

Aggregations of *Plectropomus areolatus* and *Epinephelus fuscoguttatus* (groupers, Serranidae) in the Komodo National Park, Indonesia: monitoring and implications for management

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Synopsis

We identify fishery management implications from a long-term monitoring program focusing on spawning aggregations of high valued reef fish in Komodo National Park (KNP), Eastern Indonesia. Management objectives of KNP are not only to protect biodiversity, but also to conserve spawning stocks of high-valued commercial species for the replenishment of surrounding fishing grounds. We monitored two sites twice monthly over five years for two species of grouper, *Epinephelus fuscoguttatus* and *Plectropomus areolatus*. One site had an aggregation of both *E. fuscoguttatus* and *P. areolatus*, whereas the other site contained an aggregation of *P. areolatus* only. Over the five years monitoring period, aggregations typically formed during each full moon between September and February. Additionally, *P. areolatus* occasionally aggregated during new moons between April and July. We observed spawning only once, but because formation of aggregations were correlated to a higher incidence of behavior and signs indicative of reproduction and because most fish present were adults, it is likely that the formation of aggregations was associated with spawning. Over the five years monitoring period there was a reduction in mean fish size of up to 8 cm for *P. areolatus*, and a reduction in numbers of aggregating *E. fuscoguttatus*. Despite limited protection initiated in 2001, both sites are still heavily fished by local artisanal fishers. Because the observed reductions in size and in numbers could be caused by fishing pressure, managers should follow the precautionary principle by putting additional protective management in place. Since both species are relatively long-lived, at least five years of continued monitoring may be necessary to determine the outcome of management intervention. The variability in timing of aggregation in respect to season and moon phase in *P. areolatus* indicates that long-term monitoring must cover the entire year and both moon phases.

Introduction

Many species of tropical fish aggregate annually to spawn in their tens, hundreds or even thousands. A spawning aggregation is defined as a 'group of conspecific fish gathered for the purpose of spawning, with fish densities and numbers significantly higher than those found in the area of the

aggregation during non-reproductive periods' (Domeier & Colin 1997). In many situations, the location and timing of aggregations are consistent over the long term and, as a result, these gatherings make easy targets for seasonal fisheries (Johannes 1981, Sadovy 1997, Johannes et al. 1999, Rhodes & Sadovy 2002, Claro & Lindeman 2003, Sadovy & Domeier 2005). There is growing

recognition of the vulnerability of spawning aggregations to fishing pressure following marked declines in some species (e.g. *Epinephelus striatus*), and of the need to protect this life history phase from heavy fishing (Sadovy & Domeier 2005).

While there is at least one demonstrated successful attempt in the western Atlantic to manage spawning aggregations (Nemeth 2005), the situation is different in the Pacific where little management is in force: traditional management of aggregations is known from just a handful of sites (e.g. Palau and Pohnpei), and Australia has only recently introduced protective legislation for aggregations on the Great Barrier Reef. There is growing pressure to exploit reef fishes for export, and in the last decade, there has been a rapid growth in the luxury market for live reef food fish in Southeast Asia (Johannes & Riepen 1995, Sadovy & Vincent 2002). Sometimes these fish are taken from spawning aggregations (Sadovy et al. 2003). Indonesia is a major supplier of live fish for this trade, resulting in considerable pressure on Indonesian reefs and reef fish resources, including on aggregations (Mous et al. 2000).

Komodo National Park (KNP), off Flores in Eastern Indonesia, is a United Nations Man and Biosphere Reserve and a World Heritage Site that was established by the Indonesian government as a National Park in 1980. Designated to conserve the unique Komodo dragon, *Varanus komodoensis*, and its habitat, KNP also features 1214 km² of highly diverse marine habitats harboring more than 1000 fish species (Pet & Yeager 2000). An estimated 20 000 people live in fishing villages inside and directly surrounding KNP (status as of 1998, Pet & Yeager 2000), and many take reef fishes for the lucrative live reef fish trade, putting heavy pressure on marine resources. The main management objectives for the marine component of KNP are to protect biodiversity and the breeding stocks of commercial fish and invertebrate species, with the ultimate aim of replenishing surrounding fishing grounds that sustain local fisheries (Pet & Yeager 2000).

