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GROUPER AND NAPOLEON WRASSE ECOLOGY IN LAAMU ATOLL, REPUBLIC OF MALDIVES: PART 3. FISHING EFFECTS AND MANAGEMENT OF THE LIVE FISH-FOOD TRADE

BY

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ABSTRACT

The live fish-food industry has recently developed in the Republic of Maldives targeting grouper (Pisces: Serranidae) for export to Asian markets. This study uses data collected in one central and one southern Maldivian atoll with the purpose of examining the influence of fishing on these grouper assemblages. Abundance of five grouper species targeted by the live fish-food industry and the Napoleon wrasse (*Cheilinus undulatus*), a targeted species in other countries but banned from export in Maldives, was estimated using timed transects in channel habitats of Laamu Atoll. One site in Kaafu Atoll was resurveyed using the same methods as a previous study four years previously.

Relative grouper abundance was significantly different among channels that experienced different fishing pressure. Channels which had been more intensely fished had lower *Plectropomus areolatus* and *P. laevis* abundance than more lightly fished channels. One site surveyed in 1993 and 1997 showed clear effects of intense fishing pressure. Grouper species composition changed over this time period with targeted species being less abundant in 1997 than 1993. The overall size distribution shifted towards smaller sizes in 1997. Density between the two years was not different, indicating a second-order effect where smaller, nontargeted grouper species increase in abundance once larger species are removed.

Fishing pressure on grouper continues to increase in Maldives and many sites show signs of local overfishing. It is suggested that protecting spawning aggregations within a system of marine fishery reserves and managing nonprotected areas through other measures such as export quotas could result in a sustainable grouper fishery.

INTRODUCTION

The most recent fishery to severely threaten grouper populations is the live fish food trade. Grouper are caught throughout the Indo-Pacific and shipped live to Hong Kong as well as other southeast Asian countries such as Singapore and China. The purchase of high-priced fish is a show of wealth and status in many Asian cultures. Once the grouper populations near Hong Kong were depleted, fishing fleets of small boats set out for the Philippines. Fish buyers from Hong Kong and Singapore now consider the Philippines to be nearly depleted as a source of grouper due to the low number of individuals available for harvest (Johannes and Riepen, 1995). These same buyers

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estimated that Indonesia had three to four more years before it was depleted as a source for grouper. Fishing effort for grouper has intensified, including using larger vessels and fishing farther abroad from the Maldives to the west and east to many of the Pacific island nations.

There can be considerable environmental damage done by fish collectors. In many countries cyanide is used to collect groupers. This poison stuns large fish, but kills both corals and smaller fish (Johannes and Riepen, 1995). Restrictions have been established in many countries, but generally too late and with little enforcement. Given appropriate management, live fish-food fishing can be an important sustainable source of income. However, lack of management and the insatiable demand for live grouper have resulted in the overfishing of many grouper populations in the Indo-Pacific (Johannes and Riepen, 1995).

Maldivians have traditionally relied most heavily on pelagic resources for food and economic livelihood. However, subsistence-level reef-fish fishing has always occurred, especially in atolls which are far from good tuna fishing spots. During bad weather or special times of the year (e.g. fasting month) reef fish constitute the main source of protein for the islanders. In recent years, the demand for reef fish resources by the tourist industry (e.g. lobster, reef fish) and outside markets (e.g. Napoleon wrasse, giant clams, sea cucumbers, groupers) has resulted in the commercialization of reef-fish fisheries (Maniku, 1994). This brings about intense pressure on reef resources due to the high price paid by those external to Maldives. For example, in Laamu atoll, the beach-side price for tuna in 1998 was 3.5 rf per kilogram (11.72 rf = 1 US dollar) while it was 300 rf per kilogram of dried sea cucumber. This provides great incentive to switch to these nontraditional sources of income. These developing fisheries pose two main threats: 1) overexploitation of the resources and 2) conflicts with other user groups (Shakeel and Ahmed, 1996). The main user-group conflict is with tourist resorts which rely on diving to attract many of their customers.

