Maldives Grouper Fishery and Conservation Project

PHASE 2 REPORT

Vivienne Evans, Shaha Hashim and Simon Harding

Blue Marine Foundation

May 2018

Table of Contents

Acknowledgements

The authors would like to express their gratitude to all those who have assisted with their work in achieving the outcomes of this project.

First, special thanks go to all our sponsors: Six Senses Laamu, Marks and Spencer, and the United Nations Joint Programme on Low Emission Climate Resilience Programme (LECReD). Without their financial support, this project would not have been possible.

A broad thank you to all staff at the Marine Research Center (MRC) and Ministry of Fisheries and Agriculture (MoFA) who assisted us in the various aspects of the work. Special thanks go to Fahmeeda Islam, Maeesha Mohammed and Ahmed Najeeb who provided us with technical support, participated in field trips and assisted with the data collection. Many thanks also to Minister Shainee, Sinan Hussain (MoFA) and Dr Shiham Adam (MRC Director) for their support and guidance.

We would like to express our heartfelt gratitude to all staff at Six Senses Laamu with special mention to Marteyne van Well, for their continued support throughout the project and for hosting us at the resort. A special thanks to Ocean Dimensions who facilitated logistics for our dive surveys from August 2016 to July 2017, and to Deep Blue divers who continue to facilitate logistics for our dive surveys since August 2017. Thanks also go to members of the marine team with whom we partnered with for much of our educational work but who also continually supported our work throughout; Jenni Choma, Megan O'Beirne, Oscar Ignetik, Adam Tholhat (Manta Trust), Beth Taylor (Manta Trust), Haisham Rasheed (Manta Trust), Beth Faulkner (Manta Trust), Steven Hsiao, Ibrahim Yameen, Natasha Prokop and Megan Eddy. Thanks go out again to Jenni Choma for assisting with data collection on spawning aggregation dive surveys.

We greatly appreciate the assistance of the Laamu Atoll Council and Island Councils who were so co-operative and helpful throughout our project, most notably previous Atoll council members; Yoosuf Amir and Ibrahim Rasheed, present Atoll Council members; Abdullah Shareef and Moosa Faisal, Hussain Naees and Shaheen Ismail, civil service staff of the Atoll Council; Mohamed Jameel, Athifa Zahir and Hussain Rafeeu, and Hussain Habeeb from Maamendhoo Council. You were all extremely welcoming and helpful and without your help, it would not have been possible to conduct our work in Laamu.

Many thanks to all the grouper cage owners who contributed to this research by allowing us to purchase fish from their holding cages across the country; Mushthaq Mohamed and Ahmed Ibrahim (Maavah, Laamu), Aslam Mukhthar and Ali Waheed (Maamendhoo, Laamu), Ali Nifaz Mohamed and Suhuraab Abdullah (Vaavu and Gaafu Dhaalu atolls) and Adambe (Hulhumale).

We would like to express our utmost gratitude to all the grouper fishermen on Laamu who participated in the project by allowing us to interview them.

Special thanks to all the Maldives National University students who participated in the project and assisted with data collection; Shareefa Ali, Nafha Asim, Risha Ali, Mariyam Samha, Aishath Amal, Ibrahim Yameen and Farah Mohammed. We would also like to thank Abdullah Fisam from IUCN for assisting with field work.

Many thanks also to Professor Yvonne Sadovy (University of Hong Kong) and Dr Steve Lindfield (Palau) for their scientific and technical advice, particularly regarding grouper spawning aggregations and size maturity assessment.

Executive Summary

In the last forty years fishing pressure on grouper species in the Maldives has dramatically increased mainly for external markets (export fishery) but also for internal markets (tourism). This report focuses on the grouper fishery for the export trade which poses the largest risk to Maldivian grouper populations. The export grouper fishery in the Maldives began almost thirty years ago in response to the demand for live groupers from mainland Asian markets. The fishery has been reviewed a number of times since it began in the 1980's and a pattern of overfishing has emerged.

Groupers are an iconic family of marine predatory fish that occur in warm-temperate and tropical waters. They play a critical ecological role in moderating the abundance and behaviour of prey species, with numerous direct and indirect effects on ecosystems. Groupers are also very important economically, mainly as a fishery resource but also as a non-extractive value to the (dive) tourism industry. However, groupers have life history traits that make them the most threatened reef fish family on coral reefs. They are slow to mature and exhibit a high degree of site fidelity, especially to spawning aggregation sites making them easy targets for fishermen. Almost a quarter of all grouper species are now on the IUCN Red List as either endangered or threatened with many others requiring further assessment. Many of these species are listed because of overfishing, with some listings the direct consequence of fishers targeting spawning aggregations. Any loss of grouper species is likely to have substantial socioeconomic and ecological implications.

At the request of the Ministry of Fisheries and Agriculture (MoFA), the Blue Marine Foundation (BLUE) developed a project to collect key information to support the implementation of the Maldives Grouper Fishery Management Plan whilst also raising stakeholder awareness of groupers and their key role in coral reef ecosystems. The *Maldives Grouper Fishery and Conservation Project* was initiated in early 2016 through a scoping assessment, with the main phase starting later that year. The project has been based on Laamu Atoll in partnership with Six Senses Laamu resort, Laamu Atoll Council and both the MOFA and Marine Research Center (MRC) in Male.

This document reports on the activities completed between September 2016 and December 2017 for Phase 2 of the project within four work programmes:

1. Assessment of the grouper fishery on Laamu Atoll from fisher knowledge;
2. Identification and mapping of grouper spawning aggregation sites on Laamu Atoll;
3. Determination of size-maturity relationships for selected grouper species;
4. Environmental Education and Awareness Programme, mainly on Laamu Atoll.

The main findings and details of each work programme are summarized below:

Laamu Grouper Fishery

A comprehensive fisher survey interviewed 119 fishermen from all 11 inhabited islands on Laamu Atoll. Most (88%) were opportunistic reef fishermen who fish for grouper but some (12%) specifically target grouper for export, predominantly as live fish. Three holding cages were in operation on the atoll in 2017 and some fishermen also sell directly to grouper collection vessels. Fishermen identified 17 potential grouper spawning aggregation sites on Laamu Atoll, seven of which were in the main channels. Almost all (93%) fishermen were aware of spawning aggregation sites and 95% of those who identified sites had fished them. Fourteen grouper species were reported to aggregate on Laamu Atoll with the highest number of reports for *Epinephelus fuscoguttatus* (87%) and *Plectropomus areolatus* (64%). Most fishermen stated that groupers aggregate over the new moon phase and just over half

thought that they aggregate every month. Ten reported spawning aggregation sites have been fished locally for more than 30 years. A decrease in grouper catches and sizes were reported by fishermen at most sites. The size (length) of the four most targeted species was estimated to have decreased by an average of 22 cm over the last 20 years. Catch per unit effort has fallen with fishers reporting that it takes four days to catch 100 kg now, when it took just one day twenty years ago. There is more fishing at night now with better gear to improve catch efficiency (technological creep).

There is a lack of awareness of existing national fishery regulations for grouper amongst fishermen on Laamu Atoll. More than 80% of fishermen interviewed were not aware of current management measures for the grouper fishery and none could accurately describe existing catch size limits for grouper species. However, most fishermen (85%) support management of the fishery and think this is extremely important. They recognise that grouper stocks have declined and that the fish are getting smaller and harder to catch, which is having an effect on livelihoods.

Grouper Spawning Aggregation Sites

Fisher's knowledge assessments indicated that grouper spawning aggregation sites are located predominantly in the seven main channels of Laamu Atoll. Exploratory dive surveys at all seven channel sites conducted over the new moon revealed preliminary evidence of grouper spawning aggregations at four of these sites. A comprehensive programme of timed swim surveys was then completed at three sites: Hithadhoo Corner, Maavah Kandu and Fushi Kandu for an eight-day period over the new moon, between August 2016 and September 2017. Grouper density and behaviour recorded at these sites indicates that all three are spawning aggregation sites for certain species. More detailed and repeat (monthly) surveys were also completed at Hithadhoo Corner. From these we verified that Hithadhoo Corner is a spawning aggregation site for *Epinephelus fuscoguttatus, Plectropomus areolatus* and *Epinephelus polyphekadion.* Surveys at the two other sites strongly suggest that these channels also harbour grouper aggregations, but further assessment is required to verify this. Highest densities of groupers were recorded at Hithadhoo Corner which may be an indication of lower fishing pressure at this site compared to others on the atoll. The lack of *Epinephelus* spp. at other surveyed sites compared to Hithadhoo also supports this suggestion. The research at Hithadhoo Corner is the first detailed study of a grouper spawning aggregation site in the Maldives over multiple new moon phases.

Grouper Size-Maturity Metrics

Current national size limits for groupers are too small and do not prevent the catch and export of immature fish. At the specific request of government partners, we conducted a size-maturity assessment of five highly targeted groupers species to provide evidence to support the revision of existing regulations. More than 400 groupers were sampled over the new moon at cage systems on four atolls between February and October 2017.

After analysis we identified size-maturity relationships for two grouper species (*Epinephelus polyphekadion* and *Plectropomus areolatus)* but not for the two other targeted species (*E. fuscoguttatus* and *Plectropomus laevis*). Data for a fifth species (*Plectropomus pessuliferus*) was almost sufficient to confirm size at maturity, and minimal further sampling should be able to complete this. Size maturity metrics completed for *E. polyphekadion* and *P. areolatus* show that existing size limits are as much as 50% smaller than actual size at maturation for these two species, which we determined to be 40 cm (*E. polyphekadion*) and 42 cm (*P. areolatus*). The size at maturity metrics identified in the Maldives by this study are similar to theoretical maturity lengths derived from global data. In the interest of preventing further grouper population declines and safeguarding the long-term

future of the fishery we recommend that all size limits for targeted grouper species are revised so that they are based on global size at maturity estimates.

Environmental Education and Awareness

A comprehensive environmental education and awareness (EEA) programme of activities was implemented on Laamu Atoll to engage with a wide range of stakeholders including local authorities, grouper fishermen and cage owners, coastal communities, local schools, and resort staff and guests. We also worked at the national level with the Maldivian government, Maldives National University and other non-governmental organisations. Through this programme we:

- Engaged with more than 100 local grouper fishermen
- Supported 5 undergraduate conservationists
- Inspired 500+ students from 13 schools
- Completed two hand painted wall murals on Maamendhoo and Dhanbidhoo islands
- Made educational videos that were viewed over 15,000 times on social media
- Involved 1500+ people from all 11 islands in Laamu in our project

Our EEA programme was effective in raising the awareness of grouper vulnerability and the status of the fishery with Laamu fishermen, cage managers and owners and local government (Atoll and Island Councils). Through our internship programme with Maldives National University (MNU) we supported five students and provided much needed work experience to help them secure employment in the environmental sector. Further capacity building with MRC staff has provided skills for spawning aggregation site assessment and sampling for size at maturity.

Conclusions and Recommendations

Laamu Atoll

Our research provides strong evidence that the current level of fishing pressure on Laamu Atoll for groupers targeted for export is unsustainable. Overfishing of groupers and targeting of spawning aggregations for at least thirty years has led to the decline in sizes and abundance of groupers, an increase in fishing effort and an overall reduction in income for fishermen. Grouper spawning aggregations are still present on Laamu but are likely to be fished out if they continue to be heavily targeted. Hithadhoo Corner is the first verified multi-species spawning aggregation site in the Maldives and the main stronghold for *Epinephelus fuscoguttatus* on Laamu Atoll. The scarcity of *Epinephelus fuscoguttatus* in cage systems across the country is evidence that this species is becoming increasingly rare. With this in mind, we recommend that the spawning aggregation site at Hithadhoo Corner is prioritised for protection.

National Level

Current national management regulations for the grouper fishery are not working and some such as size limits are insufficient to prevent the further decline of populations. There is an urgent need to improve existing management strategies and implement complementary regulated practical measures to ensure grouper populations are sustained and protected for the benefit of the Maldives. Based on a review of grouper fishery management and our findings we propose nine key recommendations for the Maldivian grouper fishery:

1. Prioritise the protection of grouper spawning aggregation sites across the Maldives
2. Revise minimum size limits for all groupers targeted by the export trade
3. Introduce export tariffs for both live and dead grouper shipments

4. Introduce further fishery management measures to limit catch levels and gear use
5. Strengthen monitoring, control and surveillance for the export grouper fishery and existing protected grouper aggregation sites
6. Increase the capacity for management of the grouper fishery at the national and atoll level
7. Improve fishers' awareness of both existing and proposed fishery management regulations
8. Conduct further research on targeted grouper species to improve fishery management
9. Explore both internal and external funding mechanisms to enable effective fishery management

These ten points are split into individual recommendations and actions which are summarised under six main themes: 1. Protection of Spawning Aggregation Sites; 2. National Policy and Regulations; 3. Monitoring, Control and Surveillance; 4. Management Structures; 5. Education and Awareness, and 6. Further Research.

There is an urgent need for strong action to substantially improve management and safeguard both grouper populations and the livelihoods of those involved in the fishery. If no action is taken it is likely that commercially viable populations of highly targeted grouper species will be lost from atolls and possibly whole regions of the Maldives.

Of the range of management measures proposed in this report we strongly advise to expand the use of marine reserves to protect grouper spawning aggregation sites as long as they are properly managed. Marine reserves can effectively protect grouper spawning aggregation sites while also providing benefits to local fishermen. There are compelling biological and economic reasons not to fish spawning aggregations if they are not properly managed.

Protecting key life-history stages of grouper populations should go hand in hand with improved management of grouper fisheries such as functional size limits that enable fish to become mature and species-specific catch quotas. Strengthening catch and export reporting as part of existing license conditions will significantly help to monitor and control the fishery. Better knowledge of grouper biology and life histories is also required to inform management. However, a lack of adequate scientific information should not prevent or delay the use of strong management measures at this point, but instead, be a reason for taking a precautionary approach given the history and current status of the fishery.

Grouper spawning aggregations are still present in the Maldives and can recover if adequately protected. Allowing more engagement and enforcement at the atoll level through the combined efforts of national and local authorities will enable management measures to work better on the ground. Restoring grouper populations should be considered a key part of a larger process to maintain the natural capital of the Maldives and will help to ensure that coral reef ecosystems continue to support the Maldivian economy through the provision of a range of ecosystem services for the benefit of multiple stakeholders.

The sustainability of an export fishery for grouper should also be questioned and whether it is in the long-term interest of the Maldives to continue to permit these reef resources to be lost given their importance to the ecosystem.

To ensure the future of the Maldivian grouper populations and the fishery we strongly recommend that the management measures proposed are carefully considered and implemented. BLUE is ready and willing to work with partners in order to protect groupers and improve the management of the fishery going forward.

Introduction

The Maldives

The Republic of the Maldives is an archipelago comprising of approximately 1,200 low-lying islands in 26 atoll groups covering an area of approximately 90,000 km^2 in the central Indian Ocean, running north-south along 73˚E from about 7˚N to 1˚S. The country's Exclusive Economic Zone (EEZ) covers an area of nearly one million km^2. The total land area of the Maldives is about 300 km^2 with some 190 islands inhabited by just over 400,000 people in 2014 (National Bureau of Statistics, 2014). Coral reefs in the Maldives cover more than 3,500 km^2 of coastal waters and are some of the most diverse in the Indian Ocean, hosting 250 species of corals that provide habitat for 1200 species of fish (Naseer and Hatcher, 2004).

Almost the entire Maldivian economy is dependent on marine and coastal resources through the tourism and fisheries sectors. Biodiversity-based sectors contribute more than 70% of national employment, more than half of public revenues, almost the entirety of exports, and close to 80% of GDP (The World Bank 2016). In addition, fish provide 77 percent of dietary animal protein for the people of the Maldives (Burke et al., 2011). Any threat to the ecosystem and the natural environment of the Maldives such as through climate change, overexploitation of marine and coastal resources and degradation of the marine habitat, can have adverse impacts on current socio-economic wellbeing and future development of the country and its people (UNDP 2015).

Groupers – importance and vulnerability

The 163 species of grouper, an iconic family of marine predators that occur in warm-temperate and tropical ecosystems are extremely important, both ecologically and economically. Groupers are apex or mesopredators and play a critical ecological role in moderating the abundance (Stallings, 2008) and behaviour (Madin, Gaines and Warner, 2010) of prey species, with numerous direct and indirect effects on ecosystems. Many species are also very important economically, mainly as a fishery resource but also as a non-extractive value to the (dive) tourism industry which can influence the economic viability of marine protected areas (Rudd and Tupper, 2002).

Groupers have a number of life history traits that make them the most threatened reef fish family on coral reefs (McClenachan, 2015). They are slow to mature and have complex social systems that provide cues for sex change. Groupers also exhibit a high degree of site fidelity within their home ranges and to spawning aggregation sites where they are easy to capture, particularly with improvements in fishing technology which allow for the targeting of specific spawning locations. IUCN Red List assessments show that, globally, 20 species (12%) are at risk of extinction if current trends continue, and an additional 22 species (13%) are Near Threatened (Sadovy de Mitcheson et al., 2013). In addition, 30% of grouper species assessed are categorised as 'data deficient' indicating further assessment is urgently required at the regional and global level. Any loss of grouper species will have substantial socioeconomic and ecological implications (Luiz et al. 2016).

Spawning aggregations

Many exploited marine fishes form large temporary gatherings to reproduce, including spawning aggregations, which are one of the oceans most spectacular, fascinating and biologically productive phenomena (Sadovy de Mitcheson, 2016). A spawning aggregation has been defined as '*a repeated concentration of conspecific marine animals, gathered for the purpose of spawning, that is predictable in time and space*' (Domeier, 2012) These aggregations are the foundation of many of the world's major large- and small-scale fisheries and are integral components of marine ecosystems. More than

one hundred species of coral reef fishes aggregate to spawn including groupers. The lower productivity of coral reef fishes compared to those in temperate waters makes them particularly susceptible to overfishing (Sadovy de Mitcheson and Colin, 2012).

Spawning aggregations can be quickly eradicated by intense fishing pressure (e.g. Sadovy and Domeier, 2005) and once eradicated are not known to recover (Domeier, 2012). The presence of a spawning aggregation at a particular site can therefore be considered an indicator of long-term ecological stability. Spawning aggregations also provide an opportunity to assess fish stock through direct counts at the aggregation site (fishery independent data). Conversely, landings data from spawning aggregations is not as useful for stock assessment as the aggregation may overwhelm fishing effort until it is drastically reduced through hyperstability (Sadovy and Domeier, 2005) i.e. the aggregating behaviour of the fish results in elevated catch per unit effort (CPUE) even as overall abundance declines until the stock collapses (Figure 2; Sadovy and Domeier, 2005).

Maldives Grouper Fishery

Due to high market prices, groupers are heavily targeted by commercial, recreational and artisanal fisheries globally (Sadovy de Mitcheson et al., 2013). In the Maldives the grouper fishery started in the 1980s and escalated rapidly in the early 1990s, spreading throughout the country, with the export market being the main driver. At least 41 species of grouper are known in the Maldives (Randall and Anderson, 1993; Adam et al., 1998; Anderson et al., 1998) with around 20 species targeted for the export trade. The grouper fishery has been reviewed three times since 2000 by the MRC with the first assessment between 2002 and 2005 (Sattar and Adam, 2005). A more recent review of the fishery in 2010-2011 revealed a very concerning situation: grouper stocks are declining, and smaller sized fish are being taken (Sattar et al., 2011). It is likely that larger fish have been selectively removed and that fishers are increasingly targeting spawning aggregation sites. Catch data for the ten most commonly exploited species of groupers shows an alarming pattern over time. In 2010-2011, 70% of individuals were caught prior to reaching maturity with 90% immature for highly targeted species (Sattar et al., 2011). More recent evidence indicates that 90% of fish for all these ten species are immature when caught (unpublished MRC data). During the first national review of the fishery 43% of groupers caught were immature (Sattar and Adam, 2005). Trends suggest that stocks of species targeted for the live trade are declining and are becoming more difficult to catch. The declining trend for live exports and the corresponding increasing level of fresh chilled exports has resulted in both fishermen and exporters targeting a wider range of grouper species (Sattar et al., 2011).

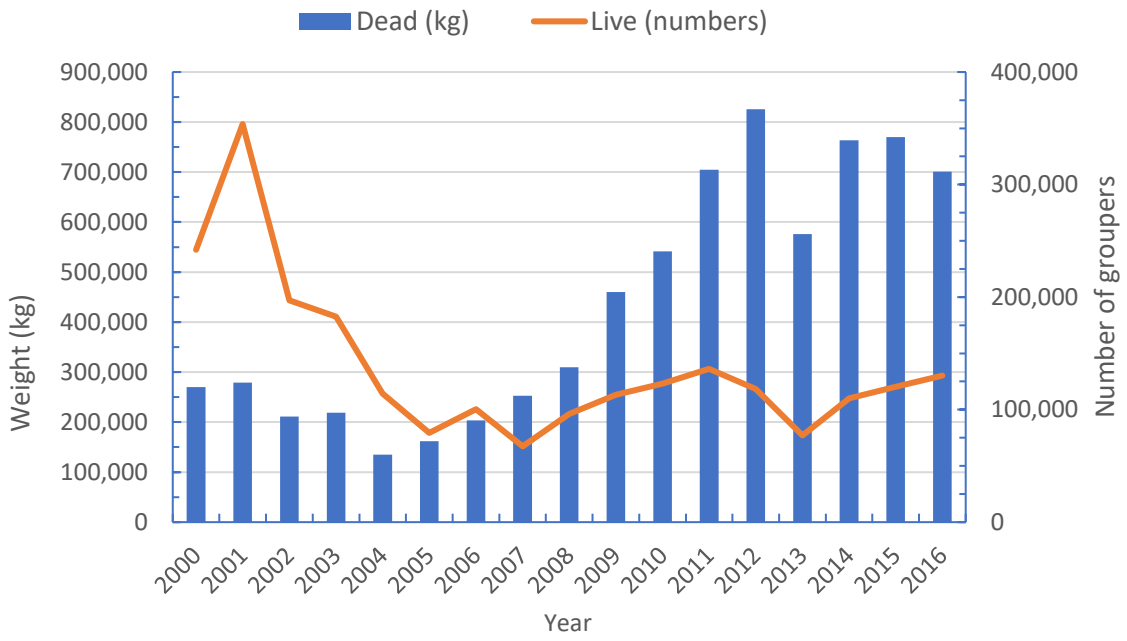
A previous study to identify reef fish spawning aggregations in the Maldives revealed that 87.5% of the fishers (interviewed) were aware of the phenomenon and were able to identify a total of 175 sites where they have seen these aggregations (Tamelander et al., 2008). The Ministry of Fisheries and Agriculture (MOFA) designated five spawning aggregation sites as Marine Protected Areas (MPAs) in 2011 in five different atolls; Dhiffushi Channel in Kaafu Atoll, Aligau Channel in Lhaviyani Atoll, Farukolhu Channel in Vaavu Atoll, Kuda adhi Bodu Channels in Meemu Atoll and Kudahuvadhii Channel in Dhaalu Atoll. However, there has been a lack of capacity to monitor these sites since designation and to enforce the MPA regulations in situ.

Grouper Exports

Grouper are mainly exported as live fish or as whole fresh/chilled although there are small volumes that leave the country as frozen or dried and salted. When exported dead / processed grouper are recorded by weight (kg) while live fish are only recorded in terms of the number of individuals. There is also no differentiation between species in export records. Grouper exports between 2000 and 2016 are presented in Figure 1 below. Since 2000, exports for live grouper peaked at just under 354,000 individuals in 2001 but then decreased annually until 2005 when 79,435 fish were exported. Live

grouper exports have mainly remained between 75,000 and 135,000 fish annually between 2005 and 2016. Conversely processed exports have risen steadily since 2000 after a slight dip in 2004/2005. The quantity of dead grouper exported increased four-fold between 2006 and 2012 from just over 200, 000 kg to almost 826,000 kg. Since the peak in 2012 these grouper exports have remained high with annual amounts over 700, 000 kg between 2014 and 2016 (Figure 1).

Figure 1. Quantity of Grouper exports from the Maldives: 2000 - 2016



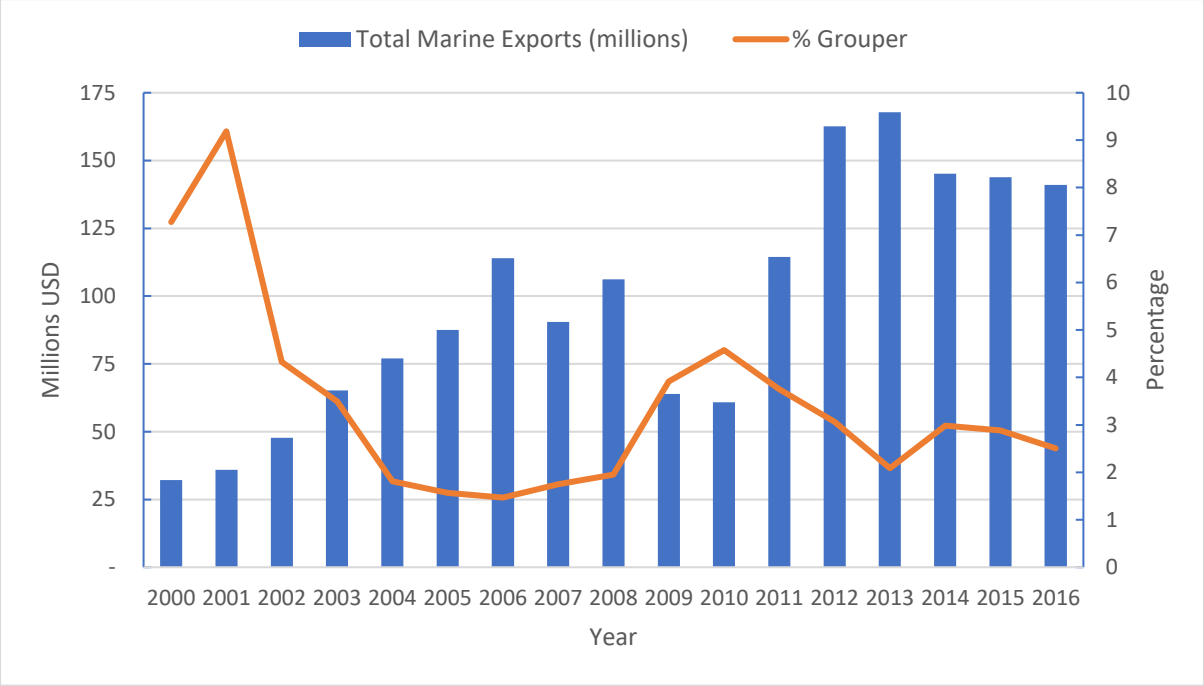
Source: Ministry of Fisheries and Agriculture.

The value of all marine exports to the Maldives economy between 2000 and 2016 is depicted by Figure 2. Total marine exports have risen overall between 2000 and 2013 with a dip in revenue for 2009 and 2010 and slight decline between 2013 and 2016. Marine exports were worth just under 168 million USD in 2013 but have since decreased to 141 million USD in 2016. Marine fisheries contribution to GDP was 2.5% in 2015; 1.3% for harvesting and 1.2% for processing in 2015[1]. Focusing on grouper exports, these have represented less than 10% of total marine exports each year since the year 2000 (Figure 2) and have decreased over this time. Groupers represented 9.2% of marine exports in 2001 but had fallen to 2.5% in 2016.

Although the contribution of grouper to marine resource export revenue has fallen since 2000 the value of grouper exports generally increased up to a peak of just under USD 5 million in 2012 (Figure 3). Most of the revenue has come from exporting dead grouper usually whole and chilled: live grouper made up more than 50% of export value until 2002 but has decreased since then and represented only 12.5% in 2013, increasing slightly to 17% in 2016. The latter slight increase is mainly caused by a drop in dead grouper revenue rather than an increase in live export value (Figure 3).

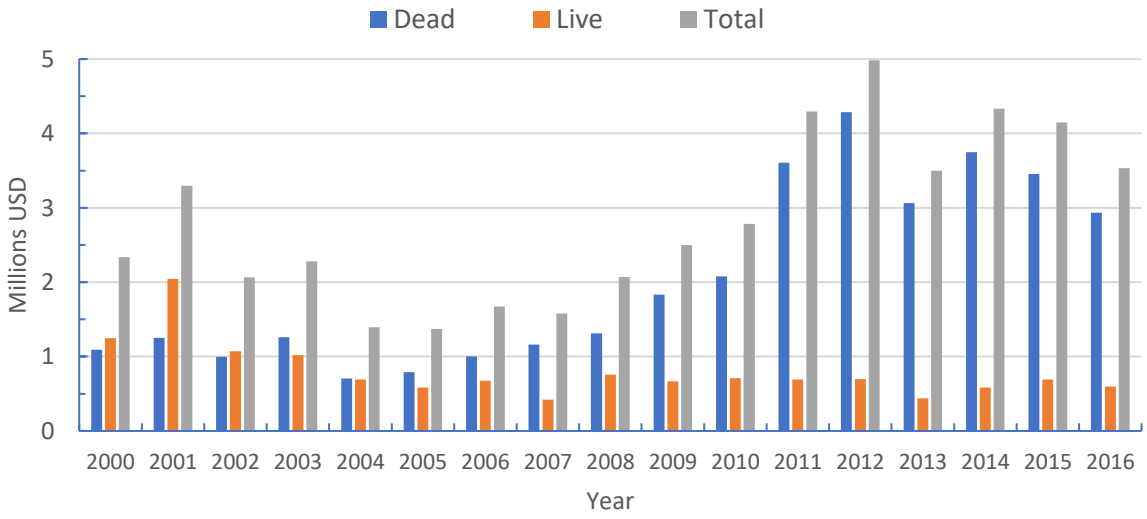
[11] http://statisticsmaldives.gov.mv/gdp-revision-october-2016/

Figure 2. Value of Grouper Exports and Total Marine Exports in the Maldives: 2000 – 2016



Source: Ministry of Fisheries and Agriculture (values converted from Maldivian Rufiyaa (MVR) to U.S. dollars (USD) using a currency rate of 1 USD = 15,42 MVR)

Figure 3: The Value of Grouper Exports for the Maldives: 2000 - 2016



Source: Ministry of Fisheries and Agriculture (values converted from Maldivian Rufiyaa (MVR) to U.S. dollars (USD) using a currency rate of 1 USD = 15.42 MVR)

Project development – Scoping and Phase 2

The initial idea for the project originated from the Ministry of Fisheries and Agriculture in 2014 who approached the Blue Marine Foundation (BLUE) for support. After extensive discussions between BLUE and MOFA alongside background research and project design by BLUE an agreement was reached to start a project on Laamu Atoll in partnership with Six Senses Laamu and the Marine Research Center (MRC). The proposed work builds on previous collaborative initiatives to improve the status of groupers in the Maldives through better management of the fishery, namely the work funded by the UK Government's Darwin Initiative undertaken by the Marine Conservation Society in partnership with MRC and MOFA between 2009 and 2013.

A scoping mission to the Maldives by BLUE technical staff was conducted in January 2016 to meet with project partners and collect preliminary information on grouper fisheries on Laamu Atoll. BLUE met with staff from Six Senses Laamu, the Marine Research Centre, the Ministry of Fisheries and Agriculture (MOFA), Laamu Atoll Council and several island councils on Laamu. Initial interviews with some grouper fishermen and fish cage owners were conducted to determine the feasibility of conducting the project activities on Laamu Atoll. Phase 1 (scoping) was completed in April 2016 with the production of a scoping report and draft work plan (Harding and Moore, 2016).

Phase Two components – work programmes

Following the scoping phase, the work plan for Phase Two was discussed and agreed between BLUE, Six Senses Laamu, MRC and MOFA (Appendix 1). Phase Two was implemented between September 2016 and December 2017 and consisted of four main activities predominantly conducted on Laamu Atoll:

1. Collect baseline information on the grouper fishery on Laamu Atoll: Conduct interviews with grouper fishers and grouper cage owners in Laamu Atoll
2. Identify and map grouper spawning aggregation sites in Laamu: Carry out dive surveys at spawning aggregations sites
3. Collect Size and Maturity Information for groupers: Conduct gonad analyses to identify size-maturity relationships for selected highly targeted grouper species
4. Environmental education and awareness work in Laamu: Engage with all stakeholders to raise awareness of groupers and the need for improved fishery management

The project addresses one of the main causes of over-exploitation by gathering information on the location of grouper spawning aggregation sites in Laamu Atoll. Detailed knowledge of these sites for selected species can then be used to begin the process of protecting these sites from fishing and increase the number of grouper MPAs designated in the Maldives. Collecting historical and current information on grouper fishing practices will provide detailed knowledge on the status of the fishery for the atoll. Discussions with grouper fishermen, fish cage owners and island councils will also increase environmental awareness of the importance of these sites for grouper populations on Laamu Atoll. The rationale for selecting spawning aggregation site protection is that preventing overfishing at these sites will help to ensure that grouper populations do not decline further by enabling spawning and natural replenishment of groupers on Laamu. Further information for each work programme is provided in the appropriate section of this report (see below).

Of the four main activities two were regarded as high priority to provide critical information to improve the management of the grouper fishery at the national level through supporting the

implementation of the grouper fisheries management plan: validation and mapping of spawning aggregation sites and determining size-maturity relationships for key grouper species targeted for live export. For the latter MOFA specifically requested this information to improve the current national catch size limits for grouper as successful lobbying by fishermen and exporters had resulted in size limits being made less effective when revised by Parliament in 2014. Grouper fishermen, the key stakeholders of the fishery, had raised doubts about using maturity sizes based on global data to set the size limits. Size maturity assessments in the Maldives were requested to account for this. While the decision in 2014 for the existing size limits involved fishermen's considerations rather than scientific evidence, the aim is to move towards a set of effective size limits based on scientific evidence through phased revision of current size limits (MoFA, pers. comm.).

Laamu Atoll

Laamu (Haddunmathi) Atoll, forms the southern limit of the central Maldives (2.0°N, 73.5°E) (Figure 4). The atoll is rimmed mostly by barrier reefs with only a few channels that join the inner atoll waters with the open ocean. There are more than 70 islands in Laamu, most of which are located along the eastern and southern boundaries. The islands on the eastern side are quite large by Maldivian standards, hosting about 67% of the resident population of the atoll[2]. Currently, 11 islands are inhabited in the atoll.

Laamu Atoll has historically been a predominantly skipjack tuna fishing community. However, in islands located further away from the channels such as Gan, Fonadhoo, Isdhoo and Kalaidhoo, the main income generating activity is either farming or increasingly commerce and small-scale business.

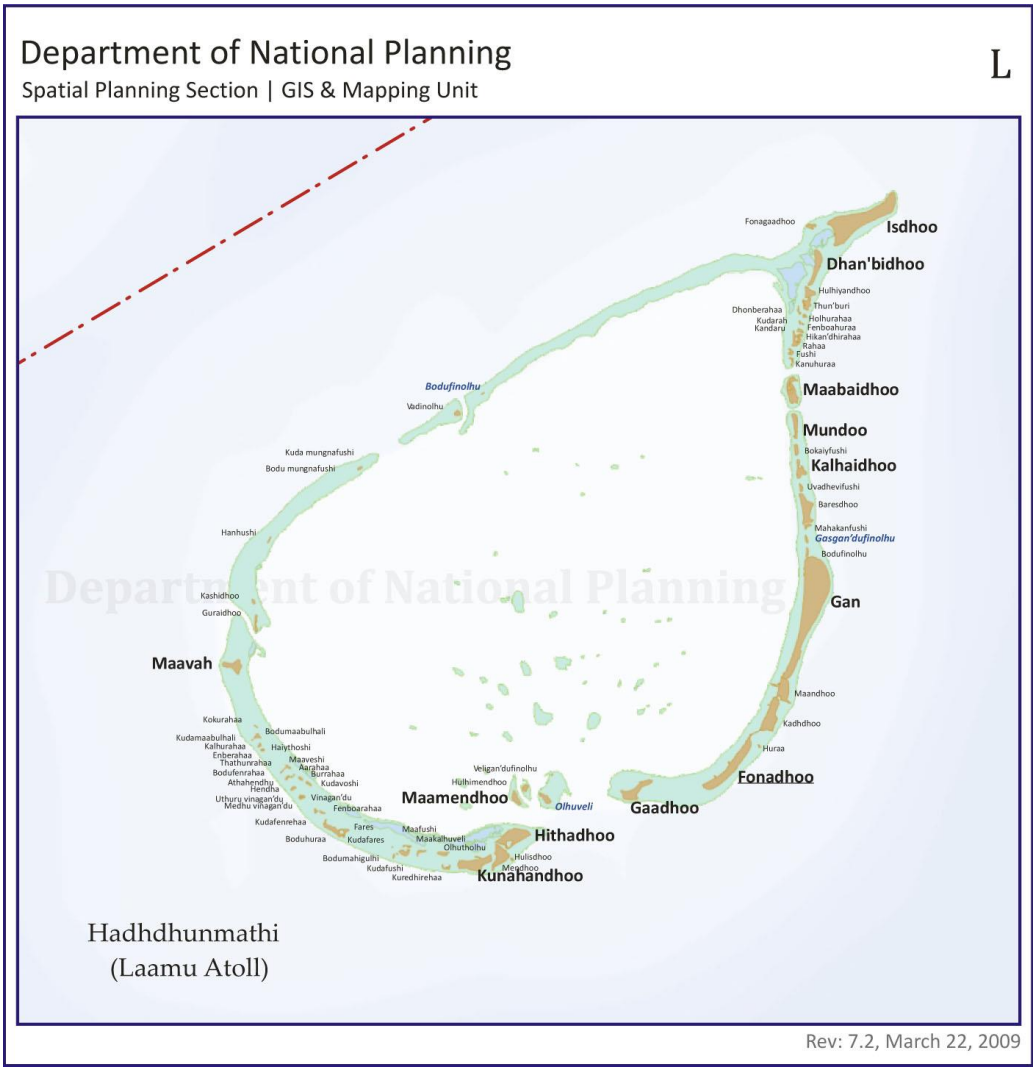
Tourism in Laamu Atoll is low compared with other atolls in the Maldives. Currently, there are only four accommodation facilities on the entire atoll. To put this into perspective, there are 268 accommodation facilities in Kaafu Atoll. Six Senses Laamu is currently the only resort in the atoll and 2 guest houses and one hotel are on the island of Gan[3]. However, a new resort is currently being built on the south-western side of the atoll, between the island of Maavah and Kunahandhoo. This resort is due to open in April 2018 with 150 rooms with plans to expand to 800, which would make it the largest resort in the country.

Laamu Atoll was also selected as a focus for the Low Emission and Climate Resilient Development Programme (LECReD), a three-year programme implemented jointly by seven resident United Nations Agencies in the Maldives. The programme which began in 2014 sought to encourage and develop the capacity of local councils to mainstream LECReD issues into local level development planning and service delivery for greater community-level ownership and sustainability of programme benefits.

[2] Maldives Population and Housing Census 2014, Table PP 5: Resident Population by Sex, Nationality and Locality (Administrative Islands), 2014

[3] 2017 Tourism Yearbook 2017, Maldives Ministry of Tourism

Figure 4. Map of Laamu Atoll



Report structure

This document is split in to four main sections that report on the work programmes listed above which were completed in Phase 2. Each of these sections discusses the main findings regarding the status and management of the grouper fishery on Laamu Atoll and in the Maldives. The main recommendations for improving the status of grouper populations and safeguarding the fishery are provided in the final section (Conclusion and Recommendations) along with suggestions for further research and monitoring. This section also reviews progress made in managing the fishery since the development of the national grouper fisheries management plan in 2011 (MRC/MCS, 2011) and summarises previous management recommendations since the fishery began.

1. Interviews with grouper fishermen and grouper cage owners

Introduction

There is a lack of information on grouper fisheries and grouper populations for many atolls in the Maldives including Laamu Atoll. Overfishing of groupers has been reported across the Maldives and was inferred by research studies on Laamu more than 15 years ago (Sluka, 2001a, b) as well as more recent small-scale studies. However, to date, there have been no systematic assessments of the grouper fishery on Laamu Atoll.

The 2015 Maldives Fisheries Survey carried out by the MRC identified approximately 50 grouper fishermen on Laamu Atoll with up to 15 fishing vessels in operation (Shimal, 2015). These fishing groups were mainly based on Maavah, Maamendhoo and Dhanbidhoo islands.

A research study was recently completed on the biodiversity and biomass of mesopredatory reef fishes on Laamu Atoll (House, 2015). Interviews with local fishermen suggested that several reef fish species were already in decline. The study recommended improved monitoring of commercially targeted grouper species and called for more robust fisheries management, including designation of a protected area at one of the sites with high abundance of reef fish, Hithadhoo Corner.

This work programme aimed to gather information from local fishermen to gain a comprehensive understanding of the grouper fishery in Laamu Atoll, including the location of spawning aggregation sites on the atoll. Data collected will be used to document the fishery using fisher knowledge and use this to help develop management recommendations at both the atoll and national level.

Methodology and data collection

Information on fisher numbers was first requested from individual island councils (Appendix 2). Before interviews fishers were asked to provide some personal details to build up a fisher profile (Appendix 3). Two questionnaires were developed for grouper fishermen to collect baseline data on the grouper fishery in Laamu Atoll and to identify grouper spawning aggregation sites (Table 1). The first questionnaire was designed to be delivered in a one-to-one setting (Appendix 4) and was adapted from those used previously for the grouper fishery (Sattar et al., 2011; Tamelander et al., 2008). Prior to interviews, fishermen were not provided with any information about the grouper fishery which could potentially bias responses. During interviews, fishermen were provided with map guides of all atolls in Maldives as well as grouper species identification guides (MRC/MCS Darwin Reef Fish Project).

