A fish-eye view of the importance of sharks in tropical marine ecosystems

PCI Expedition I Report

31 March 2015

Acknowledgments

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Executive summary

In April 2010, the United Kingdom declared the British Indian Ocean Territory (BIOT) as a fully protected no-take marine reserve (640,000 km^2) and closed the international longline and purse seine fisheries previously operating in the area. In the absence fishing pressure, the reserve has great potential to promote the health of the entire BIOT ecosystem and protect globally threatened mobile vertebrates such as reef-associated sharks. Such protection is paramount due to the important role that predators play in regulating species dynamics in tropical environments. For instance, sharks have been shown to influence both the abundance and behaviour of their prey (themselves often medium-sized predators referred to as *mesopredators*), leading to "trophic cascades" that may ultimately transform entire food webs. How such cascades propagate through ecosystems is still poorly understood, largely because there are few locations worldwide where shark abundance varies but fish assemblages remain relatively intact. The no-take BIOT Marine Reserve is well suited to understanding whether illegal fishing is removing sufficient predators to create a spatial gradient of increasing shark abundance from the remote exposed atolls of the north to the southern waters surrounding the secure US military base at Diego Garcia. Questions around how sharks regulate fish assemblages and the degree to which declines in shark abundance are signalled in the fish community form the basis of the five-year science plan developed for the Foreign Commonwealth Office in January 2015 (Meeuwig and Meekan 2015). These questions were also central to the Chagos Science Consortium Research Plan (Gollock and Koldewey 2014) and were identified as a key priority within the BIOT Interim Conservation Management Framework (Compston 2014).

Between February 28th and March 20th 2015, we conducted the first research expedition of this programme on board the M/Y *Pangaea*. Activities were designed to understand the role that reef sharks play in regulating reef ecosystems and how they may impact the abundance, diet and condition of reef fishes. Ship time was provided by Outpost Expedition Pacific (OEP) Ltd. and the expedition was supported by a philanthropic gift from Teach Green to the University of Western Australia. The expedition documented the status of reef shark and fish assemblages using stereo-baited remote underwater video systems (stereo-BRUVS) and stereo-diver operated video systems (stereo-DOVS), acoustic tags, and tissue/fin sample collection for molecular analysis of mesopredator diversity and diet. We exclusively used non-destructive techniques, with sampling either based on video camera technology or catch-and-release methods. Favourable weather conditions and excellent facilities aboard the Pangaea allowed sampling to exceed targets. We deployed 247 stereo-BRUVS in waters adjacent to five atolls and islands with the aim of replicating, and expanding on, a 2012 survey carried out by Tickler *et al.* (2014). Comparison of the 2012 and 2015 surveys will allow us to detect temporal changes in shark and mesopredator numbers. Complementary DOVS surveys were conducted at 38 sites at the same atolls and islands to further understand the structure and behaviour of reef fishes with varying shark abundance, focusing on smaller reef species. Acoustic tagging of 30 two-spot red snapper (*Lutjanus bohar*) near the existing receiver arrays at Peros Banhos and Salomon atolls will provide rare insights into the movement patterns of one of the most abundant and important mesopredators on the reef, and how reef shark occurrence may affect its spatial behaviour. In addition to providing critical information on diet and habitat use, fin clips and tissues samples from 142 individuals of 20 species representing seven families will allow us to understand whether predation pressure is driving morphological divergence in different populations of fish, as evidenced in the variability of physical traits such as eye size.

Key achievements

1. Repeated the 2012 shark and fish surveys using stereo-BRUVS, allowing assessment of changes in assemblages through time.

2. Acoustically tagged 30 two-spot red snappers, an important mesopredator species, at the Peros Banhos and Salomon atolls.

3. Completed the first collection of tissue samples for genetic and isotopic analysis to detect variation in fish genetic diversity, diet and habitat use in relation to shark abundance.

1. Introduction

The British Indian Ocean Territory (BIOT), which encompasses the Chagos Archipelago, was designated a fully protected no-take marine reserve in April 2010, with the exception of the area proximate to the southernmost atoll of Diego Garcia. The territory's exclusive economic zone (EEZ) covers approximately 640,000 km^2, of which nearly 10% is comprised of coral atolls and banks (Sheppard 2012). The establishment of the BIOT Marine Reserve led to the closure of international longline and purse seine fisheries that predominantly targeted yellowfin (*Thunnus albacares*), skipjack (*Katsuwonus pelamis*), and bigeye tuna (*Thunnus obesus*), with reef-associated sharks also caught incidentally (Koldewey *et al.* 2010).

