EXPEDITION REPORT

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Little and large: surveying and safeguarding coral reefs & whale sharks in the Maldives

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Abstract

Two weeks of coral reef surveys were carried out in July 2017 by Biosphere Expeditions in Ari, South Male', Felidhu and Mulaku atolls, Maldives. The surveys were undertaken by Maldivian placement recipients, fee-paying volunteer citizen scientists from around the world and staff from Biosphere Expeditions.

Surveys using the Reef Check methodology concentrated on re-visiting permanent monitoring sites that have been surveyed in Ari atoll, central Maldives, since 2005 for some sites, and every other year since 2011. The surveys were carried out 14 months after the El Niño coral bleaching event in 2016. Coral cover for all North Ari sites combined varied between 52% and 0% with a mean of 21% cover. Inner Ari atoll reefs (mean 4% cover) have been more severely affected by bleaching than the outer reef sites (mean 37%) over this 14-month timeframe. Some inner reefs (e.g. Kudafalhu), which had previously been affected by coral-damaging storms in 2015, Crown-of-Thorns infestations and bleaching in 2016, had extremely low coral cover (under 2%).

There continues to be strong evidence of consistent overfishing, with very few large grouper and few snapper present at most sites. Outer reefs appear to show a more promising survival (resistance) and recruitment/recovery pattern (resilience) to bleaching, with many *Porites* and other massive and encrusting colonies persisting. Relatively high parrotfish numbers at Holiday thila (12 individuals per 100m^2) Kudafalhu (7 individuals per 100m^2) may graze much of the algae away that has become established onto the reefs there. If grazing pressure is not enabled or increased, partly through fisheries management, we may see a more permanent 'phase shift' to an algal or corallimorph reef, with consequential disastrous effects on fish and overall reef biodiversity. This has already happened at two reefs surveyed in the past – Adhureys reef in the southeast of Ari atoll and Deh giri in North Male' atoll. These have shifted to *Discosoma* corallimorph-dominated reefs and therefore ecological deserts, and as such are extremely unlikely ever to become highly biodiverse coral reefs again.

A half-day effort-based whale shark survey was also carried out at the outer reef of South Ari Marine Protected Area, yielding one encounter at Maamigili. The animal was 6 m long and had previously been identified by the Maldives Whale Shark Research Project as 'Adam'.

In summary, our studies indicate some initial recovery since the 2016 bleaching event, with much of the remaining bleached proportion of the coral community appearing to recover between July 2016 and July 2017. However, much of the recovery is limited to outer reefs, with inner reefs faring much worse in comparison. Overall, urgent policy and government action to protect reefs, and therefore the economic, social and geological foundation of the Maldives, is required to combat multiple threats and trends of decline. However, there seems to be little political and public awareness, understanding or will to do so.

އެބްސްޓްރެކްޓް

ބަޔޯސްފިއަރ އެކްސްޕެޑިޝަންސްގެ ފަރާތުން ޖުލައި 2017 ގައި އަރި އަތޮޅު، ދެކުނު މާލެ އަތޮޅު، ފެލިދު އަތޮޅު އަދި މުލަކު އަތޮޅުގެ ފަރުތަކުގެ ހާލު ދެނެގަތުމުގެ ގޮތުން 2 ހަފްތާގެ ދިރާސާ މަސައްކަތެއް ކުރިއަށް ގެންދިޔައެވެ. މި ދިރާސާ މަސައްކަތުގައި ބަޔޯސްފިއަރ އެކްސްޕެޑިޝަންސްގެ މުވައްޒަފުންގެ އިތުރުން ބައިވެރިވެފައިވަނީ "މޯލްޑިވިއަން ޔޫތު ސަސްޓެއިނަބިލިޓީ ރިސިލިއަންސް" އަދި ދިވެހި ދަރިވަރުންނާއި ދިރާސާގައި ބައިވެރިވި ވޮލަންޓިއަރ ސިޓިޒަން ސައިންޓިސްޓުންނެވެ. މި އިތުރުން، އަރި އަތޮޅު ދަރަނބޫދޫގައި ހިންގަމުންދާ ސަރުކާރު (ސައުތު އަރި މެރިން ޕްރޮޓެކްޓެޑް އޭރިއާ) ގެ ބޯޓު ފަރުން ފެނިފައި ދަނޑު މިންވަރު ބަލައިލައި ދިރާސާ މަސައްކަތެއް (އެލިމަސް ބޯސްޓްގެ ސާރވޭ) ބައި ދުވަހު މުއްދަތެއްގެ މަތިން ކުރެވުނެވެ. މިދިރާސާ ކުރެވުނު ވަގުތުގައި މާލީގެ ބޭރުން އެއްވެސް އިތުރުތަކުން ފެނިފައި ނުވާނެކަމުގެ ފާހަގަ ކުރެވިއެވެ.

ރީފް ޗެކް މެތަޑޮލޮޖީ ބޭނުންކުރުމުގެން ކުރެވުނު ދިރާސާތަކުން ކުރެވިފައިވާ އަރި އަތޮޅު އަދި މުޅި ރާއްޖޭގެ ކުރީގެ އަހަރުތަކުގެ ފަރުގެން ދިރާސާކުރުމުން އައިސްލާއާ ސަރުކާރުގެ ތަފާތުވެއެވެ. މިގެ ތެރެއިން ބައެއް ސަރުކާރުތަކުގެ 2005އިން ފަރުގެން ދިރާސާ ކުރުމުން އަންނަ ސަރުކާރުގެތަކަށް (2011 އިން ފަރުގެން ހަނދު 2 އަހަރުން 1 އަހަރު). މި ދިރާސާތައް ކުރިޔަވަފައި އަދި ނިމުނީ ސަރަހައްދު ގޮތުގައި ހަރުސާ ދަތުރުވެ 14 މަސް ފަހުންނެވެ. އަރި އަތޮޅު އުތުރުބުރީގައި ދިރާސާކުރުމުން ސަރުކާރުތަކުގައި ދިރޭ މުރަކައިގެ އިންސައްތަ އެވެރި 0% އާއި 52% (އެވްރެޖަކަން 21%) އާއި ދެމެދުއެވެ. މި 14 މަހުގެ މުއްދަތުގެ ތެރޭގައި ގޮތުގައިވާ އަސަރު ބޮޑުކަމަކުވެސް އަރިއަތޮޅުގެ ބޮޑު ފަރުތަކަށްވުރެ (އެވްރެޖް ދިރޭ މުރަކައިގެ އިންސައްތަ 37%) އެވްރެޖްގެ ފަރުތަކަށް (އެވްރެޖް ދިރޭ މުރަކައިގެ އިންސައްތަ 4%) ކަމަށް ފާހަގަ ކުރެވިއެވެ. އަދި ނިންމާ ހަރުސާގެ ކުރިން، އެހެނިހެން ސަރަހައްދުތަކުން ހޯދި (2015ގައި މާލެ ސަރުކާރުތަކުގެ ސަރަހައްދުން ފަރުތަކަށް ގެއްލުންވުން، ކުރިން ޕާސެންޓް އަދި 2016ގެ ގޮތުގައިވާ ހަރުސާ) ގެއްލުން ލިބިފައިވާ އެވްރެޖްގެ ބައެއް ފަރުތަކުގެ (މިސާލަކަށް ކުޅުދު) ދިރޭ މުރަކައިގެ އިންސައްތަ ވަރަށް ދަށްކަމަށް (2% އަށްވުރެ ދަށް) ފާހަގަ ކުރެވުނެވެ.

މިގެ އިތުރުން، އާދައިގެ މިންވަރަށް ވުރެ ގިނައިން މަސްބޮޑު ކަމުގެ ހުރިއަށްވެސް ފެންނަނީކަން ފާހަގަކުރެވިއެވެ. މިގޮތުން، މަސްވެރިކަމުގައި އެކުލެވޭ ބޮޑު ފަސް އަދި ރަތްމަހާއި ގިނަމަހުގެ އާއިލާގެ ބާވަތްތައް ގިނަ ސަރަހައްދުތަކުން ފެނުނު މިންވަރު މަދުކަމަށް ފާހަގަކުރެވިއެވެ. މިއާ ހަމައަށް ބޮޑުބޮޑު ސަރަހައްދުތަކުން ގޮތުގައިވާ ބަލިވެ ސަރަހައްދުން އަސަރުކޮށް މިންވަރު ކުޑަކަމާއި، އިއާދަވާގޮތް ބާރުވެއެވެ ބޭނުކަމަށް ފާހަގަ ކުރެވިއެވެ. މިގޮތުން އަސަރުކުރުމުގައި ހުރި ގިނަ މުރަކަތަކާއި ބޮޑުވީ ގެތައް ދިރިއުޅެނިކަމަށް ފާހަގަކުރެވިއެވެ. މިގެ އިތުރުން، އަސަރުކުރުމުގެ ފަރުތަކަށް ގިނައިން ފެންނަ ފަނޑު ބާވަތްތަކުގެ ބޯވަހަށް (ހޮވާލެވުނު - ފަރުގެ ކޮންމެ 100 އަކަމީޓަރުގައި 12 ފަހަރު، ކުރަފާ - ފަރުގެ ކޮންމެ 100 އަކަމީޓަރުގައި 7 ފަހަރު) އަސަރުކުރުމުގެ ފަރުތަކުގައި ޖަހާފައިވާ ފަދަ ކުރިމަތިކުރާ ކުރެވިފައިވެއެވެ. އެހެންކަމުން މަސްވެރިކަން ކުރާ މިންވަރު ދަށްކުރުމަށް ވެރިކަން ފަރުތަކުގައި ޖަހާފައިވާ ފަދަ ކުއްލި މިންވަރު ނިކުމެގެންދިޔަ ނުވަތަ އިތުރު ނުކުރެވިދާނެކަމަށް އެފަރުތަކުގެ ދިރިއުޅުމަށް ގެއްލުން "އައުގަނު" (ފަރުޖެހުމާއި) ނުވަތަ "ކުރުފިކުރުފި" (މާގަނޑު) ފަރުތަކުގެ ބަދަލުވުން އަލިގަނޑެވެ. މިއާއެކު، އަސަރުކުރުމުގައި ދިރިއުޅޭ މުހިއްމު ބާވަތްތަކާއި އަސަރުކުރުމުގެ މާހައުލަށް ވަރަށް ނުރައްކާ އަސަރުތަކެއް ކުރާނެ އަހަރުގަނޑެވެ. މިގޮތަށް ހުރިހާއެއް މިއަދުވެސް ވޭ، ކުރިން ސުރުޚީ ދިރާސާ ކުރުމުން އައިސްލާއާ 2 ސަރުކާރުތަކަށް ދިމާވެފައެވެ. އެއީ، އަރިއަތޮޅުގެ އިރުދެކުނުގައި އޮންނަ އަދިރާ ފަރު، އަދި މާލެ އަތޮޅު އުތުރުބުރީގައި އޮންނަ ދައް ގިރި އެވެ. މިދެ ސަރުކާރުތަކުވެސް މިހާރު ވަނީ "ޖައިކާސާ ކުރުފިކުރުފި-ޖެހިންޒޯން" ފަރުތަކަކަށް ބަދަލުވެފައެވެ.

ހުޅަނގުއަށް ގެރެން، އަތޮޅަށް ފަރުގެ ދިރާސާތަކުން ދައްކާދެއްވާގައި، 2016ގެ ގޮތުގައިވާ ހަރުގެ ފަހުން، ކުންފުނިތައް ވަރަށް ފަރުތައް ނިކަމެތި އަރާމު މިނަވަރު ސިއްޙަތާއި ފުރިހަމަ އެނބުރިއެވެ. އަދި ގޮތުގައިވާ ހަރުން އަސަރުކުރި ފަރުތަކުގެ ގިނަ ސަރުކާރުތަކުން ޖުލައި 2016 އާއި ޖުލައި 2017 އާއި ދެމެދު އިއާދަވުން ފެނިފައިވާކަން ފާހަގަކުރެވިއެވެ. އަދި ހާއްސަކޮށް ބޮޑުކުރެވެން އިއާދަވުމުގެ ފުރުޞަތު، އެވްރެޖްގެ ފަރުތަކަށް ކުރަހައްދަވަނީ ފާހަގަ ކުރެވިއެވެ. ފަރުތަކުގައި ބަރަޔަކީ އިރުޕެލޭނިން، އިރުޕިލަޒިން އަދި ޖެއްވެރިގުޅޭ ޕޮންގެނެވެ. އެހެންކަމުން ފަރުގެ ހިމާޔަތް ފަރުތަކަށް ގެއްލުންދިޔަބަ އޭގެ ގޮތުން ހުޅަނގު ހުރިހާ ފަރުތަކުގެ ދުނިޔޭގެ އިރުދެކުނުގެ ސަރުކާރުތަކުގެ ކަނޑުގެ ބަދަލު ފަސޭހައެއް ހޯދުމަށް އެދުމެވެ. އެހެންނަމަވެސް މިކަންކަމުގައި ފުރަތަމަ ސިޔާސީ ފަރާތްތަކުގެ ހަރުގެ ފަރުތަކާއި ބަހުގެ ކަމަށް މިންވަރު އެދިވޭނަ ވަރަށްބޮޑު ބަރަބަރުކަމުގައި ފުރަތަމަ ސާއިސްޓިފިކަން ވަރަށް ކުޑަކަން ފާހަގަ ކުރެވޭ.

Contents

Please note: Each expedition report is written as a stand-alone document that can be read without having to refer back to previous reports. As such, much of this section, which remains valid and relevant, is a repetition from previous reports, copied here to provide the reader with an uninterrupted flow of argument and rationale.

1. Expedition review

1.1. Background

Biosphere Expeditions runs wildlife conservation research expeditions to all corners of the Earth. Our projects are not tours, photographic safaris or excursions, but genuine research expeditions placing ordinary people with no research experience alongside scientists who are at the forefront of conservation work. Our expeditions are open to all and there are no special skills (scientific or otherwise) required to join. Our expedition team members are people from all walks of life, of all ages, looking for an adventure with a conscience and a sense of purpose. More information about Biosphere Expeditions and its research expeditions can be found at www.biosphere-expeditions.org.

This expedition report deals with an expedition to the Maldives that ran from 15 to 29 July 2017 with the aim of surveying and studying recovery of reefs since the catastrophic 1998 and 2016 bleaching events. The project also ties in sightings of whale sharks with the work of a local charity – the Maldives Whaleshark Research Programme (MWSRP), based in southern Ari atoll. Although the Maldivian reef atolls comprise a rich mixture of spectacular corals and a multitude of fish and other animals, the Maldives government identified a need for further research and monitoring work as far back as 1997. With this project, Biosphere Expeditions is addressing this need and is working with the Marine Conservation Society (MCS) and the MWSRP in order to provide vital data on reef health and whale shark sightings. Reef data collection follows an internationally recognised coral reef monitoring programme, called Reef Check, and will be used to make informed management and conservation decisions. Whale shark photos will be used by the MWSRP for their conservation efforts. The expedition also included training for participants as Reef Check EcoDivers and for EcoDiver Trainers.

Coral reefs

Coral reef structures of the Maldives archipelago are extraordinarily diverse and rich. There are submerged coral mounds, often rising 50 m from the seabed to 10 m from the surface (thilas), other mounds that reach the surface (giris), and large barrier reefs surrounding these structures on the perimeter of the atolls, some of which are up to 40 km long. The islands of the Maldives are entirely made from the coral sand washed up onto the very shallowest coral platforms. More than 240 species of hard corals form the framework of a complex coral community, from the shallow branching coral dominated areas, to deeper systems of undercut caves and gullies dominated by soft corals and invertebrates. Most coral communities in the central reefs of the Maldives were still recovering from the mass bleaching event of 1998, prior to the 2016 bleaching event.

