

Spawning and aggregations of groupers (Serranidae) and Napoleon wrasse (Labridae) in the Komodo National Park

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Abstract

Spawning aggregation sites of *Epinephelus fuscoguttatus* and *Plectropomus areolatus* were visually monitored in Komodo National Park (KNP), Indonesia, from March 1998 until March 2001. Numbers, body size and behavior of several species of serranids and *Cheilinus undulatus* were recorded twice monthly at several sites in the Park. The objectives of the monitoring program were to detect grouper and Napoleon wrasse spawning (aggregation) sites in the Park, and to establish a baseline data set for the evaluation of trends in the populations, and the effect of management interventions. The objectives of the National Park are to protect biodiversity and conserve spawning stocks of commercial species for the replenishment of surrounding fishing grounds. The purpose of the present study was to determine which management measures would be needed for spawning aggregations, to obtain the latter objective. Two spawning aggregation sites, one with *E. fuscoguttatus* and one with *P. areolatus*, were identified within the Park. Aggregation of *E. fuscoguttatus* and *P. areolatus* took place during each full moon from September through February. This period was concluded to be the main spawning season for these and several other species, based on observations of courtship, gravid females (swollen bellies), wounds and coloration in males and other types of behavior and signs. Several other species of groupers and *C. undulatus* used the new moon for spawning. Occasionally aggregations of *P. areolatus* also formed outside the main spawning season and sometimes also on the new moon. Size frequency distributions differed monthly and indicated a reducing number of larger animals in the first 2 years. Many other reef fish species used the same spawning sites, indicating the importance of these sites for fisheries and Park management. These sites have been heavily fished in the past but have recently been included in fully protected no-take zones, aimed to serve as a source of replenishments for surrounding fishing grounds. Seasonal closures were recommended for traditional use zones in the Park.

Introduction

Many species of fish aggregate to spawn (Domeier and Colin, 1997). Sometimes the aggregations involve hundreds or even thousands of fishes, sometimes only tens assemble. In many cases, the location and timing of aggregations are consistent from year to year and, as a result, these aggregations make easy targets for seasonal fisheries where catchability is high and fishing particularly productive (Johannes, 1981; Ralston, 1987; Sadovy, 1997; Rhodes, 1998; Johannes et al., 1999). Both tropical and temperate species are known to aggregate to spawn. Some temperate species spawn on sea mounts in deep water, like the orange roughy, *Hoplostethus atlanticus*, or in shallow water like the common hake, *Merluccius hubbsi*. Species from at least eight coral reef-associated families spawn in shallow waters on well-defined reef promontories close to deeper water, in channels leading from lagoons towards open water or around other prominent features (e.g., Johannes, 1978; Sadovy, 1996; Domeier and Colin, 1997).

It is not known why fishes form aggregations to spawn although several hypotheses have been proposed, ranging from benefits to eggs and larvae to advantages in the synchronization of spawning behavior or in fertilization rates. Whatever the evolutionary imperative(s) for forming aggregations, it is clear that there is something biologically significant about these sites. Many have persisted over extensive periods, in some cases many decades, and in more extreme examples fish migrate for tens or hundreds of kilometers away from their regular living area to reach a particular site. For many species, it is likely that some aggregations represent sites where a major proportion of the annual reproductive output for local stocks is generated. It seems clear that disruption of such sites could seriously impact the persistence of stocks as well as the fisheries that depend on them.

There is a growing recognition of the vulnerability of spawning aggregations to fishing pressure and the need to protect this vulnerable phase in the life history of many commercially important reef species (Sadovy and Domeier, 2000). In particular, many species of the family Serranidae, the groupers, and the Labridae, the wrasses, are known to form aggregations, some of which have been heavily exploited. Although there are well-documented examples of aggregations that have been fished for many years without declining catches, these are few and are invariably cases in which fishing pressure has been low. There are many more examples of severe declines in numbers of fish or even losses of aggregations, apparently brought about by fishing pressure becoming too high. In the Caribbean, a large proportion of the Nassau grouper, *Epinephelus striatus*, assembling at an aggregation in the U. S. Virgin Islands, western Atlantic, was removed by fishing in the early 1970s; a couple of years later, the aggregation ceased to form (e.g., Sadovy 1996). This pattern has been repeated elsewhere in the Caribbean and, for this species, as many as 50% of all known aggregations no longer form. The effects of losses of aggregations on population persistence, or on the species as a whole, is not known. Declines have also been noted in the gag, *Mycteroperca microlepis*, in the Gulf of Mexico, probably as a result of aggregation fishing (Koenig et al., 1996). In the Pacific, groupers have been virtually eliminated, probably by over-fishing of aggregations, in at least five locations in: Tuamotu Islands, French Polynesia, Cook Islands, Great Barrier Reef and Palau (e.g. Johannes et al. 1999). Clearly, aggregations can withstand low levels of fishing effort but cannot persist when pressure is too high.

While there appear to be a number of attempts in the western Atlantic to manage spawning aggregations, the situation is quite different in the Pacific. There is growing pressure to exploit coastal stocks of reef fishes for foreign exchange and as a boost to the local economy.