Even as populations of sharks dwindle globally, essential questions about their role in oceanic ecosystems remain unanswered. There is evidence that sharks, like other apex predators, influence trophodynamics both directly through prey consumption and indirectly by altering prey behaviour and distribution (Britten *et al.* 2014). In the presence of predators, prey may conform to an "ecology of fear" whereby foraging less, avoiding risky habitats and switching to poorer quality food become prevailing strategies to reduce short-term risk but at the expense of long-term fitness gains (Lima and Dill 1990; Werner and Peacor 2003; Clinchy *et al.* 2013). In contrast when predators are removed, prey mortality declines and secondary consumers consequently thrive. This phenomenon is known as "mesopredator release" (Estes *et al.* 2011; Ruppert *et al.* 2013), and may have substantial effects on ecosystem structure (Myers *et al.* 2007; Ritchie and Johnson 2009) as species shifts spiral down the food web, affecting all lower trophic levels. While the impacts of changes in mesopredator abundance are documented, risk effects are more subtle, harder to observe and have only been recognized as important and pervasive in recent times (Schmitz *et al.* 2004; Heithaus *et al.* 2008; Wirsing *et al.* 2008).

The BIOT Marine Reserve offers a tremendous opportunity to address these issues and generate much-needed quantitative data on the effectiveness of marine reserves as well as the consequences of illegal, unregulated and unreported (IUU) fishing. Historically, commercial fishing in the waters now occupied by the BIOT marine reserve has created an ecological gradient of shark abundance that continues to be reinforced to this day by illegal fishing practices. This constitutes a large-scale "natural" experiment that can be mined for information relating to the impact of shark predation on mesopredator diversity, abundance, size, biomass, diet and genetic divergence. There is increasing consensus that such large-scale approaches (Friedlander and Parrish 1998; Madin *et al.* 2010; Ruppert *et al.* 2013) are the only robust way to test ecological hypotheses as localised manipulative studies have produced conflicting results (Carpenter 1990; Knowlton 1992; Schindler 1998).

In order to explore the regulation of fish assemblages by sharks in the reserve, a team of scientists from The University of Western Australia (UWA), Macquarie University and the Australian Institute of Marine Science (AIMS) travelled to the BIOT Marine Reserve in the first quarter of 2015. In the presence of sharks, we expected lower abundance and biomass of mesopredators and higher abundance and biomass of their own prey. Ruppert *et al.* (2013) reported similar trends on the north-western shelf of Australia (eastern Indian Ocean), where they contrasted a highly protected but small marine reserve with an area that remains open to traditional shark fishing, and showed sharp differences in shark abundance between the two locations. Our analysis of the BIOT marine reserve will provide an important opportunity to determine the generality of Ruppert *et al.* (2013)'s results in an independent location.

This research will also directly benefit the managers of BIOT by shedding light on the ecological impacts of IUU fishing beyond reduced shark numbers. Such information underpins decision-making under growing demands for fish protein around the Indian Ocean Rim and will support optimal allocation of often restricted financial resources available for spatial enforcement. Promising new technology will aid in the identification of IUU fishing[1] and the monitoring of its ecological impacts in the context of populations recovering from historical fishing. Improved recognition of the vital importance of healthy shark populations for ecosystem health will also help mobilise the resources required for enforcement.

The team deployed stereo-BRUVS, conducted stereo-DOV surveys along reef transects, acoustically tagged two-spot red snappers and non-destructively took fin and tissue samples for genetic and isotopic analysis. The research concentrated in locations where previous stereo-BRUVS surveys and diver transects had occurred and where acoustic arrays are in place (Figure 1). The expedition included six scientists from three organisations (Table 1).

