EXPEDITION REPORT

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

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Biosphere Expeditions

Abstract

In September 2022, Biosphere Expeditions ran its tenth annual Reef Check survey expedition to the Maldives, after a two-year year hiatus in 2020/2021 due to the COVID pandemic. Local and international citizen scientists, supervised by a professional reef biologist, performed Reef Check surveys for one week in South Male’ and Vaavu atolls at exposed, semi-exposed and sheltered sites. We repeated visits to sites last surveyed in 2019 to compare reef health from three years ago, particularly those around Guraidhoo Island, which had been subjected to land reclamation work in 2020.

Coral cover for all sites surveyed at South Male’ and Vaavu varied between 42 and 15%, very similar to the range in 2019 of between 45% and 18%. Mean coral cover at all depths was 26% (27% in 2019). In 2019, development of the islands was set to increase across the country from contracts signed by the previous (2018) Maldivian government. We mapped and digitised increased landfill areas (increasing the pre-existing land area by 70% in 2020) near to Reef Check sites at Guraidhoo backreef and forereef; the former to extend the land area of a local island and the latter to extend a resort. These areas coincide with a relative decline in shallow live hard coral cover from 30 to 14% (53% decline) at sheltered backreef areas in 3-4 m of water, and 21 to 15% (29% decline) in exposed forereef waters at 5-6 m. Coral cover in deeper areas stayed the same (Guraidhoo backreef) or increased (Guraidhoo forereef) over the same three-year time period. A further site called Coral Gardens (southern area of south Ari atoll), which was previously surveyed just before the 2016 bleaching event, showed a coral cover decline from 63 to 19% (69% decline), indicative of the long-term effect of the 2016 bleaching event. Much of the substrate at Coral Gardens was colonised by *Tydemania expeditionis* algae with rubble dominant in the deeper section, indicative of a breakdown of previously dead coral colonies, probably from the 2016 bleaching event. Coral Gardens was also notable for high sedimentation and poor visibility, estimated at only 6 m.

Isolated bleaching was observed, but only of individual, small (less than two-year-old) colonies. Such bleaching was mostly of *Pocillopora* and some *Acropora* colonies. No Crown of Thorns were recorded during the expedition. Coral-eating *Drupella* gastropods were commonly recorded, with incidents of live-coral damage in three of the six sites. One site (Guraidhoo backreef) had 17 colonies affected by *Drupella*. Litter was largely absent from the reefs we visited, although lost fishing lines were commonly found, largely encrusted into the coral framework.

As for all previous surveys, there were moderate to large-sized grouper at all sites, with an average density of 0.25 to 4.25 grouper (above 30 cm total length) per 500m^3 at outer reefs, with lower numbers (0 to 2 individuals) at inner reefs. Parrotfish (an important grazer) were present at low densities of 3.9 individuals per 500m^3, with similar densities on outer and inner reefs. Densities of all species of snapper were at similar levels (3.7 individuals per 500m^3), whilst sweetlips were rare (0.3 individuals) and butterflyfish predictably abundant (12.6 individuals per 500m^3).

Sharks (black tip reef and whitetip) were only recorded on the first check dive (not a survey) and on the last day at Coral Gardens.

A short effort-based whale shark survey was carried out at the outer reef of South Ari Marine Protected Area on 8 September 2022. No sharks were sighted.

Contents

1. Expedition review

1.1. Background

Background information, location, conditions and the general research area are as described in Solandt & Hammer (2019).

1.2. Dates & team

The 2022 annual Reef Check survey ran over a week from 3 to 9 September 2022 with a team of national and international citizen scientists, a professional scientist, and an expedition leader.

The expedition team was recruited by Biosphere Expeditions and consisted of a mixture of ages, nationalities, and backgrounds. They were (in alphabetical order and with country of residence): Mohamed Abdul Basith* (Maldives), Mark Davis (Germany), Peter Goodman (UK), Ann Ho (USA), Hamna Hussain Ali Didi* (Maldives), Kristine Klatt (Germany), Steven Neely (USA), Rick Royston (Germany), Fathmath Shuhaina* (Maldives), Oliver Soubreyand (France), Paula Thomsen (UK), and Toshia Wildasin (USA), where a *star denotes a participant of the Biosphere Expeditions placement programme.

Figure 1.2a. Expedition team 2022.

The expedition scientists was Dr. Jean-Luc Solandt, 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 managing Marine Protected Areas in the UK and northern Europe. He has been the Reef Check co-ordinator for the Maldives since 2005, and has thus far led 10 expeditions to the islands. Jean-Luc has over 1100 dives clocked up since he first trained to be a marine biologist 30 years ago.

The expedition was led by Dr. Matthias Hammer, who founded Biosphere Expeditions in 1999. Born in Germany, he went to school there, before joining the Army, and serving for several years amongst other units with the German Parachute Regiment. After active service he came to the UK and was educated at St Andrews, Oxford and Cambridge. During his time at university he either organised or was involved in the running of several expeditions, some of which were conservation expeditions (for example to the Brazil Amazon and Madagascar), whilst others were mountaineering/climbing expeditions (for example to the Russian Caucasus, the Alps or the Rocky Mountains). With Biosphere Expeditions he has led teams all over the globe. He is a qualified wilderness medical officer, ski instructor, mountain leader, divemaster and survival skills instructor. Once a rower on the international circuit, he is now an amateur marathon runner and Ironman triathlete.

1.3. Partners

On this project Biosphere Expeditions worked with Reef Check, 'Save the Beach' Maldives, the Marine Conservation Society, the Maldives Marine Research Centre (MRC) of the Ministry of Fisheries and Agriculture, Maldives Whale Shark Research Programme (MWSRP), Land and Marine Environmental Resource (LaMer) Group and the MV Theia liveaboard.

1.4. 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 citizen scientists, 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 happen. Thank you to the crew of MV Theia, our liveaboard expedition base, for being such excellent and capable hosts. Thank you also to Hussein Zahir of LaMer for guidance and advice, and Hassan Beybe and Farish Mohammed for welcoming expedition participants to Vilingili Island to discuss the work and infrastructure of 'Save the Beach' Maldives. Biosphere Expeditions would also like to thank the Friends of Biosphere Expeditions for their sponsorship and/or in-kind support. We also thank the IUCN who have collaborated with us over recent months to produce a paper on bleaching resilience (Cowburn et al. 2019).

1.5. 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.

A multimedia expedition diary is available on https://blog.biosphere-expeditions.org/category/expedition-blogs/maldives-2022/.

This and all other expedition reports of this and all other expeditions are available on https://www.researchgate.net/lab/Biosphere-Expeditions-Matthias-Hammer

1.6. Expedition budget

Each participating citizen scientist paid towards expedition costs a contribution of €2,670. 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 visas 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	22,264
Expenditure	
Staff includes local & international salaries, travel, and expenses	6,040
Research includes equipment and other research expenses	989
Transport includes taxis and other local transport	0
Base includes board, lodging and other live-aboard services	17,823
Administration includes some admin and miscellaneous costs	111
Team recruitment Maldives as estimated % of PR costs for Biosphere Expeditions	3,998
Income – Expenditure	**-6,698**
Total percentage spent directly on project	**130%***

*This means that in 2022, the expedition ran at a loss and was supported over and above the income from the expedition contributions and grants by Biosphere Expeditions.

2. Reef Check survey

2.1. Introduction and background

Review up to 2022

A review of the rationale for the expedition and the situation of the Maldives up to 2019 is described in Solandt & Hammer (2020). This includes sub-chapters on Maldivian coral reefs, fisheries, coral bleaching, previous Reef Check surveys, descriptions of Marine Protected Areas (MPAs), governance and management, as well as the 1998 and 2015/2016 bleaching events.

After nine annual expeditions in 2011-2019 (all expedition reports here), there were no expeditions in 2020 and 2021 because of the COVID-19 pandemic. There were no significant bleaching events in the Maldives recorded during this two-year gap. However, a major construction project (land reclamation and resort construction) began in the area of Guraidhoo reef in 2019, just after the survey in September 2019.

A minor bleaching event occurred in June 2020, but online forums suggest that this did not affect populations of corals in the Maldives significantly.

Summary of threats to Maldives reefs

Maldivian 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

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 (Maldives have semi-autonomous atoll councils that have some powers of local decision-making, particularly with regard to reef fishing). For example, given the small sizes of many species seen in the wild as outlined in previous reports (Solandt and Hammer 2015, 2017a, 2018, 2019, Solandt et al. 2016), it is regrettable that the trajectory for the Maldives over-fishing the grouper population and decimating the commercial fishery continues to affect revenues and the natural population.

A project by the Blue Marine Foundation has worked in the south with resort partners and the government to reform fisheries management around spawning locations at Laamu atoll[1]. However, no concerted effort to protect grouper stocks from being fished out for domestic and foreign markets is taking place. Labelling some grouper spawning locations as 'protected spawning sites' may have been counterproductive as this can lead to them being identified and then successfully targeted, due to the lack of enforcement. Word-of-mouth discussions with experienced dive guides and fishermen have indicated that 'protected' and 'known' spawning channel locations are targeted by fishermen once they are discovered or protected by law (anonymous dive guide, personal communication). Many believe it is simply 'better management' to keep those channel locations where spawning is known to occur secret, and that it is counter-productive to confer protected status or management measures in such locations when proper enforcement is not available.