The most recent of these nontraditional reef-fish fisheries is the live grouper trade. The fishery for grouper started about January 1993 (Shakeel, 1994a). Grouper export rose from 200 tons in 1994 to 1000 tons in 1995 (Shakeel and Ahmed, 1996). Exports for 1996 were expected to show about a 10-fold increase above the 1995 level (Mohammed Shiham Adam, Marine Research Section, Ministry of Fisheries and Agriculture, pers. comm.). There are at least 41 species of grouper known from Maldivian waters (Randall and Anderson, 1993; Adam et al. 1998; Anderson et al., 1998). However, only a few of these are targeted commercially. In Laamu Atoll, for example, the highest prices are paid for the *Plectropomus* species, *Epinephelus fuscoguttatus* and *E. polyphekadion* (Sluka, pers. obs.). *Cephalopholis* spp, *Anyperodon luecogrammicus*, and *Aethaloperca rogaa* may fetch one-fifth to one-tenth of the price of the former species. In fact, the *Cephalopholis* species have been used to feed the more expensive species as the exporters did not think it worthwhile to use up hold space on these less expensive species. They continued to buy the *Cephalopholis* spp. from fishermen and cut them up for food. The hold of one vessel (14-ton capacity) was filled with *E. fuscoguttatus* and *Plectropomus* spp. only (Sluka, pers. obs.). The fishery is already showing signs of overfishing. Collectors have shifted away from atolls close to Malé and now have collection sites in all atolls (Mohammed Haleem, Oceanographic Society of Maldives, pers. comm.).

Grouper are collected using small rowboats (1-2 people), sailing vessels (3-4), or large mechanized boats (7-8) (Shakeel, 1994a,b). Sailing vessels may catch 50-80 fish per day, while mechanized boats, 100-170 (Shakeel, 1994a). The fishermen use snorkeling gear and handlines directly from the water. In this manner they can identify individuals they would like to catch and pursue. The preferred bait is the goldband fusilier (*Pterocaesio chrysozona*). A hook is placed through the rear of the fusilier so that it remains alive and swimming, thus attracting grouper. The daily catch of fishermen is then either placed in their own small cages or directly brought to the collector's large cage facility. Shakeel (1994a) estimated a 5-20% mortality rate in boat holds. This is due to poor water quality in holds, overcrowding, and damage to the fish during processing. A number of fish die due to the hook being swallowed resulting in internal bleeding. Another source of mortality is the rapid expansion of the swim bladder due to the fish being pulled rapidly to the surface. The fishermen release the air from the bladder with a sharp tool but may pierce too deeply resulting in internal bleeding.

Grouper are bought from the fishermen by a local collector who acts as a middleman for a foreign exporter (usually from Hong Kong). The price paid to the fisherman depends upon demand (how imminent is the arrival of the foreign collector vessel and what has been the mortality of fish in cages), species, and size. These different groups of fish are held separately in cages approximately 4 x 3 x 2.5 (depth) m in measurement. These cages are generally supported by a framework of metal piping and held afloat by empty plastic fuel barrels. Mortality in cages can be quite high--up to 30% for the *Plectropomus* spp. (Mohammed Afeef, grouper exporter, pers. comm.). The fish are then transferred to a foreign collector vessel at which time the Maldivian intermediary receives monetary compensation.

Shakeel (1994a,b) estimated the maximum sustainable yield of grouper for all Maldivian atolls which totalled to 1,800 tons. For Laamu Atoll, Shakeel (1994a) estimated the maximum sustainable yield of groupers from shallow coral reefs at 27 tons per year. The foreign collection vessels have holds of approximately 14 to 16-ton capacity. These vessels may collect from more than one atoll depending on where the Maldivian intermediary has his collection bases. One vessel collected approximately 7-8 tons of grouper on one trip to Laamu Atoll (Sluka, pers. obs.). Another vessel was already on its way to collect the remaining fish in cages and vessels were expected at least every 6-8 weeks. If we assume that 1-2 collection trips occur every 6-8 weeks, then 42-139 tons would be collected per year. In 1994, fishermen were already reporting that their catches were declining, especially in Alifu and Vaavu Atolls (Shakeel, 1994a). Shakeel and Ahmed (1996) concluded that based on export figures for all Maldives combined (1000 tons) and the mortality rate in fishermen's and exporter's holding facilities, the maximum sustainable yield for grouper was likely surpassed in 1995.

The purpose of this paper is to review the nature of the Maldivian grouper fishery and use data collected under different fishing intensities and durations of fishing pressure to examine the impact of this fishery on grouper assemblages.

METHODS

Abundance surveys

Grouper abundance (no. fish 10 minute^{-1}) was determined for six of the seven channels (see Figure 1 in Part 2 of Sluka, 2001a) leading from the inner-atoll lagoon to the open ocean, at least once, using the same methodology detailed in Part 2 of this series (Sluka, 2001a). Briefly, eighteen 10-minute surveys with a transect width of 10 m were conducted in each sampling session. Mundoo Channel was surveyed nine times between April-June, 1998 while Vadinalhu and Fushi channels were surveyed twice during this same time period (Table 1). The other three channels were surveyed once. A one-way ANOVA was used to test for significant differences in fish abundance among the six channels for each targeted species. A percent similarity index was calculated among all six channels using the abundance of the five targeted grouper species (*Epinephelus fuscoguttatus*, *E. polyphekadion*, *Plectropomus areolatus*, *P. laevis*, and *P. pessuliferus*) and the Napoleon wrasse (*Cheilinus undulatus*). This matrix was used in unweighted, group-average linkage clustering to examine which channels were most similar with regard to targeted species abundance.