To identify a site on a reef as a spawning aggregation site, both aggregating of fish and reproduction need to be confirmed. Domeier and Colin (1997) used a threefold increase in fish density relative to the normal density outside the spawning season as a working definition of

aggregating behavior. To confirm that an aggregation has formed for the purpose of spawning, rather than for some other purpose such as feeding, evidence of reproduction is also needed. Spawning, however, may be difficult to observe *in situ* because mating may be brief, may occur after dark, may be inhibited by the presence of divers, or may take place under difficult SCUBA diving conditions such as in deep water or strong currents (Colin et al. 2003). If spawning cannot be observed *in situ*, proxies for spawning behavior may be used, such as presence of females with swollen bellies from hydrated eggs, or species-specific body coloration known to occur only during the reproductive season.

The present study assesses temporal patterns in aggregating behavior, and trends in average body size and numbers of two commercial species of grouper, *Epinephelus fuscoguttatus* and *Plectropomus areolatus*, at two sites in KNP monitored with Underwater Visual Census (UVC) over a five years period. Observations on species-specific behaviors thought to occur only during the reproductive season were used to corroborate whether aggregation was likely to be associated with reproduction. We discussed observed trends in relation to possible effects of the local artisanal fishery on the populations of aggregating groupers, and we also considered implications of observed patterns in aggregating behavior for the design of long-term monitoring programs.

Materials and methods

We based the design of our monitoring program on exploratory underwater surveys and fisher interviews conducted for the KNP Management Plan during the period 1995–2000 (Pet et al. 1999, Pet & Yeager 2000). Using observations from these exploratory surveys, which included 100s of dives at ca. 300 sites throughout the KNP, we focused the scope of the monitoring program in respect to target species, monitoring sites and monitoring periods in relation to moon phases. Besides 185 sites covered in a coral reef monitoring program, exploratory surveying also included dives at sites where artisanal fishing (mostly hook-and-line and gillnets) was observed and sites with topographies that are associated with spawning aggregations,

such as reef promontories and channels (Colin et al. 2003). Eventually, we selected 12 of the most promising sites for twice a month monitoring.

Target species commonly observed during the exploratory surveys comprised the groupers *Epinephehus tukula*, *E. polyphkadion*, *E. fuscoguttatus*, *E. malabaricus*, *E. chlorostigma*, *Plectropomus leopardus*, *P. laevis*, *P. areolatus*, *P. oligocanthus*, *Variola louti*, *Cromileptes altivelis* and the wrasse *Cheilinus undulatus*. Only *E. fuscoguttatus* and *P. areolatus* formed aggregations as indicated by a threefold or higher increase in estimated numbers present at the suspected aggregation site (Domeier & Colin 1997). Aggregating behavior of *E. fuscoguttatus* was confirmed at only one of the 12 initially selected sites. At the same site, here coded as site A, aggregations of *P. areolatus* also occurred. A second site, here coded as site B, contained an aggregation of *P. areolatus*. In this paper, we only present results from these two species and these two sites. Site A is a promontory with a steep reef slope that levels out at ca. 40 m depth into a sandy bottom. The site is located at the northwestern corner of an island in the north of the KNP. The promontory is exposed to strong currents directed away from the reef, going either north or southeast depending on the tide. Site B is situated at the western side and northern tip of a peninsula in the north of Komodo Island. The site comprises a fringing reef with little current at the western side and strong currents at the northern tip, directed away from the reef, going either east or west depending on the tide.

