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Pangaea Initiative: Cocos Report

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The Role of Sharks as Ecosystem Regulators

UWA

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EXECUTIVE SUMMARY

A team of scientists from the Centre for Marine Futures at the University of Western Australia conducted a 12 day expedition to the Cocos Keeling islands in November 2016. The expedition included two scientists and three technicians. The aim of the expedition was to test a number of hypotheses about the role of sharks on coral reefs as part of a pan-Indo-Pacific sampling program known as the Pangaea Initiative. Specifically, the expedition used catch-and-release fishing and Baited Remote Underwater Video Stations (BRUVS), both seabed and mid-water, to explore whether sharks regulate the abundance, biomass, size, biology, diet and behaviour of other fishes via predation and competition. Fishes were captured by experienced fly fishers on board the research vessel *M/Y* Pangaea and each individual was sampled for one fin clip and two muscle samples. These samples have been submitted for (a) stable isotope analysis to improve understanding of how sharks influence the diet and therefore habitat use of reef fishes and (b) genetic analysis to explore whether fishes display genetic signatures consistent with adaptations to varying levels of predation. Length and weight measurements were also recorded for each fish to allow estimation of condition.

In total, the team obtained:

- 303 fin clip and muscle samples from 101 fishes representing 6 families.
- 5 samples of coral *Acropora spp*., sea cucumber *Holothuria atra* and macroalgae for use in the stable isotope analysis.
- 203 seabed stereo-BRUVS samples from the lagoon of the southern atoll. Of these 75% have been analysed for fish identifications and lengths and a further 20% have been analysed for identifications by lab technicians.
- 110 mid-water BRUVS samples, in a longline configuration containing 5 samples per longline. As per the sampling plan, longlines were deployed as part of onshore-offshore “pairs”. Of these 75% have been analysed for fish identifications and lengths and a further 20% have been processed for ID confirmation, with the analysis on track to conclude in April 2017.

INTRODUCTION

Sharks, wolves and other apex predators regulate food webs by consuming prey [“lethal effects” (Ritchie and Johnson 2009)]. Less well understood are the “risk” effects that predators generate, causing prey and competitors to alter their behaviour in order to avoid being attacked (Preisser et al. 2005; Wirsing et al. 2008). To avoid being eaten, prey have been shown to prefer safer but less energetically profitable habitats (Wirsing et al. 2008), forage less actively (Metcalfe et al. 1987; Madin et al. 2010) and eat less food (Ibrahim and Huntingford 1989; Catano et al. 2015), leading to lower growth rates and reproductive fitness (Clinchy et al. 2013). Predators can also influence the foraging behaviour of competitors, restricting their dietary breadth and the abundance of shared prey (Schuette et al. 2013).

While sharks have traditionally been viewed as the apex predators on coral reefs, their ecological role is poorly understood (Roff et al. 2016). Indeed, most of the evidence that they are important predators on reefs has come from small-scale experiments focused not on sharks but on piscivores in general (Stallings 2008). Other evidence has been furnished by large-scale, “natural experiments” that compare reefs where large, carnivorous fishes are common and reefs that have been targeted by fishers (Barley and Meeuwig 2016). Some of these studies have failed to find evidence that piscivores exert strong top-down effects (Rizzari et al. 2014). The role of reef sharks remains hotly contested, with growing evidence that they may act as “just another mesopredator”, influencing reefs primarily via competition rather than predation (Frisch et al. 2016; Roff et al. 2016). However, a natural experiment conducted at the Northern Line islands in the central Pacific Ocean demonstrated that where predators were common, prey were scarcer, foraged less, smaller and in worse condition (Walsh et al. 2012).

The Pangaea Initiative harnesses ecological gradients in shark abundance across the Indian Ocean in order to test hypotheses about whether shark predation affects the diversity, abundance, size, biomass, diet and genetic signatures of reef fishes. Such comparisons between reefs where fishing has reduced numbers of sharks and reefs where shark assemblages are healthy represent one of the few logistically and ethically feasible approaches available to scientists to examine the role of sharks as ecosystem regulators at ecologically relevant scales (Barley and Meeuwig 2016). In particular, there is an urgent need to replicate the findings of these large-scale unreplicated natural experiments in diverse ecosystems in order to test the generality of previous findings, a prerequisite for fundamental change in global conservation policies (Barley and Meeuwig 2016). The sampling program of the Pangaea Initiative therefore includes a range of systems, including the British Indian Ocean Territory, the Cocos Keeling Islands, and northern Australia between Cairns (the Great Barrier Reef) and Broome (northwestern Australia).