Due to past political interference in the rule of law and due process, there were several developments that were patently counterproductive to the Maldives environment under the previous government. Profit-driven resort development, and other major capital infrastructure project investments from overseas, were permitted despite environmental concerns raised by The Environment Protection Agency (EPA) and MRC. Decisions by the EPA were effectively rejected by the tourism ministry[2]. Interestingly, this is not necessarily that different in western democracies, where there is an inability of citizens to challenge decisions in court due to prohibitive expense.

2.2. Methods and planning

Biosphere Expeditions uses the Reef Check methodology for its coral reef surveys (see Solandt and Hammer 2015, 2017a, 2018, 2019 Solandt et al. 2016 and earlier reports on www.biosphere-expeditions.org/reports for details). The 2022 surveys were carried out with the aims of:

- Recording patterns of recovery and resilience from the 2016 bleaching in South Male' and Vaavu atolls
- Recording patterns of reef health near to land reclamation at Guraidhoo, S Male' atoll.
- Carrying out effort-based transects of the South Ari MPA reef for whale sharks
- Training two new Maldivian citizen science divers as Reef Check EcoDiver Trainers

We surveyed six sites (see Table 2.3a.) to repeat surveys carried out in 2019 in South Male' (four sites) and Vaavu atoll (two sites). One site was surveyed at South Ari atoll (Coral Gardens) that had previously been first surveyed in March 2016, just prior to the most recent significant bleaching event. Training was conducted at reefs near Guraidhoo Island. We then trained and surveyed at eastern, central and southern South Male', at northern Vaavu and in a very sheltered site in west central Vaavu. Shallow dives were between 3 and 4 m, with deeper divers from 7 to 9 m.

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[1] http://www.bluemarinefoundation.com/project/maldives/
[2] http://www.climatechangenews.com/2017/03/20/maldives-regime-imperils-coral-reefs-dash-cash/

All training was completed on board the MV Theia during the first three days of the expedition. Biosphere Expeditions recruited citizen scientists, carried out logistics, and insured health and safety on board the research vessel. The scientific programme, training, data collection, and analysis was led by Dr Jean-Luc Solandt, Reef Check Course Director, supported by Dr Matthias Hammer, also a Reef Check Course Director.

2.3. Results

Sites surveyed

Sites surveyed during the 2022 expedition were a mixture of inner atoll sites (thilas and giris) and outer reef slopes. Sites (Table 2.3a / Fig 2.3a) were surveyed based on accessibility to Male', exposure, a mix of inner and outer reefs, and because they demonstrated a typical range of Maldivian reefs.

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

Site name	Date	Latitude	Longitude	Inner / outer reef	Atoll
Karumba*	3.9.22	3 58.415 N	73 29.457 E	Inner	South Male'
Guraidhoo inner	5.9.22	3 54.339 N	73 27.303 E	Inner	South Male'
Guraidhoo outer	7.9.22	3 53.092 N	73 28.106 E	Outer	South Male'
Beybe's bellybutton	6.9.22	3 53.574 N	73 24.202 E	Inner	South Male'
Ranikan outer	7.9.22	3 50.082 N	73 22.102 E	Outer	South Male'
Fulidhoo	7.9.22	3 40.586 N	73 28.108 E	Outer	Vaavu
Farish faru	8.9.22	3 37.018 N	73 22.373 E	Inner	Vaavu
Coral Gardens	8.9.22	3 31.423 N	72 54.212 E	Inner	Ari

*Check site (for safety and equipment checks)

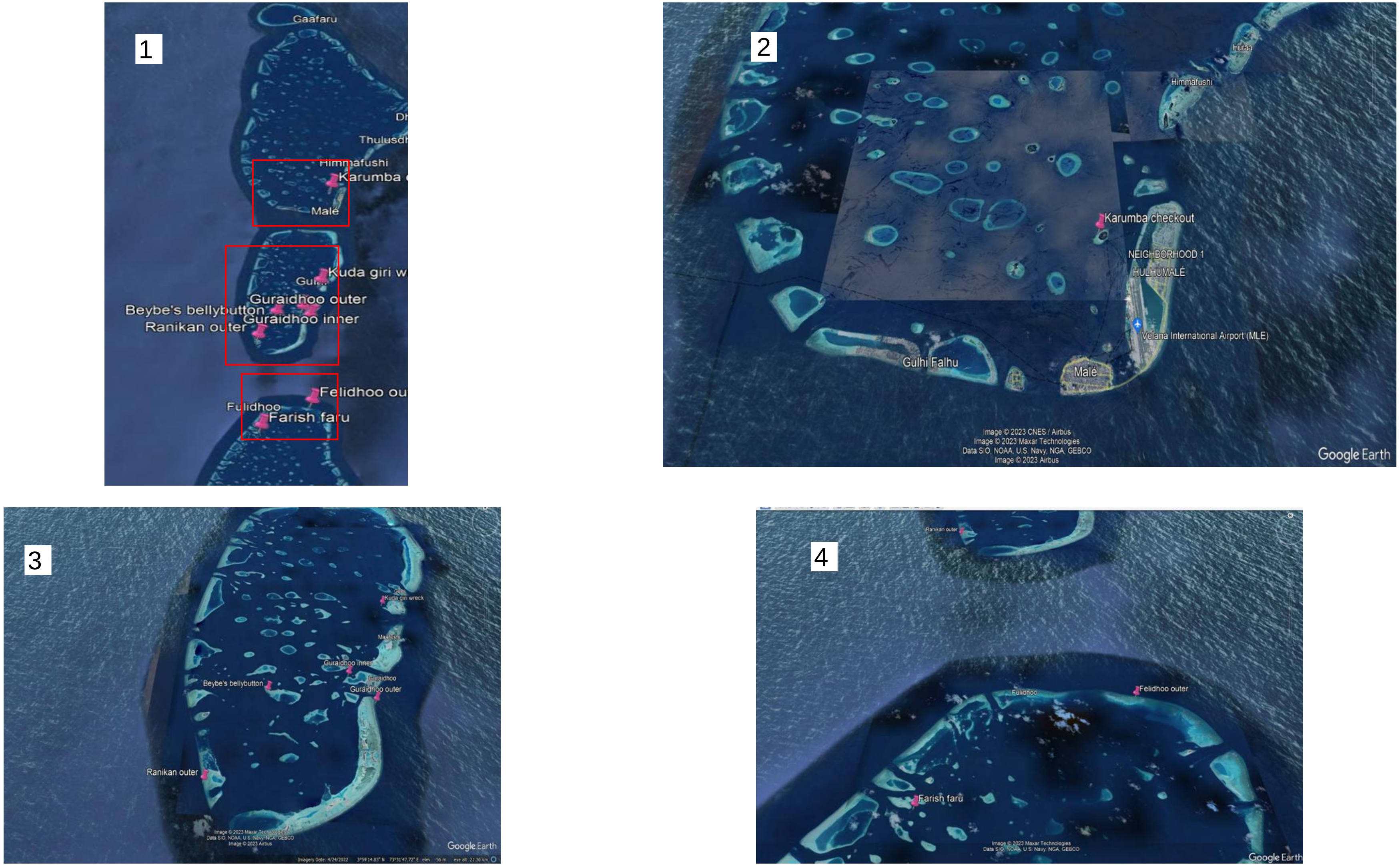

Figure 2.3a. Central Maldives atolls with survey locations. 1 – All sites; 2 - Training and 'coral frames' observations; 3 – Southern Male' sites; 4 – North Vaavu sites. See also online map.