The two sites (Figure 1) were monitored during a five years period (March 1998–March 2003) using UVC to estimate fish numbers, sizes (TL cm) and behaviors or signs indicative of spawning. During our exploratory surveys we found no evidence for aggregation during moon phases other than full moon and new moon. Therefore sites A and B were monitored twice a month, within three days period centered around full moon and new moon (i.e. day before, day of, and day after each full and new moon). Site A was surveyed during falling tide at noon, close to slack. One observer and a dive buddy descended to a depth of 30 m at the northwestern corner of the island and round the corner taking a southeastern direction while slowly ascending to ca. 15 m. Site B was surveyed during slack tide, which during full

moon and new moon is in the morning. One observer and a dive buddy descended halfway the western side of the peninsula to a depth of ca. 25 m, and swam towards the tip of the peninsula following the line where the reef slope levels out to a sandy bottom. If visibility was equal or higher than the average visibility of 15 m, observers were able to cover the complete aggregation in a single transect of ca. 200 m that was completed in ca. 30 min for each aggregation site. Observers recorded the estimated length of each fish that was spotted on an underwater data sheet. After the dive, the number of length estimates was counted to give the total number of fish present at the site. If visibility was low (lowest recorded visibility was 5 m), observers searched the complete aggregation site in a meandering pattern. Hence, the complete area covered by the researchers remained constant, and a regression analysis showed that visibility had no significant effect on numbers of fish recorded on the site (Pet et al. 1999).

During UVC, grouper behavior and other signs that are indicative for the reproductive season were scored as present or absent for each survey dive (i.e. occurrence of behavior and signs was not quantified). Behavior and signs that were scored included presence of gravid females (fish with swollen bellies), and male behavior and signs that are thought to occur more frequent during the reproductive period, such as alteration of color, frequent aggressive interactions, extensive external wounding associated with the aggression, and swimming on the side in a distinct wavering motion (courtship). Color changes involved lightening of parts of the body with black extremities of fins clearly visible. For *E. fuscoguttatus*, the lips, chin, cheeks, belly and caudal fin turned pale. In *P. areolatus* most of the body lightened, leaving a clear black margin around the caudal fin. Aggregated female *P. areolatus* were purple-olive with clear spots and a lighter margin to the caudal fin.

Observers were trained prior to monitoring to ensure correct species identification, recording of behaviors and accurate fish measurements. Training included: (1) size estimation and species identification from color-printed paper fish models of 15–150 cm, (2) underwater size estimation of wooden fish models of 10–80 cm, (3) fish species identification from a reference collection (frozen specimens), (4) fish identification under water, and

