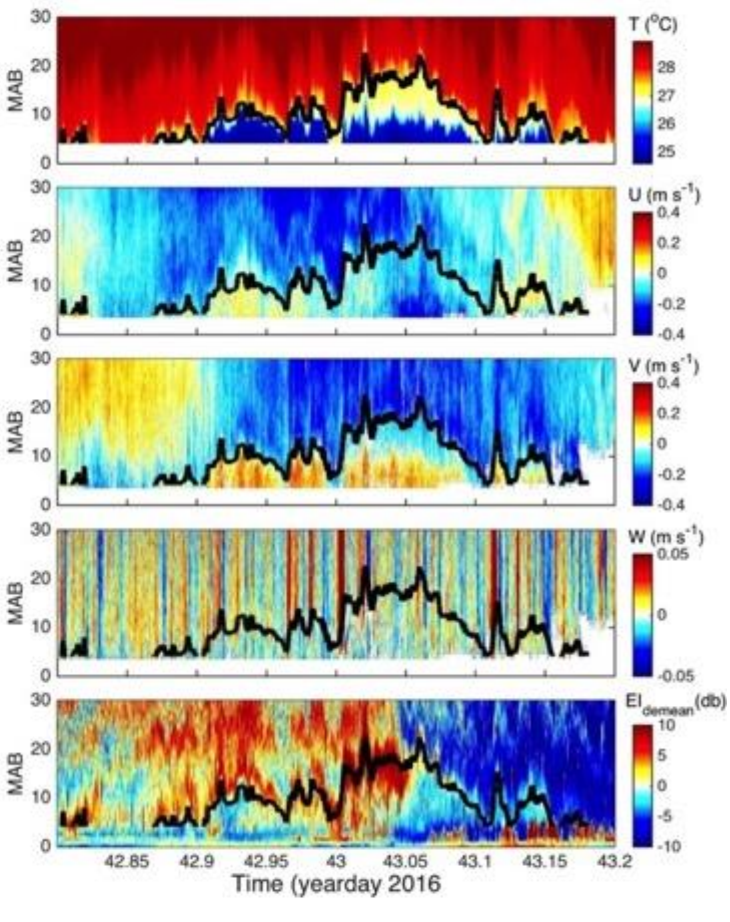

Fig. 20. Temperature and currents measured over 9 hours by the mooring over Swart Seamount. The panels represent (from top), temperature, eastward, northward and vertical velocities and the echo intensity after removing the time mean from each depth bin. This period coincided with the inundation of cold water from beneath the seamount summit. Future analysis will investigate the nutrient concentrations in this cold water and the particle characteristics with the aim of assessing the role of the inundations in promoting a diverse benthic community.

7.3.2. Drifter deployments

We hypothesised before the cruise that Victory Bank may generate an Island Mass Effect, effectively stirring the water within its wake as currents push water past this shallow obstruction. Such circulations are known to generate vertical velocities that are implicated in bringing nutrients to the sea surface where they may trigger phytoplankton blooms. To investigate this phenomena, we released 4 drifters in the western lee of the Bank, with a pair to the north of the bank and a pair to the south.

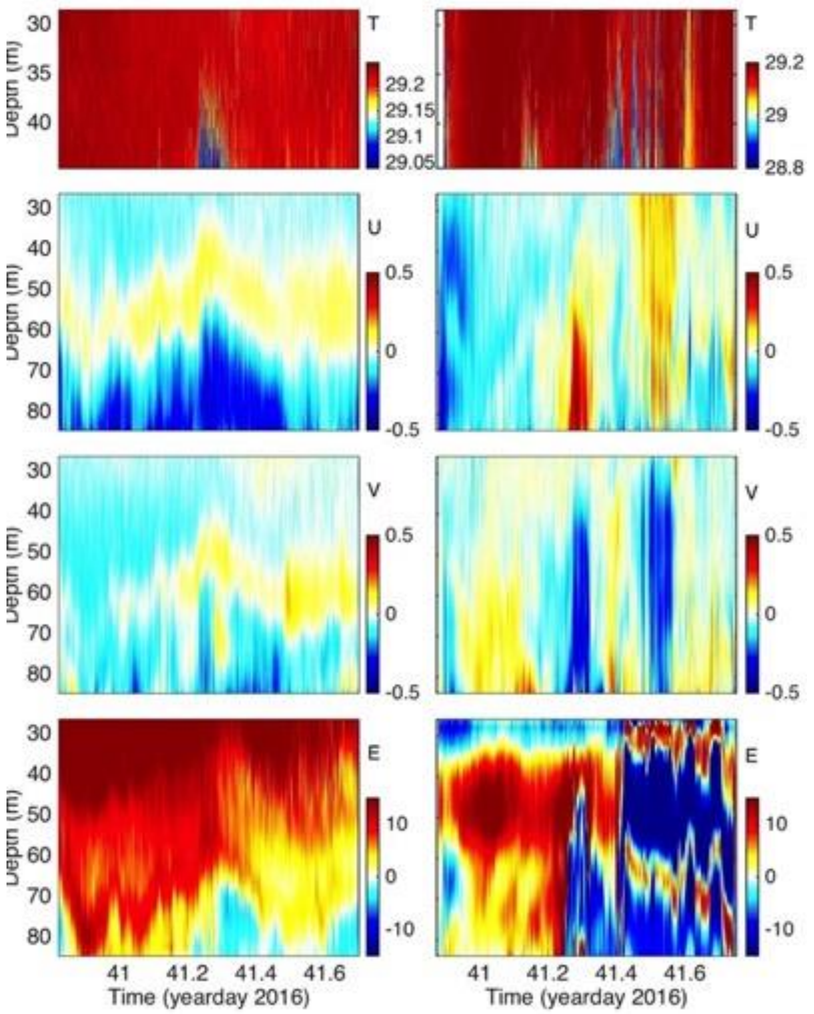

Fig. 21. (from top) Temperature, eastward and northward velocities (U and V, respectively) and echo intensity measured on the drifters deployed to the north and south of Victory Bank. At a similar time, 41.3, both drifters are passed by internal waves of elevation that bring colder water towards the surface. The wave packet is more pronounced in terms of duration at the southern drifter (on the right side); multiple waves pass the drifter and have amplitudes at least as large as the extent of the 20m line on which the temperature sensors were mounted.

The internal waves apparent in both drifters in Figure 21 are important as they represent mechanism for bring cold, nutrient rich water towards the surface. The amplitude of the internal waves, apparent as cold water extending upwards towards the surface, is routinely more than 10 m. They pass the drifters in timescales of *O* (10 minutes). The currents demonstrate a high degree of vertical shear; the eastward velocity at the northern drifter is particularly coherent and demonstrates the strong westward flow beneath 60m that was similarly observed during the 2015 expedition. This is further evidence that, not only are the currents near the surface in BIOT strongly sheared, but they are often characterised by distinct layers of thickness 10-20 m that flow in completely different directions.

7.3.3. Holocam

The holographic particle imaging camera (holocam) contained within the frame at 8m above the seabed recorded bursts of images throughout the deployment period. 62 holograms were recorded every 30mins giving a total of >45,000 independent samples. Each hologram can be digitally re-focussed to allow all particles (>20μm diameter) to be extracted, measured and identified from with the instrument's 1.4ml sample volume. A sample hologram and focussed particle (a copepod) are shown in Figure 6, along with a small selection of other particles (plankton and detritus) imaged from the period shown in Fig 22. Preliminary analysis indicates that the particle population changes associated with the tidally-driven cold-water flushing events. Future detailed analysis will focus on this.