Table 1. Subjects included in fisher surveys.

Fisher Survey type	Subject
Individual Interviews	Fishing effort Fishing locations Spawning aggregations Socio-economics Fisheries management
Focus groups	Individual Interviews Targeted species Average size and catch of species Fishing pressure from other atolls Fisheries management

The second questionnaire was delivered in a focus group setting and combined questions with an environmental educational presentation. (Table 1; Appendix 5). During these sessions, fishermen were also provided with the map and species guides.

A further questionnaire was developed for the owners of grouper holding cages to assess cage and export operations, business incentives, economics, market seasonality and trade demand. This assessment was conducted opportunistically and is not included in this report.

Results

Grouper fishermen interviews

Information received from Island Councils in Laamu suggest that there are 139 grouper fishermen currently on the atoll. Almost a third (31%) of reported fishers were categorised as opportunistic grouper fishers. Just over a third (36%) were said to be dedicated grouper fishermen but just under half of these (17%) are actively targeting groupers. These 24 fishermen are from Maavah and Dhanbidhoo islands.

Respondents

We are confident that the fishermen interviewed were a representative sample of grouper fishermen based on Laamu Atoll and that the data collected provide an accurate reflection of the fishery on the atoll. A total of 116 grouper fishermen from all 11 inhabited islands of Laamu were interviewed between November 2016 and May 2017. Most grouper fishermen (65%) were interviewed individually (Table 2). A further 41 fishermen who had not been interviewed previously attended the focus group sessions. Some fishermen (22) were interviewed both individually and in focus groups. Eleven community members, four council members, two council staff and a representative from the fishermen's community centre also joined focus group sessions but were not interviewed.

Table 2. The number of active and non-active grouper fishermen individually interviewed per island on Laamu Atoll.

Island	Current	Retired	Total
Isdhoo	4	6	10
Kalaidhoo	2	5	7
Dhanbidhoo	11	1	12
Maabaidhoo	0	2	2
Mundoo	0	1	1
Gan	0	7	7
Fonadhoo	4	5	9
Maamendhoo	8	6	14
Hithadhoo	0	1	1
Kunahandhoo	3	0	3
Maavah	7	2	9
Total	**39**	**36**	**75**

Most active grouper fishermen were from the islands of Dhanbidhoo, Maamendhoo and Maavah, where fishing is one of the predominant livelihoods for these island communities.

Demographics of grouper fishermen on Laamu Atoll

Nearly three-quarters (70%) of fishermen interviewed individually were over the age of 41 with only 9% of fishermen interviewed under 30 years. Fishermen interviewed had varied levels of experience in the fishery. Just over half of all interviewees (51%) had begun fishing for groupers in the past 5 years, while, 13% of fishermen had been fishing for between 10 and 20 years. A quarter (24%) of those interviewed had over 20 years' experience with many involved in the fishery since it first began some 30 years ago.

An even spread of both active (48%) and non-active grouper fishermen (52%) were interviewed to ensure data provided across time scales were reliable. Several reasons were given for stopping fishing for groupers. The main ones were:

- Poor income from the fishery (58% of fishermen);
- The tuna fishery is more profitable (25%);
- Sourced other types of income (17%);
- Grouper prices were very low (8%);
- Stocks had declined and catches were poor (8%), and;
- The fishery was very labour intensive (11 %).

Most of the fishermen (88%) interviewed on a one-to-one basis were opportunistic grouper fishermen. Almost half (40%) were opportunistic tuna fishers who only target groupers during the low tuna season (January - March). Most of these fishermen were from Maamendhoo Island. Almost a quarter (22.7%) of opportunistic fishers are involved in multiple reef-based fisheries including lobster and sea cucumber, while 20% were reef fishermen. Very few fishermen solely fish/fished for grouper (12%). These fishermen were mainly from Dhanbidhoo Island in the north of the atoll. However, over half (60%) of the fishermen who attended focus group sessions were either current or past dedicated grouper fishermen and only 16% were opportunistic fishers.

The Grouper Fishery on Laamu Atoll - Fisher Knowledge

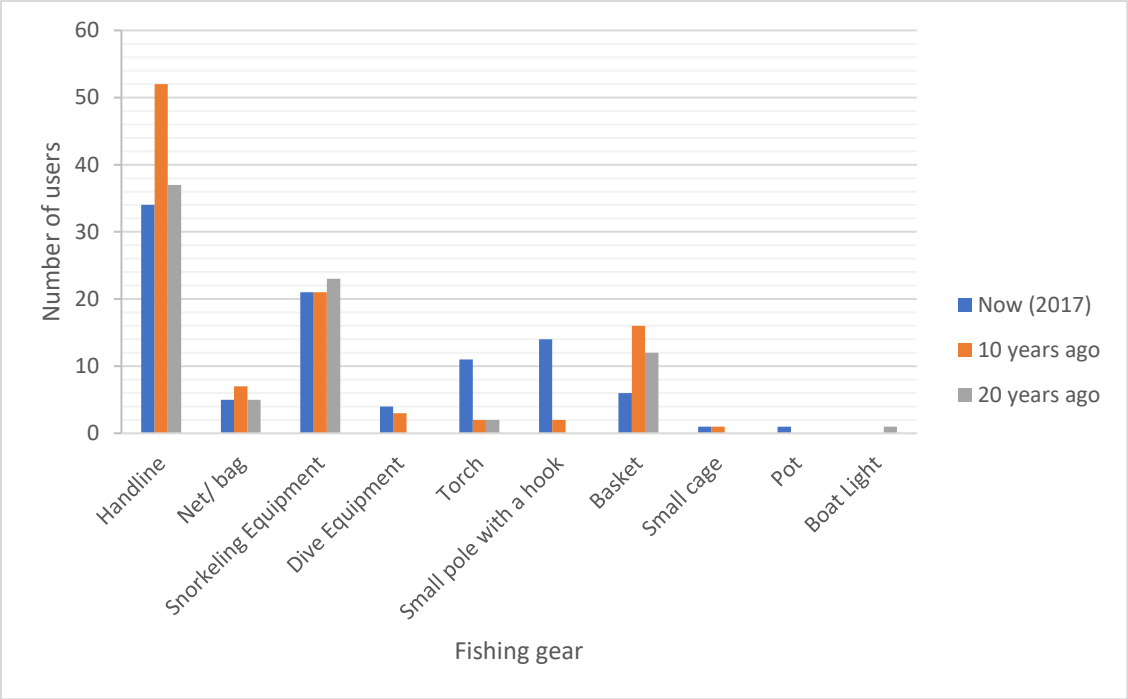
Most fishermen (80%) reported that they target groupers for commercial purposes. This proportion has decreased slightly over the last two decades (87% 10 years ago and 88% 20 years ago). The majority of commercial grouper fishermen (90%) target grouper for live export while only 10% said they trade in chilled or frozen grouper. Fishermen from all islands reported that they target the following species in order of priority because of their high market value: *Epinephelus fuscoguttatus*, *Plectropomus areolatus*, *Epinephelus polyphekadion* and *Plectropomus pessuliferus*.

At the time of writing, there were 3 small grouper holding cage systems in Laamu, all owned by one trader. The largest cage is next to Maavah island and 2 smaller sub-cages are close to Dhanbidhoo and Maamendhoo islands. Just over half of the fishermen interviewed (56%) sell their catch to the Maavah cage but some also sell to the two smaller sub-cages in Laamu as well as to cages on other atolls such as Thaa, Meemu, and Vaavu Atolls and to Hulhumale island next to the main international airport. Fishermen typically take their catches directly to the cage systems in nearby atolls e.g. Laamu fishermen will sell to the Laamu cage and Meemu cage. However, some fishermen also sell their catch to mobile vessels which then transport them back to Male'. It appears that the number of cages in Laamu has decreased. Fishermen reported that there were two other cages in Kalaidhoo and Kalhaidhoo, 10 years ago and 20 years ago respectively.

Fishing methods

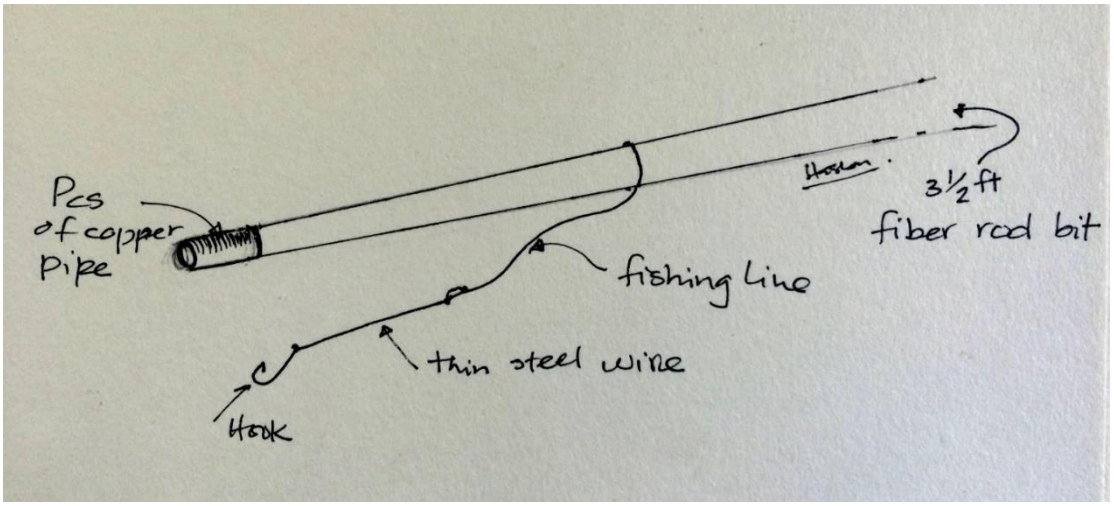
Catching groupers using a handline has remained the most common fishing method on Laamu, along with the use of snorkelling equipment (Figure 5). A combination of a handline or snorkelling gear and a basket was reported by fishermen who were fishing for groupers 20 years ago. However, since then, there has been a 24% decrease in snorkelling with a handline and an increase in the use of handlines from a boat.

Figure 5. The type of fishing gear used on Laamu and change over time (individual interviews).



Over the past 10 years there has been an almost six-fold increase in the number of individuals using underwater torches together with snorkelling gear and a basket to fish for groupers at night. Fishermen from Dhanbidhoo Island are also using a new type of fishing gear made from a small pole with a hook (Figure 6). A hook and line are attached to a short fibre rod (approximately 3.5 feet in length). A piece of copper is attached to the end of the pole to hold the hook in place. This type of gear is used when free-diving or using SCUBA to catch groupers. Over the past 10 years a few fishermen (<5%) have begun to use SCUBA.

Figure 6. Rough illustration of the pole and hook device used by fishermen (Dhanbidhoo Island).



Fishing locations

Active fishermen listed 38 different fishing locations on Laamu Atoll which included a range of different reef areas including *kandu olhis (*channel entrances), *kandu kolhus* (channel corners), *farus (*the reef slope of the island or atoll), *thilas, haas and giris* (separate coral reefs or patches rising from the inner-atoll sea floor). Giris nearly reach the sea surface, whereas thilas and haas are deeper patch reefs between 5 and 15 metres depth. Some fishermen were more specific than others mentioning large coral colonies or bommies or providing their entire fishing routes, while others said that they fish 'all over the atoll' or target 'all thilas'.

However, over half (55%) of the locations reported were channels. Vadinolhu Kandu was mentioned most often with 18 fishermen targeting this site. Fushi Kandu and Hithadhoo Corner are also popular fishing grounds with 17 fishermen targeting each of these channels.

There does not appear to have been a shift in areas targeted in Laamu over time. Non-active fishermen reported 42 fishing sites within the atoll, which was similar to those mentioned by current fishermen. Most fishing sites (49%) targeted by non-active fishermen were also channel sites. The most reported fishing locations were Hithadhoo Corner and Gaadhoo Corner, each of which were previously targeted by some 26 fishermen.

The surveys did however show that far fewer fishermen are now travelling to other atolls to fish for groupers. Only 2 active fishermen from Dhanbidhoo Island reported that they now travel to Vaavu Atoll to fish for groupers. In comparison, 28 non-active fishermen previously targeted groupers in eight different atolls, mainly the neighbouring Meemu and Thaa atolls.

Grouper Spawning Aggregations

Fishers' awareness and understanding of spawning aggregations

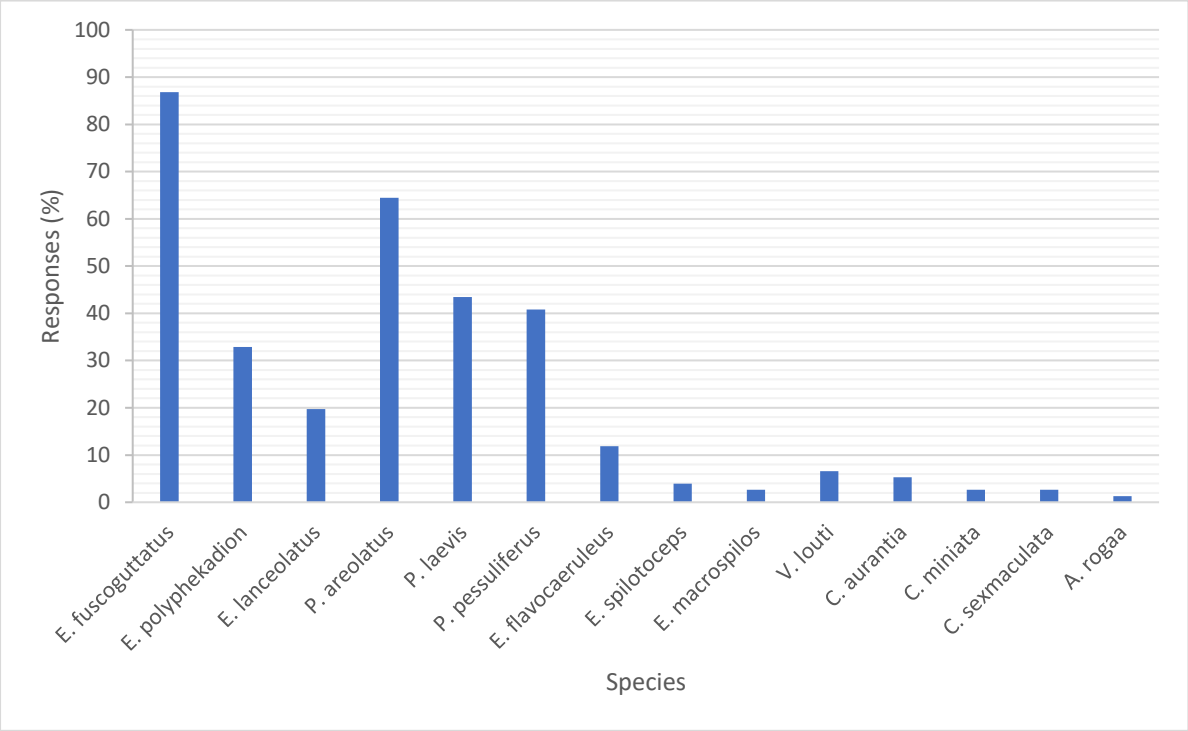
Nearly all the fishermen interviewed individually (93%) were aware of grouper spawning aggregations and most of these (84% of all fishermen) had fished spawning aggregation sites. Of the fishermen who said they were aware of spawning aggregations, over half (53%) believed that groupers were aggregating for reproductive purposes. Some fishermen believed that they aggregate to feed (21%) while a few (10%) did not know why they aggregate.

When asked why they thought it was a spawning aggregation site, 92 % of fishermen could provide at least one reliable characteristic. Fishermen commonly reported seeing large numbers of groupers (75%) and at specific times (76%). Many also had seen groupers migrating (21%) and had caught gravid females (16%).

Aggregating grouper species

Fishermen reported that 14 species of grouper were known to aggregate on Laamu Atoll (Figure 7). *Epinephelus fuscoguttatus* (87%) was the most commonly reported species followed by *Plectropomus areolatus* (64%). The main other species identified by fishermen were *Plectropomus laevis* (43%), *Plectropomus pessuliferus* (41%) and *Epinephelus polyphekadion* (33%). Of the other species one to note is *E. lanceolatus* (20%), the largest coral reef dwelling bony fish (Lieske and Myers, 2001).

Figure 7. The most commonly reported aggregating grouper species by Laamu fishermen



Temporal characteristics of spawning aggregations

Seasons

There are two monsoon seasons in the Maldives: the north-east and south-west monsoons, known as Iruvai and Hulhangu respectively. Generally, Iruvai occurs between the months of December to March while Hulhangu covers May to November.

Two-thirds of fishermen (66%) stated that groupers aggregate in both monsoon seasons. Only 8% of fishermen suggested that groupers aggregate in one monsoon with all responses bar one for Iruvai. Of those fishermen who reported groupers aggregate in both seasons, 22% said, without prompting, that aggregations were largest during Iruvai whereas only 9% said they were largest during Hulhangu. Only one fishermen said that the aggregations occur during the transition between monsoon seasons. Almost a quarter of all fishermen (22%) did not know when groupers aggregate in relation to monsoons.

Months

Just over half of all fishermen (51%) said that groupers aggregate every month. However, responses from some fishermen suggest that peak spawning periods are seasonal; 9% of the fishermen who reported that aggregations occurred every month said they were largest in the months of Iruvai. Twelve fishermen also individually specified a series of months during which groupers aggregate. January and December were most commonly reported months for aggregations (Table 3). The duration of reported spawning periods ranged from one to six months with the most commonly reported lasting between 2 and 4 months. Half of the respondents selected months which fall in the north-east monsoon (Iruvai).

Table 3. Spawning months reported by fishermen during one-to-one interviews

Month	Number of reports
January	**8**
February	**6**
March	**5**
April	3
May	3
June	1
July	0
August	0
September	0
October	0
November	**4**
December	**8**

Note: figures in **bold** fall within the north-east monsoon season (Iruvai)

During focus group sessions, fishermen were asked to rank how good fishing was during each month for the four-selected species. Findings compared well with responses in individual interviews. Fishermen from all islands mostly reported that fishing for *Epinephelus fuscoguttatus*, *Epinephelus polyphekadion* and *Plectropomus areolatus* was good throughout the year apart from during the months of June and July when they don't target groupers because of the rough sea conditions. Fishermen from Maabaidhoo and Mundoo reported that fishing was very good for *Epinephelus fuscoguttatus* during November and December while those from Isdhoo said catches for this species were best in March. Fishermen from every island in Laamu Atoll said fishing for *Plectropomus laevis* is poor throughout the year.

Lunar Phase

Maldivian people live by the Islamic calendar which is a lunar calendar with days and weeks tied to the different moon phases. Here we define six phases of the lunar monthly calendar as follows: the first quarter of the moon (1^{st}-7^{th}), the full moon (8^{th}-15^{th}), the third quarter (16^{th}-22^{nd}) and the new moon (23^{rd}-30^{th}).

When asked in which lunar phase groupers mainly aggregate, individually, fishermen reported a range of different time periods which mainly occurred during the new moon (Table 4)

Fifty-one fishermen said that groupers aggregate on 28^{th} day of the lunar month suggesting this may be the day when aggregations are largest. Many fishermen (49) also said that groupers aggregate on the 27^{th} and 29^{th} while 42 fishermen said they aggregate on 26^{th} and the 30^{th}. Some fishermen (17) reported aggregations around full moon on the 14^{th} and 15^{th} day of the lunar calendar as well as on

the 13th (14) and the 11th and 12th (11). The duration of aggregations was not clear from the responses provided as these were extremely varied.

Table 4. Lunar phases in which groupers spawn as reported by individual fishermen

Lunar phase	Lunar day	Number of reports
Waxing gibbous	1	23
Waxing gibbous	2	21
Waxing gibbous	3	14
First quarter	4	15
First quarter	5	4
First quarter	6	2
First quarter	7	2
Full moon	8	7
Full moon	9	7
Full moon	11	11
Full moon	12	11
Full moon	13	14
Full moon	14	17
Full moon	15	17
Waning gibbous	16	13
Waning gibbous	17	12
Waning gibbous	18	13
Third quarter	19	6
Third quarter	20	8
Third quarter	21	8
Third quarter	22	16
New moon	23	24
New moon	**24**	**32**
New moon	**25**	**40**
New moon	**26**	**42**
New moon	**27**	**49**
New moon	**28**	**51**
New moon	**29**	**49**
New moon	**30**	**42**

Note: Days most commonly reported are highlighted in **bold**.

The focus group sessions addressed the potential variation in spawning times between species. Not all fishermen knew when each grouper species spawned. The only species which all fishermen were able to define a spawning period for was *Epinephelus fuscoguttatus*. A broad range of spawning periods were reported for this species, each with a different duration which on average lasted for 7 days (Table 5). Overall, responses from 5 of the 8 focus groups all suggested this species spawns over the new moon period. Half of all focus groups, did not know when *Epinephelus polyphekadion* spawns. Fishermen from most islands agreed that this species spawns during the full moon for a period of between 2-5 days.

Fishermen provided a diverse range of responses for *Plectropomus areolatus* spawning, reporting aggregations in all six lunar phases. However, the most commonly reported phases for this species were during the full and waning moon between the 13th and the 18th. Only fishermen from Maavah Island claimed to know the spawning period for *Plectropomus laevis*, stating that it spawns at the same time as *P. areolatus,* i.e. during both the full moon and new moon.

Table 5. The spawning periods of four selected grouper species reported by fishermen in focus groups using the days of the Islamic lunar calendar month.

Island	*E. fuscoguttatus*	*E. polyphekadion*	*P. areolatus*	*P. laevis*
Isdhoo	3Q/NM (20-3)	NA	FM (13-17)	NA
Dhanbidhoo	NM/1Q (26-1) & FM (11-15)	FM (13-15)	FM (13-18)	NA
Maabaidhoo	NM (24-25)	FM (11-15) & NM (24-25)	NA	NA
Gan	FM (13-16)	FM (13-16)	FM (13-16) (4)	NA
Fonadhoo	NM/1Q (22-2)	NM/1Q (22-2)	NA	NA
Maamendhoo/ Hithadhoo/ Kunahandhoo	NM (28-30)	NA	FM (13-17) NM (28-31) 1Q/FM (4-11)	NA 1Q/FM (4-11)
Maavah	NM (24-30)	FM (14-16)	3Q/NM (18-26)	NM (18-26)

Note: 1Q= First Quarter, FM= Full Moon, 3Q= Third Quarter, NM= New Moon. Lunar days in brackets. NA = no answer.

Time of day

When asked about the daily timing of spawning aggregations most responses (39%) were that groupers aggregate at both dusk and dawn. Other responses were that they aggregate at night (23%), after dusk (21%) and all throughout the day and night (14%).

Environmental factors

Fishermen struggled to answer questions about how environmental factors affect grouper spawning aggregations. Many fishermen also answered questions in a manner which explained how factors affect their fishing, rather than the aggregation itself and were not able to specify what aspect of the aggregation was influenced.

Grouper Spawning Aggregation Sites

Locations

A total of seventeen different spawning aggregation sites were reported by fishermen during individual interviews. Of these eight locations were mentioned by a single respondent and were therefore not included in the analyses (Table 6; Figure 8) Seven of the sites mentioned are the main channels or channel corners of Laamu Atoll. Isdhoo Muli is an outer reef promontory and Olhuveli Corner is an inner reef promontory in the middle of the Gaadhoo channel.

Figure 8. Spawning aggregations reported by fishermen in individual interviews

The most commonly reported spawning aggregate site was Vadinolhu Kandu which was mentioned by 80% of fishermen, followed by Fushi Kandu (56%) and Hithadhoo Corner (41%). These sites were also ranked by fishermen as the three largest aggregations in the atoll.

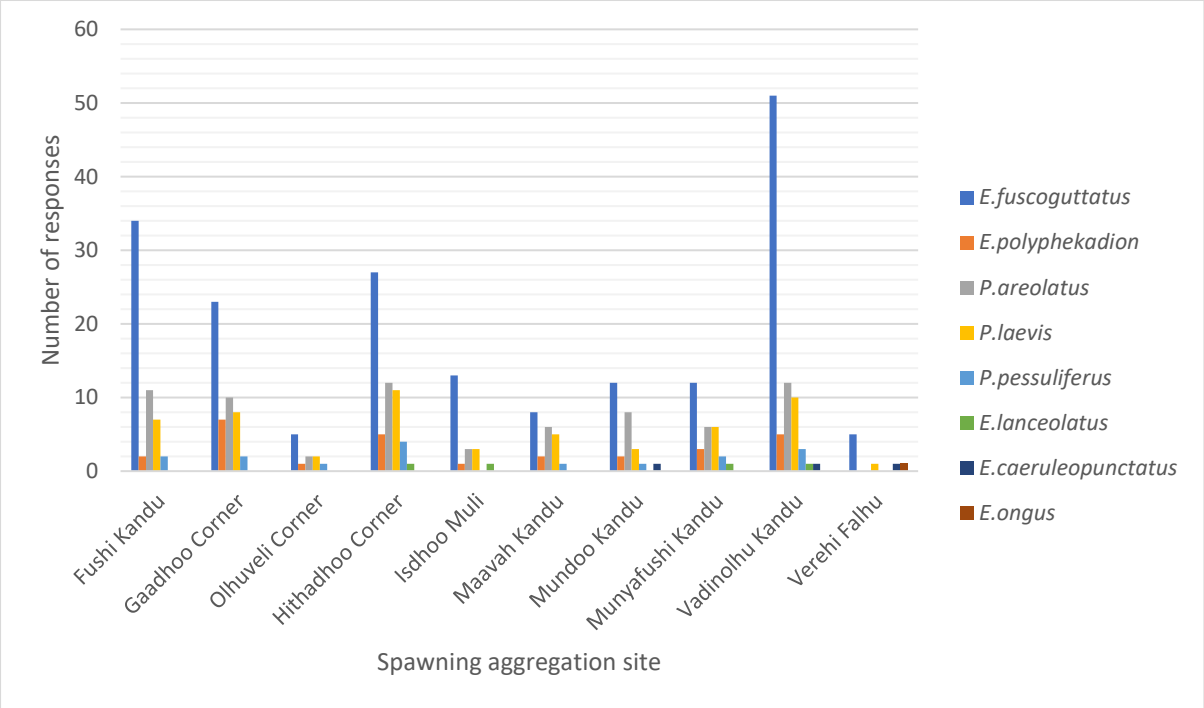
Table 6. The largest grouper spawning aggregations in Laamu Atoll as ranked by the fishermen.

Rank	Site name	No. of reports
1	Vadinolhu Kandu	53
2	Fushi Kandu	37
3	Hithadhoo Corner	27
4	Gaadhoo Corner	25
5	Mundoo Kandu	16
6	Isdhoo Muli	14
7	Muyafushi Kandu	12
8	Maavah Kandu	11
9	Olhuvelhi Corner	6
10	Verehi Falhu	6

Species composition

Five main grouper species were reported across all spawning aggregation sites*: Epinephelus fuscoguttatus*, *Epinephelus polyphekadion*, *Plectropomus areolatus*, *Plectropomus pessuliferus* and *Plectropomus laevis* (Figure 9). Fishermen reported on average 2 species per site which were commonly *E. fuscoguttatus* (52%) and *P. areolatus* (19%). *E. fuscoguttatus* was said to be the dominant spawning species at all sites in Laamu but most notably at four channel sites: Vadinolhu Kandu (62%), Fushi Kandu (61%), Gaadhoo Corner (56%) and Hithadhoo Corner (45%). The second most reported species at these four sites was *P. areolatus*.

Figure 9. Grouper species reported at each spawning aggregation site.



Fishing pressure at spawning aggregation sites

Almost all (95%) of the fishermen who reported spawning aggregations said that they had fished at the sites they had specified. When asked why they target these sites, most fishermen said it was because they knew of the aggregation there (39%) and that they can get a good catch (36%). Fishermen reported targeting spawning aggregations since the 1980's, and probably before the export trade began. There has been fishing at Gaadhoo Corner and Olhuveli Corner for over 36 years and at Fushi Kandu, Gaadhoo Corner, Olhuvelhi Corner, Hithadhoo Corner, Maavah Kandu, Mundoo Kandu, Munyafushi Kandu and Vadinolhu Kandu for between 31 and 35 years. Vadinolhu Kandu has been the most targeted spawning aggregation site, followed by Fushi Kandu and Hithadhoo Corner.

Just under half of all fishermen (49%) have noticed a decrease in local fishing pressure across all spawning aggregation sites while 34% reported an increase in fishing pressure. An equal number of fishermen reported both an increase and decrease at four sites: Olhuvelhi Corner, Maavah Kandu, Munyafushi Kandu and Verehi Falhu. There were no responses stating an increase in fishing pressure for any single site.

There is additional fishing pressure from fishermen who travel to Laamu specifically to catch groupers. Local fishermen reported vessels travelling mostly from Faafu Atoll (29%), Dhaalu Atoll (29%) and Thaa Atoll (24%) though vessels from Meemu, Vaavu and Kaafu Atolls were also mentioned.

When asked which islands of other atolls the fishing vessels were from, the top five islands listed in descending order were Bilehdhoo (Faafu Atoll), Feeali (Faafu Atoll), Vilufushi (Thaa Atoll), Bandidhoo (Dhaalu Atoll) and Meedhoo (Dhaalu Atoll). Vessels from all these islands were more commonly seen in 'Iruvai', the north-east monsoon season.

When asked which spawning aggregation the vessels from other atolls were fishing in Laamu, most fishermen said that they fish all over the atoll. However, two sites were specified as heavily targeted sites; Vadinolhu Kandu (25%) and Fushi Kandu (19%).

Catch declines at spawning aggregation sites

Across all sites, over half (57%) of the fishermen reported a decrease in the catch of groupers at spawning aggregation sites. However, just over a quarter (27%) reported no change their catch. Only four fishermen reported any increases in catch but commented that this was due to new fishing methods which have increased fishing efficiency. When sites were considered individually, most fishermen also reported decreases in catch at each spawning aggregation site, except for Verehi Falhu where 50% of fishermen reported no change in the catch. This is thought to be because this site has only recently been targeted.

At each of these sites more than half of all fishermen reported catch declines except for Fushi Kandu (43%). Sites where most fishermen reported catch declines were Isdhoo Muli (75%), Munyafushi Kandu (73%), Gaadhoo Corner (67%) and Hithadhoo Corner (60%).

Declines in the sizes of highly targeted species

During focus groups, fishermen from all islands reported a decrease in the average size of the four most targeted grouper species over the past 20 years (Figure 10). For all four species fishermen reported an average decline of 22 cm (TL). *Epinephelus fuscoguttatus* appears to have experienced the largest decline of 26 cm followed by *E. polyphekadion* and *P. areolatus* which declined by about 21 cm and *P. laevis* by about 19 cm.

Fishing trip duration and fishing effort

Currently, grouper fishermen on Laamu Atoll predominantly fish at night to catch groupers. (Figure 11). Responses from individual interviews suggest that more fishermen now only fish at night compared with 20 years ago when fishing trips were for longer periods of time. Overall responses suggest that fishing trips are getting shorter and are completed in one day or night rather than over a few days or weeks. Some fishermen did however report that they spend longer on their fishing trips now, even with motorised fishing vessels, which suggests an increase in fishing effort.

Figure 10. Change in the mean total length of groupers over 20 years as reported by fishermen (focus groups).

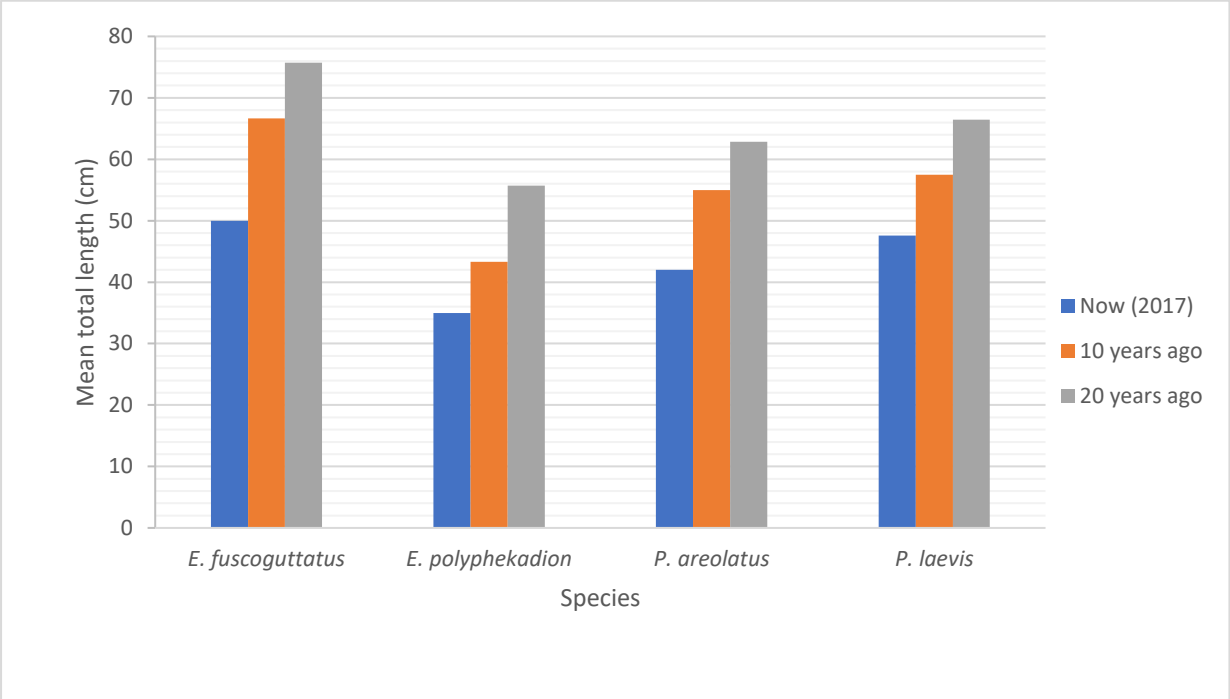
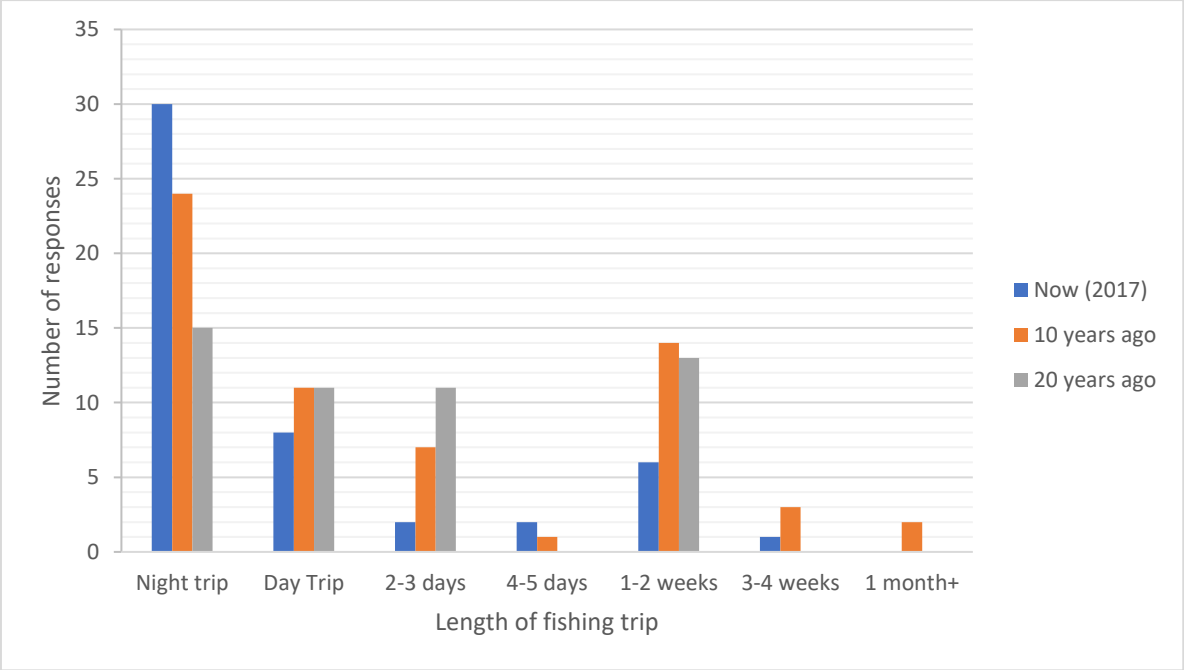


Figure 11. Change in the length of grouper fishing trips over 20 years as reported by fishermen (individual interviews).



There was a unanimous agreement between fishermen from all islands who attended focus groups that the average grouper catch has gradually declined over the past 20 years and that they must spend longer at sea to catch the same number of fish they used to catch in a day. For example, on average, it took one day to catch 100 kg of grouper twenty years ago. Ten years ago, it took two days to catch this amount, while in 2017 it took on average four days to catch 100 kg.

Fishermen's Income

Fishermen's reliance on grouper fishing as a main source of income appears to be declining. Over a third (38%) of grouper fishermen reported that the fishery contributed between 75 and 100% of their total income twenty years ago. Fewer fishermen reported that grouper fishing accounted for this proportion of their income ten years ago (29%). In 2017 most fishermen (65%) said their income from groupers constitutes on average up to 25% of their total income with only 15% of fishermen relying on grouper for their livelihood (75-100% of total income). Almost all fishermen (90%) who target spawning aggregations said that they receive a greater income by targeting these sites.

Grouper Fisheries Management

Most of the fishermen we interviewed individually (82%) were unaware of any existing management measures for grouper. Half of all fishermen who were aware of regulations mentioned catch size limits. However, none of them could correctly specify what these were. Almost a quarter of respondents (23%) believed that there is a 6-inch (15 cm) size limit while a similar number (24%) thought there were weight limits of between 300 and 400 grams. None of the fishermen were aware of the five marine protected areas for grouper spawning aggregation sites in other atolls.

Despite this, 85% of fishermen interviewed believe the fishery needs to be managed and when asked why, gave a variety of reasons. These included:

- Stock declines (34% of responses);
- Stock declines have affected livelihoods - management is needed to ensure a sustainable income for themselves and future generations (24%);
- Declines in sizes of groupers (7%);
- Management is needed for the well-being of the marine environment (6%)
- Fish stocks must be protected because of the vulnerability of marine life to climate change (2%)

A few fishermen didn't think the fishery should be managed but most of these did not provide reasons to support this. One response was that fishermen on the island of Gan only fish for groupers during low tuna season inferring that fishing pressure was low on this island.

Most grouper fishermen in Laamu (89%) believe that management of the fishery should be a priority. Almost two-thirds (64%) believe management is extremely important, 14% said it is very important whilst a further 4% said it was important. Only 11% of fishermen said they didn't think it was important.

When asked to suggest management measures, more than a quarter of the fishermen (28%) recommended the establishment of size limits (Table 7). Other measures regarding enforcement, gear use (underwater torches), and spawning aggregation sites were suggested in roughly equal proportions (Table 7).

Table 7. The top five management suggestions provided by fishermen (individual interviews).

Ranking	Management Suggestions	Proportion of fishermen
1	Establish size limits	**28%**
2	Prohibit grouper fishery using powerful lights (torches)	**17%**
3	Enforcement of regulations	**17%**
4	Protect grouper spawning aggregation sites	**16%**
5	Seasonal fishing closures on grouper spawning aggregation sites	**15%**

Fishermen were most in favour (58%) of marine protected areas with temporary fishing closures for all fisheries (Table 8). However, nearly as many fishermen (56%) were in favour of marine reserves in which all fishing is prohibited and 44% in favour of marine protected areas with restrictions on grouper fishing only. Just under half of all fishermen were in favour of export size limits (47%) or catch size limits (44%). A small proportion of fishermen (19%) were resistant to any management measures. Fishermen appeared to prefer spatio-temporal closure options to size limits.

Table 8. The most popular management options with fishermen (focus group sessions)

Ranking	Management option	No. of fishermen
1	MPA- temporary fishing closure	21
2	MPA- all fisheries restricted	13
3	Export size limits	13
4	MPA- grouper fishery restricted	12
5	Catch size limits	11
6	No measures	10
7	No size limits	8
8	No MPAs	7

Note: Fishermen could vote for more than one option.

When asked to suggest other management options (not provided), four fishermen from different islands made the following suggestions:

- Increasing awareness, a marine protected area in each atoll and a community-based management approach with legal enforcement (Dhanbidhoo);
- A temporary ban on all exports as well as increased awareness on the decrease in shark populations (Maabaidhoo):
- Implementing temporary closures on spawning grounds during peak spawning times and ensuring enforcement (Maamendhoo);
- Groupers should not be caught from any channels in the Maldives during the spawning period as well as the prohibition of powerful torches (such as the D6) on reefs and in channels.

Discussion

The fishermen surveys have provided a comprehensive assessment of the current status and change in the grouper fishery and of fishers' knowledge and use of grouper spawning aggregation sites in Laamu Atoll.

The export grouper fishery is highly specialised and is a major source of income for many fishermen in the central atolls of the Maldives (Sattar et al., 2011). For example, in Faafu Atoll, where the fishery began, the majority of fishermen in the atoll are specialist grouper fishermen, with relatively few involved in the tuna fishery (Sattar and Adam, 2005). By comparison, on Laamu Atoll, tuna fishing is and has historically been a major source of income for fishermen.