While some traditional management of aggregations is known from several sites, in general there is little effective fishery management in force. In particular, over the last decade, there has been a rapid growth in the market for live reef fish to satisfy a heavy demand for live gourmet fish in Southeastern Asia (Johannes and Riepen, 1995). These fishes sell for high prices and the businesses are lucrative. As stocks of desired species, especially the larger reef fishes and particularly the groupers, have declined in Southeastern Asia, businesses are looking further afield into the Indian and Pacific oceans for supplies, with sources now ranging from Fiji to the Seychelles (Sadovy and Vincent, in press). Indonesia is now a major supplier of live reef fish for this trade resulting in considerable pressure on Indonesian reefs (Mous *et al.*, 2000).

Komodo National Park (KNP) was established in 1980 after being declared a Man and Biosphere Reserve by the United Nations in 1977, and was declared a World Heritage Site in 1991. KNP is located between the islands of Sumbawa and Flores in Indonesia. KNP includes three major islands, Komodo, Rinca and Padar, and numerous smaller islands together totaling 603 km² of land. KNP was initially established to conserve the unique Komodo dragon (*Varanus komodoensis*), and its habitat, but also includes one of the world's richest marine environments, encompassing 1,214 km² of highly diverse marine habitats, including coral reefs, mangroves, seagrass beds, seamounts, and semi-enclosed bays (Pet and Yeager, 2000). These habitats harbor more than 1,000 species of fish, some 260 species of reef-building coral, and 70 species of sponges. Dugong (*Dugong dugon*), dolphins (10 species), whales (6 species), and hawksbill (*Eretmochelys imbricata*) and green (*Chelonia mydas*) turtles are occurring within the Park. There were approximately 3,267 inhabitants living within the Park in 1999, spread out over four settlements. An estimated 16,816 people were living in fishing villages directly surrounding the Park in 1998. Park inhabitants mainly derive their income from a pelagic lift net ('bagan') fishery that targets squid and small schooling pelagic fishes.

Destructive fishing practices such as dynamite-, cyanide-, and compressor fishing severely threaten the Park's demersal and sedentary marine resources by destroying both the habitat (coral reefs) and the resource itself (fish and invertebrate stocks). The present situation in KNP is characterized by reduced but continuing destructive fishing practices, primarily by non-inhabitants, and high pressure on demersal stocks of valuable species like lobsters, shellfish, groupers and Napoleon wrasse (*C. undulatus*). Spawning aggregation sites have been heavily fished in recent years by fishermen, which supply the Hong Kong-based live reef fish trade. Fishing with legal gear types has been permitted throughout the Park until a management plan with a zoning system and clear regulations was finalized in June 2000 and became effective in 2001.

The main objectives for the marine component of KNP are to protect the marine biodiversity and the breeding stocks of commercial fish and invertebrate species for replenishment of surrounding fishing grounds (Pet and Yeager, 2000). The main purpose of the present study was to determine which management interventions would be needed for spawning aggregations, to obtain the objective of spawning stock protection. Given the Park's objectives, the concerns over the heavy fishing pressure, and the fact that aggregations were being targeted, there was clearly a need to determine the locations and condition of spawning aggregations in KNP when the zoning system for this Park was designed between 1995 and 2000. Recommendations from the present study have been incorporated in the management plan for KNP.

To identify and monitor spawning aggregations, it is necessary first of all to define what is meant by a spawning aggregation (Domeier and Colin, 1997). Not all aggregations of fishes are for spawning, some are associated with feeding, others with pre-reproductive behavior. An aggregation can be broadly defined as a gathering of con-specific fish for the purpose of spawning that consists of fish densities significantly higher than are found during the non-reproductive period. There are two spawning aggregation types defined: resident and transient. These are distinguished according to the frequency with which the aggregations occur, the duration of the aggregation, the site specificity of the aggregation and the distance that individual fish travel to the aggregation site. What constitutes a significant increase must be established to distinguish an aggregation from a situation in which spawning occurs in regular residential areas (a rule of thumb suggested by Domeier and Colin, 1997 is that a 3-fold increase in numbers should be noted). However, this may sometimes be difficult to establish because so little is typically known of 'normal', non-spawning densities. It is also essential that it be determined that spawning occurs within the aggregation; to do so it is necessary to observe spawning or to witness behaviors or other signs known to be associated with imminent spawning.

Definitive evidence that aggregated fishes are spawning is to witness the spawning event. This is, however, often difficult because spawning may occur only briefly, at night, or when conditions are not appropriate for diving, such as in deep waters or strong currents. When aggregated fishes are observed, therefore, it is important to be able to distinguish whether there are any signs that spawning may be imminent. Collections of fish which are ready to spawn (e.g. the eggs are hydrated) is one such sign since hydration generally occurs within hours of spawning. Other signs are strongly indicative of spawning in groupers, such as intense courtship movements by males and a strikingly extended belly in the female gravid. In the Napoleon wrasse, courtship behavior has been associated with a gathering together of the caudal anal and dorsal fins to a point (Squire, unpublished data), occurring simultaneously with chasing of other individuals and pronounced courtship movements, although there is no published account of spawning in this species.

The objectives of the present study were fivefold:

1. to identify spawning aggregation sites in KNP and the species that spawn there;
2. to determine the seasonality of spawning activity;
3. to determine the numbers and sizes of fishes in spawning aggregations at identified sites;
4. to establish a baseline of data on spawning aggregations in terms of sizes, species and timing against which future monitoring efforts can be planned and compared, and changes in aggregations, in terms population structures, can be determined; and
5. to produce recommendations for the protection of spawning aggregation sites and the management of KNP as a source of recruits for surrounding fishing grounds.