Resurvey of sampling site in Kaafu Atoll

Sluka and Reichenbach (1996) reported the results of sampling Gaagandu reef slope for grouper density, diversity, and average size. Gaagandu is a small island near the capitol of Maldives, Male' in Kaafu Atoll, approximately 210 km north of Laamu Atoll. Data were collected in June and July, 1993. This represents the time period when the grouper fishery started in Maldives. Sluka and Reichenbach (1996) showed that fifteen 240 m^2 would capture about 80% of the grouper species diversity and achieve a precision around the median density of about 10%. Thus, sixteen 240 m^2 transects were surveyed at Gaagandu reef slope in March, 1997 to examine the impact of almost four years of fishing on grouper diversity, density, and size distribution. A 20 m transect line was laid haphazardly along one depth gradient. The transect was searched for groupers using a zig-zag swimming pattern, searching in all caves, crevices and holes (GBRMPA, 1978). A width of 6 m was visually estimated out from each side of the transect line. The number and size (nearest 5 cm) of each individual within transect boundaries was recorded. The total number of grouper observed per transect was compared between the two sampling dates using a t-test. Fish sizes were placed in one of five categories to match data in Sluka and Reichenbach (1996): < 5 cm, 6-15 cm, 16-25 cm, 26-35 cm, and > 35 cm total length. A Chi-square test was used to test for significant differences in the size distribution between sampling dates.

RESULTS

Abundance surveys

There was no significant difference in abundance among channels for any species ($p>0.05$) except *Plectropomus areolatus* (n=282, $F_{6,275}=2.2$, $p<0.05$) and *P. laevis* (n=282, $F_{6,275}=4.8$, $p<0.001$) (Fig. 1). The Tukey test for *P. areolatus* was inconclusive but the test for P. *laevis* showed that it was more abundant in Mundoo Channel than in Gaadhoo Channel or for one of the sampling dates in Vadinolhu Channel,

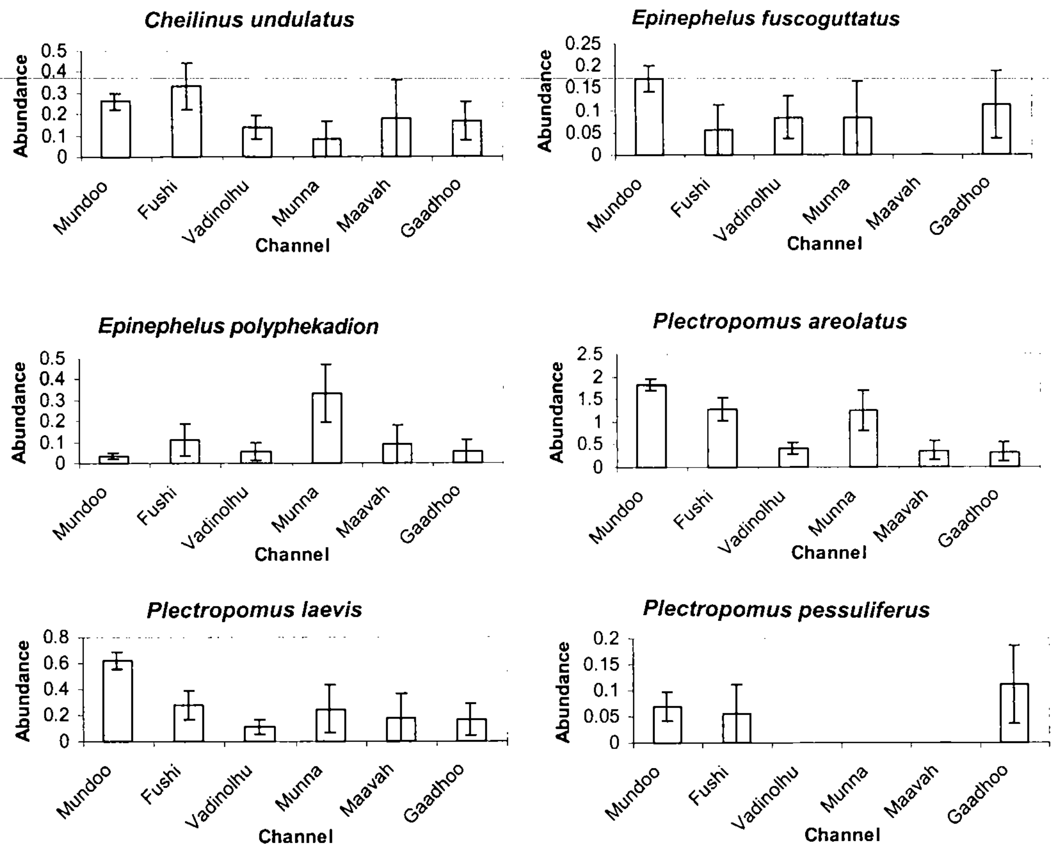

Figure 1. Mean abundance +/- 1 SE (no. fish 10-min^{-1}) of target species in all channels

but similar among all other channels. Figure 2 shows that channels clustered into two groups: Fushi, Munnafushi, and Mundoo channels were most similar as were Gaadhoo, Maavah, and Vadinolhu.

