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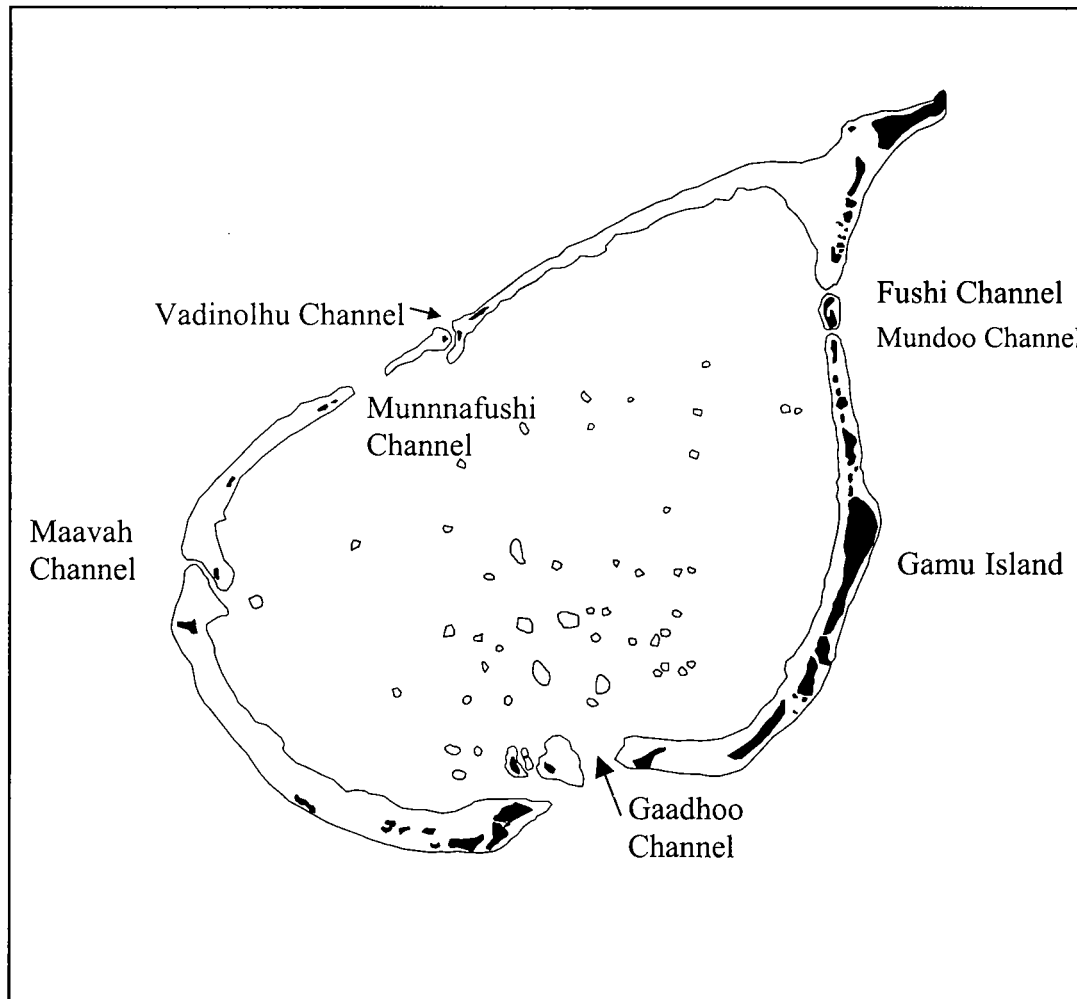
BY

ROBERT D. SLUKA

Figure 1. Laamu Atoll, Republic of Maldives. Study sites were located in the channels connecting the inner-atoll lagoon to the open ocean. Black indicates land and gray indicates coral reef or shallow-water lagoonal habitats.

GROUPER AND NAPOLEON WRASSE ECOLOGY IN LAAMU ATOLL, REPUBLIC OF MALDIVES: PART 2. TIMING, LOCATION, AND CHARACTERISTICS OF SPAWNING AGGREGATIONS

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ABSTRACT

The reproductive ecology of five species of grouper and the Napoleon wrasse was studied March-June, 1998 in Laamu Atoll, Republic of Maldives. Research focused on identifying the timing, location, and characteristics of spawning aggregations in this atoll.

Timed surveys were used to assess fish abundance and size distribution in Mundoo Channel, which is one of seven channels connecting Laamu Atoll's inner atoll lagoon to the open ocean. Through a pilot study, and later confirmed in the main study, it was concluded that observations could be conducted and compared over different times of the day, tidal cycles, current speeds, and among observers.

A spawning aggregation of *Plectropomus areolatus*, defined as a three-fold abundance increase over ambient levels, was recorded in Mundoo Channel during the new moon in April, 1998. Data collected during the pilot study suggested that an aggregation occurred in this channel during March, 1998. Courtship behavior for this species was recorded during these two months. Data suggested that *P. laevis* spawned during this time period as well. Spawning was never observed, but abundance increases and courtship behavior indicate that spawning occurred during this time.