The recovery identified by our surveys (Afzal et al. 2016, Solandt and Hammer 2012 & 2015 & 2017a, Solandt et al. 2013 & 2014 & 2016) appears to have been reasonably strong in many inner atoll reefs, with extensive recruitment and growth of branching and table *Acropora* corals (*A. hyacinthus* and *A. clathrata* – many tables exceeded 3 m in diameter at reef tops (Dega thila, Diga thila, Kudafalhu), even by 2005. It is for this reason that our expedition has regularly focused on assessing reef health in areas initially surveyed prior to the 1998 mass bleaching event.

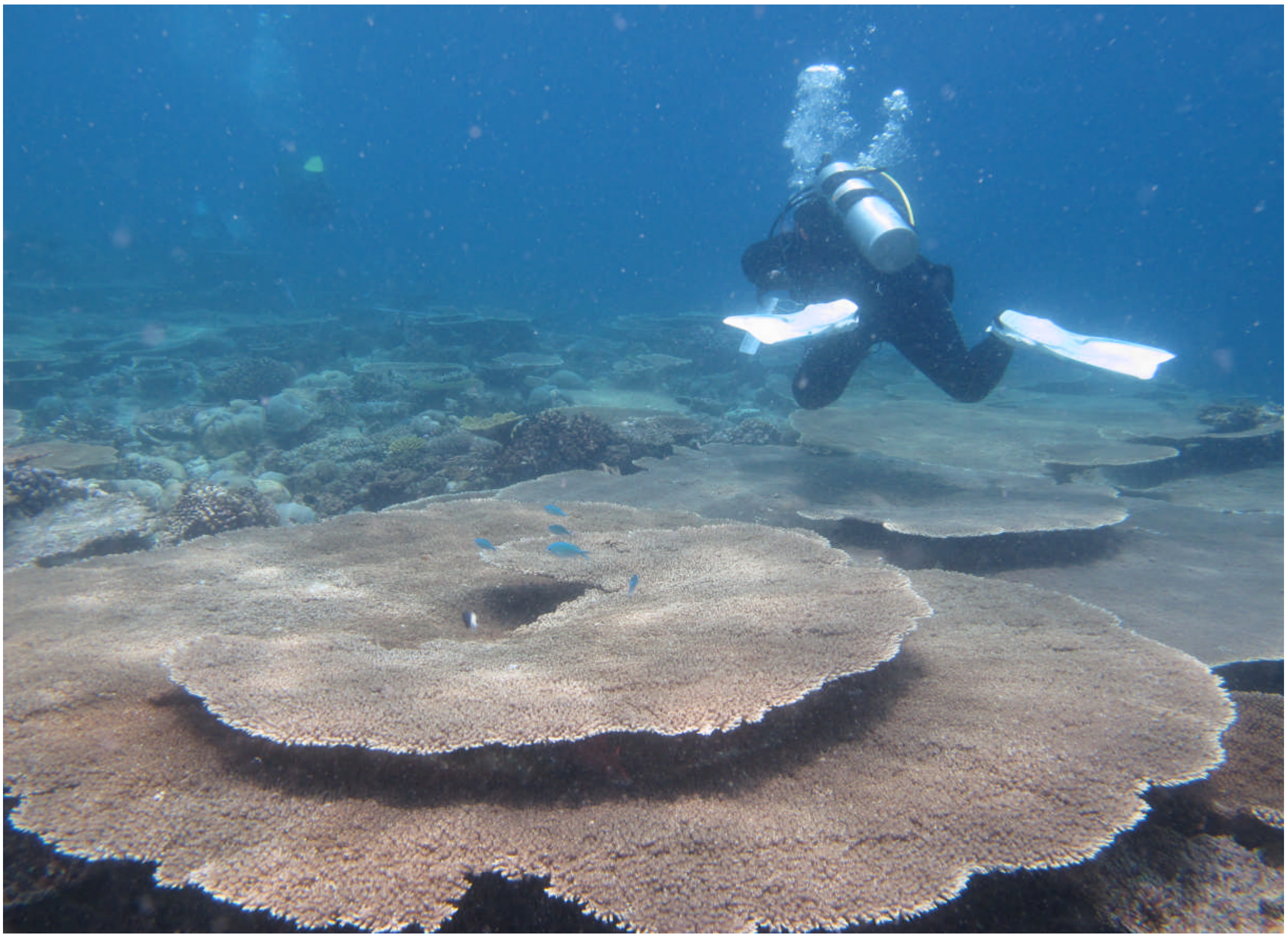

Figure 1.1a. Large *Acropora hyacinthus* colony (photo from c. 2008 at Dega giri).

Many reefs in the central Maldives – even before the 2016 bleaching event – were starting to show signs of stress. Some remain resilient and are in good condition, but others are faring much worse with disease (principally white syndrome), predators (Crown-of-Thorns starfish, *Drupella* snails) and persistent low level bleaching (Solandt et al. 2016, Solandt and Hammer 2015). Many reefs are also outcompeted by algal turfs, macroalgae and some sponges (personal observation). Indeed some reefs we have encountered have already shifted to a non-coral state dominated by turfs and corallimorphs (principally *Discosoma*) (Solandt and Hammer 2017a). The 2016 bleaching event seems to have had a long-term impact on some of the more sheltered reefs that lie inside the reef atoll rims (we call these the 'inner atoll reefs' in this report).

Apart from supporting an expanding tourism and recreation industry, coral reefs also play a critical role in fisheries and in the culture and lifestyle of the people of the Maldives. Tourism, reef fishing, coral sand mining, dredging, reclamation, the construction of maritime structures and pollution represent most of the impacts on coral reefs that can be directly managed in the Maldives. Resilience to the impacts of climate change can be monitored (e.g. to record recovery trajectories of different reefs to mass bleaching events). Reef Check can be an extremely useful tool to inform local managers where conservation action such as community-based management and Marine Protected Areas (MPAs) should be targeted.

With the introduction of tourism in the Maldives in the 1970s, the country started to gain a major source of income and employment. Mass tourism in the Maldives is still concentrated around the atolls close to Male' and its infrastructure and resources rely on rich and healthy reefs. However, there is a significant increase in the amount of licences being offered to resort developers around the more southern atolls. A new airport in Maamigili (south Ari) has opened up new areas to direct flights, increasing access to the area.

The remoteness of many reefs and their wide distribution make research and monitoring work costly and difficult. The reefs that have been best studied are in the central areas of North Male', Ari and Addu atolls (e.g. Pisapia et al. 2016).

In order to assess a broad range of reef types, we surveyed inner (giri, thila and house) reefs and the outer slopes of atoll reefs around Ari atoll during week one of the expedition. During the second week we visited the atolls of South Male', Falidhu and Mulaku, surveying sites that had been Reef Check surveyed in 1997. This range of sites and habitats gave us a useful understanding of the relative resilience of different reef types and locations to the warming event of 2016.

Data from these and previous Reef Check surveys will be used at international, regional and national levels to provide a 'status report' on the health of Maldivian reefs. At the national level, they will be used to help make informed management and conservation recommendations.

Dives ranged from thilas, farus in inner reefs, channel walls and slopes, fore- and back reefs, where gently sloping reefs are covered by hard corals and the regionally abundant black tube coral, Tubastrea. All of our survey dives were to a maximum 18 m depth, which generally are the shallow water areas that provide the richest coral growth.

Fish populations including whale sharks

The fish populations of the Maldives are exceptionally rich in terms of diversity, but the number, size and biomass of commercial species have been seriously impacted (Sattar et al. 2012). The Maldivian government in 2008 banned shark fishing within the atolls and their numbers appear to be increasing (according to anecdotal reports from some dive operators), and small reef sharks are still commonly observed in Maldivian lagoon waters. Currents feed the atolls between the outer barrier reefs that punctuate this vast archipelago, where the diving can be exciting. The unique location and geology of the Maldives also makes it a rich area for filter feeding whale sharks and manta rays, with observations of these species an exciting event for those on board live-aboard dive trips.

The expedition undertook detailed observations of encounters with whale sharks when they were encountered between reef survey locations. Photographs of the gill areas of whale sharks are being used by the MWSRP to identify individuals in order to record presence / absence of whale sharks in the archipelago. Photos of the markings in and around the gill / pectoral fin areas are unique (like a human fingerprint) for each individual, and over 200 individuals have been recorded so far. The MWSRP can then match one individual's unique markings with the photographic record and add that image and the whale shark's location to their database and see if it has been recorded before and from where. This will then allow conservationists at the MWSRP to map where individual sharks go, how often they are recorded at individual locations and whether further protection mechanisms are needed for individual hotspot locations.

1.2. Research area

The Maldives or Maldive Islands, officially Republic of Maldives, is an coral atoll-island country in the Indian Ocean formed chain of twenty-five atolls stretching in a north-south direction off India's Lakshadweep islands. The atolls of the Maldives encompass a territory spread over roughly 90,000 square km. It features 1,192 coral islands, of which only about two hundred are inhabited.

Figure 1.2a. Flag of the Maldives.

The Republic of Maldives's capital and largest city is Male', with a population of around 133,000. The total population is 314,000. Traditionally it was the King's Island, from where the ancient Maldive royal dynasties ruled and where the palace was located. The Maldives is the smallest Asian country in both population and area. But it is the 11th most-densely populated country on earth.

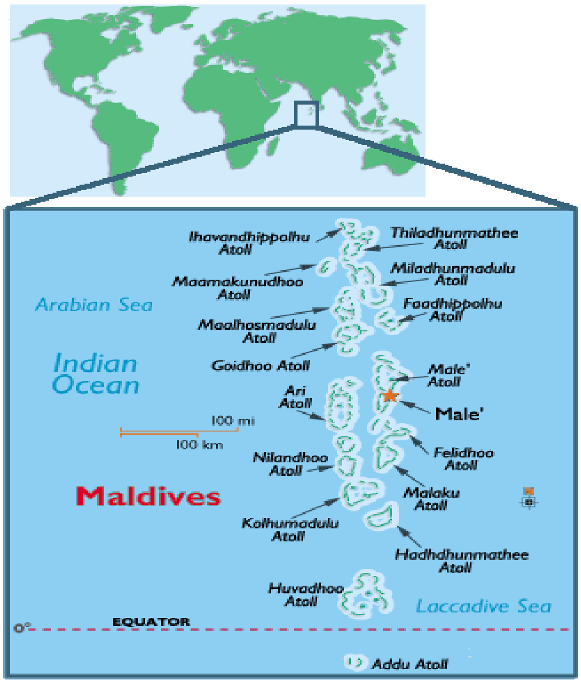

Figure 1.2b. The Maldives. An overview of Biosphere Expeditions' research sites, assembly points, base camp and office locations is at Google Maps.

Over 1,000 species of fish have so far been catalogued, including reef sharks, moray eels and a wide variety of rays such as manta rays, stingrays and eagle rays (Anderson et al. 1998). The Maldivian waters are also home to the whale shark.

Sharks, turtles, anemones, schools of sweetlips and jacks, eels, octopus and rays are also found in Maldivian waters.

To date at least 240 hard coral species have been described from 57 genera. 51 species of echinoderms, 5 species of sea grasses and 285 species of alga have also been identified.

1.3. Dates

2017: 15 - 21 July | 22 - 29 July.

The expedition ran over two seven-day periods (Saturday to Saturday) with two separate groups of participants. The first group included Reef Check training for participants, the second group was for qualified Reef Check Ecodivers only. Groups were composed of a team of international research assistants, guides, support personnel and an expedition leader (see below for team details).

1.4. Local conditions & support

Expedition base

The expedition was based on a modern four-deck, 115 feet live-aboard boat, the MV Carpe Diem, with ten air-conditioned cabins, an air-conditioned lounge and an open air dining area. The boat was accompanied by a 55 feet diving dhoni (boat) with multiple compressors, Nitrox and all facilities one would expect on a modern live-aboard. The crew provided tank refills and dive services. A professional cook and crew provided all meals.

Weather

The Maldives have a tropical and maritime climate with two monsoon seasons. The average day temperature during the expedition months was 28°C with overcast days, and occasional sunshine. Water temperature during the expedition was 28-30°C.

Field communications

The live-aboard was equipped with radio and telephone communication systems. Mobile phones worked in most parts of the study site as long as the boat was within the atolls.

The expedition leader also posted a diary with multimedia content on Wordpress and excerpts of this were mirrored on Biosphere Expeditions' social media sites such as Facebook and Google+.

Transport & vehicles

Team members made their own way to the Male' assembly point. From there onwards and back to the assembly point all transport was provided for the expedition team, for expedition support and emergency evacuations.

Medical support and insurance

The expedition leader was a trained first aider and the expedition carried a comprehensive medical kit. The main hospital is in Male' city and there are medical posts on many of the resorts. There is a recompression chamber on Bandos Island Resort near Male' and one on Ari Atoll. Emergency and evacuation procedures were in place, but did not have to be invoked as there were no emergency incidences, medical or otherwise. There was one case of an inner ear infection, which was treated on the boat.

1.5. Scientist

Dr. Jean-Luc Solandt is a Londoner with a degree in Marine Biology from the University of Liverpool. After graduating, he spent a year diving on the Great Barrier Reef assisting field scientists in studies on fisheries, and the ecology of soft corals and damselfish. He returned to the UK and enrolled in a Ph.D. in sea urchin ecology in Jamaica, based both in London and Jamaica. He went on to be an expedition science co-ordinator for projects in Tanzania, the Philippines and Fiji, and is now undertaking campaign and policy work in planning and developing Marine Protected Areas in the UK. He has been the Reef Check co-ordinator for the Maldives since 2005, and has thus far led three expeditions to undertake surveys inside and outside Marine Protected Areas on the islands. Jean-Luc has over a thousand dives clocked up since he trained to be a marine biologist 20 years ago. Dr. Solandt could not attend the expedition due to family issues, but led it remotely from the UK and analysed and wrote up the results.

1.6. Expedition leader

Catherine Edsell was born in the UK into a family of mountaineers, skiers and adventurers. With wanderlust in her blood she left England in 1997 and set off to the jungles of Central America and Indonesia, lived in the Himalaya with locals, trekked through the Namib desert in search of elusive elephants and dived the oceans surveying coral reefs. Her passion for conservation grew as she sought out and trained with expedition organisations that echoed her ecological beliefs, and for seven years straight, her feet barely touched British soil as she lived the expedition life in all manner of terrains. In 2014 Catherine was awarded a fellowship of the Royal Geographical Society for her continued contribution to conservation through expedition work. She is also a mountain leader, PADI Divemaster, coral reef ecologist and Reef Check trainer, and has led in the Azores, the Maldives and Musandam for Biosphere Expeditions. When not on expedition, Catherine teaches yoga, rock-climbs and dabbles in the flying trapeze.

1.7. Expedition team

15 – 21 July 2017: Hassan Ahmed* (Maldives), Farah Amjad* (Maldives), Ian Fergusson (UK), Nizam Ibrahim* (Maldives), Christina Klemme (USA), Hani Omar (UAE), Richard Riley (UK), Adam Saaneez* (Maldives), Ibrahim Shameel* (Maldives), Michele Steffey (USA), Ida Vincent (USA), Charlotte Youlten (UAE), Hussein Zahir* (Maldives).

22- 29 July 2017: Jenan Alasfoor (Oman), Nora Barson (UAE), Lori Cottrell (USA), Ian Fergusson (UK), Declan Madigan (Ireland), Graham McDermid (New Zealand), Janet McDermid (New Zealand), Jon Okabayashi (USA), Richard Riley (UK), Christian Schneid (China), Michele Steffey (USA), Adam Wood (USA).

*Participants marked with a star took part in the expedition as part of an education and placement programme kindly supported by the Rufford Foundation via LaMer.

1.8. Other partners

On this project Biosphere Expeditions worked with Reef Check, the Marine Conservation Society, the Maldives Marine Research Centre (MRC) of the Ministry of Fisheries and Agriculture, the MWSRP, the MV Carpe Diem, LaMer and the Rufford Foundation. Data will also be used in collaboration with the Global Coral Reef Monitoring Network and the University of York, which has a department of conservation. Our long-term dataset is not only of interest to conservationists working on monitoring the global status on reefs, such as those from the United Nations Environment Programme, the World Conservation Monitoring Centre and the International Coral Reef Action Network (ICRAN), but more locally too, especially with regard to the effectiveness of current Maldivian Marine Protected Areas in their ability to protect and recover significant numbers and biomass of commercially important finfish.