Our findings suggest that there have never been very many dedicated grouper fishermen in Laamu, with fewer currently active than in the past 20 years. Most fishermen who target groupers in Laamu are opportunistic tuna or reef fishermen who fish for groupers seasonally. Reports from fishermen also suggest that the grouper fishery in Laamu is less productive than it once was. Many fishermen have stopped fishing for groupers because it is not economically viable. Fewer fishermen rely solely on the grouper fishery for their livelihoods which suggests that income from this fishery is becoming less reliable and less able to support local people. A socio-economic survey of former shark fishermen across the Maldives in 2015 found that only 7% of fishermen sought income from grouper after shark fishing was banned nationally, while 22% became tuna fishermen and 22% engaged in reef fishing (Ali, 2015). This indicates that tuna and reef fishing are more reliable sources of income for fishermen compared with dedicated grouper fishing and may help to explain why so few young people are currently involved in the fishery on Laamu Atoll.

However, it is not just local fishermen who target grouper on Laamu Atoll. Grouper exporters are known to move their cages to new atolls that will yield a better catch than the previously fished atoll (Shakeel, 1994). The recent expansion of the cage system in Maavah Island suggests that there is a financial incentive to maintain or expand the grouper fishery in Laamu for the export trade. Although there is currently lower fishing pressure on grouper populations in Laamu than in more central atolls in terms of reef fishing for the tourist trade, the atoll is still very attractive for the export trade. Even though the abundance and size of groupers has declined according to fishermen, it appears that there are sufficient numbers of groupers at a range of sizes to support a small number of fishermen who supply the export trade but do not solely rely on grouper for their livelihood. However, the targeting of spawning aggregations gives the false impression that grouper populations are large enough to justify the continuity and even development of the export fishery on the atoll.

A lack of local chilling facilities in Laamu for grouper has prompted the fishery to focus on the live trade, namely for larger individuals of *Epinephelus* and *Plectropomus* spp. This may mean that smaller species targeted for the chilled/frozen trade are fished less on Laamu Atoll compared to other atolls with better facilities where a wider range of grouper species are harvested.

Fishermen reported that groupers predominantly spawn in all the main channels of Laamu Atoll, which have all been targeted during aggregations for the past 30 years. The largest aggregations (and most popular fishing sites) are Vadinolhu Kandu, Fushi Kandu and Hithadhoo Corner. Fishermen from other atolls are also clearly aware of these aggregations as Laamu fishermen reported seeing vessels at Vadinolhu Kandu and Fushi Kandu. Maavah channel is a less popular fishing site which may indicate historical overfishing of aggregations at this location that is close to a large fishing community on Maavah Island and a holding cage system.

The lack of continuous long-term data on the grouper fishery and spawning aggregations means that seasonality patterns in Maldives are poorly understood (Sattar et al., 2011). Laamu fishermen suggested that grouper aggregate in both monsoon seasons but that spawning aggregations are largest during the months of Iruvai (north-east monsoon) from November/December until March. This concurs with previous anecdotal reports from fishermen in other parts of the country who indicated that fishing was better during Iruvai (Sattar et al., 2011). They also reported that larger number of aggregations are seen during the transition periods between monsoons which are October/November and April/May (Sattar et al., 2011). Analyses of grouper exports across multiple years have shown peaks particularly during these transitional periods in the months of March, October and November (Sattar et al., 2011). However, fishermen on Laamu did not highlight transitional periods as peak times for aggregations or catches.

Fishermen in the Maldives commonly engage in private sector invested fisheries during the low tuna season because they provide them with additional employment (Shakeel, 1994). The low tuna season on Laamu Atoll runs from December until March during Iruvai. Concerningly, this is also the season when grouper aggregations are thought to be largest.

Clear spawning periods for the four selected grouper species were not delineated from fishers' knowledge. Though most fishermen reported spawning aggregations during the new moon, some also said groupers spawn during the full moon. This concurs with reports of fishermen from other atolls in Maldives, who also stated that spawning times vary with location (Sattar et al., 2011). Spawning periods are also known to vary between species (de Mitcheson and Colin, 2011) and fishermen's' responses support this .

Most fishermen were able to say when *Epinephelus fuscoguttatus* spawns on Laamu Atoll which is not surprising given this is one of the most sought after and valuable species for live export. However, many fishermen were unable to define a spawning period for *E. polyphekadion* which may be because they easily confuse this species with *E. fuscoguttatus.*

Previous dive research conducted in Laamu identified spawning aggregations for *Plectropomus laevis* and *P. areolatus* during the new moon at Mundoo Channel but not during the full moon (Sluka, 2001a). However, most fishermen thought that *P. areolatus s*pawns between 13th and the 18th day of the lunar cycle (full to waning moon) and interestingly, though many fishermen reported *P. laevis* as a spawning species, they also stated that fishing for this species is poor all year round.

The species which most commonly aggregate, *E. fuscoguttatus, E. polyphekadion* and *P. areolatus* are also those which are highly valued and traded live. Fisher reports of decreasing size and catches at aggregation sites for these species indicates that they are experiencing high and chronic fishing pressure on Laamu Atoll.

The incentive to fish aggregation sites is high. Despite over half of fishermen understanding that groupers aggregate to spawn, they still fish these sites as they provide high catches in a short amount of time. However, the targeting of spawning aggregation sites in Laamu has led to declines in the size of spawning aggregations and subsequently the catches from these sites. Fishermen said they have experienced a decline in their catch at nine out of the ten spawning sites reported. Most fishermen agreed that this has occurred at Isdhoo Muli, Munyafushi Kandu, Gaadhoo Corner and Hithadhoo Corner.

Overfishing of groupers has also led to declines in the average size of fish. All interviewed fishermen said that the average size of some of the most heavily targeted species (*E. fuscoguttatus, E.*

polyphekadion, P. areolatus and P. laevis) had decreased over the past 20 years with *E. fuscoguttatus* showing the greatest decrease in size.

Declines in the size and catches of groupers mean that fishermen spend more time and effort to catch the same amount. The development of a new fishing gear and techniques as well as a rise in the use of torches for night fishing suggests 'technology creep' within the fishery to increase fishing efficiency. However, most fishermen reported an overall decrease in fishing pressure across all sites. This is likely be a result of population declines leading to lower catches and less fishers engaging in the fishery compared to others such as tuna.

The gradual decline of the fishery on Laamu has had an impact on the income that fishermen derive from grouper. More fishermen in the past relied entirely upon the grouper fishery for their income whereas now grouper provide less than a quarter of their entire income from fishing.

There is a clear lack of awareness of existing national fishery regulations for grouper amongst fishermen in Laamu Atoll. Not a single fisherman could accurately describe existing catch size limits for grouper species and there was no mention of the five marine reserves to protect grouper spawning aggregations in other atolls. However, most grouper fishermen support management of the fishery and think this is extremely important. Laamu fishermen recognise that grouper stocks have declined and that the fish are getting smaller and harder to catch, which is having an effect on livelihoods. The fishermen were supportive of a range of management measures including gear restrictions, catch limits and the protection of spawning aggregation sites. The Laamu fishing community recognise the need for action to safeguard the grouper fishery on the atoll and most are willing to be involved in island- or atoll-based management to improve grouper populations using multiple approaches. Management recommendations for the fishery are presented in Section 5 of this report.

2. Verifying Grouper Spawning Aggregation Sites on Laamu Atoll

Introduction

There is a general lack of information about grouper spawning aggregation sites in the Maldives. Although 175 grouper spawning aggregation sites have been identified by fishermen (Sattar et al., 2011) there have been no comprehensive studies conducted at most of these sites to verify their existence. A programme of dive surveys at five spawning aggregation sites was conducted as part of the Darwin Initiative project[4] in order to verify the locations and collect baseline data on the aggregating grouper species. Although a systematic assessment of spawning aggregations at these sites was not completed sufficient information was gathered to propose them for full protection in the Management Plan for the Maldives Grouper Fishery (MRC/MCS, 2011). These five spawning aggregation sites were subsequently protected by MoFA in 2014.

Little is known about grouper spawning aggregations on Laamu Atoll. Research carried out twenty years ago identified spawning aggregations of *Plectropomus areolatus* and possibly *Plectropomus laevis* in Mundoo Channel during March and April (Sluka, 2000). More recently, anecdotal remarks by fishermen and cage owners during this project's scoping phase (Harding and Moore, 2016) proposed Hithadhoo Corner and Maavah Kandu as grouper spawning aggregation sites. However, to date, there have been no systematic assessments of any spawning aggregation sites on Laamu Atoll.

The Maldives Grouper Fisheries Management Plan (MRC/MCS, 2011) recommends the protection of grouper spawning aggregation sites whenever or wherever they occur. This section focuses on the identification and verification of grouper spawning aggregation sites on Laamu Atoll for four grouper species which are highly targeted for export: *Epinephelus fuscoguttatus, E. polyphekadion, Plectropomus areolatus* and *P. laevis*.

Methodology and Data Collection

Grouper Length estimation training

Prior to undertaking spawning aggregation surveys, fish length estimation training according to Bell et al. (1985) was conducted to ensure that underwater measurements were accurate and to minimise error between surveyors. Twenty-five wooden sticks were cut into various lengths between 0 and 1 m so that the length frequency distribution that was representative of a normally distributed bell-shaped curve (Bell et al., 1985). The pieces of wood were attached to a 20 m long polypropylene rope and were separated by a distance which was at least that of their own length. The string was weighted so that it lay across the sea bed. Each observer swam along parallel to the rope keeping a minimum distance of 2 m and visually estimated the length of each piece of wood. Training was repeated until estimates between surveyors were no longer significantly different as defined by a paired t-test.

Study sites

Based on information gathered during fishermen interviews (Section 1), it was determined that groupers spawning aggregation sites in Laamu Atoll are located predominantly in the seven main channels connecting the atoll lagoon to the outer reefs (Figure 12). The channels in Laamu are shallow

[4] Darwin Initiative Project Reference 17-002 (2009-2013): Final Report

compared with other atolls in the Maldives and range in depth from ca. 10 m (Munyafushi Kandu) to over 50 m (Gaadhoo Kandu) (Sluka, 2001a). Most channels in the atoll are characterised by high coral cover on the outer reef edge with sparse corals on sand in the middle. Vadinolhu and Maavah on the western side of Laamu are the narrowest channels in the atoll with well-defined coral spurs found along the channel sides. Gaadhoo Kandu located in the south is the largest channel and the middle of the channel is characterised by a large sandy area. This channel can be split into two main parts; west and east.

Figure 12. The main channels in Laamu Atoll.

Underwater visual census methods

Exploratory dives

Exploratory dives were carried out in all the main channels during the new moon period to determine the locations of described spawning aggregations (Table 9) (Appendix 6). Selection of the new moon phase was based on fishermen's knowledge (Section 1) and previous research in Laamu Atoll (Sluka, 2001a,b). Areas where there were noticeable increases in grouper abundance were preliminarily selected as spawning aggregation locations, which were all located in the outer(seaward-facing) parts of the channels.

Preliminary counts of groupers (*Epinephelus* spp. and *Plectropomus* spp.) at Hithadhoo Corner in the western part of the Gaadhoo channel on two days (02/08/2016 and 04/08/2016) over the new moon also suggested that groupers were aggregating during this lunar phase (*S. Harding, pers. obs.*). More detailed and standardised roving surveys were then conducted at this site to record the daily variation in grouper abundance over the new moon phase.

Table 9. Details of exploratory surveys at channel sites on Laamu Atoll.

Channel site	Exploratory dive survey			Lunar phase	Lunar day	Spawning aggregation site determined?	GPS location (Start)	GPS location (End)	Depth (m)
	Date	Month	Year						
Hithadhoo Corner	02, 04	August	2016	New moon	27, 29	Yes	N 1°48'0.94 E 73°24'37.68	N 1°48'1.02 E73°24'40.09	15-23
Gaadhoo Corner	15-18	October	2016	Full moon	13-16	No	N 01°48.733 E 073°27.045	Not recorded	10-12
Gaadhoo Corner	20-28	April	2016	New moon	18-26	No	N1 48.923 E73 26.241	Not recorded	10-12
Vadinolhu Kandu	26	January	2017	New moon	27	No	Not recorded	Not recorded	15-25
Maavah Kandu	26, 28, 29	January	2017	New moon	27, 29, 1	Yes	N 01°54.576 E 073°14.469	N 1°54.871 E 73°14.481	15-23
Fushi Kandu	27	January	2017	New moon	28	Yes	N 02°02.330 E 073°32.207	N 2°02.370 E 73°32.212	13-25
Mundoo Kandu	26	May	2017	New moon	29	No	Not recorded	Not recorded	13-25

Timed Swim Surveys

An initial scoping survey was conducted at Hithadhoo Corner over the new moon phase for a period of 20 days (22nd August - 19th September 2016) from 9 days before the new moon (9dbnm) to 10 days after new moon (10danm). Surveys were carried out in the morning between 08:00 and12:00. A single observer completed a roving timed swim of the site, along a pre-determined route for a period 55 minutes using SCUBA. All grouper species and their abundance were recorded over the same set area. Based on these observations, four grouper species; *Epinephelus fuscoguttatus*, *Epinephelus polyphekadion*, *Plectropomus areolatus* and *Plectropomus laevis*; were deemed to be aggregating species at this site. Possible bias caused by double counting was assumed to be consistent between counts.

Following the confirmation of an increase in grouper abundance around the new moon, underwater visual census (UVC) surveys were repeated in subsequent months at Hithadhoo Corner and three other channel sites (Gaadhoo Corner, Fushi Kandu and Maavah Kandu) between October 2016 and September 2017 (Table 10). Hithadhoo Corner was surveyed extensively because of its close proximity to the project base and availability of dive boats for this site. Surveys were typically carried out between 14:00-15:45 (GMT/UTC + 05:00). At least one assessment at each site was conducted involving daily grouper counts for an 8-day period over the new moon (6dbnm-2danm), though occasionally, logistical complications prevented this. A full month-long survey was also conducted once at Hithadhoo Corner (14th November-15th December 2016) to record non-aggregating grouper densities. One survey over the full moon was also conducted at Gaadhoo Corner (15th-18th October 2016).

Table 10. Details of completed roving surveys at channel sites on Laamu Atoll.

Channel site	Exploratory dive survey period			Lunar day	
	Days	Month	Year	New Moon	Full Moon
Hithadhoo Corner	22-09	August/September	2016	1	
Hithadhoo Corner	30-5	September/October	2016	1	
Hithadhoo Corner	28-2	October/November	2016	30	
Hithadhoo Corner	14-15	November/December	2016	29	14
Hithadhoo Corner	21-28	April	2017	26	
Hithadhoo Corner	16-23	August	2017	21	
Hithadhoo Corner	19-21	September	2017	20	
Gaadhoo Corner	15-18	October	2016		16
Gaadhoo Corner	21-28	April	2017	26	
Maavah Kandu	20-27	February	2017	26	
Maavah Kandu	18-26	June	2017	24	
Fushi Kandu	20-27	May	2017	26	

For each UVC survey, two observers completed a roving timed swim for a period of 55 minutes following the same route on each dive. Grouper species, abundance, fish length (in 5-cm size classes) as well as behavioural observations of the four selected species were recorded in a 10-metre band (five metres either side of the central swim line). When underwater visibility was less than 5 metres then the width of the survey band was adjusted accordingly. Individual observers recorded different

species consistently (Table 11). Behavioural characteristics associated with spawning aggregations were recorded, including colour changes/states, courtship, distended abdomens in females and male-to-male aggression.

Table 11. Grouper species recorded by observers during surveys.

Observer 1	**Observer 2**
Epinephelus fuscoguttatus	*Plectropomus areolatus*
Epinephelus polyphekadion	*Plectropomus laevis*

Spawning seasonality was not known prior to sampling but results from preliminary surveys at Hithadhoo Corner revealed that species aggregated over the new moon. On this basis, the full moon period was assumed as a non-spawning period at this site. For each species, a baseline non-spawning density at Hithadhoo Corner was calculated from the mean abundance of species over the full moon phase surveys in November 2016 (Lunar Days: 8-15) (Table 12). However, it was not possible to determine non-spawning density at the two other channel sites (Maavah Kandu and Fushi Kandu) as surveys were not conducted over the full moon at these locations.

Table 12. Abundance and density thresholds calculated for grouper species at Hithadhoo Corner.

Grouper Species	Non-spawning abundance	Spawning abundance threshold	Non-spawning density (No./m^2)	Spawning density threshold (No./m^2).
Epinephelus fuscoguttatus	4	16	0.0008	0.00024
Epinephelus polyphekadion	1	4	0.0002	0.0006
Plectropomus areolatus	12	48	0.0024	0.0072
Plectropomus laevis	4	16	0.0008	0.00024

Spawning aggregations in this study were defined based upon criteria in (Colin et al., 2003) and (Domeier, 2012): (1) An increase in fish density 3-fold or an increase in abundance 4-fold and (2) the direct or indirect verification of spawning (Pet et al., 2006; Colin et al., 2003). Direct verifications include 1) undisputed spawning observations, 2) females with hydrated eggs and 3) presence of post-ovulatory follicles in the ovaries of aggregating females. Indirect signs include behaviours or colour patterns if these are demonstrably known to be associated only with spawning. Gonadosomatic Index (GSI) data, swollen abdomens and other proven indications of spawning can also be used to verify spawning aggregation sites. For Hithadhoo Corner we calculated the abundance and density thresholds for the four selected species at the site (Table 10). The spatial dimensions of the core areas surveyed are provided in the site descriptions below.

Results

Scoping survey at Hithadhoo Corner

Over the 20-day period in August/September 2016, a total of 501 grouper sightings[5] were recorded (*Plectropomus laevis:* 41; *Epinephelus fuscoguttatus: 217; P. areolatus*: 226; *E. polyphekadion*: 17). Scoping survey observations strongly suggested spawning activity during the new moon period for all four species, but most noticeably for *Epinephelus fuscoguttatus* and *Plectropomus areolatus*. The abundance of *E. fuscoguttatus* started to increase just after the full moon and almost tripled from 26 individuals the day before the new moon, to 74 on the day of the new moon. *Plectropomus areolatus* abundance almost quadrupled over the same time period from 12 to 45 individuals. Considerably fewer *P. laevis* and *E. polyphekadion* individuals were observed but their abundance also increased up to one day after new moon. The abundance of all species dropped substantially two days after the new moon. The pattern of increased abundance during the new moon was highlighted by a lack of increased abundance for all four species around the full moon period.

Spawning aggregation sites

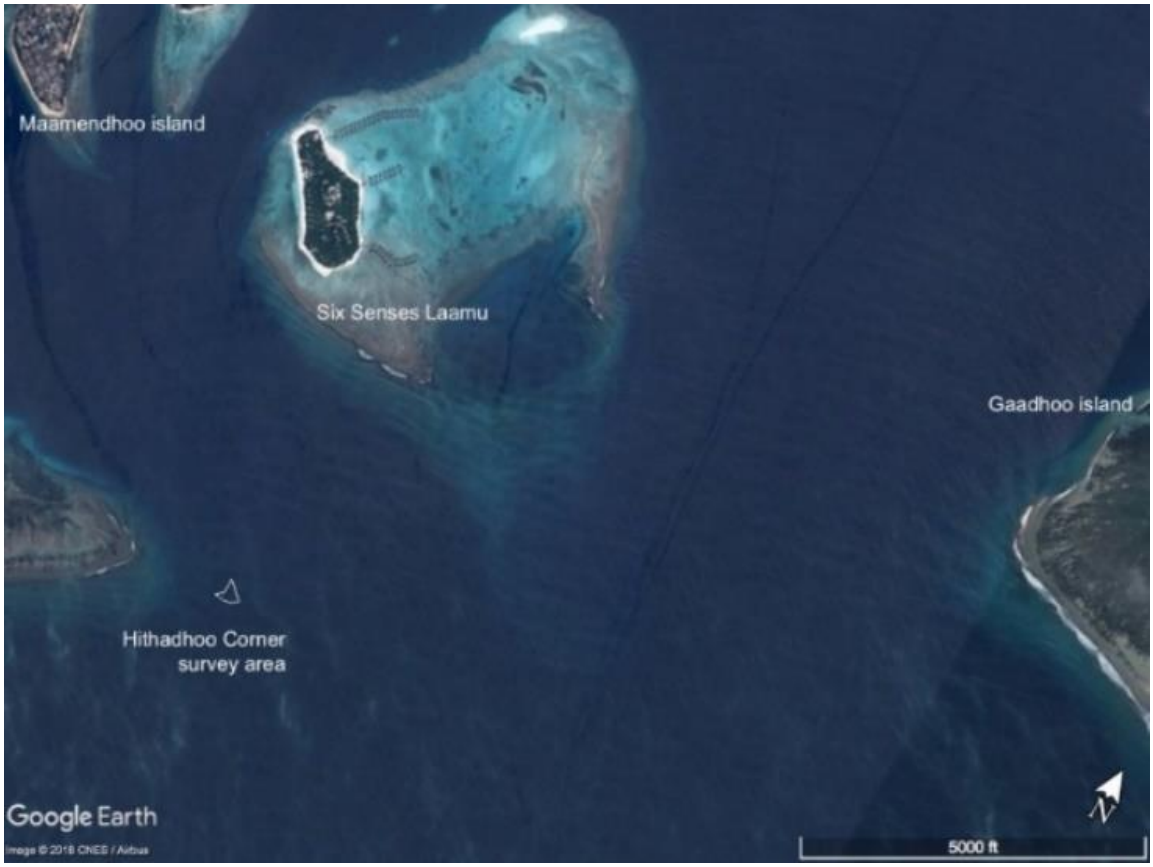
Spawning aggregations of all four species (*E. fuscoguttatus*, *P. areolatus, E. polyphekadion* and *P. laevis*) were verified at Hithadhoo Corner based on a combination of an increase in abundance and observations of spawning-related behaviour as per the criteria above. Although grouper abundance was not determined outside of the aggregation period at Maavah Kandu or Fushi Kandu, indirect evidence of pre-spawning behaviour suggests that the selected grouper species also aggregate at these sites.

Hithadhoo Corner

The site, located on the western side of the Gaadhoo channel, is a long plateau which slopes gently down towards the mid-channel at approximately 15 degrees and is characterised by six large distinct *Porites sp*. coral bommies between 15 and 23 m depth. The top of the reef further inshore is ca. 11-12 m depth and slopes gently seaward to a sand-and rubble bottom. Strong currents and swell characterise the channel. The core area has a perimeter of 336 m and an area of 4,998 m^2.

[5] Individual groupers at the site were very likely to be counted more than once over the new moon phase as all groupers observed each day were recorded.

Figure 13. Location of the spawning aggregation site known as Hithadhoo Corner.



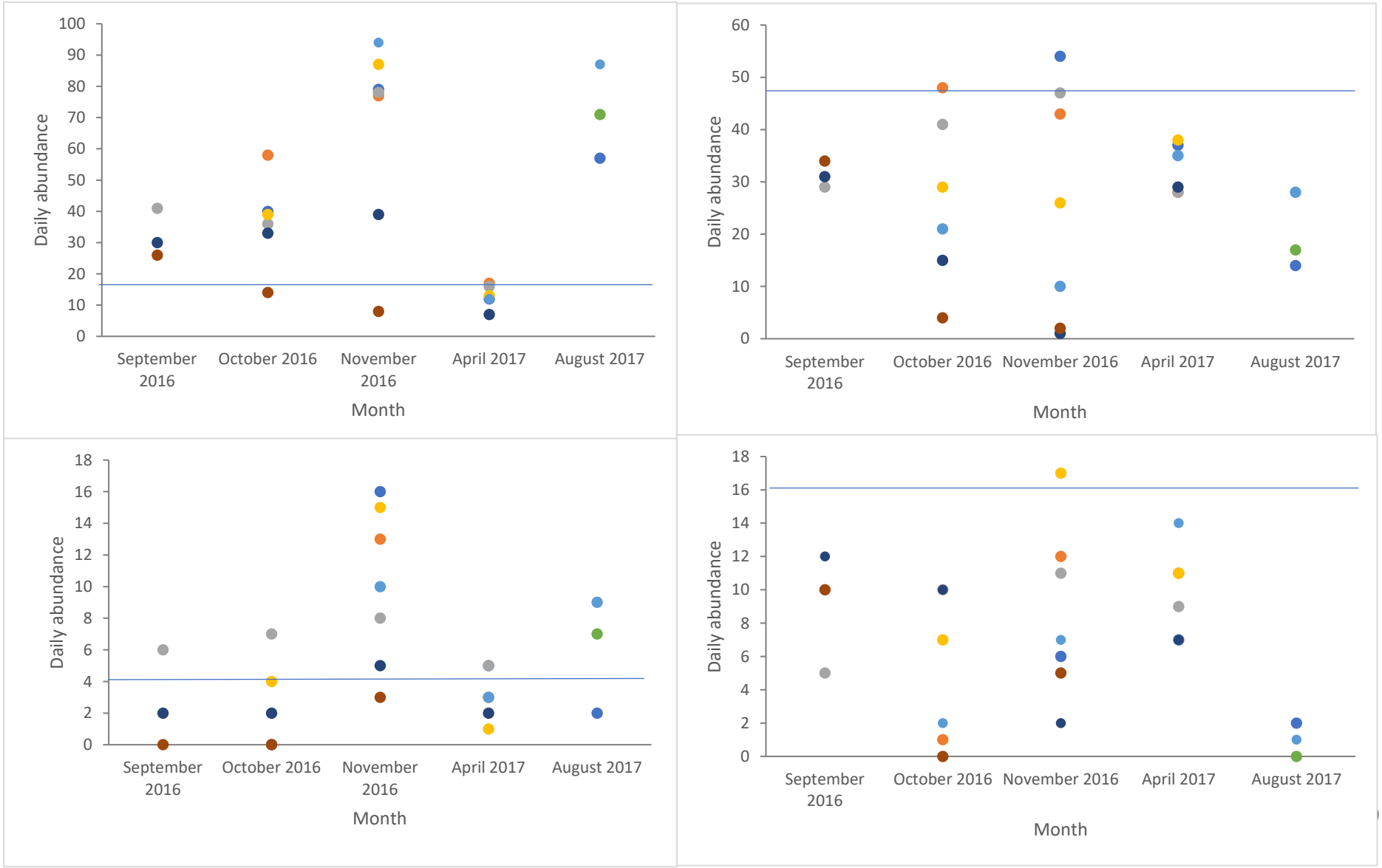
Verification and size of spawning aggregations

Spawning seasonality

Epinephelus fuscoguttatus was the most consistently abundant species observed at Hithadhoo Corner across all months other than April 2017. Counts from September 2016 to August 2017 (LD[6] 25-2) ranged from 7 to 94 individuals in the core area and exceeded the spawning aggregation threshold for each month surveyed (Figure 15a). Abundance was greatest during November 2016 (94) and August 2017 (87). Counts were lowest in April when the maximum number seen was 16 individuals.

[6] LD = lunar day

Figure 15. Seasonal variation in the grouper abundance at Hithadhoo Corner between September 2016 and August 2017 for (a), *Epinephelus fuscoguttatus* (b), *Plectropomus areolatus* (c), *Epinephelus polyphekadion* (d) and *Plectropomus laevis*



Plectropomus areolatus was the second most commonly observed species at Hithadhoo Corner. Based on criteria 1, 24 individuals would constitute a spawning aggregation of *P. areolatus* at this site. Counts from September 2016 to August 2017 (LD 25-2) ranged from 1 to 54 and aggregation size exceeded the spawning threshold during October and November (Figure 15b). Numbers peaked during October (48) and November 2016 (54). *P. areolatus* was least abundant in August 2017 when a maximum of 28 individuals were counted.

Epinephelus polyphekadion abundance was consistently low throughout surveys. Counts from September 2016 to August 2017 (LD 25-2) ranged from 0 to 16 and the number of individuals exceeded the calculated spawning threshold every month (Figure 15c). Like *E. fuscoguttatus,* aggregations were largest in November 2016 and August 2017.

Similarly, the number of *Plectropomus laevis* observed was consistently low across all months surveyed. Counts from September 2016 to August 2017 (LD 25-2) ranged from 0 to 17. The number of individuals only exceeded the aggregation threshold during November 2016 (Figure 15d).

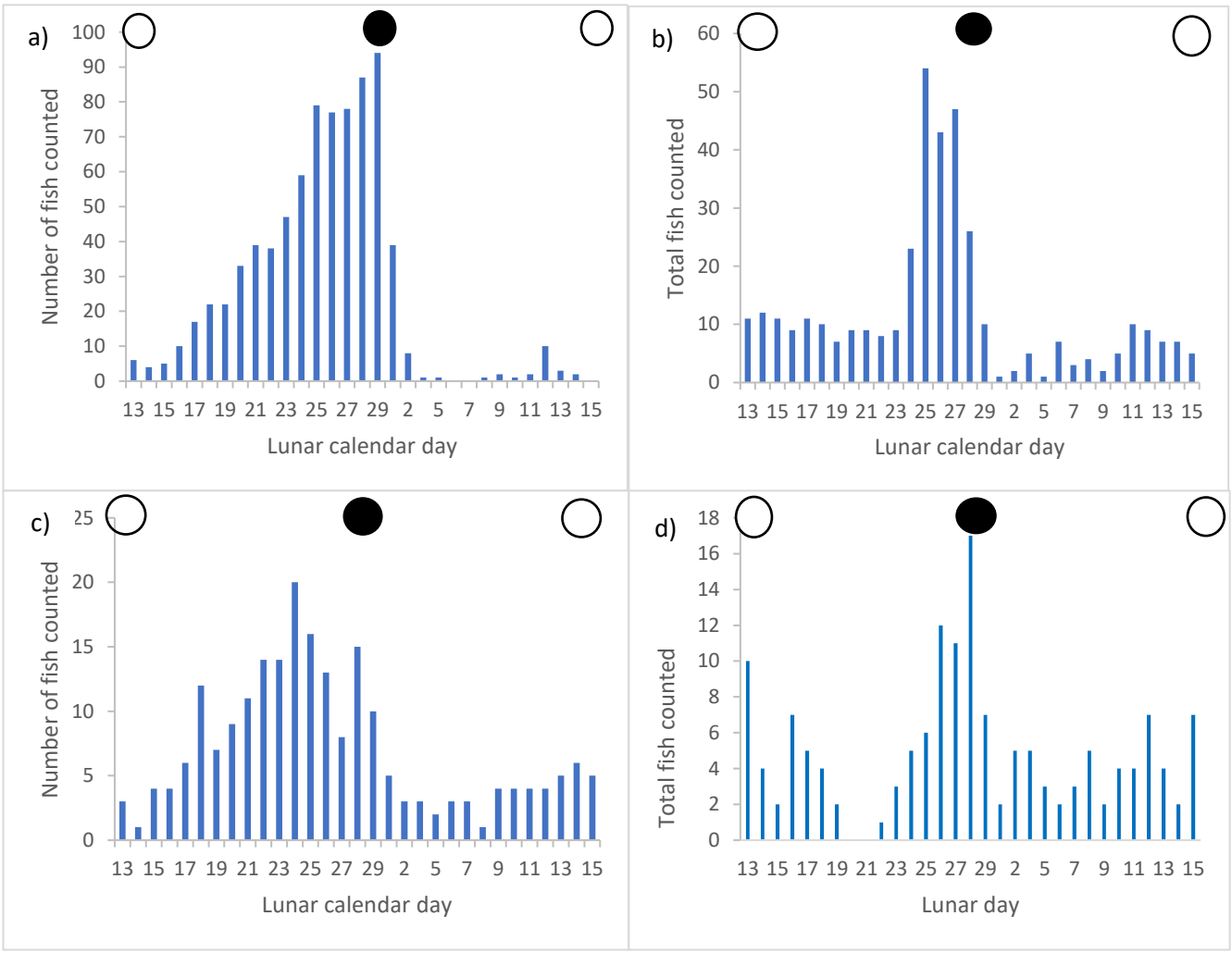
Lunar phase

Daily counts plotted against lunar day for the whole month of November 2016, indicate that all four selected species form aggregations around the new moon. However, aggregations of different species showed different temporal patterns over the month (Figure 16).

A gradual and steady increase in the number of *E. fuscoguttatus* was observed for a two-week period, beginning during the full moon (LD,14) with a peak of over 90 individuals corresponding to the new moon (LD 29) (Figure 16a). Aggregation numbers subsequently abruptly dropped by 99% two days later by LD 3. Like *E. fuscoguttatus,* numbers of *E. polyphekadion* began gradually increasing following the full moon (LD 14) and peaked on LD 23 (20 individuals) before dropping to 1 individual by LD 3 (Figure 16c). For both *Epinephelus spp.* lower numbers of fish were observed over the full moon period (LD 13-15).

By comparison, *P. areolatus* numbers abruptly increased on LD 23 and numbers peaked slightly earlier on LD 25 (Figure 16b). Numbers dropped by 98% much more gradually over a period of 5 days. This rise and fall pattern is typically observed at spawning aggregation sites. Temporal monthly variations for *P. laevis* were less defined (Figure 16d). Though the typical rise and fall pattern was observed over the new moon during which numbers peaked on LD 28, numbers did not decrease so drastically and abundance of *P. laevis* was still variable over the new moon period. It should be noted that these data are for a single month (November to December 2016) and further assessment is needed to verify that the temporal patterns reported here are consistent between months.

Figure 16. Total number of fish counted at Hithadhoo Corner in November and December 2016 for a) *Epinephelus fuscoguttatus* b) *Plectropomus areolatus* c) *Epinephelus polyphekadion* d) *Plectropomus laevis*



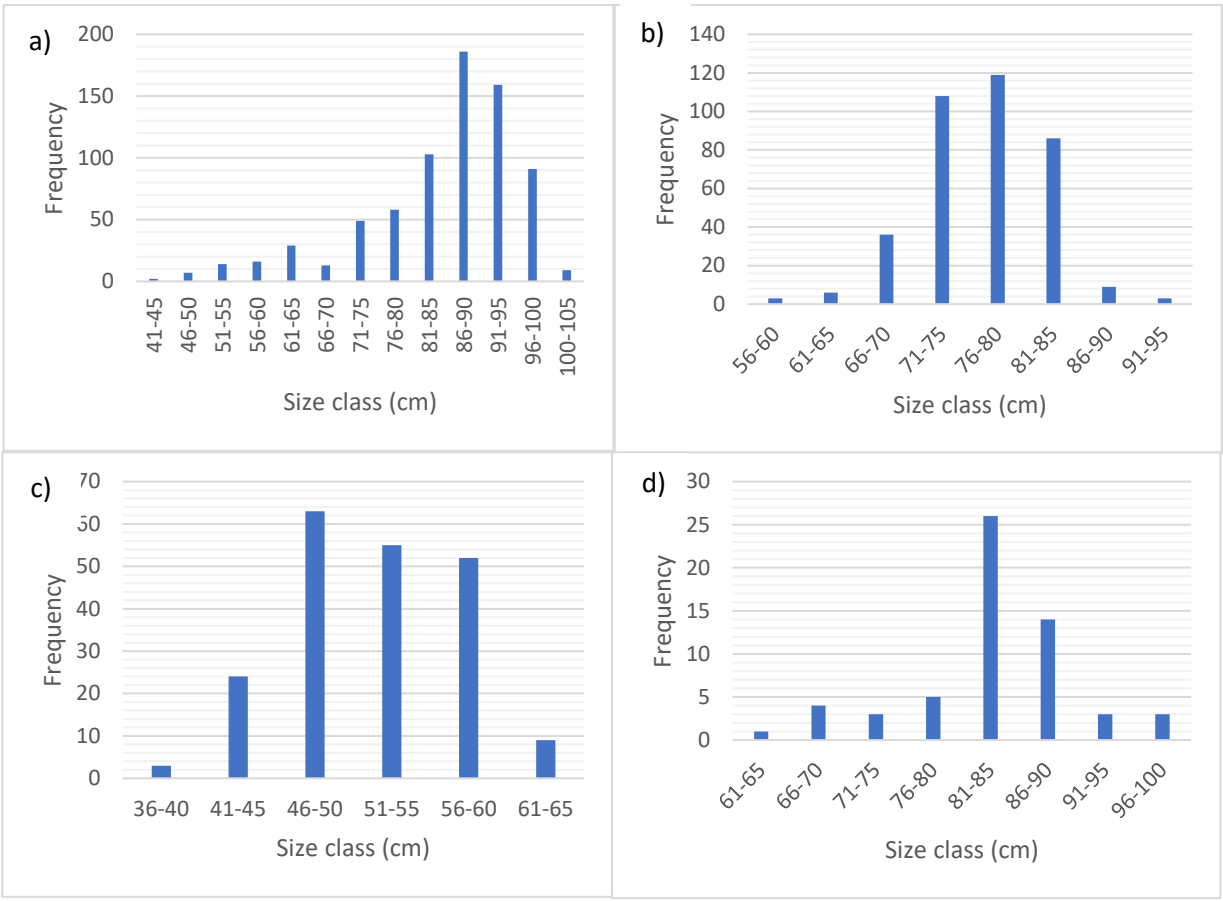
Note: Black circles represent the day of the new moon and white circles represent the day of the full moon

Size distribution of aggregating groupers at Hithadhoo Corner

Size frequency plots for the four-selected species for November 2016 counts (31 days) are depicted by Figure 17 a-d. The size ranges of aggregating fish were: 41-105 cm TL (*E. fuscoguttatus*); 46-95cm TL (*P. areolatus)*; 36-65cm (*E. polyphekadion*) and 61-100cm (*P. laevis)*.

The greatest size range of *E. fuscoguttatus* was observed during November and December 2016 when the largest individuals (>100 cm TL) were also seen. The greatest variety of different sized *P. areolatus* were observed during April 2017. However, the largest individuals (>95 cm TL) were seen during November and December 2016.

Figure 17. Size structure of selected grouper populations at Hithadhoo Corner in November 2016 (*E. fuscoguttatus* (a), *P. areolatus* (b), *E. polyphekadion* (c) and *P. laevis* (d).



Verification of spawning behaviour

Grouper behaviour associated with spawning was observed for all four species at Hithadhoo Corner, providing strong evidence for reproductive aggregations at this site. However, spawning rushes and gamete release, which are more common at night or dawn/dusk were not observed (de Mitcheson and Colin, 2011). All behaviour except for gravid females and colour changes were recorded opportunistically by observers. Individual colour phases were not documented during dive surveys, only a visible colour change, and thus no associated behaviour and/or sex orientation of individuals displaying colourations were described.

Spawning Behaviour observed for Epinephelus fuscoguttatus

E. fuscoguttatus was most commonly seen exhibiting spawning behaviour in November 2016 and August 2017, when aggregations were largest. Notably, gravid females were only seen during these months.

Individuals assumed to be males behaved very territorially leading up to the new moon and were commonly seen exhibiting male colouration and chasing one another. Marks on the body and tail caused by biting were commonly seen on individuals and once, during August 2017, an assumed male was seen to bite another male on the caudal fin (VE/SH pers. obs.).

Groupers were also seen displaying courtship behaviour in pairs (Appendix 8: behaviour 5). Courtship acts involved two individuals lying next to each other and occasionally rubbing against each other. Typically, either one or both displayed colouration phase and one of the individuals was turned on their side.

During November, individuals were seen to hover mid-water column which was unusual given that this species is commonly seen swimming close to the seabed or to coral bommies. This same behaviour has been documented in Robinson et al. (2008b).

Spawning behaviour observed for Plectropomus areolatus

P. areolatus was most frequently seen displaying spawning behaviours during October 2016, November 2016 and April 2017. Individuals were regularly seen chasing one another in pairs and the 'shaking' behaviour in which one individual turns onto its side and swims towards another 'waggling' itself was also frequently observed. Bite marks visible on the head and body of some individuals also suggest aggressive behaviour.

P. areolatus was also commonly observed in pairs or sometimes in larger groups of up to six individuals. Often gravid females were seen amongst groups but not consistently. When in groups, one or more individuals were commonly seen 'shaking' towards others within the group. On one occasion at this site, between 15 and 25 individuals ca. 35-45cm in length, all dark in colour, were observed swimming in a tight group.

This species displayed the greatest diversity of colour patterns and fish often displayed rapid colour changes in groups and pairs (Appendix 9; CC1-CC8).

Spawning behaviour observed for Epinephelus polyphekadion and Plectropomus laevis

Some gravid females of *Plectropomus laevis* were seen in November 2016, particularly on LD 3 and several colour changes were observed (Appendix 10). Six individuals were also seen forming small groups of more than three individuals. Individuals assumed to be males often displayed distinct colouration patterns, which were different to those typically observed, and were seen 'shaking' towards one of more individuals.

Gravid *E. polyphekadion* females were seen in November and December 2016 on LD 26 and LD 27 several days after aggregation numbers had peaked. Assumed males were seen engaging in aggressive 'head to tail' behaviour pressed closely up against each other and displaying colouration (appendix 11). Chasing behaviour was also witnessed.

Additional Spawning Aggregation Sites

In addition to Hithadhoo Corner a further two channels (Maavah Kandu and Fushi Kandu) were assessed in some detail at sites identified as likely spawning aggregation sites by preliminary surveys. Both sites were only surveyed over one new moon phase.