Coral cover

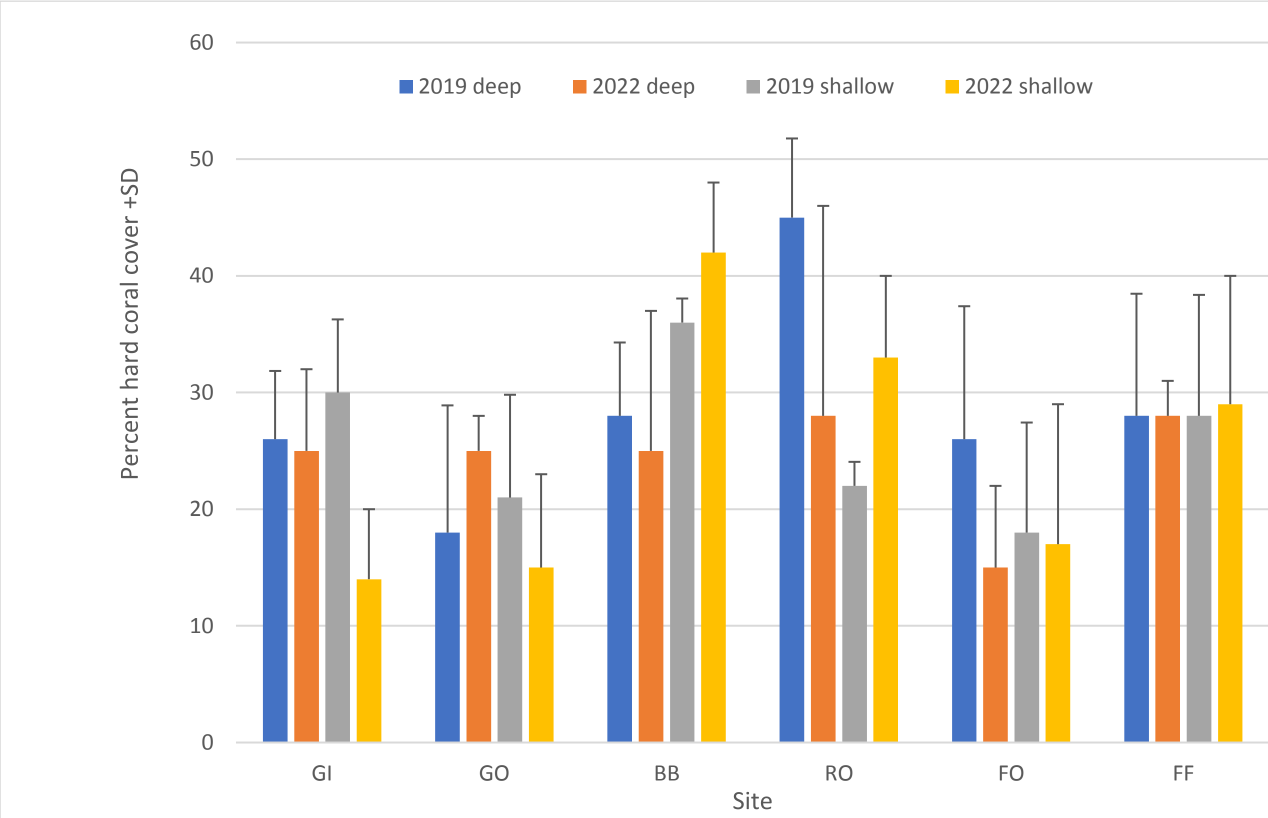

Figure 2.3b. Mean hard coral cover (+SD) at 7-10 m (deep) and 3-4 m (shallow) depths (also Fig 2.3a). GI – Guraidhoo Inner; GO – Guraidhoo Outer, BB – Beybe's Bellybutton, RO – Ranikan Outer, FO – Fulidhoo, FF – Farish Faru.

Hard coral (HC) cover ranged from 18 to 45% (Fig. 2.3b) in 2019 and 14 to 42% in 2022. The diversity of corals was greatest at sheltered inner atoll locations (particularly Beybe's Bellybutton and Farish Faru). There was very little change in coral community and cover at Farish Faru between years and depths (only 1% difference). Ranikan Outer showed the greatest decline in coral cover at the deep site, and a rise at the shallow site, largely because the tape was laid in different places at this site (a very difficult and exposed site to survey).

Guraidhoo Island showed a decline in shallow coral cover at both inner reef (from 30 to 14%) and outer reef (21 to 15%). Both these sites were adjacent (for the Guraidhoo inner site to the west and Guraidhoo Outer site to the east) to considerable infrastructure works on local islands and reef flats.

Depth in sheltered inner reefs was generally correlated with greater diversity of coral lifeforms at 7 – 10 m compared to 3 – 4 m (Fig 2.3c). Corals were diverse and dominated by very delicate large branching colonies of *Acropora* at Farish Faru – an extremely sheltered site (from three sides, north, west, and south), to the east of Vaavu atoll (Fig. 2.3d).

Coral recruitment was most prevalent on forereef exposed slopes (e.g. Ranikan) (Fig. 2.3e).

A further site was visited after a whale shark survey at South Ari atoll (Coral Gardens) on 8 September 2022. Here coral cover has declined from 63% just before the 2016 bleaching event to 6%.

Figure 2.3c. Coral reef at 10 – 12 m at Guraidhoo backreef, showing the wide diversity of coral lifeforms and species – particularly adjacent to the sandy seabed. Various branching, submassive foliose and massive lifeforms were present including *Pavona clavus* (top left); *Acropora* sp. branching (bottom left); *Diploastrea heliopora* (top right); *Turbinaria mesenterina* (middle right); *Prites cylindrica* (bottom right).

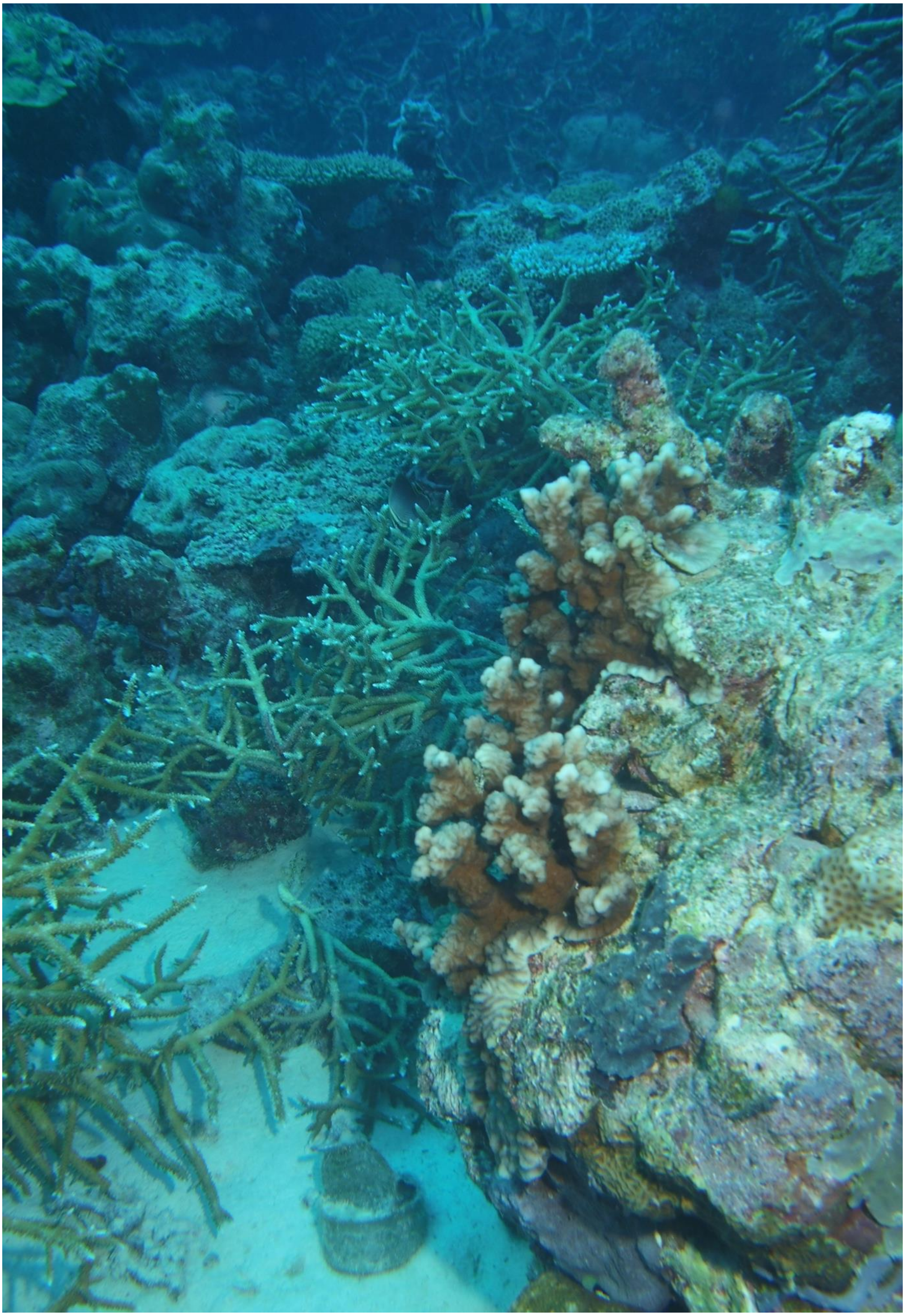

Figure 2.3d. Largely dead coral mounds on sand at sheltered Farish Faru site with associated corals.

Figure 2.3e. Coral recruits observed at the exposed Ranikan outer forereef at approximately 10 m depth. The largest recruit shown (on left) is an *Acropora* species. The others are *Pocillopora verrucosa*.

Fish populations

Bleaching episodes in the past have caused a loss of diversity and complexity of the three-dimensional habitat (Jones et al. 2004). Previous research conducted after the 1998 global bleaching event found that the loss of habitat had a considerable impact on the diversity and abundance of many reef fish species and families (Pratchett et al. 2011). It is therefore important to monitor the diversity and abundance of fishes present on reefs to determine the effects of such disturbance events on the wider marine community.

Mean fish surveyed (per 500 m^3 replicate) from all sites in 2022 are shown in Figure 2.3f (error bars not included as they are very large). Of note was the absence of the larger and more predatory species of fish (moderate to large groupers, all snappers and *Haemulidae* / sweetlips). There was an anomaly at Ranikan outer, where a large population of snappers were resident.