1.9. Acknowledgements

This study was conducted by Biosphere Expeditions, which runs wildlife conservation expeditions all over the globe. Without our expedition team members (listed above) who provided an expedition contribution and gave up their spare time to work as research assistants, none of this research would have been possible. The support team and staff (also mentioned above) were central to making it all work on the ground. Thank you to all of you and the ones we have not managed to mention by name (you know who you are) for making it all come true. Thank you also to Hussein Zahir of LaMer for guidance and advice. Biosphere Expeditions would also like to thank the Friends of Biosphere Expeditions for their sponsorship and/or in-kind support. Support from the Rufford Foundation via LaMer for the placement programme is gratefully acknowledged also.

1.10. Further information & enquiries

More background information on Biosphere Expeditions in general and on this expedition in particular including pictures, diary excerpts and a copy of this report can be found on the Biosphere Expeditions website www.biosphere-expeditions.org.

Copies of this and other expedition reports can be accessed via at www.biosphere-expeditions.org/reports. Enquires should be addressed to Biosphere Expeditions via www.biosphere-expeditions.org/offices.

1.11. Expedition Budget

Each team member paid towards expedition costs a contribution of £1,770 per seven-day slot. The contribution covered accommodation and meals, supervision and induction, all maps and special non-personal equipment, all transport from and to the team assembly point. It did not cover excess luggage charges, travel insurance, personal expenses such as telephone bills, souvenirs, etc., as well as visa and other travel expenses to and from the assembly point (e.g. international flights). Details on how these contributions were spent are given below.

Income	£
Expedition contributions	34,670
Grants	10,000
Expenditure	
Staff includes local & international salaries, travel and expenses	2,335
Research includes equipment and other research expenses	557
Transport includes taxis and other local transport	171
Base includes board, lodging and other live-aboard services	30,870
Administration includes some admin and misc costs	119
Team recruitment Maldives as estimated % of PR costs for Biosphere Expeditions	6,733
Income – Expenditure	**3,885**
Total percentage spent directly on project	**91%**

Please note: Each expedition report is written as a stand-alone document that can be read without having to refer back to previous reports. As such, much of this section, which remains valid and relevant, is a repetition from previous reports, copied here to provide the reader with an uninterrupted flow of argument and rationale.

2. Reef Check survey

2.1. Introduction and background

The Maldives comprises 1,190 islands lying within 26 atolls located in the middle of the Indian Ocean approximately 700 km southwest of Sri Lanka and at the tip of a submerged ridge (the Chagos – Maldives – Laccadive ridge), rising 3,000+ metres from the abyssal plain to the surface, where the islands emerge to form the atolls (Fig. 1.2b). The Maldives covers approximately 90,000 km^2, yet the land area covers less than 1% of this total (Spalding et al. 2001). Together, the Lakshadweeps and the Maldives constitute the largest series of atolls and faros in the world (Risk and Sluka 2000).

The highest point of the islands is approximately 2.4 m as all the islands are naturally made from fine coral sand. About 10% (200) of the islands are inhabited, with by far the largest population living in Male' - the capital. Of the (approx.) 440,000 population of the nation, a little over 130,000 people live in the 1.8 km^2 of Male', making it one of the most densely populated urban areas on Earth (United Nations 2018 estimates[1]).

The atoll lagoons range from 18 to 55 m deep and within these are a number of patch reefs. Reef structures common to the Maldives include 'thilas' (submerged reefs with tops from a few metres below the surface), smaller 'giris' and 'faros' (the latter similar to giris, but ring-shaped reefs with a central lagoon) (Fig. 2.1a).

Figure 2.1a. Common reef structures of the Maldives (from Tim Godfrey).

[1] http://www.worldometers.info/world-population/maldives-population/

The outer reefs that fringe the atolls have the greatest expanse of coral growth, growing upwards and outwards towards the incoming current, thereby acting as breakwaters of swell and tide. Dead coral material from these atolls and inner patch reef drifts to the leeward sides of the outer reefs. This process of constant erosion of the reef material and deposition of sediments is responsible for constructing the 1,190 islands of the archipelago. This natural dynamic process has been altered by the numerous human habitations and stabilised to a degree by the colonisation of many of the islands by natural vegetation.

The Maldives has two monsoon (wind and current) seasons. The Northeast Monsoon brings in dry winds from the Asian continent that last between January and March. The relatively wet Southwesterly Monsoon runs from May to November. Global warming may have affected these seasonal trends in recent years, with less clear discrepancy between wet and dry seasons. The current direction, however, has remained relatively constant. Air temperature ranges between about 31°C and 21°C and varies little between seasons. The monsoon currents have a key bearing on the distribution of pelagic planktivorous animals across the archipelago. For example, Manta rays (*Manta birostris*) are often found in the sheltered sides of reefs relative to the incoming current, feeding on the plankton that drifts to the leeward side of the reef system (Anderson et al. 2011).

In terms of biodiversity, the Maldives atolls form part of the ‘Chagos Stricture’ and are an important stepping-stone between the reefs of the eastern Indian Ocean and those of East Africa (Spalding et al. 2001). The fauna therefore comprises elements of both eastern and western assemblages. Diversity is high with over 240 scleractinian corals, with maximum diversity reported towards the south (towards Huvadhoo Atoll) (Picheon and Bnezoni 2007, Risk and Sluka 2000). Over 1,000 fish species have been recorded from the Maldives, a large proportion of which are reef associated (Anderson et al. 1998).

Fisheries

Tourism and fisheries are the two main generators of income for the Maldives[2]. Most of the finfish taken from the Maldives are tuna (by weight) with both yellowfin and skipjack species dominating the catch with small amounts of bigeye also taken (Marine Stewardship Council[3]). Up until 2010, Maldives fishermen solely used pole, line and hand line fishing techniques to take skipjack and yellowfin tuna. As such, the Maldivian tuna fishery has been marketed by many supermarkets in the UK as sustainable, because the volume of catch taken by pole and line is relatively small compared to many longline fisheries around the Indian Ocean and there is minimal by-catch of other fish, cetaceans and turtles. The Maldives has also recently banned shark fishing (2010), which can be regarded as a major conservation measure because of the catastrophic declines in the global populations of reef and pelagic predatory shark species (Graham et al. 2010). Although this is a commendable measure undertaken by the Maldives government, it is very difficult to enforce without significant investment in water-borne vessels. The Maldives has a relevant enforcement department (the Environmental Protection Agency, EPA), but

[2] https://tradingeconomics.com/maldives/gdp-growth-annual
[3] https://fisheries.msc.org/en/fisheries/maldives-pole-line-tuna/about/

this is woefully underfunded, nor is there the sophisticated satellite-based ship tracking equipment that is used in the Indian Ocean. The ban on the export of shark products introduced in 2011 has undoubtedly made it more difficult for Maldives-based fishers to trade in shark parts and anecdotal evidence from Maldives dive operators suggests that in some areas sharks appear to be increasing in number.

A decision made by the Maldives government in March 2010 to open the Maldives waters to domestic long-line fishing, whilst excluding vessels from other nations (principally from Sri Lanka), is highly controversial. This was a reaction to the reduction in yellowfin catch by Maldivian fishermen recorded between 2005 (186,000 tonnes) and 2008 (117,000) (Minivan News 2010)[4], making traditional pole and line fishing techniques from larger vessels unprofitable.

There has been a growing demand for reef fish species in recent decades, partly because of the expansion in the numbers of tourist resorts across the nation (Wood et al. 2011) and mostly because of the growth in the export market to the Far East, which is serviced by grouper cages that have been set up within a number of atolls. Wholesalers periodically visit the grouper cages that are stocked by local fishers to buy the fish to export live and fresh-chilled to foreign markets. A report by the Maldives Marine Research Centre (MRC) in 2005 highlighted a declining catch since 1997, three years after the commercial fishery started in 1994 (Sattar and Adams 2005). A further report by MRC in 2008 showed that demand for reef fish had tripled in the last 15 years and that a management strategy for grouper was needed to ensure sustainable catches into the future (Sattar 2008). MRC has recently worked with the Marine Conservation Society to develop a management plan for grouper. Some of the recommendations from past reports, including provision to increase the minimum landing sizes for some species into the grouper cages and for market, have met with resistance in some atolls. Given the small sizes of many species seen in the wild as outlined in a previous report (Solandt and Hammer 2015), it is regrettable that the trajectory for the Maldives fishing out their grouper population as a viable commercial species is a distinct possibility over the next ten years. A new project by the Blue Marine Foundation is working in the south with resort partners and government to reform fisheries management around spawning locations at Laamu atoll[5], but other than that there appears to be no concerted effort to protect grouper stocks from being fished out.

Coral bleaching

Probably the most serious current threat to global coral reefs is the effect that global warming has by bleaching hard corals. Coral bleaching is a stress response by corals whereby corals expel symbiotic algae (zooxanthellae) from their tissues as temperature rises for a prolonged period above an ultimately lethal threshold. Although the temperature threshold at which corals bleach varies by region and coral type, the temperature threshold at which corals become stressed in the Maldives is regularly cited as 30ºC (Edwards et al. 2001). The exact temperature and how long it persists elicits different responses in different coral species and genera. Broadly speaking, the longer the corals are in contact with elevated sea surface temperatures, the greater the likelihood that the corals will

[4] http://minivannews.com/environment/cabinet-approves-long-line-fishing-for-maldivian-vessels-5385
[5] http://www.bluemarinefoundation.com/project/maldives/

bleach. And the longer the coral host is unable to re-acquire zooxanthellae, the greater the likelihood that the coral will die from starvation, as it gains most of its energy from the sugars produced by the algal cells within its tissues.

1997 and 1998 Reef Check surveys and bleaching event

During April and May 1998 a temperature of over 32ºC was recorded in the Maldives for a period of more than four weeks. This led to mass bleaching down to at least 30 m (Edwards et al. 2001). Shallow reef communities suffered almost 100% mortality with live coral cover of central reefs decreasing from about 42% to 2%, a 20-fold reduction from pre-bleaching cover. Since 2005, Reef Check surveys have observed few large colonies of massive reef building corals, and a much higher proportion of faster growing Acroporids and Pocilloporids, particularly at sheltered inner atoll reefs (personal observations and Cowburn et al., in press). This suggests there has been patchy recovery due to recruitment of new, more ephemeral corals, rather than recovery from survival and regrowth of older colonies that recovered zooxanthellae immediately after the warming event.

The 1997 and 1998 Reef Check surveys were carried out by both MRC staff (Zahir et al. 1998) and by local resort marine biologists. Zahir and co-authors showed that the principal families to bleach were the shallow-water *Acroporidae* and *Pocilliporidae*. More resilient corals included the *Agariciidae* and *Poritidae* families that form more massive coral species. Others (e.g. Clark et al. 1999) found that the coral cover in the range of 23-70% cover pre-bleaching fell to 0-10% post-bleaching in many sites.

The 2015/2016 El Niño / bleaching event

The El Niño of 2015/2016 was the second largest bleaching event on record for the Maldives since the 1998 event, with large tracts of Indian Ocean reefs bleaching between March and May 2016 (see Fig. 2.1b). Before the bleaching event reached the Maldives it devastated the reefs of Asia (Thailand, Malaysia, Indonesia and the Philippine archipelago). In addition 22% of the reefs in the Great Barrier Reef were very seriously bleached and the wider Pacific Ocean saw bleaching throughout most of 2015.

Seawater temperatures were recorded by colleagues at Baros Maldives throughout the 2016 bleaching event. They recorded the temperatures at their house reef on the island from April to May 2016 (Table. 2.1a).

Table 2.1.a. Surface seawater temperatures (SST) recorded at Baros Maldives from 1 April through to 26 May 2016.

	Temperature degrees C			
	5 m	10 m	15 m	20 m
1-Apr	30	30	29	29
7-Apr	30	30	29	29
14-Apr	31	30	30	30
21-Apr	32	31	30	30
28-Apr	32	32	31	31
5-May	32	32	31	31
12-May	31	30	30	30
19-May	30	30	30	30
26-May	30	30	30	30

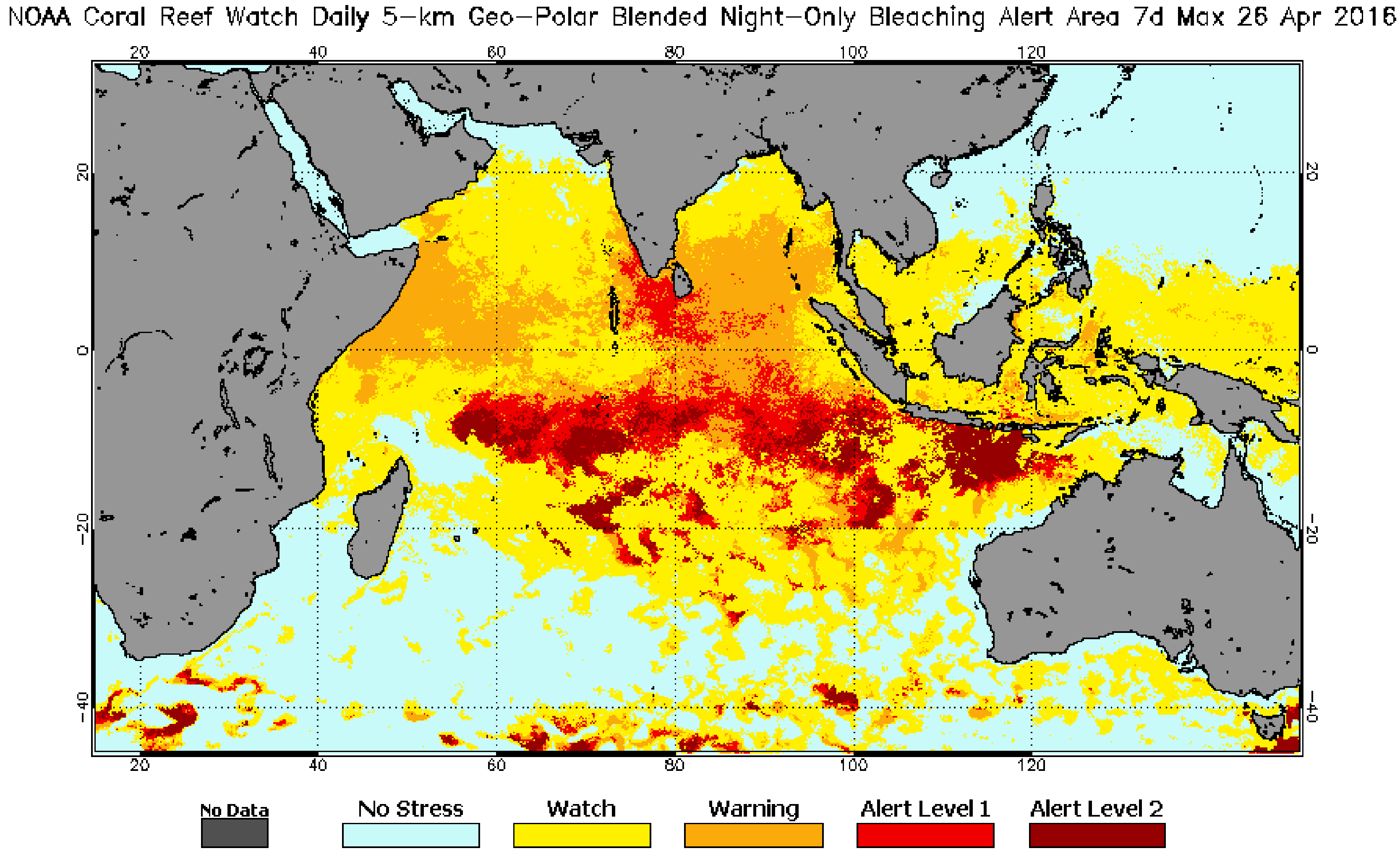

Figure 2.1b. Coral bleaching coincided with a warm water ‘pulse’ that moved from south to north over the islands between April and May 2016.