COCOS KEELING ISLANDS

The Cocos Keeling islands represent a crucial “piece in the puzzle” in the Pangaea Initiative’s approach to examining the role of sharks on coral reefs. Cocos Keeling is an Australian territory located approximately 2,750 km north-west of Perth and 966 km southwest of Java (**Fig 1)**. There are two atolls, with the southern, inhabited atoll comprised of 26 islands. Three aquatic habitats are present around the islands: sub-tidal outer reef slope, reef flat and sub-tidal lagoon (Bellchambers et al. 2011). The latter has an area of 102 km^2 and is divided into two zones, a shallow southern region (<3 m) and a deeper northern region (10-20 m) that are connected via a system of deep (<20 m) “blue holes” in the centre of the lagoon (**Fig 2**). South-easterly trade winds blow for over 85% of the year (Falkland 1994) and live coral cover at most sites ranges between 50–75% (‘good’ category; (2005)). Over 500 fish species are found on the islands (Hobbs and Mcdonald 2010), and the region is home to more hybrid coral reef fishes than any other marine location due to its location at the nexus between the Indian and Pacific Oceans (Hobbs et al. 2009).

Fig 1 Map showing the location of the Cocos Keeling islands (blue shaded box).

Fig 2 A chart of the southern atoll of Cocos Keeling created in 1840 by the explorer James Holman, also known as “the Blind Traveller”.

FISHING PRESSURES

The Cocos Keeling islands were first colonized in 1827, with ~600 people now living on Home and West Island (2005). In the 1950s, subsistence fishers caught ~80 tonnes of fishes per year but catches rose dramatically in the 1980s, with signs of overexploitation present since 2000 (Harper et al. 2012). Today, it is estimated that over 250 tonnes of fishes are caught annually. Groupers now constitute 15% of total annual catch compared to >60% prior to the 1990s (Harper et al. 2012). A long-term survey of the southern atoll between 1997 and 2005 also noted consistently low densities of snappers, bumphead parrotfish, humphead wrasses and moray eels (2005). Bag limits, bans on fishing certain species including coral trout *Plectropomus* sp. and limited usage of nets were proposed by the Department of Fisheries of Western Australia in February 2016 for Cocos Keeling islands, however the guidelines are not yet in force (Proposed Rules for Sustainable Fishing, WA Fisheries Report, 2016).

Unusually, the Cocos Keeling islands have not experienced significant levels of shark fishing historically [21]. Shark abundance is therefore exceptionally high around the atolls, with densities far exceeding those in no-take zones on the Great Barrier Reef Marine Protected Area and equivalent to the GBRMPA's no-entry zones (**Fig 3**; Robbins et al., 2006). As a result, the Cocos Keeling islands provide an important "control" to the "treatments" that have been created at other locations in the Indian Ocean by shark fishing. Previous research on sharks and other predators suggests that where sharks are abundant, prey and competitors should be in worse body condition (Walsh et al. 2012; Barley et al. 2017a), consume lower risk food items that allow them to stay close to the shelter of the reef (Heithaus et al. 2008), be less abundant and lower biomass (Ruppert et al. 2013; Barley et al. 2017b) and display subtle changes in their genetic signatures that give them a competitive advantage in predator-rich environments (Reznick et al. 2001).

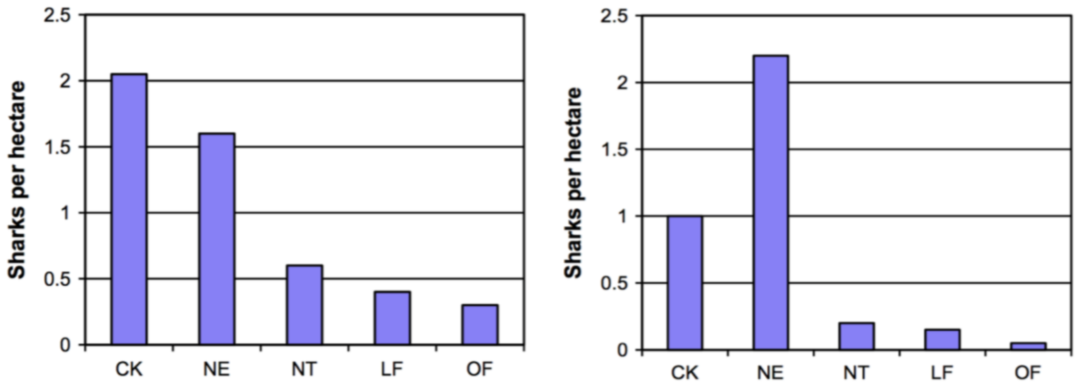

Fig 3 Shark abundance at Cocos Keeling (CK) relative to sections of the Great Barrier Reef MPA, including no-entry (NE), no-take (NT), limited fishing (LF) and open to fishing (OF) reefs for white tip (left) and gray (right) reef sharks. From Robbins et al. (2006).