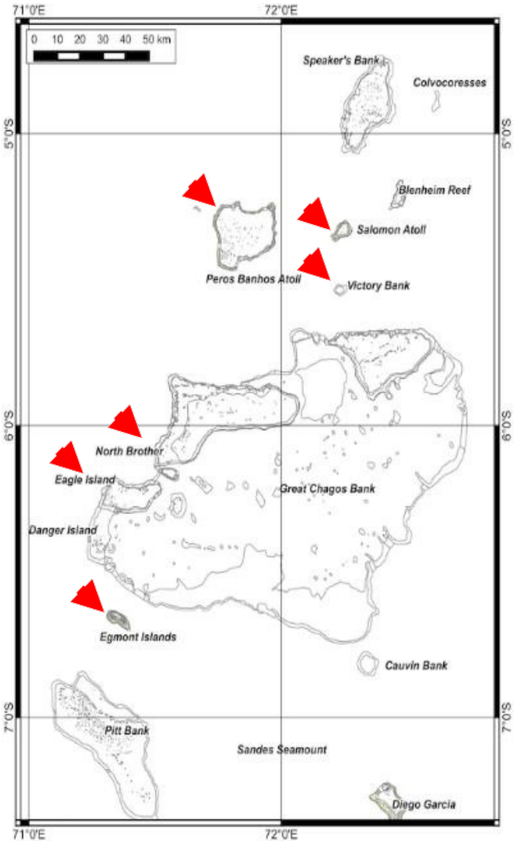

Figure 1: *Location of study sites in the BIOT Marine Reserve*

This expedition was supported through a philanthropic gift from The Teach Green Foundation to the University of Western Australia with ship time on the M/Y *Pangaea* provided by OCS. The BIOT administration and the UK FCO provided permits and logistical support.

Here we report on the results of the first expedition on the M/Y *Pangaea* to the BIOT Marine Reserve. Individual report sections contain background and preliminary results from the field. Sample processing will take approximately one year with the results to be reported on completion of that processing.

2. Objectives, strategies and participants

The following expedition objectives were identified:

1) Quantify the relative? density and biomass of sharks and reef-associated fishes using stereo-BRUVS and stereo-DOVS.
2) Describe the spatio-temporal distribution and movements of mesopredators using acoustic telemetry in order to understand the effects of shark abundance on their behaviour.
3) Identify the diets and condition of reef fishes using stable isotope and morphometric analysis as indicators of the status of shark populations.

[1] http://www.pewtrusts.org/en/research-and-analysis/fact-sheets/2015/01/virtual-watch-room

4) Determine connectivity among sharks and mesopredators using genetic kinship analysis to understand resilience to shark removal.
5) Develop metrics that indicate the status of reef shark populations and signal the scale of illegal fishing.

The overarching goal of our research is to improve our understanding of the role that sharks play in maintaining healthy coral reef ecosystems. This objective directly supports Action 1b of the BIOT Interim Conservation Management Framework ("monitor status of reef sharks and fish assemblages to evaluate the impact of no-take and IUU controls, in a range of representative habitats") and contributes to refining enforcement activities by identifying locations exhibiting signs of shark removal (Compston 2014). It also links strongly to the objectives of the Geneva Workshop, such as objective 2: "monitor key species, habitats and environmental parameter" and objective 4: "establish the resilience of the BIOT Marine Reserve's biodiversity and ecosystems" (Gollock and Koldewey 2014). Finally, the research builds on existing scientific infrastructure (i.e. the acoustic arrays installed at Peros Banhos and Salomon).

Based upon the previous experience of the expedition leader, it was decided that the overarching sampling strategy would be to follow a daily schedule with systematic replication of the key sampling activities (stereo-BRUVS, stereo-DOVS, catch-and-release sampling) with specific times dedicated to the acoustic tagging. A typical day of science on the M/Y *Pangaea* consisted of 20 stereo-BRUVS deployments carried out on the small catamaran, *I'm OK,* by two scientists, DOVS transects at 2-3 sites from *Speedball*, by a team of two scientists and three appropriately qualified crew members (including safety diver at the surface), and catch-and-release sampling by two scientists and three citizen scientists on the skiffs. Acoustic tagging was completed by three scientists on *I'm OK*. The responsible scientists are listed in Table 1.

Sampling was undertaken across six locations in the northern atolls and islands of the BIOT Marine Reserve: Egmont Island, Eagle Island, the Brothers Islands, Victory Bank, and Peros Banhos and Salomon atolls (Figure 1).

Table 1: Participants, their organisation and research activities.