In addition to surveying for targeted grouper species, any grouper species was recorded that was present in the channel. This yielded a species list for each channel (Table 1). A total of 18 grouper species was observed in channel habitat in Laamu Atoll.

Resurvey of sampling site in Kaafu Atoll

Mean grouper density (no. 240 m^2) was not significantly different between 1993 and 1997 (t=1.299, df=35, P>0.05). The mean density in 1993 (1 SE) was 25.2 (1.5) grouper 240 m^2, while in 1997, 22.1 (0.5) (Fig. 3). The size distribution, however, was significantly shifted towards smaller sizes (X^2= 156.8, df=4, p<0.001). Figure 4 shows that there were fewer larger fish, especially greater than 35 cm, in 1997 than in 1993. In 1997 targeted grouper species were rare, with only two *Epinephelus polyphekadion* observed and no *Plectropomus* spp. These targeted species were not abundant in 1993, but were commonly observed. The species composition was similar, with the aforementioned exception. There were 17 grouper species observed in 1993 and 13 in 1997. However, sample size was much higher in 1993 than in 1997, 48 and 16 transects, respectively. When the number of species observed in 1997 is corrected for sample

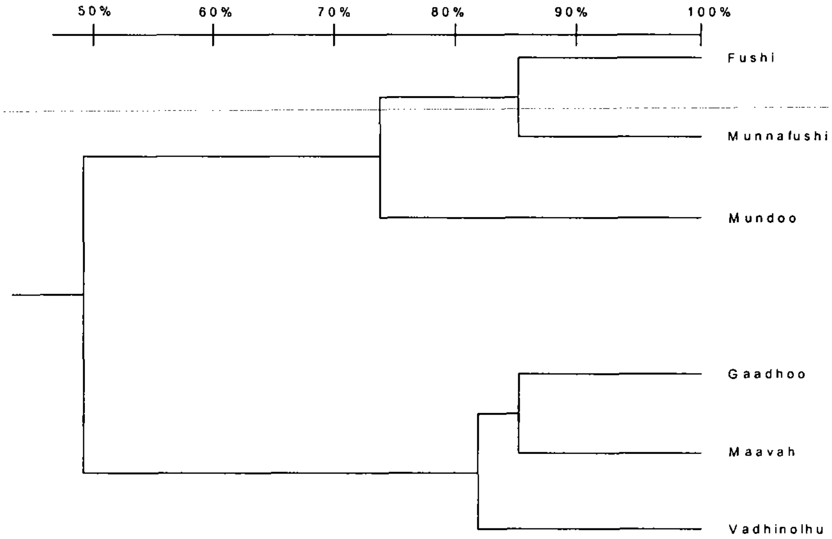

Figure 2. Cluster diagram showing the relationship between all study channels based upon the abundance of targeted species.

Table 1. Grouper species observed in Laamu Atoll channels.

Species	Mundoo	Fushi	Vadinolhu	Munnafushi	Maavah	Gaadhoo
Date surveyed	3/31-6/19[1]	4/26, 5/24	4/23, 6/9	6/9	6/10	5/23
Aethaloperca rogaa		X	X	X	X	X
Anyperodon luecogrammicus	X	X	X		X	X
Cephalopholis argus	X	X	X		X	X
C. leopardus	X		X			
C. miniata	X	X	X		X	X
C. sexmaculata	X					
C. urodeta	X	X	X	X		X
Epinephelus caeruleopunctatus	X				X	X
E. fasciatus	X					
E. fuscoguttatus	X	X	X	X	X	X
E. polyphekadion	X		X	X		X
E. spilotoceps	X		X			X
E. tauvina	X					
Gracila albomarginata	X	X	X	X	X	X
Plectropomus areolatus	X	X	X	X	X	X
P. laevis	X	X	X	X	X	X
P. pessuliferus	X					
Variola louti	X		X	X	X	X

[1]This channel sampled multiple times during this time interval.

size using the graph in Sluka and Reichenbach (1996), 16 species can be assumed to be present in 1997.