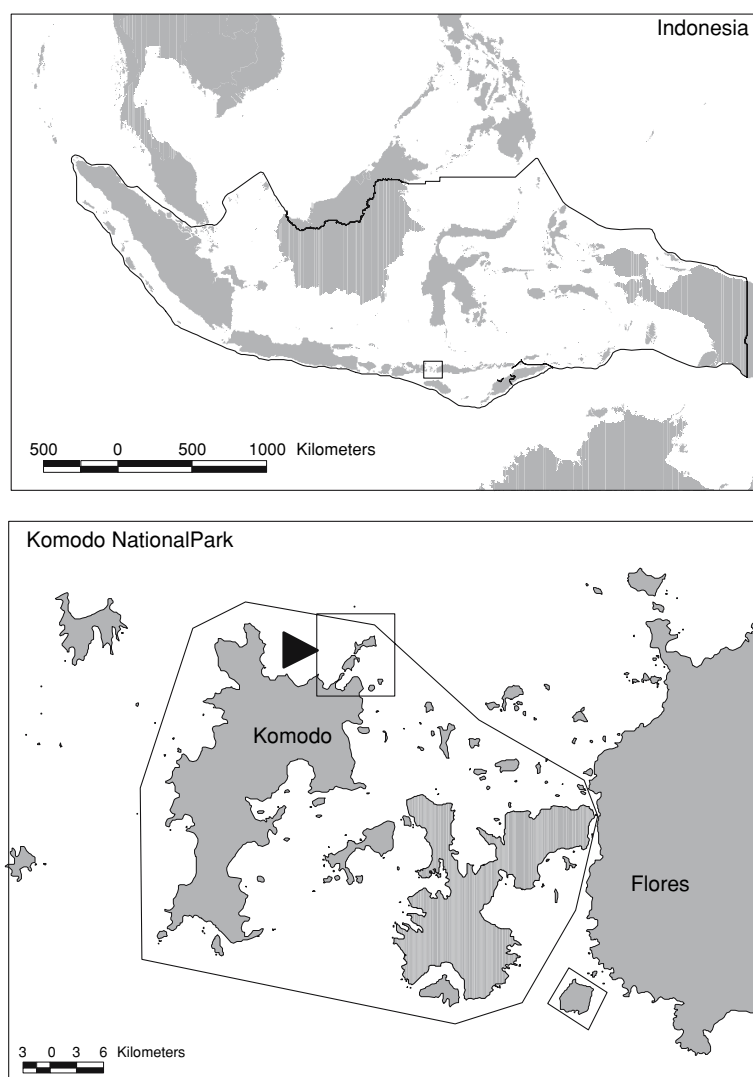


Figure 1. Location of Komodo National Park in Indonesia (top panel, showing territorial waters) and the area where the two spawning aggregation sites within KNP are situated (lower panel). In accordance with recommendations of the Society for the Conservation of Reef Fish Aggregations (www.scrfa.org), the precise location of these vulnerable sites within the indicated square is not indicated.

(5) identification of fish behavior. Training continued until observers could correctly estimate, under water, the lengths of at least 75 out of 100 wooden fish models with a maximum allowable error of 3 cm for all size classes. Retraining was carried out periodically, at least once per year. In total, a group of six trained divers from the KNP authority and The Nature Conservancy's Komodo Field Office collected data throughout the five years monitoring period. These divers inter-

changed observer and buddy roles between survey dives.

We conducted simple regressions of mean body length on survey date to identify trends in body size over time. Differences in body length between years, months and moon phases were analyzed using a factorial ANOVA, with body length as a dependent variable and moon phase (MOON, taking the values 'full' or 'new'), sampling year (YEAR, starting in March and ending in

February), as well as their interaction, as independent variables. Spearman rank correlation coefficients were calculated to test whether number of fish present at aggregation sites was correlated with occurrence of behaviors and signs indicative of spawning. Analyses were performed with Stat-View 5.0.1 and SAS 9.1.

Results

Monthly fish counts revealed seasonal and lunar patterns in aggregating behavior in *E. fuscoguttatus* and *P. areolatus* (Figures 2 and 3). Both species clearly showed net seasonal increases in fish numbers at the survey sites by a factor of at least three. Aggregations formed for between 4 and 6 months annually, mainly between September and February, and were most distinct during the full moon periods. Occasionally, *P. areolatus* also aggregated during new moon around the period April–July (Figure 3). The highest number of fish recorded during a single survey dive was 82 *E. fuscoguttatus* at site A, and 77 *P. areolatus* at site B. Numbers of *E. fuscoguttatus* declined during the aggregating period over the five years monitoring period (Figure 2), while those of *P. areolatus* appeared stable at both sites (Figure 3).

Spawning was observed only once during the monitoring period, in *P. areolatus* during a new moon survey (July 1, 2000) at site B. Spawning took place about one hour before high tide in the

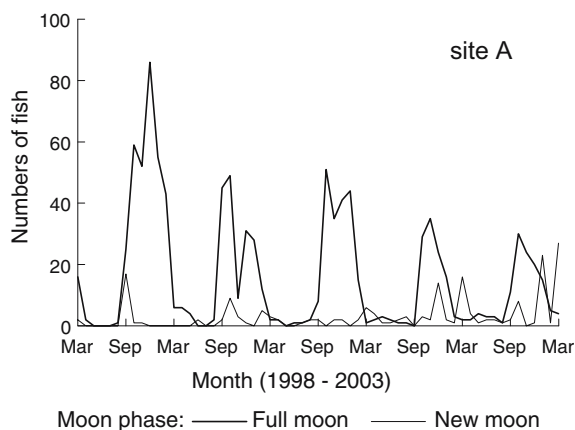


Figure 2. Number of *E. fuscoguttatus* observed at spawning aggregation site A during full moon and new moon over the period March 1998–March 2003.