Material and Methods

The surface area of marine waters in KNP is 1,214 km², with 17 km² of reef slope habitat. Hundreds of potential sites within the Park have been surveyed repeatedly in recent years. Sites were selected for monitoring when larger numbers of target species were observed and showing signs of imminent spawning. The fish monitoring program in KNP focused on 12 target species out of two families, the Serranidae (groupers) and the Labridae (wrasses). These species were chosen since they were commonly observed in the Komodo area, were heavily

targeted by the commercial fisheries (mainly by the live reef fish trade), and could therefore serve as indicators for the impact of the fisheries on larger demersal reef fishes. The species included in the monitoring program were:

1) *Epinephelus tukula*, 2) *E. polyphekadion*, 3) *E. fuscoguttatus*, 4) *E. malabaricus*, 5) *E. chlorostigma*, 6) *Plectropomus leopardus*, 7) *P. laevis*, 8) *P. areolatus*, 9) *P. oligocanthus*, 10) *Variola louti*, 11) *Cromileptes altivelis* and 12) *Cheilinus undulatus*.

The monitoring program started in March 1997 with training, site identification and preliminary monitoring. All potential spawning aggregation sites in the Park, such as reef promontories, rocky outcrops and channels, were surveyed repeatedly and additional sites were checked when interviews with fishermen indicated that these could be spawning sites. Within the framework of the Park's routine coral reef monitoring program, 185 additional sites were surveyed every 2 years. Potential sites were short-listed when they had relatively large numbers of fish of target or non-target species, when individuals of target or non-target species showed signs that spawning might be imminent, and when the general characteristics of the site were such, that further visits seemed warranted. Important characteristics included currents directed away from the site into open water, lots of hiding places such as caves or coral structures and sites being located at reef promontories or corners of channels. Short-listed sites were visited repeatedly over several years during different seasons and lunar phases to determine whether they served as spawning sites for target species or not.

Seven types of behavior and other signs were recorded as signs that spawning might be imminent (further referred to in this paper as "spawning signs") and were assigned increasing weight factors, with higher weight factors assigned to those signs which are closer related to spawning. Each spawning sign was recorded as either occurring or absent at a specific site. The seven spawning signs with their weight factors are listed below.

1. Grouping of fish in clusters more dense than normally observed at other times or locations.
2. Frequent male-male aggression, chasing and fighting.
3. Coloration not seen at other times or locations.
4. Fresh bite wounds (fang scars in *Plectropomus* and patchy scars in *Epinephelus* spp.).
5. Females gravid (bellies becoming highly visibly swollen).
6. Courtship: pronounced movements by males, and pointed tails and fins in *C. undulatus*.
7. Spawning.

By the beginning of 1998, 12 sites were short-listed as sites where spawning of target species was likely to take place (Fig. 1). Sites 3 to 8 were considered the most important sites at that time, in terms of numbers of aggregating specimen and behavior of target species, and were monitored since March 1998. Monitoring on these sites is continuing ever since. Sites 1 and 2 have also been identified as spawning sites for several target species and have been monitored since March 1999. Sites 9 and 10 had low numbers of spawning *P. leopardus* but were not monitored since access is difficult and they contain relatively few fish. Sites 11 and 12 had low numbers of the largest groupers, *Epinephelus tukula*, *E. malabaricus* and even *E. lanceolatus*. These sites were also not regularly monitored.

For all 12 target species, numbers, sizes and spawning signs were recorded on standard data sheets. Lengths were recorded in cm total length. Spawning signs were also recorded for non-target species. Since March 1998, the monitoring of 6 sites (site numbers 3 to 8) was carried out twice a month, once during a three-day period around the new moon and once during a