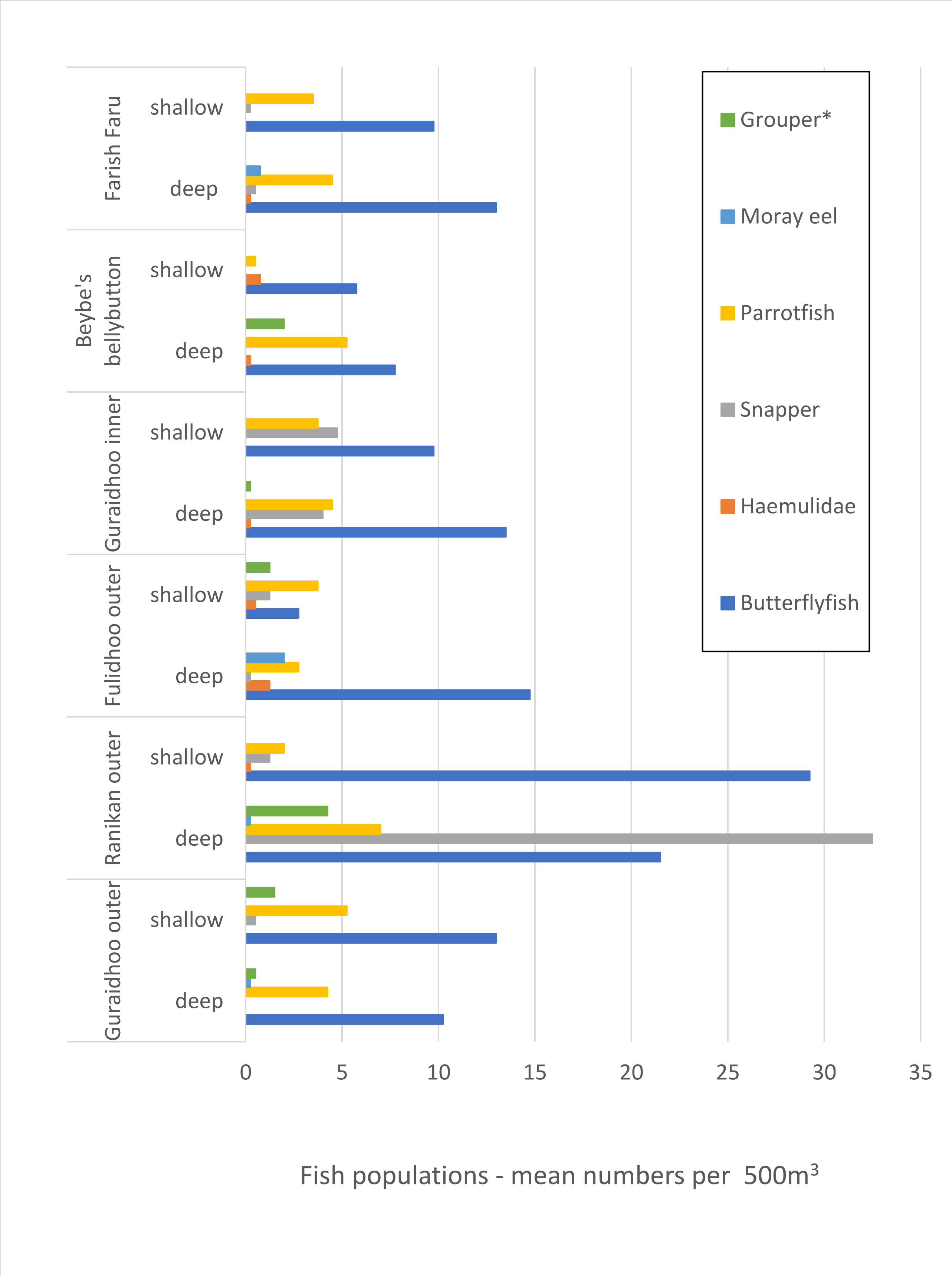

Figure 2.3f. Fish populations (per 500 m^3 replicate) from all sites surveyed in 2022.
*Grouper are pooled data from all size classes (>30cm). Parrotfish are only recorded over 20 cm.

As with previous years, butterflyfish were the most abundant Reef Check lifeform, dominating all sites (Fig. 2.3f), particularly at Ranikan outer reef where a mean of 29 individuals was recorded per 500m^3. Forereef habitats are dominated by planktivorous butterflyfish more than inner reefs (e.g. by *Heniochus diphreutes* and *Hemitaurichthys polylepis*). Ranikan outer had larger numbers of snappers than other sites.

Figure 2.3g. Fish populations at Ranikan Outer site were dominated by omnivores: *Lutjanus kasmira* (blue-stripe snapper) and *Gnathodentex aureolineatus* (a species of bream) in a mixed school.

Invertebrate populations

Low numbers of invertebrates were observed during the 2019 survey trip. Giant clams, *Tridacna* spp., were relatively common, but on the lower end of their size range. Crown of Thorns sea stars (*Acanthaster planci*) individuals were previously (during September 2019) recorded at Beybe's bellybutton – an isolated site a considerable distance from the nearest developed island within the south-central part of South Male' atoll. During the 2022 surveys, Crown of Thorns were entirely absent from the surveys at this site (Fig. 2.3h). They were also absent from all other survey sites during the expedition, both on survey and non-survey dives. Larger numbers of *Diadema* were recorded than for previous surveys. Banded coral shrimp were recorded at four of the six survey sites.

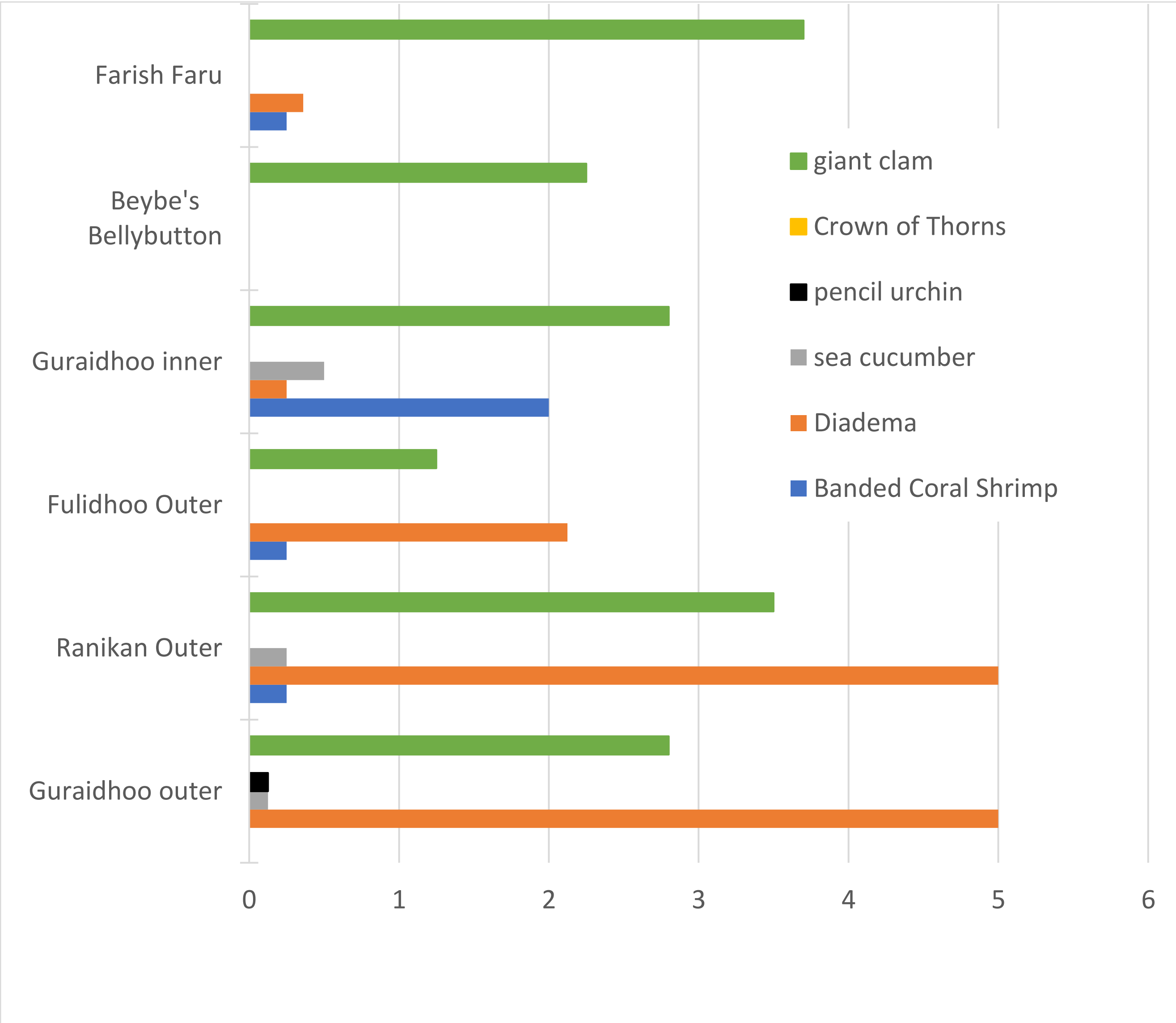

Figure 2.3h. Mean numbers of invertebrates at each site recorded on Reef Check dives in 2022 (no SD were plotted due to the large numbers affecting the scale of the chart). Crown of Thorns were absent.