INTRODUCTION

The demand for live reef fish by southeast Asian markets has resulted in intense fishing pressure on coral-reef fish resources throughout the Indo-Pacific region. In many countries these resources are now fully- or over-exploited (Johannes, 1997). The main coral-reef fish in demand are the Napoleon wrasse (*Cheilinus undulatus*) and groupers (*Epinephelus* spp. and *Plectropomus* spp.).

The Republic of Maldives is a nation of some 1200 coralline islands stretched across the central Indian Ocean. The main fishery in the Maldives has traditionally been, and still is, for tuna. However, in recent years, coral-reef-based export markets have developed so much that many fishers are turning to more profitable fisheries such as beche-de-mer, giant clam, shark, and most recently grouper. Intense fishing for sea cucumber and giant clam resulted in an almost total depletion of commercially important species prompting banning of giant clam export and regulations on the beche-de-mer fishery (Maniku, 1994). Recently, the Maldivian government has banned shark fishing in 11 atolls where tourist resorts are located (Haveeru, Maldivian newspaper, 1998). This was due to complaints from the tourist industry about the reduction in shark numbers and

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its potential effect on diving tourism. Currently there are no regulations on the grouper fishery and it is showing signs of local overexploitation. Export of Napoleon wrasse is currently banned due to their high value to local and expatriate recreational divers.

Sound biological information on the ecology of targeted species in the live fish food trade is needed to develop sound management. The reproductive ecology of these species is poorly known, yet this knowledge is essential for effectively implementing such management measures as spawning season or area closures and marine fishery reserves (Johannes, 1997). While export of Napoleon wrasse is already banned in Maldives due to the urging of several conservation-minded groups, almost nothing is known about this species' reproductive patterns.

This report focuses on the reproductive ecology of the Napoleon wrasse and several grouper species exported in the live fish food industry. The goal of this research was to identify the timing and location of spawning aggregation sites in one atoll in the south of the Maldives.

METHODS

Study area

Laamu Atoll is located at approximately 2N latitude 73.5E longitude (Fig. 1). There are seven channels in this atoll that connect the inner atoll lagoon to the open ocean. Much of this study focused on Mundoo channel, located on the eastern side of this atoll. This was mainly due to its proximity to the Oceanographic Society's laboratory which is located at the northern tip of Gamu Island. The channels range in depth from approximately 10 m (Munnafushi) to over 50 m (Gaadhoo). Most channels have high coral cover on the sides and front (defined as the edge of the channel mouth emptying into the open ocean). The centers of the channels were usually devoid of any structure and showed scarring due to strong currents. Two of the western channels (Vadinolhu and Maavah) were narrow and had large, high-relief coral spurs running along the middle. In between these spurs was sand or exposed limestone. Mundoo channel, the site where most of this study occurred, was 20 m deep at the center with steeply sloping channel walls. The front of the channel emptied into open ocean over a sill that sloped steeply to about 50 m. At that depth, the slope became less pronounced for about 0.5 km, after which it dropped steeply to abyssal depths (Anderson, 1992).

Pilot study

This study focused on five grouper species (*Epinephelus fuscoguttatus*, *E. polyphekadion*, *Plectropomus areolatus*, *P. laevis*, and *P. pessuliferus*) and the Napoleon wrasse (*Cheilinus undulatus*). Factors that could affect grouper and Napoleon wrasse abundance in channel surveys include: time of day, current speed, tidal cycle, and observers. A pilot study was conducted to examine the influence of these variables on the accuracy and precision of fish-abundance estimates. Timed surveys were used to assess abundance instead of transect lines due to strong currents in the channel. Timed surveys have been used in numerous fish surveys and have been shown to be a reliable and repeatable method for accurately and precisely assessing abundance (Russ, 1984a,b, Newman et al., 1997). Other studies of Indo-Pacific groupers, as well as anecdotal accounts in Maldives, suggest that grouper gather to spawn a few days before the new

moon and that the aggregation quickly dissipates on, or soon after, the new moon (Johannes et al., 1994, Samoilys and Squire, 1994). Based upon previous research and anecdotal reports by fishermen, grouper were expected to spawn in the channels connecting the inside of the atoll with the open ocean. From March 23-28, 1998, five of the seven channels in Laamu atoll were visited using scuba and snorkeling in order to gain an understanding of their layout and to determine how best to survey for grouper and Napoleon wrasse. Grouper habitat mainly occupied the channel sides and front, while the middle and inner atoll edge were mainly barren. It was decided to focus surveys on the front edge and sides of the channels.

The optimal duration for each survey was examined on March 30, 1998. Ten 20-minute surveys were completed by three scuba divers with observers searching five meters on each side for a total transect width of 10 m (during this length of time the entire length of the study channel could be surveyed). During the 20-minute surveys, observers counted and estimated the size of each target species. Observers were trained to estimate fish length and transect width using methods detailed in Sluka (2001). The number of minutes into the dive when the individual was observed was also recorded. The cumulative frequency of all species observed was graphed by time of observation in order to determine if there was some asymptotic value; thereafter few individuals were observed. The relationship between time and cumulative frequency was linear, with no asymptote (Fig. 2). The total number of fish of targeted species observed per 20-minute survey ranged from 2-8, except for one survey during which 23 were observed. This survey was dropped from the analysis as an outlier, but could be indicative of an aggregation occurring during this time. There was a significant relationship between time surveyed and total abundance (all species combined). The relationship was linear and can be described by the following equation: abundance = 0.23*time + 0.55 (df=18, $R^2 = 0.99$). As there was a significant linear relationship between abundance and time, the choice of survey duration was arbitrary. It was then decided to use 10 minutes as the survey length in order to have sufficient replication for accurate and precise estimates.