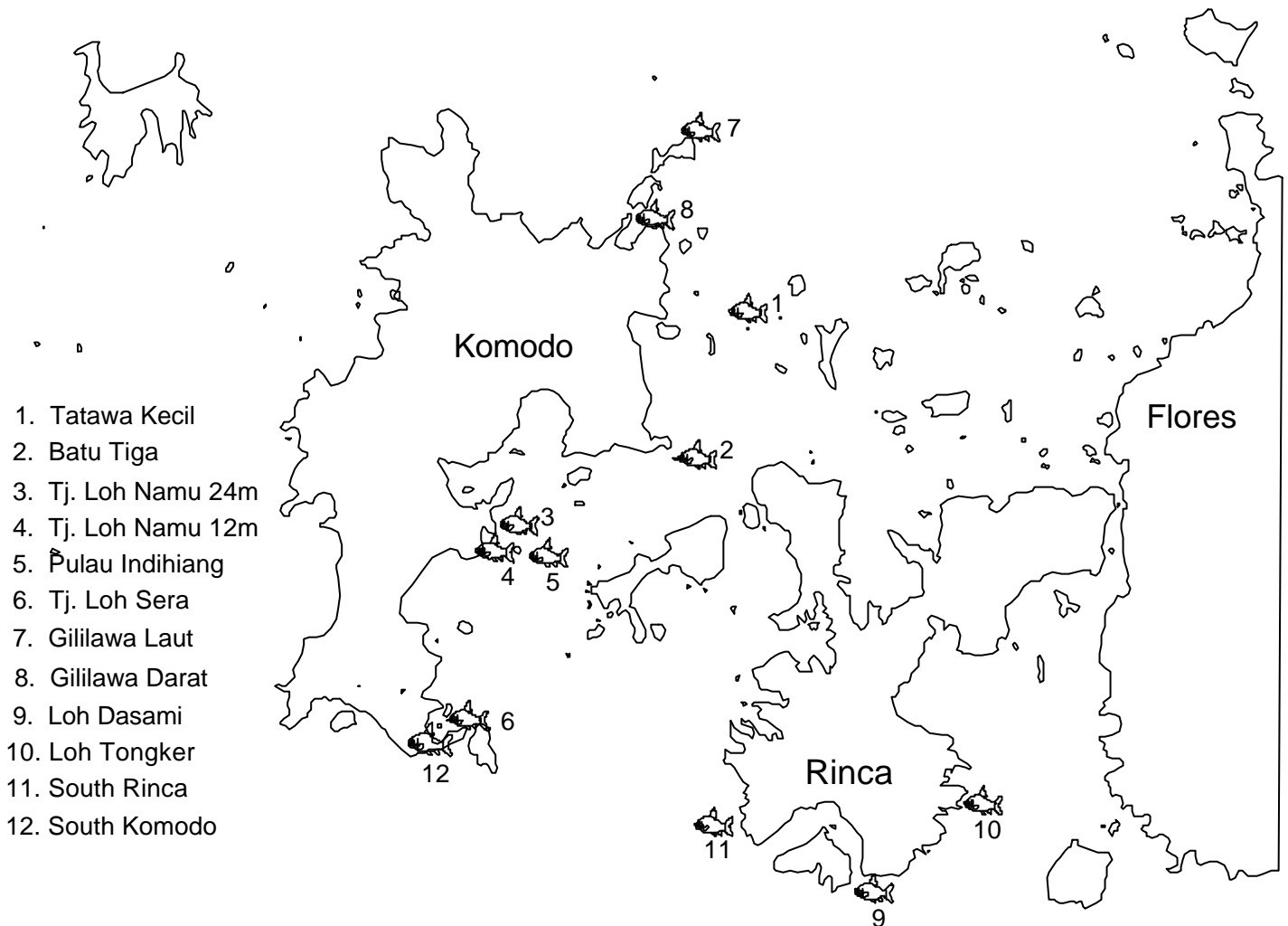


Figure 1. Komodo and Rinca Island with 12 reef fish spawning sites and including 2 grouper spawning aggregation sites (sites 7 & 8).

three-day period around the full moon. Monitoring at sites 7 and 8 was always carried out 1 day before the full and new moons, sites 3 and 6 were covered one day later and sites 4 and 5 on the final day. During preliminary monitoring and site selection in 1997 it was found that aggregations and spawning signs were only observed during full and new moons. Numbers of fish were always lower in the weeks before and after the full and new moons. All sites were always monitored during the same time of day, during slack tide. During each monitoring period the observers dived at 2 sites per day. Each site was searched for target fish at a specific depth-profile, which had been established for that site. The length and position of the monitoring transect was fixed for each site, so that the entire site was searched for fish, to maximum depths of 35 m. All transects were around 200 meters long, included the aggregation sites in their entirety, and were surveyed during dives lasting around 30 minutes per transect.

Training of the monitoring team was carried out up to a point where individuals were able to improve their capacities by self-training. Training included 1) size estimation and species identification from color-printed paper fish models, 2) under water size estimation of wooden fish models, 3) fish species identification from reference collection (frozen specimens), 4) fish identification under water and 5) identification of fish behavior and fish spawning sites. Length estimation and species identification training was continued on a regular basis. In the size estimation training, the candidates were expected to reach a high level of accuracy. Team members were able to estimate, under water, the lengths of 100 wooden fish models with an accuracy of 75%, with a maximum allowable error of 3 cm. Fish species of the 12 target species had to be identified under water with an accuracy of 100%. The candidates were also expected to recognize signs and behavior indicative of spawning, in both target and non-target species, and to identify to species level non-target species using field guides.

Visibility in Komodo waters roughly varies between 1 and 30 meters, with visibility recorded during fish monitoring ranging from 5 to 20 meters. The most common visibilities range from 8 to 18 meters. The first years of monitoring led to the conclusion that there was no visibility effect on the numbers of fish recorded on the site (Pet *et al.*, 1998). Visibility was never below 5 meters. The monitoring team members knew their sites very well and searched them in their entirety for fish present there.

Results

Records of abundance from March 1998 to March 2001 show the formation of aggregations for *E. fuscoguttatus* and *P. areolatus* during the full moons of roughly the period September through February in three consecutive seasons (Fig. 2). The length of the aggregation seasons of both species varied and ranged from 4 to 6 months during the study period. The aggregation season in some cases only started in October and could end as early as January. None of the other target species showed any clear aggregations, and numbers were consistently low at all sites surveyed in the Park (Fig. 3). The observed aggregation of *E. fuscoguttatus* at site number 7 contained a maximum of 86 fish during the full moon of December 1998, a maximum of 49 individuals in October 1999 and a maximum of 51 individuals in October 2000. The aggregation of *P. areolatus* at site number 8 contained a maximum of 58 individuals during the full moon of November 1998, 72 fish in October 1999 and 64 fish in December 2000. Other sites had much lower numbers of *E. fuscoguttatus* and *P. areolatus*, but still showed increasing abundance, compared to numbers present during non-spawning periods, during the full moons of September through February.

