NATURE CONSERVATION FOUNDATION

The status and growth of a coral reef fishery targeting groupers (Epinephelids) in the Lakshadweep archipelago, India

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EXECUTIVE SUMMARY

In the emerging Anthropocene epoch, coral reefs are beleaguered by human-induced disturbances, ranging from climate-change, hunting, resource exploitation, habitat degradation, pollution etc. While it can be argued that coral reefs have sustained overfishing and pollution for centuries, these are now fast spreading to the remotest of reefs, where local pressures have been largely absent (Heron et al., 2016). On the other hand, climate change is turning out to be the ultimate leveller – indiscriminately affecting regions of even varying management regimes. Under this duress, some groups of species are more affected than others, resulting in an unraveling of species assemblages to previously unseen assemblage configurations (Graham et al.,2014). Caught at the cross-section between local fishing, and global climate-related, habitat disturbances are benthic top predatory fish like groupers (epinephelids), an ecologically and commercially important but highly vulnerable reef fish guild (Craig et al., 2011; Sadovy de Mitcheson et al., 2013).

It is rare to find regions of high human population density, where environmental impacts and reef fishing pressure are relatively low. Up until 2013, the Lakshadweep archipelago in the Northern Indian Ocean was one such unique region. Until very recently, commercial fisheries in Lakshadweep were focused entirely on offshore tuna (Arthur 2000). With the support of the local Fisheries Department, fishers were actively trained in live-bait fishing with pole and line, targeted primarily towards skipjack and yellow-fin tuna. One upshot of this commercial pelagic fishery was that it greatly reduced fishing pressure on the nearshore coral reef (Arthur and Done 2005). Despite Lakshadweep being one of the most densely populated territories in India, the focus on tuna fishing ensured healthy and abundant near-shore coral reef fish assemblages. In the aftermath of catastrophic coral mass mortalities, like the ones documented in 1998 and 2010, healthy fish populations were cited as critical for enhancing reef resilience and rapid recovery from these disturbances (Arthur et al. 2008).

However, benthic reef fish are highly susceptible to habitat degradation and a rapid recovery of reefs from disturbances does not guarantee the recovery of fish populations. In our earlier studies, we documented the response of benthic predatory groupers to repeated mass-bleaching disturbances in the Lakshadweep archipelago (Karkarey et al 2014). A critical finding was that rapid coral recovery from mass-bleaching disturbances does not guarantee the recovery of populations of long-lived grouper species in reefs. Even highly adaptable species like the peacock grouper (*Cephalopholis argus*) experience significant adverse demographic and physiological consequences in degraded reefs (Karkarey et al., 2017a). Another study from the region (Alonso et al. 2016), showed that extinction risk from habitat degradation is highest for top predatory fish. Thus far, our understanding of fish responses to habitat degradation was based on the assumption that the Lakshadweep supported very low levels of reef fishing pressure, allowing us to assess the impacts of climate-change disturbances on reef fish independently of anthropogenic pressure. It appears that

even the lack of commercial reef fisheries cannot stem the losses of top predatory fish in Lakshadweep to repeated climate-change disturbances.

In 2011, we documented a unique, high-density spawning aggregation of squaretail groupers (*Plectropomus areolatus*) in one of the islands in Lakshadweep. In this unfished spawning aggregation, aggregation density was found to be among the highest across the Indo-Pacific for squaretail groupers. More interestingly, from this high-density population we reported rare alternative mating behaviours (Karkarey et al. 2017b). Considering the uniqueness of the aggregation, we worked with local fishermen, the local governing council (Village Panchayat) and the Lakshadweep Fisheries Department towards the protection and management of the fish spawning aggregation. As a result of a local collaborative effort, the squaretail grouper spawning aggregation has been protected by means of a temporal fishing closure since 2014. While compliance of the closure appears to be high, our ongoing monitoring of the aggregating population is suggesting sharp population declines, leading us to re-evaluate management strategies in the light of a new understanding of changing fisheries practices.

Commercial fisheries in Lakshadweep today are on the cusp of a major shift from a predominantly offshore tuna fishery, to a near-shore reef fishery. Top predatory fish like groupers (epinephelids) appear to be at the crux of this transitioning fishery. Given the susceptibility of functionally important predatory fish to climate-change disturbances, uncontrolled fishing can be catastrophic for their populations. This transition threatens not only reef resilience but will also have unforeseen consequences for the livelihoods of the dependent fishing community and island biosecurity. This study was undertaken as a preliminary assessment of transitioning fisheries in the Lakshadweep. The main goal of the study was to document the current status, growth over a decade and the socio-economic drivers underlying a shift towards commercial reef fishing in the Lakshadweep.

OBJECTIVES

The main objectives of this study were to understand key aspects of Lakshadweep's changing fisheries, particularly;

1. How prevalent is reef fishing compared to the historically dominant pelagic tuna fisheries?
2. What is the difference in the cost of reef and tuna fishing operations?
3. How do market linkages (local and export) of reef and tuna fisheries differ?
4. What are the patterns and differences in the local catch and consumption of reef fish in the islands?

METHODS

Study area

The study was conducted in the Lakshadweep archipelago, which is situated in the Arabian Sea in the south western coast of the Indian subcontinent. The total land area of all the islands in total is 32 sq. km and the lagoon area covers 4200 sq. km. Lakshadweep consist of 12 atolls, 3 reefs and 5 submerged banks. Interestingly, Lakshadweep constitutes the only atoll formation in India and is the northern-most portion of the