The influence of time of day, tidal cycle, current speed, and observer on grouper abundance was examined March 31-April 2, 1998. Six to nine surveys were completed three times a day: a.m. (0900-1200), midday (1201-1500), and p.m. (1501-1800). The direction of current flow (flood, slack, or ebb), current speed, and observer were noted for each survey. A one-way ANOVA was used to determine if mean abundance of all species combined and each species separately was significantly different among current directions. Due to prevailing wind patterns, sample size was highly skewed towards flood tide. A two-way ANOVA was then used to assess differences in mean abundance by time of day and observer. There was no significant effect of tidal cycle, time of day or observer on the results. Thus, results could be compared from surveys at different times of the day and on different tidal cycles using several observers. Current speed was measured using a hand-held General Oceanics current meter. The relationship between current speed and fish abundance was tested using a Pearson correlation coefficient (n=38). Values of the coefficient among species ranged from –0.12 to 0.18 and were always highly insignificant indicating that surveys could be compared over a wide range of current speeds.
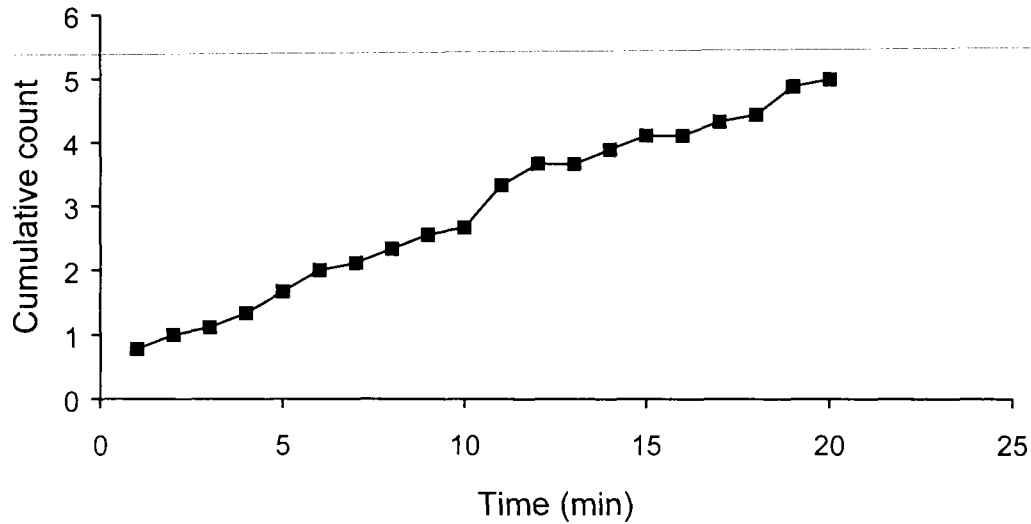
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Figure 2. Cumulative count of all target species by total search time.

A spawning aggregation has been defined in the recent literature as an abundance of individuals three times greater than ambient levels (Samoilys, 1997). Using this definition, I calculated the number of replicate surveys necessary to differentiate statistically a three-fold change in abundance, given the variability recorded (Zar, 1984). It was determined that eighteen, 10-minute surveys needed to be completed in each channel to be able to differentiate statistically a three-fold change in abundance using a t-test.

Sampling in Mundoo Channel

Mundoo channel was sampled on nine separate occasions, generally spaced one week apart. The intent was to sample the channel during each of the following lunar phases: new moon, first-quarter moon, full moon, and third-quarter moon. A sampling date fell into a particular lunar category if the sampling occurred three days before or after the calendar date for that period. For example, a new moon occurred on April 25. Sampling occurring April 22-28 was labeled as occurring during a new-moon period. Each sampling event consisted of eighteen, 10-minute surveys: six along the wall nearest Mundoo Island, six along the wall nearest Maabaidhoo Island, and six along the front edge of the channel (nearest the open ocean). Two observers using scuba gear entered the water and surveyed two separate, parallel transects at the same time. There was a distance of at least 10 m separating the two observers, and usually more. If a fish traveled through both transects, it was only counted once, and by the first person who observed it. The size of each fish observed was estimated to the nearest 5 cm.

Even though the pilot study indicated no significant effect of observer, tidal state, lunar period, and date on fish abundance, these factors were more closely analyzed to detect any longer-term effects. Ideally, the data collected could be analyzed as repeated measures, three-factor ANOVA with observer, tidal state, and lunar period as fixed factors, and the repeated measure dated. However, there was unequal replication among

all fixed factors with several categories having only one or no observations. Thus, several separate analyses were made to determine which factors were significantly influencing fish abundance. Data were log(x+1) transformed to help achieve homogeneous variances and normality (Zar, 1984).