Other impacts, including bleaching

Coral damage is recorded by the Reef Check methodology in terms of direct impacts on corals, including diseases (‘counts’ rather than the identification of specific ‘pathogens’) (Fig. 2.3i). Coral damage ‘other’ is most regularly from parrotfish scars (Fig. 2.3j) and from *Drupella* coral-eating snails (Fig. 2.3k) (particularly at Guraidhoo outer and back reef, with 17 coral colonies with *Drupella* infestations at the backreef site).

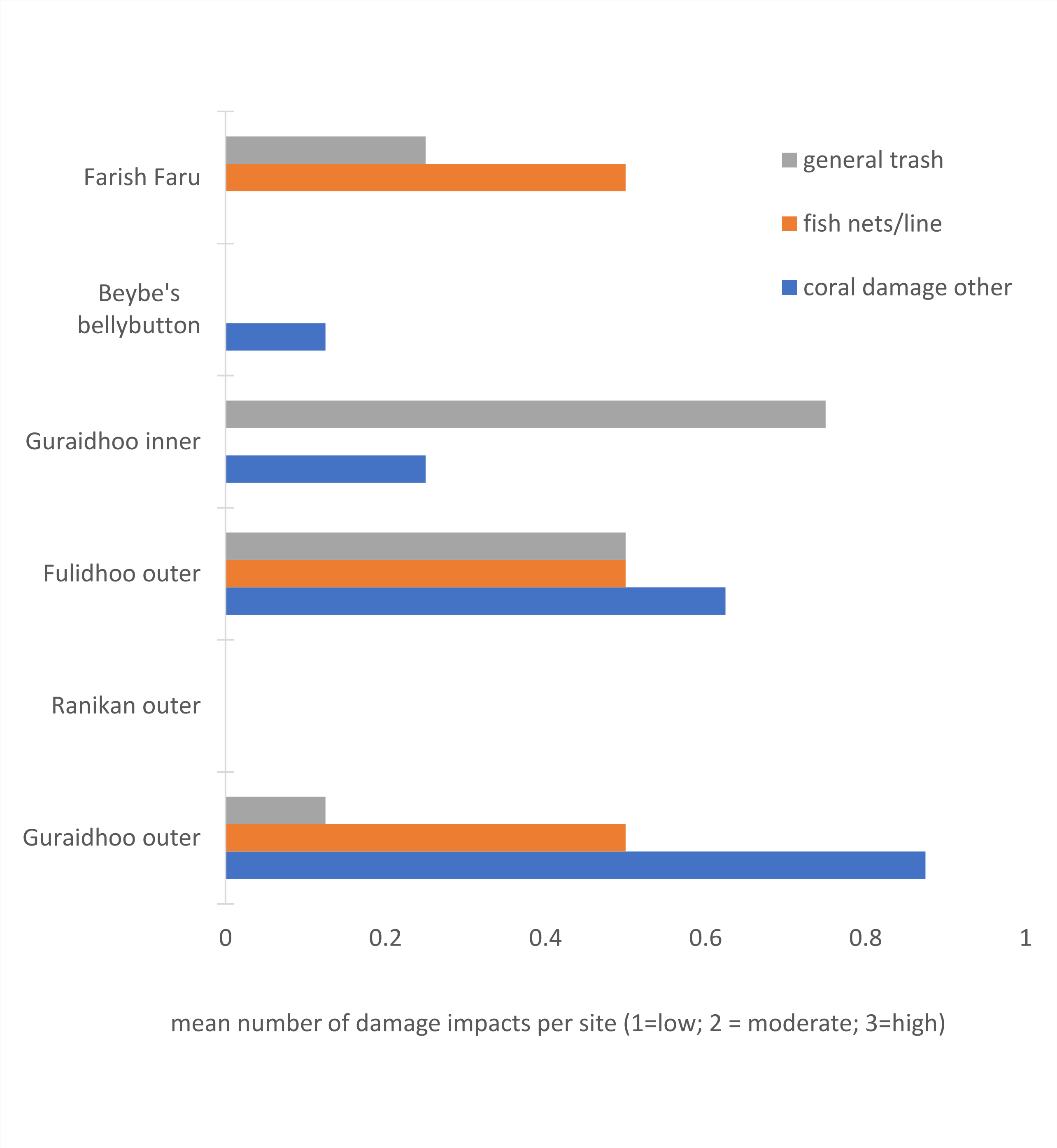

Figure 2.3i. Impacts observed across all sites and recorded on a semi-quantitative scale (on the x-axis, 1 = 1-2 observations, 2 = 3-4 observations, 3 = ≥5 observations).

Figure 2.3j. Parrotfish scars.

Figure 2.3k. *Drupella* infestations were a common occurrence.

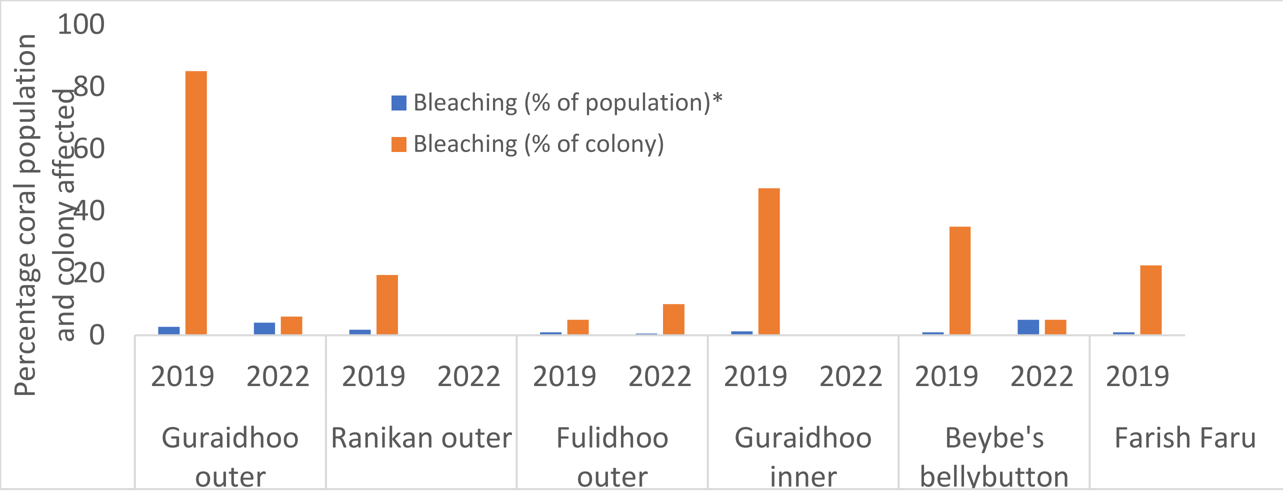

Figure 2.3l. Percentage of total live hard coral population per site that is bleached (blue bars) and percentage of each colony that was bleached (orange bars) in 2022..

Reef Check also estimates the amount of bleaching as a proportion of the live population and the proportion of bleached compared to live tissue for each bleached colony (Fig. 2.3l) – the data suggest no mass-bleaching event at the time of the survey.

Little impact from human activity was recorded at the sites in 2022. 'Trash' was predominantly discarded fishing lines that had snagged on the reef.

Other marine life and noteworthy observations

Reef Check surveys record incidences of unusual, rare, or threatened marine life, both on and off transect (Table 2.3b). Only one (blacktip reef) shark was recorded on or off transect for any of the survey locations – and that was at the 'shake down' dive location of Kurumba where a survey wasn't made.

Table 2.3b. Other noteworthy observations – off transect (not observed during survey).

Site name	Observations	Atoll	Reef type
Guraidhoo inner	Sediments affect coral health.	South Male'	Inner
Guraidhoo outer	1 green turtle.	South Male'	Outer
Beybe's bellybutton	1 hawksbill turtle, Large numbers of snapper deep off transect. Large triple-saddle grouper deep off the line.	South Male'	Inner
Ranikan outer	1 manta ray. Hawksbill turtle, eagle ray, midnight snapper off transect.	South Male'	Outer
Fulidhoo outer	1 dogtooth tuna on deeper transect. Long-nose emperor.	Vaavu	Outer
Farish faru	Lots of small parrotfish.	Vaavu	Inner
Coral Gardens	Whitetip reef shark.	South Ari	Inner

Whale shark sightings

A 2-hour effort-based whale shark survey was conducted at the outer reef of South Ari MPA, yielding no sightings of whale sharks. Conditions were not good for whale shark sightings.