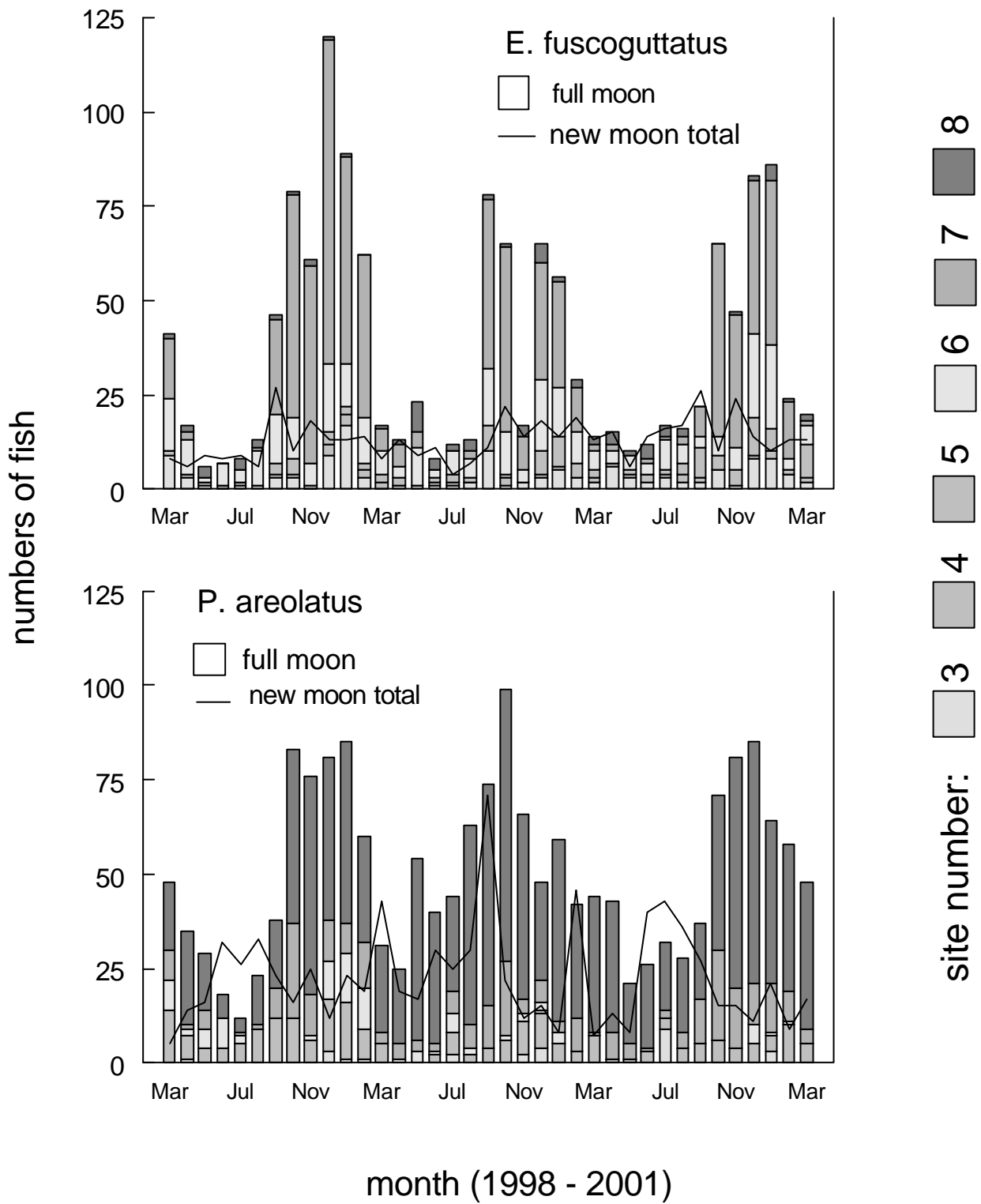


Figure 2. Temporal patterns of abundance at various sites by *E. fuscoguttatus* and *P. areolatus* in Komodo National Park.