A one-way ANOVA was used to test whether or not there were significant differences in the mean abundance (no. fish 10-minute^{-1}) of each fish species among tidal states (ebb, flood, or slack tide). A two-way ANOVA was used to test for significant differences in mean fish abundance among lunar periods and observers. As Mundoo channel was sampled repeatedly, the sampling date was examined in a repeated measures model. The model examined whether or not there were significant differences in abundance among the four species or among dates. Two time periods (April 30 and June 8) had missing values which were substituted with the average value for that time period. The size of each grouper observed was estimated and recorded. A one-way ANOVA was used to test for significant differences in mean fish size among sampling dates.

RESULTS

The total numbers of fish observed in Mundoo channel during the course of this study were: *Cheilinus undulates,* 46; *Epinephelus fuscoguttatus,* 31; *E. polyphekadion,* 7; *Plectropomus areolatus,* 295; *P. laevis,* 96; and *P. pessuliferus,* 12. As this channel was sampled repeatedly, many fish were likely observed several times both within the same sampling date and among sampling dates. Due to low numbers of observations, *P. pessuliferus* and *E. polyphekadion* were not used in statistical analyses.

There was no significant influence of tidal state on fish abundance (Table 1). One-way ANOVA results were always insignificant (n=175, df=2,172,p>0.05). There was no significant difference in *C. undulatus, P. laevis,* or *E. fuscoguttatus* abundance among lunar periods or observers (Table 1). There were also no significant interaction effects for these species. *P. areolatus* abundance was significantly different among lunar periods, but not among observers. This species was more abundant in the time period surrounding the new moon than the first-quarter or full moon (Fig. 3). There was no significant difference in mean abundance between the new moon and third-quarter moon lunar periods. Fish abundance was significantly different among species and dates. *Plectropomus areolatus* was the most abundant species during the study, followed by *P. laevis*. The only species which appears to have a recognizable pattern in abundance over time is *P. areolatus* (Fig. 4). It appears that abundance increased during the study until the time period on, and after, the new moon on April 25th. After this date, abundance decreased.

Size-frequency distributions for each species are given in Figure 5. The data conform to known maximum size limits for these species (Randall 1992). Small individuals (<30 cm) were rare. The test showed that there were significant differences in mean fish size among sampling dates only for *P. areolatus* (Fig. 6).

New moons occurred on March 28, April 26, and May 25. Courtship behavior was recorded for *P. areolatus* one and four days prior to the new moon in April. Courtship occurred in pairs, with the larger, presumably male, fish approaching from behind. When the two fish were side by side, the male would turn his body laterally so that he was at a 45-90 degree angle to the female. This placed his vent near the lateral

and ventral side of the female. He then made a shivering motion which consisted of an exaggerated, sustained wave proceeding along the length of his entire body. Once he was ahead of the female, the male would swim directly in front of the female so that the length of his body would pass closely to the female's head region. The larger individual would sometimes shiver in front of the female as well. During most of the courtship displays by *P. areolatus*, the larger individual was dark in color while the smaller was a lighter color. Many of the dark individuals had light bars on the side of their bodies.

Plectropomus laevis usually was not observed in groups but as solitary individuals. However, just after the new moon in March and just before the new moon in April, a small group of 4 to 5 individuals was observed. The largest individual in the group, presumably the male, was 10-20 cm larger than the others. This individual was also colored differently; it was dark with white coloration on the head and tail. Courtship behavior was observed for *Plectropomus laevis* four days following the new moon in March.

No spawning was observed by either species despite several observations at dusk. Once the sun set, individuals retreated to crevices and holes in the coral reef and were not observed swimming out in the open.

Table 1. Summary of Analysis of Variance (ANOVA) results. Tidal state refers to results of a one-way ANOVA testing for significant differences in a species' abundance among periods with ebb, flood, or slack tide. Lunar period refers to results of a two-way ANOVA testing for significant differences in a species' abundance among new, first-quarter, full, and third-quarter moon periods. Observer refers to results of a two-way ANOVA testing for significant differences in a species' abundance among three observers. Ns = not significant, *** = p < 0.001.

Species	Tidal state	Lunar period	Observer
Cheilinus undulatus	Ns	Ns	Ns
Epinephelus fuscoguttatus	Ns	Ns	Ns
Plectropomus areolatus	Ns	***	Ns
P. laevis	Ns	Ns	Ns