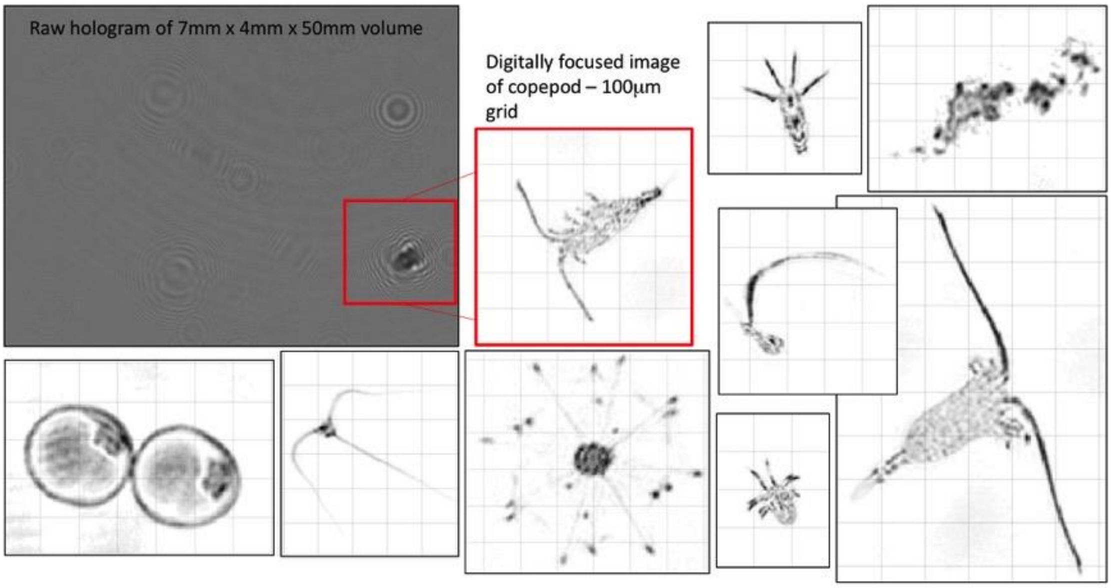

Fig. 22. Sample hologram showing a digitally focussed region revealing a copepod. Further sample focussed images are also shown of a wide variety of phytoplankton, zooplankton (including copepods and fish larvae), and delicate aggregates of detritus that acts as a food source for filter feeders.

8. Manta ray tagging

This work was conducted as part of the greater on going sentinel species tagging programme in BIOT. These activities, included the expantion of the array, are reported in the Vava2 leg 2 expedition report.
Reef manta rays (*Manta alfredi*) are one of the largest mobulid species (Subfamily: Mobulinae) reaching a wing span of up to 5 meters. They are found in tropical and subtropical waters of the Indian Ocean extending to the Western and Central Pacific Oceans. Sighting records of reef manta rays suggest preferential occupation of nearshore tropical waters with strong site affinity and limited movements, although horizontal excursions of over 500 km have been documented occasionally venturing into the mesopelagic zone (Braun *et al.* 2014).
Movements of *M. alfredi* coincide with predictable manta aggregations at several known locations associated with mating, cleaning, food availability, and currents (Jaine *et al.* 2012). Although recent efforts have significantly increased our knowledge on the biology and ecology of this enigmatic species many aspects still remain unravelled.
Reef mantas exhibit typical K-selected life history traits such as slow growing rate, late maturity, low fecundity and long lifespan making them extremely slow to recover from a state of depletion.

An increasing demand for dried mobulid gill plates in the Chinese Medicine trade is driving fisheries to target these species globally, with some regional manta populations plummeting by 87% in recent years. Due to such growing target fisheries, coupled with their conservative life strategy, reef manta rays are now listed as “Vulnerable” on the IUCN Red List of Threatened Species (IUCN, 2014) and listed under Appendix II of the Convention of International Trade in Endangered Species of Wild Fauna and Flora (CITIES) as well as Appendix I and II of the Convention on the Conservation of Migratory Species of Wild Animals (CMS).

M. alfredi and other mobulid species are known to be present in the Chagos Archipelago. Frequent and regular sightings of reef mantas (with aggregations of over 50 individuals) have been reported at various locations such as Egmont Atoll, Diego Garcia and Salomon Atoll (Stevens, pers. comm., Meeuwig, pers. comm & BIOT administration, pers. comm.). Satellite tagged *M. alfredi* in the Red Sea and in eastern Australia, and actively tracked *M. alfredi* in Hawaii, have shown regular movements of individuals offshore, possibly exploiting rising layers of mesopelagic zooplankton that move up into the photic zone at night (Deakos, Baker, & Bejder, 2011; Braun et al., 2014; Jaine et al., 2014) and preliminary satellite tracking data have shown a similar pattern in the Chagos Archipelago, with some individuals venturing as far as 100km (Fernando et al., in prep.).

BIOT’s proximity to Sri Lanka, where mantas and other mobulid rays are heavily targeted, may pose a serious threat to the protected status of mantas in the region as these animals may occasionally leave the MPA boundaries during large scale migrations. Sri Lankan fishermen venture far into international waters and

EEZs of neighbouring countries, sometimes venturing into the BIOT reserve for illegal fishing, targeting primarily sharks and rays (Stevens, pers comm. & BIOTA, pers comm.). BIOT police have already reported sightings of dead manta rays from confiscated Sri Lankan vessels caught within the BIOT reserve, which are most likely *M. alfredi*. While mega-MPAs such as the BIOT reserve provide unquestionable value to coral reef habitats and many invertebrate and fish species in these ecosystems, it remains unclear whether they can effectively protect more mobile marine megafauna such as manta rays.

Objectives of the expedition are to deploy 4 pop-up archival transmitting (PAT) tags (mini-PAT; Wildlife Computers, Redmond, WA) and 2 individually coded acoustic transmitters (V16-4H; Vemco, Halifax, Nova Scotia) on reef manta rays (*M. alfredi*). Photo-IDs (photographs of the unique ventral spot pattern) of as many individuals as possible will be collected as well for identification purposes and, whether possible, tissue biopsy samples will also be collected and stored in ethanol for genetic analyses.

8.1 Methodology

8.1.1. Study Site

Egmont atoll was selected as the main study site and tagging location within BIO.T. Previous expeditions have, in fact, reported regular occurrence of reef manta rays feeding in its shallow lagoon. Furthermore, the relatively small size of this atoll (roughly 4 km^2) makes Egmont an ideal location for an in-depth investigation of its topography, zooplankton distribution and water dynamics involved in driving planktonic preys in the shallow lagoon where mantas aggregate to feed.

8.1.2. Tags deployment

Mantas are first located either by sight from the rigged inflatable boat (RIB) or drone (DJI Phantom 3 Professional). Manta were tagged with 4 miniPAT tags and 2 acoustic tags. Tags were deployed on free-swimming individuals while free diving using a customised tagging pole and titanium dart inserted into the dorsal musculature near the trailing edge of the wing, at the margin between the wing and the axial musculature. The insertion region has been chosen to avoid injuries which may occur when tags are deployed close to life threatening organs.

MiniPAT tags were programmed to stay on the fish from 90 to 180 days. The tags record pressure (depth), light (geolocation) and water temperature at 60 s intervals and detach from the individual after 90 to 180 days.