EXPEDITION AIMS

In order to test the generality of these findings, a team of scientists from the University of Western Australia travelled to the Cocos Keeling islands in November 2016 (**Table 1**). The team deployed seabed and mid-water BRUVS and non-destructively extracted fin and tissue samples from sharks and other reef fishes for genetic and isotopic analysis with the latter data used to explore whether reef fishes respond to high predation environments via genetic adaptations and dietary shifts to lower risk foods. The team also took length and weight measurement in order to assess the condition of reef fishes, predicting that reef fishes would demonstrate better condition where sharks were rarer. Moreover, analysis of the seabed BRUVS samples will be used to improve understanding of how sharks “shape” reef fish communities in terms of their diversity, abundance, size and biomass, following Barley et al. (2017b). The mid-water BRUVS, in contrast, examine the role of sharks in the “big blue” pelagic zones, an understudied ecosystem that is nonetheless tightly interconnected to the health of reef assemblages by mobile predators and the early life stages of fishes (Treml et al. 2012).

The research will generate the type of large-scale data that will be required to galvanise fundamental policy changes in shark conservation both in Australia and globally, providing a contrast to the data collected through the Pangaea Initiative in the Chagos archipelago (British Indian Ocean Territory; BIOT). This is particularly important in Australia given the opportunity to strengthen protection across the recently established network of Commonwealth Marine Reserves which include both highly protected “no-take” green zones and multiple-use zones that allow varying degrees of exploitation. Our trans-Indo-Pacific approach is also essential to understanding the status of marine ecosystems across the Indian Ocean Rim where population growth places significant pressure on marine resources with relatively limited capacity for research and management.

Table 1 Science team members that participated in catch-and-release fishing (CnR), mid-water BRUVS and seabed BRUVS.

Member	**Organisation**	**Role**
Dr Shanta Barley	UWA	Expedition leader, CnR sampling
Dave Tickler	UWA	Mid water BRUVS, CnR sampling
Jemma Turner	UWA	Mid water BRUVS,
Louis Maserei	UWA	Seabed BRUVS
Hanna Jabour Christ	UWA	Seabed BRUVS
Richard Schumann	Pangaea	CnR sampling

RESEARCH ACHIEVEMENTS

CATCH AND RELEASE FISHING

In total 101 fishes were sampled spanning six families (Carangidae, Carcharhinidae, Lethrinidae, Lutjanidae, Scombridae and Serranidae). Samples were extracted from a total of 20 blacktip reef sharks, 20 honeycomb groupers, 13 island trevallies, in addition to 11 grey reef sharks (**Table 2**). The average length of blacktip reef sharks was 83.4 cm, reflecting the status of the lagoon as a possible nursery for juveniles of this species. The average length of grey reef sharks was 103 cm, with individuals far larger on the outer reef (average length: 135 cm) than in the lagoon (average length: 91 cm). We also collected five samples of coral *Acropora spp*., sea cucumber *Holothuria atra* and macroalgae from the lagoon to use as baseline indicators in the stable isotope analysis.

Table 2. Summary of fish species caught-and-released and the number of each species sampled.

SPECIES	COMMON NAME	NUMBER
Carcharhinus melanopterus	blacktip reef shark	20
Epinephelus merra	honeycomb grouper	20
Decapterus sp.	scad	16
Carangoides orthogrammus	island trevally	13
Carcharhinus amblyrhynchos	grey reef shark	11
Caranx sexfasciatus	bigeye trevally	3
Aphareus furca	small toothed jobfish	2
Aprion virescens	green jobfish	2
Epinephelus polyphlekadion	camouflage grouper	2
Lethrinus obsoletus	orange-striped emporer	2
Plectropomus areolatus	squaretail coralgrouper	2
Plectropomus maculatus	spotted coralgrouper	2
Thunnus albacares	yellowfin tuna	2
Acanthocybium solandri	wahoo	1
Caranx ignobilis	giant trevally	1
Cephalopholis urodeta	darkfin hind	1
Elagatis bipinnulata	rainbow runner	1
	TOTAL	101

The samples have been submitted for stable isotope analysis, with results expected in March 2017. The results will shine light on the feeding habits of a range of important reef species including trevally, sharks and scad *Decapterus sp.* The latter, which consume zooplankton in the water column, have been included in the analysis as a "baseline species" that will be used to calibrate trophic levels between locations. Genetic samples collected at the Cocos Keeling islands have been sent to Oxford University for analysis by PhD student Ms. Abigail Bailey.