DISCUSSION

It appears that *P. areolatus* and *P. laevis* spawn near the new moon in March and April in Laamu Atoll, Republic of Maldives. Release of gametes was not observed, but spawning courtship was observed during those times. No courtship behavior was recorded during non-new moon times or during observations near the new moon in May. Based upon abundance data, the major spawning month for *P. areolatus* is April, with minor spawning in March. Formal surveys were not completed in March, but a large number of *P. areolatus* were observed during one portion of the pilot study which occurred two days after the new moon during this month. This timing corresponds with the monsoonal transition from the NE to the SW monsoon. Surveys only spanned the period of March-June, so conclusions cannot be made about other times of the year.
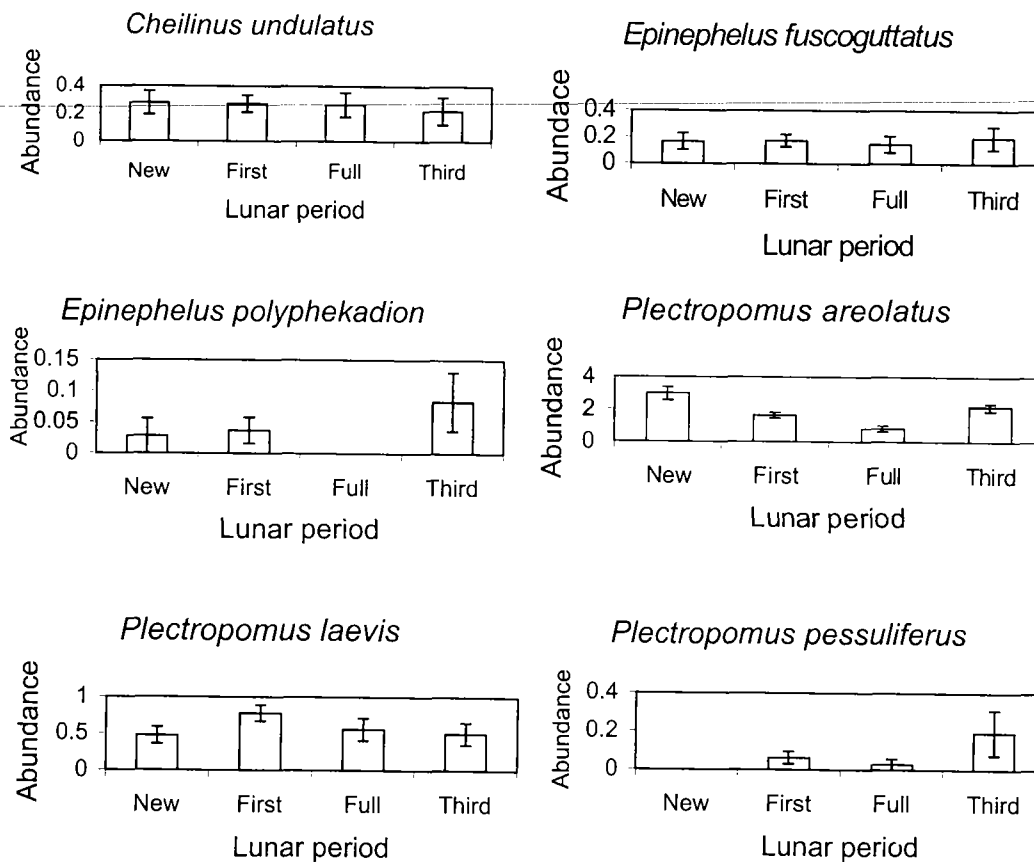
Cheilinus undulatus

Epinephelus fuscoguttatus

Epinephelus polyphekadion

Plectropomus areolatus

Plectropomus laevis

Plectropomus pessuliferus

Figure 3. Mean abundance +/- 1 SE (no. fish 10-min^{-1}) of each targeted species in Mundoo Channel by lunar period.

However, spawning may occur during the other monsoonal shift occurring September-October. There is limited evidence that bimonsoonal spawning occurs for some species and locations in the Western Indian Ocean (Morgans, 1962; Nzioka, 1979; Ntiba and Jaccarini, 1990), but other evidence suggests otherwise (McClanahan, 1988).

Courtship behavior of *P. areoloatus* was similar to that of *P. leopardus* observed on the Great Barrier Reef, Australia by Samoilys and Squire (1994). They observed that *P. leopardus* courtship behavior "...involved a specific courtship display whereby the male swam towards a female with his body tilted at 45-90 degrees, quivering along his full length, and making repeated lateral shakes of the head. Continuing in this mode, the male would approach the female and then pass close by the female's head or body, with either the dorsal or ventral side of his body nearest to the female. He would frequently circle and repeat the process." This species pair spawned. Courtship behavior and timing of spawning (new moon, near dusk) may be similar for all Plectropomids.