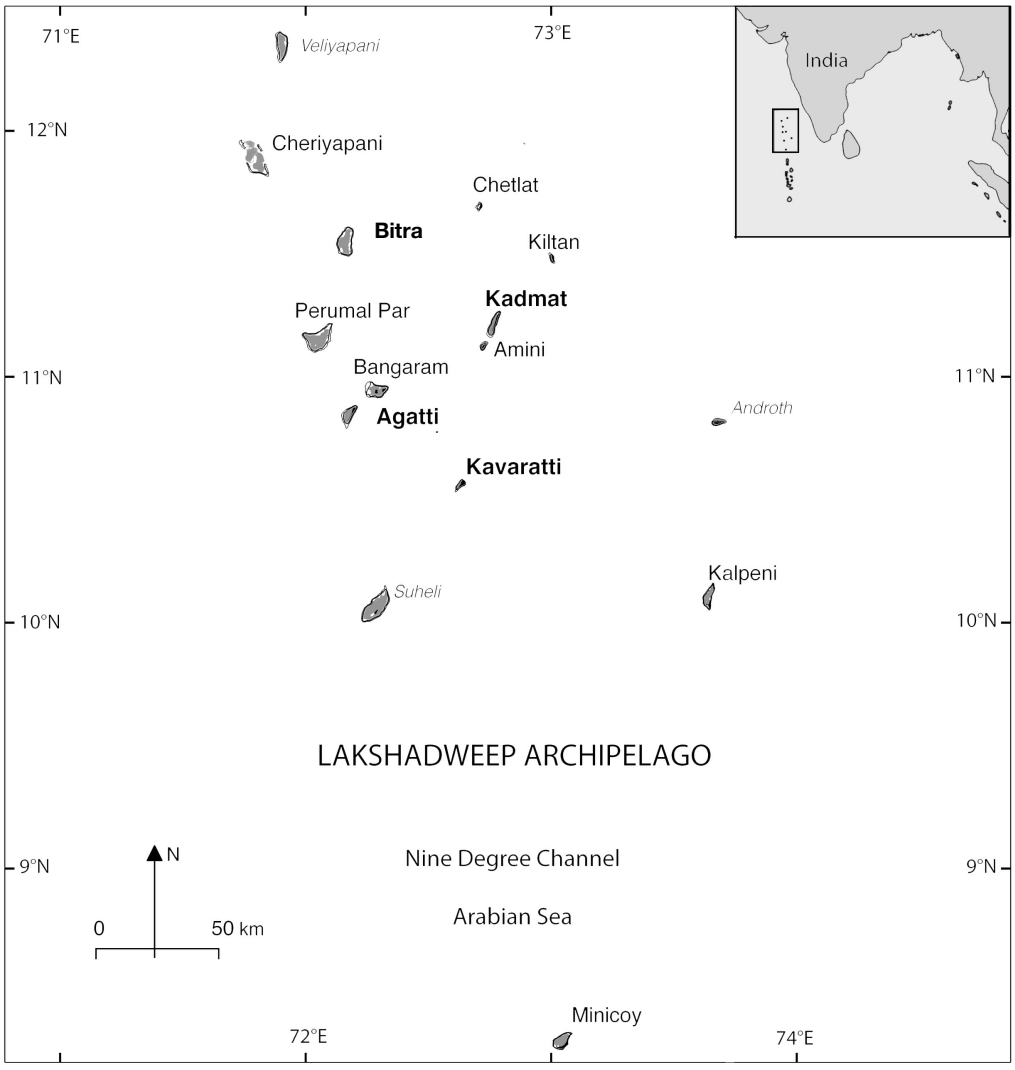

Figure 1: Map of the Lakshadweep archipelago. The study was conducted in the islands indicated in bold text.

Chagos-Maldives-Laccadive oceanic ridge. Lakshadweep is the smallest Union Territory in India and is

declared as a no industry area by the government of India because of its environmental limitation. The major source of income is from fisheries. Fisheries of Lakshadweep can be broadly divided as tuna fisheries and non-tuna fisheries comprising reef fish, reef-associated fish, pelagic fish other than tuna, rays etc. Of all types of fisheries, over 90% of catch is from pelagic fisheries. It is estimated that 13% of the total population in Lakshadweep are active full time fishermen and 60% of the population is directly dependent on the fisheries sector (Zacharia 2007). Most people with other jobs also engage in subsistence fishing.

Approach

The idea behind conducting the reef fish catch surveys was to estimate how much reef fish is being commercially caught and what is the fate of the catch (whether it is being sold in the islands or being exported to the mainland). We conducted a structured interview survey with local fishermen to estimate reef fish catch. In addition, we conducted separate surveys with household consumers to estimate consumption of reef fish on the islands. From these two surveys, we were able to estimate the proportion of fish that is consumed on the island from total fish caught, assuming that all the rest is exported to the mainland. Independently, we conducted a preliminary survey of seafood exporting companies on the mainland who collect and distribute fish from the Lakshadweep along with other places along the mainland coast.

The study was conducted in four atolls : Agatti, Kavaratti, Kadmat and Bitra (Figure 1). The atolls are sites of a long-term monitoring study (of underwater fish and benthic condition) conducted by the Nature Conservation Foundation since 1998. The study was conducted between December (2016) and April (2017) in Lakshadweep, which forms the peak fishing season in Lakshadweep. May-September is the monsoon season and is a lean fishing period where fishing is largely concentrated within the lagoons. A survey of mainland seafood exporting agents was conducted during the lean fishing period, ie. between August - November (2017).

Types of boats: We broadly divided the types of fishing boats in Lakshadweep into two types (1) commercial boats; and (2) mother boats. Commercial boats are both mechanized and non-mechanized (row) boats which sell catch either locally within the islands of Lakshadweep or to Motherboats for export to the mainland. We sampled 15-20% of the total number of registered boats in every atoll. Local commercial boats are typically designed to catch fresh tuna and do not have long-term storage facilities. We referred to those commercial fishing boats that had huge storage capacities (> 10 tonne) as Motherboats, which have only recently started operating in Lakshadweep. These boats collect fish from local fishermen and transport the catch to the mainland markets. Few motorboats fish directly. Motherboats have a unique ownership model, where they are registered locally but are owned by individuals/ companies on the mainland. Motherboats travel between islands to collect fish from local fishermen often operating out of uninhabited islands and sunken banks. It is therefore difficult to find them in the islands where they are registered. A total of 250 commercial fishermen were interviewed between December 2016 and April 2017, from the four islands. Two rounds of interviews were conducted (December-January & March- April) to capture variation in catches across the peak fishing

season. A similar study was piloted in 2014. Both small and large-scale local fishermen (with mechanized and non-mechanized boats) were interviewed (n=71 in 2014 and n=250 in 2017). A total of 11 motorboats were interviewed in this study.

Estimating reef fish catch

Selection of respondents:

Commercial boat interviews: One of our main objectives was to enumerate the catch of reef fish from the Lakshadweep archipelago. There are no centralized fish landing centres and fish markets in the atolls. Most of the local boats directly land their catch on the beach where their boats are anchored. As a result, it is logistically difficult and very effort intensive (in terms of time and people required) to directly sample enough catches from every atoll to get a usable sample size. We therefore used an interview-based approach to estimate catches. Fishermen were well aware of catch composition of their recent trips and many times even keep logs of their catches. We conducted our interviews from 7:00 AM to 10:00 AM in the morning and from 4:30 PM to 6:30 PM in the evening, as this seemed to be the time when fishermen were available on the islands. We interviewed fishermen either close to their landing sites or in their houses. Interviews were conducted in the local language of Malayalam. We focused on fishermen who were actively fishing in that season.