The 2016 bleaching event was similar to the 1998 bleaching event for its severity, longevity and impacts (Afzal et al. 2016). It is clear from the state of Maldives reefs that the 1998 event has had a long-term impact on the coral cover and population of some reefs of the nation (see all Maldives Biosphere Expedition reports since 2011 by Solandt and various other authors, cited in the literature below). Direct loss of coral cover was less during the 2016 than the 1998 bleaching event, but only because reefs were at a lower baseline condition in 2015 than they were in 1997 (own observations, Pisapia et al. 2016 and Fig 2.1c).

The concern regarding the Great Barrier Reef and the Maldives, where such bleaching events appear catastrophic in the short term, is that of the ability of reefs to continue to recruit and grow whilst staving off the deleterious effects of repetitive bleaching events, as well as increasing ocean acidification, which makes it more difficult for corals to assimilate carbonate skeletons (e.g. Perry and Mason 2017). Growth and a continuous assimilation of the entire coral structure of the Maldives (a so-called net positive carbon budget) is quite literally the foundation of the nation. It allows the Maldives to be structurally secure and to keep pace with a number of potentially catastrophic events such as (1) increased storminess (related to increased energy in the seas due to increased surface warming translated to ocean-derived weather events), (2) thermal expansion of our seas (due to increased temperature effects on the surface of the ocean) and (3) sea-level rise (due to melting ice-caps).

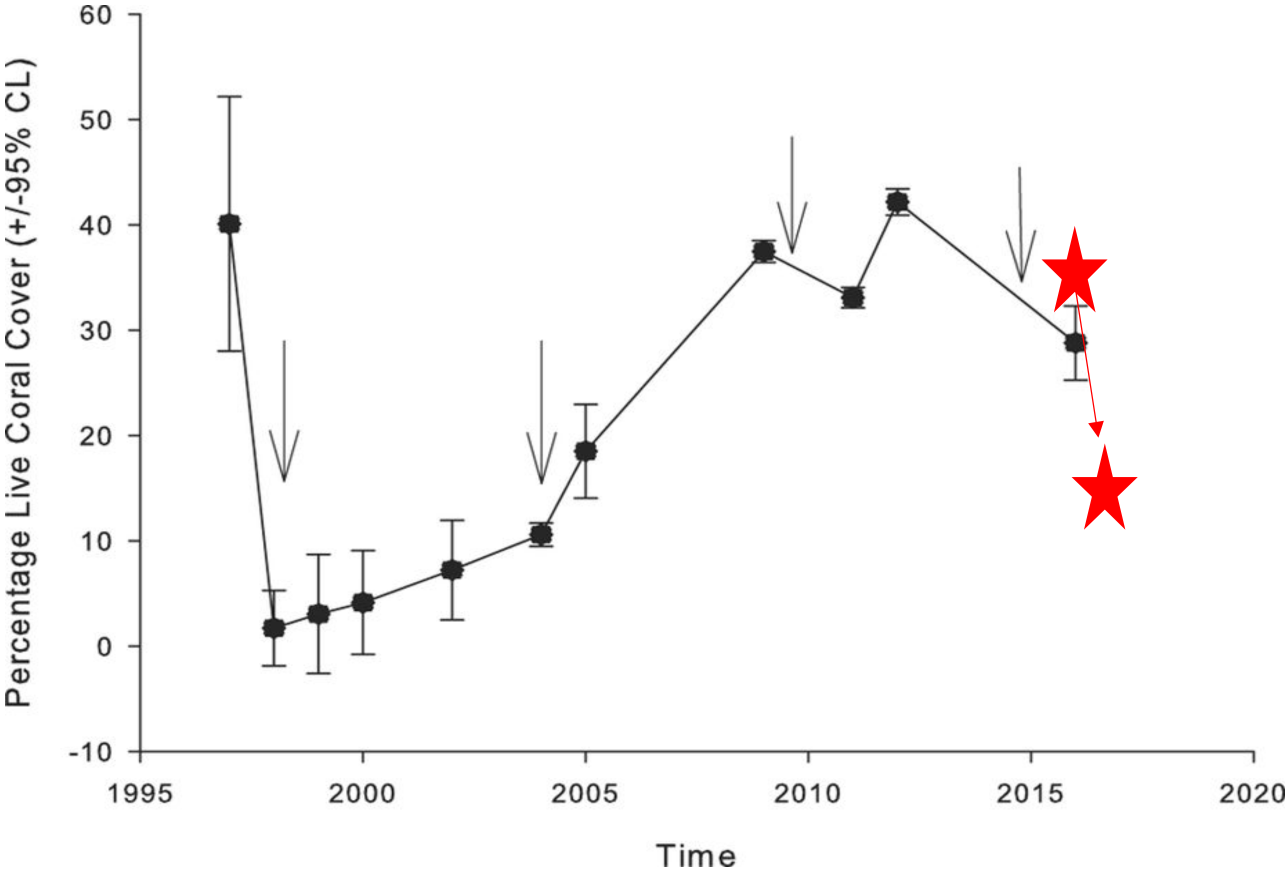

Figure 2.1c. Coral cover through various events in the recent Maldives history (from Pisapia et al. 2016). Major events (arrows) are: 1998 - bleaching, 2004 – tsunami, 2010 – bleaching, 2015 – Crown-of-Thorns outbreak. The 2016 event impact (coral cover from 34% to 12% for the sites discussed in this report) is superimposed in red on this plot to give a sense of our own recent perspective (Solandt et al. 2016).

Longer-term effects of bleaching events include erosion of dead coral skeletons to sand and rubble, which leads to less buffering of wave action around the atolls, which in turn leads to beach erosion. This carries significant potential cost for the Maldives[6], as explained above.

Indeed many of the surveys in recent years by our expeditions have identified rubble slopes at around 10-15 m depth at some of the more sheltered reefs. We believe these predominantly consist of corals that died during the 1998 bleaching event and were broken down by subsequent wave action and the boring action of worms and bivalves (Solandt et al. 2013). Under gravity, they fell to the lower reaches of the reef. Such coral rubble is a problem, as its continuous movement and erosion makes it near impossible for corals to recruit onto the moving substrate and grow.

A University of British Columbia[7] survey by Hauert et al. (1998) undertook extensive Reef Check surveys in Angaga Island in June 1998, three months after the catastrophic bleaching event. 80% of corals were dead and covered by fine filamentous algae.

Biosphere Expeditions and MCS undertook the first 'bleaching recovery' surveys in 2012, and found that the reefs of Ari atoll were generally recovering well, from the outer channel reefs of the north east, to the inner south central house reefs (including those at Angaga Island in the centre of the atoll) (Solandt et al. 2013). Surveys carried out in September 2015 found many sites to be affected by storms, leading to breakage of corals and damage to shallow and deeper reefs. Ari was considered to have been less affected by the 1998 bleaching event than reefs nearer the capital, at Male' atoll (Zahir, personal communication).

Environmental threats to Maldives reefs

Maldives reefs are under threat from both local anthropogenic and global climate-induced pressures. Key threats are:

- Climate change and associated sea surface temperature increases leading to coral bleaching (from human caused increases in CO_2 concentration)
- Increased atmospheric CO_2 concentration that results in seawater acidification; this leads to decreased skeletal strength of calcium carbonate-dependent corals, decreased growth rate, and decreased reproductive output of corals
- Overfishing of keystone species (e.g. predators of Crown-of-Thorns and herbivorous fish).
- Sedimentation and inappropriate/unsustainable atoll development
- Poor water treatment
- Solid waste

[6] http://ecocare.mv/beach-erosion-a-vulnerable-scenario-in-the-maldives/
[7] http://www.math.ubc.ca/~hauert/publications/ReefCheck98/index.html

Governance and management issues

There are a number of governance, socio-economic and political issues within the Maldives that reduce the ability of local, atoll and national management of these pressing issues. Perhaps paradoxically, the recent past has seen the Maldives embark on a process to establish more marine protected areas, and to lobby for decreases in global CO_2 emissions. At the same time, there is a push to develop more islands for tourism. There is a chasm between the understanding of political leaders in what constitutes good resource management (e.g. the establishment of MPAs on paper) and the requirements to make them work – for both biodiversity and local communities. This is a problem in the UK as much as it is in the Maldives. Solutions require extensive interaction between community-based scientists and practitioners with government officials – at the highest levels. Only with this investment into developing solutions and effective marine protection systems – from local individuals being empowered to report on declines and necessary management implementation (and enforcement) – will nations start to recover biodiversity where it has been damaged and preserve it where it has remained in a good condition during the last 50 years of rapid population expansion.

Biosphere Expeditions surveys are carried out on an annual basis to record conditions at permanent monitoring sites in North Male' and Ari atolls, and to undertake bleaching recovery survey assessment dives. They are relatively cost-effective as fee-paying citizen scientists and external funding (from the Rufford Foundation) help support the work. But in order to really expand the knowledge of reefs and their status, we need many more Maldivians to progress Reef Check-style projects, which is why Biosphere Expeditions has a placement programme with the aim of seeding community-based monitoring programmes.

Out of this programme have come various initiatives such as educational booklets in 2011, the first-ever all-Maldivian Reef Check survey in 2014, continued community-based survey efforts in 2016 and 2017. Most recently, graduates of the placement programme founded Reef Check Maldives. However, in the current political and economic climate it is hard to retain traction with graduates as they avoid controversial subjects such as reef protection and seek paid, rather than voluntary, work.

Maldives reef surveys

In order to help the Maldives in facing up to some of these issues, Biosphere Expeditions and the Marine Conservation Society have been developing a survey and training programme. Our aims are to:

- Increase the information base on the status of Maldives reefs in collaboration with local partners (e.g. the MRC / MWSRP / MDA)
- Build capacity in local marine management and resource assessment
- Provide educational resources at key sites around the Maldives
- Collaborate with environmentally-sensitive tourism operators and resorts in undertaking reef protection measures, and reef survey assessments

In order to undertake this, we have:

- Undertaken Reef Check surveys at over 30 sites in seven years, compiled and quality-assessed the data, and sent it to Maldivian and international coral reef monitoring programmes

- Trained eight individuals employed in government marine resource assessment surveys, NGOs and from the tourist and diving industry whilst on liveaboard expeditions; we have also undertaken training of ten individuals (private consultants, resort marine biologists and MRC staff)

- Designed, printed and distributed (with the 'Live and Learn' Foundation) over 500 guides on the effectiveness of coral reef conservation to school children

- Undertaken training in resorts and with local dive operations and have collaborated with resorts to train staff and provide them with Reef Check and other reef survey resources

2.2. Methods and planning

Aims

The 2017 surveys were carried out in order to

- Record any incidents of recovery from the 2016 bleaching

- Carry out effort-based transects of the South Ari Marine Protected area reef for whale sharks

- Undertake Reef Check Trainer training for three and Reef Check EcoDiver training for another three local people

- Conduct Reef Check surveys at sites in central east Maldives Reef Check locations that were surveyed in 1997

For the first week of the expedition (15 - 21 July 2017) we surveyed seven sites (see Table 2.3a.) in Ari atoll: The training site at Baros Maldives, as well as Rasdhoo Madivaru, Bathalaa maagaa, Kudafalhu and Holiday thila to the south of the atoll. For the second week (22 - 29 July 2017), we selected sites that had been surveyed by MRC in 1997 with the aim of giving an indication of the 20-year pattern in reef change across larger parts of the central Maldives. Reefs surveyed in week two were Embudhoo kandu (just to the south of the north/south Male' channel), Felidhoo faru (to the north of Felidhoo atoll), Ambaru faru (an inner reef site in the centre of Felidhoo atoll), Fotteyo faru (to the eastern edge of Felidhoo atoll), Vattaru faru (to the southern edge of Felidhoo) and finally Maduvaree faru (to the north-eastern side of the atoll (see Fig. 2.3a)).

Reef Check

Reef Check has been carrying out volunteer citizen scientist dive surveys since 1997 - the International Year of the Reef (Hodgson 1999). It was designed to increase the amount of information of the health status of the world's coral reefs in the absence of funding and manpower to mobilise enough reef scientists to carry out surveys themselves. It has successfully increased the capacity to record the health (and changing health) of reefs and their natural resources (Hodgson and Liebeler 2002). It has been used by visitors to developing countries, but more importantly, has led to increased capacity amongst local populations to record the condition of their own reefs.

Reef surveys were carried out in the Maldives by MRC staff from 1997 to 2009 (Zahir et al. 2005), but the opportunity to undertake research on board either the liveaboards and / or tourist islands of the country has not been fully realised. MCS has carried out sporadic Reef Check surveys with liveaboards since 2005 and trained the Baros Maldives resort in Reef Check survey techniques in 2010. However, training and surveying has been fairly piecemeal up until 2010, only providing data from a few survey locations (Solandt et al. 2009). Reef Check requires surveys to be carried out over relatively flat (<45 degree slope) reef profiles in areas of limited current at between 3 m and 12 m, and ideally year on year. This limitation often excludes surveys at the most well-known dive sites of the Maldives that tend to be in waters too deep or charged by currents too dangerous to carry out safe line-transect Reef Check surveys. Most channel dives are at 30m depth – too deep for transects to be laid with air, and in current conditions too challenging for recreational divers. Therefore dedicated survey trips aboard Maldivian liveaboard vessels, such as the ones carried out by Biosphere Expeditions for the purpose of this study, are necessary to fully realise the potential to gather data safely from a greater range of sites.

Biosphere Expeditions carried out logistics, health and safety on board the research vessel and recruitment of citizen scientists. The scientific programme, training and data collection and analysis was led by Dr Jean-Luc Solandt, Reef Check Course Director.

All training was carried out on board the MV Carpe Diem during the first three days of the expedition in week one. The second week of the expedition was for Reef Check qualified divers only, so there was no training necessary. In-water refresher training was undertaken at Baros Maldives house reefs in southern North Male' atoll.

The methodology used was the internationally accredited Reef Check method as described in previous reports (Afzal et al. 2016, Solandt and Hammer 2012 & 2015 & 2017a, Solandt et al. 2013 & 2014 & 2016).

In addition, up to 20 images were taken along the transect for subsequent analysis for assessing coral lifeforms. Images were taken of frames between 20 and 50 cm wide (identifiable along the Reef Check transect, with the transect within the image frame).

Images were subsequently loaded into Coral Point Count (CPC), which was used to generate ten random points over each image, and subsequently record the proportion of different coral lifeforms at four sites: two outer reef sites (Rasdhoo madivaru and Bathalaa maagaa); and two inner reef sites (Holiday thila and Kudafalhu).

2.3. Results

Sites surveyed

Sites surveyed during the 2017 expedition were a mixture of inner atoll sites (thilas and giris) and outer reef walls and slopes. Sites (Table 2.3a / Fig 2.3a) were selected on the basis that Biosphere Expeditions and MCS had surveyed these areas since 2005 (Rasdhoo madivaru) and 2008 (Dega thila), thus giving a longer-term perspective to the data of reefs that had recovered since the 1998 bleaching event. We also wanted to understand any differences in patterns between the more sheltered inner atoll reefs with lesser water circulation and depth, and the outer reefs, which are adjacent to much greater water depths.

The second week of surveys focused on easily accessible sites that were first visited and surveyed by Reef Check and MRC (including Hussein Zahir) in 1997.

Table 2.3a. Site names and locations. See also Figure 2.3a below.