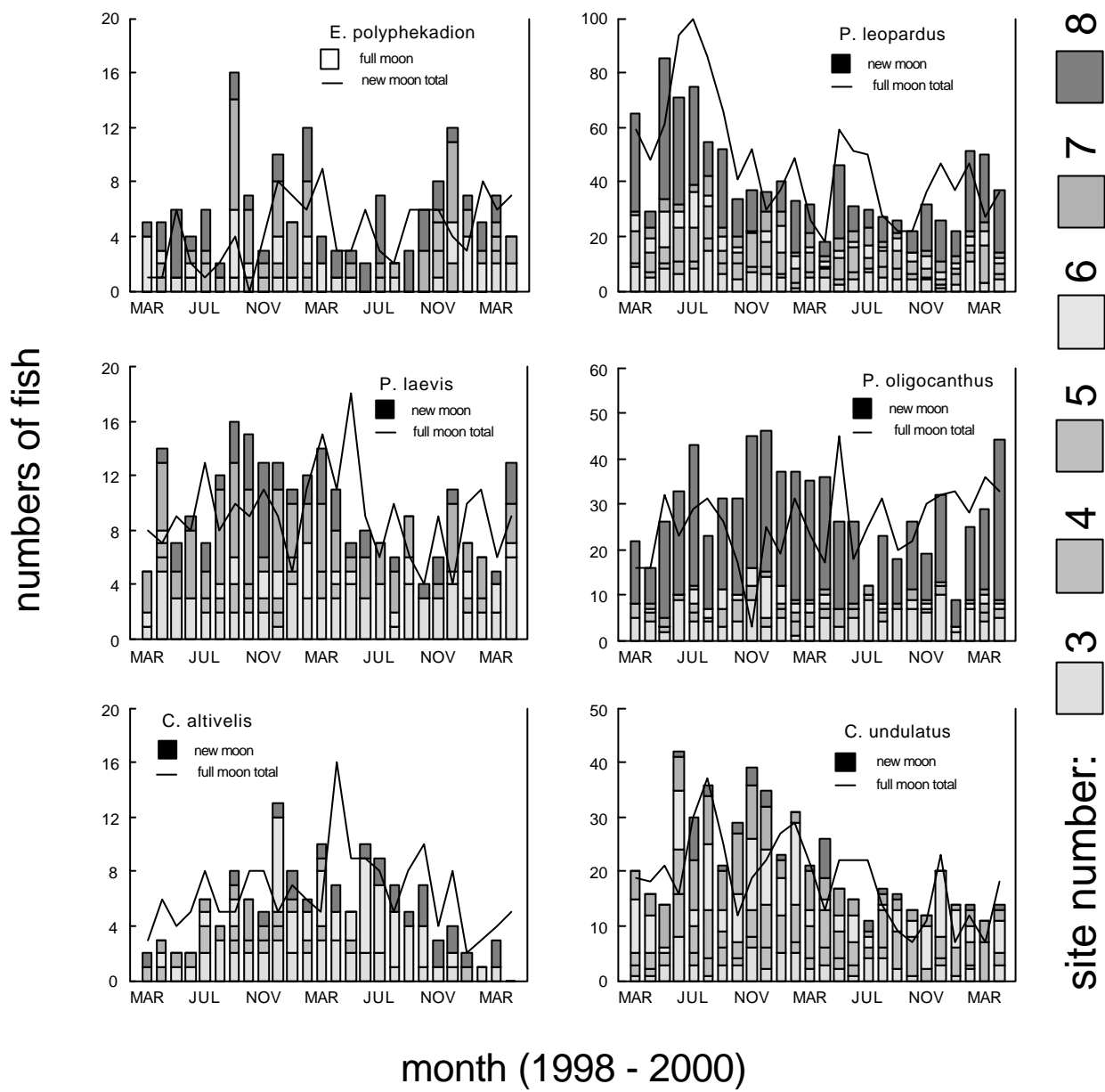


Figure 3. Temporal patterns in abundance at various sites and two moonphases for other species in Komodo National Park.

During the new moons of the aggregation season, both *E. fuscoguttatus* and *P. areolatus* were usually present at their aggregation sites, but in much lower numbers than during the full moons. Abundance during the new moons of the aggregation season was comparable to abundance outside the aggregation/reproductive season at either moon phase. Notable exceptions were the aggregations of *P. areolatus* present at the new moons of September 1999 and several other full moons. The numbers of *E. fuscoguttatus* in the aggregation at site 7 varied both between and within the 3 aggregation seasons covered by the survey and were markedly lower in November 1999 in the middle of that season.

Spawning of groupers was not observed during this study and only once for Napoleon wrasse, during daytime, at the new moon on October 10, 1998. Records of spawning signs from March 1998 through March 2001 show periods of increased frequency of occurrence for *E. fuscoguttatus* and *P. areolatus* during the full moons of September through February in the 1998-1999 and 1999-2000 seasons (Fig. 4). The increased occurrence of spawning signs lasted through March in the 2000-2001 season and in that year also started 1 month later, in October, for *E. fuscoguttatus*. The signs most closely related to spawning (“gravid” and “courtship”), showed the same temporal pattern of increased occurrence as the other 4 signs (“grouping”, “fighting”, “color” and “wounds”), and provide evidence that the latter are reliable indicators of reproductive activity in the study species. For both species, all spawning signs were notably absent during some months in the middle of several of the spawning seasons. Spawning signs for both species were always infrequent or absent during new moon phases.

Several other species in the monitoring program (*E. polyphkadion*, *P. laevis*, *P. oligocanthus*, *C. altivelis* and *C. undulatus*) showed increased occurrence of spawning signs in roughly the same season as *E. fuscoguttatus* and *P. areolatus*, in several of the study years (Fig. 5). The most consistent temporal pattern in the occurrence of spawning signs, in this group of other species, was observed for *P. laevis*. This species showed spawning signs for 3 consecutive seasons during the new moons from August to December but also showed signs for the same three years during the full moons of February. These 2 groups (the new moon group and the full moon group) were two separate groups of this species, based on the marks and scars of spawning males. The new moon group of *P. laevis* at site 7 usually had one large dominant male in the center of the site and a few smaller males swimming around it. The large male on site 7 could easily be recognized from a large scar in the anal fin. This individual was present on the site for 3 years, showing spawning color (dark purple body, white belly, light purple head and bright purple lips) and other signs around the new moons of September and October when fully ripe females were also observed. *P. leopardus* showed spawning signs on various sites both during the full moon and during the new moon phases. Small aggregations of some 20 to 30 fish were observed on several occasions, with fish aggregating in areas not larger than 100 m². *P. oligocanthus* and *C. undulatus* seemed to be new moon spawners, based on the increased frequency of spawning signs during this moon phase.

When all spawning signs (1-7) are combined for all species, for all sites and for both lunar phases over 12 months (Fig. 6a), a clear spawning season for full moon spawners is revealed from September through February. New moon spawners seem to be more active in the beginning of this season and show reduced frequency of spawning signs already by December. A minor second peak of activity may exist in May. When records of spawning signs are combined for individual species (Fig. 6b), a clear preference for the full moon phase is revealed for *E. fuscoguttatus* and *P. areolatus* and a preference of new moon phases by *P. laevis*, *P. oligocanthus* and *C. undulatus*. The preference for any particular lunar phase is least obvious for *P. leopardus*.