Motherboat interviews: The motherboat interviews we designed as opportunistic interviews. As mentioned earlier they mostly operate out of uninhabited atolls and are difficult to trace on the inhabited islands. Whenever a mother boat was anchored in an island where we were, we tried to conduct an interview. In addition we also used a snowball sampling approach, where local fishermen introduced us to the mother\boat operators they worked for.

Questionnaire:

For commercial boasts, the questionnaire was designed to have four main parts. The first set of questions documented basic information about the interviewee, like age, main occupation, and family size. The second set of questions were about the reef fishes that they caught over the last fortnight, specifically the name (local), size, weight and number of species that were caught. We ask them to show the size of fish that they caught on a measuring tape. The third set of questions was about their fishing operations- the type of boat (Mechanized/non-mechanized, size of boat), gear and hook size used, and the usual area in the reef where fished regularly. To get a sense of changes over a decadal time scale, we asked questions about the availability of reef fish and changes in fishing locations over time. The last set of question was about the economics of fishing. The type of boat used, engine power, cost and quantity of fuel used per trip, the size of crew and the wage distribution among crew.

For motherboats we asked two sets of questions. Firstly, we asked about the details of species of fishes caught like price and quantity caught/purchased per trip. The next set of questions broadly explored market links and markets trends of Lakshadweep reef fish.

Estimating reef fish consumption

Our other major objective was to determine the local consumption of reef fish within the atolls. The reef fish catch and consumption surveys were conducted simultaneously on the same four atolls. For the reef fish consumption survey, we chose households as a sampling unit. We found out the total number of households in an atoll from the most recent population census data (2011). We sampled 2-10%% of the total number of households in every atolls.

Selection of respondents:
We used a stratified sampling approach to survey households. The islands have a north-south distribution of landmass, where the north part is broadest and it tapers off towards the south. We broadly divided atolls into 3 zones; northern, central and southern. The proportion of respondents selected from each zone was based on the proportion of area in each zone. This was done under an assumption that because of general high density in the islands, the number of households per unit area in any part of island is comparable. The choice of respondents was haphazard in nature with no prior biases (ie. men or women). We interviewed people in or near their houses between 7:00 AM to 10:00 AM in the morning and from 6:30 PM onwards in the evening.

Questionnaire:
In the interviews we asked questions about the basic information about the household like, number of members, main source of income, whether they were local or not. In the next set of question we asked about the reef fish that they consumed over the last fortnight- specifically name (local), size, weight, and number of times that they consumed that fish in last two weeks. We showed them a measuring tape to estimate size of each fish that they consumed. If they were unfamiliar with the name of species, we showed them a pictorial representation of local reef fishes. In the next set of questions we also attempted to understand local dietary preferences and the reason why they picked a specific fish for consumption. Questions were also asked about the source of the fish (ie. whether sources from a market, landing site or whether they caught it themselves).

RESULTS AND DISCUSSION

From a primary investigation of reef fisheries in the Lakshadweep archipelago conducted in 2016-2017, it is abundantly clear that commercial reef fisheries in the islands have grown rapidly since 2011 and are beginning to offset the traditional pole-and line pelagic tuna fishery in the Lakshadweep. The burgeoning reef fishery is largely catering to an export market, with very little input into local seafood consumption. The scale and unregulated nature of reef fisheries in Lakshadweep is threatening populations of predatory fish like groupers in the islands with potential future consequences for livelihoods and biosecurity of the dependent community. Some of the main findings of our study are summarised in the section below.

1. The prevalence of commercial reef fisheries

As per our initial understanding (prior to 2011), reef fishing was undertaken by fishermen of non-mechanised, row boats (artisanal fishermen) or from land, and was largely subsistence in nature (Tamelander and Hoon, 2008; Arthur et el. 2008). Mechanised boats were built primarily for tuna fishing and were heavily subsidised by the Fisheries Department to promote the pelagic tuna fishery. These mechanised boats only occasionally engaged in fishing off the reef, at times when tuna were unavailable. An earlier preliminary survey of reef fishing conducted in 2014 attested to this, where over 90% of fishermen interviewed (n=71) across four islands (Agatti, Kavaratti, Kadmat and Bitra) engaged only in tuna fishing, with the remaining 10% fishing facultatively off the reef, only in times of low tuna availability.

Behaviour of fishermen

In this survey, we classified the type of boat used for reef fishing as – mechanised boats (tuna boats) fishing on the reef, and row boats fishing on the reef. Row boats do not go for tuna fishing. However, within the mechanised tuna boats, fishing behaviour can be classified into three broad types – boats that only catch tuna, boats that only catch reef fish, and boats that may catch both.

Within this classification, we found that the proportion of boats engaging in reef and tuna fishing varies a lot between islands (Figure 2). The proportion of sampled mechanised boats engaged exclusively in tuna fishing is highest in Kavaratti (88%) followed by Agatti (50%), then Bitra (25%) and Kadmat (16%). Contrastingly, the proportion of sampled mechanised boats engaged exclusively in reef fisheries is highest in Bitra (75%), followed by Kadmat (50%), Agatti (22%), and no boats in Kavaratti were found to exclusively fish for reef fish. These differential pattern of reef versus tuna fishing could be reflective of the access to reef catchment areas around different atolls. For example, Bitra is a small atoll with a large enclosing lagoon and coral reef, in the northernmost part of Lakshadweep. It is also close to several submerged banks and uninhabited atolls in the northern fringes of Lakshadweep. Historically, Bitra has been an important resource catchment area (primarily for tuna) for locals from different atolls within Lakshadweep. Currently, it's large reef area and proximity to other

reefs is drawing the attention of reef fishermen. Similarly, Kadmat, being centrally located in the archipelago is conveniently located close to several catchment areas (Pitti, Amini reef, Bitra, Perumal par) and proximity to reef fishing resources likely determines the switch in fishing behaviour.