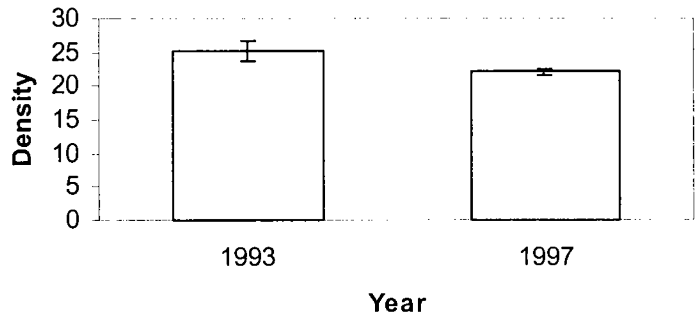

Figure 3. Mean grouper density (all species combined, no. 240 m^{-2}) for two separate years at Gaagandu Island, Kaafu Atoll.

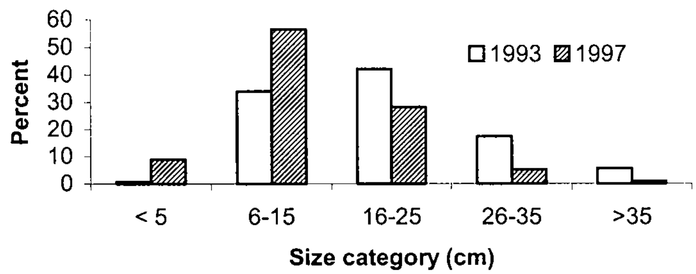

Figure 4. Size-frequency distribution of all grouper species combined for two different years at Gaagandu Island, Kaafu Atoll.

DISCUSSION

Grouper species diversity was similar to that found in a previous study in Laamu Atoll (Sluka 1998). A total of 18 grouper species in seven genera were observed in this study, while 25 species in seven genera were identified by Sluka (2001b). Both counts are much less than the total number observed for all Maldives of 41 (Randall and Anderson, 1993; Adam et al., 1998; Anderson et al.,1998). The main species differences between channels surveyed in this study and the previous study by Sluka in Laamu Atoll were in fewer small, cryptic and rare species. This could be due to lower sampling time or related to habitat differences among channels and other types of reefs. Sluka (2001b) found 19 grouper species on reef slopes on the ocean side of the atoll, 24 on reef slopes inside the atoll rim, 17 on faros, and 3 in lagoonal habitats. Channel habitat grouper diversity was most similar to outer-reef slopes and least similar to lagoonal habitats.

Data from all channels indicate two separate groups of channels cluster together: deeper, more intensely fished channels and shallow, less intensely fished channels. While there is currently only one grouper-collection site in Laamu Atoll (located on the island of Kashi Guraidhoo, next to Maavah Channel), in the past several years there was another site located near Maamendhoo which is next to Gaadhoo Channel. Grouper fishermen from Laamu and other atolls bring their fish to these sites and sell them to the grouper collectors. According to local villagers, much of the fishing for grouper in the past several years has been conducted on the western side of the atoll which includes the areas around Kashi Guraidhoo and Maamendhoo. Figure 2 shows that *Plectropomus areolatus* and *P. laevis* abundance was lower in these more heavily fished channels than in less intensely fished channels. Munnafushi Channel (also located on the western side of the atoll) is a shallow channel (approximately 10 m depth) with extremely high current speeds (pers. obs.). These physical differences likely account for less fishing pressure in this channel. These data reinforce the already overwhelming evidence that intensive fishing results in sites with significantly decreased grouper abundance relative to unfished sites (see Sluka, 1998 for a review).

Resurvey of sampling site in Kaafu Atoll

It appears that fishing pressure at the site near Gaagandu Island has resulted in a shift in species composition and size distribution, but not in mean density. This may indicate compensation, the so-called second order effect shown by other researchers (Bohnsack, 1982; Goeden, 1982; Watson and Ormond, 1994; Sluka et al., 1996; Sluka and Sullivan, 1998). When larger grouper species are removed, smaller species become more abundant. This may be due to a reduction in competition or predation, but no experimental evidence is available to suggest the most likely mechanism for this occurrence. Bohnsack (1982) found that graysby were more abundant in sites unprotected from spear-fishing than in protected sites. Watson and Ormond (1994) found that the relative contribution of smaller *Cephalopholis* spp. was significantly greater in sites unprotected from artisanal fishing than in those protected. Grouper species in an unexploited condition may significantly compete for resources intra- and interspecifically. The release of this competition and/or predation may allow the smaller species to increase in abundance due to the increase in resources available to them. There are no data that I am aware of to suggest that larger grouper species are preying on smaller grouper species (Randall, 1967; Randall and Brock, 1960; Kingsford, 1992). Stomach contents of *Epinephelus merra* (n=481), *Cephalopholis argus* (n=280), *C. miniata* (n=48), *C. urodeta* (n=71), and *Plectropomus leopardus* (n=7) contained no grouper (Randall and Brock, 1960).