Site name	Latitude	Longitude	Inner / outer reef	Atoll	Surveyed in week
Baros Maldives*	4 16 59.4 N	73 25 40.2 E	Inner	Ari	Not surveyed
Rasdhoo madivaru	4 15.947 N	73 0.17 E	Outer	Ari	1
Bathalaa maagaa	4 3.34 N	75 57.41 E	Outer	Ari	1
Kudafalhu	4 1.052 N	72 48.311 E	Inner	Ari	1
Dega thila	3 50.665 N	72 45.083 E	Inner	Ari	1
Holiday thila	3 29 40.56 N	72 49 21.85 E	Inner	Ari	1
Embudhoo kandu	4 7 7.76 N	73 28 1.95 E	Inner	South Male’	2
Felidhoo faru	3 40 39.50 N	73 28 8.80 E	Outer	Felidhoo	2
Ambaru faru	3 26 6.42 N	72 25 19.59 E	Inner	Felidhoo	2
Fotteyo faru	3 26 54.14 N	73 45 16.37 E	Inner	Felidhoo	2
Vattaru faru	3 13 26.97 N	73 26 0.27 E	Outer	Felidhoo	2
Litholhu kandu	3 26 49.08 N	73 35 48.12 E	Outer	Feliddhoo	2
Maduvaree faru	3 5 57.60 N	73 33 57.96 E	Channel	Mulaku	2
Dhigaru faru	3 6 20.00 N	73 37 5.00 E	Outer	Mulaku	2

*Training site.

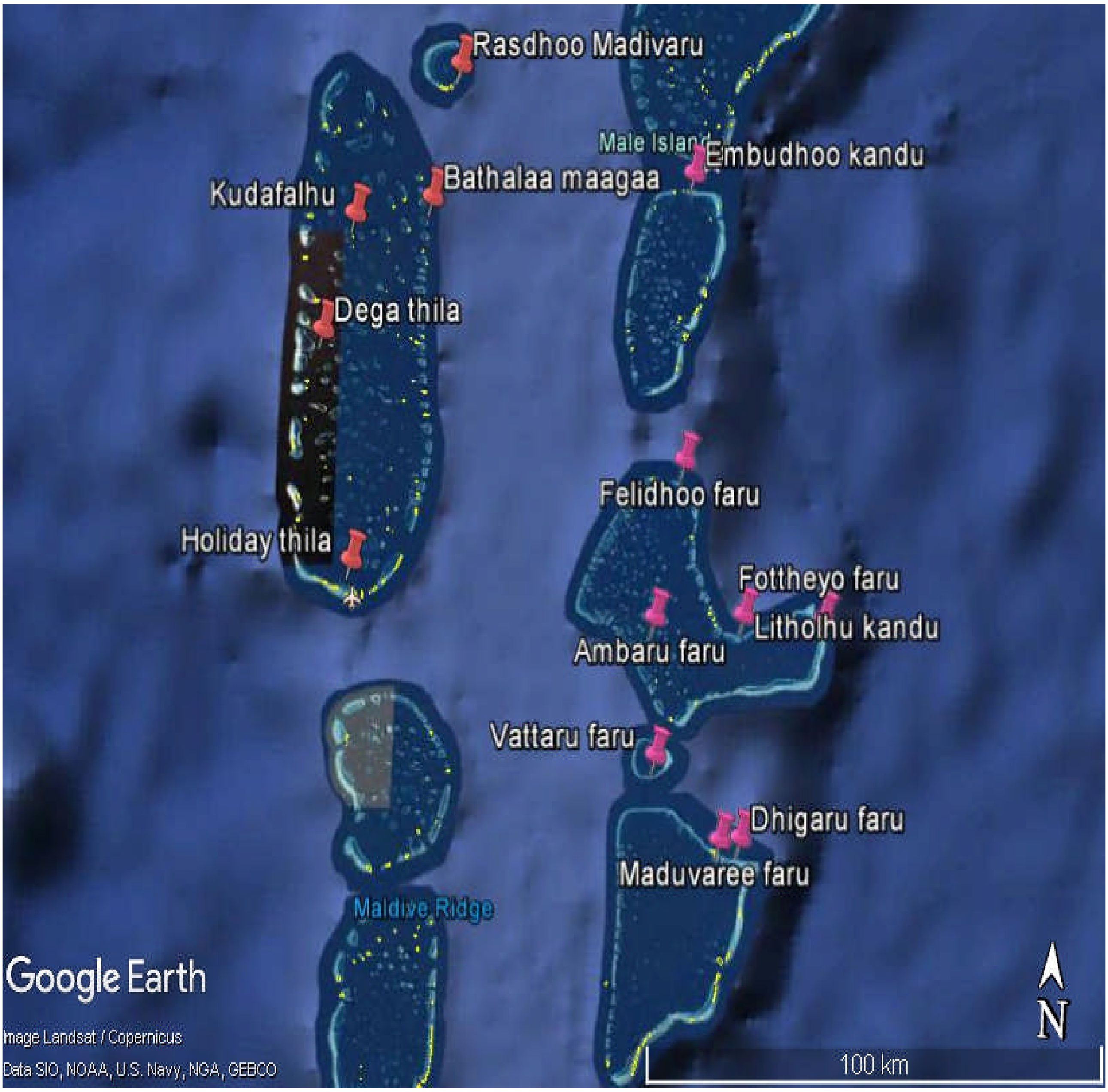

Figure 2.3a. Central Maldives atolls with the survey locations.
Week 1 surveys (red pins), week 2 surveys (pink pins).

Reef Check results & coral cover

Site-by-site survey results of all Reef Check surveys in the categories of fish, invertebrates, substrate, bleaching/coral disease/trash/other, as well as off-transects sightings of megafauna and other interesting species are available via the Reef Check database[8]. Extracted from these, Figs. 2.3b and c show the decline in hard coral cover (at inner and outer reefs) over all years of surveys.

[8] http://data.reefcheck.us/

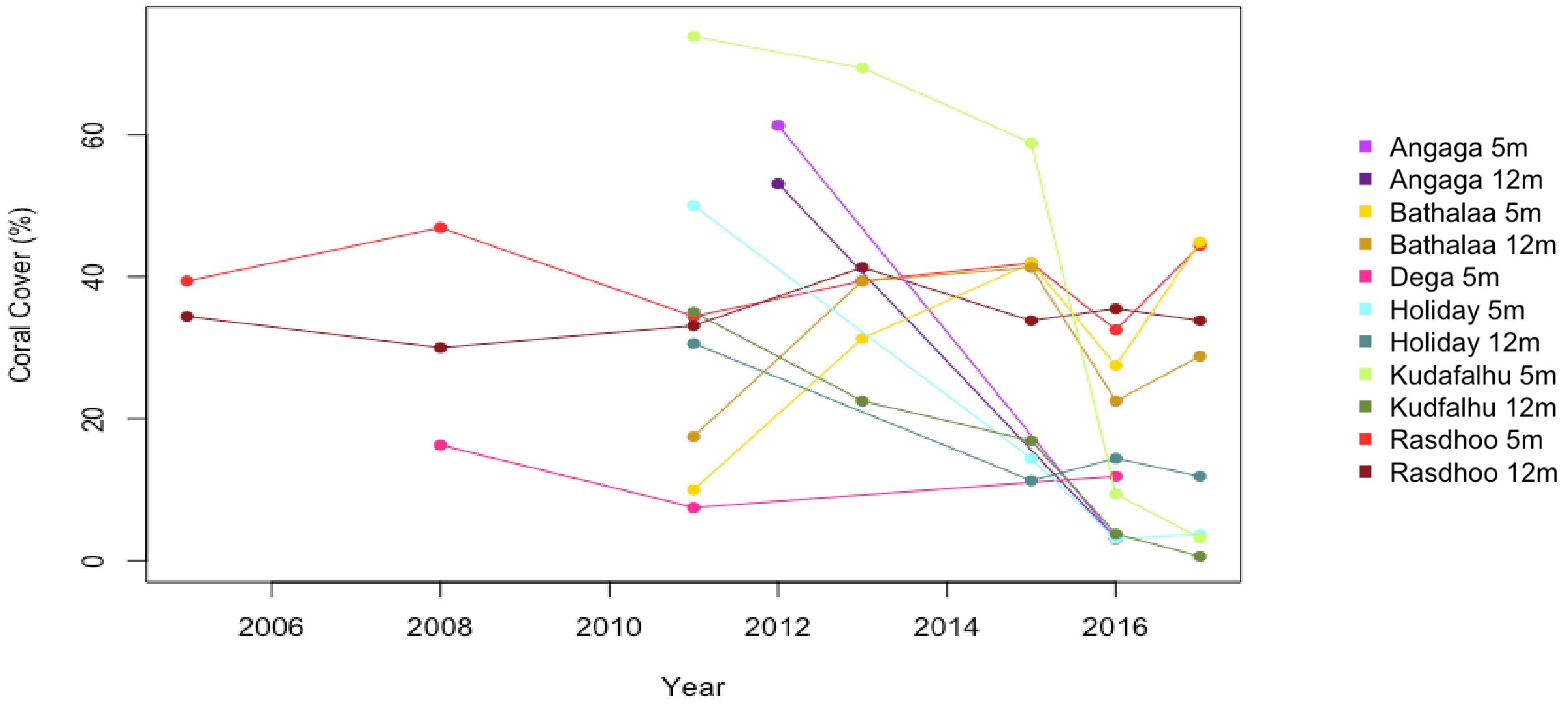

Figure 2.3b. The overall pattern of coral reef decline and recovery of Ari atoll over the six years of Biosphere Expeditions surveys 2011-2017. Angaga, Dega, Holiday and Kudafalhu are inner reefs that have declined at shallow (5 m) and medium (12 m) depths from a range of 10-70% cover to a range of 0-15%. Outer reefs had a range of 10-40% in 2011 rising to 30-45% by 2017 (from Cowburn et al. in prep).

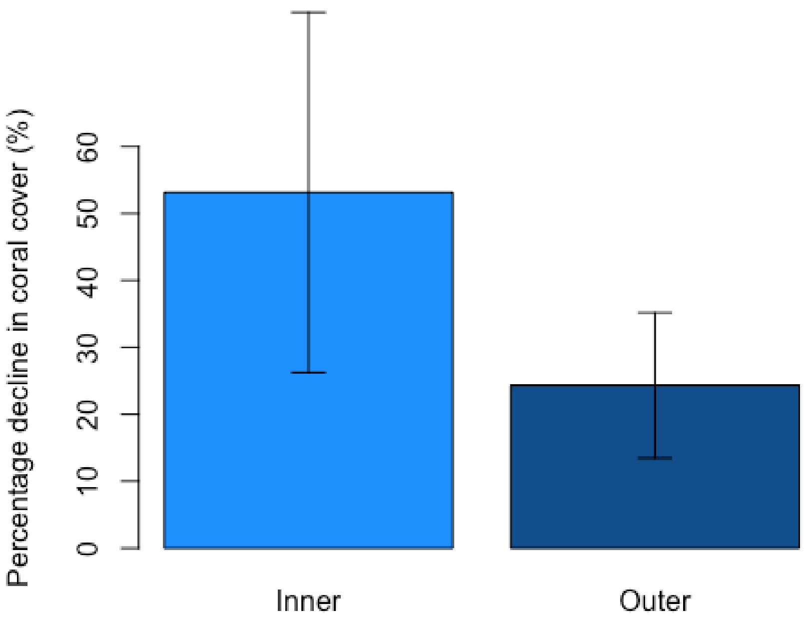

Figure 2.3c. Mean % hard coral and (bleached) hard coral cover decline in inner and outer reefs of North Ari atoll visited between 2011 (the first year of Biosphere Expeditions surveys) and 2017 (the most recent year). Error bars are Standard Deviation.

CPC results

CPC results are summarised in Table 2.3b. It is clear from the data that there was an overwhelming dominance of massive and encrusting coral colonies in the outer reefs (Rasdhoo and Bathalaa) compared to inner more sheltered reefs (Kudafalhu and Holiday) (Table 2.3b). Sheltered reefs were dominated by branching and table colonies.

Table 2.3b. Mean identifiable coral lifeform percentage cover at Reef Check sites in Ari atoll. Figures are generated from points randomly generated by CPC_e and overlayed onto seabed images taken from a number of photos (beween 15 and 26 per site) at 5 m depth in July 2017 All photos were taken along the 100 m Reef Check transect from sites in Fig 2.3a.

Lifeform*	Site			
	Kudafalhu (n=26)	Holiday (n=19)	Rasdhoo (n=15)	Bathalaa (n=18)
Massive	6.51	1.76	25	17.58
Foliose	0	0	0	0
Encrusting	1.77	2.35	12.12	7.27
Branching	12.37	1.76	12.88	0
Table	21.24	17.64	0.76	0
Corymbose	10.85	10	9.1	2.42
Solitary	0	0	0.76	0
Total 'live' population[$]	**0.4**	**1**	**43.95**	**20.6**

*Lifeform denotes all corals, whether dead or alive that had an identifiable lifeform. See http://krupp.wcc.hawaii.edu/BIOL200/powerpnt/pdffiles/coralanatomy.pdf for a list of lifeform examples.
[$]The mean % of points that were live hard corals from all randomly generated points from all images.

Site name	Mean depth (m)	2017 % hard coral cover	Historical % coral cover (year)
Bandos	8	1.9	34.4 (2009)
Embudhoo	5	9.4	32.5 (2012)
Felidhoo	6	20	No data
Litholhu	5	53.1	No data
Fottheyoo	9	37.5	56.9 (2012)
Ambaru	9	6.5	28.1 (2012)
Vattaru	8	5.3	31.9 (2012)
Maduvaree	6	10.9	43.8 (1997)
MEAN		**18**	**38**

Figure 2.3d. Week 2: South Male', Felidhoo (Vaavu) and Mulaku atoll historic average percentage hard coral cover at sites, relative to Reef Check surveys in 2017. Historic data are from Reef Check surveys in the past either by Biosphere Expeditions or Marine Research Centre staff.

Coral populations at eastern central atolls differed significantly in their change from historical baseline conditions, with declines in cover recorded from pre-bleaching (2016) conditions at 6 out of 8 sites, with the other 2 sites not having any baseline data (Fig. 2.3d).

Invertebrate populations

Invertebrate populations (of significant and/or keystone species) generally were higher in the reefs of Ari atoll compared to eastern atolls (Fig. 2.3e).

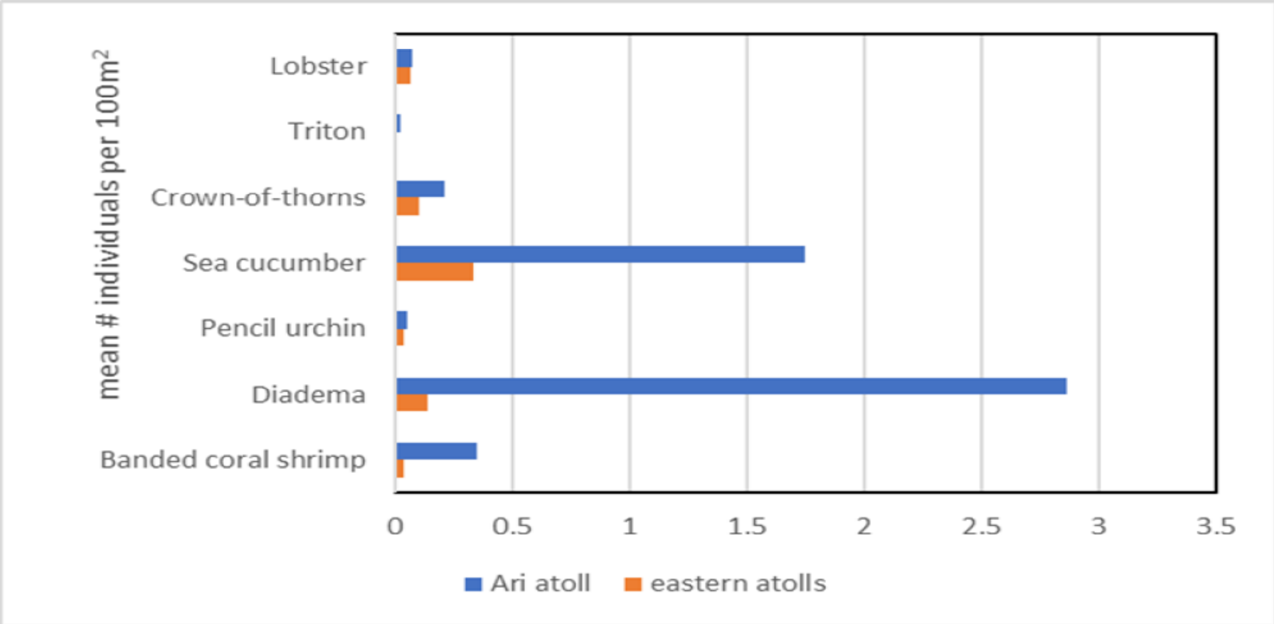

Figure 2.3e. Numbers of different invertebrates recorded on the dives at Ari compared to eastern atoll sites. Crown-of-Thorn numbers were dramatically reduced at Kudafalhu (0.06 per $100m^2$) compared to 2016 (14 per $100m^2$).