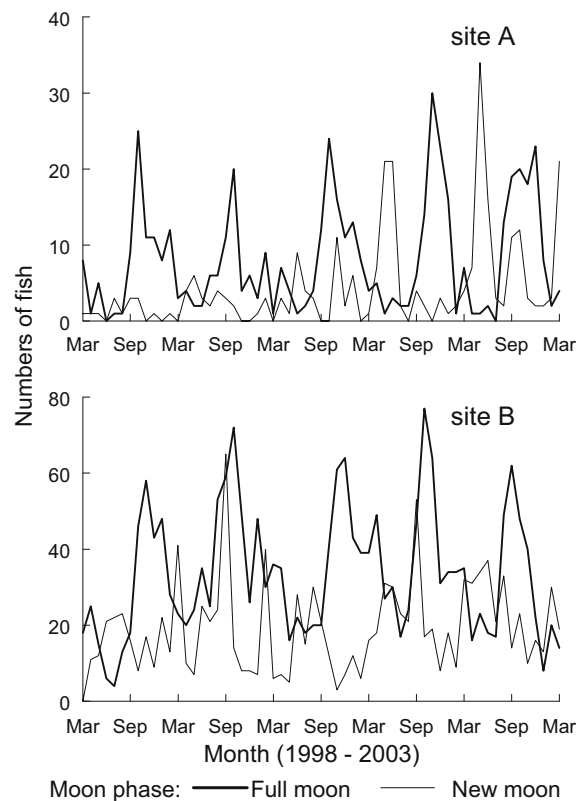


Figure 3. Number of *P. areolatus* observed at spawning aggregation site A (top panel) and B (lower panel) during full moon and new moon over the period March 1998–March 2003.

morning, when four separate pairs from the aggregation were observed to swim up from the coral substrate (about 9 m depth) to about 4 m below the surface where they released eggs and sperm. Each pair parted immediately after spawning and quickly returned to the substrate. Spawning was also observed for one other species, Napoleon wrasse, *C. undulatus*, at site A during mid-day at new moon (October 20, 1998). The spawning group comprised a large animal (presumably the male) and several smaller animals (presumably females). The larger animal was observed to spawn with a single smaller animal while swimming close together, in a wavering motion just below the surface.

Correlations between observed numbers of fish and occurrence behaviors and other signs that are indicative for the reproductive season were assessed by calculating Spearman rank correlation coefficients between fish numbers and occurrence

of gravid females and courtship combined, and for coloration changes, body wounds and aggressive behavior, combined. All correlations were significant at the $p < 0.05$ level (2-tailed) for both species and for both full and new moon periods. Therefore, the spawning season was inferred to occur sometime during the months of aggregation for both *E. fuscoguttatus* and *P. areolatus*.

Length-frequency distributions (LFD) for each moon phase and each year were unimodal, with a mean length varying between 62 and 75 cm TL for *E. fuscoguttatus*, and a mean length varying between 46 and 56 cm TL for *P. areolatus*. The average standard deviation in body length was

7 cm TL for *E. fuscoguttatus*, and 11 cm TL for *P. areolatus* (Figure 4).

For *E. fuscoguttatus* at site A, body length differed between years as well as between moon phases, and the significant ($p < 0.01$) interaction term indicates that although body lengths differed between years, this difference was not consistent for each moon phase throughout the monitoring period (Table 1a). Combining observations from new moon and full moon periods, body length showed no significant linear trend over time (linear regression analysis of body length on survey date, $n = 1189$, $p = 0.7$). For *P. areolatus* at site A, body length differed between sampling years