The shift in size distribution from larger average size in 1993 to smaller average size in 1997 is likely due to the direct effects of fishing. In 1997 no Plectropomid species were observed. These species are among the most highly sought after for the live fish-food trade. While these species were not abundant in 1993, they were regularly observed. Data from Sluka and Reichenbach (1996) underestimated the abundance of the *Plectropomus* spp. due to using fixed area transects. These species are highly mobile and are more amenable to sampling using timed counts (Newman et al., 1997). This shift in species composition and size distribution is consistent with shifts observed in other grouper populations subjected to heavy fishing (Russ, 1985; Russ and Alcala, 1989; Sluka et al., 1997; Sluka and Sullivan, 1998).

Effects of fishing on grouper populations

Intensive fishing for grouper results in a population that has different characteristics than an unexploited population. Grouper in fished areas, relative to unfished ones, tend to be smaller in average size, less dense, and collectively produce fewer eggs. There are also significant genetic changes where fishing selectively removes individuals with particular life history features such as large size. Sixteen grouper species were recommended for inclusion in the IUCN Red List of Threatened Animals (Hudson and Mace, 1996). Most of these species are the larger groupers, which are the target of commercial and recreational fisheries. The largest of all grouper species, the giant grouper *Epinephelus lanceolatus*, is included in the proposed list and occurs in Maldives.

The growth and reproductive characteristics of groupers render these species especially susceptible to overfishing (Shapiro, 1987; Bannerot et al., 1987; Huntsman and Schaaf, 1994). Groupers which are targeted by fishing generally grow slowly to a large maximum size (Manooch, 1987). The removal of larger individuals leaves behind smaller individuals to spawn. Over many generations, this can result in a decrease in the size/age at sexual maturity (Ricker, 1981) and also decrease the average size of the population (Roberts and Polunin, 1991). Fishing pressure can cause genetic shifts in the age/size at first reproduction, growth rate and decrease the genetic variation in the population (Sheridan, 1995).

Many grouper species are protogynous hermaphrodites, changing sex from females to males later in life (Shapiro, 1987). Larger groupers are generally males, and at intensive fishing levels, the number of males in the population can be drastically reduced. If too many males are removed, sperm can become limited for reproduction (Bannerot et al., 1987). If sperm is limited, protogynous stocks are more vulnerable to overfishing than gonochoristic stocks (Huntsman and Schaaf, 1994). Species which are protogynous may experience a drastic reduction in reproductive capacity, even at moderate levels of fishing (Huntsman and Schaaf, 1994). In addition to protogyny, the reproductive behavior of groupers may increase their susceptibility to overfishing.

Many species of grouper aggregate to spawn in one or two months of the year. Grouper spawning aggregations are the focus of commercial, recreational, and artisanal fisheries throughout subtropical and tropical regions of the world (Olsen and LaPlace, 1978; Johannes, 1988). Groupers appear to be especially susceptible to overfishing at this time due to: 1) behavioral changes rendering them less wary of fishers; 2) fishing of spawners prior to gamete release; 3) selective removal of larger males, potentially resulting in sperm limitation (Bannerot et al., 1987); 4) aggregations returning to the same place at the same time each year; 5) concentration of populations. Intense fishing of grouper spawning aggregations has lead to decreases in abundance and mean size of individuals as well as strongly female-biased sex ratios (Sadovy, 1994; Coleman et al., 1996; Koenig et al., 1996). This results in reduced average fecundity of the population and, ultimately, decreased population size, reduced population growth, and extinction (Coleman et al., 1996). Extinction could be economic, as there are too few individuals of a species for a fishery to exist--locally due to a lack of any individuals at a particular site, or regionally because of a lack of any individuals of a species anywhere.

Coleman et al. (1996) have shown that the nature of a grouper species' reproductive behavior influences their susceptibility to fishing pressure. For example, two heavily fished species in the Gulf of Mexico that migrate to spawn in aggregations and have spatially segregated sexes (i.e. males and females live in different places throughout the year) had severely reduced sex ratios. However, in the same location, a species where males and females have access to each other throughout the year, and do not aggregate to spawn, have not had marked size or sex ratio changes in the past 25 to 30 years, despite intensive fishing pressure. It is thus imperative to understand the reproductive ecology of the species sought after in the live fish-food trade. The two *Epinephelus* species studied herein, *E. polyphekadion* and *E. fuscoguttatus*, have been shown to aggregate to spawn in other places (see review by Domeier and Colin, 1997). Similarly, Plectropomids have been observed to aggregate for spawning in other studies (Goeden, 1978; Johannes, 1988; Samoilys and Squire, 1994). Part 2 of this study (Sluka, 2001a) indicates that *Plectropomus areolatus* aggregates to spawn in Maldives, based upon a three-fold increase in numbers at a spawning site (Samoilys, 1997). It is not known how the separate sexes are distributed spatially. According to Coleman et al. (1996), if these species were able to judge the population sex ratio throughout the year (i.e. sexes not spatially segregated), intense fishing would not alter population sex ratios. If the only time a female can judge the population sex ratio, and thus determine whether or not to change sex to a male, is during the spawning aggregation, then intense fishing pressure would significantly alter population sex ratios. In either case, aggregating species are highly susceptible to local extinctions (Coleman et al., 1996). In some cases, aggregations that were successfully fished artisanally have disappeared due to the increased pressure brought about by gear improvements or outside markets.