Both the pilot and main studies indicate that grouper abundance surveys can be undertaken and compared over different times of the day, tidal cycles, current speeds, and among separate observers. Sluka et al. (1994) and Sullivan and Sluka (1996) have also shown that multiple observers and time of day, respectively, do not influence the ability
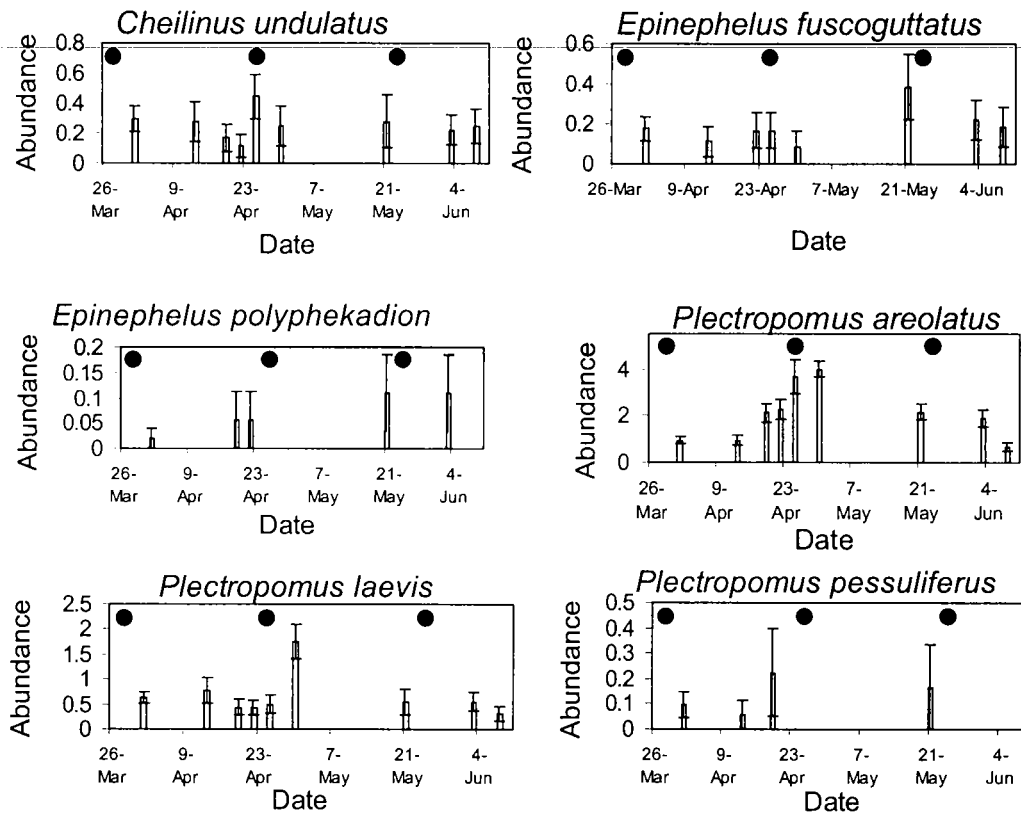
Figure 4: Mean abundance +/- 1SE (no. fish 10-min^{-1}) of each targeted species in Mundoo Channel by date. Dark circles indicate date of new moon.

to assess grouper abundance. This results in greater flexibility in the timing of sampling as well as being able to use many observers so that larger sample sizes can be collected. The linear relationship between sampling time and target species abundance suggests that timed surveys of different duration can be compared by normalizing to a specific duration. More research is needed to confirm this result. But it highly suggestive and would mean that the duration of each timed survey could be tailored to the specific site as long as transect width remains the same. However, nonparametric ANOVA should be used as variances will not be homogeneous between transects of different lengths (T. McClanahan, pers. comm.).

Several studies have linked increases in water temperature with the timing of grouper spawning (Colin, 1992; Tucker et al., 1993; Samoilys and Squire, 1994; Samoilys, 1997). Samoilys (1997) noted that the first increase in *Plectropomus leopardus* on her site in the northern Great Barrier Reef coincided with water temperatures rising about 24°C, which is below the maximum temperature for that region. However, in Maldives, the timing of *P. areolatus* spawning coincided with the warmest month on record and occurred during a time of much coral bleaching. The maximum temperature in Mundoo Channel during the study period at 17 m depth was 32.4°C, while the minimum was 29.3°C (Sluka, 1998). This period of high temperature
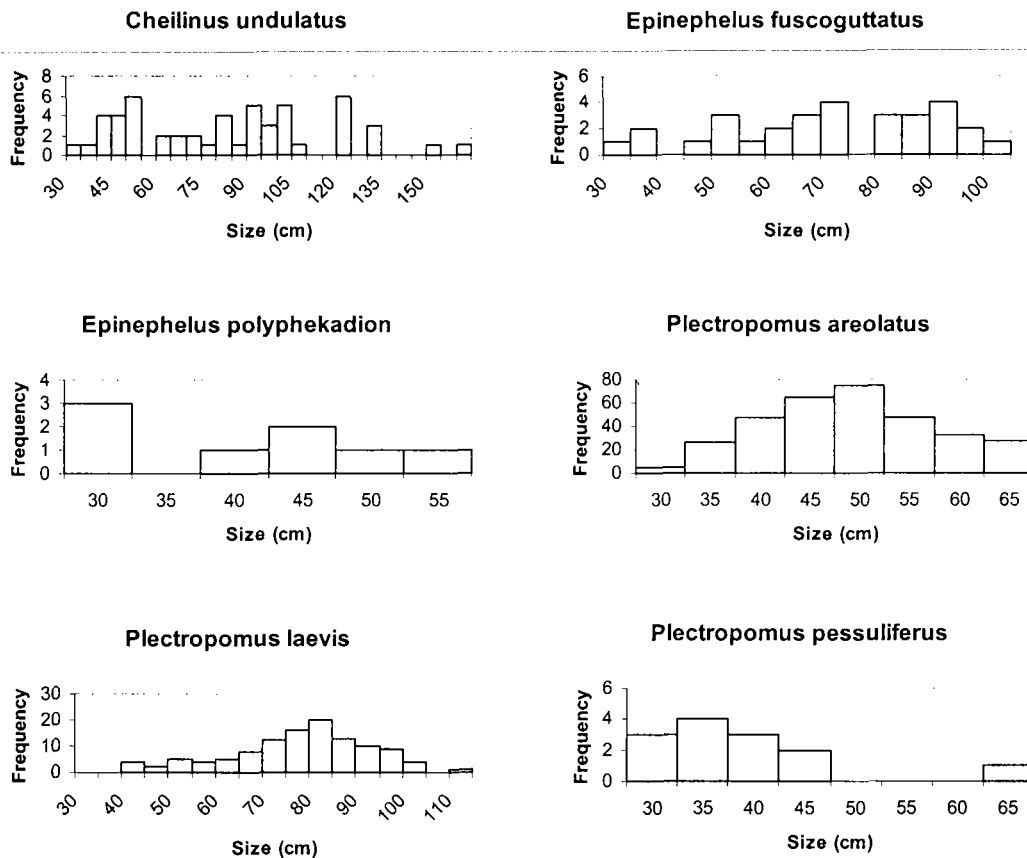
Cheilinus undulatus