8.1.3. Biopsy Sampling

Tissue biopsy samples (approx. 5 grams) of reef manta rays (*M. alfredi*) were collected on free-swimming individuals while free-diving in combination with the tags deployment using a customised spear pole. Samples were stored in 95% ethanol for genetic analyses.

8.1.4. Photo ID

When possible photographs of the unique ventral spot pattern were taken while free-diving using a Canon G10 camera. For each photograph, the name of the photographer, location and date of image capture were recorded. Only good-quality photographs with a clear image of at least the abdominal and inter-branchial areas were used for identification (see Fig. A4.1). Anthropogenic and predatory wound marks were also noted when observed to assess the level of human related threats and natural predation. Although most manta rays were identified using several photographs from the same sighting event, a single photograph of an individual was considered sufficient for positive identification when the entire ventral side of the body was clearly visible. The sex of individuals was determined by the presence or absence of claspers when the pelvic fins of the animal were clearly apparent on the photographs. Images were matched visually against both the Chagos Archipelago and Maldives databases.

8.2 Preliminary Results

Three full day surveys have been conducted in Egmont Atoll between February 16th and 19th. Due to rough sea conditions no surveys were possible on the 18th. Two further half day surveys have been carried in Diego Garcia with permission and RHIB support from BIOT Royal Navy Force. Most mantas were sighted on the north western side of Egmont Atoll in contrast to what was expected based on 2015 tagging results (see Appendix Fig. A4.2 and A4.3).

All four miniPAT and two acoustic tags were successfully deployed on juvenile and mature females in Egmont Atoll. Males could not be tagged due to the lack of sightings. Future expeditions should focus on deploying tags (SPOT, miniPAT and acoustic) on males to investigate the possibility of behavioural, site fidelity or movements variations between sexes. Of the four miniPAT tags, two were set to release after 90 days, and two after 180 days. The acoustic transducers will provide data on site fidelity and habitat utilisation thanks to the extensive acoustic array established over the years by consortium members (see Appendix image 4 for a detailed map of the current acoustic array).

A total of 9 new individuals have been photographed and successfully added to the BIOT ID database bringing the total number of individuals identified in the archipelago to 53. No individuals were re-sighted suggesting that a much higher number of mantas might present in the region. Interestingly, one of the individuals identified on the first surveying day had an old acoustic transmitter (from 2015) implanted on the dorsal musculature (see Appendix Fig. A4.5), evidence of the little impact that tagging has on these animals.
One tissue biopsy sample was also successfully collected off one of the tagged females and stored in 95% ethanol for genetic analyses.

The relatively small size of Egmont Atoll provides ideal conditions to study manta rays' habitat in fine details and obtain detail topography, current movement, DSL diel migration and other physical oceanographic data in order to

identify the drivers of mantas' small scale movements and highlight the factors contributing to high zooplankton concentration in the region upon which manta rays feed.
Throughout the four surveying days in Egmont detailed bathymetry of the northern reef crest was obtained by our colleagues of St. Andrews University using a Multibeam. To further investigate current circulation, plankton composition and water stratification along the reef crest of Egmont a mooring holding CTD, ADCP, Holocam and various T-sensors was deployed by our colleagues of Plymouth University. Data are currently being analysed and will provide insights into the water dynamics and properties at Egmont Atoll which are ultimately responsible for mantas' prey distribution and thus key to understand manta rays' movements.

Due to its small size, accessibility and consistency of manta ray sightings, Egmont Atoll proves to be an ideal location for a dedicated long term (1-2 weeks) land based project focusing on extensive tagging, collection of population structure data through photo-ID and tissue biopsy sampling for genetic and isotopic analyses. Longer term acoustic and oceanographic data using eco-sounder (EK60), moored CTD and ADCP would also be possible allowing a better understanding of the dynamics and features responsible for the high plankton densities observed in and along the reef crest of the atoll.

To date there is still a lack of knowledge on mantas' prey composition. We suggest thus, for future expeditions, to carry out consistent horizontal plankton tows and sampling at feeding sites when mantas are both present and absent as well as at sites not regularly visited by manta rays. The use of a custom design manta tow board to carry out in water visual surveys along the reef could be used to locate mantas feeding as well as cruising below the surface as well as locating cleaning stations,which are known to be generally found along reef crests at depth ranging between 5-25 meters. This survey methodology has been successfully adopted by various Manta Trust projects in different countries.

A drone flown from the RIB has been successfully adopted to locate and follow individual manta rays during the surveys in Egmont Atoll and the footages are currently being analysed to get measurements of the mantas filmed (e.g. wingspan). We suggest to continue and increase the employment of remotely operated drones to carry aerial surveys as well as collect morphometric measurements of the animals.

9. Ornithology

9.1. Introduction

The third pelagic expedition to the BIOT Marine Reserve afforded the opportunity to refine multi-disciplinary research techniques in to the associations between oceanographic phenomena, marine biological processes and the use of the reserve by feeding and foraging seabirds. It has long been known that tropical seabirds are incapable of the deep-diving feeding techniques of their northern and southern-ocean counterparts and are reliant upon subsurface predators driving prey to the surface for food (Au and Pitman 1986a). What is far less clear, particularly in a marine ecosystem such as the BIOT Marine Reserve, where small-scale, oceanographic and topographic features are only beginning to be researched and understood, is how these localised factors influence the feeding associations between trophic levels. To understand these "drivers" of the BIOT Marine Reserve will afford a better position to assess the efficacy of the newly created marine reserve – the overarching research aim of the expeditions.

<u>Objectives</u>

The specific objective of the marine ornithologist on the expedition was to conduct scientifically robust and repeatable censuses of seabirds at sea in the CMR. The secondary objective was to assist in refining multi-disciplinary research techniques into understanding the subsurface influences upon the feeding and foraging strategies of the seabirds present in the CMR at that period in time.

9.2. Method

Protocols for counting seabirds at sea followed Tasker (1984) with slight variations to accommodate ship's routines, the concurrent multi-disciplinary scientific activities occurring aboard and meteorological conditions. Counts were undertaken from the bridge-wing (9m asl.), observing a 180° arc forward of the vessel. All birds noted within a 30-minute period, out to approximately 300m were logged. The time, longitude and latitude were recorded (from the ship's Furuno 213S radar) at the start and finish of each transect. In addition, all seabird feeding aggregations witnessed throughout the expedition had their location, species composition and numbers present recorded and, if possible, what marine predators were being associated with noted. All sightings of marine mammals, cetaceans and dragonflies (at sea) were recorded.

In addition to the standard seabird at sea counting technique from the mothercraft, at the latter end of the expedition forays were made by a multi-disciplinary (ornithological, oceanographic and marine biology) team to attempt a coordinated census of a seamount using a suite of subsurface monitoring equipment and above water counts of seabirds.

9.3. Preliminary results

A total of 132, 30 minute transects were censused, recording 5178 birds of 17 seabird species. A species' list is at Appendix 5. In addition, 31 feeding aggregations were sighted holding an estimated 7093 birds of nine species. All feeding aggregations were associated with subsurface predators dominated by (small) tuna species. One new species of seabird for BIOT was identified and photographed in the Small Boat's Basin of Diego Garcia, a Lesser Black-backed Gull *Larus fuscus*. One dragonfly (Odonata) was recorded at sea, the not unexpected Globe Skimmer *Pantela flavescens*.

There were six sightings of cetaceans during the expedition involving *c*. 300 animals of two species, bottlenose (*Tursiops aduncus*) and spinner dolphins (*Stenella longirostris*). These were sightings of pods in areas where they are known to occur regularly, namely inside the lagoons of Diego Garcia, Peros Banhos and the Salomons and, in the vicinity of Victory Bank.