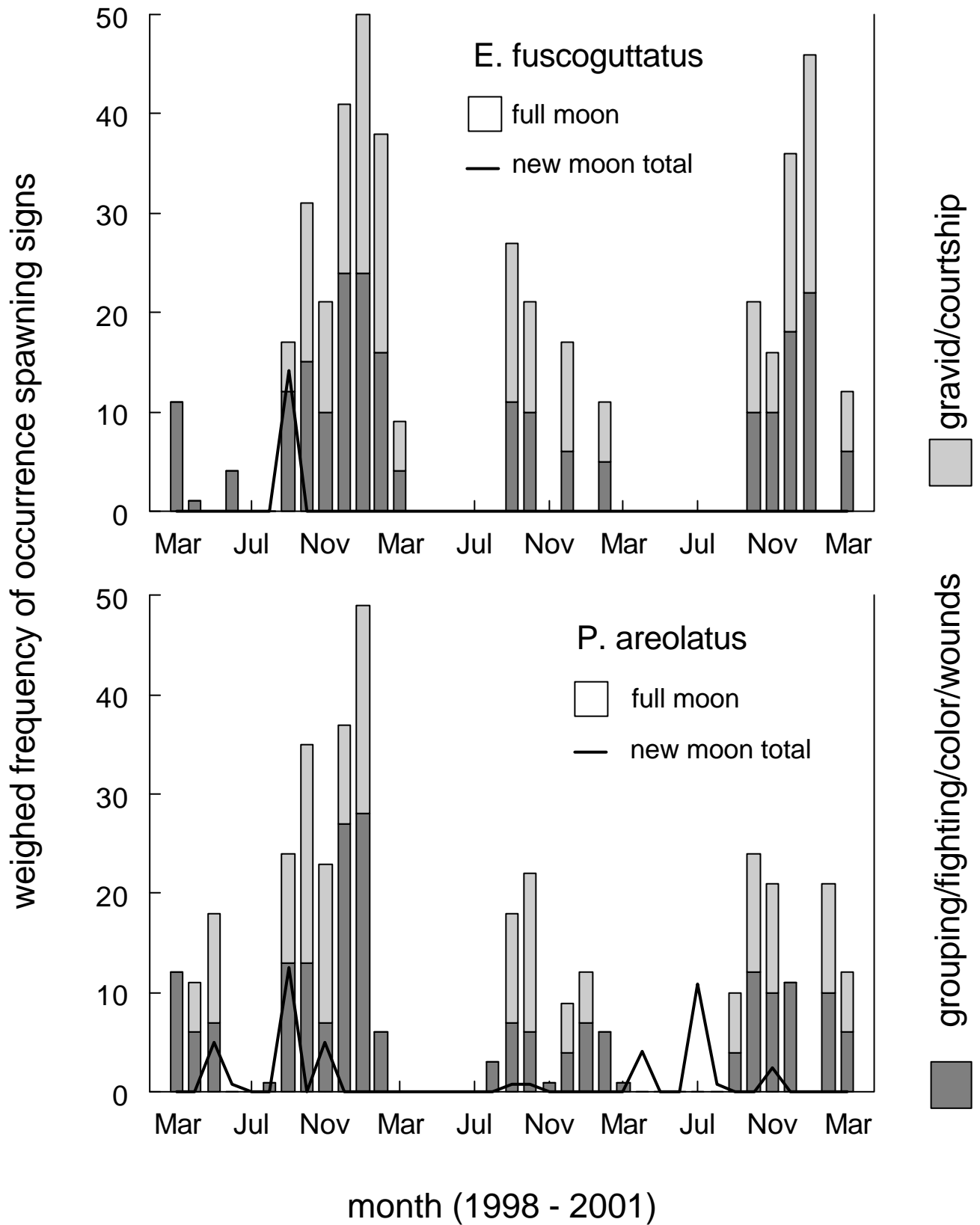


Figure 4. Temporal patterns in the occurrence of spawning signs in populations of *E. fuscoguttatus* and *P. areolatus* over sites 3 to 8 in Komodo National Park.