Maavah Kandu

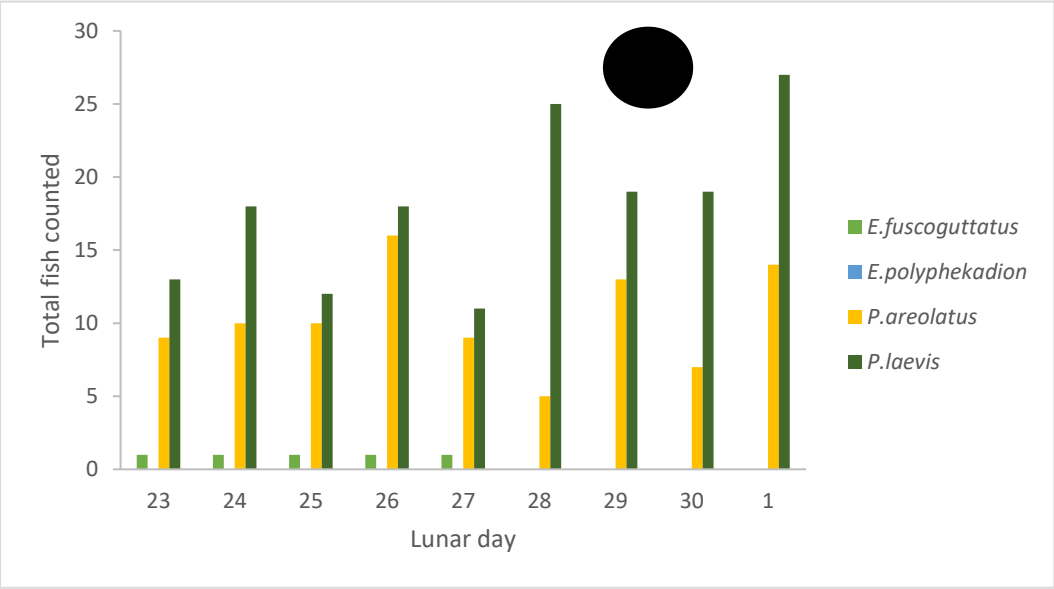
Maavah Kandu is located on the western side of Laamu Atoll next to Maavah Island (Figure 12; Table 9). The aggregation site identified is in the middle of the channel on the seaward side. Here the reef slopes ca. 25° degrees into a sandy bottom area at 30 m depth. The aggregation site was found between 14 and 30 m depth. The area surveyed was 10,910 m^2.

Figure 18. Location of the site surveyed in Maavah Kandu channel during June 2017.

Verification and size of spawning aggregations

A total of 260 grouper sightings were recorded over a nine day survey period (*P. laevis:* 162, *P. areolatus*: 93, *E. fuscoguttatus*: 5). The two *Plectropomus* species (*P. laevis* and *P. areolatus*) were the most abundant groupers observed at Maavah Kandu with the latter more abundant. Very few *Epinephelus fuscoguttatus* and no *E. polyphekadion* were observed during surveys. Counts of *P. laevis* in June (LD 23-1) ranged from 13 to 27 individuals per day, peaking on LD 1, several days after the new moon. *P. areolatus* numbers ranged between 9 and 16 individuals per day and peaked on LD 26 (Figure 19).

Figure 19. Grouper abundance at Maavah Kandu over the new moon period in June 2016.

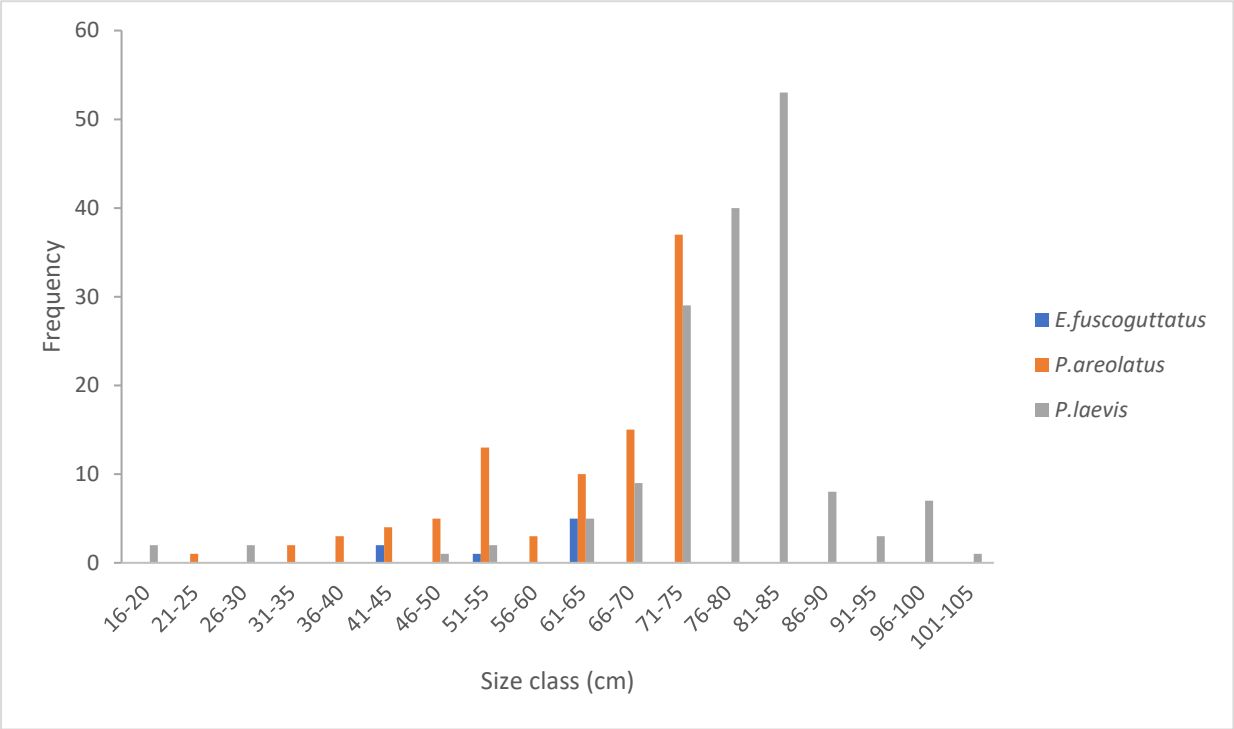


Note: The black circle represents the day of the New Moon.

Grouper size distribution at the aggregation site

Size frequency plots (Figure 20) of all grouper sightings recorded at Maavah revealed that the size range for the three observed species were: 16-105 cm TL (*P. laevis)*; 21-75cm TL (*P. areolatus*) and 41-65cm TL (*E. fuscoguttatus*).

Figure 20. Size structure of *groupers* observed at Maavah Kandu over the new moon in June 2016.



Verification of the spawning aggregation site: behavioural observations of groupers

Individuals of *P. laevis* were seen to change colour most frequently on LD 26, a behaviour which is indicative of increased aggression. Individuals also began to form small groups over the new moon and these were most commonly recorded on LD 30. Gravid females were seen throughout the survey period but were most often observed on LD 1. *P. laevis* were also found to form smaller groups and pairs at this site more frequently than at any other sites and observed displaying the same "shaking" behaviour which had been seen at Hithadhoo Corner.

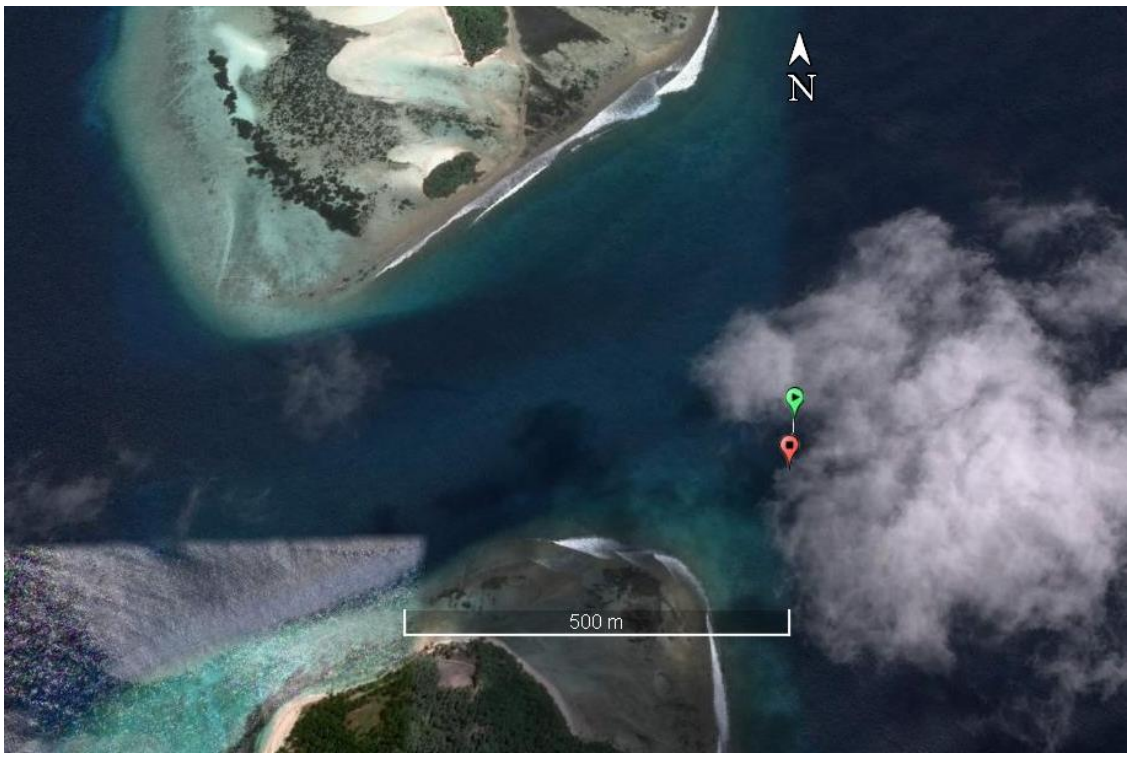
Behaviours displayed by *P. areolatus* are comparable to those seen at Hithadhoo Corner but were seen less often. Overall, fewer gravid females were noted and there was less chasing and shaking behaviour seen. Individuals were still commonly found in pairs and smaller groups and were often seen changing colour.

Fushi Kandu

Fushi Kandu is located on the eastern side of Laamu Atoll between the islands of Maabaidhoo and Fushi. The area is characterised by a single massive *Porites* sp. coral bommie located at 12 m on the reef crest as well as a healthy area of *Porites sp.* and tabulate *Acropora* starting at 14 m on the reef

edge and extending down the reef slope at a steep gradient (ca. 40 degrees) to a depth of 30 m. The total area surveyed was 1480 m^2.

Figure 21. Location of the site surveyed at Fushi Kandu over the new moon in May 2017.



Verification and size of spawning aggregations

A total of 241 grouper sightings were recorded at Fushi Kandu in May 2017 over a seven day period (*P.* areolatus: 120, *P.* areolatus: 92, *E. fuscoguttatus*: 29). *P. areolatus* and *P. laevis* were the most abundant and like Maavah Kandu, very few *E. fuscoguttatus* and no *E. polyphekadion* were observed. *P. areolatus* numbers ranged between 5 and 46 individuals and peaked on LD 25 (Figure 22). However, a group of 15-20 individuals were observed that day which had a substantial influence on the daily count. Abundance of *P. laevis* (LD 23-30) ranged from 8 to 20 individuals, peaking on LD 29, two days before the new moon.

Grouper size distribution at Fushi Kandu

Size frequency plots (Figure 23) of the groupers recorded at Fushi Kandu revealed that the size range for the four species were: 66-105 cm TL (*P. laevis)*; 31-75cm TL (*P. areolatus*) and 36-80cm TL (*E. fuscoguttatus*).

Figure 22. Grouper abundance at the Fushi Kandu site over the new moon period in May 2017

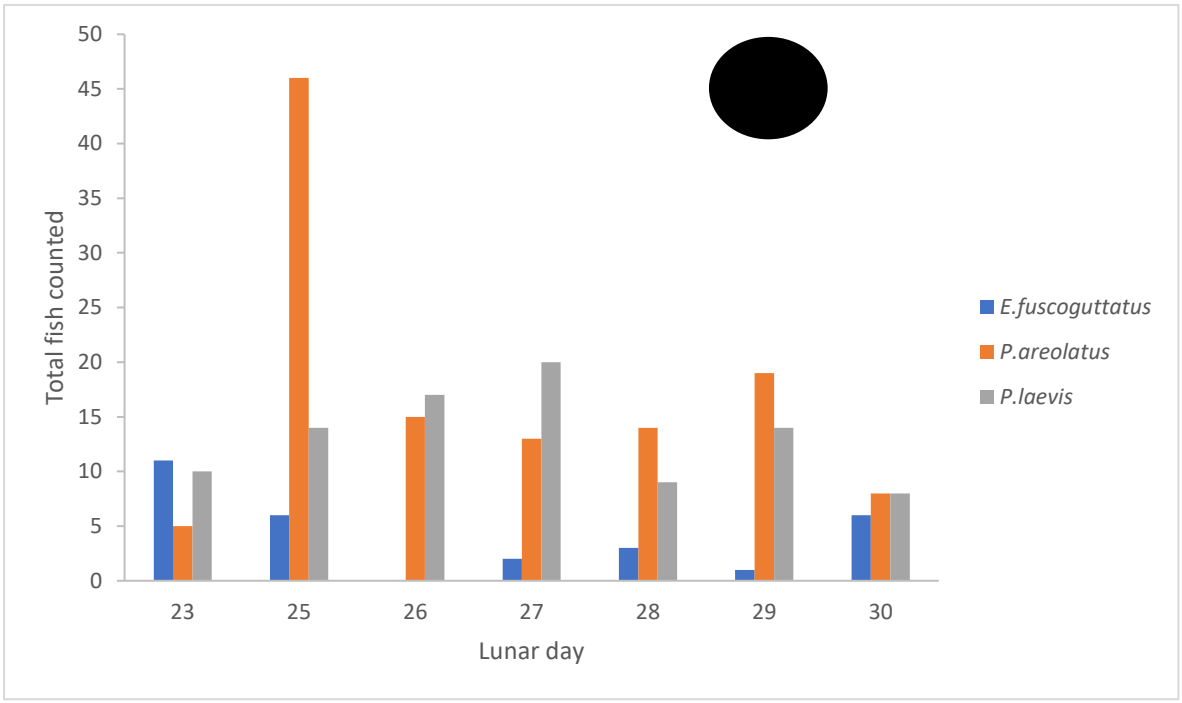
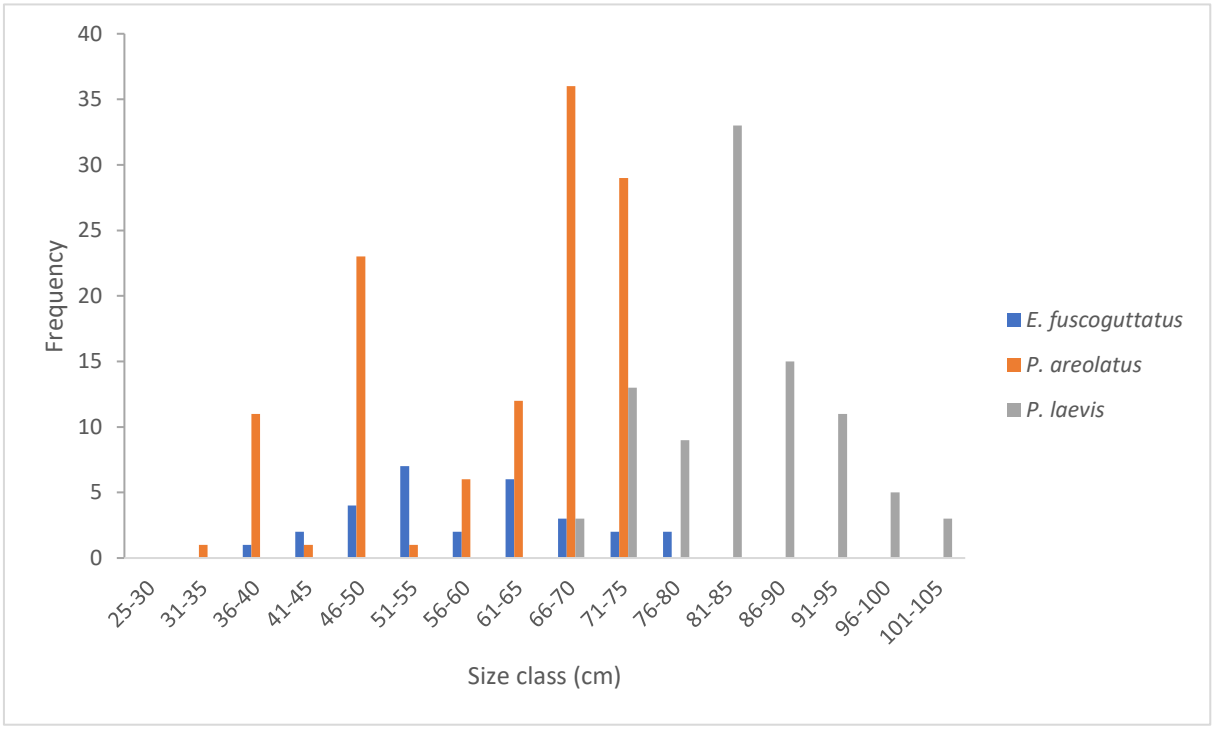


Figure 23. Size structure of groupers observed at Fushi Kandu over the new moon in May 2017.



Important megafauna species at spawning aggregation sites

A number of other megafauna species were recorded opportunistically during dive surveys at channel sites (Appendix 12). These included cetaceans (dolphins, 2 spp.), elasmobranchs (10 spp. of ray, 7 spp. of shark), turtles (2 spp.) and large bony fish such as humphead wrasse, tuna and barracuda. Twenty-

four species were recorded at Hithadhoo Corner, while both other sites revealed fourteen species each. The IUCN Red List status of the observed species are also provided (Appendix 12) and indicates that each channel site provides habitat for some vulnerable and endangered species including marine turtles, sharks and rays. An oceanic manta ray was observed at Hithadhoo Corner while a reef manta ray cleaning station was also discovered at the Fushi Kandu site.

Discussion

The increased densities of groupers and spawning-related behaviour observed at Hithadhoo Corner for *Epinephelus fuscoguttatus, Plectropomus areolatus* and *Epinephelus polyphekadion* provide strong evidence that this location is a spawning aggregation site for these three species. We therefore achieved one of our main aims of Phase 2; to identify and confirm at least one grouper spawning aggregation site on Laamu Atoll. Additional assessment of two other sites (Maavah Kandu and Fushi Kandu) strongly suggests that these channels also harbour grouper aggregations at particular times, but further assessment is required to verify this.

Groupers are clearly spawning during the new moon period, which agrees with fishers' reports from this study (Section 1) and across the Maldives (Sattar et al., 2011). However, spawning at full moon cannot be completely disregarded. Only a few surveys were conducted over the full moon period. No evidence of spawning was identified but further research is needed to confirm this over longer time scales. It is possible that lunar spawning periods may differ regionally within the Maldives but also that some species spawn over both lunar phases. Spawning aggregations at both the new moon and full moon have been reported in the Solomon Islands (Hamilton, Potuku and Montambault, 2011).

The repeat surveys at Hithadhoo Corner were not able to clearly show a seasonal pattern in spawning aggregations over a year but the higher densities recorded in particular months suggest that there is some annual seasonal variation for grouper species. Further assessment of this site each month should enable us to determine whether there is a clear seasonal pattern in aggregations for groupers.

The main points concerning spawning aggregations for each of the four selected grouper species are summarised below:

Epinephelus fuscoguttatus

Hithadhoo Corner is clearly a stronghold for this species, with up to 94 individuals observed congregating over one new moon and aggregations identified in five different months suggesting that they aggregate on a monthly basis. Documented spawning behaviour for *E. fuscoguttatus* such as colouration patterns and clear demarcation of territories have been previously been reported in Palau, the Seychelles and the Western Indian Ocean (Robinson, Samoilys and Kimani, 2008b; Johannes et al., 1999). Clear observations of spawning-related behaviour at Hithadhoo Corner provide further support to confirm that this is a spawning aggregation site for this species.

Few individuals were observed at Fushi Kandu and Maavah Kandu. This could be caused by a seasonal variation in aggregations, local differences in channel characteristics or higher fishing pressure at these sites. However, both of these sites were only visited on two occasions with one full survey completed. Further work is required to understand why this species was observed more regularly at Hithadhoo Corner than at the other sites.

Aggregations of *E. fuscoguttatus* in Palau comprise as many as 350 individuals, while those in Seychelles are known to comprise between two and five thousand fish (Robinson et al., 2008a; Johannes et al., 1999). By comparison, the aggregations observed in Laamu are relatively small. Local fishermen recalled a time when the "sea was black with groupers" and they could catch over a hundred fish in one night. This suggests that long-term fishing pressure in Laamu Atoll is having a strong effect upon *E. fuscoguttatus* aggregations.

The size (lengths) of individuals in the aggregation at Hithadhoo Corner compare well to those of reproductively active *E. fuscoguttatus* recorded on the Great Barrier Reef, Australia where individuals first matured at 32 cm (Pears et al., 2006). All individuals identified in this study were greater than 32 cm in length which suggests fish were mature. However, geographical differences in size should also be considered.

Plectropomus areolatus

This species was observed at all three sites but most abundant at Hithadhoo Corner during October and November. Documented spawning behaviour was observed in all survey months, indicating that, even during periods of low abundance, Hithadhoo Corner is a spawning aggregation site for this species. This "shaking" courtship behaviour, which is indirect evidence of *P. areolatus* spawning, was first described on the Great Barrier Reef for *Plectropomus leopardus* and subsequent pair spawning has been observed in other *Plectropomus spp.* across the Indo-Pacific region (Johannes et al., 1999), including at Laamu Atoll (Sluka, 2001a).

Two travelling schools of females were observed at both Hithadhoo Corner and Fushi Kandu. This behaviour has been previously documented at a verified spawning aggregation site in Palau and further supports that both these channels are spawning aggregation sites for *P. areolatus* (Johannes et al., 1999).

The size (lengths) of individuals in this study compare well to those of reproductively active individuals recorded in the Western Pacific Ocean where individuals first matured at 350 mm (Rhodes et al., 2013). In this study we identified groupers between 21 cm and 96 cm which may suggest populations are still viable. We were not able to find any published reports of size-maturity relationships for this species in the Indian Ocean.

Epinephelus polyphekadion

This species was only recorded at one site (Hithadhoo Corner) where we believe it aggregates to spawn each month in common with *E. fuscoguttatus*. Abundance at Hithadhoo Corner was lower than expected for this species. Aggregations in the Seychelles and Palau range from around 100 individuals to nearly 2000 (Robinson et al., 2008a; Johannes et al., 1999). For our surveys, abundance never exceeded 16 individuals in the core area. Despite the low numbers, spawning behaviour observed for this species agreed with those reported for aggregations in the Pacific and Indian Ocean (Robinson et al., 2008a; Bijoux et al., 2013). Behaviour was most evident in November and August, which may be peak spawning months.

E. polyphekadion was not observed at Maavah Kandu and Fushi Kandu, although considerably less time was spent underwater at these sites compared to Hithadhoo. This absence agrees with findings from other parts of the Maldives, where very low numbers of *E. polyphekadion* have been recorded (Sattar et al., 2011). More recently, *E. polyphekadion* was recorded in low abundance at both Boamas Kandu in Vaavu Atoll and Muli and Mulah Channels in Meemu Atoll (Shimal, 2015).

Plectropomus laevis

Spawning patterns of *Plectropomus laevis* are the least understood of the four species studied (de Mitcheson and Colin, 2011), and remain unclear. Globally, aggregations of *P .laevis* are extremely uncommon, with only one probable aggregation described in the Pacific Ocean (de Mitcheson and Colin, 2011). On Laamu Atoll a possible aggregation was reported for Mundoo Kandu but was also regarded as 'speculative' (Sluka, 2001a).

It may be that *P. laevis* does not aggregate in the same manner as the other species studied. Although abundance was generally below the threshold to meet the criteria for an aggregation site, "harem" spawning behaviour, similar to that described at Mundoo Channel and in the Chagos archipelago (Andrews, 2015), was observed at Hithadhoo Corner and Maavah Kandu. This behaviour is characterised by the formation of small groups (4 to 5 individuals) in the days approaching the new moon, with one much larger individual (the male) displaying a colouration (Sluka, 2001a; Andrews, 2015).

Plectropomus laevis abundance only exceeded the threshold for an aggregation in November at Hithadhoo Corner with no more than 18 individuals recorded per survey. *P. laevis* daily abundance was greatest at Maavah Kandu (27 individuals) but given the lack of global baseline data available for aggregations of this species, it is not possible to make aggregation size comparisons. Collecting non-spawning density data at this site and others on Laamu Atoll will help to determine whether this number of *P. laevis* constitutes a spawning aggregation.

Summary

Our research at Hithadhoo Corner is **the first detailed study of a grouper spawning aggregation site in the Maldives over multiple new moon phases**. This site has the highest abundance of *Epinephelus fuscoguttatus* and *E. polyphekadion*, two species not found at the other two sites we assessed. Our findings at Hithadhoo show strong similarities to other confirmed aggregation sites across the Indo-Pacific and Western Indian Ocean that have the same or similar species composition (Johannes et al., 1999; Sadovy, 2005; Robinson et al., 2008b) as well as in the Maldives at Kaafu Atoll (Shimal, 2015).

It is possible that grouper abundance is higher at Hithadhoo because of reduced fishing pressure. There is an informal agreement between the nearby resort (Six Senses Laamu) and local fishermen so that it is used as a dive site in the day and only fished at night. However, fishing vessels from other atoll targeting grouper are not part of this agreement. Fishermen have also reported that Hithadhoo Corner was one of the largest grouper aggregations on Laamu, suggesting that this site could be the one of the few locations with a recognisable spawning aggregation on the atoll.

The lack of *Epinephelus* spp. at the two other channel sites surveyed could be a result of chronic targeted fishing pressure at peak aggregation times for these species. Research has shown that the life history traits of *Epinephelus* spp. make them more vulnerable to fishing pressure compared to Plectropomus *spp.* (Rhodes et al., 2012; Rhodes et al., 2013). Probable aggregations of *Plectropomus* spp. were identified at both Maavah Kandu and Fushi Kandu.

The size and structure of the *E. fuscoguttatus* spawning aggregation at Hithadhoo Corner, although likely to be greatly diminished in numbers, does suggest that the local population is still viable and is more likely to recover if fully protected at this site. 'Fishwatch' surveys since 2010 revealed that the abundance of *Epinephelus* spp. on 'protected' resort house reefs, were higher than those on reefs open to fishing (MRC/MCS, 2011: Figure 4). This pattern was also very evident for the two *Plectropomus* spp. with nine times more *P. areolatus* and 3.6 times more *P. laevis* on resort house

reefs compared to areas open to fishing (MRC/MCS, 2011). However, effective management of grouper fishing outside of protected areas will also be required to enable populations to rebuild.

As surveys were not conducted every month throughout the year, it remains unclear which months have the largest aggregations of groupers for the sites assessed. However, our findings for Hithadhoo Corner suggest larger aggregations in some months such as November which may be linked to the monsoon transition period.

Further research will be needed to document and confirm the other potential spawning aggregation sites on Laamu, identified by local fisher knowledge (Section 1), and to delineate clear spawning periods for targeted species. The data collected provide a comprehensive baseline for one site (Hithadhoo Corner) which can be used as a reference point for future studies to monitor this aggregation and better understand spawning patterns of highly targeted groupers. The survey techniques we employed can also be used at other sites in the Maldives to build up a better picture of grouper spawning aggregations across the country. Management recommendations for spawning aggregation sites both on Laamu Atoll and nationally are provided in Section 5.

3. Size-Maturity Relationships for Highly Targeted Grouper Species

Introduction

Between 70 and 90% of all groupers caught in the Maldives for export are immature (Sattar et al., 2011, MRC unpublished data). Catching fish before they reach maturity reduces the reproductive potential of populations and the number of young that can replenish stocks. In the Grouper Fishery Management Plan (MRC/MCS, 2011) minimum and maximum catch and export size limits were recommended for all grouper species exported from the Maldives to reduce the catch of immature grouper to below 20%. However, the size limits proposed were based on estimates from global data (Table 13) which fishermen and exporters lobbied against, as these were not deemed to be representative of local (Maldivian) maturity sizes. Consequently, size limits gazetted for the grouper fishery in 2014 were substantially reduced for all species (Table 13) but with the mutual understanding between MoFA and the fishermen that these size limits would be revised following the verification of global data after size-maturity assessments in the Maldives (MoFA, pers. comm.).

The aim of this work programme was to collect data in the Maldives to determine size-maturity relationships for highly targeted grouper species. The assumption being that the results would provide strong evidence to support the revision of existing national size limits.

The four most highly valued and targeted groupers species in the Maldives are *Epinephelus fuscoguttatus*, *Epinephelus polyphekadion*, *Plectropomus areolatus*, and *Plectropomus laevis*. These species were selected as priority for size-maturity assessment. However, due to difficulties in acquiring sufficient samples of *E. fuscoguttatus*, a fifth species *Plectropomus pessuliferus*, was also sampled opportunistically towards the end of the research phase. Cage owners from Vaavu Atoll and Gaafu Dhaalu Atoll were much more willing to sell us this species rather than *E. fuscoguttatus*.

Table 13. Theoretical maturity lengths, proposed and current catch size limits for exported grouper species.

	Scientific Name	Dhivehi Name	IUCN Red List Status	Theoretical maturity lengths (cm)	Proposed Size limits, 2011 (cm)	Current size Limits, 2014 (cm)
1	*Aethaloperca rogaa*	Ginimas faana	DD	30	27	20
2	*Anyperodon leucogrammicus*	Boalhajehi faana	LC	32.5	31	25
3	*Cephalopholis argus*	Mas faana	LC	30	26	20
4	*Cephalopholis leopardus*	Raiy thiki faana	LC	Unknown	20	20
5	*Cephalopholis miniata*	Koveli faana	LC	25	26	20
6	*Cephalopholis sexmaculata*	Landaa faana	LC	Unknown	20	20
7	*Cephalopholis sonnerati*	Veli faana	LC	28.5	20	20
8	*Cephalopholis urodeta*	Kanfaiy kalhu faana	LC	Unknown	20	20
9	*Epinephelus areolatus*	Thijjehi faana	LC	Unknown	30	
10	*Epinephelus caeruleopunctatus*	Hudhu lah faana	LC	Unknown	32	25
11	*Epinephelus fasciatus*	Raiy galhi faana	LC	20	25	25
12	*Epinephelus flavocaeruleus*	Dhon noo faana	LC	45	30	30
13	*Epinephelus fuscoguttatus*	Kas faana	NT	57	<31 and 45-63	<25 and 45-60
14	***Epinephelus lanceolatus***	**Mudu faana**	**VU**	Unknown	NA	NA
15	*Epinephelus macrospilos*	Fijjehi faana	LC	29	32	25
16	***Epinephelus merra***	**Lah faana**	**LC**	Unknown	NA	NA
17	*Epinephelus ongus*	Kirulhi faana	LC	Unknown	28	20
18	*Epinephelus polyphekadion*	Kula faana	NT	45	31	20
19	*Epinephelus spilotoceps*	Asdhaanu faana	LC	22	28	20
20	*Plectropomus areolatus*	Olhu faana	VU	46	35	25
21	*Plectropomus laevis*	Kandu rasgefaanu	VU	62.5	35	25
22	*Plectropomus pessuliferus*	Dhon olhu faana	NT	60	35	25
23	*Variola albimarginata*	Kandu raiy haa	LC	32.5	25	22
24	*Variola louti*	Kandu haa	LC	41.5	31	22

Note: Species in bold are those not included in the current grouper fishery management plan. Theoretical maturity length data are from ww.fishbase.org. Proposed size limits are those in Sattar et al., (2011) and current size limits are existing legislation. IUCN Red List Categories are provided at http://www.iucnredlist.org/

Methodology and Data Collection

Monthly gonad analyses were conducted on groupers purchased from cage systems in the Maldives between December 2016 and October 2017 (Table 14).

Table 14. Dates and locations of grouper sampling for size-maturity assessment.

Trip No.	Cage location		Sampling period			
	Atoll	**Island**	**Year**	**Month**	**Dates**	**New Moon**
1	Laamu	Maavah	2016	December	17th-21st	29th
2	Laamu	Maavah	2017	February	20th-27th	26th
3	Vaavu	Thinadhoo	2017	March	21st-31st	28th
4	Kaafu	Hulhumale	2017	April	1st-2nd	NA
5	Laamu	Maamendhoo	2017	April	22nd	25th
6	Gaafu Dhaalu	Thinadhoo	2017	July	18th-25th	23rd
7	Vaavu	Keyodhoo	2017	October	15th-22nd	19th

To ensure ripe gonads were sampled, all groupers were purchased from the cage owners or fishermen directly daily, between 4 and 6 days prior to the new moon lunar phase. Groupers sampled in December 2016 were the only fish not sampled over the new moon period as this was a pilot study. Sampling continued for up to 4 days after the new moon to ensure that spawning had concluded.

Individuals were selected, where possible, to represent each 5 cm size classes over a length distribution of between 20 and 95 cm. When possible, a larger number of individuals were sampled around estimated maturity stages for each species to improve the reliability of data.

The time and location of the catch of fish sampled were recorded if fish were purchased directly from fishermen, although this information was often not known as most fish were purchased from holding cages. The total length (TL) and standard length (SL) of each fish was measured to the nearest millimetre. The weight of each fish and the total weight of both gonads were measured to the nearest gram. Maturity stage estimates were based on criteria for visual estimations published in Pet *et al.,* (2006) (Table 15).

Active mature individuals were categorised based on the size and colour of the gonads which are typically creamy and noticeably enlarged (Table 15). Males were typically identified based on the presence of milt which can be seen visually. Females were sexed based on the appearance of hydrated eggs.

Table 15. Criteria used in the visual determination of maturity stage for sampled groupers, after Pet *et al.,* (2006).

Maturity Stage	Appearance
OVARIES (females)	
Immature	Ovary small, strand-like, compact, pink or cream; oocytes (eggs) not clearly distinct; not obviously different from immature or inactive males
Maturing	Ovary relatively small but rounded, less strand-like in appearance, greyish with thickened gonad wall; eggs not clearly distinct and small; not clearly different from mature males prior to the development of yolk within the eggs
Mature, active	Ovary large and yellow, orange or pinkish with transparent gonad wall; large yolky eggs becoming clearly visible and tightly packed (see Figure 6).
Mature, ripe	Ovary relatively large, clear, watery (hydrated) eggs visible through wall; typical of individuals just prior to spawning; egg release possible with application of light abdominal pressure
Post-spawn	Ovary flaccid with obvious capillaries (small blood vessels); few eggs visible
TESTES (males)	
Immature/inactive	Testes not obviously different from immature females (see the description of immature females)
Maturing	Testes expanding and becoming rounded and large; greyish in appearance; early maturing individuals are not clearly different from maturing females until sperm becomes evident in the sperm sinus along the gonad wall
Mature, active	Testes large and white with sperm visible in sinuses along the gonad wall; sperm release with light abdominal pressure
Post-spawn	Testes flaccid and bloody; sperm release still possible on application of abdominal pressure

Gonadosomatic index (GSI) is an index of the relationship between the gonad weight and the body weight of a fish. It is widely used as a tool to identify reproductive seasonality and also size at maturation (Pet et al., 2006; Colin et al., 2003). As the fish gonad ripens in readiness for spawning, it increases in size and weight. After spawning the gonad becomes much smaller and lighter, having released the sperm or eggs.

The gonadosomatic index (GSI) was calculated where gonad weight is expressed as a percentage of total body weight without gonads. The GSI was calculated for each individual using the following calculation:

GSI= gonad weight/ (total fish weight-gonad weight) x 100

GSI values are used to (1) determine size at maturation and (2) delineate spawning seasons depending on the quantity and quality of the sampled fish. For this study the main goal was to achieve the first point. However, GSI values were also tentatively assessed with regards to spawning seasonality. A subsample of gonad tissue was also collected from 96 randomly selected individuals across all maturity stages and preserved in 10% formalin. Samples were stored at the Marine Research Centre (MRC) for future analysis. In addition, left and right sagittal otoliths from 206 individuals were removed, cleaned and stored dry at MRC.

Results

A total of 433 groupers were sampled from six cages systems in four different atolls (Table 16). Across all species, 92 (21%) females, and 77 (18%) males were identified based on macroscopic criteria, while 263 (60%) individuals were either immature or mature but could not be sexed using visual estimates (Table 15). The number of *Epinephelus fuscoguttatus* individuals sampled was roughly half of the number of any other species except for *Plectropomus pessuliferus*, which was added later as a fifth species. Only 20% of the *E. fuscoguttatus* individuals sampled were mature compared to 43% for E. polyphekadion and 61% for *Plectropomus areolatus*. The number (Table 16) and sizes (Table 17) of groupers sampled varied per species based on the availability of fish at the holding cages and the willingness of cage owners to sell different species (Appendix 13).

Table 16. Total numbers of immature, female and male grouper sampled per species.

Species	Immature or Maturing	Mature		Number sampled
		Females	Males	
Epinephelus fuscoguttatus	45	5	6	56
Epinephelus polyphekadion	59	21	24	104
Plectropomus areolatus	50	38	39	127
Plectropomus laevis	89	8	5	103
Plectropomus pessuliferus	20	20	3	43
TOTAL:	**263**	**92**	**77**	**433**

The size range of *Plectropomus laevis* individuals sampled was the most variable (e.g. Figure 23) whereas the range for *P. pessuliferus* samples was much narrower (Table 17). The minimum sizes of *P. laevis and P. areolatus* individuals sampled were both below 25 cm in length (the current legal size limit for these two species). Seven *Plectropomus spp.* individuals purchased from holding cages were below 25 cm.

Table 17. Size (length) parameters of five groupers species in centimetres.

Species	Minimum	Maximum	Range	Total Length) Mean	SD	Maximum recorded*
Epinephelus fuscoguttatus	27	88	61	43.7	11.7	120
Epinephelus polyphekadion	22.3	58.2	35.9	43.9	11.6	90

Plectropomus areolatus	15.6	62.1	46.5	41.3	13.1	80
Plectropomus laevis	24.5	91	66.5	43.2	11.4	125
Plectropomus pessuliferus	31	57	26	42.9	11.6	120

*: Maximum recorded lengths per species were from www.fishbase.org.

Table 18. Maturity stages, GSI values and sex ratio evaluation of all groupers sampled.

Species	No. Immature	No. Mature	Maximum GSI	Sex	
				F	M
Epinephelus polyphekadion	59	45	10	21	24
Plectropomus areolatus	49	76	11	38	39
Plectropomus laevis	90	13	7	8	5
Plectropomus pessuliferus	20	23	5	20	3
Epinephelus fuscoguttatus	45	11	5	5	6

Figure 23. Size range of *Plectropomus laevis* individuals purchased from the holding cage in Thinadhoo, Vaavu Atoll.

Note: the largest individual is ca. 95 cm (TL) and the smallest 20 cm (TL)

Figure 24. Images of grouper reproductive organs in various stages of maturity

a. Immature gonads (*Epinephelus polyphekadion*)

b. Maturing gonads (*Plectropomus areolatus*)

c. Mature active gonads (*Plectropomus areolatus*)

d. Hydrated eggs visible to the naked eye (*P. areolatus*)

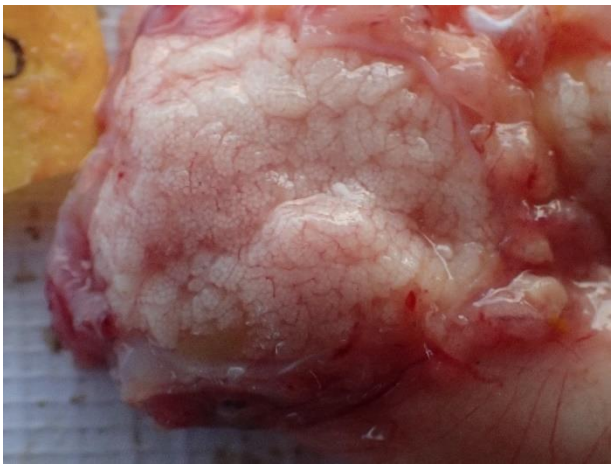


Figure 24 (continued)

e. A pair of mature ripe female gonads with released eggs visible (*Plectropomus laevis*)

f. Sperm being extruded from a mature male (*Epinephelus polyphekadion*)

g. A pair of mature male gonads (*Epinephelus polyphekadion*).

Size-Maturity Relationships

The calculated gonadosomatic index (GSI) values were plotted against size (total length) for each species. Results for individual species are provided below in Figures 25-29.

Figure 25. Gonadosomatic Index plotted against size for *Epinephelus polyphekadion*.