Participants	Primary Research Activities
Professor Jessica Meeuwig, UWA	Expedition Leader / Stereo-BRUVS
Charlotte Birkmanis, PhD Candidate, UWA	Catch-and-Release sampling
Dr. Kate Lee, Macquarie University	Acoustic tagging
Dr. Mark Meekan, AIMS	Stereo-DOVS
Chris Thompson, UWA	Stereo-BRUVS
David Tickler, UWA	Stereo-DOVS
Todd Calitri, Pangaea	Catch-and-Release sampling
Andrew Parsons, Pangaea	Catch-and-Release sampling
Richard Schumann, Pangaea	Catch-and-Release sampling

3. Characterising Shark and Fish Assemblages with Stereo-BRUVS

Stereo-BRUVS are designed to provide quantitative measures of the diversity, relative abundance and size of marine wildlife, and is the preferred method for sharks and mesopredators (Watson *et al.* 2010; Bernard *et al.* 2014). Each rig consists of a tripod frame to which two GoPro small action cameras are fixed 70 cm apart on an inward convergent angle of 8 degrees (Figure 2), allowing for accurate measurements of body size. The camera mounts are integrated with a bait bag and deployed from a vessel to sit remotely on the seabed for a minimum of one hour prior to being recovered. The imagery collected by stereo-BRUVS allows us to identify individuals to species level, estimate their relative numbers, and individual body length. Data can be aggregated to determine assemblage attributes such as species richness, total abundance/size distribution, and total biomass (by converting fish length to fish weight). These metrics can also be calculated across different trophic levels, as appropriate. Stereo-BRUVS are a global standard for documenting the status of sharks and fish assemblages. Our sampling efforts in the BIOT Marine Reserve builds upon previous sampling in November 2012.

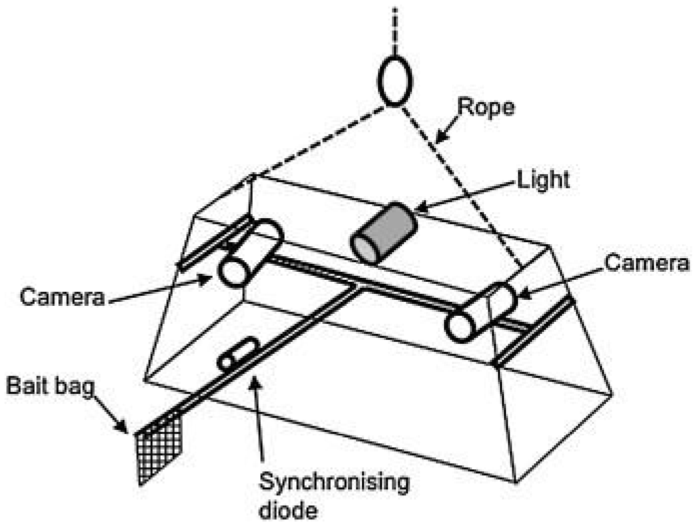

Figure 2: *Schematic of a stereo-BRUV*

<u>Objectives</u>

1) To describe the shark and fish assemblages in the lagoons of major atolls in the BIOT Marine Reserve in order to determine whether fish assemblage structure varies in terms of the number, size and behaviour of mesopredators and their prey in relation to the abundance of sharks.
2) To determine how the shark and fish assemblages in these lagoons have changed from March 2012, when the first stereo-BRUVS survey was completed; thereby beginning ongoing monitoring of the marine reserve.

3.1 Preliminary results

A total of 247 stereo-BRUVS deployments were completed during the Expedition (Table 2). In addition to resampling the 2012 locations (Figure 3), we completed additional sampling at 105 locations stratified by depth (12-20 m and 25-35 m) including a range of hard and soft bottom habitats. The balanced sampling design and high effort at each location enables characterisation of the fish assemblage in relation to shark abundance and the determination of changes through time.

Table 2: Number of samples (n) for stereo-BRUVS, by location.

Location	***n***
Eagle Island	20
Egmont Islands	24
Peros Banhos Atoll	140
Salomon Atoll	40
Three Brothers Islands	20
Total:	***244***