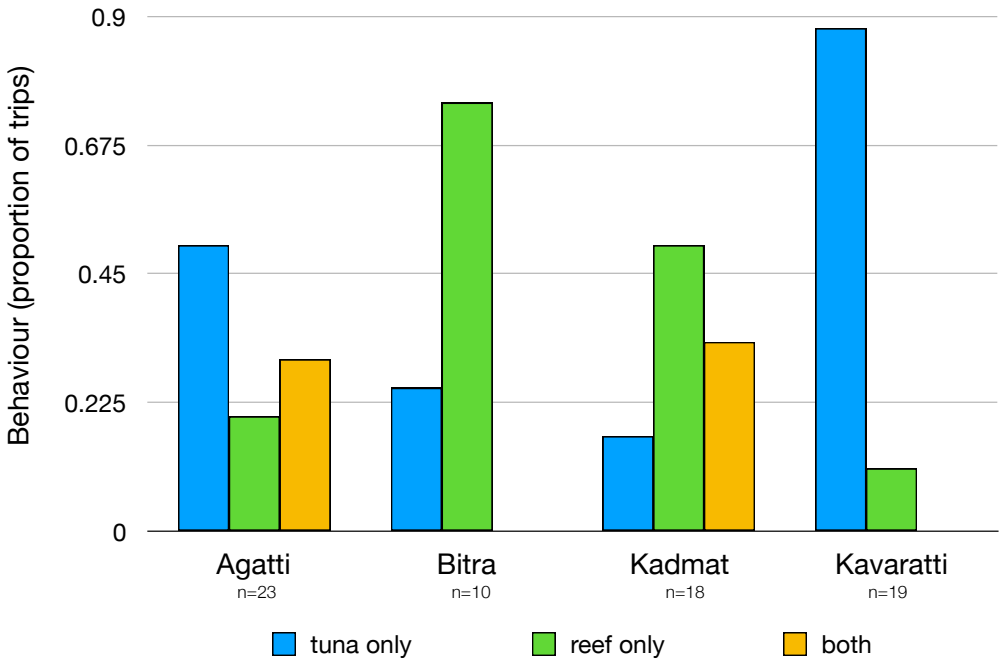

Figure 2. Fishermen behaviour. Proportion of mechanised boat going fishing exclusively for tuna or reef or for both in different islands.

In 2017, it upto 30% of boats are facultatively fishing for reef fish, which appears to have increased (from 10%) since 2014. In most cases, reef fishing was conducted on the same day as a tuna fishing trip, as the boat returned back to the island. This is a major shift in behaviour since 2014, where fishermen fished commercially for reef fish only when tuna were unavailable.

Effort

Fishing effort (number of trips per fortnight) varies a lot between boats that fish only for tuna, reef fish or both. Among the boats which fish exclusively for tuna, the effort is very consistent in all the islands of about 10-13 trips per fortnight. Whereas among the boats which engage exclusively in reef fishing it varies a lot - It is minimum in Agatti (2 trips/fortnight), while it is maximum in Bitra (~6 trips/fortnight). This difference can be explained because fishermen in Bitra fish around the atoll, while those of Agatti and other atolls make day trips to distant uninhabited atolls and banks for fishing. In many cases, reef fishing trips are multi-day trips. Contrastingly, fishermen using small row boats in reefs close to all atolls, fish upto 6 days per fortnight.

Local catch of reef fish

Of the many species of reef fish that are caught locally (see consumption section below), three fish families dominate the commercial catch that is exported to the mainland - groupers (epinephelids), snappers (lutjanids, red snappers and paddle tail snappers) and emperors (lethrinids) making up for nearly 95% of total exported reef fish catch.

Cost of reef fishing

At the moment, reef fishing appears to be far more cost effective than tuna fishing, despite heavy governmental subsidies available for the latter.

Fuel: The clearest difference lies in the amount of fuel used per trip - boats engaged in reef fishing require half the amount of fuel used by boats that are engaged exclusively in tuna fishing. This could predominantly be due to the way fishing is conducted for reef fish and for tuna. For tuna there is a large “search effort” involved

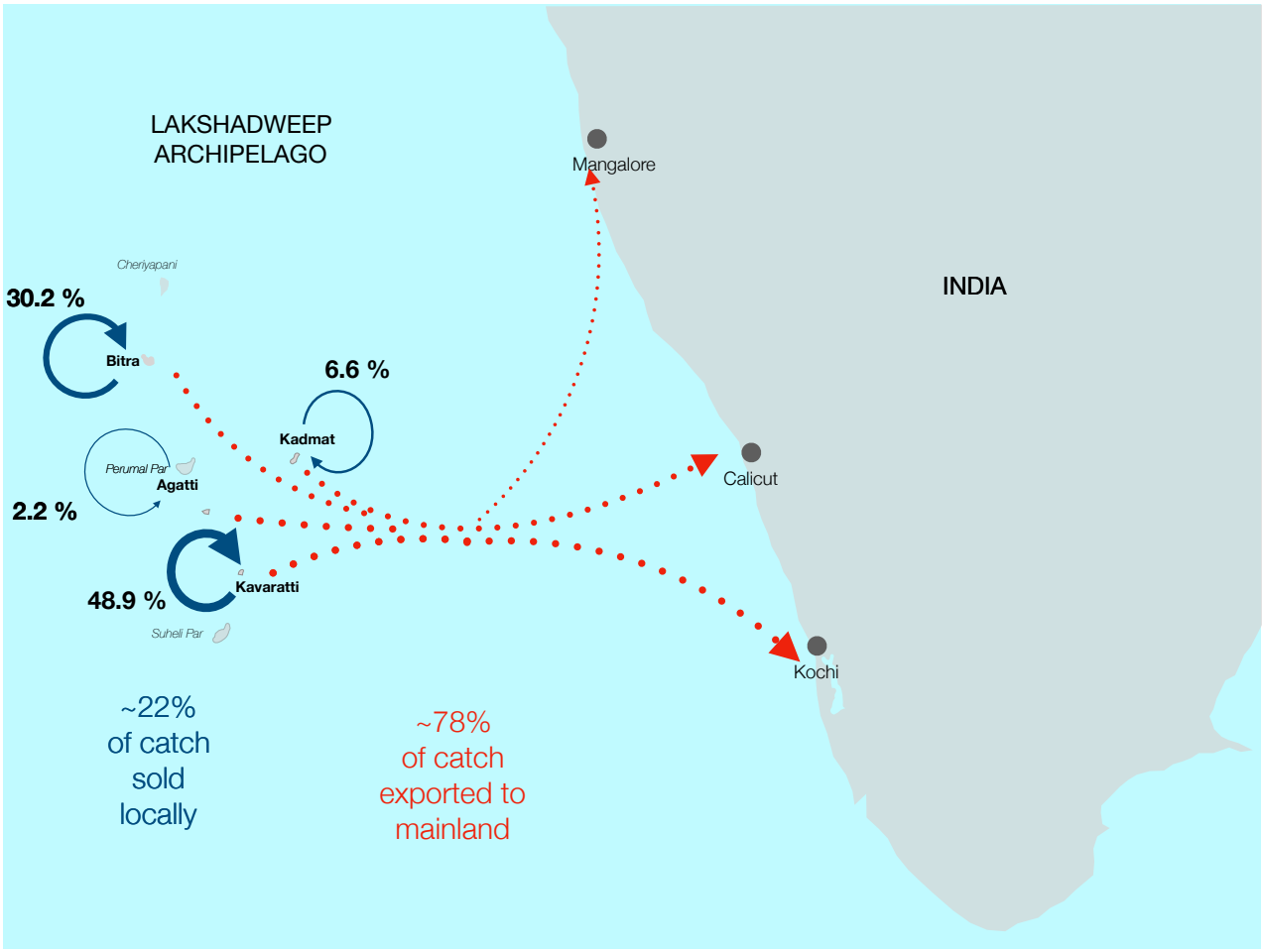

Figure 3. The percentage of total reef catch (groupers, snappers and emperors) sold locally (blue arrows) and exported to the mainland (red). The thickness of arrows indicates relative proportion of catch.