Continued analysis of pelagic seabird data from BIOT is confirming that there is certainly a "near-obligate association" (Au and Pitman 1986b) between the breeding seabirds both in terms of species richness and abundance and subsurface predatory tuna and associated species. Preliminary analysis also suggest these associations are mainly occurring, but are not restricted to, on or around marine features such as banks and seamounts. Further multi-disciplinary research into this phenomenon is desirable to better comprehend the subsurface drivers of these occurrences (possibly leading to a better understanding of the value of the BIOT Marine Reserve). The understanding of the seasonality of such phenomena is also desirable. Tracking of breeding seabirds within BIOT is recommended, and is integrated into the overall scientific research plan as sentinel species. This is in order to ascertain the comprehensiveness of the coverage achieved by recording seabirds at sea from a multi-disciplinary research vessel, and whether it is capturing the true "biological hot-spots" of the reserve.

The occurrence of Lesser Black-backed Gull in BIOT CMR (Fig. A5.1) is not unexpected and requires monitoring. Whilst more pelagic than some other species of Laridae, they are known to feed and forage on land and are attracted to refuse dumps in particular. The positive identification of this species brings the total number of avian species recorded in BIOT to 124.

10. Daily activities

Date	location	Lat	Lon	Activity Pacific Marlin	Plankton net	mid-water BRUVS	ADCP	EK60	CTD	ROV	Towed body	Drifters	Mantas tagged
01/02/16	Bahrain			TBL+PC Fly UK to Bahrain									
02/02/16	Diego Garcia			TBL+PC arrive DG									
03/02/16	Diego Garcia			PreExped preparation									
04/02/16	Diego Garcia			Arrival ALL PAX									
05/02/16	Diego Garcia			Mobilisation - sail asap									
06/02/16	Diego Garcia	-7.14	72.195	Depart for Swart at 1600									
07/02/16	Seamount Site 1 (Swartz)	-7.14	72.195	Daily activity+Transit (Transect 1)	1	10	yes	yes					
08/02/16	Transect WPA-B-C			Transit							yes		
09/02/16	Salomon (oceanic)	-5.45	72.36	Daily activity	1	20	yes	yes	1			4	
10/02/16	Salomon (oceanic)	-5.45	72.36	Daily activity	1	20	yes	yes	1				
11/02/16	Contingency day (PB)	NA	NA	NA+poss manta tagging						1	Calibration		
12/02/16	Seamount (Perhos Banhos)	-5.354	71.3	Daily activity	1	10	yes	yes	1		yes	1	
13/02/16	Seamount (Perhos Banhos)	-5.354	71.3	Daily activity +transect into the middle	1	20	yes	yes	1				
14/02/16	NorthW to SouthE	-6.402	70.83	GCB Transect -recover early as weather deteriorate							yes		
15/02/16	Great Chagos Bank			Adverse weather sail to Egmont for shelter								1	
16/02/16	Egmont (lagoon)	-6.63318	71.33496	Manta tagging+ multibeam surveys	1	20			1	1			3
17/02/16	Egmont (lagoon)	-6.63318	71.33496	Adverse weather									
18/02/16	Egmont (lagoon)	-6.63318	71.33496	Manta tagging+ multibeam surveys	1	20			1				
19/02/16	Egmont (lagoon)	-6.63318	71.33496	Manta tagging+ multibeam surveys									3
20/02/16	Great Chagos Bank	-6.239	72.037	Daily activity	1	20		yes	1		yes		
21/02/16	Seamount Site 2 (Sandes)	-7.146	72.125	Daily activity	2	20	yes	yes	1				
22/02/16	Contingency day (Swartz)	-7.14	72.195	Oceanography mooring recovery									
23/02/16	Diego Garcia (demob)			Demobilisation									
24/02/16	Diego Garcia (depart)			Return flight delayed for 24 hrs									
01/03/16	Diego Garcia (depart)			All Pax leave DG									

11. Reference

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APPENDIX

Appendix #1

Table A1.1. Transducer properties. TB – Towed body.

mount	name	Serial number	Frequency (kHz)	Power (W)	EBA (steradians)	Pulse duration (ms)	Gain (dB re $1m^{-1}$)	Sa	Angle sensitivity along (degrees)	Angle sensitivity athwart (degrees)	3 dB beam width along (deg)	3 dB beam width athwart (deg)	Angle offset along (deg)	Angle offset athwart (deg)
pole	ES 38-12	38	38	1000	-16.2	1.024	21.5	0	12.5	12.5	11.9	11.9	0	0
pole	ES120-7	120	120	500	-20.7	1.024	25.7	0	21	21	6.9	7.0	0	0
TB	ES 38B	28218	38	1000	-21.0	1.024	26.5	0	21.90	21.90	6.7	6.8	0	0
TB	ES120-7DD	27381	120	500	-20.9	1.024	25.1	0	21	21	7	6.8	0	0
TB	ES200-7C	254	200	150	-20.8	1.024	27	0	23	23	6.9	6.9	0	0

Table A1.2. Calibration settings

Variable	value
temperature (degrees)	29.17
salinity (ppt)	34.2
sound speed (ms^{-1})	1542.81
38 kHz target strength (dB re $1m^{-1}$)	-42.279
120 kHz target strength (dB re $1m^{-1}$)	-40.116
200 kHz target strength (dB re $1m^{-1}$)	-38.89
pulse duration (ms)	1.024
depth range (m)	10 - 15

Table A1.3. Calibration results

mount	name	Frequency (kHz)	Gain	Sa	Athwart beam angle	Along beam angle	Athwart offset	Along offset	RMS beam model	RMS poly model
pole	ES 38-12	38	TBA	TBA	TBA	TBA	TBA	TBA	TBA	TBA
pole	ES120-7	120	TBA	TBA	TBA	TBA	TBA	TBA	TBA	TBA
TB	ES 38B	38	26.09	-0.69	6.81	6.85	-0.07	-0.02	0.31	0.27
TB	ES120-7G	120	24.48	-0.38	6.94	6.94	-0.02	0.17	0.13	0.12
TB	ES200-7C	200	24.76	-0.24	6.79	6.77	0.03	-0.05	0.14	0.12