Other impacts, including bleaching

Impacts beyond bleaching were relatively limited on the reefs surveyed. Most incidences of observed damage were caused by *Drupella* gastropods feeding from deep within the corals of branching *Acropora* colonies. There is some indication in 2017 from diver observation that the sites in eastern atolls were more significantly affected by bleaching than the population in Ari atoll. However, these incidences were very low relative to the overall population of living corals (Fig. 2.3f), suggesting that there was negligible bleaching in 2017.

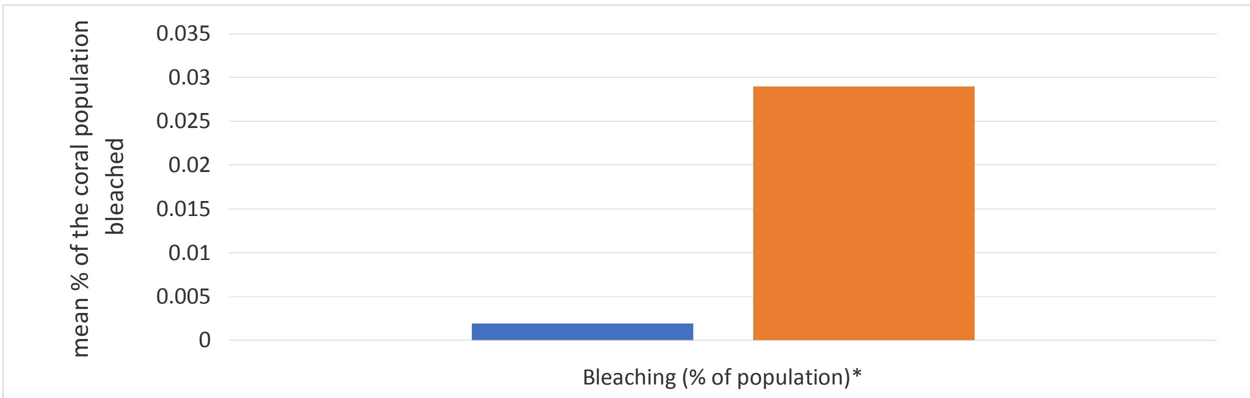

Figure 2.3f. The percentage of the live coral population that was bleached, combined from all sites visited in 2017. The mean proportion of the living population bleached is very low (blue), and amount per colony (orange) is also low.

In terms of other impacts, there was significantly more fishing-associated litter debris in Ari atolls compared to eastern atolls. Fragments of line were generally calcified monofilament fishing line. Not nets or traps were recorded.

Other marine life and noteworthy observations

Reef Check recorded incidences of unusual, rare or threatened marine life, both on transect and off transect (Fig 2.3g; Table 2.3c).

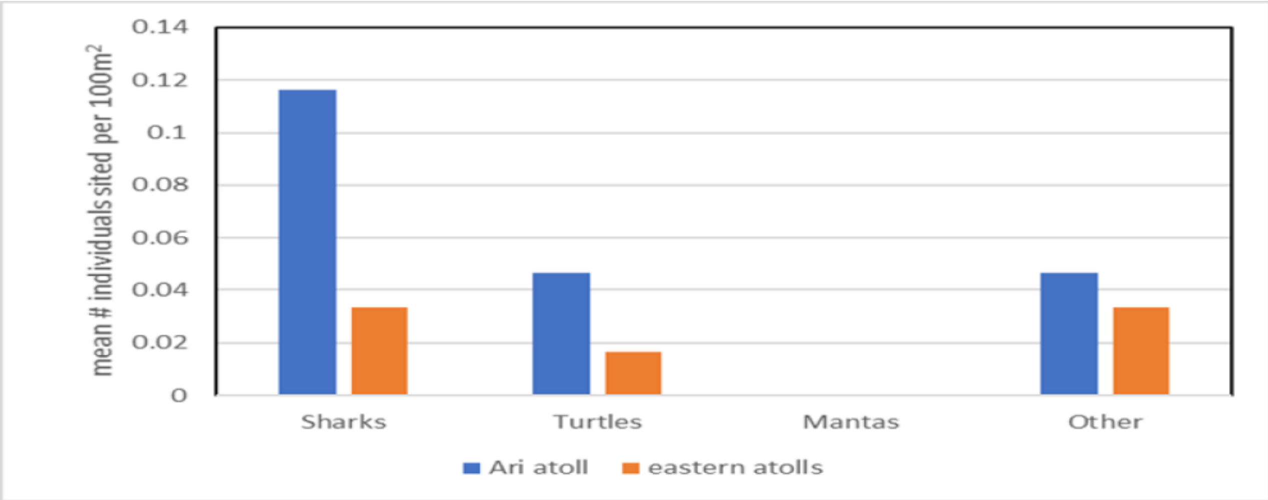

Figure 2.3g. Numbers of unusual or rare species, or species of conservation concern combined from each dive site visited during the 2017 expedition.

Table 2.3c: Other noteworthy observations.

Site name	Observation	Atoll	Inner/outer reef
Rasdhoo Madivaru	1 stingray, 1 manta, 2 hawksbill & 1 green turtle	North Ari	Outer
Bathaalaa	2 white tip reef sharks	North Ari	Outer
Kudafalhu	1 COT; 4 dead giant clams	North Ari	Inner
Dega thila	4 white tip reef sharks; 2 dead giant clams	South Ari	Inner
Holiday thila	1 banded sea snake; 1 dead giant clam	South Ari	Inner
Bandos	1? Octopus	North Male'	Inner
Embudhoo Kandu	None	South Male'	Inner
Felidhoo faru	1? Octopus; 1? small cowrie & many *Drupella* snails	Felidhu	Outer
Ambaru Faru	3 Mobular rays (off transect)	Felidhu	Inner
Fotteyoo Faru	None	Felidhu	Inner
Vattaru Faru	Lots of herbivorous fish	Felidhu	Inner
Litholhu kandu	1? Spotted eagle ray; school of 80 parrotfish	Felidhu	Outer
Maduvaree Faru	None	Mulaku	Outer
Dhiggaru faru	Pod of spinner dolphins	Mulaku	Outer

A half-day effort-based whale shark survey was also carried out at the outer reef of South Ari Marine Protected Area, yielding one encounter at Maamigili on 21 July 2017. The animal was 6 m long and had previously been identified by the Maldives Whale Shark Research Project as 'Adam'.

Fish populations

Fish populations were recorded at both Ari atoll in the west and more easterly atolls to ascertain if there was a longitudinal difference in the fish populations (Figs. 2.3h and i). There was a small difference in diversity, with a greater abundance of butterflyfish, snapper and parrotfish at Ari than at eastern atolls. However, there were slightly greater numbers of grouper in the eastern atoll sites, perhaps because of the lack of resorts in Felidhu and Mulaku atolls (only two resorts in each according to 2004 figures). Ari atoll alone (north and south) has 27 resorts (2004 figures)[9]. As such, the eastern atolls are highly likely to receive less direct fishing pressure of these highly prized food fish from resort-based and/or local island fishers.

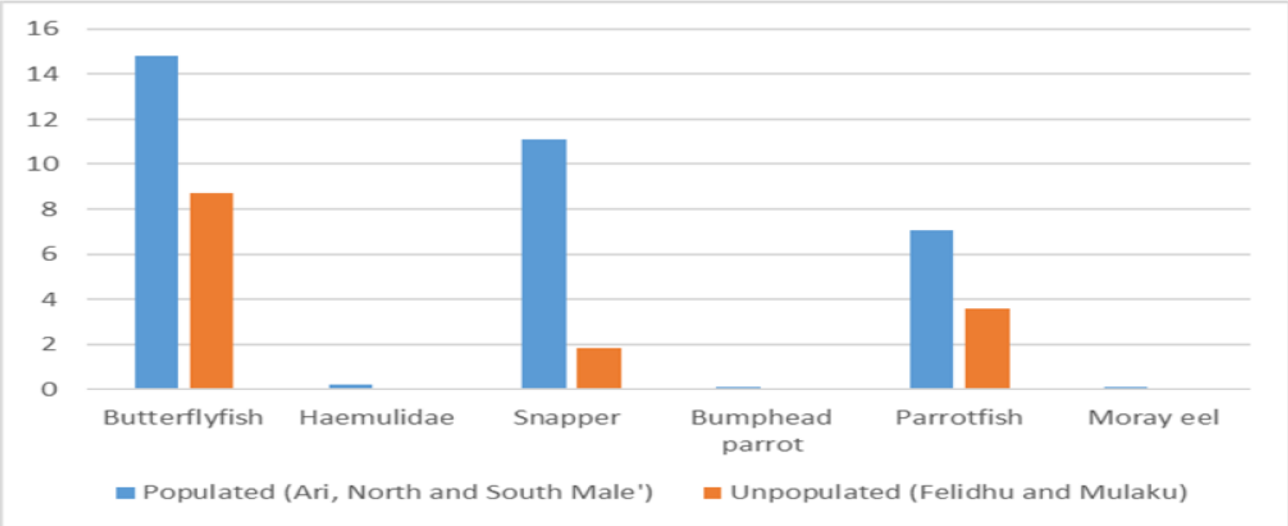

Figure 2.3h. Fish populations in heavily populated atolls (Ari, North and South Male') vs eastern relatively under-populated eastern central atolls (Felidhu and Mulaku). Y-axis values are numbers of fish per $100m^2$.

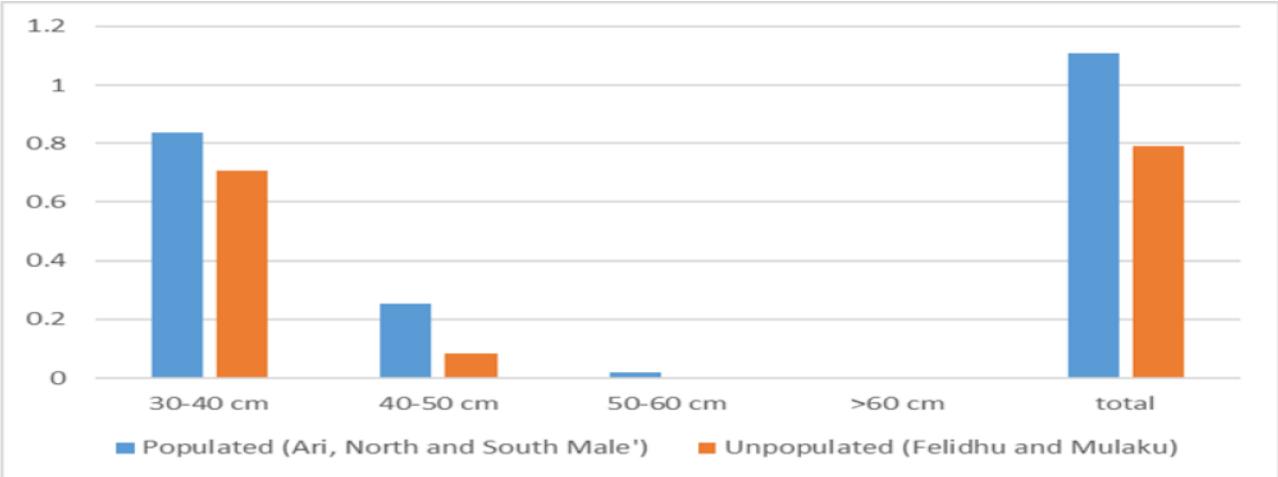

Figure 2.3i. Grouper numbers and size in heavily populated atolls (Ari, North and South Male') vs eastern relatively under-populated central eastern atolls (Felidhu and Mulaku). Y-axis values are numbers of fish per $100m^2$.

[9] Atlas of the Maldives (2007) – www.atolleditions.com.au

Fish were also observed and compared between inner reef vs outer reefs (Fig. 2.3j).

Butterflyfish made up the most dominant numbers of fish recorded at most reefs.

There was a much greater abundance of snapper on inner reefs compared to outer reefs. Parrotfish numbers appeared to be similar on both inner and outer reefs. These are important grazers of algae, so their relatively high numbers are a good sign for local reefs. These fish should never be fished in order to allow reefs to be in a reasonable condition to enable coral recruitment after a bleaching event.

Grouper populations were dominated by moderate numbers of relatively small individuals (Fig. 2.3i) – most sizes for the larger-growing species were very much below maximum size, which is in line with previous reports (Afzal et al. 2016, Solandt and Hammer 2012 & 2015 & 2017a, Solandt et al. 2013 & 2014 & 2016).

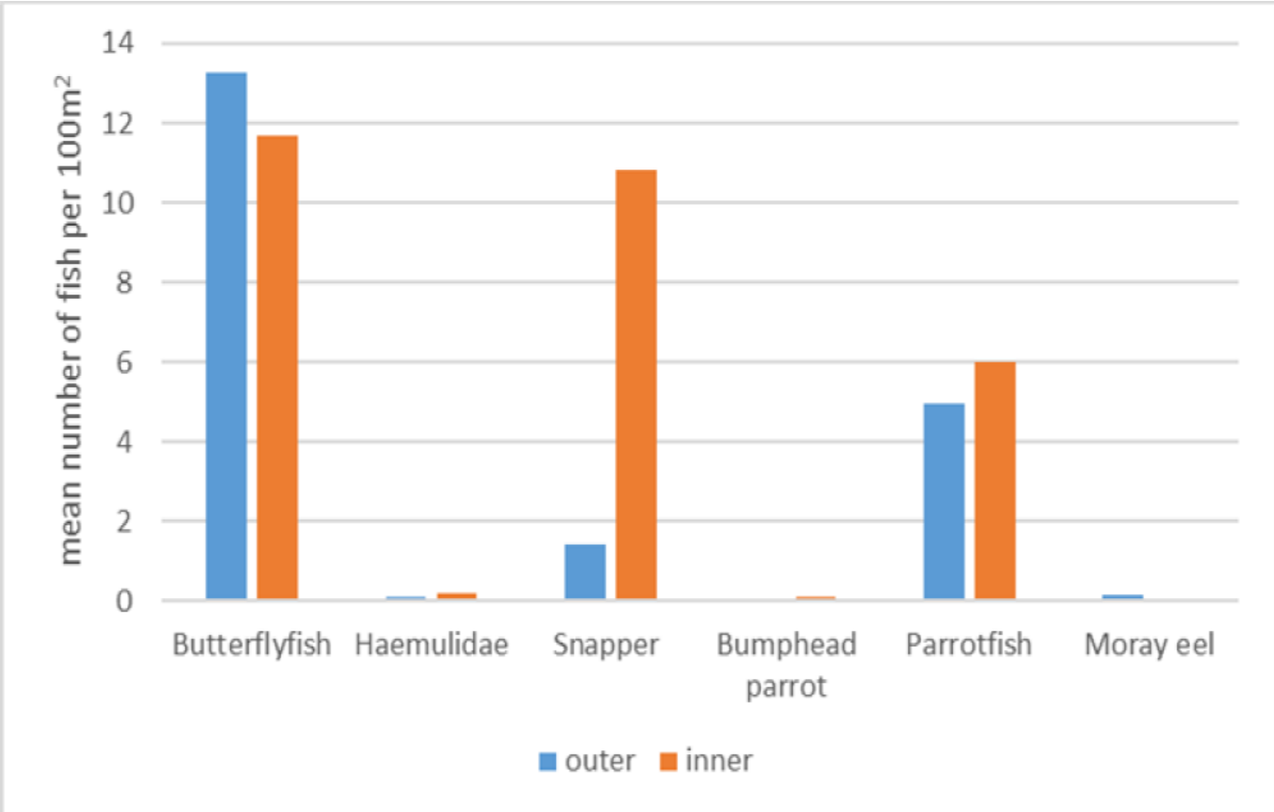

Figure 2.3j. Mean number of different fish populations at all outer (n=5) vs inner (n=8) reefs.