around the islands and nearby fish aggregation devices (FADS), which is fuel heavy. On the other hand, reef fishing is spatially limited to near-shore reefs for which the search effort is much lower. Additionally, row boats that are engaged in reef fishing have no fuel requirements and are therefore highly cost effective.
Crew size: The average crew sizes are similar for mechanised boats fishing for tuna, reef fish or both but is as low as 2 persons on average for row boats. The main difference between costs of mechanised boats and row boats also comes up in profit sharing arrangements – in row boats, all members divide the profits equally, whereas in mechanised boats, half the profits are given to the owner of the boat, while the remaining half are divided equally between all the crew members.

Fate of the reef fish catch

In the Lakshadweep islands, apart from selling it fresh, fish may be processed in three different ways – icing, sun-drying and as *mas*. *Mas* is a process of salting and drying used only for skipjack tuna. This process is time and effort intensive - taking 3-4 weeks or more and large initial investments for equipment. Only half of the tuna caught is sold fresh and the rest is processed into *Mas,* which is often stocked and sold in batches. On the other hand, 88% of reef fish is sold fresh, thereby eliminating time and costs of processing and guaranteeing instant cash with each exchange.

Some reef fish are sun-dried and sold as dried fish locally and to the maniland.

We analysed the markets links for reef fish in the Lakshadweep (Figure 3). We found that on an average 78% of the total reef fish catch is exported to the mainland, while only 22% is sold locally. The proportion of catch sold locally varies between islands - 50% of reef fish caught by Kavaratti boats is sold locally, while only 3% of reef fish caught by Agatti boats is sold locally. The unusually large market for reef fish in Kavaratti is explained in the consumption section below.

It is abundantly clear that the commercial reef fishery in Lakshadweep is catering largely to a demand from the mainland. The price of groupers exported for instance, has more than tripled (250rs/kg) since 2014, but locally it has remained more or less constant (60rs/kg), or even declined (~40rs/kg). On the mainland, the main collection centres for reef fish from Lakshadweep appear to be in Mangalore and Calicut. But the fate of the fish from these ports is less clear (what proportion is exported versus consumed on the mainland). Fish appear to be exported to the Middle-East, USA and Europe from these ports.
Both fresh and processed fish are being carried back to the mainland by motorboats and are landed at the main ports. Many fishermen and local agents also export fish to individual agents on the mainland via passenger ship and potentially air freight.

A typical catch of reef fish sold to the motorboats. Catch comprises of groupers, snappers and emperors caught using hook and line.

Local consumption of reef fish

Comparing the local consumption of the three commercially exploited fish families (i.e. groupers, snappers and emperors), we found that less than 5% of the catch of these species is consumed locally (Figure 4). Instead, a diverse range of reef fish are preferred and consumed locally (Figure 5), ranging from groupers, surgeonfish, jacks, needlefish, goatfish, silverbiddies, mackerel, snappers, wrasses and halfbeaks. The diversity of fish consumed is highest in Kavaratti as compared to the other islands. Kavaratti is the capital island in Lakshadweep and supports a very high migrant population that is dependent on local fishermen.
In many other atolls, independently of full-time fishermen, people in other professions also engage in fishing - in the lagoon using nets or cast lines from the beach and jetties. These small-scale fishing incidents were largely overlooked by our study, that focused largely on understanding the pressure exerted by commercial fishing crafts. Thus, our estimates of reef fish catch may be much lower than that estimated, because we have overlooked subsistence and artisanal fishermen in the islands that can have a potentially large impact on local consumption (Tamelander and Hoon, 2008). In our consumption interviews too, several respondents were identified as subsistence fishermen and many rare fish were eaten that were not reflected in the commercial fish catch. These rare fish were caught mostly by the subsistence fishermen and have been excluded from our analysis. A future monitoring strategy needs to capture the extent of both commercial and subsistence reef fishing in these islands.

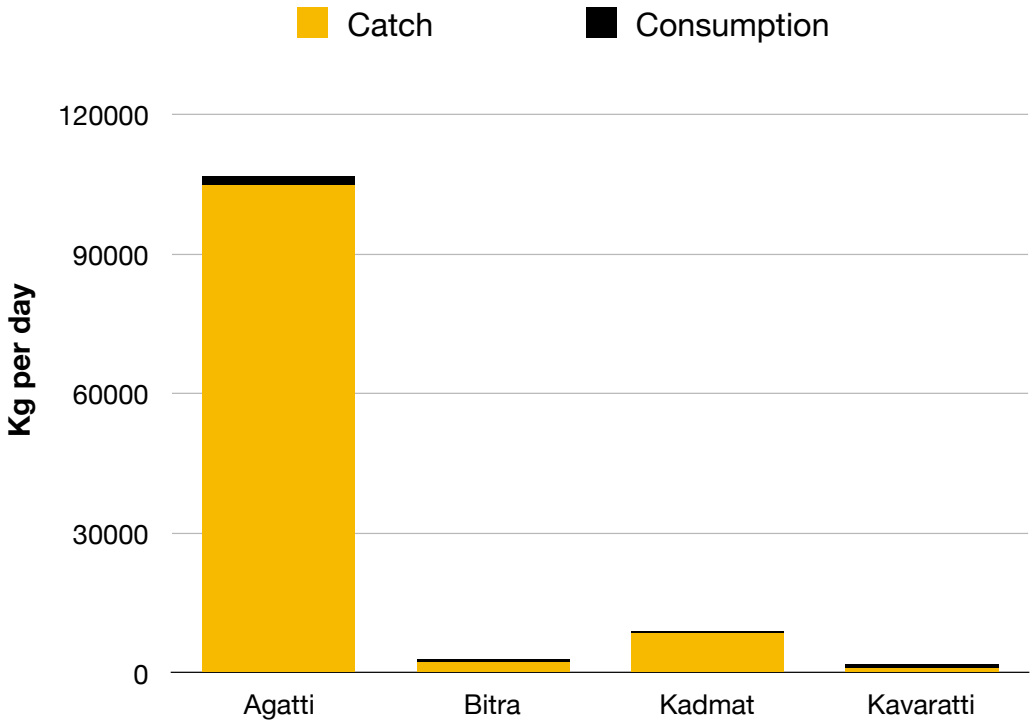

Figure 4. Total catch and total consumption of three fish families (groupers, snappers and emperors) that make up for 95% of the exported catch.