Appendix #2

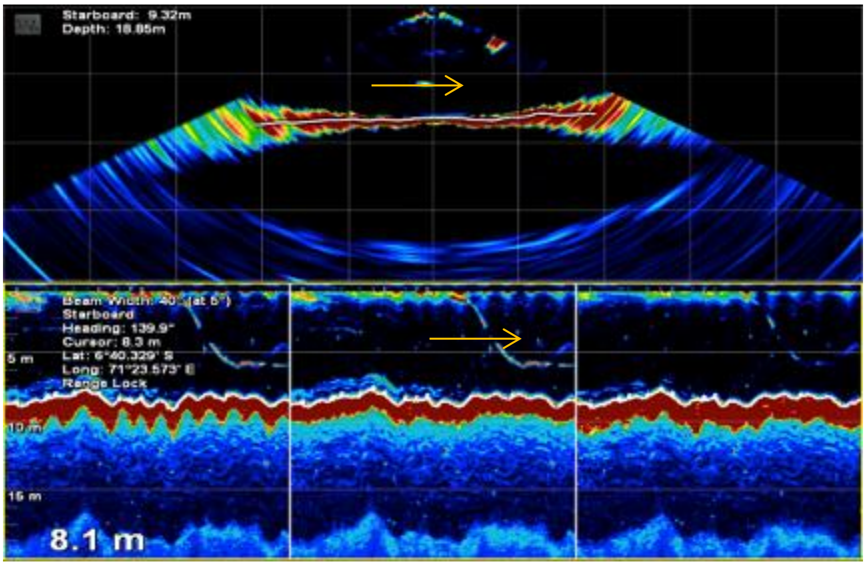
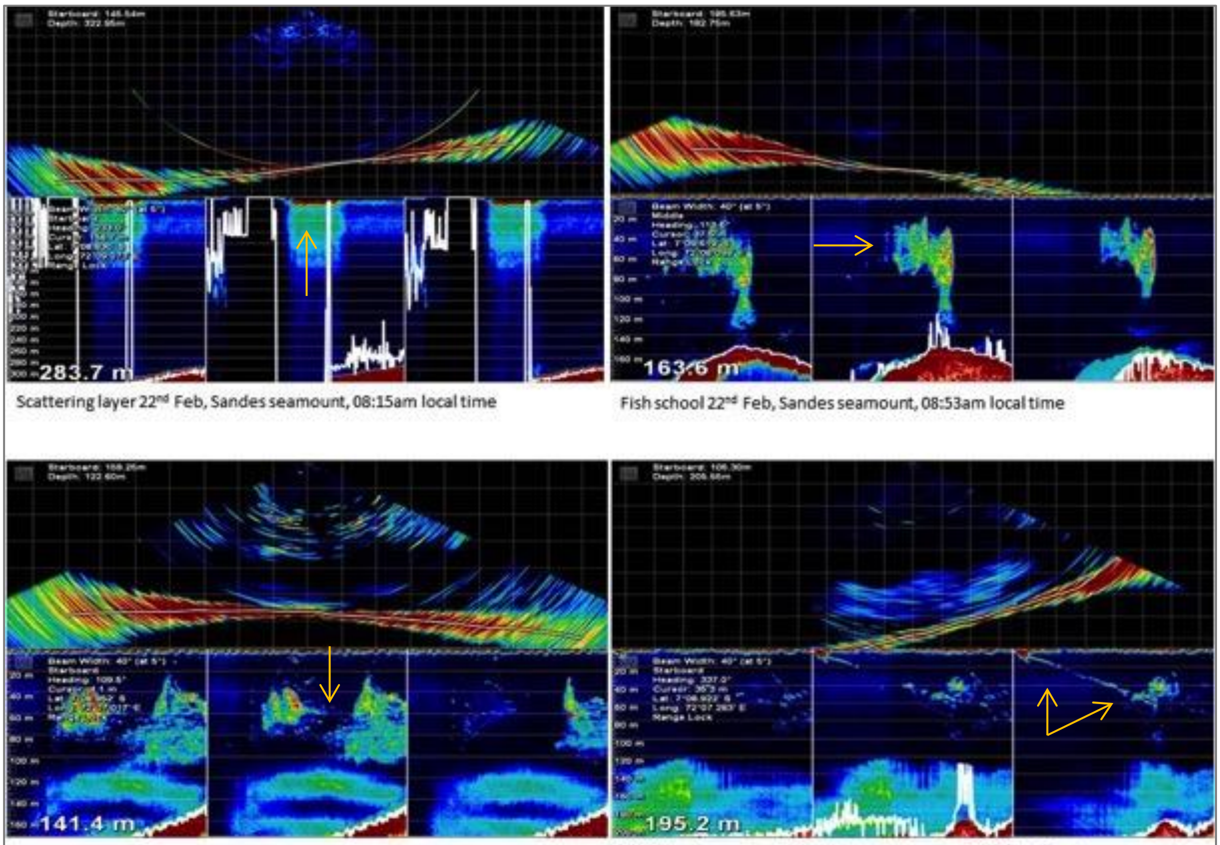


Fig. A2.1. Calibration 18th Feb, Egmont Islands: Upper sonar display showing the sphere, lower (echogram view) sonar display shows the track of the sphere over time.



Scattering layer 22nd Feb, Sandes seamount, 08:15am local time

Fish school 22nd Feb, Sandes seamount, 08:53am local time

Fish school 22nd Feb, Sandes seamount, 09:28am local time

BRUV deployment and single targets on sonar, 22nd Feb, Sandes seamount, 09:53 local time

Fig. A2.2. Display of scattering layer, fish schools and BRUV deployment during multibeam circular survey around Sandes seamount, 22nd Feb.

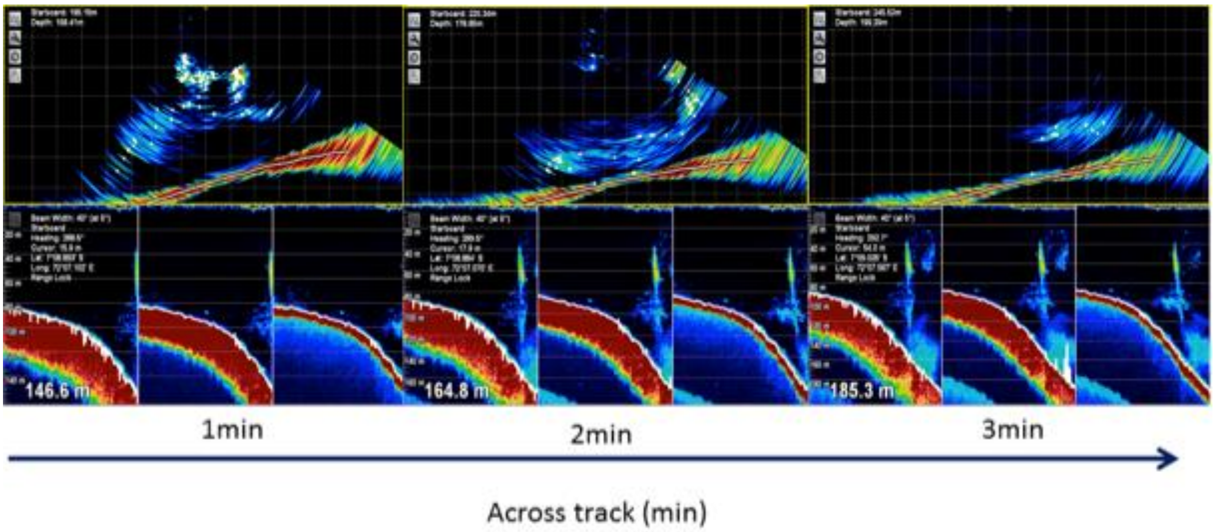


Fig. A2.3. Example of a fish school shown on sonar display (upper display) and corresponding echogram view (lower display) over time.