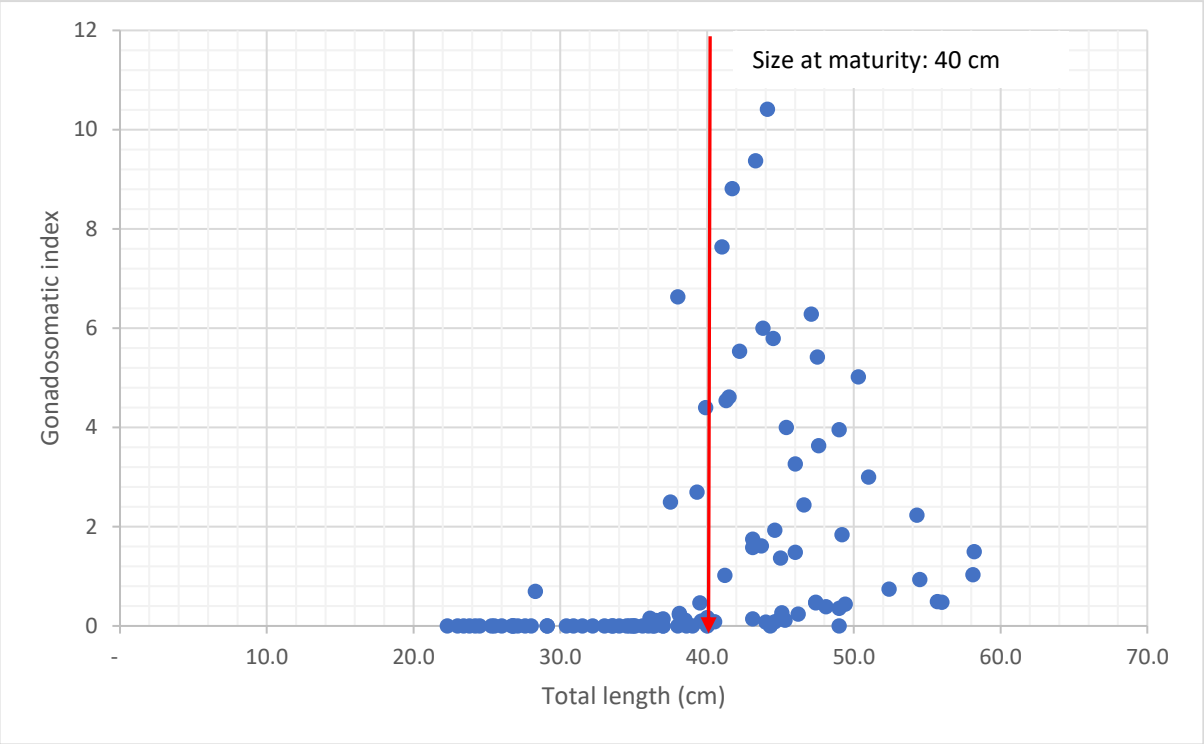


Figure 26. GSI plotted against body size for *Plectropomus areolatus*.

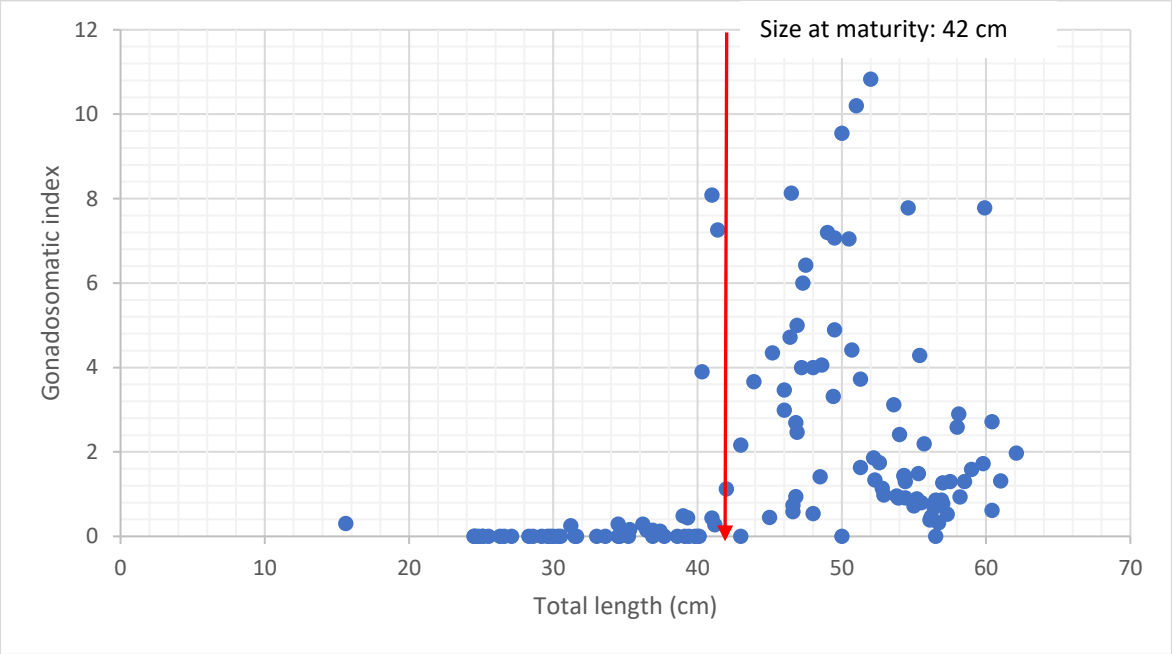


Figure 27. GSI plotted against body size for *Plectropomus laevis*.

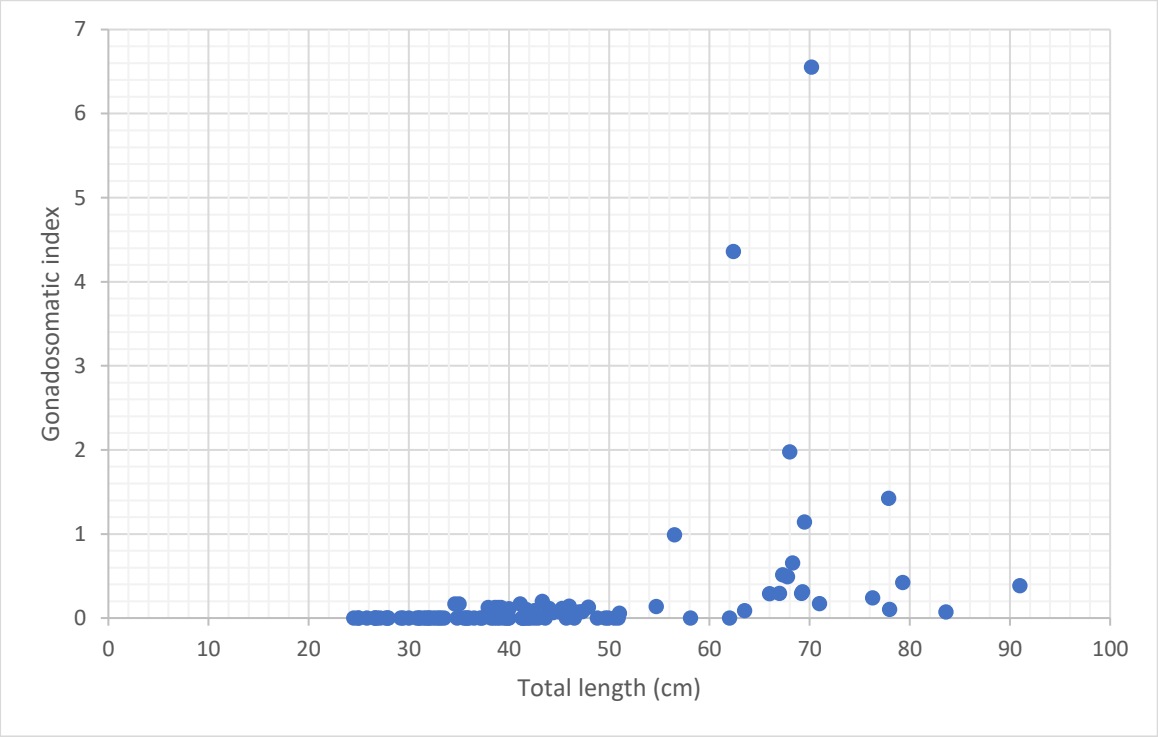


Figure 28. GSI plotted against body size for *Plectropomus pessuliferus*.

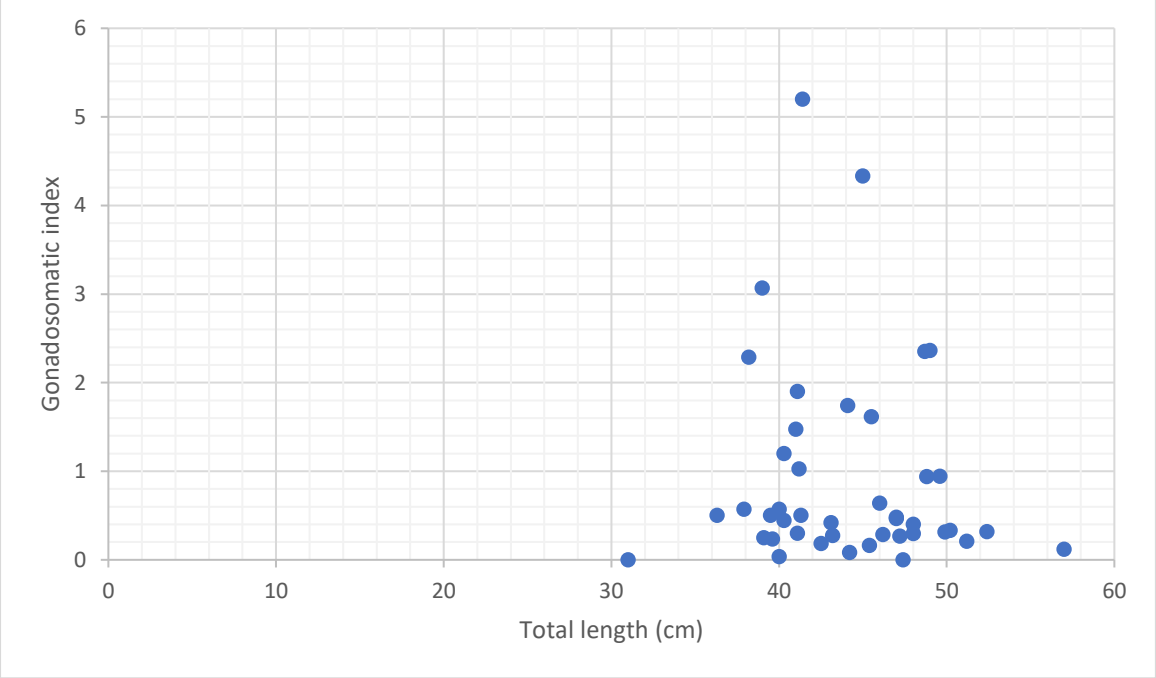
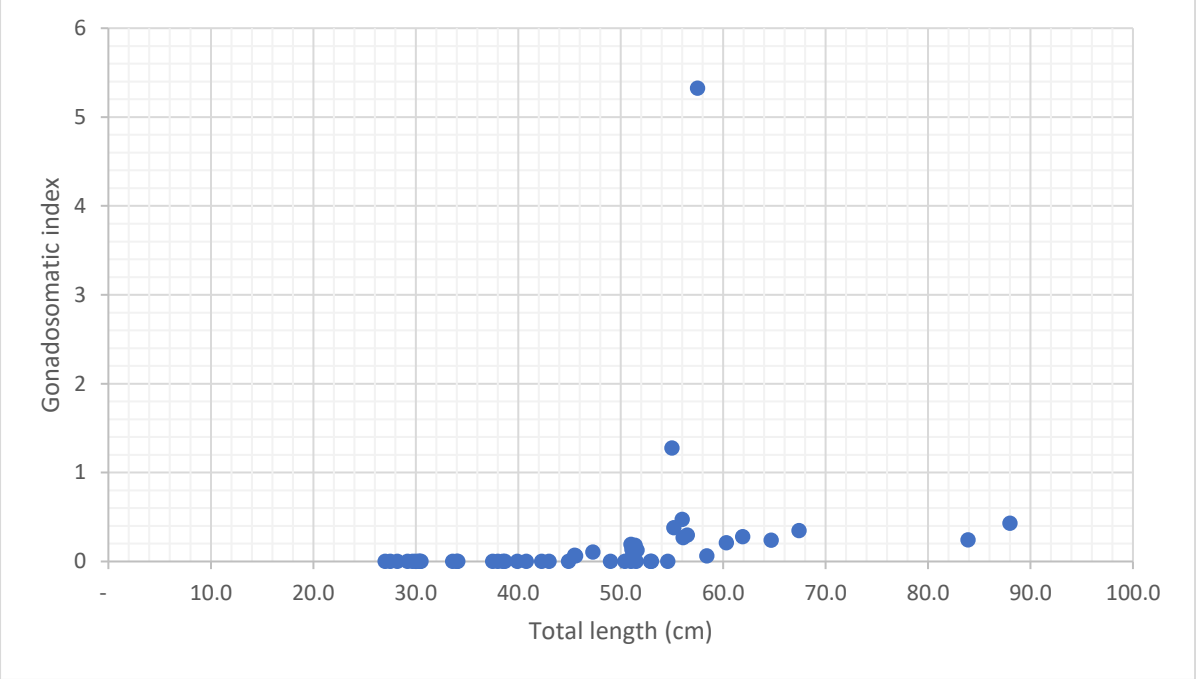


Figure 29. GSI plotted against body size for *Epinephelus fuscoguttatus*.



Gonadosomatic index (GSI) is used to accurately identify size at sexual maturation. As the gonads of juvenile, immature, fishes are very small relative to body weight a plot of GSI against body size (TL) will show a large increase in GSI at the size of sexual maturation (Sadovy de Mitcheson, 2013). We estimated size at maturity using this technique for two species (Figures 25 and 26). Our estimates were confirmed by Professor Yvonne Sadovy (University of Hong Kong), a global expert in grouper biology and their conservation, through visual assessment of the above plots. The confirmed size at maturation for the two species are listed below:

1. ***Epinephelus polyphekadion*: 40 cm**

2. ***Plectropomus areolatus*: 42 cm**

Data collected were insufficient to determine size at maturation for *Epinephelus fuscoguttatus* and *Plectropomus pessuliferus.* However, GSI values for the latter suggest that the size at maturation is close to being determined and could be verified with some additional sampling. Our preliminary estimate for *P. pessuliferus* size at maturity is 38 cm. Despite sampling over 100 individuals across four months, data are inconclusive for *Plectropomus laevis.*

The length at which *Epinephelus polyphekadion* was mature (40 cm) is twice the length (20 cm greater) of the legal size limit, 9 cm greater than the size limit proposed in 2011 but only 5 cm smaller than the theoretical maturity length (Table 18).

The size at maturity for *Plectropomus areolatus* (42 cm) is 17 cm larger than the existing minimum legal size limit for this species, 7 cm greater than the size limit proposed in 2011 but only 4 cm smaller than its theoretical maturity length (Table 18).

Table 18. Size at Maturity metrics (length in cm) for the two species of grouper successfully sampled: *Epinephelus polyphekadion and Plectropomus areolatus.*

Species	Theoretical size at maturity	Proposed Size limits (2011) *	Minimum legal size limit (2014)	Size at maturity: this study
Epinephelus polyphekadion	45	31	20	**40**
Plectropomus areolatus	46	35	25	**42**

*: Maldives Grouper Fishery Management Plan – MRC/MCS, 2011.

Spawning Seasonality

Spawning seasonality patterns could not be determined for species due to low numbers of larger mature and post spawn individuals. However, maximum GSI values found for *Epinephelus polyphekadion*, *Plectropomus areolatus* and *Plectropomus laevis* were all attained in the month of March (2017). GSI values for *E fuscoguttatus* and *P. pessuliferus* were greatest during July and October 2017 respectively although sample sizes for these two species were much smaller.

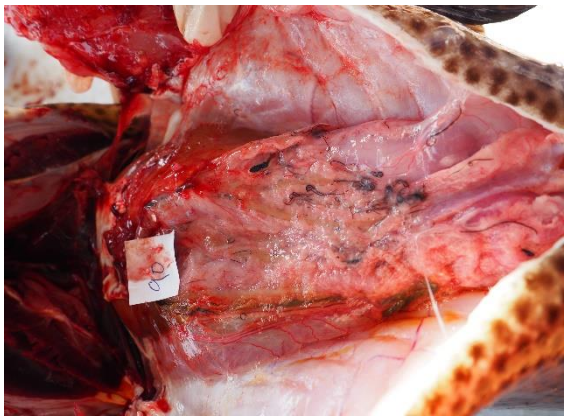
Additional Observations

The ingestion of plastic marine debris by a grouper (*Plectropomus areolatus*) was noted during the cage sampling trip to Vaavu atoll in March 2017. This grouper had clearly ingested a plastic (polyethylene) bag which had become lodged in its oesophagus (Figure 25). We believe this is the first documented ingestion of plastic by a grouper / reef fish in the Maldives. Domestic plastic waste is a concerning issue across the Maldives and has significant implications for marine life through both ingestion and entanglement. Many of the cages visited for sampling were also in poor condition and not well maintained. Plastic debris was often observed inside the fish cages.

Many of the groupers sampled were found to host numerous parasites including nematode worms within the body cavity (Figure 26) and isopods on gills and scales which may be linked to overcrowding within cages.

Figure 25. A green plastic bag in the oesophagus of a grouper.

Figure 26. Parasitic nematode worms commonly found in groupers.



Discussion

Size at Maturity

We identified size-maturity relationships for two grouper species (*Epinephelus polyphekadion* and *Plectropomus areolatus)*. Size-maturity relationships were not identified for the two other targeted species (*Epinephelus fuscoguttatus* and *Plectropomus laevis*) as there were insufficient mature fish available for sampling. Data for a fifth species (*Plectropomus pessuliferus*) was almost sufficient to confirm size at maturity, and a minimal amount of further sampling is required to define size at maturation for this species. Overall, the information collected provides for the first time, size maturity relationships of groupers in the Maldives and the wider central Indian Ocean region, which contributes to a better understanding of the reproductive biology of these five species.

Our findings show that there is a clear need to revise existing minimum size limit legislation for the grouper export fishery. Size maturity metrics completed for *E. polyphekadion* and *P. areolatus* show that existing size limits are as much as 50% smaller than actual size at maturation. Current legal limits are ineffective as they do not prevent fishermen from catching immature groupers. Moreover, it is highly likely that minimum size limits for other targeted grouper species not assessed by this study are also too low. However, a lack of data for species must not be used as a justification to avoid management action. Instead, when evidence is lacking a more precautionary approach should be adopted. The size at maturity metrics identified in the Maldives by this study are most similar to the theoretical maturity lengths derived from global data. Therefore, in the interest of preventing further population decline and safeguarding the long-term future of the fishery we **recommend that all size limits for targeted grouper species are revised so that they are based on global size at maturity estimates**.

Observations during sampling trips also confirmed that fishermen are not adhering to existing size limit regulations; cage owners and managers are purchasing undersized immature fish. Discussions with the cage owners indicate that fishermen pressurise grouper cage owners to buy smaller sized individuals by threatening to take their business to other cage owners in future. Fishermen are also often unaware of legal size limits. Minimum size limits were not known by most Laamu fishermen. It is crucial that further revision of size limits is effectively communicated to fishermen and cage owners and that they are fully aware of the penalties in place for any infringements.

Grouper sampling at cages

Purchasing groupers to carry out gonad analyses is not very cost-effective and rather time consuming. Given that there is variation between (seasonal) and within (lunar) months for spawning periods for different grouper species, it would take a considerable amount of effort and expense to determine size-maturity length relationships for all twenty three grouper species targeted for export.

Secondly, because cage sampling was conducted sporadically and at different locations, seasonality patterns were not delineated, although monthly GSI values are indicative of spawning seasons for different species. High GSI values over the new moon period during March suggest that this is a clear spawning period for *E. polyphekadion, P. areolatus and P. laevis*. This coincides with the transition from the south west to north east monsoon and supports the idea that there is greater spawning activity during monsoonal transition periods.

Despite extensive sampling of individuals, a lack of large (mature) *P. laevis* individuals available at the cages meant that we were unable to determine size at maturation. Very few individuals we sampled had mature gonads. Those with the highest GSI values were typically larger than 60 cm which suggests

that the size at maturation for this species is greater than this. However, fish of this size were rarely available in the cages; only 19% of *P. laevis* individuals sampled were greater than 60 cm TL.

Cage owners were also unwilling to sell *E. fuscoguttatus* individuals for research due to their rarity and high value for export. Very few individuals were present in cages, apart from the cage at Maavah Island (Laamu Atoll). Individuals that were sampled were typically small and immature. This grouper is the most highly targeted species in the Maldives and all indications from the fishery point to long-term over-exploitation that has severely depleted populations. Research by Sattar et al., (2011) found that 96% of *E. fuscoguttatus* individuals from catches sampled were immature. Laamu fishermen (Section 1) reported that this species had shown the greatest decrease in the size of individuals caught.

The lack of large fish at cages is indicative of heavy fishing pressure. Removal of larger fish in populations results in an overall reduction in the average size of fish and is characteristic of overfished populations (see Pauly et al., 2002). The scarcity and high value of *E. fuscoguttatus* is also driving overfishing to meet demand resulting in a negative feedback loop. We are concerned that, unless strong action is taken, this species will become economically, and potentially locally extinct as remaining populations are too small to support successful recruitment. The combination of historical evidence of the fishery and the findings in this study justify the need for extreme and stringent management to prevent a population collapse, such as a moratorium on the catch and trade of this species. Further management recommendations are presented in Section 5.

4. Environmental Educational and Awareness Programme

Introduction

As groupers are an important and valuable national resource, both ecologically and economically, it is crucial that the Maldivian people, particularly those who work in fisheries and tourism, are well informed about management of this common good. It is also important that the international community, namely tourists and resort managers or owners are fully engaged and aware of the issues. With this in mind we developed and implemented a comprehensive environmental education and awareness (EEA) programme of activities both on Laamu Atoll at the national level. Through this work programme we engaged with a wide range of stakeholders including local authorities (Atoll and Island Councils on Laamu Atoll), grouper fishermen, grouper cage owners, the Laamu community, local schools, Six Senses Laamu resort staff and resort guests. We also took our work beyond Laamu and worked with the Maldivian government, Maldives National University and other non-governmental organisations (NGOs),

EEA Programme Activities

A detailed summary of all EEA activities conducted both on Laamu Atoll and within the Maldives is provided in Appendix Z.

Local level Activities on Laamu Atoll

Fishermen and cage owners

Since September 2016, BLUE has worked closely with over one hundred small-scale fishermen in Laamu Atoll. Seventy-five fishermen from all eleven islands in Laamu Atoll were individually interviewed between November 2016 - May 2017. A further 63 fishermen attended focus group discussion sessions (Figure 27) held in July 2017, 41 of whom were not interviewed previously. Seven fishermen who were individually interviewed also attended the presentation of the preliminary findings of the fishermen interviews and dive surveys held in September 2017. Two grouper cage owners from Laamu Atoll and one local exporter were interviewed as well as two major cage owners who own multiple cages and export groupers from across the Maldives. All fishermen and cage owners we interacted with were briefed about the ongoing project prior to discussions.

Prior to the individual interviews, fishermen were not provided with any information about the grouper fishery which could potentially bias responses. The focus group questions and educational session were provided in sequence order to eliminate the possibility of bias during the survey. However, fishermen were given information about the status of the fishery and best management practices at the end of focus group sessions purposefully before answering questions about their preferred management measures. This allowed for comparisons between responses during focus groups after fishermen were more informed and those given in individual settings in the absence of the educational session.

The material presented to fishermen in the PowerPoint presentation at the focus group sessions was supported with the delivery of a video of Fijian grouper fishermen discussing their experience of the demise of grouper populations[7]. Subtitles were edited from English to Dhivehi. The presentation of

[7] Set Size campaign video from Fiji, https://www.youtube.com/watch?v=kWuB8elYg2g&t=211s

preliminary research findings was supported by showing the *'Ask a fisherman'* video made by BLUE documenting the testimonials of grouper fishermen from Laamu Atoll discussing how the fishery has changed and the need for management.

During focus groups the principle of 'spill-over' of fish from marine reserves was demonstrated through an interactive game in which attendees were nominated to mimic the boundaries of a marine reserve, fishermen, police and fish inside the reserve and play out the scenario under direction from project staff.

After each focus group, a knowledge assessment exercise was conducted to gauge how the fishermen responded to the educational material. Table 19 below provides a comparison of responses from individual interviews and focus groups.

Table 19. Comparison of fishermen's environmental knowledge before and after educational sessions.

	Response from individual interviewees	**Focus group knowledge assessment**
1	**53%** of respondents said that groupers form spawning aggregations for reproduction.	**75%** of respondents correctly said that groupers form spawning aggregations for reproduction.
2	Not evaluated	**83%** of respondents said that targeting spawning aggregations can lead to fishery collapse.
3	**18%** of respondents were aware of grouper fishery management measures in place, of these, only 12% could identify a measure, i.e. size limits.	**56%** of respondents correctly specified the grouper fishery management measures in place, i.e. catch and export size limits and marine protected areas.
4	**No** respondents correctly identified the current size limits for the grouper fishery in the Maldives.	**51%** of respondents correctly identified the size limits in place for grouper fishery in the Maldives.
5	Not evaluated	**62%** of respondents correctly identified reasons for the adaptation of size limits, i.e. a) because Maldives grouper population is declining, b) to give groupers a chance to reach maturity, c) to give groupers a chance to spawn at least once in their lifetime and d) to make sure there are enough grouper to catch in the future
6	**64%** of respondents said it was very important to manage the fishery	**95%** of the respondents said it was very important to manage the fishery.

An educational infographic leaflet was developed in both English (Appendix 17) and Dhivehi (Appendix 18). The Dhivehi version was distributed across Laamu Atoll as a reference tool of information about the fishery. These were also distributed to local councils and communities. The English leaflet was distributed at the 'Marine Expo' event held in Male' and to staff and guests at Six Senses Laamu.

Figure 27. Laamu Fishermen at Focus Group Sessions

Local Government Authorities on Laamu Atoll

The project team individually met with the Atoll Council and all eleven Island Councils of Laamu Atoll to introduce and present the project, between December 2016 and February 2017 (Figure 28). The team engaged with 81 individuals in the councils to explain the project rationale and the need to improve the status of groupers through education, conservation and better fisheries management.

Six Senses Laamu resort holds quarterly "Eku-ekee" (meaning 'together') meetings with all Council Presidents, Permanent Secretaries and Head teachers in Laamu to discuss a multitude of atoll-related issues. The team presented and discussed their research with 40 attendees at two meetings held in November 2016 and July 2017. The team, together with Laamu Atoll Council, organized a ceremony on 23/11/17 to celebrate the end of the LECReD funded small grants project component which was attended by more than forty people. Local stakeholders present included grouper fishermen, Island Council members and Six Senses Laamu staff. Partners from the United Nations Development Programme (UNDP), MoFA and the MRC also travelled to Laamu Atoll for the event. Preliminary findings from fishermen interviews and dive surveys were shared with attendees. Certificates and awards were given to community members who had substantially contributed to the project's success. The marine protected area game which was played with fishermen in focus groups was also re-enacted and successfully demonstrated the potential benefits of MPAs for fishermen.

Figure 28. BLUE Project Team meetings with Government Authorities on Laamu Atoll

Clockwise from top left: Mabaidhoo Island Council; Isdhoo Island Council; The LECReD closing ceremony; Hithadhoo Island Council.

EEA Programme in Schools on Laamu Atoll

There are twelve senior schools in Laamu Atoll and one college in Gan which is affiliated with the Maldives National University. BLUE, in partnership with Six Senses Laamu and the Manta Trust, formed a 'marine team' that created a seven-module educational programme which was delivered to 68 students in grades 6-10 at schools on Kunahandhoo and Hithadhoo islands on multiple visits.

To ensure that all schools on Laamu Atoll were included in the educational programme, a condensed version of the curriculum was developed which could be delivered in a one-day session. These educational visits were held between February and October 2017 and involved more than 375 school children from eight different islands (Figure 29; Appendix 21.7). The school sessions were designed to include fun and practical activities which would fully engage children and ensure that the environmental issues communicated were remembered. The project team designed the following activities:

- A board game[8] which demonstrates the life cycle of groupers. Players begin the game as grouper larvae and their goal is to mature successfully and reach the grouper spawning aggregation site.

[8] Locally adapted from the "Grouper Race for Survival" game from the Bahamas Reef Environmental Education Foundation, https://groupereducation.edublogs.org/files/2015/12/Grouper-Race-For-Survival-Game-247iebd.pdf

Along the way, players (as developing groupers) are faced by perils such as warming sea temperatures, predators, dredging and fishing which set them back in the game. Players can advance to become adults by consuming prey such as parrotfish and seeking refuge in seagrass beds and marine protected areas (Appendix 19)

- A paper fortune teller (a form of origami used in children's games) which reveals the meaning of fisheries management terms (Appendix 20)

Specific grouper fishery management sessions were conducted in the two biggest grouper fishing islands of Maavah and Dhanbidhoo for over seventy marine science pupils from grades 8-10. To involve students in the practical work outside of the classroom, the team trained 38 pupils from Maavah school in the dissection and analysis of grouper reproductive organs, as an activity that could run alongside the grouper size-maturity sampling work programme (Figure 29).

Figure 29. EEA sessions in local schools on Laamu Atoll

Top left: Isdhoo school children play the "Grouper Race for Survival" board game. Top right: School children in Kunahandhoo create a bait fishery poster. Bottom left: Maavah marine science students dissecting groupers. Bottom right: Isdhoo school student celebrate an educational session.

Island Communities on Laamu Atoll

BLUE, together with Six Senses Laamu and the Manta Trust also conducted a community education programme in eight different islands in Laamu Atoll over ten months (Appendix 21.1). This gave

residents the chance to learn about the on-going marine research projects based at the resort and created a platform for attendees to ask questions and raise any issues.

The two-hour community meetings were organized through the Island Councils and covered topics including sustainable tourism, sustainable fisheries and plastic pollution. We also investigated potential opportunities to work with local communities for the benefit of marine life in Laamu Atoll. More than 350 people attended these community sessions from the islands of Isdhoo, Kalaidhoo, Dhanbidhoo, Maabaidhoo, Mundoo, Fonadhoo, Hithadhoo and Maavah.

Two wall murals were painted as part of the EEA programme on the islands of Maamendhoo and Dhanbidhoo (Figure 30). The first mural promotes sustainable fishing practices while the second emphasizes the importance of protecting spawning aggregations. Wall murals are an effective way of communicating long-lasting conservation messages to communities on small islands as they are visible to both residents and visitors to the islands. The combined resident population of these two islands is 1543 (2014 Census).

Figure 30. Educational Wall Murals on two islands in Laamu Atoll

Left: Dhanbidhoo island, depicting the importance of spawning aggregations. Right: Maamendhoo island, emphasising the importance of ecosystem connectivity

BLUE was closely involved in the 2017 Laamu Atoll Turtle Festival held on Gan island on 23/09/2017, organised by Six Senses Laamu in close collaboration with the Maldives Police Service and Gan Island Council. The theme of the festival was *"Turtles in Laamu - Safe and Protected"*. BLUE had a stall at the festival which featured information about the grouper fishery of the Maldives and fun games for local children. The team also painted a third wall mural which encouraged participants to pledge to protect turtles. The festival was attended by children, teachers, parents and local councils from all communities in Laamu and special invitees from relevant stakeholders at the national level. It is estimated that the festival was attended by more than 1000 people.

Six Senses Laamu Resort Staff and Guests

More than half (56%) of staff at Six Senses Laamu resort are Maldivian and of this proportion, two-thirds are from Laamu Atoll. BLUE made seventeen oral presentations to over 160 resort staff about the grouper fishery and the project. Educating resort staff is an effective way of promoting awareness about the marine environment at the island and atoll level and to a lesser extent, the national level.

Tourists from over fifty countries visit Six Senses Laamu every year. Over fifty presentations were delivered to more than 200 resort guests over the course of seventeen months.

National level Activities

During Phase Two, project staff regularly met with national level stakeholders and delivered seven different presentations to the following Ministries, Departments and organizations:

- Ministry of Fisheries and Agriculture
- Marine Research Center
- Ministry of Environment and Energy
- Maldives National University
- United Nations Development Programme (UNDP)
- Food and Agriculture Organization (FAO)
- International Union for Conservation of Nature (IUCN) Maldives

Preliminary results of the Phase Two research programmes were presented at the first meeting of the Grouper Management Committee held in Male' on 24 July 2017. Nine key stakeholders were in attendance from the Ministry of Fisheries and Agriculture, Marine Research Center, Maldives National Defence Force, Maldives Customs Service and Sea Partners (grouper exporter).

Maldives National University

BLUE worked hard to actively provide field experience for environmental graduates from the Maldives National University (MNU) which conducts the only environment-based degree course in the country. The internships proved invaluable exposure to research work for the students, who gained practical experience in the field working together with the BLUE team on project activities (Figure 31). This field experience contributed to their overall marks for the Environment Affiliate Project module as part of the course. Details of the students and their internships are provided in the table below.

Table 20. Summary of internships provided for Maldives National University students.

Name of student	Internship period	Location	Internship activities
Shareefa Ali	6 weeks	Vaavu and Laamu Atolls	Fish dissection, gonad analysis, otolith removal, fishermen interviews, data recording, data entry, resort-based activities, snorkelling, educational sessions.
Nafha Asim	10 days	Gaafu Dhaalu Atoll	Fish dissection, gonad analysis, otolith removal, snorkelling, data recording, data entry, social media and outreach and logistical planning.
Risha Ali	10 days	Gaafu Dhallu Atoll	Fish dissection, gonad analysis, otolith removal, snorkelling, data recording, data entry, social media and outreach and logistical planning.
Mariyam Samha	10 days	Vaavu Atoll	Fish dissection, gonad analysis, otolith removal, snorkelling, social media and outreach, data recording, data entry and snorkelling.
Aishath Amal	10 days	Vaavu Atoll	Fish dissection, gonad analysis, otolith removal, data recording, data entry and snorkelling.
Ibrahim Yamin	Opportunistic	Laamu Atoll	Fishermen focus group sessions

Figure 31. Interns from Maldives National University participating in the project

Left: Shareefa Ali isolates an immature grouper gonad.

Right: Nafha Asim and Risha Ali dissect groupers for BLUE's research.

Marine Science Community

Initial findings from the grouper spawning aggregation surveys were presented at the first Maldives Marine Science Symposium, held in Male' on 27th October 2016 (Figure 32). Over fifty scientists and researchers working across the Maldives attended the event which was hosted by the Marine Research Center in collaboration with IUCN, Mangroves for the Future (UNDP), Maldives National University and Banyan Tree Maldives. The BLUE Maldives project team won the award for the best poster presentation.

Figure 32. BLUE Maldives Project Team at the Maldives Marine Science Symposium

BLUE gave an oral presentation entitled "The first comprehensive assessment of a grouper spawning aggregation site in the Maldives" at the European Coral Reef Symposium held in Oxford in December 2017. The symposium was hosted by Reef Conservation UK (RCUK) in association with the International Society for Reef Studies, the Zoological Society of London (ZSL) and the University of Oxford. Over 500 scientists and conservationists from a multitude of coral reef related disciplines were in attendance.

The project was further publicised at the Maldives Marine Expo 2017 held in Male' in September 2017; an annual official exhibition of the Liveaboard Association of the Maldives. The team presented as part of the marine talk session which advocated environmental awareness for the marine industry of the Maldives. Approximately 50 people attended BLUE's presentation.

Film and Social Media

Social media was used throughout to promote awareness about the grouper fishery amongst the wider Maldivian and the international community. A number of films were collectively viewed almost 12,000 times on the Blue Marine Foundation Facebook page alone (Table 21). The *"Ask a Fishermen"* is a short documentary filmed and created by BLUE featuring fishermen describing how the grouper fishery has changed over time and the impact of this on their livelihoods. This video was uploaded on BLUE's website[9] and shared on social media via BLUE and Six Senses Laamu's Facebook and twitter pages.

Three live videos were also aired on BLUE's Facebook page featuring BLUE's project staff and interns providing information the project while involved in project activities, including cage sampling and wall murals.

Table 21. A summary of Videos made during the project and their reach.

Video Title	No. of Facebook Views
'Ask A Fishermen'[10]	2800
MNU Students discussing what they learnt from the internship[11]	1000
Project Coordinator discussing how grouper size maturity data is collected[12]	6600
Project Team discussing the message on the Dhanbidhoo wall mural[13]	1200

[9] http://www.bluemarinefoundation.com/
[10] http://www.bluemarinefoundation.com/film/ask-a-fisherman-maldives/
[11] https://www.facebook.com/Bluemarinef/videos/1598283220247134/
[12] https://www.facebook.com/Bluemarinef/videos/1586155708126552/
[13] https://www.facebook.com/Bluemarinef/videos/1622616177813838/

Six blog articles about the project were uploaded on BLUE's website and subsequently shared on BLUE's Facebook and Twitter pages:

1. Saving the Maldivian Grouper, 22 February 2016: BLUE's Project Manager, Rory Moore, describes the beginning of a new project to reverse the decline of Maldivian grouper[14]
2. The new moon brings hope to Blue's researchers in their quest to save the Maldivian grouper, 16 February 2017: Simon Harding, BLUE's Head of Conservation and project lead writes about a visit to the Maldives in January 2017 and the exploratory dives to identify grouper spawning aggregation sites.[15]
3. The Maldives project team win a prize at the first Maldives Marine Science Symposium, 17 November 2016.[16]
4. BLUE's grouper groupies, 10 March 2017: Vivienne Evans, Maldives Project Coordinator writes about the educational programme the project team have devised.[17]
5. Vivienne Evans's, (Maldives Project Coordinator) graphic account of collecting data to prove that grouper is being exported too young, 19 June 2017.[18]
6. Shareefa Ali describes her internship experience working alongside the 'grouper girls' in the Maldives, 26 July 2017.[19]
7. Shaha Hashim, Maldives Project Officer was featured in Maldives lifestyle magazine dho.mv, as a Maldivian woman working in the field of marine conservation. The project was featured through Shaha's eyes in the article. Dho.mv has over 20,000 followers on Facebook.[20]

At the time of writing[21], BLUE's social media webpages had the following numbers of followers: Facebook page[22] 7841; Twitter account[23] 7880 and Instagram 5184 followers. Six Senses Laamu also regularly posts updates about the work that BLUE undertake with the resort on their Facebook page[24] and twitter account[25].

[14] http://www.bluemarinefoundation.com/2016/02/22/saving-the-maldivian-grouper/
[15] http://www.bluemarinefoundation.com/2017/02/16/maldives-visit-23rd-to-31st-january-2017/
[16] http://www.bluemarinefoundation.com/2016/11/17/win-prize-first-marine-science-symposium/
[17] http://www.bluemarinefoundation.com/2017/03/10/blues-grouper-groupies/
[18] http://www.bluemarinefoundation.com/2017/06/19/vivienne-evans-maldives-projects-coordinator-gives-a-graphic-account-of-what-is-involved-in-gathering-data-to-prove-to-the-maldivian-government-that-groupers-are-being-exported-too-young-warning/
[19] http://www.bluemarinefoundation.com/2017/07/26/10645/
[20] https://dho.mv/lifestyle/26621?ref=mhr-home
[21] 20th March 2018
[22] https://www.facebook.com/Bluemarinef/
[23] https://twitter.com/Bluemarinef
[24] https://www.facebook.com/SixSensesLaamu/
[25] https://twitter.com/SixSensesLaamu

EEA Work Programme Summary

The environmental education and awareness work conducted in Phase Two was extensive. We engaged with all major stakeholders in the grouper fishery and successfully made them aware of the current issues. Through the work programmes we engaged with communities in four different atolls; predominantly Laamu Atoll but also on Kaafu, Vaavu and Gaafu Dhaalu Atolls where the most active grouper cages in the country are located.

We are confident that the EEA programme was effective in raising awareness about groupers and the status of the fishery. This was very evident for Laamu fishermen who clearly showed a better understanding of the biological principles which make groupers so vulnerable to fishing pressure. More grouper fishermen understood that groupers aggregate for reproduction and that overfishing groupers could lead to a fishery collapse. After clearly explaining existing grouper regulations, we also noticed an increase in the awareness of fishermen regarding the regulations for size limits. By emphasising the importance of spawning grounds and providing examples of effective management measures, we found a noticeable change to fisher's perceptions and understanding of the fishery. After our sessions, almost all (95%) of the fishermen said they believe management of the grouper fishery is very important.

The partnership between an NGO, the private sector and both local and national government was an effective conservation approach which helped our work to be inclusive and successful. The relationship with MRC, MoFA and the Laamu Atoll Council was instrumental in facilitating formal introductions with local government bodies, the Island Councils. It was during these meetings that we could involve the local authorities in our work and build up a strong rapport. Subsequently, council members were extremely helpful identifying grouper fishermen in their communities and orchestrating meetings.

Collaborative delivery of the EEA schools programme with Six Senses Laamu and the Manta Trust enabled us to collectively work towards a common goal; to enthuse the younger generation about the marine environment and provide 'hands-on' interactive activities for local children. By sharing expertise and resources we were able to deliver this programme to a wider audience all across Laamu Atoll.

Through our programme we helped to develop in-country capacity for fisheries research with government staff and young environmentalists. Our internship programme was very well received. The students who completed internships mentioned that it is very difficult for them to gain practical experience in the field as there are limited opportunities. None of the project interns, graduates or students enrolled in the BSc in Environmental Management at the Maldives National University were aware that groupers were being exported at a commercial scale prior to joining the project.

After having participated in internship activities, students were well informed and gained relevant experience to help pursue careers in marine science or environmental management. For example, Shareefa Ali has been recruited as an Environment Analyst at the Ministry of Environment and Energy while Nafha Asim has since assisted MRC conducting length sampling sessions at grouper cages and secured a research internship position with Banyan Tree Resort on Kaafu Atoll. The training provided to MNU students will help to create a larger network of marine professionals in the Maldives.