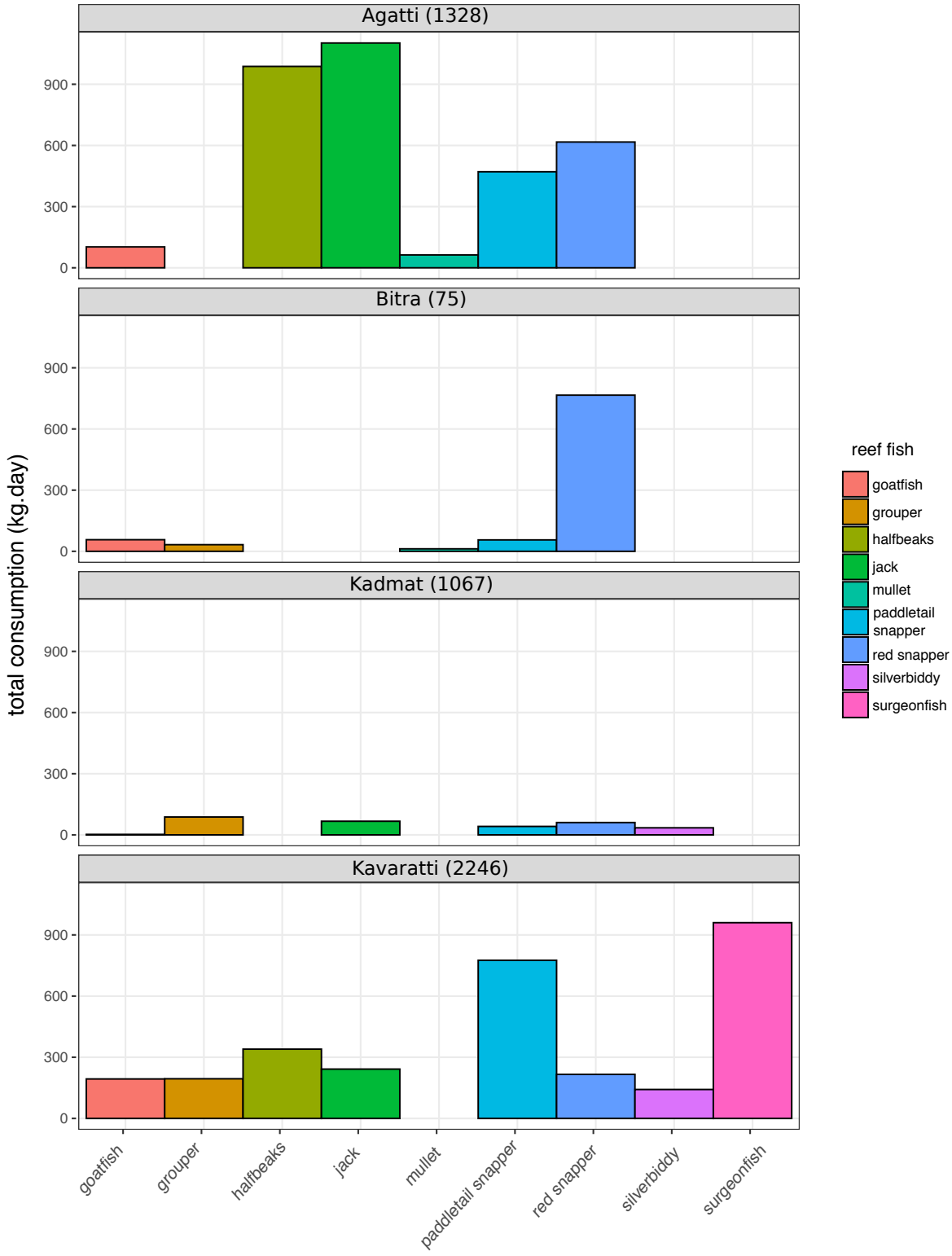

Figure 5. Daily total consumption of different reef fish families in islands. Numbers in front of island names indicate the number of households in the islands.

While it may appear that the consumption of reef fish is very high within the islands, locally people still consume tuna nearly70% of the time. The patterns reported above represent only 30% of the period when reef fish were consumed. The proportional consumption of reef fish (in relation to tuna) has increased from 10 to 30% across the islands since 2014.

Fate of the squaretail grouper spawning aggregation

The squaretail grouper spawning aggregation observed in early 2012.

The Lakshadweep archipelago is the only place in India, where grouper spawning aggregations are proactively protected by the local community and the Lakshadweep administration, by means of seasonal fishing closures.

Since 2011, our team has been monitoring the densities and behaviours of a unique squaretail grouper (*Plectropomus areolatus*) spawning aggregation at Bitra, one of the northernmost atolls of Lakshadweep . We found that when this aggregation was unfished between 2011-2013, it was one of the largest aggregations of squaretail groupers in the tropical Indian Ocean. In this high-density and 'pristine' state, we observed a novel mating behaviour in the aggregation, called 'shoal spawning' – where large males spawned with a group of females in large shoals in the water column. This was an alternative reproductive tactic (ART) in addition to the commonly observed 'pair spawning' tactic seen in squaretail grouper spawning aggregations globally.

In early 2013, we observed a change in reef fishing practices in Lakshadweep which posed a threat to the squaretail grouper aggregation. Therefore, to protect this unique aggregation against a steadily growing reef

fishery in the Lakshadweep, we worked closely with the local community, the Lakshadweep Fisheries Department, Department of Science and Technology and the Lakshadweep Administration to set up a seasonal fishing closure in Bitra, which restricted commercial fishing of the spawning site during critical spawning periods. For the last four years, the local governing council (*Village Panchayat*) together with the Lakshadweep Fisheries Department has been managing commercial fishing activity on the reefs of Bitra Island (where the spawning aggregation is located) for five days (new moon period) of every month during the squaretail grouper spawning season (December-April), by issuing an official Fisheries Order.