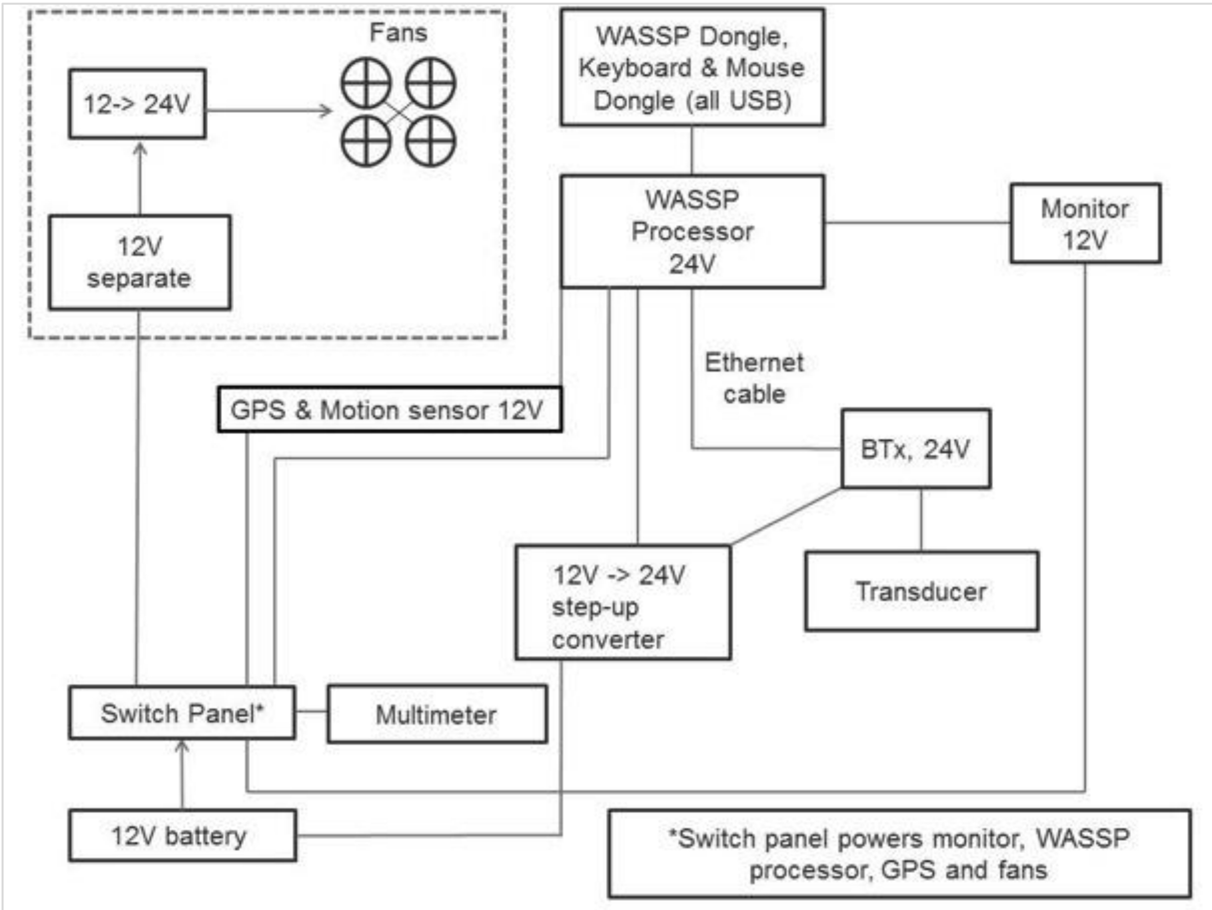


Fig. A2.4. Overview of the electronic setup of the WASSP multibeam sonar system.

Appendix #3

Oceanographic mooring set up

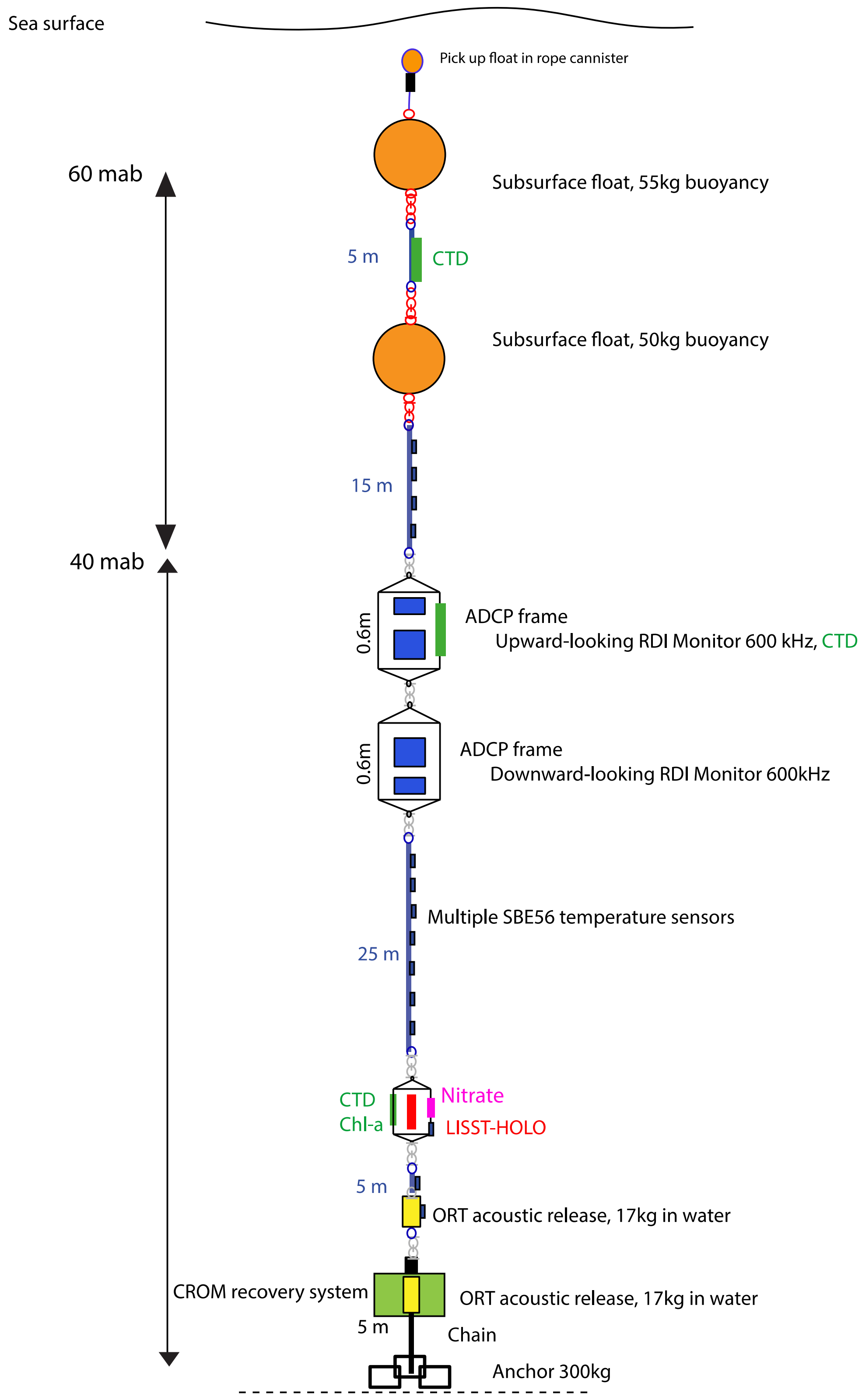


Fig. A3.1. Schematic of mooring deployed over Swart Seamount summit.