Frequency

Size (cm)

Epinephelus fuscoguttatus

Frequency

Size (cm)

Epinephelus polyphekadion

Frequency

30   35   40   45   50   55

Size (cm)

Plectropomus areolatus

Frequency

30   35   40   45   50   55   60   65

Size (cm)

Plectropomus laevis

Frequency

Size (cm)

Plectropomus pessuliferus

Frequency

30   35   40   45   50   55   60   65

Size (cm)

Figure 5. Size-frequency distributions of each targeted species in Mundoo channel.

occurred after the new moon on April 25, but temperatures prior to the new moon were much higher than those previously recorded for the timing of grouper spawning in other countries. This is expected as Laamu Atoll is located close to the equator. The data do not confirm nor contradict the notion that water temperature is linked to the timing of spawning in groupers.

Size data indicate that no small (less than 30 cm) fish were observed in Mundoo Channel. Individuals of this size are rarely observed, but at least one *P. pessuliferus* (approximately 15 cm) was observed on the inner-atoll reef slope off Maabaidhoo Island, which is situated between Mundoo and Fushi channels (Sluka, pers. obs.). It appears that the studied species do not recruit to the channel habitat. Very few small individuals were observed in this atoll (Sluka, 2001). When small individuals of the targeted species were observed, it usually occurred on an inner-atoll reef slope or faro reef slope. Several small (10-20 cm) *P. areolatus* have been observed amongst *Acropora* spp. thickets on the lagoon floor near the inner-atoll reef slope drop off or on the slope itself.

The reproductive ecology of Napoleon wrasse is essentially unknown (Turnbull and Samoilys, 1997). This species will aggregate to spawn in large numbers at sites that appear to be similar to sites where grouper aggregate (Johannes and Squire, 1988; in
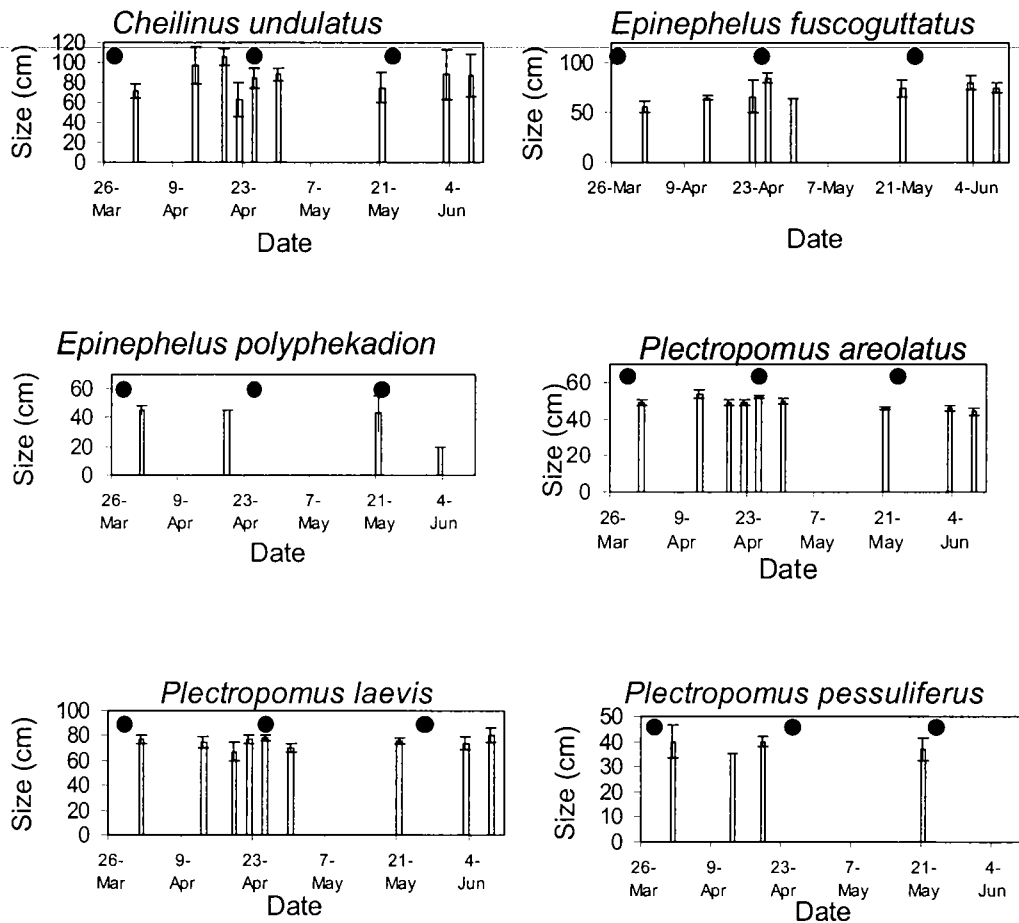
Figure 6. Mean size +/- 1 SE (cm) of target species in Mundoo channel by sampling date. Dark circles indicate date of new moon.