2.4. Discussion and conclusions

Reef resilience: inner vs outer reefs

It is apparent that at the two outer reef sites where MCS and Biosphere Expeditions have been undertaking longer-term monitoring (Rasdhoo madivaru and Bathaalaa maagaa), there is greater resilience of live coral than at the inner atoll sites (Fig 2.4a). Live hard coral cover increased from 25 to 36.5% between 2016 and 2017 at Bathalaa maagaa; and from 33.4 to 39.1% at Rasdhoo madivaru. Both of these are outer sites. Concurrently, coral cover at inner sites fell from 14.7 to 7.8% at Holiday thila, and 6.6 to 1.9% at Kudafalhu. This clearly indicates greater resilience in the outer reefs.

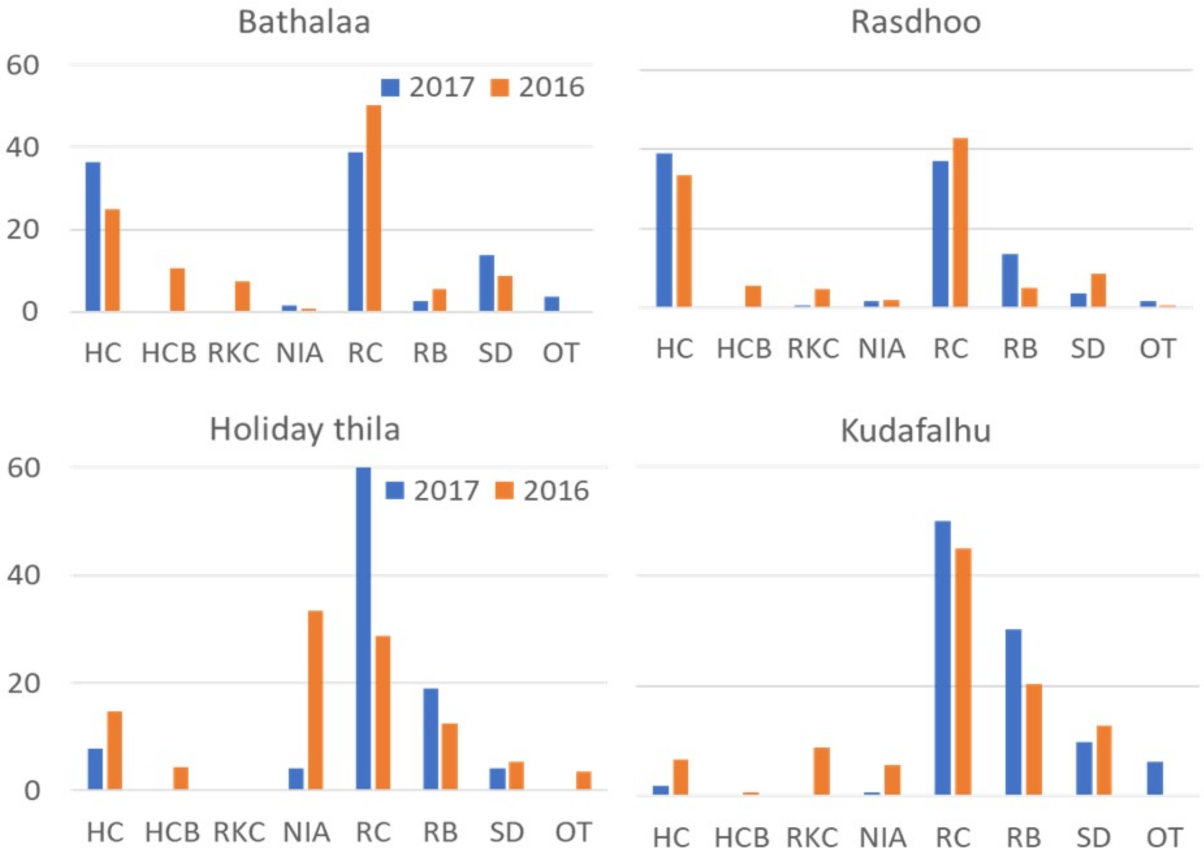

Figure 2.4a. Difference in benthic cover at four sites in 2016 and 2017. Two of these sites are in more exposed outer reef locations (Rasdhoo and Bathalaa). Two reefs are inner reefs (Kudafalhu and Holiday thila). The plot clearly shows recovery in live hard coral cover (HC) by the outer reef sites (upper plots) compared to the inner reef sites, which show further declines in live hard coral cover. HC = hard coral, HCB = hard coral bleached, RKC = recently killed coral, NIA = nutrient indicator algae, RC = rock, RB = rubble, SD = sand, OT = other.

Rasdhoo madivaru, Dhigurah wall (surveyed in 2016 at the southern end of Ari atoll, outside of the island of Mamigili), Fotteyoo and Litholhu appear to be the most resilient reefs to bleaching. These are all outer reefs, or (in the case of Fotteyoo) a backreef wall adjacent to a very exposed outer reef (at the eastern end of Felidhoo atoll).

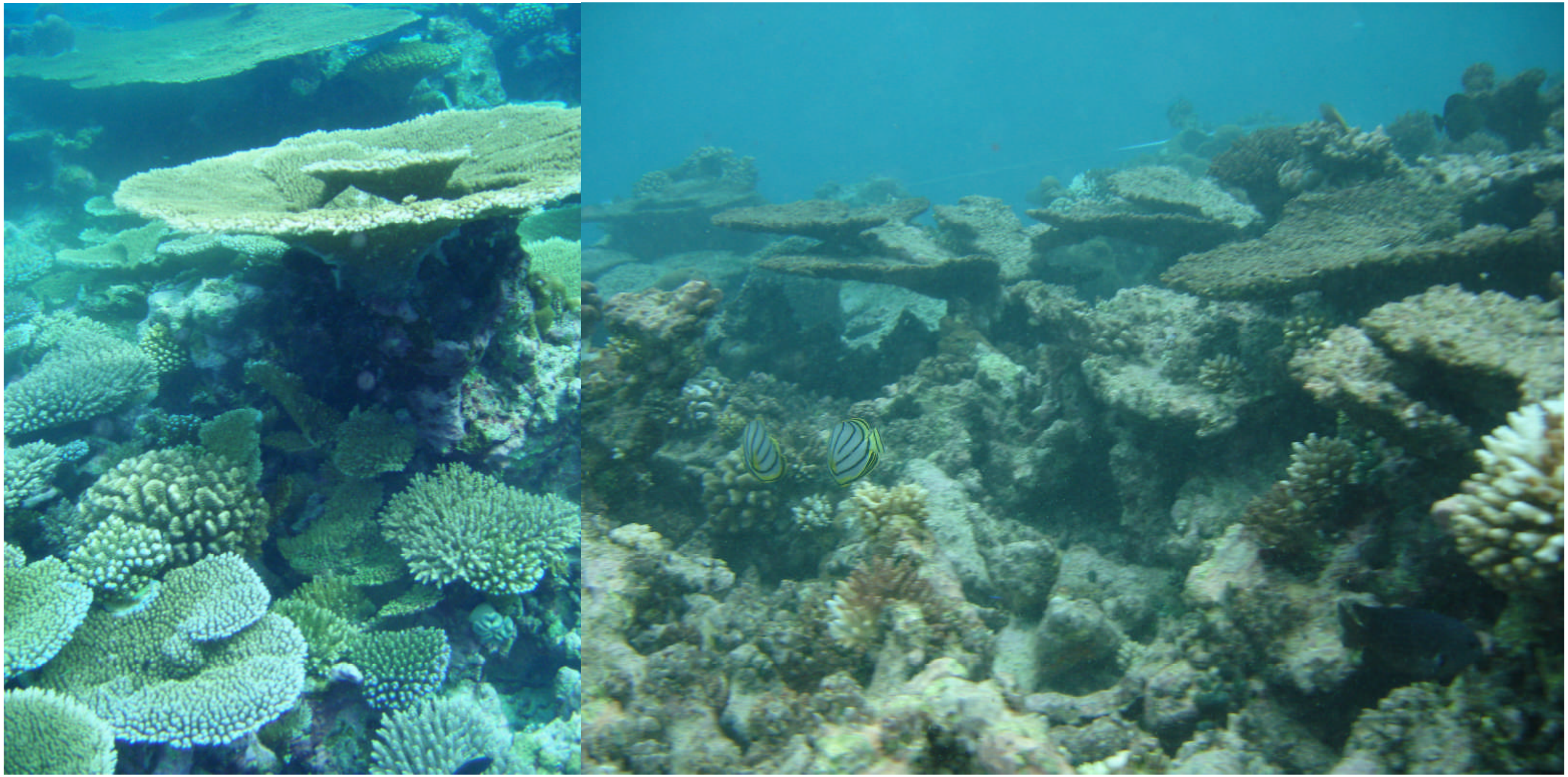

Figure 2.4b. Left: Dega thila (western Ari atoll, sheltered inner reef) in 2011. Right: Same site, same depth (2 m) in 2016, two months after the bleaching event. Relative hard coral cover was 68% in 2011, 16% in 2016 and 14% in 2017.

Understanding historical change in coral cover and assemblages

It is important to understand historical change, not only in the absolute cover of live hard coral, but also the coral assemblages themselves. It appears that massive and encrusting lifeforms are more resilient than table life forms. Massive and encrusting life forms are more prevalent on exposed forereef crests and drop-offs. The robust life forms that are more resistant to breakage from wave action also happen to be more resistant to temperature-induced bleaching (Baird and Marshall 2002). Badly damaged reefs from central parts of the atolls in sheltered areas (where wave action is relatively low), have been dominated by faster-growing, more delicate Acroporids (e.g. Solandt et al. 2013). For example, a visual comparison (Fig. 2.4b) of Dega thila before the bleaching event (in 2008) shows that table corals (*Acropora hycathinthus, A. cytherea* and *A. clathrata*) dominate the substrate of these sheltered sites.

The *Acropora* genera is known to be more susceptible to bleaching (Baird and Marshall, 2002), in part because of the relative exposure of the branching and table polyp corallites to external temperature compared to *Porites* corallites (Fig 2.4c).

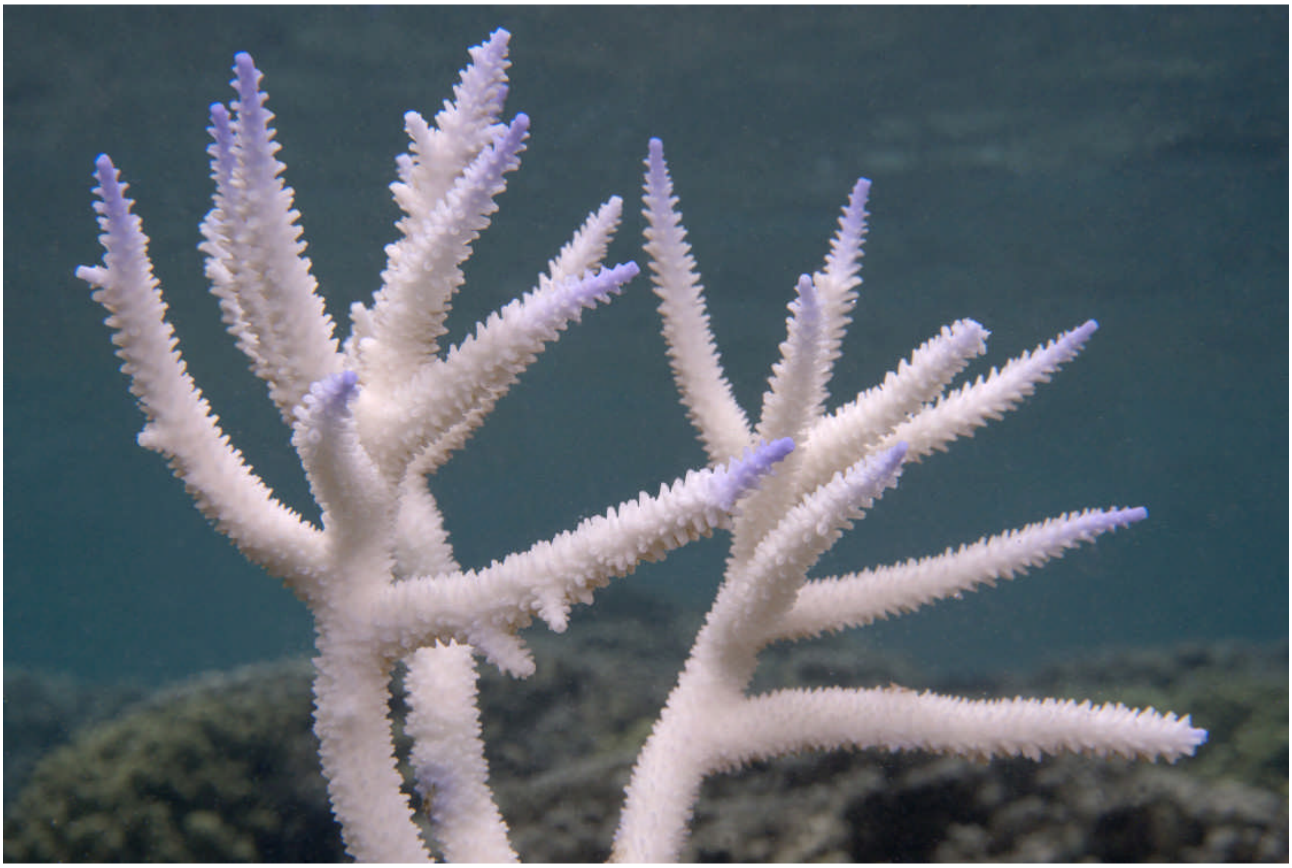

Figure 2.4c. A branching *Acropora* colony. Note the 'exposed' corallites along the whole colony (the bumps and spikes). Faster-growing *Acopora* are more susceptible to thermal-induced bleaching compared to genera with more recessed polyps (e.g. *Poritdae* family) (Baird and Marshall 2002)[10].

[10] http://www.reefresilience.org/coral-reefs/stressors/bleaching/bleaching-susceptibility/

Historical perspective

There have been four recorded bleaching events in the Maldives. Anecdotal reports exist (Al Edwards, Newcastle University) of one in the 1970s, another in 1982, then in 1998, 2010 and 2016 (Pisapia et al. 2016, Schumacher et al. 2005). The 1998 and 2016 events were significant, affecting a larger swathe of reefs of the nation, with bleaching also being recorded at many sites in eastern atolls in 2017 again. We see fewer of the susceptible taxa on reefs now – *Seriatopora hystrix* are absent, as are *Stylophora pistillata*. *Pocillopora* spp., whilst being extremely dominant in other shallow Indian Ocean, Red Sea and Persian Gulf reefs nearby (such as in Musandam, northern Oman, and Sharm el Sheikh region of the Red Sea), are very rare in the Maldives, as are representatives of the *Montiporidae* family. Some *Acropora* colonies do persist in the corymbose growth form, but the more slender branching, staghorn and almost all table growth forms were extremely rare in our monitoring sites in Ari in 2016 and 2017. However, their fast growth rates and high rates of recruitment from the 1998 bleaching event allowed them to recover from that event rapidly (Pisapia et al. 2016). It will be interesting to see if the recovery from the recent bleaching will be similar to that from 1998. If so, we believe that a more resilient form of zooxanthellae/coral association will have to accrue, as warming events are going to be more commonplace, particularly in a part of the Indian Ocean where the coolest temperatures are around 28ºC.