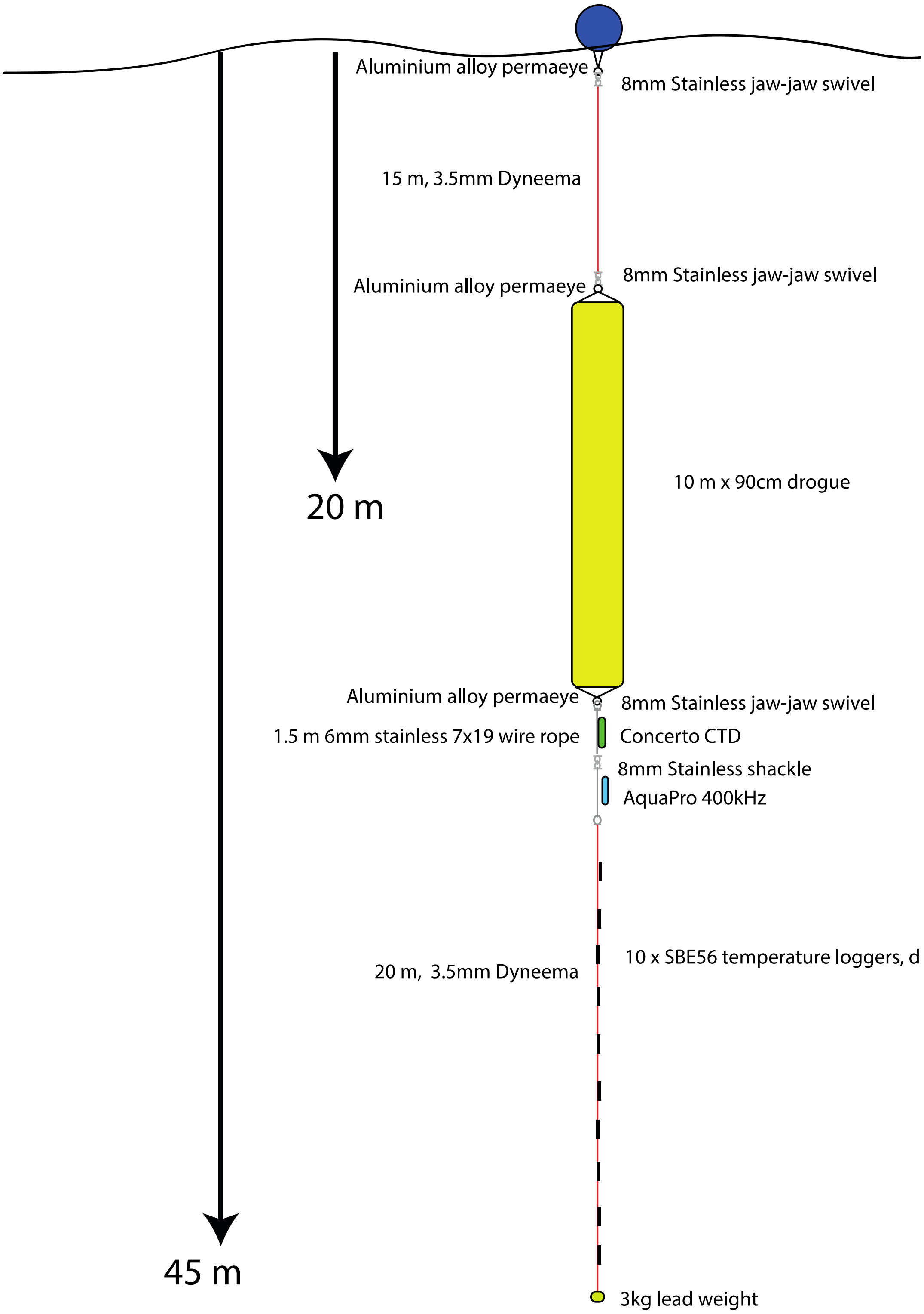


Fig. A3.2. Schematic of instrumented drifter deployed at multiple locations during the Expedition.

Table A3.1 List of sensors and their respective positions on the Swart Seamount mooring

Sensor/Component	Serial Number	Height (mab)	Variable
SBE 56	5879	58.95	T
Concerto CTD	60252	56.55	S, T, P
SBE 56	5878	54.85	T
SBE 56	5877	52.85	T
SBE 56	5876	50.65	T
SBE 56	5875	48.65	T
SBE 56	5874	46.65	T
SBE 56	5873	44.65	T
SBE 56	5871	42.65	T
Concerto CTD + Chl-a	65753	40.4	S, T, P, Chl-a
RDI 600 kHz ADCP	11193	40.4	U, V, W, Backscatter
SBE 56	5870	40.4	T
RDI 600 kHz ADCP	1517	38.75	U, V, W, Backscatter
SBE 56	5869	38.75	T
SBE 56	5868	36.5	T
SBE 56	5867	34.5	T
SBE 56	5866	32.5	T
SBE 56	5865	30.5	T
SBE 56	5864	28.5	T
SBE 56	5863	26.5	T
SBE 56	5862	24.5	T
SBE 56	5861	22.5	T
SBE 56	5860	20.5	T
SBE 56	5857	18.5	T
SBE 56	5859	16.5	T
SBE 56	5858	14.5	T
SBE 56	5856	12.5	T
SBE 56	5855	10.5	T
SBE 56	5854	9.5	T
LISST-Holo			Particles
Concerto CTD + Chl-a	65754		S, T, P, Chl-a
Nitrate sensor	70F1		NO_3
SBE 56	5853	8.55	T
SBE 56	5852	7.15	T
SBE 56	5851	6.15	T
SBE 56	5850	5.15	T
SBE 56	5841	4.15	T
ORT	073	3.5	
ORT + CROM	072	2.5	
Anchor		0	

Appendix #4

Fig. A4.1. Example of a photo ID image showing the spot pattern primary and secondary ID areas (respectively the inter-branchial and abdominal region). The pelvic region, just below the abdominal, allows sex determination (presence/absence of claspers). The individual in the below image is an immature female (no reproductive wounds observed and lack of claspers).

Fig. A4.2. During the 2015 pelagic expeditions the Manta Trust successfully tagged 5 reef mantas in Egmont with smart position or temperature transmitting (SPOT) tags. The image below shows Kernel densities and pings location in Egmont Atoll region. Note the high density of pings on the eastern region of the lagoon which contradicts this year's observation of mantas found mostly on the opposite end of the lagoon (see Fig. A5.3)

Fig A4.3. Reef manta rays' sightings locations during the 3 days survey period in Egmont Atoll (yellow stars) and during the 2015 Pelagic Expedition (red star).

All sightings were recorded along the north-north-western area of Egmont Lagoon, similarly to what observed during the 2015 pelagic expedition (se red star). Curiously though, SPOT tag data from 2015 show a higher density of mantas on the western side of the lagoon. The difference between these results may be due to small sample size. Only a few visual surveys have been conducted during the past two expeditions while satellite data are representative of over one month of manta rays presence in the lagoon.

Most mantas observed inside the lagoon of Egmont were juvenile and sub-adult individuals while mantas sighted cruising and feeding along the northern reef drop-off were all mature. This is in line with findings in other regions such as the Maldives shallow lagoons act as nursery grounds (Stevens, pers. comm.). The shallow waters of wide lagoons such as Egmont provide a safe environment where the large mantas' predators such as tiger sharks and false killer whales don't occur. Adult individuals are more prone to leave the safe environment of the lagoon and venture into deeper water probably seeking more reliable food source. Further telemetry and photo-ID data is necessary to investigate behavioural differences between juvenile and adult individuals as well as between the sexes.