Video created in this project was the most effective means to successfully engage local people. The *"Ask a fisherman"* video has been a great success and continues to be the most useful educational tool to inform project partners, stakeholders and a wider audience of the need for management of

the grouper fishery. Live videos on Facebook were extremely successful at spreading awareness about the project amongst the wider Maldivian community. We highly recommend the use of media for future conservation projects and activities.

Towards the end of Phase Two, the stakeholders, especially local councils and fishermen, demonstrated improved understanding of the fishery and the need for management measures. However, in a country that relies so heavily on coral reefs for local livelihoods, it was concerning that resource users were unaware of the long-term impacts that the current scale of fishing could have on grouper populations and the health of coral reefs. Clearly further engagement and awareness work is needed.

Regular contact with stakeholders is crucial to first build and then maintain good working relationships. Throughout Phase Two, the project team met with all stakeholders regularly to provide them with updates on progress. As we move into the next phase of the project, close collaboration with partners and engagement with stakeholders will be essential for further success and implementation of proposed activities.

To prepare for Phase 3 of the project where a management plan for at least one grouper spawning aggregation site on Laamu Atoll will be developed, more in-depth education sessions on MPAs and Managed Areas should be held with all stakeholders. This is currently in progress, led by BLUE's project officer based in Laamu Atoll who is working in close collaboration with Laamu Atoll Council and Six Senses Laamu.

The size at maturity results and recommendations for revision of the size limits need to be proposed to the largest grouper fishing communities in the Maldives, as agreed in the project work plan for Phase 3 and recommended by the Grouper Management Committee in 2017. There needs to be an educational aspect to these discussions to ensure that fishermen are well informed and fully understand the need for change. BLUE will work closely with MRC and MoFA to conduct these sessions in other atolls of the Maldives.

To strengthen the capacity of local authorities and communities in Laamu for community-based MPA/ Managed Area planning and management, we suggest that there should be a knowledge exchange with communities who have successfully managed to implement such measures. BLUE will explore the possibility for such exchange visits with well managed community-based marine reserves in the region. The locally managed marine area network developing in the Western Indian Ocean may be suitable or local fisheries / marine management systems operating in western Sumatra, Indonesia such as Aceh province.

5. Conclusion and Recommendations

Laamu Atoll

The research presented in this report provides strong evidence that the current level of fishing pressure on Laamu Atoll for grouper species targeted for export is unsustainable. Commercial exploitation of groupers on Laamu has been occurring for at least 30 years with signs of overfishing reported in 1998 (Sluka, 2001b). The situation has become progressively worse over time and the decline of the fishery is very likely to continue unless strong action is taken. The decline of the grouper fishery in Laamu is affecting the livelihoods of fishermen who rely on groupers as a main source of income. Overfishing of groupers and targeted fishing of spawning aggregations has led to the decline in sizes and abundance of groupers, an increase in fishing effort and an overall reduction in income from groupers for fishermen in Laamu.

The incentive to fish for the export trade is still very high. Despite reductions in fishermen's catches, depleted grouper stocks in Laamu are still economically viable for exporters, mainly through the targeting of spawning aggregations. This is supported by the fact that the cage systems in Laamu, have been expanded in the last 18 months.

Grouper spawning aggregations are still present on Laamu but are likely to be fished out if they continue to be heavily targeted. Although fishermen clearly recognise that grouper numbers at aggregation sites have declined, they are still the easiest and most lucrative way to catch grouper and so are very attractive for fishers relying on grouper as their main source of income.

Hithadhoo corner is the first fully verified[26] multi-species spawning aggregation site in the Maldives and is the main stronghold for *Epinephelus fuscoguttatus* on Laamu Atoll. It was the only spawning aggregation site assessed on Laamu with this species in abundance. The scarcity of *Epinephelus fuscoguttatus* in cage systems across the country and the unwillingness of cage owners to sell fish to us for research strongly suggests that this species is becoming increasingly rare. Although two other sites on Laamu Atoll have been identified (Fushi Kandu and Maavah Kandu) we **recommend that the spawning aggregation site at Hithadhoo Corner is prioritised for protection**.

There is sufficient evidence to confirm that *Epinephelus fuscoguttatus*, *Epinephelus polyphekadion* and *Plectropomus areolatus* spawn over the new moon on Laamu Atoll which is likely to be the case across the Maldives. However, spawning seasonality trends at aggregation sites remain unclear and further research is needed to define these and identify whether these vary at geographical scales. It is likely that groupers aggregate all year round, but aggregations were largest and most concentrated during the 'Iruvai' monsoon season (December to March). This is a critical and vulnerable stage in their life history. This time of the year also coincides with the low tuna fishing season meaning that fishermen who would usually be solely fishing for tuna are also targeting groupers in these months.

The National Level

Current national management regulations for the grouper fishery are clearly not working well and some, such as size limits, are insufficient to prevent the further decline of populations. Most fishermen we interviewed (on Laamu) did not know about existing regulations and many fishermen, cage managers and exporters are not adhering to them. However, fishermen on Laamu were supportive of

[26] According to the criteria defined in Colin et al. (2003) and Domeier (2012)

better national management of the fishery, particularly catch and export limits and protection of spawning aggregation sites.

There is an urgent need to improve existing management strategies and implement complementary regulated practical measures to ensure grouper populations are sustained and protected for the benefit of the Maldives environment and people.

Management recommendations for the grouper fishery were first made in 1994 (Shakeel, 1994), several years after the export fishery began. In 2014, five spawning aggregation sites for grouper were designated as marine protected areas and legal minimum catch and export size limits were implemented. Certainly, this was positive progress. However, the majority of recommendations which have been consistently made over the last two decades (Shakeel and Ahmed, 1996; Sattar and Adam, 2005; Sattar et al., 2011; Sattar et al., 2012; Sattar et al., 2014) have either been only partly implemented or not at all (summarised in Appendix 22). Based on a historical review of grouper fishery management and our findings we propose **nine key recommendations for the Maldivian grouper fishery.**

1. **Prioritise the protection of grouper spawning aggregation sites across the Maldives**
2. **Revise minimum size limits for all groupers targeted by the export trade**
3. **Introduce export tariffs for both live and dead grouper shipments**
4. **Introduce further fishery management measures to limit catch levels and gear use**
5. **Strengthen Monitoring, Control and Surveillance for the export grouper fishery and existing protected grouper aggregation sites**
6. **Increase the capacity for management of the grouper fishery at the national and atoll level**
7. **Improve fishers' awareness of both existing and proposed fishery management regulations**
8. **Conduct further research on targeted grouper species to improve fishery management**
9. **Explore both internal and external funding mechanisms to enable effective fishery management**

These recommendations are a combination of both new management measures and those previously made for the fishery with some revision. The ten broad-scale points can be split further into individual recommendations and actions which are summarised under six main themes below:

1. Protection of Spawning Aggregation Sites
2. National Policy and Regulations
3. Monitoring, Control and Surveillance
4. Management Structures
5. Education and Awareness
6. Further Research

The rationale behind our recommendations and actions for the current and future management of the Maldivian grouper fishery is set out below under the six main themes mentioned. These should be considered in combination with the full list of recommendations and actions provided in Appendix 23, which is split into six sections according to the main themes.

Protection of Grouper Spawning Aggregations (Appendix 23.a.)

The foundation for a sustainable fishery is ensuring that sufficient fish spawn to produce the next generation. Spawning aggregations are the sole opportunity for most species of grouper to reproduce. If the Maldives export grouper fishery is to continue, protection of grouper spawning aggregation sites must be prioritised. Although five no-take marine protected areas exist to protect grouper spawning aggregations in five different atolls, management for these have not been effective to date. A lack of outreach work with communities has meant that local people are unaware of these protected areas and fishermen continue to fish these sites during aggregation periods (Vivienne Evans, *pers. comm*.).

These sites require clear, comprehensive and communicated management plans to be effective. Research has shown that successful marine reserves are those which have in place clear reserve boundaries, community acceptance and effective enforcement (de Mitcheson and Colin, 2011; Edgar et al., 2014).

There is a need for a minimum of one protected spawning aggregation site in each atoll across the Maldives to protect local grouper populations. Grouper migratory pathways in Maldives are not yet known but since atolls are isolated by deep water barriers, it is likely that populations are localised to individual atolls, such as those in Cayman Islands and Belize (Starr et al., 2007).

The newly verified grouper spawning aggregation site on Laamu Atoll requires permanent protection from fishing. While seasonal closures at spawning aggregation sites are often the selected management option because they are less restrictive, these are not recommended. Seasonal closures require detailed knowledge of spawning seasonality which is yet unknown in Maldives. Temporal closures in Australia failed to protect stocks due to incomplete knowledge of spawning seasons for *E. fuscoguttatus* (Pears et al., 2006). Seasonal closures also do not prevent fishing of groupers outside of the spawning season.

Permanent area closures have been repeatedly shown to be the most effective form of marine protection for reef fish populations and allow fish stocks to recover faster (Edgar et al., 2014; Costello and Ballantine, 2015; Kelaher et al., 2014). No-take marine reserves also protect other species within reserve boundaries and allow for spill-over, recruitment subsidy and habitat protection (de Mitcheson and Colin, 2011).

Protection of spawning aggregation sites inclusive of a wider buffer is recommended. Ideally, spatial protection should also account for migration pathways to and from aggregation sites and be adequately buffered for shifts in core aggregation areas between and within years.

Strengthening National Regulations (Appendix 23.b.)

Groupers require management both within and outside of the spawning times. Therefore, in addition to protecting spawning aggregation sites, fishery input and output measures are required to manage the much wider non-aggregation component of the fishery.

Reviewal and Strengthening of the Registration and Licensing System

Input controls

There are currently no restrictions on the number of fishermen or exporters who are involved in the grouper fishery. **Legally setting a limit on fisher or vessel numbers** would create a right to participate in the fishery and prevent the entry of additional fishing or collection vessels and/or fishers, thereby helping to control the overall fishing effort. Limiting entry also helps to prevent 'outsiders' from participating in the fishery. Many opportunistic reef and tuna fishers target groupers seasonally when other fisheries cannot support them.

Opportunistic fishers or exporters may be less likely to act responsibly and adhere to regulations than atoll-based ones and are also harder to manage. **Restricting the use of mobile collection vessels is recommended**. Limiting entry to the grouper fishery will discourage short-term opportunism, help to conserve grouper populations and in the long-term could generate higher incomes for license holders. However, restricting entry into the fishery will only work if there is adequate monitoring of fishing activity and strong enforcement of regulations.

Moratorium for *Epinephelus fuscoguttatus*

The sheer lack of availability of *Epinephelus fuscoguttatus* at holding cages coupled with scarce underwater observations across multiple sites suggests that this species is becoming increasingly rare. Concerningly, most individuals that were seen were immature, except for those surveyed at Hithadhoo Corner. To prevent economic and possibly also biological local extinction we recommend that a moratorium on the catch, sale and export of *Epinephelus fuscoguttatus* is considered. A ban on fishing would allow the process of population recovery to begin for this species.

Size limits

Minimum landing size limits are supposed to ensure that fish grow to a large enough size to reproduce at least once before they are fished. However, existing minimum catch and export size limits for groupers targeted by the export fishery are too low and do not ensure spawning as individuals are removed from the population before they reach maturity.

Based on size-maturity data collected for two species (Section 3) we strongly recommend that the existing size limits are revised as follows:

a. **Increase the minimum size for *Epinephelus polyphekadion* from 20 cm to 40 cm TL**
b. **Increase the minimum size for *Plectropomus areolatus* from 25 cm to 42 cm TL.**

The vast discrepancies between existing minimum size limits and actual size at maturity for the above two species justifies the need for **a precautionary management approach across the fishery**. Moreover, as the new size at maturity metrics specified by this study for these two species in the Maldives are very similar to the previous recommendations generated by global data (Sattar et al., 2011) we **strongly recommend that the size limits for all other grouper species are based on global estimates for theoretical maturity length data** as defined in the grouper fishery management plan (MRC/MCS, 2011).

We also strongly suggest that **maximum size limits should be implemented together with minimum size limits for all species targeted for export**. Currently, there is only a maximum size limit in place in the Maldives for *Epinephelus fuscoguttatus*. Larger coral reef fish are exponentially more fecund than medium sized ones (DeMartini and Smith, 2015; Pears et al., 2006). Larger females also have longer-lasting spawning seasons and have been shown to spawn more frequently than smaller conspecifics (DeMartini and Smith, 2015). Older and larger females therefore clearly merit protection because of their ability to act as reserves of spawning potential which is required to replenish fish populations (DeMartini and Smith, 2015). Implementation of a 'slot fishing' approach for groupers with both maximum and minimum size limits would improve the recruitment of new individuals into the fishery.

In many countries fishermen are not aware of the size of the fish until it is brought up to the surface. The fishery in the Maldives differs in that most specialist grouper fishermen visually select the fish they target underwater whilst free diving. New size regulations combined with a comprehensive public

awareness programme to inform fishers provides an opportunity to maximize the fishing of legally sized groupers in situ and minimize the taking or subsequent damage to undersize fish when released.

Fishing gear restrictions

A relatively new fishing method has emerged in the Maldives whereby fishermen use powerful underwater torches to target groupers at night whilst freediving or diving. This technique allows fishermen to fish more efficiently, as groupers are easier to locate resulting in higher catches. As groupers are resting at night they are easier to catch and therefore prone to over-harvesting. **A complete ban on the use of powerful underwater torches to target groupers is recommended**.

Export measures

There are currently no export tariffs in place for grouper exports from the Maldives. Export tariffs present an opportunity for the government to generate further revenue from the grouper export trade. **The implementation of tariffs is recommended for all grouper exports.** The revenue generated should be used to fund management strategies for the grouper fishery, particularly to build national capacity and for effective MCS (see Appendix 23.c. and below). Some of the funds received could also be used to conduct research to improve management (see Appendix 23.f.).

Monitoring, Control and Surveillance (MCS)

A key aspect of effective fisheries management is adequate monitoring, control and surveillance of the fishery in question. Monitoring includes the recording of catches, fishing practices and compliance with existing regulations. Control of the fishery ensures that fishers are aware of the rules and regulations and there is an effective enforcement and penalty system in place to detect infringements and prosecute those who conduct illegal activities within the fishery.

Data collection and monitoring of the fishery

A core part of effective fisheries management is data capture and analysis, including the recording, compiling and disseminating of fisheries catch and fishing effort data to managers. The following types of data are lacking in the Maldives for the grouper fishery: details on production (catch per species per fishing area), fishing effort and gear use, and capacity (type and number of vessels and people employed in the fishery).

Data collection for the grouper fishery has clearly presented an ongoing historical challenge as recommendations made almost 25 years ago (Appendix 22) have not been fully implemented. There is a strong need for a review of existing monitoring systems and the implementation of a revised and functional system that is both cost-effective and logistically feasible for such a spatially wide-ranging fishery.

Recording of catches when they are landed at the holding cage system needs to be mandatory and undertaken by the cage manager. Groupers should be recorded to the species level with some information collected on fishing location if possible[27]. More detailed information on grouper metrics (length, weight, age, maturity) can be collected by regular monitoring visits to cage systems by MRC staff and research interns (see research section below).

Detailed records of exports are also required. Recording exports to the species level would enable managers to identify species-specific trends and adjust management accordingly. Grouper species vary in their susceptibility to fishing pressure (Robinson et al., 2008a; Rhodes et al., 2013).

[27] Depending on whether catches between atolls are mixed on the vessel

Plectropomus areolatus has been identified as a fast-growing, early maturing (ca. two- three years) and relatively short-lived species (Rhodes et al., 2013). By comparison, the life span of a female *Epinephelus fuscoguttatus* can exceed thirty years and individuals are late to mature, ca. nine years (Pears et al., 2006). Disregarding intra-specific differences in life-history traits for sex-changing and aggregating species leads to ineffective management of fish stocks.

Emerging technology to facilitate monitoring should be implemented for larger grouper vessels and cage systems. The MoFA together with the MRC are in the process of developing a 'catch log' app. for fishermen and exporters to record catch and export data. Noting the progress made by previous work undertaken for 'catch log' development we suggest that data recorded by the app includes certain fishing or cage system parameters which are listed in Appendix 23.c.

Enforcement and Surveillance

Effective enforcement is needed to ensure resource user compliance. To date, a lack of enforcement capacity in Maldives has prevented this. Undersized groupers were regularly observed in grouper holding cages and when catches were landed at cage systems by fishermen (V. Evans, *pers. obs.*). Fishermen also continue to fish within existing marine reserves (Ahmed Najeeb, *pers. comm.*).

Strong penalties need to be implemented and enforced to discourage illegal fishing. Suggested revised penalties are provided in Appendix 23.c. for infringements. A clear and user-friendly reporting system needs to be developed and communicated to stakeholders wishing to report offenders. For example, a 'hotline' to call or text reports of infringements by stakeholders should be set up that is linked to the appropriate authority.

Vessel monitoring systems are commonly implemented in commercial fishing fleets to investigate spatial and temporal patterns of fishing (Kourti et al. 2005; Witt and Godley 2007; Lee et al. 2010) and detect activity within MPAs. Further development of a 'fully' documented grouper fishery involving 'catchlog apps' and iVMS is recommended as per the proposed activities in the work plan for Phase Three of the existing project. However, it must be noted that this may only apply to those larger vessels used by dedicated grouper fishermen from specific atolls such as Kaafu, Faafu and Vaavu.

Effective enforcement at marine reserve sites is a key predictor of their success (Edgar et al., 2014). Following on from future educational work with communities, there needs to be a body who accepts the responsibility of surveillance at protected sites across the Maldives. At the grouper management committee held in 2017, Maldives National Defence Force (MNDF) Coast Guard expressed their willingness to assist with work to monitor protected spawning aggregation sites across the country. A two-tiered system involving local stakeholders and national authorities should be developed to combine 'eyes and ears on the ground' with government authorities who have the power to detain and prosecute those who conduct illegal activities within protected sites.

Management Structures and Capacity

There is a need to build management capacity for the grouper fishery. We recommend that new staff positions are created at the national and atoll level (Appendix 23.d.). Firstly, there should be the appointment of new MOFA staff member to specifically work on the fishery to coordinate activities and be the point of contact for external partners and regional staff. Secondly, we strongly recommend that a team of MOFA fisheries officers is developed so that one officer can be deployed on each atoll to oversee and co-ordinate fisheries management with the Atoll and Island Councils. For example, the post could be shared between MOFA and the Atoll Council but based on the atoll, embedded within the council. Laamu Atoll is the suggested candidate atoll to pilot this initiative, which can then be

rolled out to other atolls. Finally, a specialist Fisheries Customs Officer is needed to monitor and check grouper exports and report any infringements to the relevant authorities.

It is imperative that the Maldives Grouper Management Committee convene at least once a year to review and discuss management of the grouper fishery. This meeting is the sole opportunity to bring all parties together to make collaborative decisions on management measures in response to outcomes and recommendations from technical reports and stakeholder workshops. To date, only one meeting has been held since the committee first formed in 2014. The committee should also be able to make decisions regarding the fishery rather than be an advisory body.

Communication, Education and Awareness

There is a clear need for outreach work to ensure fishermen and other stakeholders across the country understand the ecological and socio-economic reasoning for improving grouper fishery management and protecting spawning aggregation sites. Educational work is required in atolls where marine reserves exist and on islands where communities are heavily reliant on grouper fishing. In Laamu, most fishers recognize the need for management and protection of marine resources. However, further educational sessions are needed to ensure fishers understand how marine reserves can provide benefits for them.

As well as informing participants in the fishery of the need for better management it is important that they are kept fully informed of both current and future regulations and management systems. Presently, there are insufficient systems or staff in place to ensure that existing fishery regulations are filtered down from the national level and communicated to fishermen. There is also a need to maintain contact with local stakeholders and communicate additional management measures as they come online for the fishery.

An important threat to groupers which has not been addressed in this project to date, and which merits attention is the additional pressure on grouper stocks from the reef fishery, specifically to supply the tourism trade. Local reef fisheries supply fish directly to resorts and groupers are amongst the most targeted (Najeeb et al., 2014). This fishery is currently unmanaged. Tourism, the mainstay of the national economy, continues to grow rapidly and the demand for groupers will increase unless awareness of the issue is raised, and action taken. Direct engagement with the resort staff as well as tourists on site is recommended to inform them of the need for grouper fishery management. Local resort-based conservation measures[28] for grouper and other overexploited reef fish are a useful first step, but future regulation of the reef fishery is also likely to be needed.

Further Research and Training

Historically, a lack national capacity has limited research and monitoring for the grouper fishery in the Maldives. As well as building technical and human resource capacity in the existing government institutes by appointing new staff (Appendix 23.b.) we recommend recruiting Maldives National University Environmental Management (BSc) students to assist MRC or MoFA staff on research and inspection trips. Students who completed internships with the project in 2017 expressed that it is difficult to secure work experience in the Maldives which delays career development. Developing an internship or work placement programme with MoFA/MRC for undergraduates will help to increase in-country capacity for marine resource management and train the next generation of staff.

[28] For example, sustainable seafood guidelines and codes of conduct including no-take lists for threatened species

Currently, there is minimal data available for the five existing marine reserves for grouper spawning aggregation sites. Ideally underwater visual census surveys should be conducted to collect both baseline and monitoring data of the aggregations to help develop management plans.

Further research is also needed to identify spawning aggregations in atolls not previously assessed. Spawning aggregations are highly dynamic and challenging to study. Firstly, we suggest that a fisher survey, similar to the one conducted on Laamu, is carried out on atolls not surveyed in the 2007 assessment (Tamelander et al., 2008). Satellite imagery has proven successful in delineating specific reef geomorphologies such as shelf edges and reef promontories where grouper spawning aggregations are likely to occur (Heyman, 2001). Using a combination of both local fisher knowledge and satellite imagery, the most promising sites can then be assessed by diving. For underwater surveys a programme which involves resort marine biologists working with government and NGOs could be an effective way to collect baseline data on spawning aggregations across the Maldives. We suggest a phased approach to this work with prioritisation for atolls where grouper fishing is more prevalent.

There is a need for an up-to-date stock assessment of the grouper fishery for targeted species both at the national and regional level. Stock assessments which can be done with minimum data such as Productivity and Susceptibility Analysis (Patrick et al., 2009) and/or Decision Trees and Traffic Lights (Prince et al., 2011) are recommended. Once completed, management measures such as species-specific catch and export quotas can then be developed and implemented. Quotas should be updated on an annual basis using a number of fishery parameters. In future quotas should also consider grouper fishing for internal markets (mainly tourism) as well as for export.

Additional research to inform fishery management should include grouper tagging studies at known aggregation sites to identify migratory pathways and help define boundaries for marine reserves. To develop a 'slot fishing' approach further it will be necessary to identify maximum size limits for heavily targeted species.

Training programmes need to be developed for the implementation of the monitoring and recording programme as part of the revised licensing system for the export fishery. For example, training sessions will need to be carried out with fishermen and exporters to ensure they understand how to operate any implemented catch apps.

Funding Mechanisms

In the long-term the sustainability of the grouper fishery depends on the availability of financial resources to enable effective management. **We recommend that the costs of management are mainly covered by the revenue generated from participants and processes within the fishery** such as fishing and export licenses, penalties from infringements and export tariffs. Additional external funding should be used to build up the management system to begin with but with the premise that internal revenue streams will eventually be sufficient to support effective fishery management. The feasibility of such an approach should be assessed and examples from other non-Maldivian fisheries considered to help develop a functional model for the Maldives grouper fishery.

Conclusion

The grouper fishery in the Maldives is in a poor state. Overfishing of groupers has been occurring for at least 20 years and most fish now being caught are immature. Furthermore, spawning aggregation sites are still being targeted by fishermen across the country, a practise widely known as highly unsustainable. Although there have been numerous recommendations made to manage the fishery over the last decades, relatively few have been put in place and these are, overall, poorly implemented. Many grouper species remain heavily exploited and the fishery is at risk of collapse. There is now an urgent need for strong action to substantially improve management and safeguard both grouper populations and livelihoods of those involved in the fishery. If no action is taken it is likely that populations of the highly targeted grouper species will be lost from atolls and possibly whole regions of the Maldives.

Of the range of management measures proposed in this report we strongly advise to expand the use of marine reserves to protect grouper spawning aggregation sites as long as they are properly managed. Marine reserves have been shown to effectively protect grouper spawning aggregation sites while also providing benefits to local fishermen (Erisman et al. 2015). Fishermen's livelihoods have already been affected because of grouper population declines. Marine reserves offer a small loss in fishing grounds for a large gain in fish numbers, fish sizes and ultimately the fishermen's' catch and subsequent income (Nemeth 2005, Hamilton et al. 2011). There are compelling biological and economic reasons not to fish spawning aggregations if they are not managed (Sadovy de Mitcheson, 2016). In fact, where there is insufficient management and enforcement, no fishing of spawning aggregations should occur until appropriate measures are implemented to ensure their sustainable use (Sadovy de Mitcheson, 2016).

Coupled management whereby the protection of spawning aggregation sites is complemented by other management measures is fundamental. Protecting key life-history stages of grouper populations should go hand in hand with improved management of grouper fisheries such as functional size limits that enable fish to become mature and species-specific catch quotas. Implementing a 'fully documented fishery' for grouper will take time but will substantially improve the ability to manage grouper stocks in the Maldives for all types of fishing pressure. Improving catch and export reporting as is required as part of the license condition will significantly help with this process. Better knowledge of grouper biology and life histories is also required to inform management. Increasing staff capacity at the national and local level to manage and co-ordinate research and management of the grouper fishery must be prioritised. A lack of adequate scientific information should not prevent or delay the use of strong management measures at this point, but actually a reason for taking a precautionary approach given the history and current status of the fishery.

Management of grouper fisheries to date has been reactive rather than proactive, but there is an opportunity to change this and put a series of strong measures in place. Grouper spawning aggregations are still present in the Maldives and can recover if adequately protected. Allowing more engagement and enforcement at the atoll level through the combined efforts of national and local authorities will enable management measures to work better on the ground, help to maintain relationships between managers and stakeholders and generally keep people better informed. There is a need to increase staff capacity at both the national and local level to lead on and co-ordinate grouper management strategies.

Restoring grouper populations should be considered as a key part of the larger process to maintain the natural capital of the Maldives and will help to ensure that coral reef ecosystems continue to support the Maldivian economy through the provision of a range of ecosystem services for the benefit of multiple stakeholders.

Lastly, we have concerns whether high value export fisheries on coral reefs can be sustainable. Although coral reef ecosystems are biologically highly productive, they naturally export only about 1% of their gross primary productivity, meaning that potential fisheries yields are low (Nixon, 1982). Most production of the ecosystem is consumed by the diverse range of marine life present on the reef (Birkeland, 2017). Moreover, economists consider the export of long-lived, or irregularly recruiting, coral-reef species as a ‘‘gold rush,’’ i.e., depleting the local resource and moving on (Anonymous, 2000). The expense of operating a fishery such as a live-reef-fish trade requires extraction beyond the level of production i.e. the coral-reef resource needs to be liquidated to make a profit above the expense of operation (Birkeland, 2017). The globalization of small-scale fisheries of low productivity, combined with a lack of management poses a very real risk in many developing countries (Sadovy de Mitcheson, 2016). However, smaller economies can exercise control over their exports. For example, Fiji and Palau banned the export of live groupers because of concerns about overfishing (Sadovy de Mitcheson and Yin 2015). The pros and cons of such an approach should be considered for the Maldives, including the availability of alternative livelihoods for grouper fishers, potentially by switching to fishing nearshore pelagic species that are fast-growing, early reproducing, short-lived, wide-ranging fishes (see Birkeland, 2017).

We look forward to the next stage of the Maldives Grouper Fishery and Conservation Project, working closely with both new and existing partners, to make tangible progress in improving the management of the fishery and status of grouper populations, building on the achievements made so far.

References

Adam, M. S., Merrett, N. R., Anderson, R. C., Randall, J. E., Kuiter, R. and Adam, M. S. (1998). Part 1: An annotated checklist of the deep demersal fishes of the Maldive Islands. *Ichthyological Bulletin,* 67**,** 1-32.

Ali, K. (2015). Socio-economic impact assessment of the shark fishing ban in Maldives.

Anderson, R., Randall, J. and Kuiter, R. (1998). New records of fishes from the Maldive Islands, with notes on other species. *Ichthyol. Bull. JLB Smith Inst. Ichthyol,* 67**,** 20-32.

Andrews, S. (2015). *Grouper Aggregation* [Online]. Living Oceans Foundation: Living Oceans Foundation. Available at: https://www.livingoceansfoundation.org/grouper-aggregation/ [Accessed 27 February 2018].

Anonymous (2000) What price coral? The Economist, 2 Nov 2000.

Bijoux, J., Dagorn, L., Cowley, P. D., Simier, M., Adam, P.-A. and Robinson, J. (2013). Spawning aggregation dynamics of brown-marbled grouper and camouflage grouper at a remote Indian Ocean atoll. *Endangered Species Research,* 22(2)**,** 145-157.

Birkeland, C. (2017). Working with, not against, coral reef fisheries. *Coral Reefs* 36:1–11.

Burke, L., Reytar, K., Spalding, M. and Perry, A. (2011). *Reefs at Risk Revisited*.

Colin, P. L., Sadovy, Y. J., Domeier, M. L. and Graham, R. T. (2003). *Manual for the study and conservation of reef fish spawning aggregations*: Society for the Conservation of Reef Fish Aggregations.

Costello, M. J. and Ballantine, B. (2015). Biodiversity conservation should focus on no-take Marine Reserves: 94% of Marine Protected Areas allow fishing. *Trends in ecology & evolution,* 30(9)**,** 507-509.

De Mitcheson, Y. S. and Colin, P. L. (2011). *Reef fish spawning aggregations: biology, research and management*: Springer Science & Business Media.

Demartini, E. E. and Smith, J. E. (2015). 14 Effects of fishing on the fishes and habitat of coral reefs. *Ecology of Fishes on Coral Reefs***,** 135.

Domeier, M. L. (2012). Revisiting Spawning Aggregations: Definitions and Challenges. In SADOVY DE MITCHESON, Y. & COLIN, P. L. (eds.) *Reef Fish Spawning Aggregations: Biology, Research and Management.* Dordrecht: Springer Netherlands.

Edgar, G. J., Stuart-Smith, R. D., Willis, T. J., Kininmonth, S., Baker, S. C., Banks, S., Barrett, N. S., Becerro, M. A., Bernard, A. T. and Berkhout, J. (2014). Global conservation outcomes depend on marine protected areas with five key features. *Nature,* 506(7487)**,** 216.

Erisman B, Heyman W, Kobara S, Ezer T, Pittman S, Aburto-Oropeza O, Nemeth RS. (2015). Fish spawning aggregations: Where well-placed management actions can yield big benefits for fisheries and conservation. *Fish and Fisheries*. doi:10.1111/faf.12132

Harding, S. and Moore, R. (2016). Maldives Grouper Fisheries and Conservation Project: Scoping Phase Report. April 2016. Blue Marine Foundation, London. 24 pp.

Hamilton, R. J., Potuku, T. and Montambault, J. R. (2011). Community-based conservation results in the recovery of reef fish spawning aggregations in the Coral Triangle. *Biological Conservation,* 144(6)**,** 1850-1858.

House, J. (2015). Quantifying the biodiversity and biomass of mesopredatory reef fishes on Laamu Atoll. Placement thesis, M.Sc. Marine Environmental Management. University of York. 41 pp.

Johannes, R., Squire, L., Graham, T., Sadovy, Y. and Renguul, H. (1999). Spawning aggregations of groupers (Serranidae) in Palau. *The nature conservancy marine research series publication,* 1**,** 1-144.

Kelaher, B. P., Coleman, M. A., Broad, A., Rees, M. J., Jordan, A. and Davis, A. R. (2014). Changes in fish assemblages following the establishment of a network of no-take marine reserves and partially-protected areas. *PloS one,* 9(1)**,** e85825.

Kourti, N., Shepherd, I., Greidanus, H. et al. (2005) Integrating remote sensing in fisheries control. Fisheries Management and Ecology 12, 295–307.

Lee, J., South, A.B. and Jennings, S. (2010) Developing reliable, repeatable and accessible methods to provide high-resolution estimates of fishing effort distributions from vessel monitoring system (VMS) data. ICES Journal of Marine Science 67, 1260–1271.

Lieske, E. and Myers, R. (2001). Collins Pocket Guide to Coral Reef Fishes: revised edition. *Publishers: Princeton University Press. 400Pp*.

Luiz, O.J., Woods, R.M., Madin, E.M.P. and Madin, J.S. (2016). Predicting IUCN Extinction Risk Categories for the World's Data Deficient Groupers (Teleostei: Epinephelidae). *Conservation Letters* 9(5): 342–350. doi:10.1111/conl.12230.

Madin, E. M., Gaines, S. D. and Warner, R. R. (2010). Field evidence for pervasive indirect effects of fishing on prey foraging behavior. *Ecology,* 91(12)**,** 3563-3571.

Marine Research Center and Marine Conservation Society. (2011). Management Plan for the Maldives Grouper Fishery. September 2011. Darwin Reef Fish Project. MRC, Maldives and MCS, UK. 29 pp.

McClenachan, L. (2015). Extinction risk in reef fishes. *Ecology of fishes on coral reefs. Cambridge University Press, Cambridge***,** 199-207.

Najeeb, A., Wood, E., Islam, F., and Najeeb, A. (2014). Current Status of the Reef Fisheries of the Maldives and Recommendations for Management. Marine Research Center, Male'. 84 pp.

Naseer, A. & Hatcher, B. G. (2004) Inventory of the Maldives' coral reefs using morphometrics generated from Landsat ETM+ imagery. *Coral Reefs* 23: 161 - 168

National Bureau of Statistics. (2014). Population and Housing Census 2014 Shaviyani Form: Information on Households and Individuals. Male': National Bureau of Statistics, Ministry of Finance & Treasury.

Nemeth RS. (2005). Population characteristics of a recovering US Virgin Islands red hind spawning aggregation following protection. Marine Ecology Progress Series 286: 81–97.

Nixon SW (1982) Nutrient dynamics, primary production and fisheries yields of lagoons. Oceanologica Acta Special Issue. In: Proceedings of the international symposium on coastal lagoons SCORI lABO/UNESCO, Bordeaux, 8–14 Septembcr, 1981, pp 357–371.

Pauly, D., V. Christensen, S. Gue´ nette, T. J. Pitcher, U. R. Sumaila, C. J. Walters, R. Watson, and D. Zeller. (2002). Towards sustainability in world fisheries. Nature 418:689– 695.

Patrick, W. S., Spencer, P., Ormseth, O. A., Cope, J. M., Field, J. C., Kobayashi, D. R., Gedamke, T., Cortés, E., Bigelow, K. and Overholtz, W. J. (2009). *Use of productivity and susceptibility indices to determine stock vulnerability, with example applications to six US fisheries*: US Department of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service.

Pears, R. J., Choat, J. H., Mapstone, B. D. and Begg, G. A. (2006). Demography of a large grouper, Epinephelus fuscoguttatus, from Australia's Great Barrier Reef: implications for fishery management. *Marine Ecology Progress Series,* 307**,** 259-272.

Pet, J. S., Mous, P. J., Rhodes, K. and Green, A. (2006). *Introduction to monitoring of spawning aggregations of three grouper species from the Indo-Pacific: A manual for field practitioners*: Version.

Prince, J. D., Dowling, N. A., Davies, C. R., Campbell, R. A. and Kolody, D. S. (2011). A simple cost-effective and scale-less empirical approach to harvest strategies. *ICES Journal of Marine Science,* 68(5)**,** 947-960.

Randall, J. E. and Anderson, R. C. (1993). *Annotated checklist of the epipelagic and shore fishes of the Maldives Islands*: JLB Smith Institute of Ichthyology.

Rhodes, K., Mcilwain, J., Joseph, E. and Nemeth, R. (2012). Reproductive movement, residency and fisheries vulnerability of brown-marbled grouper, Epinephelus fuscoguttatus (Forsskål, 1775). *Coral Reefs,* 31(2)**,** 443-453.

Rhodes, K., Taylor, B., Wichilmel, C., Joseph, E., Hamilton, R. and Almany, G. (2013). Reproductive biology of squaretail coralgrouper Plectropomus areolatus using age-based techniques. *Journal of fish biology,* 82(4)**,** 1333-1350.

Robinson, J., Aumeeruddy, R., Jörgensen, T. L. and Öhman, M. C. (2008a). Dynamics of Camouflage (Epinephelus Polyphekadion) and Brown Marbled Grouper (Epinephelus Fuscoguttatus) Spawning Aggregations at a Remote Reef Site, Seychelles. *Bulletin of Marine Science,* 83(2)**,** 415-431.

Robinson, J., Samoilys, M. and Kimani, P. (2008b). Reef fish spawning aggregations in the Western Indian Ocean: current knowledge and implications for management. *Ten years after bleaching–facing the consequences of climate change in the Indian Ocean, CORDIO Status Report***,** 263-276.

Rudd, M. A. and Tupper, M. H. (2002). The impact of Nassau grouper size and abundance on scuba diver site selection and MPA economics. *Coastal Management,* 30(2)**,** 133-151.

Sadovy, Y. (2005). Troubled times for trysting trio: three aggregating groupers in the live reef food-fish trade. *SPC Live Reef Fish Information Bulletin,* 14**,** 3-6.

Sadovy, Y. and Domeier, M. (2005). Are aggregation-fisheries sustainable? Reef fish fisheries as a case study. *Coral Reefs* 24: 254-262.

Sadovy de Mitcheson, Y. (2016). Mainstreaming Fish Spawning Aggregations into Fishery Management calls for a Precautionary Approach. BioScience 66: 295-306.

Sadovy de Mitcheson Y, Colin PL, eds. 2012. Reef Fish Spawning Aggregations: Biology, Research, and Management. *Fish and Fisheries*, vol. 35. Springer. 621 pp.

Sadovy de Mitcheson Y, et al. (2013). Fishing groupers towards extinction: A global assessment of threats and extinction risks in a billion dollar fishery. *Fish and Fisheries* 14: 119–237

Sattar, A. S., Najeeb, A., Afzal Shidha, M., Islam, F. and Wood, E. (2011). Review of the Maldivian Grouper Fishery and Export Industry. Darwin Reef Fish Project / Marine Research Centre / MCS UK.

Sattar, S. A. and Adam, M. S. (2005). Review of Grouper Fishery of the Maldives with additional notes on the Faafu Atoll Fishery. *Msrine Research Centre, Malé, Republic of Maldives. 55pp*.

Sattar, S. A., Najeeb, A., Islam, F., Afzal, M. and Wood, E. (2012) Published. Management of the grouper fishery of the Maldives. Proceedings of the twelth international Coral Reef symposium, Cairns, 2012. 1-5.

Sattar, S. A., Wood, E., Islam, F. and Najeeb, A. (2014). Current status of the reef fisheries of Maldives an recommendations for management. Marine Research Centre/ Marine Conservation Society (UK).

Shakeel, H. (1994). Grouper fishery: Benefits, threats and challenges. *Rasain,* 14**,** 183-196.

Shakeel, H. and Ahmed, H. (1996) Published. Exploitation of reef resources: grouper and other food fishes. 1996.

Shimal, M. (2015). Maldives Fishery Survey 2015. Marine Research Center, Male', Maldives. 36 pp.

Sluka, R. D. (2001a). Grouper and Napoleon wrasse ecology in Laamu Atoll, Republic of Maldives: Part 2. Timing, location, and characteristics of spawning aggregations.

Sluka, R. D. (2001b). Grouper and Napoleon wrasse ecology in Laamu Atoll, Republic of Maldives: Part 3. Fishing effects and management of the live fish food trade. Atoll Res Bull 493:118

Stallings, C. D. (2008). Indirect effects of an exploited predator on recruitment of coral-reef fishes. *Ecology,* 89(8)**,** 2090-2095.

Starr, R. M., Sala, E., Ballesteros, E. and Zabala, M. (2007). Spatial dynamics of the Nassau grouper Epinephelus striatus in a Caribbean atoll.

Tamelander, J., Sattar, S., Campbell, S., Hoon, V., Arthur, R., Patterson, E. J. K, Satapoomin, U., Chandi, M., Rajasuriya, A., and Samoilys, M. (2008) Reef fish spawning aggregations in the Bay of Bengal: awareness and Occurrence. *Proceedings of the 11th Coral Reef Symposium*, Ft. Lauderdale, Florida.

UNDP (2015). Maldives Marine Science Symposium Information Document. Mangroves for the Future Programme, UNDP Maldives.