SEABED STEREO-BRUVS

The team deployed 203 stereo-BRUVS on the sea floor at an average depth of 5.6 m. The maximum depth sampled was 18.9 m while the shallowest drop occurred at 0.8 m. The seabed BRUVS were deployed throughout the lagoon (see **Fig 4**). Over 75% of samples have been analysed for fish identifications and lengths and a further 20% have been analysed for fish IDs by lab technicians. Preliminary assessments of the footage suggest that blacktip sharks are abundant throughout the lagoon, however mesopredatory species such as red bass *Lutjanus bohar* and island trevally *Carangoides orthogrammus* are predominantly located in the NE of the lagoon. The southern side of the lagoon is sandy and has high macroalgae coverage and poor visibility relative to the northern reaches, where coral bommies were more common, and is similar to the southern lagoon at Diego Garcia in the British Indian Ocean Territory.

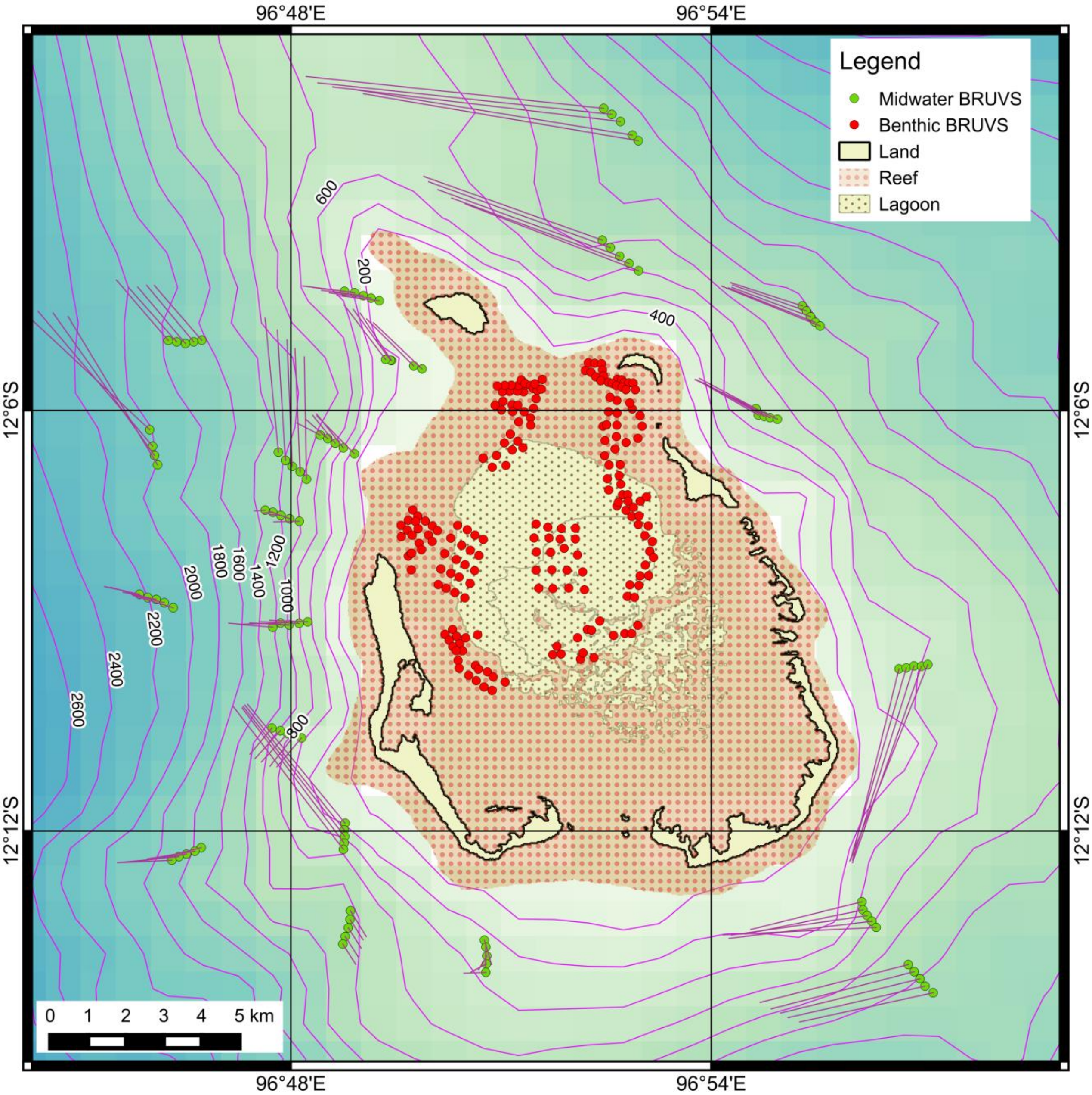

Fig 4 Sampling locations for seabed (or benthic) BRUVS (red dots) and mid-water BRUVS (green dots). Seabed BRUVS were deployed within the lagoon whereas mid-water BRUVS were deployed offshore. Straight purple lines indicate the distance drifted by the mid-water BRUVS.

MID-WATER BRUVS

A total of 110 mid-water BRUVS (22 longlines) were deployed in the waters around the Cocos Keeling islands, with each longline comprised of five rigs. As per the sampling plan, longlines were deployed as onshore-offshore “pairs” and 8 full pairs in total were achieved, with the remaining 6 longlines deployed singly (see **Fig 4**). Rigs were suspended in 10 m of waters in deep (up to 2600 m) and allowed to film for at least two hours. A preliminary analysis of the footage captured by mid-water BRUVS suggests that the Cocos Keeling islands are home to a diversity of sharks, including grey reef, silky, tiger and scalloped hammerheads. Rainbow runners and barracuda were also relatively abundant, with the latter filmed on ~15% of the samples.

COMMUNICATION & OUTREACH

During the expedition, Dr Shanta Barley and Mr Dave Tickler provided presentations at the community centre on West Island at Cocos Keeling that was extremely well-attended. Dr Barley discussed the crisis affecting shark populations globally and presented the results of her PhD research, including the effect of reef sharks on the abundance, size, biomass, condition, diet and growth rate of prey and competitor fish species. Mr Tickler presented on the methods that the science team uses to sample reef and mid-water shark and fish assemblages. The presentation concluded with a highlights reel of footage captured on the expedition to Cocos Keeling, including a tiger shark dragging a seabed BRUVS rig up into the water column. The presentation was well-received and inspired a lively but considered discussion of the role of sharks within ecosystems.