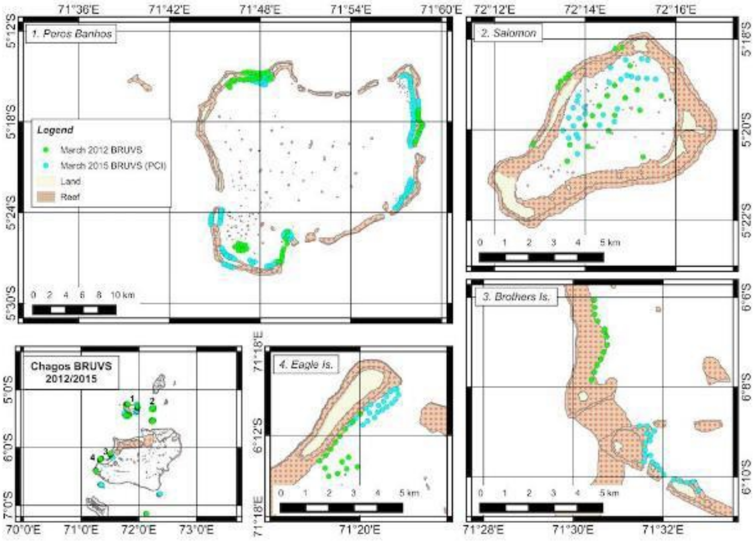

Figure 3: *Distribution of stereo-BRUVS stations in 2012 (green) and 2015 (blue).*

Preliminary review of stereo-BRUVS video footage revealed a similar suite of species as in 2012, including grey reef shark (*Carcharhinus amblyrhynchos*), mesopredators such as the two-spot red snapper, humpback red snapper (*Lutjanus gibbus*), bluefin trevally (*Caranx melampygus*), giant trevally (*Caranx ignobilis*), peppered moray eel (*Siderea picta*), and blacksaddled coral grouper (*Plectropomus laevis*), and prey species such as schooling fusiliers (*Caesonidae* spp.) and the night surgeonfish (*Acanthurus thompsoni*). Stereo-BRUVS also captured dense schools of baitfish that were frequently observed within the lagoons. Shark diversity appeared low relative to 2012, and individuals were small.

4. Characterising Shark and Fish Assemblages with Stereo-DOVS

Figure 4: *Operation of stereo-DOVS rig with mounted GoPros.*

Stereo diver operated video systems (stereo-DOVS) (Figure 4) are also used to sample fish assemblages on coral reefs. Analogous to the stereo-BRUVS, the camera mounts are integrated into a lightweight frame. However, unlike stereo-BRUVS, stereo-DOVS are unbaited and are operated by a diver, swimming slowly (0.3 m sec^{-1}) along a transect, approximately 70 cm above the substrate. The standard method has the divers surveying five 50 x 2 m-meter transects at each site with transects separated by an approximately 10 m distance. Each transect is swum twice, the first time for larger, more mobile species and the second pass for smaller cryptic species, with the stereo-DOVS rig pointed towards the seabed. Stereo-DOVS complement stereo-BRUVS in that they provide estimates of fish density (i.e. the number of fish per square metre) rather than relative estimates of abundance. They also preferentially sample smaller, relatively cryptic fish species compared to stereo-BRUVS (Watson *et al.* 2010; Barley *et al.* 2015; Callaghan *et al.* 2014; Goetze *et al.* 2015).

Objective

To describe the shark and fish assemblage on the shallow, outer reefs of the major atolls in the BIOT Marine Reserve in order to determine whether fish assemblage structure varies in relation to the abundance of sharks in terms of the number, size and behaviour of mesopredators and their prey.

4.1 Preliminary results

A total of 190 stereo-DOV stereo transects were completed at 38 sites during the expedition (Table 3; Figure 5). Preliminary viewing of the DOV video footage revealed many mesopredators on the shallow, outer reefs of the BIOT reserves, including two-spot red snapper and tawny nurse sharks (*Nebrius ferrugineus*).

Table 3: Number of samples (n) for DOVS, by location.

Location	*n (DOVS)*
Eagle Island	3
Egmont Islands	4
Peros Banhos Atoll	22
Salomon Atoll	6
Three Brothers Islands	3
Total:	**38**