Witt, M.J. and Godley, B.J. (2007) A step towards seascape scale conservation: using vessel-monitoring systems (VMS) to map fishing activity. PLoS ONE 2, e1111

Appendices

List of Appendices

Appendix 1: Maldives Grouper Fishery and Conservation Project Work Plan: September 2016 – December 2017

WORK PROGRAMME	ACTIVITIES	TIMEFRAME	LOCATION	NOTES / COLLABORATORS
1. EXPORT FISHERY MONITORING	1.1 Collect grouper catch data from fish cages on Maavah and Maamendhoo islands (Laamu Atoll) 1.2 Collect grouper catch data from fish cages on Meemu or Thaa Atoll	September 2016 – February 2017	Laamu Atoll and Meemu or Thaa Atoll	Work closely with fish cage owners and island councils Catch data includes length, weight, maturity stage, GSI and sex
2. GROUPER SPAWNING AGGREGATION SITES	2.1 Assessment of spawning aggregation sites in main channels	September 2016 – February 2017	Laamu Atoll	Six Senses, MRC (possible additional surveyors from other NGOs in the Maldives)
3. FISHER SURVEYS	3.1 Fisher and Fish cage owner interviews	September 2016 – February 2017	Laamu Atoll	Selected islands / communities
4. ENVIRONMENTAL EDUCATION & AWARENESS (EEA)	4.1 Implement fisheries and marine conservation EEA programme at the atoll level 4.2 Meetings with grouper fishermen across the Maldives to present the grouper maturity size data	September 2016 – February 2017 March – July 2017	Laamu Atoll Selected Atolls of the Maldives (and Male?)	Audience: fishers, councils and local communities With MRC/MOFA
5. GROUPER SPAWNING AGGREGATION SITE PROTECTION	5.1 Selection of 1-2 sites for designation as areas protected from fishing during spawning 5.2 Begin process for site designation and develop management plan	March – December 2017	Laamu Atoll	MRC / MOFA Laamu Atoll Council Relevant Island Councils Local fishermen
6. ATOLL-BASED GROUPER FISHING REGULATIONS	6.1 Development and implementation of local regulations for grouper fishing	March – December 2017	Laamu Atoll	Discuss feasibility with MRC/MOFA and Laamu Authorities. Work closely with local fishermen and Authorities
ADDITIONAL POTENTIAL WORK PROGRAMMES				

7. UNESCO BIOSPHERE RESERVE	7.1 Support initiatives to designate Laamu Atoll as a UNESCO Biosphere Reserve	Ongoing	Laamu / Maldives / International?	Requires further discussion with UNDP, Laamu Atoll Council, project partners and local stakeholders
8. MONITORING AND MANAGEMENT OF EXISTING PROTECTED GROUPER SPAWNING SITES	9.1 Assess monitoring and management needs for current grouper MPAs 9.2 Conduct monitoring of spawning aggregations / grouper abundance at grouper MPAs to determine success 9.3 Develop and implement improved management measures for current grouper MPAs	2017 -2018+	Maldives wide – five sites on selected atolls	Potential work programme dependent on funding / resources available
9. FDF GROUPER FISHERY	8.1 Development of a fully documented fishery for vessels targeting grouper involving 'catchlog apps' and iVMS.	Late 2017 or 2018	Maldives wide (selected island communities which focus on grouper fishing)	Potential work programme dependent on funding / resources available

ADDITIONAL NOTES

Depending on the availability of funding, work programme 1 (grouper sampling from cage systems) could be extended beyond March 2017 either on Laamu or at another atoll such as Meemu

Appendix 2. Fishermen List Request Form

Maldives Grouper Fishery and Conservation Project
ދިވެހި ގަރާހީ ފަރާތްތެރިކަމާއި ރައްކާތެރިކަމުގެ ޕްރޮޖެކްޓް

Island:

	ނަން	ލިބޭ ތަން	ފޯނު ނަންބަރު	ގަތުން ކުރާ ގޮތް
	Name	**Address**	**Phone Number**	**Type of fishermen**
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				
11				
12				
13				
14				
15				
16				
17				
18				
19				
20				

ގަތުން ކުރާ ގޮތް Type of fishermen

ކުރިއަރ ގަރާހީ ގަތުމުގެ ތަޖުރިބާ ލިބިފައިވާ ފަރާތްތައް Past grouper fishermen

ވަރަށް ގަރާހީ ގަތުމުގެ ތަޖުރިބާ ލިބިފައިވާ ފަރާތްތައް Current grouper fishermen

ދުވަސްތަކުގެ ގޮތުގައި ގަރާހީ ގަތުމުގެ ތަޖުރިބާ ލިބިފައިވާ ފަރާތްތައް (ދަނޑުވެސް، ކަނޑުގައި ވެސް ގަތުމުގެ ތަޖުރިބާ ލިބިފައިވާ ފަރާތްތައް) Oppotunistic fishermen (tuna, billbish, seacucumber fishermen)

ގަރާހީ ގަތުމުގެ ތަޖުރިބާ ލިބިފައިވާ ފަރާތްތައް Reef fishermen

ގަރާހީ ގަތުމާ ގުޅުންހުރި ފަރާތްތައް Knowledgable people

Appendix 3: Fisher's Profile Form

Island:

Date:

Personal details of fisher

1. Name:

2. Address:

3. Phone number:

4. Age group:

Age group	Tick
< 20	
20 – 30	
31 – 40	
41 – 50	
51+	

5. Which fishery/fisheries do/did you engage with?

Fishery	**Currently**	**10 years ago**	**20 years ago**
Grouper fishery			
Reef fishery			
Tuna fishery			
Sea cucumber fishery			
Other			

6. Number of years fishing for groupers

No. of years	Tick
<1	
1-5	
6-10	
11-15	
16-20	
20+	

7. Are you still actively fishing for groupers?

Answer	**Tick**
Yes	
No	

If answer is NO please specify reason for stopping fishing.

8. What role do/did you play in the grouper fishery?

	Currently	**10 years ago**	**20 years ago**
a. Commercial- export internationally			
b. Commercial- selling to exporter			
c. Commercial- selling to mobile buyers			
d. Commercial –selling to cage owner			
e. Commercial – selling to collector vessel			
f. Commercial- selling to resorts/ guest houses			

g. Opportunistic			
h. Artisanal- Selling to community			
i. Artisanal- For own consumption			
j. Other (please specify)			

9. If you sell/sold commercially, which type of grouper trade forms the majority of your shipments?

Type of grouper	Currently	10 years ago	20 years ago
Selling live groupers			
Selling chilled groupers			

10. Please provide the name(s) of the buyer(s).

Type of grouper	Currently	10 years ago	20 years ago
Live grouper buyer/s			
Chilled groupers buyer/s			

Appendix 4. Individual Fisher Questionnaire

Grouper Fishery Questionnaire Laamu Atoll, Maldives,

Discussions with individual fishermen

Island:

ID Number:

Section 1 **Fishing effort**

1.1. What is/was the average no. of individuals on fishing trips?

	Currently	**10 years ago**	**20 years ago**
No. of individuals			

1.2 Roles and responsibility of the fisher i.e. Skipper, crew etc.

	Currently	**10 years ago**	**20 years ago**
Roles/responsibility			
Boat owner			
Net owner			
Captain			
Crew member			
Main diver/collector			
Assistant diver/collector			
Other (specify)			

1.3. If you are a boat owner, what type of vessel and how many of these vessels do/did you own? If you do not own your own boat, how many vessels do you work on?

Vessel Type	**No. of vessels**	**Length (m)**	**Tick**
Boat with sail			
Inboard motored boat			
Outboard motored boat			

Dinghy			
Other (specify)			

1.4. Main gear used (may be more than 1)

Gear type	**Currently**	**10 years ago**	**20 years ago**
Handline			
Net/ bag			
Snorkelling equipment			
Dive equipment			
Torch			
Other (specify)			

1.5 What kind of bait do you use to catch groupers? *Please specify the bait for each grouper family.*

Grouper family	**Type of bait**
Epinephelus sp.	
Plectropomus sp.	

1.6 How long is/was your average fishing trip?

Year	**Daytrip**	**Night trip**	**2-3 days**	**4-5 days**	**1 week**	**1-2 weeks**	**Other (specify)**
Currently							
10 years ago							
20 years ago							

1.7 If it is a day/night trip please specify how many hours your average trip lasts

1.8. When do you usually fish for groupers and what is/are the reasons for doing so?

Section 2. **Fishing locations**

2.1. Location of local fishing areas usually fished currently (Maps provided)

Fishing areas **Current**	**Atoll**	**Map block reference**

2.2 *Location of local fishing areas fished currently in the past?*

Past	**Fishing areas** **Current**	**Atoll**	**Map block reference**

Section 3 **Fish spawning aggregations**

3.1. Do you know/ have seen/ fished from areas where groupers gather together?

Answer	**Aware of aggregations**	**Have seen aggregations**	**Fished aggregations**
Yes			
No			

If the answer to Question 3.1 is NO, go to section 4.

3.2 *What site characteristics cause you to believe it is an aggregation?*

N.B Interviewers must not prompt fishermen with answers.

Characteristics	**Tick**
Large numbers of groupers	
Occurs at specific time periods	
Seen/heard of migration	
Pregnant females are caught	

3.3. Why do you think they aggregate there?

N.B Interviewers must not prompt fishermen with answers.

Reasons for aggregating	**Tick**

3.4 What species of groupers do you see at these aggregations and what are the local names that you use to describe each species?

Scientific name	**Local name**

Please now refer to section 3.5

3.6 At what time of year (month, lunar phase, time of day) do you usually fish/see spawning aggregations?

Season	
Month	
Lunar phase	
Time of day	

3.7. Do you think that any of the following sea conditions influence the aggregation? *If yes, could you please specify what effect they have.*

Sea condition	**Yes/No**	**Comments**
Current		
Tidal State		
Wind		
Water temperature		

Section 3.5 Fish spawning aggregations

NB: Questions in section 3.5 focused on one spawning aggregation site at a time

	Questions	**Site 1**	**Site 2**	**Site 3**	**Site 4**
1.	**Site name**				
2.	**Map reference**				
3.	**Species:** Clarify the species' identification using the fish id sheets				
4.	**Habitat, reef profile and depth**				
4.1	Can you give details about the type of marine habitat where the spawning aggregation occurred?				

4.2	What was the depth of the spawning aggregation?	Minimum: Maximum:	Minimum: Maximum:	Minimum: Maximum:	Minimum: Maximum:
4.3	Have you observed this site being associated with other species such as sharks, manta rays?				
4.4	How long did the spawning aggregation last? e.g. number of days				
4.5	For how many years have you seen this aggregation?				
5.	**<u>Fishing pressure on the spawning aggregation</u>**				

5.1	Do you/ have you fished from this aggregation site?				
5.2	Reason for fishing from this site				
5.3	For how many years have you been fishing from this spawning aggregation site?				
5.4	How often do you fish at this spawning aggregation site?	Now: 10 years ago: 20 years ago:	Now: 10 years ago: 20 years ago:	Now: 10 years ago: 20 years ago:	Now: 10 years ago: 20 years ago:
5.5	How many boats fish the site currently?				
5.6	Have you noticed an increase/decrease of other fishers/boats targeting this aggregation? If so, by how much?				
5.7	Is there any sort of traditional management of spawning aggregations – e.g. seasonal closures				
6	**<u>Catch size per fisher</u>**				
6.1	If (when) the spawning aggregation is (was) fished, is (was) the average catch larger				

	than usual on this site compared to other fishing sites? If so by how much?				
6.2	Have you noticed a change in the fish catch since you first fished it? If so how has it changed? (increase/decrease)				
6.3	If so, when did you first notice a change in catch at the site?				

Section 4. **Socio-economics of grouper fishery**

N.B First ask the fisherman if they are happy to discuss their personal income with the interviewer. If they confirm they are happy to do so proceed with questions.

4.1 Do you/did you have any other income earning activity besides grouper fishing?

4.2 What proportion of fishing income comes/came from groupers?

Proportion of income	**Currently**	**10 years ago**	**20 years ago**
0-25%			
25-50%			
50-75%			
75-100%			

4.3 How much on average do you/did you get as income from the grouper fishery on a monthly basis?

Currently	**10 years ago**	**20 years ago**

4.4 Do you get a greater income from targeting spawning aggregations compared with non-spawning aggregation sites and if yes please specify how much more income you make?

4.5 What year was your income from the grouper fishery at its peak?

If answer is YES, **please provide details.**

Section 5. Grouper fishery management

5.1 Are you currently aware of any grouper management regulations or local agreement?

5.2 Do you think that the grouper fishery needs to be managed?

If answer is YES please provide reason for answer.

5.3 How important do you believe this is (1=not important, 5=extremely important)?

5.4 Do you have any concerns about spawning aggregations?

5.5 What are your thoughts and ideas on how to manage the grouper fishery to ensure a sustainable fishery?

***N.B Interviewers must not prompt fishermen with measures listed below**.*

Management measures	*Tick (✓)*
Size limits on catch	
Size limits on exports	
Temporal fishing closures	
Temporal ban on, fishing, exports and purchase	
Catch quotas per vessel	
Regular monitoring of cages	
Grouper culture	
Increase awareness of importance of management	
Other please specify	

Thank you for your assistance

Appendix 5. Fisher Focus Group Questionnaire

Activity 1: Seasonal Fish Calendar (20 mins)

What is fishing like for each of these species throughout the year (for the side of the Atoll the island is located on?

Excellent

Fair

Poor

Don't know

Month/Species	E. fuscoguttatus	E. polyphekadion	P. areolatus	P. laevis
January				
February				
March				
April				
May				
June				
July				
August				
September				
October				
November				
December				

Activity 2: Targeted species (10 mins)

In order of importance, list the 5 most targeted species a) currently, b) 10 years ago and c) 20 years ago? What is/was the main reason for targeting specific species?

The following can be listed among the reasons: highly priced, easy to catch, species found in the fishing areas etc.

Currently	10 years ago	20 years ago	Reason

Activity 3: Changes to total catch over time (10 mins)

Do you feel that the total annual catch has changed over the past 10,20 years?

Answer	10 years (2000's)	20 years (1990's)
Yes Tick (✓)		
No Tick (✓)		

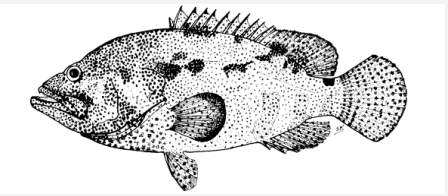
On average how many days does it take to catch 100kg of groupers now. 10 years ago and 20 years ago?

Now	10 years ago (2000's)	20 years ago(1990's)

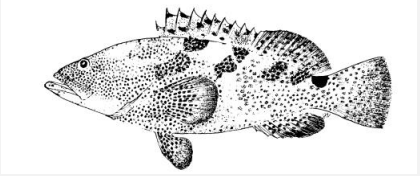
Activity 3: Changes to average size of groupers over time (10 mins)

What size are the fish that you usually catch of each of these species a) currently, b) 10 years ago and c) 20 years ago?

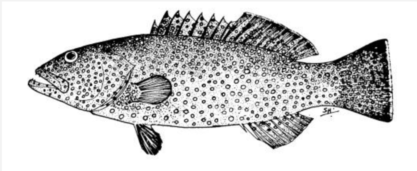
1. ކަނޑުދަށަ Epinephelus fuscoguttatus

20 years ago	10 years ago	Currently	
			Average size of groupers caught (estimate to every 5 cm)

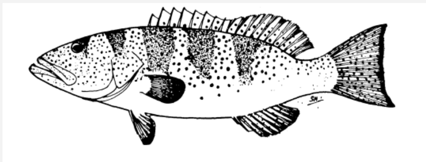
2. ކުއްލިދަށަ Epinephelus polyphekadion

20 years ago	10 years ago	Currently	
			Average size of groupers caught (estimate to every 5 cm)

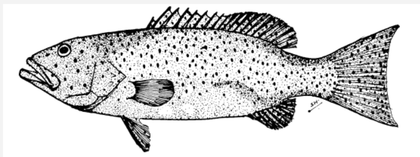
Plectropomus areolatus އޮޅުފާނަ/ ބައިގަރު .3

20 years ago	10 years ago	Currently	
			Average size of groupers caught (estimate to every 5 cm)

Plectropomus laevis ކުރައޮޅުފާނަ/ ކާނޑު ރަސްގެފާނު .4

20 years ago	10 years ago	Currently	
			Average size of groupers caught (estimate to every 5 cm)

Plectropomus pessuliferus ދޮންއޮޅުފާނަ .5

20 years ago	10 years ago	Currently	
			Average size of groupers caught (estimate to every 5 cm)

Activity 3: Fishing vessels from other Atolls (10 mins)

Grouper fishing vessels from which atolls/islands come to Laamu most often? please specify the atolls/islands in order?

Order	Atoll	Islands
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		

Do they visit at certain time periods of the year, if so which months or seasons?

Do you know in particular if they are visiting particular site, if so which ones? (in order to most visited) (Maps provided)

	Site	Map block reference	Additional info
1			
2			
3			
4			
5			
6			
7			
8			

Activity 5: Grouper fishery management (10 mins)

Select the grouper fishery management option you would recommend by putting stickers by the options you support.

	Management option	
1	*Marine protected area with no restrictive activities*	
2	*Marine protected area with grouper fishery restriction*	
3	*Marine protected area with temporary fisheries closure during spawning aggregation period*	
4	*Catch size limits*	
5	*Export size limits*	
6	*No protected areas needed*	
7	*No size limits needed*	

8	*No management required*	
9	*Other:*	

Appendix 6. Focus Group Knowledge Assessment

2. Why do groupers form aggregations? (Check all that apply)

a. For feeding
b. To meet their family
c. For reproduction
d. It is not yet understood

3. Targeting grouper spawning aggregations can lead to fishery collapse.

a. True
b. False

3. What are the fisheries management tools in place for grouper fishery in the Maldives? *(check all that apply)*

e. Export size limits
f. Marine protected areas (restricted activities)
g. Catch size limits
h. Periodic fishery closure
i. No current management measures in place

4. What are the size limits in place for groupers? *(check all that apply)*

a. Less than 5 inches for all species
b. Less than 500g for all species
c. Minimum lengths ranging from 20-30cm for different species (except E. fuscoguttatus)
d. Less than 25cm and between 45-63cm for E. fuscoguttatus

5. Why are size limits so important? *(check all that apply)*

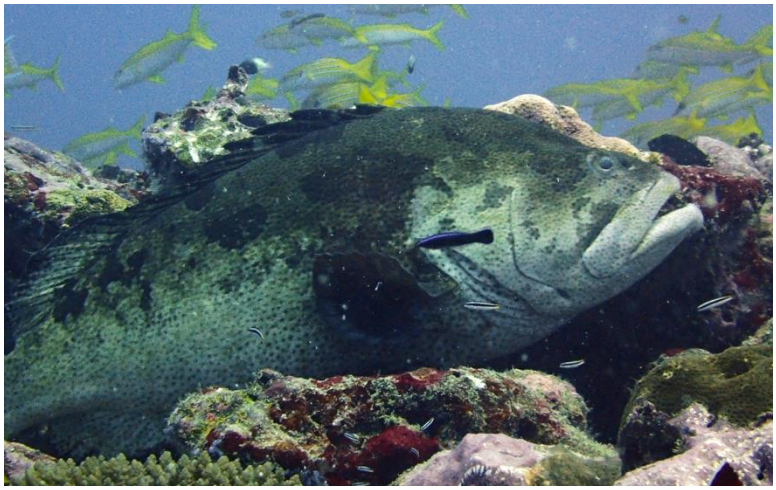
f. Because Maldives grouper population is declining
g. To give groupers a chance to reach maturity
h. To give groupers a chance to spawn at least once in their lifetime
i. To make sure there are enough grouper to catch in the future

6. How important do you believe this is (1=not important, 5=extremely important)?

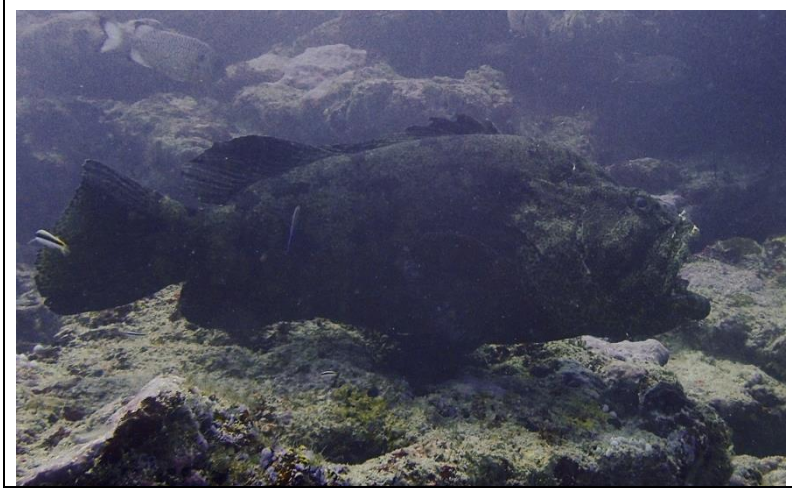
Appendix 7. Spawning Aggregation Dive Survey Form

Date:			**Current:**			
Time:			**Tide:**			
Site:			**Lunar phase %:**			
			Temperature:			
Data recorded by:			**Visibility (in meters):**			
SPECIES	**LENGTH (CM)**	**SWIMMING/HIDING**	**DISTENDED ABDOMEN (Y/N)**	**COLOUR CHANGE (Y/N)**	**BEHAVIOUR**	**Other**

Appendix 8. ***Epinephelus fuscoguttatus*** **Spawning Behaviour**

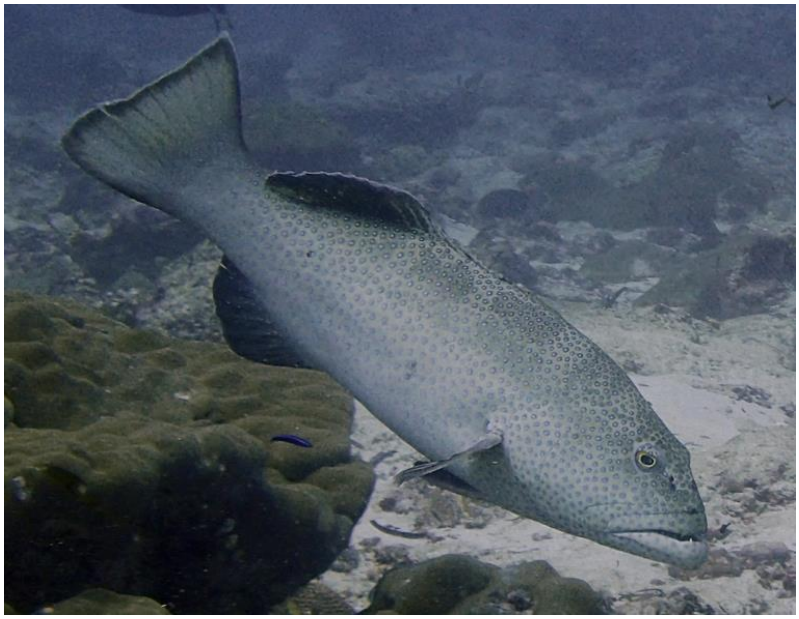
Behaviour and appearance	Description
	**CP1: Normal phase** Normal phase, overall beige colouring with dark brown/black mottled markings all over the body; dark caudal, pectoral, second dorsal and anal fins
	**CP2: Male colouration** The usual brown-and-black marbled colour pattern (CC1) disappears on the upper half of the body; fish displays white ventrally, on the opercula, and on dorsal, caudal and anal fins. Fin edges darken to black, and dorsal half of body blackens. This colour phase is assumed to be indicative of dominant males displaying to females within their territory. Possibly not all males display this colouration. When in this colour pattern, individuals typically swim rapidly and display signs of aggression.

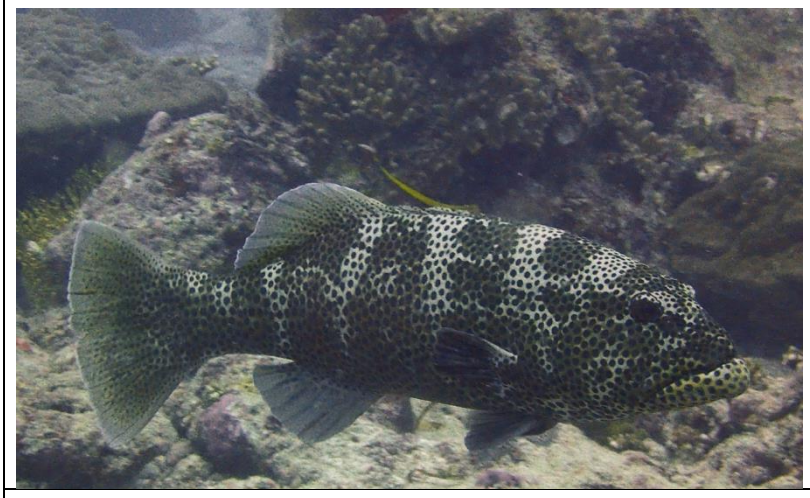
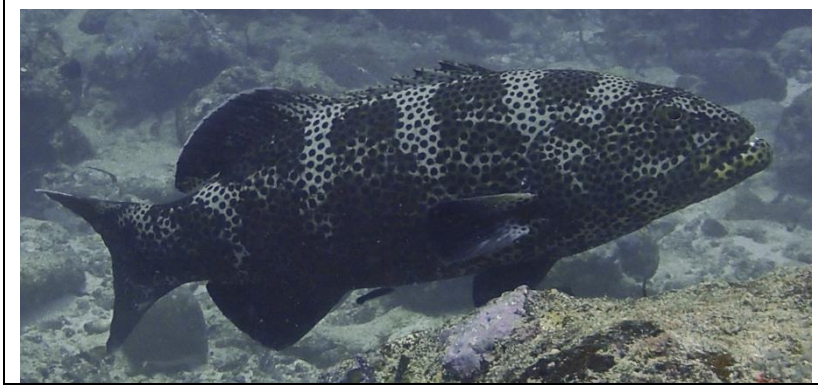
	**Behaviour 1: Aggression**
	**Behaviour 2: Gravid female**
	**CC3: Courtship colouration** The usual brown-and-black marbled colour pattern (CC1) becomes much paler on the upper half of the body and less black mottled markings are found. The abdomen becomes noticeably white and fins also lighten. Individuals of this colouration were often found showing courtship behaviour in pairs.

	**Behaviour 3** **Hovering in mid-air**
	**CC4: Indistinct colour phase** Overall beige colouring on the body and fins with grey mottled markings. Mottled markings absent on the face, but small spots present.
	**CC5: Indistinct colour phase** Overall dark green appearance with black mottled markings and dots all over the body; dark caudal, pectoral, second dorsal and anal fins.

Appendix 9. ***Plectropomus areolatus*** **Spawning Behaviour**

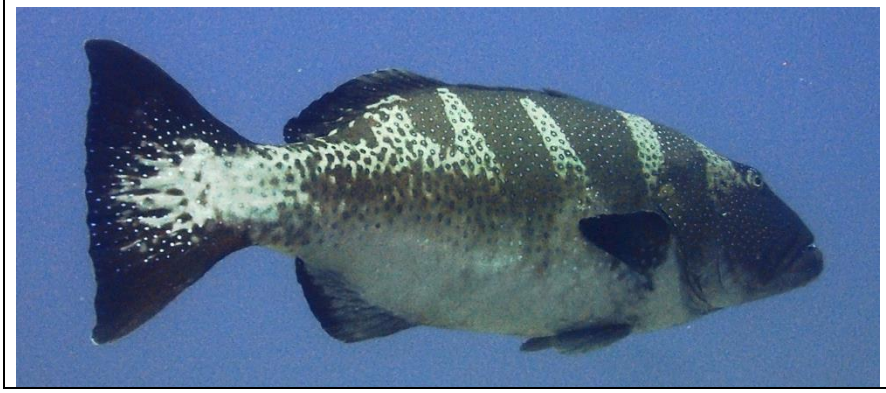
Behaviour and appearance	Description
	Behaviour 1: Gravid female
	Behaviour 2: Pair formation
	Behaviour 3: Shaking

	Behaviour 6: Harem of female groupers
	CC1: Body and fins very pale and light brownish; brown spots with black outline; brown and white margin on caudal fin
	CC2: The body appears very pale/light grey. There is a distinct black margin to the poster edge of the caudal fin. Blue spots are visible on, with those on upper body with black outline. Saddles are faintly visible on the upper body. N.B. Described in (Johannes et al., 1999)

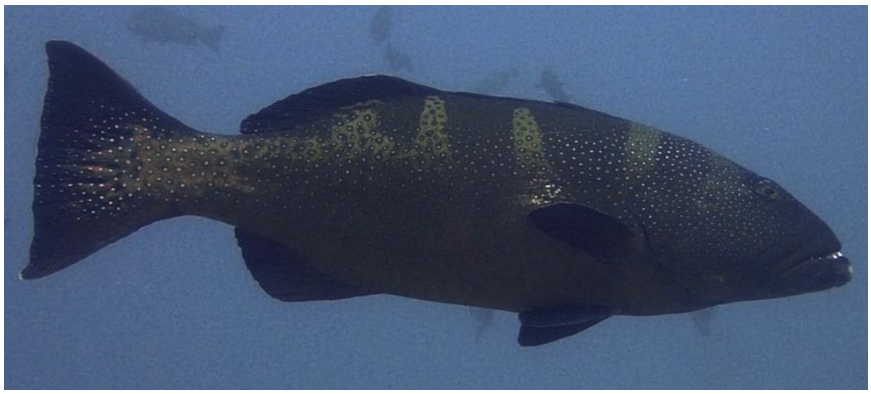
	CC4: Body dark yellow/green; black spot outlines; dark pectoral fins; pectoral, anal and caudal fins are same colour of the body; white margin on caudal fin; visible saddles
	CC5: similar to CC4, but with white blotches on the body and tail.
	CC6: Very dark green/brown body and fins with white blotches and a bit of yellow on the lips; black spots; white margin on caudal fin, visible saddles

	CC7: Whole body and fins very dark; purple spots, white margin on caudal fin
	CC8: Dark greenish body; purple spots; pale dorsal and anal fins; yellow margin on caudal fin
	CC9: Dark reddish body; white spots; yellow dorsal and anal fins; yellow margin on caudal and pectoral fins, yellowish lips

Appendix 10. ***Plectropomus laevis*** **Spawning Behaviour**

Behaviour and appearance	Description
	Behaviour 1: Small group formation
	CC1: Pale body with black caudal fin; black outer margin on pectoral fin, dorsal and anal fins; grey face
	CC2: Visible black saddles on the body, black caudal and pectoral fins and face, black outer margin on dorsal and anal fins

	CC3: Saddles joined together in a black patch on the body; black caudal and pectoral fins; black inner margin on dorsal and anal fins; white lower lips, belly and where body meets caudal fin
	CC4: Saddles joined together in a black patch on the body which extends down to the belly; black caudal fin; white dorsal rea and where body meets caudal fin
	CC5: Dark grey patch in the middle of the body, black caudal fin and lower lips, black outer margin on pectoral, dorsal and anal fins
	CC6: Very dark black saddles, all fins and face black. White patches on the belly in this individual

	CC7: Brown body, black fins, saddles and face.
	CC8: White body; black saddles; yellow caudal, dorsal, anal and pectoral fins; yellow line across the middle of the body and on the face.

Appendix 11. ***Epinephelus polyphekadion*** **Spawning Behaviour**

Behaviour and appearance	Description
	CC1: Normal phase Overall white appearance with black mottled markings all over the body; brownish tint on the face and belly
	CC2 & Behaviour 1: Aggression Overall beige appearance with black mottled markings on the upper body; mottled markings absent on the face, but small black spots

Appendix 12. Megafauna observed at Spawning Aggregation Sites

Species	Common name	IUCN status	Hithadhoo Corner	Maavah Kandu	Fushi Kandu
Manta alfredi	Reef manta ray	Vulnerable	✓	✓	✓
Manta birostris	Oceanic manta ray	Vulnerable	✓		
Stenella longirostris	Spinner dolphin	Data deficient	✓	✓	✓
Tursiops truncatus	Bottlenose dolphin	Least concern	✓	✓	✓
Carcharhinus amblyrhynchos	Grey reef shark	Near threatened	✓	✓	✓
Carcharhinus leucas	Bull shark	Near threatened	✓		
Galeocerdo cuvier	Tiger shark	Near threatened	✓		
Triaenodon obesus	White tip reef shark	Near threatened	✓	✓	✓
Triaenodon obesus	Black tip reef shark	Near threatened	✓	✓	✓
Carcharhinus falciformis	Silky shark	Vulnerable			✓
Ginglymostoma cirratum	Nurse shark	Vulnerable		✓	
Aetobatus narinari	Spotted eagle ray	Near threatened	✓	✓	✓
Himantura granulata	Mangrove ray	Vulnerable	✓	✓	✓
Pastinachus sephen	Cowtail ray	Near threatened	✓		
Pateobatis jenkinsii	Jenkins whipray	Vulnerable	✓		
Pateobatis fai	Pink whipray	Vulnerable	✓		
Mobula japanica	Spine tailed devil ray	Near threatened	✓		
Torpedo marmorata	Marbled electric ray	Data deficient	✓		
Urogymnus asperrimus	Porcupine ray	Vulnerable	✓		
Cheilinus undulatus	Napoleon wrasse	Endangered	✓	✓	✓
Gymnosarda unicolor	Dogtooth Tuna	Least Concern	✓	✓	✓
Sphyraena qenie	Blacktail Barracuda	Not Assessed	✓	✓	✓
Sphyraena barracuda	Great Barracuda	Least Concern	✓	✓	✓
Chelonia mydas	Green turtle	Endangered	✓	✓	✓
Eretmochelys imbricata	Hawksbill turtle	Critically Endangered	✓	✓	✓

Appendix 13. Grouper Cage Systems used for Size-Maturity Sampling

Island	Atoll	Owner	Cage size (m)	Source of grouper	Observations
Maavah	Laamu	Ahmed Ibrahim	2x2	Laamu Atoll, mainly from Maavah and Maamendhoo	Owner unable to collect enough groupers to fulfil the minimum shipment requirement, soon after sold the cage to Mushthaq.
Maavah	Laamu	Mushthaq Mohamed	4x2	Both Laamu Atoll, and from other Atolls.	
Maamendhoo	Laamu	Aslam Mukhthar and Ali Waheed	2x1	Laamu Atoll, mostly from Maamendhoo	Sub-cage of Maavah cage, very small scale Started operating in mid-2017
Dhanbidhoo	Laamu	Hassan Muruthala	2x1	Laamu Atoll, mainly from Dhanbidhoo & Kalaidhoo	Sub-cage of Dhanbidhoo cage, very small scale. Sold to Maavah cage and occasionally to cages in other Atolls
Thinadhoo	Vaavu	Harp Maldives		Vaavu Atoll and other Atolls further south.	Very productive cage shipment, 2-3 shipments per week Mainly exported fresh/ chilled
Hulhumale	Kaafu	Sea Partners		Both northern and southern Maldives	Largest cage system
Keyodhoo	Gaafu Dhaalu	Harp Maldives		Southern Atolls.	Only exported fresh/ chilled Observed Faafu Atoll fishermen landing catches to this cage after fishing southern atolls

Appendix 14. Grouper Gonad Sampling Survey Form for Size Maturity Assessment

Date:	
Cage Origin:	
Fished from:	
Date Caught:	

FISH #	SPECIES	TOTAL LENGTH (CM)	STANDARD LENGTH (CM)	WEIGHT (KG)	GONAD LENGTH (MM)	GONAD WIDTH (MM)	GONAD WEIGHT (G)	GONAD COLOUR	EGG/SPERM VISIBLE?	ESTIMATED MATURITY STAGE	SEX (M/F)	PHOTO #1 TAKEN	PHOTO #2 TAKEN	PHOTO #3 TAKEN	SAMPLE STORED	OTOLITHS STORED	PARASITES PRESENT	Gonad stored in Foamalin

Appendix 15. Size Classes of Grouper Species Sampled

15.1 *Epinephelus fuscoguttatus*

Epinephelus fuscoguttatus								
Size classes (cm)	Laamu (December)	Laamu (February)	Vaavu (March)	Kaafu (April)	Laamu (April)	Gaafu Dhaalu (July)	Vaavu Atoll (October)	Total
20-24.9								
25-29.9				5				5
30-34.9			7	6			2	15
35-39.9	1			4		1		6
40-44.9				2	1		1	4
45-49.9	1			3		3		7
50-54.9	6				2	4		12
55-59.9				3	2	2		7
60-64.9				2	1			3
65-69.9					1			1
70-74.9								
75-79.9								
80-84.9					1			1
85-89.9					1			1
90-94.9								
95-99.9								
TOTAL	**8**			**26**	**9**	**10**	**3**	**56**

15.2 *Epinephelus polyphekadion*

Size classes (cm)	*Epinephelus polyphekadion*							GRAND TOTAL
	Laamu (December)	Laamu (February)	Vaavu (March)	Kaafu (April)	Laamu (April)	Gaafu Dhaalu (July)	Vaavu Atoll (October)	
20-24.9			6					6
25-29.9			12					12
30-34.9			11					11
35-39.9			23			2		25
40.44.9			14		1	6		21
45-49.9	1		11		1	7		20
50.54.9			4			1		5
55-59.9			4					4
60-64.9								
65.69.9								
70-74.9								
75-79.9								
80-84.9								
85-89.9								
90-94.9								
95-99.9								
TOTAL	**1**		**85**		**2**	**16**		**104**

15.3 *Plectropomus areolatus*

Size classes (cm)	*Plectropomus areolatus*							GRAND TOTAL
	Laamu (December)	Laamu (February)	Vaavu (March)	Kaafu (April)	Laamu (April)	Gaafu Dhaalu (July)	Vaavu Atoll (October)	
10-14.9								
15-19.9				1				1
20-24.9			4					4
25-29.9		2	4	5				11
30-34.9		2	6	1		2		11
35-39.9		7	4			4		15
40.44.9		3	2			6		11
45-49.9		2	7			14		23
50.54.9		2	11			9		22
55-59.9		2	10	4		8		24
60-64.9		1	3					4
65.69.9								
70-74.9								
TOTAL		**21**	**51**	**11**		**43**		

15.4 *Plectropomus laevis*

Size classes (cm)	*Plectropomus laevis*							GRAND TOTAL
	Laamu (December)	Laamu (February)	Vaavu (March)	Kaafu (April)	Laamu (April)	Gaafu Dhaalu (July)	Vaavu Atoll (October)	
20-24.9			2					
25-29.9			11					
30-34.9		5	8				2	
35-39.9		1	6			5	7	
40.44.9		1	8			5	3	
45-49.9		2	3			5	3	
50.54.9		1	4					
55-59.9			1			1		
60-64.9		1	2					
65.69.9		3	6					
70-74.9		1	1					
75-79.9		2	1			1		
80-84.9								
85-89.9							1	
90-94.9			1					
95-99.9								
TOTAL		**17**	**53**			**17**	**16**	**103**

15.5 *Plectropomus pessuliferus*

Size classes (cm)	*Plectropomus pessuliferus*							GRAND TOTAL
	Laamu (December)	Laamu (February)	Vaavu (March)	Kaafu (April)	Laamu (April)	Gaafu Dhaalu (July)	Vaavu Atoll (October)	
20-24.9								
25-29.9								
30-34.9						1		
35-39.9						5	2	
40.44.9						10	5	
45-49.9						16		
50.54.9						3		
55-59.9						1		
60-64.9								
65.69.9								
70-74.9								
75-79.9								
80-84.9								
85-89.9								
90-94.9								
95-99.9								
TOTAL						36	7	43

Appendix 16. Grouper Species Metrics for Size Maturity Assessment: Total Length, Gonadosomatic Index Values and Sex Ratio

16.1 *Epinephelus polyphekadion*

Months	*n* (Immature)	*n* (Mature)	MTL+SD	MGSI +SD	♀: ♂
December	0	1	49	0	All female
March/April	49	35	41.6±12.69	1±1.77	17:18
April	1	1	48.76±5.3	0±0.19	All female
July	8	8	47.05±7.98	2±2.18	1:3

16.2 *Plectropomus areolatus*

Months	*n* (Immature)	*n* (Mature)	MTL+SD	MGSI +SD	♀: ♂
February	14	6	43.8 ±9.34	0±0.16	2:1
March/April	27	35	41.23±13.03	1±1.26	13:22
July	8	35	47.24±8.81	2±5.62	4:3

16.3 *Plectropomus laevis*

Months	*n* (Immature)	*n* (Mature)	MTL+SD	MGSI +SD	♀: ♂
February	15	2	47.5±9.44	1±1.68	1:1
March/April	44	9	41.28±12.44	1±1.72	7:2
July	15	2	42.98±8.68	0±0.17	All males
October	16	0	41.2±10.12	1±1.39	NA

16.4 *Plectropomus pessuliferus*

Months	*n* (Immature)	*n* (Mature)	MTL+SD	GSI +SD	♀: ♂
July	16	20	47.23±8.97	2±5.80	17:3
October	4	3	36.85±5.18	1±1.46	All female

Appendix 16 (continued)

16.5 *Epinephelus fuscoguttatus*

Months	*n* (Immature)	*n (*Mature)	MTL+SD	MGSI +SD	♀: ♂
December	7	1	49.59±5.13	0	All male
March/April	23	3	42.61±14.42	0±1.12	All female
April	4	5	59.5±15.05	0±0.16	All female
July	8	2	47.35±8.85	1±2.12	All male
October	3	0	35.47±6.93	0±0.34	NA

Where: MTL = Mean Total Length; SD = Standard Deviation; MGSI = Mean Gonadosomatic Index; ♀: ♂ = Sex Ratio (Female: Male).

Appendix 17. Project Educational leaflet - English Version

WHAT ARE GROUPERS?

- Groupers are top predatory fish on coral reefs.
- They feed on smaller reef fish but are also an important food source for larger species like sharks.
- There are 40-45 species of grouper in the Maldives. These are four common species:

Plectropomus Laevis
Black-Saddled Coral Grouper
Kandu Rasgefaanu / Kula Olhu Faanu

Plectropomus Areolatus
Squaretail Coral Grouper
Tigaru or Olhufaana

Epinephelus Fuscoguttatus
Brown-Marbled Grouper
Kasfaana

Epinephelus Flavocaeruleus
Blue & Yellow Grouper
Dhon Noo Faanu

WHY ARE GROUPERS IMPORTANT?