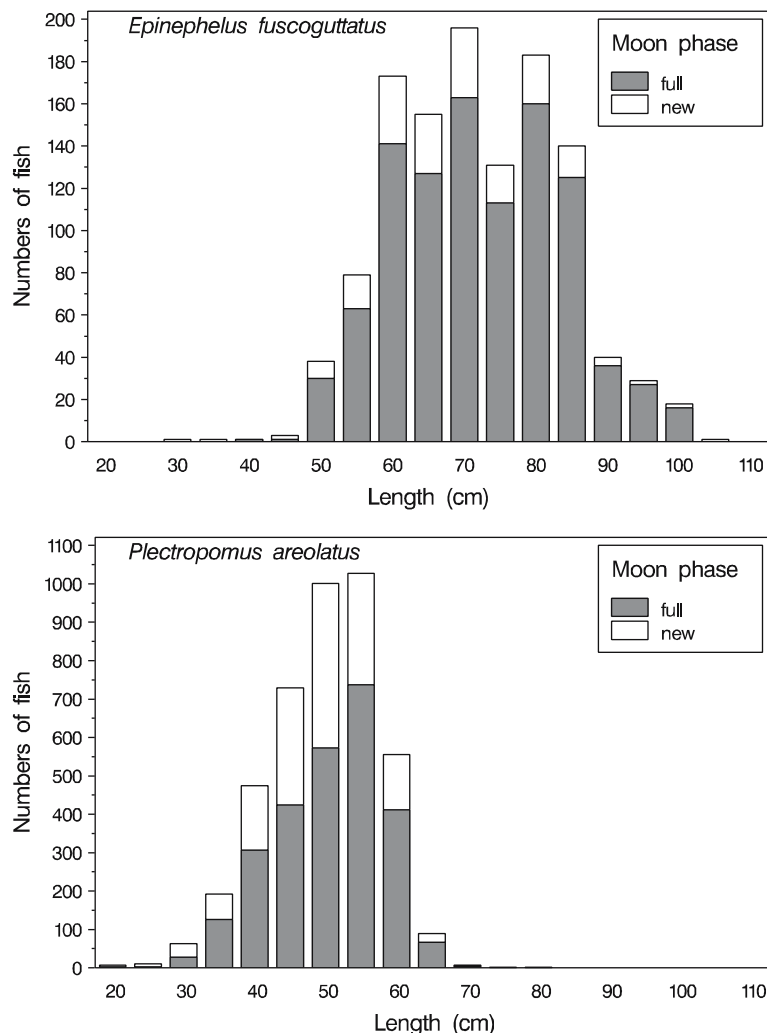


Figure 4. Length-frequency distributions (cm TL) of all fish observed at the two spawning aggregations sites in KNP during the study period for *E. fuscoguttatus* (top panel) and *P. areolatus* (lower panel).

Table 1. ANOVA table for the analysis of body length of *E. fuscoguttatus* and *P. areolatus* at site A and B. MOON = moon phase (full or new), YEAR = sampling year (March–February).

Source	DF	SS	<i>p</i>
(a) <i>E. fuscoguttatus</i> , site A			
MOON	1	1330	0.0013
YEAR	4	3227	< 0.0001
MOON*YEAR	4	1823	0.0069
Residual	1179	151288	
(b) <i>P. areolatus</i> , site A			
MOON	1	3	0.80
YEAR	4	3572	< 0.0001
MOON*YEAR	4	220	0.26
Residual	800	33036	
(c) <i>P. areolatus</i> , site B			
MOON	1	1780	< 0.0001
YEAR	4	8290	< 0.0001
MOON*YEAR	4	1413	< 0.0001
Residual	3337	194419	

($p < 0.0001$), but not between moon phases ($p = 0.8$) (Table 1b). At site B, moon phase and the interaction between moon phase and sampling year were significant ($p < 0.0001$), but together they explained only 40% of the variance explained by sampling year alone (Table 1c). Combining observations from new moon and full moon periods, body length showed a strongly significant decreasing trend at both site A and B (linear regression analysis of body length on survey date, $p < 0.0001$). Over the five years monitoring period, average length of *P. areolatus* at site A decreased from 54 to 46 cm TL, whereas at site B the average body length decreased from 52 to 48 cm TL (Figure 5).

Discussion

Although ca. 300 of sites within KNP's 17 km² of reef slopes were surveyed repeatedly during all lunar phases between 1995 and 2000, distinctive aggregating behavior was identified for two fish species at two sites only: *E. fuscoguttatus* and *P. areolatus* aggregated at one site, whereas another site contained an aggregation of *P. areolatus*. The apparent scarcity of spawning aggregation sites underlines how important these two sites are in the life-histories of *E. fuscoguttatus* and *P. areolatus* in KNP.