2.4. Discussion and outlook

The difference between our surveys before 2020 (pre-COVID-19) and 2022 is the great amount of construction, landfill and development that the Maldives has been undergoing since 2020. Our results from Guraidhoo inner and outer reef show clear declines in shallow coral communities, with a lesser affect in deeper waters (a decline in coral cover at Guraidhoo inner from 30 to 14%, and at the Outer reef site from 21 to 16% in shallow waters (4 m deep). In the deeper water, where the sediments may be more easily dispersed, the coral cover at Guraidhoo inner reef only dropped from 26 to 25%. At the outer reef at the deeper depth, cover rose from 18 to 25%. The outer reef is near to the Guraidhoo channel and as such is exposed to oceanic conditions (Fig. 2.4a), so would be less susceptible to sediments remaining in situ over the course of the tidal cycle. This is not the case for the extremely sheltered Guraidhoo inner reef site that also is in an area of greater surface area reclamation. The area of reclaimed land in the Guraidhoo area (upper large circle in Fig. 2.4a) measures 211,216 m^2 – a 70% increase in area compared to the historical (pre-2020) land area of Guraidhoo and the adjacent resort island. It is clear from the satellite imagery that extensive areas of seagrass beds have been built on from the construction, leading to loss of this efficient carbon capture habitat, and habitat that is essential for reducing the erosion of land by buffering wave energy (see right hand image below for directly observable impact to seagrass habitat extent). Seagrass is also a very effective and important juvenile fish habitat important to local fishers and wider society in the fight against climate change.

Figure 2.4a: Left: image taken in July 2019 (Google Earth) and right in April 2022. Note the red circles at where landfill started in 2020. Also note the proximity of our survey locations (pink pins) – undertaken in September 2019 (before construction) and September 2022 (post-construction). The total surface area of reclaimed land in the photo is 211,216 m^2 – a 70% increase in the land area of the original area of Guraidhoo.

Figure 2.4b: A further large area of reclaimed land lies to the north of this image (yellow arrow - 282,755 m^2) on the fringing outer reef. The reclaimed areas near to our survey sites at Guraidhoo inner, and Guraidhoo outer (all blue arrows) measure 211,21 6m^2.

The great diversity of corals (particularly at Guraidhoo backreef) provided many niches for different assemblages of species and made for interesting diving. The complex nature of the reef geomorphology and diverse coral lifeforms led to a heterogenous habitat structure in very sheltered reef conditions, with whips and sea fans, and *Antipathes* colonies (Fig 2.4c).

Water clarity appears to have diminished between 2019 and 2022 according to estimates of horizontal visibility from the author, with sediment settling on species such as *Tydemania expeditionis* algae and branching corals (Fig. 2.4d).

Many of the colonies dominant at the backreef of Guraidhoo appear somewhat sediment-tolerant already. Dominant assemblages, and even extensive stands of *Porites cylindrica* (Fig. 2.4e), occur at Guraidhoo, whilst the back reef site of Beybe's Bellybutton has extensive *P. rus* (Fig 2.4f). Meta-analyses from around the globe suggest that the extensive mucous coats and small recessed polyp structure of most *Poritidae* lifeforms make them more capable of sloughing off extensive sediment and as such better adapted to producing large quantities of mucous secretions, used to eject sediments from the polyps (Bessell-Brown et al. 2017).

Figure 2.4c. Guraidhoo backreef in 2019, showing the sheltered nature of the reef. Note the lack of sediment apparent both in the water column and on the substrate and living benthos. Diverse fish assemblages were present in 2019.

Figure 2.4d: The same area in 2022. Note the sediments on the coral and particularly on the algae between the coral branches.

Figure 2.4e: Some species such as this *Porites cylindrica* colony are better adapted than *Acropora* to coping with heavy sediment conditions. *P. cylindrica* were dominant in large patches (over 4 m square) at Guraidhoo backreef.

Figure 2.4f. *Sarcophyton* spp. soft coral to the left, and *Porites rus* to the right. *Porites rus* is the dominant benthic lifeform for much of the area of Beybe's Bellybutton – a backreef habitat over 6 km away from significant development.

The significance of the 2016 bleaching impact was observed at Coral Gardens, a site first visited in March 2016 by a Maldivian Reef Check team, just prior to the April/May bleaching event (Fig 2.4g&h). Here, the coral cover had been reduced from 63% (dominated by temperature-intolerant branching *Acropora*) to only 19%. This site was highly indicative of the vulnerability of inner clear-water *Acropora* branching and table-dominated reefs to temperature anomalies.

Figure 2.4g. *Acropora* thickets at Coral Gardens in March 2016, just prior to the bleaching event of April and May that year that led to nation-wide bleaching (Solandt and Hammer 2017).

Figure 2.4h. Coral colony at 9 m at Coral Gardens on 8 September 2022. Note the green water colour.

Sully et al. in 2019 showed that reefs nearer the equator that experience daily temperature variance (perhaps due to current-induced upwelling) are more resistant to bleaching. Bleaching response variability is also complicated by environmental variables (surge/light) that influenced the coral community before mass bleaching events became common from the 1980s onwards. However, extrapolating observations of coral response to bleaching at large global spatial scales must be treated with caution because of the coarse scale at which such assessments operate. The fine-scale nature of Reef Check surveys (over 100 m of reef) shows the stochastic nature of reef populations that are the result of recruitment, succession and idiosyncratic environmental variables (e.g. tide, depth, aspect, wave action, oxygen and temperature). Outer reefs of South Male' and Vaavu atolls (Ranikan, Guraidhoo outer and Fulidhoo outer) are very similar to those surveyed in the past at Ari atoll (Rasdhoo, Bathaalaa and outer Dhigurah wall) (Solandt and Hammer 2019) (Table 2.4a). Outer reef crests are dominated in shallow waters (<6 m) by *Porites* mounds (*P. lobata*). Although outer reef coral cover appears higher comprising more robust and bleaching tolerant lifeforms, species and growth form diversity is lower than at backreef sites. But, in slightly deeper water for some outer reef sites such as at Ranikan, there was considerable recruitment of young *Acropora* and *Pocillopora*. However, the amount of large, mature *Acropora* colonies (reaching over 20 cm in length) of outer reefs is low. We consider this to be a factor of bleaching, wave action and competition by more successful coral lifeforms.

Table 2.4a. Coral cover and recovery potential of reefs at Ari, South Male' Vaavu sites.

Site name	Atoll	% cover (3-6 m)	% cover (6-12 m)	Surveyed	Pre 2018 % cover	Recovery potential
Rasdhoo	N Ari	39	NA	July 2018	30	Resilient
Bathaalaa	N Ari	27	30	July 2018	29	Resilient
Dega giri	N Ari	3	6	July 2018	74 (2008)	V. Low
Kuda falhu	N Ari	1	3	July 2018	75 (2014)	Low
Dhigurah Wall	S Ari	14	29	July 2018	35	Resilient
Guraidhoo outer	S Male'	21	18	Sept 2019	data missing	Resilient
		16	25	Sept 2022	Sediment stress	Reclamation
Guraidhoo inner	S Male'	30	26	Sept 2019	data missing	Adaptable
		14	25	Sept 2022	Sediment stress	Reclamation
Bebe's BB	S Male'	36	28	Sept 2019	data missing	Adaptable
		42	25	Sept 2022		
Ranikan outer	S Male'	22	45	Sept 2019	data missing	Resilient
		33	28	Sept 2022		
Felidhoo outer	Vaavu	18	26	Sept 2019	20 (2017)	Resilient
		17	15	Sept 2022		
Farish Faru	Vaavu	31	28	Sept 2019	data missing	Vulnerable
		29	28	Sept 2022		

Other biological findings in this report

Over the past 10 years some of the inner reef sites that we have observed at Ari atoll are progressing through a ‘phase shift’ (Hughes, 1994) from coral reefs to algal and sponge-dominated seabed biotopes. However, this effect was not apparent at South Male’ and Vaavu, with the exception of a very sheltered reef - Farish faru to the west of Vaavu, which was suffering from an infestation of a fast-growing sponge (Fig 2.4i&j).

A ‘phase shift’ occurred in Jamaica and over much of the Caribbean in the early 1990s (Knowlton and Jackson 2008) due to a loss of herbivores over a chronic amount of time due to overfishing (of parrotfish) and disease (of *Diadema* urchin that has also been repeated in 2022). Coupled with land-based nutrient input and catastrophic impact from hurricanes that destroyed the living coral framework, the Jamaican marine environment shifted from a coral-dominated state to an algal dominated state within three years over 33 years ago. This shift appears to be occurring on many inner atoll reefs of the Maldives. When the reefs are free of herbivory (largely due to overfishing of parrotfish and surgeonfish), the remaining fish and invertebrate populations are not adapted to consume the species of algae that start to dominate affected reefs (e.g. *Dictyota, Padina, Tydemania, Halimeda*). Some larger, more complex algae (e.g. *Sargassum* sp. and *Padina* sp.) are leathery and/or defended from herbivores by toxic secondary metabolites and/or calcification of tissues. At the Great Barrier Reef, for example, certain acanthurid species (surgeonfishes, tangs and unicornfishes) preferentially feed on small *Sargassum* plants, whilst chubs (Kyphosidae) preferentially fed on larger plants (Hoey 2010). *Padina* sp. was particularly dominant at Theluveligaa inner reef (Ari atoll) that was severely affected by bleaching in 2016. This reef had already experienced a ‘phase shift’ from coral to macroalgal dominance when surveyed in July 2018 (Solandt and Hammer 2019). This is why it is essential that natural food webs are maintained in reef systems.

Figure 2.4i. Farish faru reef at Vaavu atoll. The lack of inhabited islands near to this reef, and its extreme sheltered natura may have resulted in a different response to bleaching stress of 2016 (and perhaps 1998) by becoming dominated by opportunistic sponges.