- Groupers are an important economic resource for fishermen.
- A healthy grouper population keeps numbers of other species on coral reefs balanced.
- A balanced coral reef ecosystem can better resist the effects of climate change, such as coral bleaching and beach erosion.

PROJECT ACTIVITIES

1. FISHERMEN INTERVIEWS:
Fishermen interviews will be carried out across all 11 islands in Laamu Atoll to gather local knowledge about the grouper fishery.

2. UNDERWATER DIVE SURVEYS:
Surveys will be carried out to identify grouper spawning aggregation sites within Laamu Atoll and to study local grouper populations.

3. GROUPER SAMPLING AT THE HOLDING CAGES:
Gonad sampling of the groupers held in cages will be carried out to identify the sexual maturity sizes for different species. This research has never before been carried out in the Maldives.

4. ENVIRONMENTAL EDUCATION AND AWARENESS:
Educational outreach work will be conducted with local schools, councils, communities and fishermen to increase environmental knowledge and awareness throughout the project

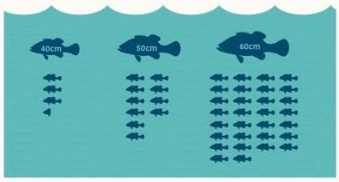
IMPLEMENTED AND SUPPORTED BY:

BLUE MARINE FOUNDATION
SIX SENSES
M&S EST. 1884
L'CReD

THE GROUPER FISHERY & CONSERVATION PROJECT

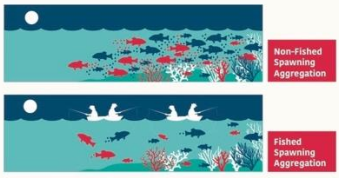
WHY ARE GROUPERS VULNERABLE TO OVERFISHING?

- Groupers take a very long time to become mature. Fishing groupers before they are mature means they have not had the chance to spawn and produce offspring.
- Groupers change from females to males as they get older and larger. Catching smaller fish means there are not enough males left on the reefs to mate with females. This means fewer juveniles are produced to re-populate the reefs
- Taking large fish as well as small fish also reduces the number of offspring produced. This is because larger and older fish produce a lot more eggs and larvae.



WHAT IS A SPAWNING AGGREGATION?

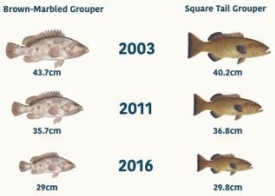
- At certain times of the month, groupers leave their home and travel in large numbers to channels to find a mate. Here, they release eggs and sperm (spawn) to produce the next generation of fish.
- Spawning aggregations are the only time groupers reproduce. Taking too many groupers during these times means that large numbers of groupers can be removed over a few days. This can have a big effect on the next generation by reducing the number of eggs released.



WHAT IS THE STATUS OF GROUPER FISHERY IN THE MALDIVES?

Data for groupers in the Maldives from the last 30 years has shown a clear decline in the numbers of groupers and the size of groupers that are being caught, particularly those species which are highly valued and targeted.

Change observed for average size (length) of Brown-marbled grouper and Squaretail coral grouper:



Under the Maldivian Government's Grouper Management Plan of 2014, two management measures in place which can be effective are:

1. Size limits: each type of grouper caught must be larger and/or smaller than a given size (length)
2. Marine protected areas for grouper spawning aggregation sites: 5 areas are currently designated

Well managed protected areas and improved size limits are recommended to prevent grouper stock collapse and to have a sustainable grouper fishery.

WHAT ARE SIZE LIMITS?

Size limits ensure that:

- Groupers are only fished once they have had a chance to spawn.
- Larger individuals which produce more offspring than smaller ones are not removed.
- There is an even ratio of females and males within populations.

MISMANAGED GROUPER FISHERY:

1. Fishing without adhering to size limit regulations.
2. Unbalanced population: Few large individuals, mostly small females, reduced mating success
3. Reduced production of offspring
4. Stock decline, reduced income from fishery, decrease in coral reef health

SUSTAINABLE GROUPER FISHERY:

1. Fishing within size limit regulations
2. Balanced population: Larger males and females present, better chance of mating successfully
3. More offspring produced
4. Stock maintained, income from fishery is maintained or increased, coral reef health maintained

WHY DO WE NEED MARINE RESERVES?

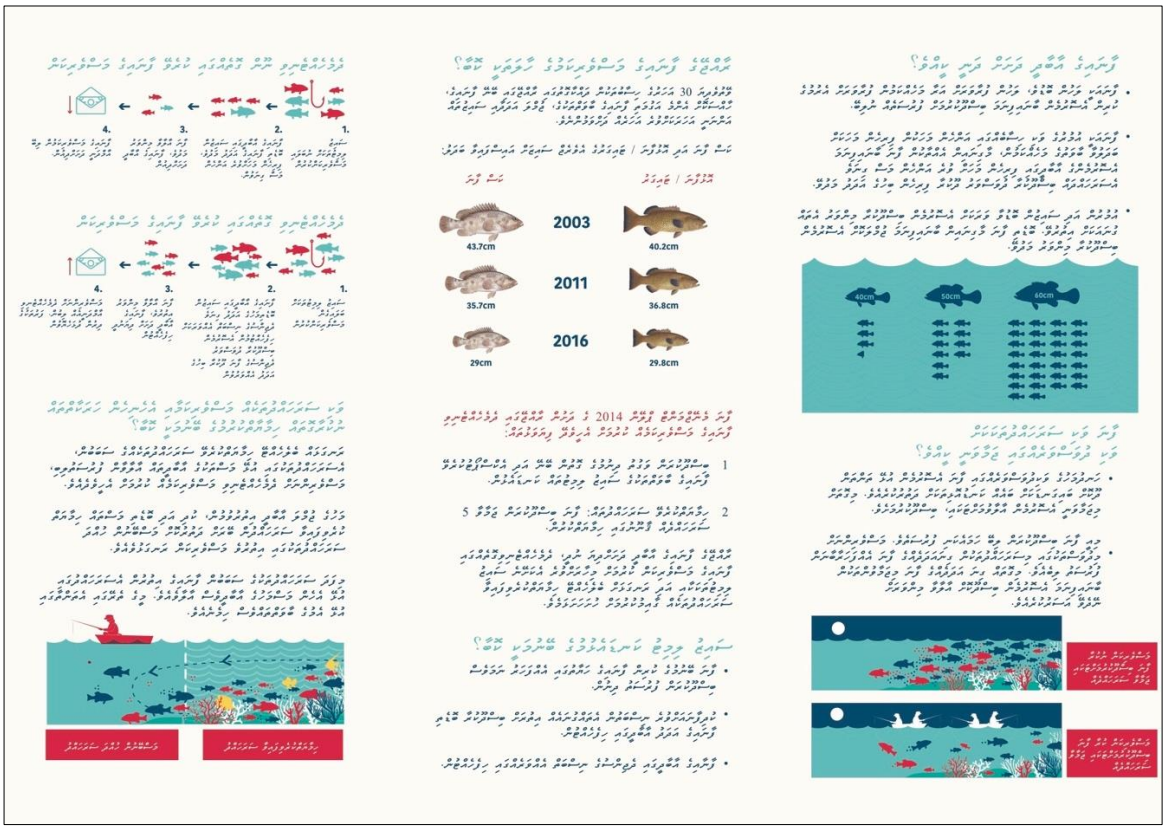
Well managed marine reserves help support local fisheries by maintaining fish stocks in the area.

As the numbers and size of fish increase within a reserve, both adults and juveniles will move out of the reserve into surrounding areas open for fishing.

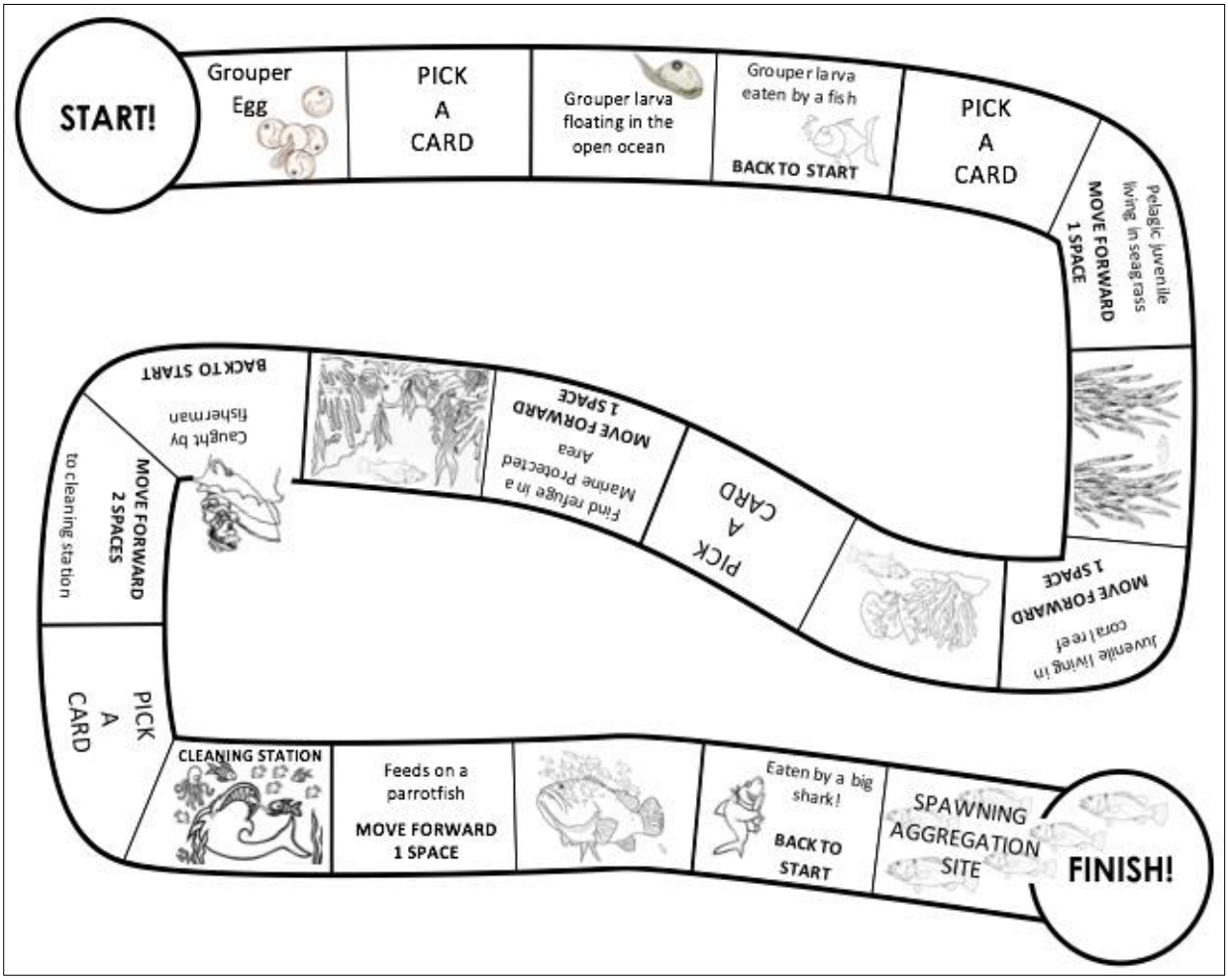
Protecting spawning aggregation sites would provide a refuge from fishing, allowing fish to spawn successfully.

Marine reserves would not only help protect grouper populations but all marine life within the area including other reef fish and bait fish.

Appendix 18. Project Educational leaflet - Dhivehi Version

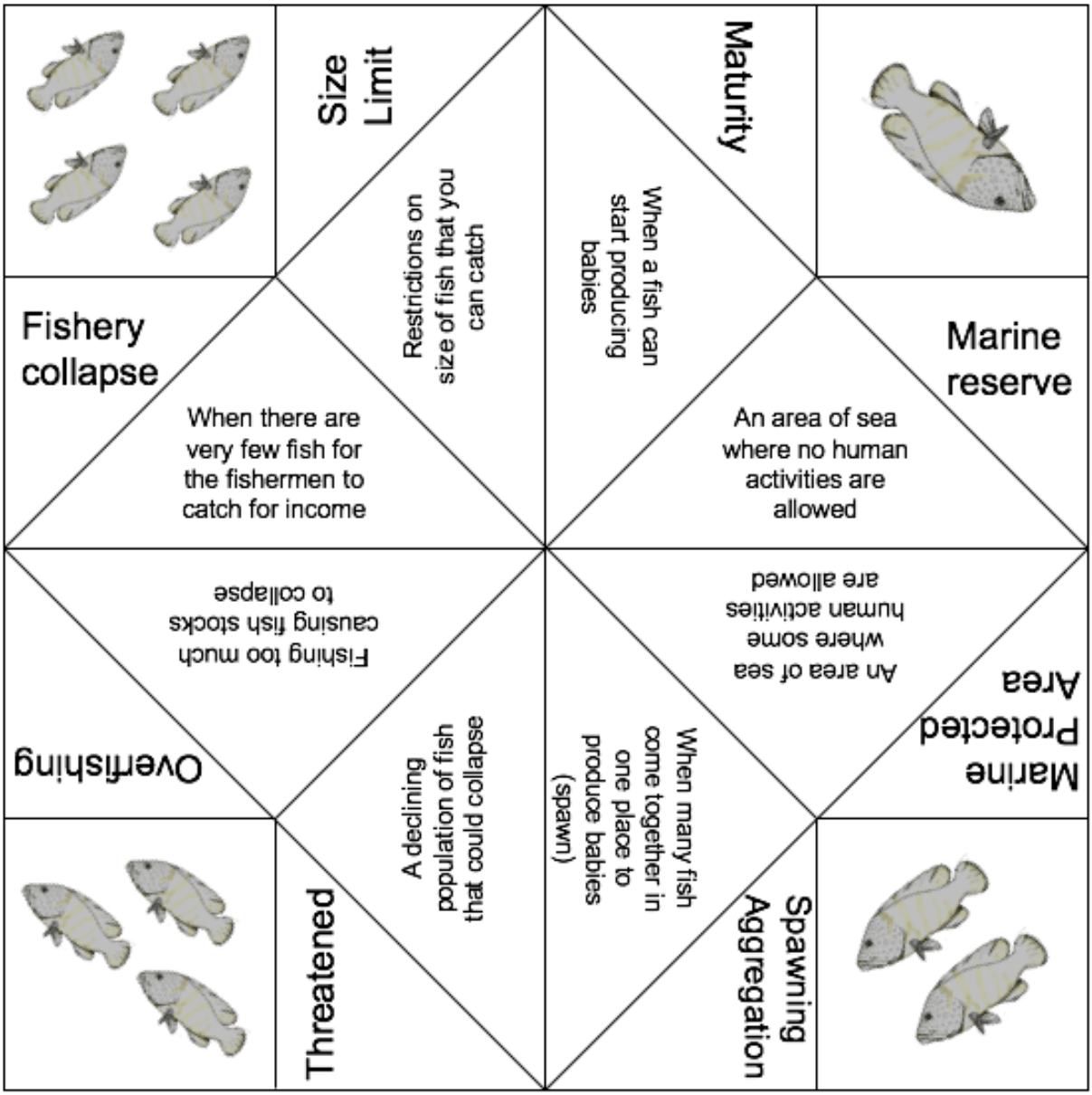


Appendix 19. Board Game[29] to Demonstrate the Life Cycle of Groupers.



[29] Locally adapted from the "Grouper Race for Survival" game from the Bahamas Reef Environmental Education Foundation, https://groupereducation.edublogs.org/files/2015/12/Grouper-Race-For-Survival-Game-247iebd.pdf

Appendix 20. Paper Fortune Teller that Reveals the Meaning of Fisheries Management Terms



Appendix 21. Detailed Summary of Environmental Education and Awareness Approaches Adopted for a Range of Target Groups

	EEA approach	Target group	Reach
1	**Information sessions** covered the following topics: 1. Ecological and economic importance of groupers; 2. Biological characteristics of groupers that make them so vulnerable to overfishing; 3. Status of grouper stocks in the Maldives; 4. Introduction to project components and approach	Local Councils	15 sessions (80+ people)
		Local Councils + school teachers	2 sessions (40 people)
		Marine Science students (Grades 8-10) from Maavah and Dhanbidhoo schools	2 sessions (70+ students)
		Local communities from 8 islands	8 sessions (350+ people)
		Government counterparts (MRC, MoFA, MEE, MNU)	4 sessions (15 people)
		Other national stakeholders (UNDP, FAO, IUCN)	3 sessions (5 people)
		Six Senses Laamu staff	14 sessions (130+ people)
		Six Senses Laamu guests	30 sessions (60+ people)
2	**Focus group information sessions** covered the following topics and delivered using multiple tools: videos, activity and games: 1. Ecological and economic importance of groupers; 2. Biological characteristics of groupers and their vulnerability to overfishing; 3. Global status of grouper stock with examples of stock decline from Fiji, Caribbean and Maldives; 4. Maldives Grouper Fishery Management Regulation; 5. Successes and failures of fisheries management interventions with examples from Fiji and Caribbean.	Fishermen from all 11 islands in Laamu	8 sessions (60+ people)
3	**Infographic leaflets** in both Dhivehi and English included information about: 1. Ecological and economic importance of groupers; 2. Vulnerability of groupers 3. Spawning aggregations 4. Fisheries management 5. Marine protected areas	Multi-stakeholder	300 leaflets distributed both locally and nationally

4	**Wall murals** to communicate fisheries management messages emphasizing the following topics: • Promoting sustainable fishing practices • Importance of protecting spawning aggregations	Maamendhoo and Dhanbidhoo communities	2 communities (combined resident population of 1500+)
5	**Internships for Maldives National University graduates/ students** Internships spanning from 10 days to 2 months for students to gain practical field experience in project activities	MNU interns	5 students
6	**Training** in the dissection and analysis of grouper reproductive organs, for size-maturity sampling	School children (Grades 8-10) from Maavah Island	35+ pupils
		Marine Research Center staff	2 staff
		MNU interns	5 interns
7	**Comprehensive modular marine education programme** in partnership with Six Senses Laamu marine team and Manta Trust. 1. Atoll formation; 2. Marine ecosystems; 3. Corals, Invertebrates and Fish; 4. Marine Reptiles and Megafauna; 5. Climate Change; 6. Fisheries Management and MPAs (BLUE led); and 7. Sustainability, Tourism and Waste Management. Module 6 involved creating locally relevant fisheries posters with the students which depicted different lifecycles, fishing gears used, threats and management measures.	School children (Grades 6-10) from Hithadhoo and Kunahandhoo Island	2 schools (75+ students)
8	**Condensed version of the marine education programme** in partnership with Six Senses Laamu marine team and Manta Trust. The following games were developed by the project team: • A board game[30] which demonstrates the life cycle of groupers.	School children (Grades 6-10) from Maavah, Fonadhoo, Gan, Mundoo, Dhanbidhoo, Maabaidhoo, Isdhoo and Kalaidhoo islands	8 sessions (375+ pupils)

[30] Locally adapted from the "Grouper Race for Survival" game from the Bahamas Reef Environmental Education Foundation, https://groupereducation.edublogs.org/files/2015/12/Grouper-Race-For-Survival-Game-247iebd.pdf

	• A paper fortune teller (a form of origami used in children's games) which revealed the meaning of fisheries management terms		
9	**Information session communicating preliminary research findings** from fishermen interviews and dive surveys.	Local grouper fishermen, government authorities, police, school teachers and national representatives	40+ people
10	**Marine Symposiums.** The team presented the research at three events: 1. Maldives Marine Science Symposium, October 2016 2. Maldives Marine Expo, September 2017 3. European Coral Reef Symposium, December 2017	In-country scientific community & general public	2 events (100 people)
		International scientific community	1 event (500 people)
11	**Films and live-videos**	Multi-stakeholder	4 videos
12	**Blog articles**	Multi-stakeholder	6 blog articles

Appendix 22. Summary of Previous Management Recommendations for the Grouper Fishery and Level of Implementation

Main Area	Source	Recommendation	Purpose	Implementing bodies	Implemented (Y/N)	Additional notes
Management bodies	Regulation 2014/R-376 Article (6)	Establishment of the Maldives Grouper Fishery Management Committee	i) Review all documents and research on grouper fisheries ii) Review proposals and decisions made at the meetings held to develop the management plan for grouper fisheries iii) To decide on the management plan and actions to be taken based on the meetings as per article 7 (a) (i) and (ii) as well as data from research and studies on grouper fishery	a) Chairperson b) Fisheries Management Agency representative c) MOFA Legal representative d) Director of MRC/or Head of MRC at the time e) Research officers with special knowledge of the Grouper Fishery f) Elected fishermen representatives g) Elected exporter representatives h) Maldives Customs Services i) Marine Police/Maritime Agencies j) Ad-hoc specialists/advisors on invitation of Council	Yes (partly)	The committee have only met once in the last four years. No annual grouper fishery stakeholder workshops have been held.
National fisheries management and policy	Regulation 2014/R-376 Article (3)	Export quota system for species most commonly exported:	To reduce and monitor the amount of grouper exported.	Not specified	Yes (partly)	The Ministry has authority to stipulate an export quota however this has not been implemented.
	Sluka (2001b)	Improved fisheries management during non-spawning times	To protect grouper stocks outside of spawning season	Not specified	Yes	Minimum catch size limits, but, these are ineffective.

	Regulation 2014/R-376 Article (4)	Establishment of minimum catch size limits	Limit the percentage of immature fish in the catch to less than 20%.	Not specified	Yes	Stipulated minimum catch size limits are too small and require revision. MRC has conducted several sessions to communicate new policies however, these educational awareness programme conducted need strengthening. There must be an increase in efforts to enhance and strengthen compliance.
Atoll -based management	Shakeel (1994)	Grouper fishing limited in each atoll according to sustainable yield.	To ensure local stocks are managed according to each atoll's sustainable yield.	Not specified	No	
Fishery monitoring	Shakeel (1994); Sattar (2005); Sattar et al., (2011)	Monitor and record catch	To ensure size of individuals caught in the fishery fall within set size limits	• Grouper fishermen • Island Councils • Grouper exporters • Marine Research Centre • Fisheries Management Agency	Yes (partly)	MRC conduct visits to grouper cages several times a year and collect CPUE data on board fishing vessels. The frequency of these trips is limited as per staff availability and budget.

	Shakeel (1994), Sattar et al., (2011)	Monitor and record exports	Validation of catch in compliance with national and international requirements	• Grouper exporters • Maldives Customs Services • Marine Research Centre • Fisheries Management Agency	No	
	Shakeel (1994); Sattar (2005)	Monitor and record fishing effort	On-going monitoring to collect data fishing effort	Marine Research Centre	Yes (partly)	MRC staff collected CPUE data on board fishing trips. The frequency of these trips is limited as per staff availability and budget.
	Sattar et al., (2011)	Cage and fish catch sampling trips	On-going monitoring to collect data on size and numbers of fish being caught	Marine Research Centre	Yes (partly)	MRC conduct visits to grouper cages several times a year and collect CPUE data on board fishing vessels.
	Sattar et al., (2011)	Surveys of grouper stock through 'Fishwatch' and National Coral Reef Monitoring Programme	On-going monitoring to collect data on abundance, size and distribution of groupers	• Private Sector: carry out in-water surveys. • Marine Research Centre: co-ordination, data analysis &reporting	Yes	Data needs to be analysed and published.

Registration and licensing	Regulation 2014/R-376 Article (8) and (9) Fisheries Act No. 4/93 of 19th April 1993	All operations in the Maldives relating to the commercial harvest and sale of groupers will be registered and licensed. This includes: a) Fishing vessels b) Sea cages/ vessels used as holding facilities /collecting vessels which travel from one Atoll to another c) Land-based holding / processing facilities d) Export companies	To monitor the numbers of vessels fishing for grouper. To ensure those who purchase licenses can be held accountable for offenses pertaining to the fishery.	Not specified	Yes	Monitoring of this needs to be strengthened. Many small-scale opportunistic reef fishermen who fish for groupers seasonally do not hold licenses.
		Conditions will be applied to the licences. These conditions will be formulated by the Grouper Fishery Management Committee and may be changed from time-to-time in response to management needs, agreed through the adaptive management approach.	To ensure conditions for licenses are agreed to in writing. To ensure license conditions are kept current and up to date if changes occur within the fishery.	Not specified	No	

Spatial management	Sluka (2001b), Sattar (2005); Sattar et al., (2011)	Protection of grouper spawning aggregation sites	To protect grouper breeding stock	Not specified	Yes (partly)	Five sites designated as marine protected areas. However, areas were fully not communicated to stakeholders and there is no enforcement so fishing still occurs within MPAs.
	Sattar (2005)	Designation of two grouper no-take zones in Faafu Atoll	To protect grouper spawning aggregation sites	Not specified	No	
	Sattar (2005)	Faafu atoll grouper management plan	• Ban all types of fishery from the 2 selected sites • Improve status of all coral reefs and their resources in Faafu Atoll • Encourage conservative use of biodiversity • Facilitate better and alternative income opportunities	• Faafu Atoll Development Committee • Representative from Ministry of Atolls Development • Two representatives from the Ministry of Fisheries and Agriculture • One fishermen from each island in Faafu	No	
	Sattar et al., (2011)	Protected area surveys	To monitor size and species composition of grouper spawning aggregations in the five designated protected areas	Marine Research Centre	No	MRC will conduct surveys using World Bank funds in 2018

Enforcement and surveillance	Sattar (2005)	Enforcement of minimum catch and export size limits	To ensure fishermen and exporters are adhering to fisheries policy.	Ministry of Fisheries and Agriculture	Yes (Partly)	MoFA conducts random bi-annual visits to Male' cages. MoFA conducts cage inspections in response to reports of cages breaching size limits.
	Sattar et al., (2011)	Penalties for purchase of fish below minimum catch size limits	1st offence - fine of MRF 50,000 and release (or confiscation) of smaller individuals in cage 2nd offence - fine of MRF 100,000 and release (or confiscation) of smaller individuals in cage 3rd offence - revoke license for 6 months and ban purchase from company cages for the duration	Not specified	No	
	Sattar et al., (2011)	Penalties for export of fish below minimum catch size limits	1st offence: value of shipment based on customs invoice and confiscate shipment 2nd offence: value of shipment x2 based on customs invoice and confiscate shipment 3rd offence - revoke license for 6 months and ban purchase and export from company cages for the duration	Not specified	No	

	Sattar et al., (2011)	Penalties for fishing in protected areas	1st offence - fine the captain of vessel by MRF 10,000 and release healthy fish and confiscate remaining 2nd offence - fine the captain of vessel by MRF 20,000 and release healthy fish and confiscate remaining 3rd offence – Send case to trial	Not specified	No	
	Sattar et al., (2011)	Licences will be renewed annually. All holding facilities which do not renew their license should be asked to cease their operations and close down/remove the holding facilities. All fishermen who do not renew their license should not be able to sell to exporters	To ensure fishermen and exporters are adhering to license conditions and are penalised if in breach of the agreement.	Not specified	Yes	
Education and awareness	Shakeel (1994); Sattar (2005)	Awareness building, Community awareness programme	To inform the community about the threats to groupers and existing management measures	Yes (Partly)	Yes	During the formulation of the Grouper Management Plan, several meetings with grouper fishermen were held and fishermen were made aware of the threats and management

						measures planned for the fishery. An awareness session was conducted by MOFA/MRC to major fishermen following their proposal to revise size limits stated in the management plan.
	Sattar (2005)	Training of MRC staff at postgraduate level	To build in country capacity	Not specified	Yes	Ahmed Najeeb (Senior Project Officer) and Fahmeeda Islam (Senior Project Officer), Nizam Ibrahim (Senior Research Officer)
	Sattar et al., (2011)	Logbook training	To ensure data on resource use is recorded in compliance with agree national and international requirements	• Grouper fishermen • Island Councils • Grouper exporters • Marine Research Centre • Fisheries Management Agency	Yes (partly)	A consultation and logbook training for 5 vessels landing near Male' was conducted in early 2014. Further training needs to be conducted.
	Sattar et al., (2011)	Data entry training	Validation of catch in compliance with national and international requirements	• Grouper exporters • Maldives Customs Services • Marine Research Centre • Fisheries Management Agency	No	

		Design and produce awareness materials / messages	To produce a range of materials / messages that will explain the purpose and benefits of managing the grouper fishery	• Marine Research Centre • Ministry of Education	Yes	This study
		Deliver outreach programme to target audiences	To ensure fishermen, public and other stakeholders are fully aware of the Management Plan and regulations.	• Marine Research Centre • NGOs • Island Councils • Ministry of Education • Ministry of Tourism	Yes	This study
Further research and science	Sattar et al., (2011)	Gonad sampling of groupers caught in the fishery and groupers at	To identify age and/or size of fish at maturation (both female and male).	Marine Research Centre	Yes	This study
	Shakeel (1994); Sattar (2005)	Experimental aquaculture	To support government's plans to build an aquaculture industry.	Not specified	Yes	MRC developing a grouper aquaculture project
	Sattar (2005)	Additional sampling and surveys to identify extent and timing of SPAGs	To identify and protect more grouper spawning aggregation sites across the country	Not specified	Yes	MRC/MCS Darwin Project; This study

Appendix 23. Recommendations and Actions to Improve the Management and Sustainability of the Maldivian Grouper Fishery

Note: Recommendations in *Italics* are measures that have been recommended previously but updated in most cases.

23.a. Protection and Management of Grouper Spawning Aggregation Sites

Note: Protection of spawning grounds was previously recommended in three different reports (Shakeel 1994; Sattar and Adam 2005; Sattar et al., 2011).

Recommendation	Purpose	Implementing bodies
Protect identified grouper spawning aggregation site(s) on Laamu Atoll Develop and implement management plan for sites involving national/local authorities and stakeholders	To safeguard grouper populations and fisher livelihoods on Laamu Atoll Use Laamu as a test case / model to develop management process for the protected site and then roll out to other atolls	• MoFA • Marine Research Centre • Ministry of Environment / EPA • Atoll Council / Island councils • Blue Marine Foundation • Six Senses Laamu Resort • Coast guard • Maldives Police • Local fishermen
Protect a minimum of one grouper spawning aggregation site on each atoll in the Maldives (implement using a phased approach as sites in each atoll are identified / verified)	Develop a network of protected sites across the Maldives that can safeguard / replenish grouper populations on each atoll	• MoFA • Marine Research Centre • Ministry of Environment / EPA • Atoll Council / Island councils • Blue Marine Foundation • Resorts on each atoll • Coast guard • Maldives Police • Local fishermen

23.b. Strengthening National Regulations

Recommendation	Purpose	Implementing bodies
Consider implementing moratoria for highly targeted species such as *Epinephelus* spp.	Prevent economic / ecological extinction of threatened grouper species	• MOFA / MRC • Atoll Fisheries Officers • Atoll / Island Councils
Implement an annual species-specific export quota system for all targeted grouper species (once species stock assessments have been completed)	To develop sustainable levels for grouper exports for the country.	• MoFA • MRC • Maldives Customs • Ministry of Economic Development
Establishment of minimum catch size limits for all targeted grouper species based on theoretical maturity lengths	To prevent the catch of undersized (immature) individuals in the fishery.	• MoFA • Fisheries Management Agency • MRC • Atoll / Island Councils
Restrict or ban the use of underwater torches during night fishing for groupers	Prevent overharvesting of groupers and 'technology creep'.	• MoFA • MRC • Atoll / Island Councils • Maldives Police
Implementation of export tariffs for the grouper fishery for both live and dead fish	To increase revenue for grouper fishery management	• MoFA • Fisheries Management Agency • MRC • Ministry of Economic Development • Maldives Customs

Reviewal and Strengthening of the Registration and Licensing System

Recommendation	Rationale	Implementing bodies
Control the number of fishing and export licenses for grouper • *All operations relating to the commercial harvest and sale of groupers to be registered and licensed fishing vessels, including:*	**To limit the number of fishers and exporters targeting groupers.**	• MoFA • Fisheries Management Agency • Marine Research Centre

cage systems, vessels used as holding facilities, collecting vessels, land-based holding / processing facilities and export companies • *Licenses to be renewed annually with strict penalties for non-compliance or operating without a license (see MCS section)* • *Grouper fishing and export licenses to have specific defined conditions and revised according to management needs, following an adaptive management approach.* • *All holding facilities without a license to cease operations.* • *Cage systems / collectors to only purchase groupers from licensed fishermen*	To monitor the numbers of fishers, vessels and companies involved in the fishery To ensure: • license holders are held accountable for infringements pertaining to the fishery • conditions for licenses reflect grouper fishery management needs.	• Ministry of Economic Development • Maldives Customs • Coast Guard • Maldives Police • Atoll/island councils • Grouper exporters • Grouper fishermen

23.c. Monitoring, Control and Surveillance

Main Area	Recommendation	Purpose and Proposed Measures	Implementing bodies / Participants
Export Fishery monitoring	Strengthen the monitoring and recording of landings to cages (to species level)	Validation of catch in compliance with national requirements Catches to be reviewed annually at Grouper Management Committee Meetings	• Grouper fishermen • Atoll / Island Councils • Grouper exporters • Marine Research Centre • Fisheries Management Agency • Maldives Police
	Monitor and record exports to species level as a licence condition for the exporter	Validation of exports in compliance with national and international requirements Export levels to be reviewed annually at Grouper Management Committee Meetings	• Grouper exporters • Maldives Customs Services • Marine Research Centre • Fisheries Management Agency • Customs Fisheries Officer
	Regular cage sampling trips	On-going monitoring to collect independent grouper catch data	• MOFA • Marine Research Centre
	Further develop the Fisher / Exporter catch app including training programmes	To train fishers, cage managers and exporters in app use, data entry and reporting. Users to record vessel details, fishing gear used, sites fished, time spent fishing, catch per species and possibly length per species	• Grouper fishermen • Cage managers/exporters • Maldives Customs • MoFA

			• Marine Research Centre • Blue Marine Foundation
Enforcement and Surveillance	*Enforcement of minimum catch size limits* Regular checks of grouper fishing and cages systems by the Atoll Fisheries Officer	To ensure fishermen and exporters comply with size limit regulations.	• MOFA / Atoll Research Officer • Marine Research Centre • Maldives Customs • Maldives Police • Atoll / Island Councils • Coastguard • Cage managers / owners • Grouper fishermen
	Random checks at grouper cage systems by MoFA/MRC staff (preferably a minimum of two visits per cage system per year)	To enforce size regulations. To maintain relationships with grouper exporters and fishermen. To disseminate information about the grouper fishery.	• MOFA • Marine Research Centre • Maldives Police • Atoll Councils • Island Councils • Grouper cage owners • Grouper fishermen
	Regular checks of grouper exports at Customs	To ensure exporters comply with size limit regulations.	• Fisheries Customs Officer • MOFA • Marine Research Centre • Maldives Customs • Maldives Police
	Penalties for purchase of fish below minimum catch size limits (cage managers/owners or collection vessels)	1st offence - fine of 100,000 MVR and release of undersize individuals in cage 2nd offence -revoke license for 12 months 3rd offence – 10-year ban from the grouper fishery	• MoFA • Marine Research Centre • Maldives Police • Atoll Councils • Island Councils • Grouper cage owners • Grouper fishermen
	Penalties for export of fish below minimum catch size limits	1st offence: fine of value of shipment x2 based on customs invoice and confiscate shipment 2nd offence: revoke export license for 12 months 3rd offence – 10-year ban on export of grouper	

	Enforcement of existing marine protected areas at grouper spawning aggregation sites: *Penalties for fishing within protected sites*	1st offence - fine of MRF 50,000 and revoke license for 6 months 2nd offence - fine of MRF 100,000 and revoke fishing license for 12 months 3rd offence – fine of 200,000 MVR and a 5-year ban from grouper fishing	• Maldives Police • Maldives National Defence Force • MoFA / Atoll Fisheries Officer • Cage owners • Fishermen • Coast guard

23.d. Management Structure / Capacity to Manage

Recommendation	Purpose	Suggested Participants
Maintenance of Maldives Grouper Management Committee • The committee to meet annually • Grant the committee power to make management decisions for the fishery	Review technical and other reports pertaining to the Grouper Fishery. Review the outcomes and recommendations made at the Annual Grouper Fishery Stakeholder Workshop. Make decisions on management measures in response to the outcomes and recommendations from the technical reports and Stakeholder Workshops.	• Chair (MoFA) • Fisheries Management Agency • MoFA legal representative • Director of MRC • MRC research officers (grouper fishery) • Blue Marine Foundation • Elected fishermen representatives • Registered grouper cage owners • Ministry of Economic Development • Maldives Customs Services • Marine Police/Maritime Agencies • Maldives Coastguard • Atoll Fisheries officers • Ad-hoc specialists/consultants
Appointment of a Senior Grouper Fishery Coordinator in MRC/MoFA	To coordinate research and MCS activities pertaining to the grouper fishery with all other relevant ministries and organisations.	• MoFA • MRC • Maldives Customs • Ministry of Economic Development
Appointment of Atoll Fisheries Officers	To lead and coordinate all fishery related matters at the atoll level.	• Atoll Council • MoFA

(propose to use Laamu Atoll as the first 'test case')	To be an intermediary between the national and local authorities and local fishermen	• MRC
Appointment of a Fisheries Enforcement Officer	To conduct detailed checks of grouper exports. To collate detailed records of grouper exports and infringements and report these to the relevant authorities	• Ministry of Fisheries and Agriculture • Marine Research Centre • Maldives Customs • Ministry of Economic Development

23.e. Communication, Education and Awareness

Recommendation	Purpose	Implementing bodies / Participants	Additional notes
Grouper Fishery Education and Awareness sessions to be held in: Faafu Atoll, Meemu Atoll, Dhaalu Atoll, Kaafu Atoll, Lhaviyani Atoll (and Laamu Atoll)	To inform communities about existing protected areas in these atolls. To communicate current/new grouper fishery regulations. To deliver educational materials explaining: • Status of the grouper fishery • Biology of groupers • Importance of spawning aggregations • Benefits of minimum size limits • Benefits of marine protected areas	• MoFA • MRC • Blue Marine Foundation • Maldives National University • Resort marine biologists • Atoll / Island Councils • Grouper cage owners • Grouper fishermen • Other fishermen • Community members	As agreed in the last management committee meeting as part of Phase 3 of the ongoing grouper project
Improve communication of fishing regulations from the national to the atoll level	Ensure that all fishers and cage managers at the atoll level are aware of the regulations and the penalties for infringements	• MoFA / Atoll Fisheries Officers • MRC • Atoll / Island Councils	

23.f. Further Research and Training

Recommendation	Purpose	Implementing bodies	Additional notes
Conduct regional / national stock assessments of targeted groupers	Update catch and export quota limits for species on a regular basis	• MoFA / MRC • External consultancy?	Factor in grouper mortality in cage systems for catch and export quotas
Conduct dive surveys at five existing grouper spawning aggregation sites	Collect data to verify aggregations and monitor them for adaptive management	• Marine Research Centre • Blue Marine Foundation • Maldives National University	
Conduct fisher surveys in atolls not previously assessed	Collect fisher knowledge on fishing practices and spawning aggregation sites	• Marine Research Centre • Blue Marine Foundation • Maldives National University	
Conduct satellite research across the Maldives	To identify probably grouper spawning aggregation sites across the whole of Maldives at minimum cost and time	• MoFA • Marine Research Centre • Blue Marine Foundation • Maldives National University	Potential to partner with a foreign academic institution for research.
Conduct grouper spawning aggregation site dive surveys in all other atolls	Verification of at least one grouper spawning aggregation in each atoll Determine grouper spawning patterns across the Maldives	• MoFA • Marine Research Centre • Blue Marine Foundation • Maldives National University • Resort marine biologists	Request resorts in these atolls to assist with or conduct surveys. Training programmes to be developed and organised by BLUE and MRC
Improve national assessment of grouper populations through 'Fishwatch' and National Coral Reef Monitoring Programme	On-going monitoring to collect data on abundance, size and distribution of groupers	• Resorts: carry out in-water surveys. • MRC: co-ordination, data analysis and reporting	MRC to encourage more resorts to contribute data via their newly appointed resort liaison officers
Collect data to define maximum size limits for all targeted species and facilitate a 'slot-fishing' approach	Provide evidence to set maximum size limits for targeted groupers	• MoFA • Marine Research Centre • Blue Marine Foundation • Maldives National University	May need advice from external experts

Develop grouper tagging studies for known aggregation sites	Determine migration pathways to inform marine reserve planning	• MoFA • Marine Research Centre • Blue Marine Foundation • Maldives National University	
Conduct research to improve survival and condition of grouper in holding cage facilities	To reduce grouper mortality rates in cages and wastage in. the fishery	• Marine Research Centre • MoFA	
Training of MRC staff to the postgraduate level	Increase technical capacity for MRC / Maldives fisheries management	• Blue Marine Foundation • Marine Research Centre	
Increase in-country capacity for marine resource management and conservation	Internships or work placements to be developed for MNU students to gain field and technical experience Opportunities to be provided for MNU students to assist on government or collaborative project research trips.	• Maldives National University • MoFA • Ministry of Environment • Marine Research Centre • Blue Marine Foundation • Resorts • NGO's	