Turnbull and Samoilys, 1997). This species exhibits a parading behavior where individuals will swim in a line, one behind the other (Donaldson, 1995a). However, it is not known if this precedes spawning as spawning has not been observed.

The reproductive ecology of groupers is influenced greatly by the biology and behavior of these species. Most species of grouper are considered to be protogynous (changing sex from female to male at some stage in the life history). However, males may develop directly from juveniles in some species (Sadovy and Colin, 1995). Transition from female to male appears to be socially rather than biologically mediated, as there is a wide range of ages and sizes at which transitional individuals have been recorded (Shapiro, 1987).

Indo-Pacific groupers exhibit a wide variety of spawning patterns including non-migratory pair spawning (e.g. *Cephalopholis spiloparea, C. urodeta*), nonmigratory haremic spawning (e.g. *C. argus, C. miniata*), and migratory pair and group spawning (e.g. *Epinephelus fuscoguttatus, Plectropomus areolatus, P. leopardus*) (Goeden, 1978; Johannes,1981, 1988; Shpigel and Fishelson, 1991; Samoilys and Squire, 1994;

Donaldson, 1995b). The migration of large numbers of groupers to specific sites during a few months of the year has been termed a spawning aggregation. Spawning aggregations have been shown to be very predictable in both space and time (Sadovy, 1994; Samoilys, 1997). Individuals gather a few days before the new moon (in the western Atlantic, full moon) at specific locations, many times at the outer end of a channel or promontory, to begin spawning. Spawning aggregations persist for several days around the appropriate moon (Johannes, 1988; Samoilys, 1997). Spawning behavior, such as males nudging the vent of females, occurs throughout the day culminating in external fertilization approximately 10-20 minutes before dusk (Johannes, 1988; Samoilys and Squire, 1994; Turnbull and Samoilys, 1997; Zabala et al., 1997). The eggs are pelagic and spend about a month in the water column before settling to coral-reef habitats (Leis, 1987).

This study cannot conclusively place the target species into any of these categories due to lack of observation data. However, this study does suggest that *P. areolatus* is a migratory pair spawner, rather than a migratory group spawner. Courtship behavior was always observed between two individuals, never more than that. Also, abundance in the channel rose near the new-moon spawning times suggesting migration. Data on *P. laevis* from this study is scant and could be interpreted as nonmigratory haremic or migratory group spawning. This is due to groups of four to five individuals being observed together in Mundoo channel near the new moon, but during no other time. It cannot be confirmed that this species migrated to the channel for spawning. The assessment for this species is highly speculative.

The identification of grouper spawning aggregation sites as well as the timing of the aggregations in Maldives remains an urgent question for research. Research should be focused around the monsoonal shifts. If grouper can be confirmed to spawn during these times in several atolls, this would make a temporal closure of the fishery feasible as it is unlikely that all or most of the grouper aggregation sites in the Maldives will be located in the next several years.

Important questions to answer in regard to the aggregations include:
1) Where and when do the aggregations occur?
2) How much of the population spawns during each aggregation season?
3) What are the movement patterns between home ranges and spawning aggregation sites?
4) How are the sexes distributed throughout the nonspawning season?
5) Do larvae produced in spawning aggregations stay within a particular atoll or is there inter-atoll transfer of larvae?

Armed with this information, a system of marine fishery reserves could be designed to potentially protect grouper within Maldives so that the important live fish-food industry can continue and can be sustainable. However, numerous studies have shown the pervasive negative effect of intense fishing pressure on targeted species (see review in Sluka, 1998). It is clear that marine fishery reserves protect fish biomass, size structure, and reproductive output (Sluka et al., 1997). Several studies have also shown that these reserves export biomass through fish movement to surrounding areas that becomes available for fishers (Russ and Alcala, 1996; Sluka et al., 1997; Zeller and Russ, 1998). Studies on the patterns of larval dispersion via currents are likely to show that marine

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fishery reserves are a source of recruits to fished areas (PDT, 1990). It is, therefore, more important to establish marine fishery reserves sooner rather than later when more information becomes available. Once the research questions listed above are answered, the system of reserves can be adjusted to maximally protect the populations. In the short run, however, lack of protection from fishing has been proven to be extremely detrimental to intensely fished grouper populations.

ACKNOWLEDGEMENTS

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