Little is known about how many times an individual grouper will travel to an aggregation in one spawning season or how far an individual generally swims to arrive at these points. Johannes et al. (1995) in Zeller (1997) observed an individual *Epinephelus polyphekadion* in Palau travel 10 km to an aggregation site. Tagged Nassau grouper (*E. striatus*) have been shown to migrate to spawning aggregations up to 110 km (Colin, 1992) and 240 km (Carter et al., 1994) distant in the Bahamas and Belize, respectively. However, Samoilys and Squire (1994) found aggregation sites for the grouper *P. leopardus* as close together as 1 km. In addition, both Samoilys (1997) and Zeller (1997) found smaller aggregations near the primary aggregation sites. Thus, it is unknown how many aggregation sites occur in an atoll. If there is only one site per atoll and this site is heavily fished during the aggregation time, the entire reproductive output for the atoll could be diminished to the point where the population could not sustain itself and abundance levels would fall to the level of being economically extinct. However, recent research by Zeller (1997) suggests that not all sexually mature *Plectropomus leopardus* traveled to spawning aggregation sites. He suggested that, if less than a third of the population moves to spawning aggregations during the spawning season, this species may be more resistant to overfishing than other grouper species.

Management options

The Maldivian grouper fishery is under considerable stress. There is currently fishing for grouper in all atolls. Grouper exporters complain about reduced abundance and smaller individual sizes in some atolls. This study also showed that fishing pressure is negatively influencing the relative abundance of targeted species in Laamu Atoll and that the size distribution and species composition of groupers at one site in Kaafu Atoll have been significantly reduced and altered towards smaller sizes and fewer commercially important individuals. These are classic signs of intense fishing pressure. Adam et al. (1997) noted that the grouper fishery is rapidly expanding and that a pattern has been established of overfishing one atoll and then moving on to overfish the next. Clearly, based upon the experience of other countries and the present state of development of the Maldivian grouper fishery, management action is necessary. Research suggests that the best management strategy for both maintaining grouper fisheries and conserving natural population size, structure and diversity is to protect grouper spawning aggregations within a series of marine-protected areas (Sadovy, 1994; Turnbull and Samoilys, 1997). Sadovy (1994) noted that protecting spawning aggregations alone may not be sufficient to prevent overfishing. The management strategy most likely to succeed in both maintaining a population that can sustain substantial fishing pressure and avoiding overfishing focuses on both the spawning and nonspawning times and areas. Spawning aggregations should be closed to fishing, either by permanently closing these areas to fishing or using temporal closures surrounding the time of spawning. The population should also be managed during nonspawning times using methods such as marine fishery reserves, quotas and/or size limits. Fifteen dive sites have been designated as marine-protected areas where fishing activity is banned. However, these sites are small, only located in three atolls, and regulations are not enforced (Adam et al., 1997).

Fisheries management regulations can basically be divided into two categories: controlling the amount of fish caught or the effort used to catch them. Managers throughout the world have used a variety of regulations within these two categories including limiting the total number of grouper caught and the individual or collective weight of an individual fisherman's catch. Effort limitations include restricting gear types, seasonal or spatial closures to fishing, and requiring gear to be less efficient.

Shakeel and Ahmed (1996) made several suggestions for the management of the Maldivian grouper fishery: 1) limiting fishing in each atoll; 2) limiting export; 3) closed areas (but not necessarily permanently closed); 4) size restrictions; 5) improved data collection; 6) aquaculture.

The potential yield of grouper for each atoll was calculated by Shakeel (1994b). He gives a total maximum sustainable yield for the whole country of 1,800 t, a figure which was likely reached in 1995. The problem with using this method, as pointed out by Shakeel, is that there is a variable and significant grouper mortality before export and no method of collecting species-specific data, and the accuracy of the yield estimate is in question. There is already a problem of fishermen moving to other atolls to catch grouper and this would likely cause more tensions between atolls with low quotas and those with high quotas. Quota systems are a common means of managing grouper fisheries, but appear, based on the fact that grouper populations are almost universally overfished, to be ineffective as a management system for these species. While theoretically sound, catch quotas are dependent upon detailed biological and catch data as well as efficient enforcement. Practically speaking, quotas are usually surpassed before the statistics are collected that show the quota has been reached.