Figure 2.4j. Whilst the literature is mostly concerned with the dominance of algae, such as turf and macroalgae, as post-bleaching reef colonisers, the Maldives has a multitude of species and phyla settling on the substrate post-bleaching. Top: Baros Maldives in July 2018, dominated by two species of sponge. The encrusting pink form, *Haliclona nematifera* is particularly effective at growing around the base of live corals, competing with them for space and nutrients. The black sponge is likely *Aka mucosum* that has been reported to 'bore' its way through living coral. Bottom: Farish faru was dominated by this unidentified sponge in 2019 and 2022. Many coral heads featured this distinctive lifeform.

The backreefs we surveyed away from resorts at South Male' we describe as 'Adaptable' (Table 2.4a). This is because the coral lifeform abundance appears to have moved from branching *Acropora* to branching *Porites* lifeforms such as *P. cylindrica* and *P. rus*. Similar sites in central Ari atoll appeared not to have these sediment- and temperature-tolerant coral lifeforms. There, we regard the recovery capacity of local reefs as extremely low due to heavy infestion with algae, and rubble littering the shallow slopes and probably preventing recruitment as it is not being cemented in place by coralline algae. *Discosoma* colonising dead reefs post-bleaching is also likely to result in a phase shift to non-coral lifeforms, and this is increasingly the case at Dega Giri – a very sheltered site to the west of Ari atoll.

In previous years, medium (30-50cm) to large-size (>50cm) predatory reef fish were only seldomly recorded. Relatively high numbers of snapper and bream were recorded at many sites, and typically at least 1 shark was noted passing by the survey teams every other dive. Surprisingly, no sharks were recorded during the 2022 ReefCheck surveys. The only sharks observed during the 2022 expedition were 4 whitetips recorded during our equipment-check dive at Kurumba reef prior to starting the surveys. Sharks are generally not recorded 'on' transect, because they tend to avoid the depths at which the divers work.

Outlook

We are living in unprecedented times, with climate breakdown 'locked in' for at least the next 20+ years (Brown and Caldera 2017). If we were to reduce CO_2 emissions today to below 350 ppm (the level at which most scientists believe we will reduce global temperatures), we will still have a lag-phase from the CO_2 that remains in the atmosphere and to be released from the planet's ongoing use of fossil fuels (Zickfield and Herrrington 2015).

The impacts of climate breakdown will continue to be multifarious and overwhelmingly negative to human existence, threatening the continuation of human civilisation as we know it today. The central Maldives can serve as a particularly stark example with a very worrying trend emerging: one of long-term and short-term impacts making a lasting impression on the coral assemblages, fish populations (Sattar et al. 2012, Richardson et al. 2018) 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), Drupella predation and corallimorph outbreaks (Norstrom et al. 2009)). This trend is not new and has been observed since the mid to late 1990s.

The decline of Maldives reefs was set in motion in the 1990s by four principal factors: (1) The first mass-bleaching event in 1998 triggered by El Niño, ocean acidification and overall increased sea surface temperature, not caused by El Niño but climate change, (2) the development of commercial fisheries for the live-fish trade (principally targeting grouper), (3) the large-scale expansion of the tourism infrastructure, (4) the inaction of recent governments to balance economic growth with societal and environmental stability.

Added to this is the recent island expansion programme that has locked the Maldives into debt to foreign investors for generations[3] [4], whilst at the same time reducing or destroying environmental natural capital (seagrass beds and coral reefs)[5] [6].

Industrialisation of the Maldives has had associated costs. Many Maldivians would argue that the tourism and fisheries sectors have helped to provide jobs for Maldivian citizens. This is undoubtedly true, but at what cost? Immediate concerns over climate-driven sea-level rise were recently addressed by the policies and actions of former President Mohammed Nasheed (in office 2008 – 2012). He was concerned over climate predictions resulting in sea level rise and increased storms that have already inundated parts of the country. Climate models predict that most of the Maldives islands will be underwater within 10 to 80 years (e.g. Viner and Agnew 2000[7]).

President Nasheed was from the Maldives Democratic Party (MDP). The current government is also MDP and has emphasised good governance including respect to the environment. The 2018 MDP election manifesto used the catchphrase 'blue economy' and they have published a policy document for 2019-2023[8].

A ‘green tax’ has been levied[9] on tourists since October 2016 (Adedoyin et al., 2023). The tax is $6 per night at all-inclusive resorts, and $3 per night at guest houses on local islands. The Maldives collected over $30 million in the first half of 2019[10] from this resource. Projects that create tangible ‘capital’ outputs, such as water and sewerage, as well as waste management plants and associated infrastructure are needed. Whilst the latter is a good use of the green fund, there is no process for public or civil society to tap into green tax funds, nor are there projects or programmes to track marine environmental quality and trends for improving adaptive management and environmental governance. As such, environmental groups in the Maldives need to seek external donor money to undertake monitoring, research, to help protect MPAs, enhance fish populations and to establish the best conditions to promote coral recovery. A good further use of public funds would be to protect the numerous MPAs from illegal fishing activity that has been successful in other countries, and at the only adequately protected Maldivian MPA – Hanifaru Bay.

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[3] https://www.reuters.com/article/us-maldives-election-debt-idUSKCN1LY1QR
[4] https://www.tourism-watch.de/en/article/maldives-island-state-in-debt/
[5] https://theconversation.com/the-maldives-is-threatened-by-rising-seas-but-coastal-development-is-causing-even-more-pressing-environmental-issues-170144
[6] https://www.climatechangenews.com/2022/03/25/maldives-greenlights-destructive-dredging-to-build-housing-and-luxury-resorts/
[7] https://crudata.uea.ac.uk/cru/posters/2000-11-DV-tourism.pdf
[8] https://storage.googleapis.com/presidency.gov.mv/Documents/SAP2019-2023.pdf
[9] https://www.mira.gov.mv/Pages/View/whatisgreentax
[10] https://greenfiscalpolicy.org/the-maldives-collects-nearly-30m-as-green-tax-in-six-months/

This results in the MPA recovery work being neglected, a problem that also occurs in the other countries including the UK, where we have over 350 MPAs with only a small proportion of which are adequately managed. One issue common to all countries is that politicians want results within their term of government. This time frame is typically too short for the 10+ years that may be needed for MPAs to show their effectiveness. Therefore, investment in environmental projects, which by and large do not show positive effects within the timeframe of most politicians, is difficult to come by.

In the Maldives there has been a push to increase tourist numbers since 2015. In 2018, visitor numbers increased to 1,403,000 (from 1,088,000 in 2014[11]). The total number of resorts now stands at 171[12], with 521 'guest houses' being developed on local islands as an increasing share of the tourism market (the author stayed at the local island 'Fulidhoo' during the training of the Fulidhoo dive centre staff in Maldives RC methods in 2019). The Maldives has been proactive in developing new markets in the face of more traditional tourism markets from Europe declining. However, investment in tourism has not been matched by environmental precaution or the "polluter pays" principle that is seen in UK and EU laws, with the intent to stave off the worst impacts of capital growth on the environment (in UK there is the Environment Act that calls for Environmental 'Net Gain'' whereby development projects need to be offset by nearby environmental enhancement and restoration efforts).

Although '100-day' pledges such as protecting one coral reef, mangrove and island per atoll were made by the current government, they were not followed through. Proper financial accounting of healthy marine ecosystems[13] would help to showcase the importance of nature for the country's wellbeing[14].

The political changes in the Maldives over the past decade[15], along with increased national debt from major internationally funded capital projects (e.g. the Hulhumale bridge funded by the Chinese government), have led to increased land and island reclamation for island creation – to make space for indigenous populations, capital infrastructure, but also for tourism expansion. Combined with other environmental issues, these major capital projects move environmental degradation well beyond sustainable limits for essential coral protection and natural resource management (at least for central atoll reefs where we regularly survey). Construction has an attractive short-term positive impact on the country's Gross Domestic Product, and is politically attractive, but the impacts on the wider ecosystem and population are not effectively accounted for. Many of the islands of the Maldives are built on naturally shifting sand islands, so the concretion of the foundations of islands works against nature's natural change of island development (Kothari and Arnall 2020). The development of hard 'sea walls' and other concrete structures around islands only borrows time away from natural erosion and movement.

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11 https://www.tourism.gov.mv/dms/document/f5f522de183dde8f0f012884cecb1706.pdf
12 https://tourism.gov.mv/en/registered/facilities/filter-t1
13 https://www.dropbox.com/s/0b64j69s76et3r8/Summary%20-%20bottom-contact%20fishing%20MPA%20report%20%281%29.pdf?dl=0
14 https://www.gresham.ac.uk/watch-now/series/natural-capital
15 https://www.bbc.com/news/world-south-asia-40827633

Employing policies and actions at national and local levels for the good of citizens within environmental limits has been theoretically detailed by Raworth (2018), and is being employed by some cities now (e.g. Amsterdam).

Recent resort developments in the Maldives permitted under the previous Maldivian government have not considered the on-costs (e.g. social, coral reef degradation, fish habitat and waste treatment costs) of developments to the environment in planning and remedial works. As a result of over-exploitation, development and climate change impacts, the Maldivian environment is now less able to deliver local food (fish), coastal protection, homes, and a clean environment to its people. Infrastructure, such as capital investment in waste treatment, reef habitat protection or creation and fish population enhancement tools, are needed to 'buffer' resort or other commercial development.