In January 2017 (four years after the seasonal fishing closures were initiated), we wanted to evaluate the effectiveness of the seasonal fishing closure in protecting the spawning aggregation from fishing. To this end, we conducted extensive fishermen interviews across four main fishing islands (Kavaratti, Kadmat, Agatti and Bitra) to understand changes in reef fishing pressure and practices since 2000. Apart from the fisheries surveys mentioned in this report, our team has been annually monitoring the squaretail grouper spawning aggregation in Bitra since 2011. The aggregation is annually monitored in January and February, during the

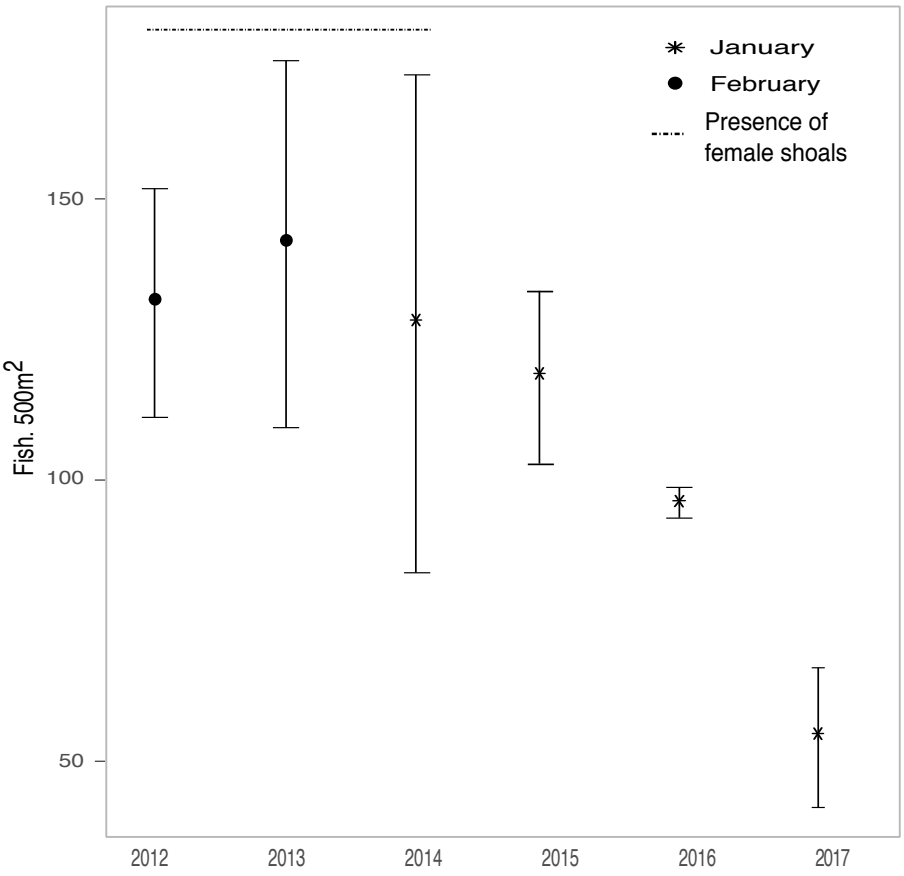

Figure 6. Mean density ± 95% Confidence intervals (CI) of aggregating groupers estimated on new moon nights in January and February (2012-2017), which are the peak aggregation months.

peak of the six month aggregation season. In both months, the aggregation is surveyed for five days around the new moon (two days before and after the new moon). On each day, five permanent belt transects are swum and the population density in the peak aggregation area (2500m^2) is estimated. Information on individual sizes (cm) is collected based on trained visual estimation. Two trained divers conduct these underwater censuses.

A catch of squaretail groupers from the aggregation site in 2013, before the seasonal fishing closure of the spawning aggregation was put into place.

We found that there is a high compliance of the seasonal fishing closure and no fishing activity has been reported at the site during the aggregation periods since 2014. However, despite high compliance, we observed a dramatic 60% decline in the overall density of the aggregating population since we first documented it in 2012 (Figure 6).

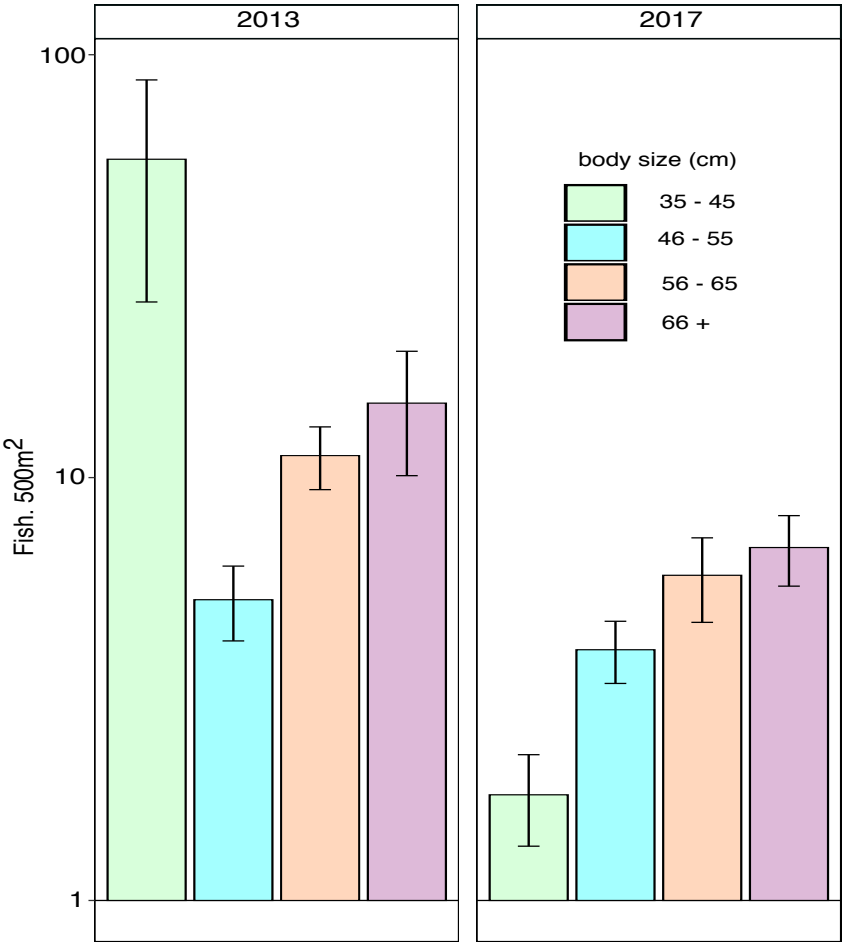

Figure. 7. Decline in mean density of four size classes observed at the aggregation site in 2013 and 2017. Values represent means ± 95% CI.