Export could be stopped once the maximum sustainable yield is reached. However, this method is dependent upon timely and accurate data collection. This method could be rendered ineffective by significant poaching, lack of data, and/or mortality due to catching, handling, or holding procedures (Wilson and Burns, 1996; Shakeel, 1994a,b).

Limiting the number and/or size of fish collected can easily be rendered ineffective due to significant mortality of undersized fish (Wilson and Burns, 1996). Measures such as effort limitation and size limits are unlikely to rehabilitate overfished grouper stocks (Huntsman and Schaaf, 1994). For example, size limitation is complicated by release mortality (Huntsman and Schaaf, 1994). Groupers brought up from relatively deep water (>30 m) suffer injury and likely mortality from the expansion of the swim bladder and other internal air cavities. Wilson and Burns (1996) showed that the survival rate of undersized grouper caught deeper than 44 m was less than 33%. They concluded that this rate is too low for the size limit in place to be effective in increasing yield. Render and Wilson (1996) showed that the mortality rate of snapper brought from 21 m depth to the surface and then released (either with the gas bladder inflated or deflated) was 20%. It appeared that there was a higher, but variable, mortality rate in fish caught deeper than 21 m. They concluded that gas bladder deflation did not significantly reduce mortality and may introduce another source of mortality when not performed properly.

Marine fishery reserves

Coral-reef fisheries are usually managed by limiting catch and/or effort. However, grouper populations throughout the world have shown drastic changes in their population structures despite these management measures (Sadovy, 1994). One management option that has been proposed to combat overfishing of coral-reef fish stocks is to establish marine fishery reserves (MFRs) (PDT, 1990). The Plan Development Team (1990) defined MFRs as "areas permanently closed to consumptive usage". The benefits of MFRs are numerous and include protecting the age structure of the population, maintaining genetic variability, and providing brood stock to replenish other areas. Based on previous experience with MFRs throughout the world, it is expected that MFRs will have similar beneficial effects on any reef-fish populations.

Several reviews of the benefits and design of marine fishery reserves have recently been completed (PDT, 1990; Roberts and Polunin, 1991; Dugan and Davis, 1993; Rowley, 1994). Marine fishery reserves result in a higher abundance and larger commercial species in the reserve than outside the reserve and protect the spawning stock biomass of these species (Russ et al., 1993).

There are two general means by which reserves benefit local fishermen in terms of increased catch: larval transport and spillover of adults. Little research has been carried out on these two processes. Most coral-reef fish have a bipartite life cycle with relatively sedentary adults and pelagic larvae (Sale, 1991). The fecundity of fish is related exponentially to their length, so that a large fish may reproduce hundreds of times as much as a fish half its size (PDT, 1990). Adults spawn eggs that are buoyant and float downstream on the prevailing current patterns. These eggs develop and settle in areas that are fished, thus replenishing those populations. While adults are relatively sedentary, a certain percentage of the population will make large-scale movements in a short period of time and many of the adults will move distances of several miles throughout their lives (PDT, 1990). The movement patterns of a porgy (*Coracinus capensis*) in South Africa were studied by tagging and releasing individuals (Attwood and Bennett, 1994). Over several years, they found that 17.8% of the tags were returned outside of the reserve. Those found outside of the reserve had moved a minimum of 25 km and a maximum of 1044 km. This is similar to most tagging studies in which most individuals of sedentary-type fish remain in a small area with a few nomads that travel long distances. Through the movement of adults out of the MFR, the yield to fishermen along MFR edges is increased. Sluka et al. (1997) showed that mean Nassau grouper density was higher in the 5 km adjacent to the park than at distances farther from park boundaries.

CONCLUSION

Management of the live grouper trade in Maldives is urgent. Evidence from around the world suggests very strongly that unmanaged or improperly managed grouper fisheries will become overfished quite quickly. There is already evidence of over-fishing in Maldives and the fishery is only four to five years old. Several management options are available. Scientific evidence suggests that protecting a significant portion of the coastal habitat in marine fishery reserves is the best management option for both the resource and resource users. Reserves designed for grouper management need to protect spawning aggregations. As a prelude to a reserve system, the banning of fishing grouper spawning aggregations would provide the next best strategy for long-term use of the resource. Given the current lack of a detailed data-collection system for reef species (Shakeel and Ahmed, 1996), it is unlikely that limiting catch or export using maximum sustained yield figures will provide long-term protection for the resource and resource users.

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