Prior to the 1990s, before mass-tourism developed in the Maldives, a healthy marine environment offered previous generations long-term security. Citizens are now most concerned about housing, food and security. Centralisation of decision-making by the previous president and poor decision-making resulted in the rejection of proposed conservation measures by local islands in North Ari (Grimsditch, personal communication). A June 2018 article interviewed the ex-environment minister in office (Mohamed Aslam who was minister up to 2009) about the attitudes of the Maldivian public regarding environmental issues[16]. In the article he implied there was no need for the two major political leaders to consider environmental issues in their election campaigns, as these were not vote-winning issues (this despite the designation of three very small MPAs prior to the 2018 election), despite the fact that environmentally conscious government policy (e.g. the green 'new deal'[17]) would benefit the public by providing clean drinking water, clean energy, secure housing, schools, education, health, etc.

Whilst the new Maldives government appears to be more environmentally aware, the impact of the previous government has been to leave the country indebted to investment from outside countries and partners. These debts will need to be paid in future years. This too may further weaken investment in environmental policy, action and protection.

Reversing the trend

Before 2008, the Maldives lacked a champion for the protection and recovery of marine resources. However, the Maldives government of Nasheed once made 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 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 like that of Baa atoll that had UNESCO status. Despite the progressive political intentions of such statements, there was no strategy forthcoming from government agencies, such as the EPA or MRC. Similar promises by the UK government to designate a world-class network of MPAs have been met with meagre budgets for enacting and enforcing subsequent controls and enforcement on fishing vessels. So, the trend is global, not national, for many policies not to be followed through with effective action at a national scale.

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[16] https://magazin.zenith.me/de/politik/mohamed-aslam-%C3%BCber-klimawandel-extremismus-und-politik-auf-den-malediven (published online in 'Zenith', June 18, 2018)
[17] https://neweconomics.org/2008/07/green-new-deal

Regular monitoring of sites that informed the international community of the health status of Maldives reefs has predominantly been undertaken by outside agencies (such as IUCN, international scientists, and Biosphere Expeditions), until bleaching events occur. Many Maldives citizens have strong scepticism towards western conservation work. This is likely a result of Western tourists being tainted with the colonial brush as well as 'foreign' conservation efforts being considered alongside unsustainable foreign investment in the tourist industry that is at odds with the cultural norms (e.g. de Vos 2020). The Marine Conservation Society and Biosphere Expeditions can do all the monitoring they want, but without enforcement, boats, trained officers, surveillance of vessels (that all costs millions) and without a judiciary that actually fines companies and individuals that fish in MPAs, and damage the coral reefs beyond the terms of any Environment Impact Assessment (EIA), there will be little support for conservation from the wider population (Zubair et al. 2011)). Only after investments are made in coral reef protection, fisheries restrictions and water and waste treatment will 'conservation' start to deliver for people.

We believe that an entirely different approach is needed to manage the Maldives: a system whereby power is granted to atoll councils with a need to sustain local economies, growth and all within environmental limits. 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, MPA and fisheries enforcement).

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. The UK and many western economies have also seen recent wealth gaps between the richest and poorest, with associated declines in the state of society[18].

The Maldives is a 'canary in the coal mine' for global environmental degradation and the results of unbalanced power structures[19]. The dire situation of the past can improve, but only if the current administration delivers some of the profits (largely from tourism) into public services and proper environmental protection. The Maldives government has the power to make the 'paradise effect' of the Maldives help to pay for its recovery.

[18] https://theconversation.com/dont-listen-to-the-rich-inequality-is-bad-for-everyone-81952
[19] https://www.euractiv.com/section/justice-home-affairs/opinion/unbalanced-politics-leads-to-unchecked-power/

Conclusions

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 very few isolated sites, but the general trend is that the inner reefs have been impacted – particularly in North Ari and North Male' atolls.

This is apparent both within the coral diversity itself (see Guraidhoo backreef in particular), but also in the different types of organisms and phyla that appear to be in competition for space with coral. For example, Dega giri in western central Ari atoll is dominated by corallimorphs, Banyan Tree and Baros in North Male' atoll are being colonised by forms of encrusting sponges that grow close to the substrate, whereas Farish faru reef in the west of Vaavu atoll has fleshy lobed sponges that are in direct competition with hard corals.

The outer reefs, in shallow water in particular – appear to be very similar in almost all locations – particularly where the drop-off is more extreme. Dhigurah, Rasdhoo, Ranikan and Guraidhoo outer all resemble one another, have similar coral, coral rock, sponge, and algal counts.

After a decade of annual Reef Check surveys, we posit that there are five types of reef location and environmental condition, four of them inner reef types:

1. **Exposed outer reefs** associated with greater current, wave action and adjacent to very deep water are generally more resilient to bleaching (because of dominance of greater bleaching-resistant coral lifeforms and cooler, deeper adjacent seawater – Cowburn et al. 2019).

2. **Inner reefs**, which were dominated by temperature-intolerant species such as branching *Acropora* and *Pocillopora*, which are subsequently more vulnerable to disease, *Drupella* predation, Crown of Thorns grazing, sponge/algal recruitment and growth. In the central atolls of the Maldives, inner reefs are dominated by coral rock and turf algae. They may still be able to recruit corals and grow back to being coral dominated (e.g. Kudafalhu in central Ari) compared to those that have recruited toxic species such as *Discosoma* corrallimorphs, that appear to have few predators. It would appear from the literature that there may be a 'resort' affect, with lower recovery trajectories after bleaching being observed at inhabited reefs – but this is highly variable (e.g. Montefalcone et al. 2020).

We observe the following status of the reefs:

A. In general, outer reefs that are exposed to colder oceanic waters appear to be more resilient than inner reefs that suffer more heat, pollution, fishing and nutrient stress.

B. Some inner reefs are exhibiting a phase change from a coral-dominated state to an algal, sponge and *Discosoma* (non-coral) state (e.g. Dega giri).

C. Some inner (S Male' atoll) reefs have adapted to climate-induced bleaching with more bleaching- and sediment-tolerant coral species, e.g. *P cylindrica* and *P. rus* persisting or outcompeting *Acropora* recruits, sponge, algae and other competitors (e.g. Guraidhoo backreef and Beybe's).

D. Certain reefs show some resistance to bleaching impacts, supporting species that were hitherto described as having low thermal tolerance (e.g. Farish faru) with large thickets of *Acopora* corals in deeper (>15m) water. The greater shelter and deeper nature of the colonies may have released these colonies from shallow water extreme SSTs during bleaching (waters under 5m) Note that this is the rarest form of reef we observed in our surveys since the 2016 bleaching event.

Our recommendations on issues related to coral reef vulnerability have been highlighted in previous reports available from the Biosphere Expeditions page on ResearchGate. Our observations and training will hopefully increase awareness. Research has shown that recovery projections from bleaching events become more protracted over time, whilst more frequent bleaching events occur. Therefore, the Maldives will need decades to recruit and grow corals to resemble the reefs before the 1998 bleaching event. However, with the 2020 bleaching event occurring just four years after the last event (and another one predicted in 2023), the ability to be resilient to such events is being tested more than ever before. As such, it is likely that the reefs will never regenerate to the levels seen in 1997 and before, and indeed, the species guilds – of corals at the very least – will be very different, particularly for inner atoll reefs.

Our recommendations are:

1. Invite either the 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. Pay them sufficiently such that they are not tempted to fish themselves or ignore illegal fishing. Re-visiting the de-centralisation act would help facilitate local protection.

2. Fund sufficient EPA officers and atoll council law courts and enforcement officers to arrest and fine people who break environmental rules/laws in MPAs and at island house reefs. A Protected Areas Act with a duty to monitor and enforce could enable progress in this area.

3. Give the EPA funding to investigate & prosecute (fine) tourism or other developments where environmental damage is being caused (such as sediment outflows on live healthy reefs) above levels stated in Environment Impact Assessments. Enable EPA to do its job properly by divesting funds from developers to enforcers such that they have the staff and materials to effectively enforce their duties.

4. EPA officials must have knowledge of pristine (or semi-pristine) environmental baseline conditions to assess the relative scale of impact. They need funding to visit pristine reefs in remote parts of the archipelago to support them.

5. Ensure that fisheries department officials work collaboratively with the EPA in assessing fisheries' activities at resorts, grouper cages[20], processing facilities and at airports.

[20] Grouper cages exist in at least five atolls where fish are corralled before being shipped to Asian 'live fish' markets.

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 allow 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 (Wood et al., 2011), which includes:
   a. regulated fishing
   b. mandatory logbooks and data collection
   c. long-term monitoring of catch, abundance and spawning aggregation sites
   d. national level awareness-raising programme
   e. a mobile-phone technology Vessel Monitoring scheme for Maldives-registered fishing vessels such that enforcement can be done by using satellite technology.

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. 2.4k).

10. Ensure that the EPA is provided enough budget (via for example a tourism tax) to enable it to be present (with an officer) 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.

Figure 2.4k. 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 regulation (from Wood et al, 2011).

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