Since spawning was observed only once during this study, the reproductive nature of the aggregations could only be inferred from the occurrence of behavior and signs indicative of the reproductive season. Johannes et al. (1999) reports similar color changes during aggregations of the same species. Furthermore, almost all fish at the aggregation site were close to or above the approximate size of sexual maturation (42 cm TL for *E. fuscoguttatus* and 35 cm TL for *P. areolatus*; Chao et al. 1993, Ferreira 1995, Johannes et al. 1999). We conclude that temporal patterns in abundance at survey sites A and B were likely associated with spawning, and that the likely spawning seasons for *E. fuscoguttatus* and *P. areolatus* in KNP fell between September and February and mainly during full moons. A possible second spawning season was found for *P. areolatus* during new moon between April and August.

Our study suggests that observations on behavior and other signs that are indicative for the reproductive season may be useful to study temporal patterns in reproduction if spawning cannot be observed directly or if fish cannot be collected for inspection of gonads because of practical or conservation concerns. Care, however, must be exercised in using such behaviors and signs, given how little we know of the reproductive biology of most of the larger species of reef fish, or of their behavior or color changes outside of the reproductive season.

Over the five years monitoring period, mean body size of *P. areolatus* declined significantly, while numbers of aggregating *E. fuscoguttatus* showed more than a twofold reduction in maximum aggregated numbers. Various factors could account for observed patterns in numbers and size of fish at spawning aggregation sites, including size-selective fishing pressure, variation in recruitment strength over time, variation in growth, or variation in sex-specific differences in the timing of migration to or from the spawning aggregation sites. Though we cannot rule out the possibility that natural variation in fish population dynamics caused observed long-term patterns in numbers and size, fishing pressure remains a possible explanation for the observed trends. This is corroborated by similar trends observed in body size and abundance of another commercially important grouper, *P. leopardus*, in the same area during

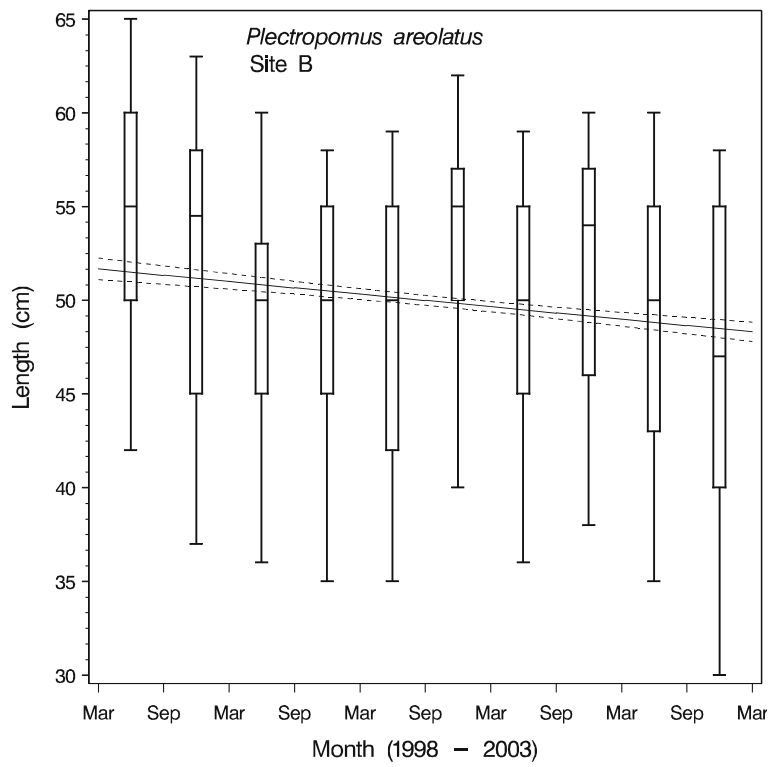
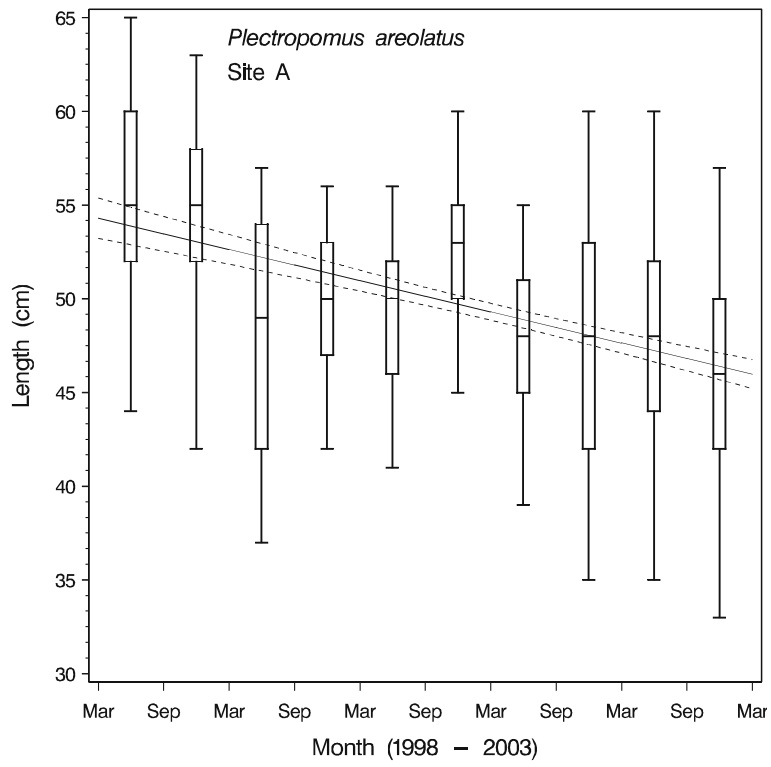