We found that particularly, smaller sized individuals (35-45 cm total length), which tend to be females in this sex-changing species, have declined by 80% in the last four years (Figure 7). In addition to this dramatic population population decline, we observed that the novel mating tactic of 'shoal spawning' was absent in the aggregation since 2015, ie. when the aggregation density had declined by a mere 20%.

From our work (Table 1), it appears that although the seasonal fishing closure is successful in curtailing fishing activity during the spawning periods, there is an overall increase in reef fishing pressure in Lakshadweep, which is targeting groupers during the non-spawning periods. In 2017, groupers made up for more than 22.5% of total reef fish catch of motherboats and ~ 10% of total catch of local commercial fishing boats.

The average catch per unit effort (CPUE = groupers per boat per trip) of motherboats was eighty times higher than the average CPUE of local commercial boats in 2017 and two hundred times higher than average CPUE of local commercial boats in 2014 (Table 1). Grouper CPUE of local commercial boats has more than doubled since 2014. However , effort (frequency of trips per boat) has not significantly changed since 2014. The local market price of groupers has nearly tripled since 2014 and can garner upto 1.5 times its current local rate on the mainland, representing an increasing demand for groupers from Lakshadweep.

More interestingly, the mean size of groupers caught did not differ between 2014 (39.39 ± 4.56) and 2017 (35.05 ± 10.35). Most of the groupers caught are under 45 cm, representing the size-range of small, shoal-forming female squaretail groupers in the aggregation. This targeted fishery (size and species) is threatening the novel behaviours and population density of the unique squaretail grouper spawning aggregation.

Our work demonstrates how a few years of fishing activity can rapidly decimate a population and dramatically impact behaviours. Our work indicates that in addition to seasonal fishing closures, which serve to protect the reproductive fish stock during spawning aggregations, extra steps need to be taken to regulate reef fisheries during non- spawning periods. More direct management and control of harvest, such as size or catch- quotas may need to be implemented to mitigate impacts of targeted reef fishing in Lakshadweep in the future.

Table 1. Table comparing the effort and catch per unit effort (CPUE) of a sample of local fishing boats in 2014 and 2017. Values for commercial motherboats (n=11) are provided for comparison of scale of fishing between local and commercial fisheries. Percentage groupers of total catch could not be estimated in 2014, owing to differences in sampling.

Year	Vessels (n)	Trips per boat per fornight	CPUE (groupers per boat per trip)	Percentage groupers of total catch	Market rate groupers.kg (INR)
2014	local commercial boats (71)	9 ± 0.89	6.5 ± 1.4	na*	60 (local market)
2017	local commercial boats (250)	8.1 ± 1.3	19.14 ± 8.9	7.9 ± 3.4	160 (local market)
2017	motherboats (11)	1	1596 ± 591	22.5 ± 5	280 (mainland)

OUTCOMES AND WAYS FORWARD

This study has been valuable in many ways. Firstly, it is one of the only studies undertaken to explore the magnitude and growth of commercial reef fisheries in the Lakshadweep Archipelago in the last five years. An earlier study by Tamelander and Hoon (2008) explored in detail an artisanal lagoon and reef-based fishery in the Agatti atoll. While the artisanal fishery in Agatti prior to 2007 was largely subsistence in nature, the authors cautioned that there would be a rise in a reef fishery for export to South East Asia. Our study explored the status of this newly developing commercial reef fishery (involving small and large mechanised and non-mechanised boats) across four representative atolls in the Lakshadweep. We conclude that since 2014 there has indeed been a rapid growth of a commercial, export-based reef fishery targeting specific fish of high value like groupers, snappers and emperors. This new reef fishery poses a management challenge, because on the one hand, it can be an opportunity for fishermen to gain high temporary profits but on the other hand it can lead to a rapid decline and collapse of key fish populations, as has been seen around the region (Jaini et al., 2017, Murty 2002). Secondly, the study helped us re-evaluate the notion that reef fishing pressure in the Lakshadweep archipelago is comparatively low as compared to other locations in the region and country. What emerges clearly from our preliminary study is that reef fishing has increased exponentially and there is now a growing dependency and transition towards near-shore coral reefs as a more accessible and efficient source of income for local fishermen.

Our work highlights that the commercial reef fishery is export-based and targeted towards few families of high-valued fish, particularly groupers (epinephelids), snappers (lutjanids) and emperors (lethrinids). These are typically long-lived, slow growing and late-maturing species with restricted spatial distributions in near-shore coral reefs. Aspects of the biology and ecology of these species, like their ability to form temporally and spatially explicit spawning aggregations make them particularly susceptible to overfishing. Our work with the squaretail grouper spawning aggregation in Bitra suggests that even current scale of commercial fishing pressure appears to be unsustainable. Despite the protection of key aggregation periods at a historically unfished site, the population of aggregating squaretail groupers continues to decline. The primary reason for this decline is the year-round exposure to targeted fishing all around Bitra. Moving forward, it has become necessary to evaluate the seasonal fishing closure for the aggregation and in addition consider other options of regulating the reef fishery throughout the year (example, catch/ size/ export quotas etc.).

Considering that commercial reef fishing is rapidly expanding in the Lakshadweep, it is of utmost importance to continue to monitor the growth and extent in order to evaluate reasonable management and regulation strategies. Our study is an example of one such attempt, in a snapshot in time. However, the scale of the fishery is already vast and we feel that it is beyond the scope of individual researchers and research organisations like ours to tackle. We strongly recommend that the monitoring of reef fisheries needs to be institutionalised and be undertaken on a continuous basis. The Lakshadweep Fisheries Department has been consistently monitoring the catches of tuna and pelagic reef fish by means of a catch-reporting programme since 1970. This has provided invaluable information on long term trends in the catch and production of pelagic resources in Lakshadweep. A similar programme could potentially be initiated by the Fisheries Department for near-shore reef fisheries across all islands. Because reef fishing can be commercial and/or

subsistence in nature, apart from catch-reporting by fishermen, there is a need for trained staff to monitor fish landings (whether commercial or subsistence) in the islands. Community monitoring programmes, like those lead by the Dakshin Foundation for tuna and baitfish are another valuable option to consider to monitor catches of representative fishermen and track changes in fishing practices through time. We have been engaging with the Fisheries Department and the local governing council (District Panchayat) to explore both these options.

Owing to the past two decades of repeated mass-bleaching catastrophes in the region, reef fish populations (especially of long-lived and benthic predatory fish) are under decline in Lakshadweep. If the current scale and magnitude of developing reef fisheries is left unregulated, the decline can only be hastened, with unforeseen consequences for Lakshadweep's reefs, people and their livelihoods.

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