Fig 5 Presentation to Cocos Keeling islanders at the community centre.

PEER-REVIEWED PUBLICATIONS

The CnR sampling and seabed BRUVS research conducted at Cocos Keeling will support publication of an article examining the diet and trophic ecology of reef sharks at the Cocos Keeling islands based on condition data, stable isotope analysis and BRUVS-derived data on shark abundance and fish biomass. This will enable identification of possible trophic cascades following removal of sharks in Cocos Keeling. The data will also ultimately feed into four meta-analyses examining the effect of sharks on the condition, abundance, biomass, diet and genetic variation of prey and competitor reef species across the Indo-Pacific Ocean. The analyses will draw on a range of locations including BIOT, north-western and north-eastern Australia. Analysis of the mid-water BRUVS footage will, similarly, feed into a large-scale meta-analysis that examines the ecological role of sharks in pelagic ecosystems across over 15 locations globally and in particular, along the Great West Ozzie Transect in which Pangaea is participating.

Coral reefs support some of the most biodiverse communities in the world yet they are declining globally due to human activity (Descombes et al. 2015). Reefs in the Indian Ocean in particular are among the most threatened, with some having experienced up to 99% coral mortality in the 1998 bleaching event (Goreau et al. 2000). The Cocos Keeling islands are particularly vulnerable to disturbance due to their isolation and the understudied nature of their fish communities (Hobbs 2014). The Pangaea Initiative’s Cocos survey will therefore provide an important step forward in terms of understanding the conservation status of the Cocos Keeling shark and fish assemblages in what is essentially a knowledge “blind spot”. Moreover, due to the exceptionally high abundances of reef sharks that we observed, the Cocos Keeling survey will provide critical insights into how a reef assemblage subject to strong “top down” control should look like, providing a useful baseline against which other less predator-dominated systems can be compared.

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