Figure 5. Decreasing trend in body length of *P. areolatus* at site A (top panel) and site B (lower panel). Box-and-whisker plots represent 5th, 25th, 50th, 75th and 95th percentiles of body length observations grouped in six-month intervals. (March–August, September–February, etc.) Solid lines are fitted with linear regression analysis (body length vs. date), whereas dashed lines represent 95% confidence limits of the mean ($p < 0.0001$, $n_{\text{site A}} = 810$, $n_{\text{site B}} = 3347$).

the same five years period: abundance of *P. leopardus* decreased with 40% and average body size decreased with 10% from 44 cm TL to 40 cm TL (linear regression analysis, $p < 0.001$; J.S. Pet, unpublished data). Furthermore, monitoring of resource utilization by the KNP authorities has shown that the two spawning aggregation sites in KNP identified in this study were more heavily fished than most other areas in KNP (Pet et al. 1999).

Some protective management has been effectuated. Before 2001, diving fishermen on hookah or snorkel, using cyanide or other gears, targeted groupers, and blast fishing was common until the year 1996 (Pet et al. 1999). Since 2001, fishing by diving on hookah compressor has been banned throughout KNP, and the ban on blast fishing has been effectively enforced (Mous et al. 2003). Furthermore, no-take areas were declared along most of the coast of KNP, comprising the two spawning aggregation sites identified in this survey. Although blast fishing, cyanide fishing and the use of hookah compressors have stopped, and although fishers hailing from other areas in Indonesia are kept from fishing inside KNP, fishing with hook-and-line and other artisanal gears such as gillnets in no-take areas by local fishers is still condoned by the KNP authority. Our results do not show any recovery of the two spawning aggregations since 2001. Though it is possible that continued monitoring will reveal positive effects of limited protection, it may be that the current level of fishing effort is still too high. Especially since the value of aggregated fish to dive tourism in KNP is greater than the value of the fish at current stock levels (Ruitenbeek 2001), the best management option at present is to fully protect these two spawning aggregation sites from fishing. The effectiveness of seasonal protection and no-take areas in the recovery of spawning aggregations has already been demonstrated for red hind *Epinephelus guttatus* in the US Virgin Islands (Nemeth 2005).

The occurrence of a new moon spawning aggregation of *P. areolatus* during April–July at a site where aggregations were initially observed during full moon in the period September–February suggests that management of these exploited grouper populations through permanent no-take areas encompassing aggregation sites is likely to be more effective than management through short-term temporal closures in KNP. From the perspective of monitoring program design, the observed temporal variation in formation of spawning aggregations suggests that long-term monitoring must be conducted year-round, during different moon phases, to avoid misinterpreting a shift in timing of spawning aggregation as a change in fish abundance. Given that both species are relatively long-lived, at least five years of continued monitoring may be necessary to determine the outcome of management.

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