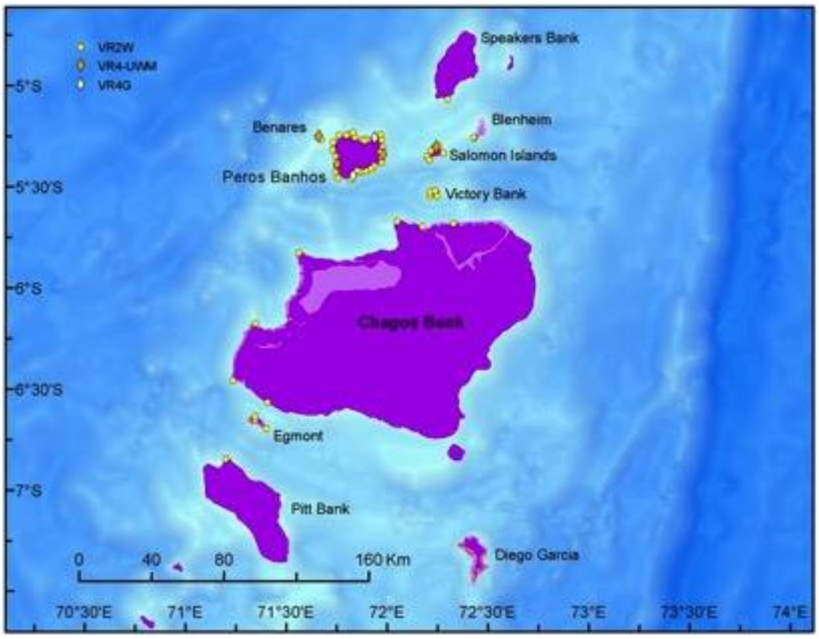


Fig. A4.4. Acoustic array currently present in BIOT.

Fig. A4.5. Previously tagged manta sighted on the first survey day in Egmont Lagoon. Note the acoustic transmitter still attached to the dorsal musculature of the manta.

The limited amount of metadata (See Table A5. 1 below) does not allow to infer any conclusion on possible correlations between manta ray presence and environmental variables such as tidal cycle, wind speed and direction, time of the day. Throughout the three survey days most mantas were sighted in the morning (as observed in similar shallow lagoons in the Maldives). It is a possibility that Egmont Lagoon acts as a barrier to the diel migration of the zooplankton found in the DSL when organisms try to migrate into deeper waters in the morning making this the best time for manta rays to target their prey in shallow waters. Investigating the planktonic composition of Egmont Atoll might help investigate such possibility.

Table A4.1. Survey record including various metadata collected throughout the surveys. Note that confirmed number of individuals refers to the total number of manta rays identified through photo-ID. Since priority was given to tag deployment not all individual sighted were able to be photo-identified.

Weather Conditions (1-6)	Wind/Sea State (Beaufort Scale 0-12)	Wind Direction (NESW)	Water Visibility (Metres)	Current Direction (In or Out Atoll)	Current Strength (0-3)	Plankton Density (0-5)	Data Entered By?	Comments (more specific notes on mantas feeding, courtship behaviour, environmental conditons, type of plankton, etc.)
2	3	NW	10-15m	N/A	1	1	Niv	3 mantas at first on the eastern inner edge, 2 more later (1 tagged), 6 together feeding in chain in the middle of the lagoon (1 with old acoustic tag) - 2 tagged (1 acoustic, 1 pop-up). Mostly arrow worms in the water. Tags deployed: 1207112 (acoustic on mature female), 13P0060 (pop-up on female no ID),
2	4	NW	10-15m	N/A			Niv	Much rougher in the lagoon, no mantas sighted
2	4	NW	15-20m	N/A			Niv	Extremely rough sea, plume of sand washing out from Egmont in SE direction making the water extremely murky.
2	5	NW	15-20m	N/A			Niv	Extremely rough sea, plume of sand washing out from Egmont in SE direction making the water extremely murky. One manta spotted toward the end on the outer reef (north east side) briefly at the surface but disappeared before
1	2	W	20-25m	N/A	2	1	Niv	Mantas feeding at the north western end of the lagoon along bommies and inner reef edge. Peak early morning then current changed. Plume still present in the centre and east end of the lagoon. Two tags deployied: 1207114 -
1	2	SW	20-25m	N/A	1	1	Niv	Towing on the north western outer reef, 2 mantas spotted moving along the outer reef swimming west (one male!). Later one manta barrel rolling on the outer reef (north western edge) close to the plume. Another one swam by
1	1	NW	10-15m	N/A	0	0	Niv	Surveyed the entire southern part of DG lagoon focusing on the areas where mantas have been previously reported by BIOT and previous expedition. No
1	1	NW	20-25m	In	1	0	Niv	Two RIBs surveyed the northern part of the lagoon but no mantas were sighted by either boat. A snorkel check was done on the corner of the north-western channel to look for possible cleaning stations. No mantas sighted, a few grey reef sharks and many groupers. Site to be further explored with outgoing

Dive/Snorkel Site	Sighting Date	Start Time (in water)	Finish Time (out water)	Peak Manta Encounter Time	Researcher/Observer (on the trip/survey)	ID Images Taken (Y/N)	Manta Encounter Duration (min)	Approx Number of Mantas Seen	Confirmed Number of Sightings	Manta Breaches
Egmont Lagoon	16/02/2016	09:00	11:30	10:00-11:00	Niv, Rob, John, Lilian, Phil, Andy, Roland, Sian	Y	60	10	8	0
Egmont Lagoon	16/02/2016	14:30	16:40	N/A	Niv, Rob, Andy, Sian	N	0	0	0	0
Egmont Lagoon	18/02/2016	08:30	11:30	N/A	Niv, Rob, Andy, Lilian, Roland	N	0	0	0	0
Egmont Lagoon	18/02/2016	14:30	17:45	17:15	Niv, Rob, Andy, Lilian, Roland	N	0	1	0	0
Egmont Lagoon	19/02/2016	08:30	11:30	08:30-09:30	Niv, Rob, Alex, Pete	Y	60	5	1	0
Egmont Lagoon	19/02/2016	14:15	17:15	16:00-17:00	Niv, Rob, Tom, Sian & Margiorie	N	10	4	0	0
Diego Garcia	25/02/2016	13:00	16:15	N/A	Niv, Rob, Zosia, Jem, Tom, Marj	N	0	0	0	0
Diego Garcia	29/02/2016	09:30	13:20	N/A	Niv, Rob, Phil, Andy, Sian, Jem, Marj, Zosia	N	0	0	0	0

Appendix #5

Table A5 Species list

SPECIES	COMMENT
Bulwer's Petrel *Bulweria bulwerii*	Now confirmed as a regular northern hemisphere winter visitor to BIOT CMR
Wedge-tailed Shearwater *Puffinus pacificus*	
Tropical Shearwater *Puffinus bailloni*	
Red-tailed Tropicbird *Phaethon rubricauda*	Limited to very few breeding pairs in the CMR found only on Diego Garcia, this was a very rare sighting at sea
White-tailed Tropicbird *Phaethon lepturus*	
Greater Frigatebird *Fregata minor*	
Lesser Frigatebird *Fregata ariel*	
Red-footed Booby *Sula sula*	
Brown Booby *Sula leucogaster*	
Great Crested Tern *Sterna bergii*	
Black-naped Tern *Sterna sumatrana*	A species restricted to near islands and inside lagoons
Bridled Tern *Onychoprion anaethetus*	
Sooty Tern *Onychoprion fuscatus*	
Brown Noddy *Anous stolidus*	
Lesser Noddy *Anous tenuirostris*	
Common White Tern *Gygis alba*	
Lesser Black-backed Gull *Larus fuscus*	First confirmed record for BIOT

Fig. A5.1. Lesser Black-backed Gull: a species new to the BIOT CMR