Long-term temporal change and resilience between Ari atoll sites

MCS has been collaborating with IUCN to put together an analysis on the broader spectrum of community change before and after the bleaching and the 2015/2016 Crown-of-Thorns outbreak (Pisapia et al. 2016). Data analysis shows a net increase or stability in coral cover in Ari atoll outer reefs (even with an increase in cover at Bathalaa maagaa and Rasdhoo madivaru) since 2011, whereas reefs in central atolls have either catastrophically declined (Kudafalhu, Holiday Thila) or have remained at quite a low baseline level (Dega Thila).

Our observations since 2011 indicate that the central atoll reefs of Ari and North Male' atolls are being increasingly colonised by non-coral lifeforms. There are fewer healthy shallow water reefs in the Maldives compared to other places in the nearby Arabian seas, e.g. northern Oman, (Solandt and Hammer 2017b) and Red Sea Ras Mohammed Marine Park, Sinai Peninsula (personal observations). Oman and the northern Red Sea appear to have escaped the worst effects of ocean warming, as their seas have not seen such large temperature rises in recent years and have more thermally tolerant species (e.g. Osman et al. 2017).

Much research is being undertaken throughout the world on the resilience of both coral zooxathellae adaptation and DNA variation between reslient and non-resilient zooxanthellae clades, along with the coral species that are able to withstand warming events (e.g. Roche et al. 2018). It has been established that there are coral lifeforms that are more resilient to bleaching, such as massive, brain and encrusting species and genera (dominated by Montipora, Porites and Faviids). Indeed our observations from images taken on the expedition show that the outer reefs of Rasdhoo Madivaru and Bathalaa Maagaa do host more *Porites* massive lifeforms than inner more sheltered reefs, making their resilience to bleaching more effective (Table 2.3b) (Cowburn et al., in preparation).

Whale shark sighting

The one sighting of a single 6 m male whale shark at Mamagili (Fig. 2.4d) re-confirms the value of the Maldives Whaleshark Reasearch Project (MWSRP) being in that location[11]. Recent research carried out by the University of York[12] has identified common oceanographic factors between areas of whale shark hotspots around the world (Australia, Belize, Mexico and Mamigili in the Maldives). All these sites are in areas of upwelling, or where deep water is adjacent to warm shallow areas (Copping et al. 2018). It is thought that as the sharks are ectotherms (cold blooded), they need to rise to shallow depths to warm up before plunging to (on average) over 400m in order to feed in persistant horizontal 'fronts', where their planktonic food is thought to aggregate. The other interesting fact about these hotspots is that they tend to be dominated by young sharks (<10 m length), perhaps suggesting that at a smaller size, they are more vulnerable to stress from their deep-water dives.

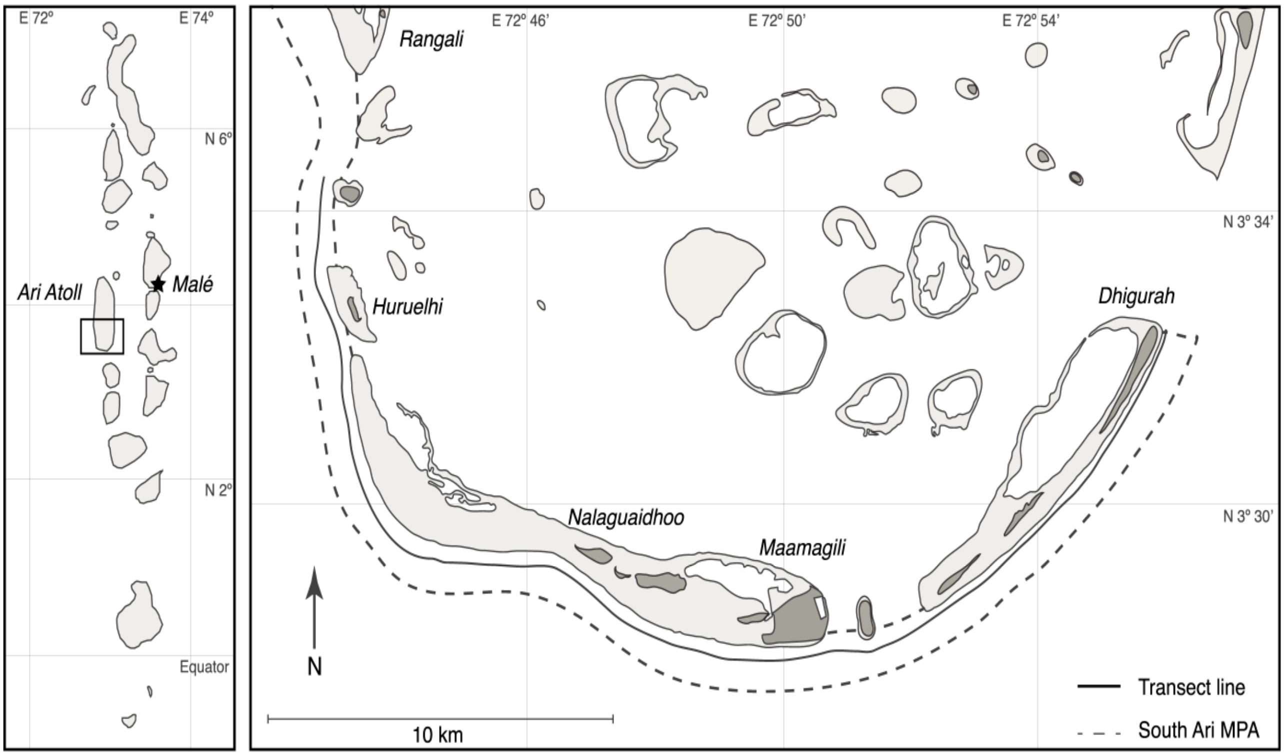

Figure 2.4d. The Mamigili MPA in South Ari atoll, Maldives. At a size of only 42km^2, it is narrow, but it extends along a large exposed southerly facing reef. It runs from the reef crest out in a southerly and westerly direction 600 and 900m out to the open sea.

[11] https://youtu.be/AKIHE9ULDuE
[12] https://www.york.ac.uk/news-and-events/news/2018/research/research-reveals-secret-to-whale-shark-hotspots/

Governance, politics and economics

A very worrying trend is emerging in the central Maldives: One of long-term and short-term impacts making a lasting impression on the coral assemblages, fish populations (Sattar et al. 2012) and the general health of the marine life surrounding the islands, with increasing incidences of disease (Montano et al. 2012), Crown-of-Thorns (Saponari et al. 2014) and corallimorph outbreaks. This trend is not new, and has been emerging since the mid to late 1990s. The decline of the Maldives reefs was set in motion in the 1990s by three principal factors:

1. The first mass-bleaching event in 1998 triggered by climate change events such as El Niño, ocean acidification, and increased sea surface temperature
2. The development of commercial fisheries for the live fish trade (principally targeting grouper)
3. The large-scale expansion of the tourism infrastructure beyond sustainable limits.

All of these three issues have had associated costs. Many Maldivians would indeed argue that the second and third points have helped provide jobs for Maldivian citizens. This is undoubtedly true; but at what cost? The initial area of concern (point 1) has recently been initially mitigated for by the policies and actions of former President Mohammed Nasheed (president 2008 – 2012). He was concerned over climate predictions resulting in sea level rise and increased storminess that could inundate the country. There are various climate models that predict the Maldives to be underwater within 50 to 100 years (e.g. Viner 2000[13]). However, since his political demise in early 2012, there has been scant regard to adapting local policies to reduce CO_2 emissions, nor to establish environmental policies that will benefit the most needy in outer island society, away from the commerce of Male' and the tourism industry.

Since 2015 there has been a push to increase tourist numbers. In 2017, visitor numbers increased to 1,389,542[14], with 27 new resorts planned for construction in 2017 alone. The proportion of tourists from China was 25% of the total in 2017, showing that the Maldives have been flexible in acquiring new markets whilst more traditional tourism markets from Europe fall (in the face of political unrest in the Maldives and the availability of alternative, less controversial holiday destinations). Investment in tourism is not matched by environmental precaution, or the "polluter pays" principle that is seen in UK and EU laws.

The instability of the political situation in the Maldives[15], along with the national debt, have led to a policy response to increase land and island reclamation for tourism expansion, which we argue goes well beyond any sustainable limit. This may have a short-term positive impact on the GDP of the islands, but the impacts on the wider ecosystem and population are very likely to be negative in the long run. Many of the islands of the Maldives are built on naturally 'shifting sands', so the concretion of the foundations of islands works against nature's natural buffering – that is to literally 'move' the sands at the tops of reefs into new areas from time to time.

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[13] https://crudata.uea.ac.uk/cru/posters/2000-11-DV-tourism.pdf
[14] http://divemagazine.co.uk/travel/7979-is-paradise-lost-maldives-special-report
[15] https://www.bbc.com/news/world-south-asia-40827633

The development of 'sea walls' and other concretions around islands only borrows time away from natural erosion and movement of island development.

In the past, the Maldives has lacked a champion for the protection and recovery of marine resources. However, the Maldives government has recently been making very well intended statements to reverse this trend. In June 2012, Dr Mariyam Shakeela, the (then) Minister for Environment and Energy, announced a programme of work between 2013 and 2017 in order to achieve UNESCO Biosphere Reserve status for the entire nation. According to this plan, at least half the atolls of the nation were to implement marine conservation efforts similar to that of Baa atoll. Despite the progressive political intentions of such statements, there was no strategy from government agencies tasked with dealing with this – such as the EPA or MRC. This is in part due to recent political turmoil, but also due to a government that seems to have no interest in investing into stewardship of its marine estate on a national basis. Indeed, since Biosphere Expeditions started working in the Maldives in 2011, cuts to the MRC have seen drastic reductions in its staff, and the monitoring team that existed since 2009 has been effectively disbanded. This means that regular monitoring of sites that informed the international community of the health status of Maldives reefs is now only undertaken by outside agencies (such as IUCN and Biosphere Expeditions). Many Maldives citizens have strong scepticism towards western conservation work in their islands. This is likely as a result of 'foreign' conservation efforts being considered alongside unsustainable foreign investment in the tourist industry that is at odds with the cultural norms – and indeed, the environmental limits of the nation. This is not ideal, because conservation projects for the Maldives then have to seek investment from foreign trust and grant foundations for long-term (decadal scale) monitoring programmes. It is not easy to 'sell' long term monitoring projects to funders who like to see 'new' projects, and want to see short-term results.

We believe that an entirely different approach is needed to managing the Maldives: a system whereby power is devolved to atoll councils with a need to sustain local economies, growth and all within environmentally sensible and sustainable limits. Will this require a reduction in some aspects of national GDP? Undoubtedly yes, but with a sense of justice, resources and entitlement that local people deserve. This will also result in well-being and security for local islands and populations, with funding available for local infrastructure moved away from private to public areas (e.g. better housing, schools, shoreline protection). For example, the revenue from points 2 and 3 above does not necessarily stay within the Maldives, because of corporate foreign ownership of many of the businesses. This is inevitable to a certain degree within the tourism sector, but is regrettable within the export business for live fish. The latter will only ever result in the demand of the market being met overseas, with no intrinsic value associated with the quality of the local resource or quality of life. The demand from foreign markets can be met from another fish-rich nations if the Maldives runs out of larger fish. But where does this leave the island communities themselves? Indeed prices for some fish are now so high (large live grouper can fetch hundreds of US dollars per kilo in restaurants) that an expensive supply-side economy will continue, even if fishers have to travel to increasingly remote atolls and countries. Clearly the environmental assets that allow income for foreign markets do not 'feed the nation', but do provide large incomes for a few within the political and business elite.

A view on the patterns in this report and twelve years of observations

So how do we explain the multifarious factors that affect the current condition we see on the reefs of the Maldives? It is hard to tell what is going on from a few isolated sites, but the general trend is that the inner reefs have been widely and largely impacted, whilst the outer reefs are less affected, and some sites actually recovered 14 months after the initial bleaching event. There is also the propensity for the bleaching severity to be not as bad at depth. However, these patterns are only from a few sites, with little time over the course of the Biosphere Expeditions / MCS surveys to really understand the pattern on a much wider scale. Impacts coincident with depth appear to be observed by other surveyors (e.g. IUCN) from a greater array of North Ari sites (Cowburn et al., in preparation).

We posit that there are three types of reef location and condition:

1. Outer reefs associated with greater current and wave action that are generally more resilient to bleaching
2. Inner reefs that are more affected by disease, *Drupella*, Crown-of-Thorns and bleaching-intolerant assemblages of corals
3. Inner reefs that are exhibiting a phase change from a coral-dominated state to an algal and *Discosoma* (non-coral) state

Our recommendations on issues related to the vulnerability have been highlighted in previous reports available from the Biosphere Expeditions website www.biosphere-expeditions.org/reports. Our observations and training will hopefully increase awareness. It is possible that the Maldives can withstand – in the short term – such a major bleaching event. But in the long term, the equitable provision of high quality reefs and their resources to all Maldivian citizens will further diminish, unless drastic actions are taken by government.

Recommended actions

1. Resource either the Environment Protection Agency (EPA), or each atoll council, environmental officers to be present (with an office, officials and boats) on each island atoll to control unsustainable fishing, dredging and construction.
2. Fund sufficient EPA officers to fine and arrest transgressions in MPAs, and island house reefs (that are protected from fishing).
3. Give the EPA finance to stop developments where environmental damage is being caused (such as sediment outflows on live healthy reefs) above levels stated in Environment Impact Assessments.
4. Provide adequate funds to monitor baseline environmental condition to inform enforcement powers of the EPA and fisheries department (where necessary). For example, in setting sediment traps near to coastal development to understand likely effects on downstream coral reefs.

5. Ensure that fisheries department officials work collaboratively with the EPA in assessing fisheries activities at resorts, grouper cages[16], processing facilities and at airports.
6. Ensure that every resort has to enact reef enhancement programmes, that are not solely based on construction of reef walls, but enable the development and growth of reef pyramids and fore-reef coral structures to enable sustainable growth under the water of a living wave barrier. Ensure advice from the MRC scientists and engineers is used to guide these efforts.
7. Introduce size limits on grouper fisheries as previously recommended to government[17], which includes:
    - i. regulated fishing
    - ii. mandatory logbooks and data collection
    - iii. long-term monitoring of catch, abundance and spawning aggregation sites
    - iv. national level awareness-raising programme.
8. Ensure that the fisheries department have enforcement officers based at fish cages to ensure that grouper size limits are met.
9. Ensure that EPA and fisheries department officers are stationed at protected grouper spawning areas (see below, Fig. 2.4e).
10. Ensure that the EPA is provided enough budget – (via for example a tourism tax) such that it is able to be present (with an officer present) on most tourism islands, and can enforce law and, if necessary, prosecute.
11. Ensure that the MRC is enabled, through an environment tax, to undertake rapid reef health assessment monitoring at all Maldivian resorts as a matter of law, and that the reports from the standard monitoring assessment are annually reported to government and made public.
12. Ensure all enforcement, fines and prosecutions under the powers of the EPA and fisheries department are vetted by an independent body of accountants, lawyers and governance experts that includes officials, managers and scientists from the EPA, MRC and fisheries department of the Maldives.

[16] Grouper cages exist in at least 5 atolls where fish are corralled before being shipped to Asian 'live fish' markets.
[17] https://www.mcsuk.org/downloads/coral_reefs/Maldives_Grouper%20_fishery_Management_Plan.pdf (page 19).

Figure 2.4e. Location of the protected spawning areas that have bans on fishing in five atolls, as agreed by law after consultation with industry and government in 2011, but with little implementation of monitoring or control of activity.

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Appendix I: Expedition diary and reports

A multimedia expedition diary is available on https://blog.biosphere-expeditions.org/category/expedition-blogs/maldives-2017/

All expedition reports, including this and previous expedition reports, are available on www.biosphere-expeditions.org/reports.