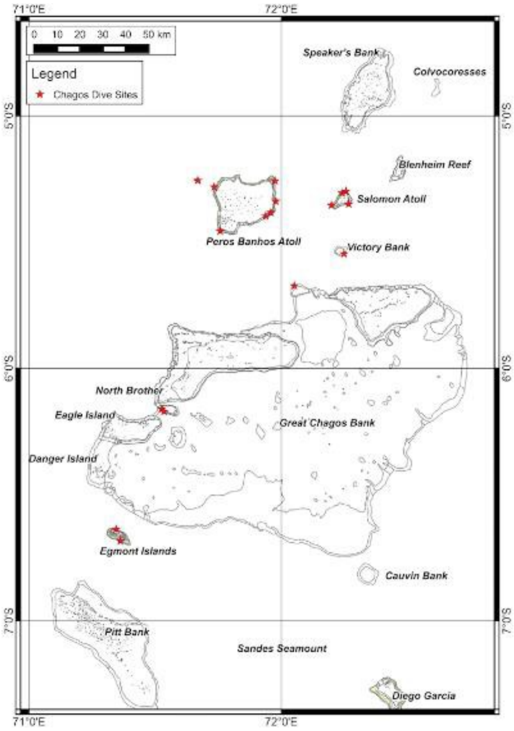

Figure 5: *Locations of stereo-DOVS surveys*

5. Mesopredator behaviour based on acoustic tagging

Acoustic tagging allows the movements of animals to be detected by arrays of receivers that triangulate acoustic signals to determine their position in space relative to habitat and to other acoustically tagged animals (Heupel *et al.* 2006; Kessel *et al.* 2013; Lee *et al.* 2015). Arrays were installed by a team from Stanford and UWA in 2013. Currently there are 34 receivers at Peros Banhos and eight receivers at Salomon Atoll with an additional 21 located across the Maine Reserve (Figure 6). The primary purpose of these arrays is to track shark movements around and between the atolls and prior to this work, 98 individual sharks, including blacktip (*Carcharhinus melanopterus*), grey reef, and silvertip (*Carcharhinus albimarginatus*) had been tagged.

Objective

Describe the spatio-temporal distribution and movements of mesopredators using acoustic telemetry in order to understand the effects of shark abundance on their behaviour.

5.1 Preliminary results

A total of 30 two-spot red snapper were caught on two days of targeted sampling (Table 4; Figure 6). Acoustic tags were placed in 20 individuals at Peros Banhos (7-8 March 2015) and in 10 individuals at Salomon (12 March 2015). Fish were on average 54.3 cm and ranged between 39.5 and 69.0 cm. Individual fish were slightly larger at Salomon than at Peros Banhos. Measurements and tissue samples for genetics and isotopes were also taken from each fish (Appendix 3). Movement data on these fish will be generated when the receivers are downloaded by the Stanford/UWA team in the first half of 2016.

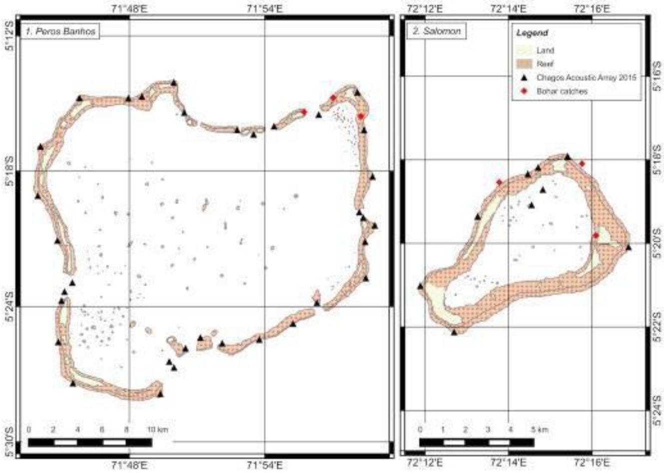

Figure 6: *Locations of acoustic receivers (black) and acoustic tagging sites (red) at Peros Banhos and Salomon atolls*

Table 4: Descriptive statistics for two-spot red snapper acoustically tagged at all locations and at Peros Banhos and Salomon, including the number of fish (N), and their mean, standard error (se), minimum (min) and maximum (max) fork length (cm).

	N	mean	se	min	max
All	*30*	*54.3*	*1.3*	*39.5*	*69.0*
Peros Banhos	20	53.9	1.5	39.5	69.0
Salomon	10	55.2	0.8	46.0	61.0

6. Mesopredator condition, diet and genetic diversity on reef flats as revealed by catch-and-release sampling

Reef flats often support active feeding grounds for sharks and mesopredators, and thus provide insights into their interactions and the potential for changed behaviour with varying shark abundance. Supported by professional marine fly fishers, mesopredators foraging on these flats were targeted for measurements indicative of fish condition and morphometry, and tissue samples were collected to allow diet assessment and genetic analyses. A combination of skiffs and wading was used to maximise the chance of speedy capture and to allow most effective targeting of priority species. Condition is determined by taking length and weight measurements to determine if their ratio is lower with shark presence (Barley *et al.* subm.). Morphometric measurements are determined from high resolution still images that allow, for instance, the calculation of eye diameter and tail height relative to body length and to assess whether systematic differences occur in relation to shark abundance (Hammershlag *et al.* subm.) Evidence of diet variation can be inferred from stable isotopes, a non-intrusive alternative to lethal sampling of guts (Cocheret de la Morinière 2003). The ratio of heavy to light isotopes of nitrogen and carbon indicate where the animal is feeding in the food web and on what primary producer (algae, seagrass, mangrove) the food web is based, respectively. The isotopes are analysed from a tissue punch of dorsal muscle, just behind the dorsal fin. Genetic variability in the sampled individuals and their connectivity to other conspecifics across BIOT can also be assessed by taking fin clips (Bay et al. 2004).

Objectives

1) Identify whether condition, morphometry, diet and genetics vary systematically with the abundance of sharks and in a manner consistent with trophic cascades and mesopredator release.
2) Determine connectivity among sharks and mesopredators using genetic kinship analysis to understand resilience to shark removal.

6.1 Preliminary results

A total of 142 fish from 20 species were sampled across locations during the expedition (Table 5). These include two-spot red snapper, bluefin trevally (*Caranx melampygus*), yellowspotted trevally (*Carangoides fulvoguttatus*), bonefish (*Albula* spp.), green jobfish (*Aprion viresceus*), kawakawa (*Euthynnus affinis*) and white-edged lyretail (*Variola albimarginata*).

Table 5: The number (n) and mean total length (TL) of fish sampled for morphometrics, condition, diet and genetics.

Family	***Scientific name***	***Common name***	***n***	***Mean TL (cm)***
Albulidae	*Albula sp.*	bonefish	17	142
Carangidae	*Carangoides orthogrammus*	island trevally	9	293
	Caranx ignobilis	giant trevally	1	nm
	Caranx melampygus	bluefin trevally	18	200
	Elagatis bipinnulata	rainbow runner	1	nm
	Trachinotus baillonii	small spotted dart	2	nm
Carcharhinidae	*Carcharhinus melanopterus*	blacktip reef shark	2	nm
Lethrinidae	*Lethrinus microdon*	small tooth emperor	1	25
	Lethrinus olivaceus	longface emperor	3	69
	Lethrinus xanthochilus	yellowlip emperor	1	590
Lutjanidae	*Aprion viresceus*	green jobfish	7	78
	Lutjanus bohar	two-spot red snapper	58	423
	Macolor niger	black and white snapper	1	nm
Scombridae	*Euthynnus affinis*	kawakawa	7	48
	Gymnosarda unicolor	dogtooth tuna	2	86
	Thunnus albacares	yellowfin tuna	1	64
Serranidae	*Cephalopholis argus*	peacock hind	1	35
	Epinephelus malabaricus	malabar grouper	4	491
	Mycteroperca rosacea	leopard grouper	1	54
	Variola albimarginata	white-edged lyretail grouper	5	206
Total:			***142***	***298***

Figure 7: *Photograph of two-spot red snapper on measuring board with tag.*

7. Progress towards metrics for the ecological detection of IUU fishing

The first PCI expedition was very successful in establishing an understanding of the ecological implications of IUU fishing. The stereo-BRUVS surveys undertaken as part of this expedition have been a critical step forward in extending the 2012 survey to begin monitoring change through time. The importance of this work became clear following the release of the Clark et al. (2015) report indicating a rise in IUU fishing within BIOT. Additional information suggests that the State of Tamil Nadu in southern India is providing a 50% subsidy on the construction of new longline / gillnet vessels to enhance offshore fishing capacity. Such vessels are now being arrested in the BIOT Marine Reserve and worryingly have significantly greater capacity than the Sri Lankan vessels that were typically arrested previously. These signals point to a likely increase in the impact of IUU fishing on the BIOT Marine Reserve, and the need for both improved enforcement and monitoring of ecological impacts. To this latter end, the data on condition, morphometry, isotopes and genetics are powerful indicators of these impacts, and will provide important justification for increased investment in enforcement based on rapidly-evolving technology.

8. Safety

There were no health or safety issues of note. Mild sunburn and dehydration occurred during the first days, with team members rapidly adapting to the local conditions. The M/Y *Pangaea* small boats were ideal for the research being undertaken with respect to safety.

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