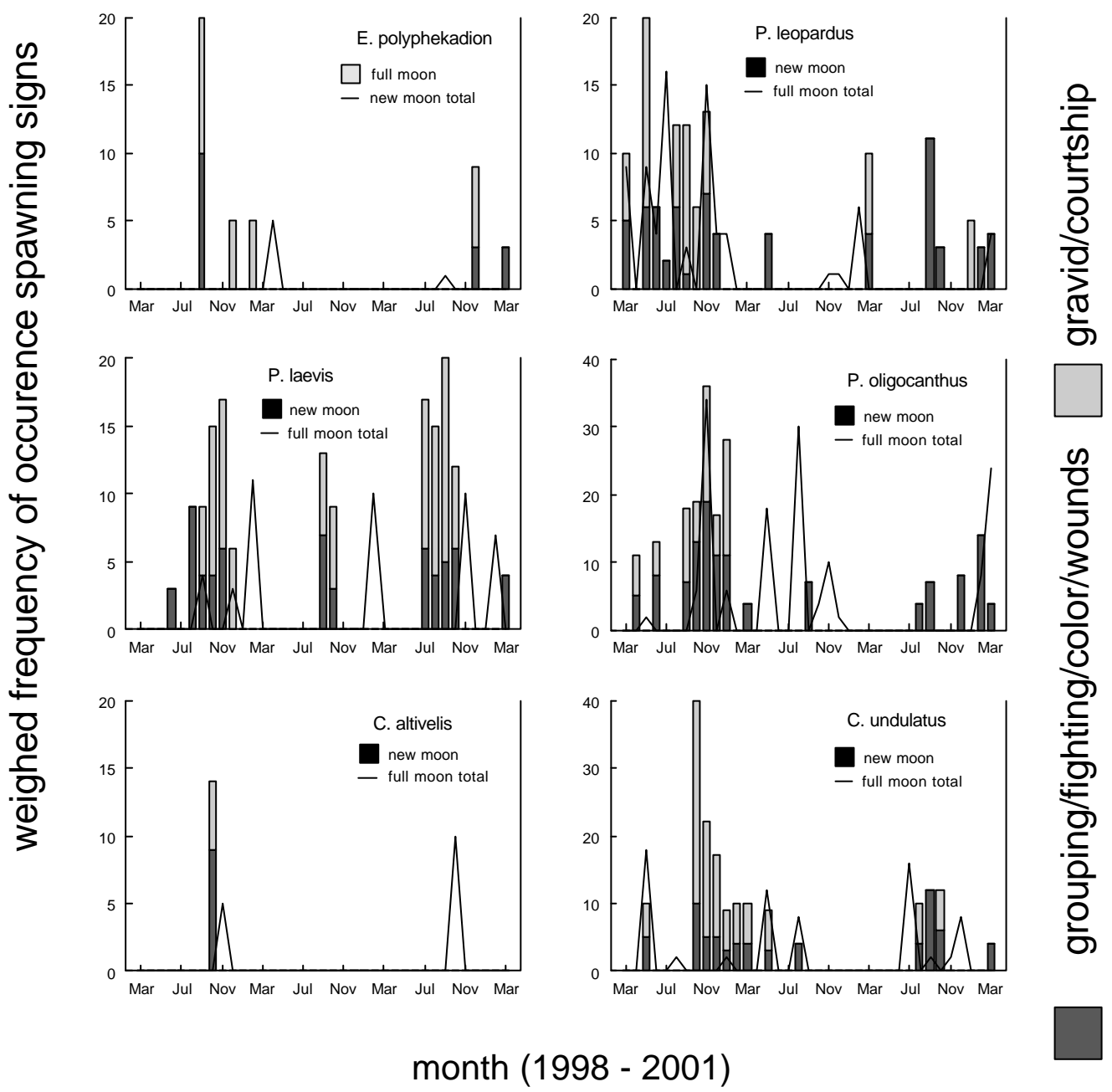


Figure 5. Temporal patterns in the occurrence of spawning signs in populations of other species over sites 3 to 8 in Komodo National Park.

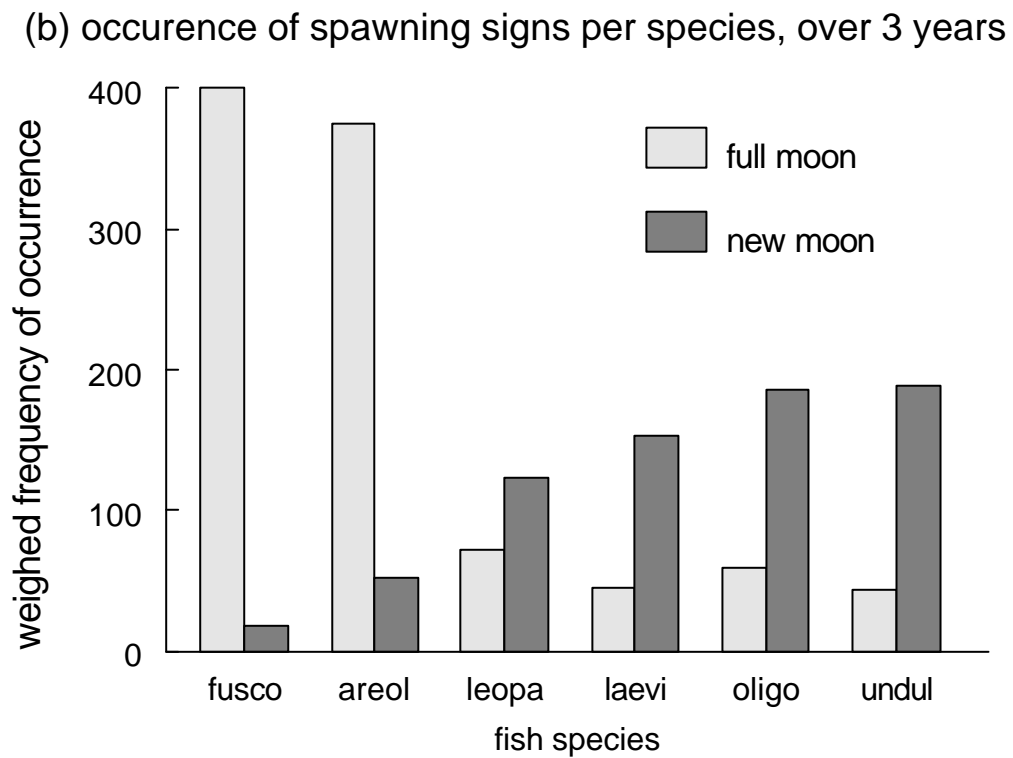
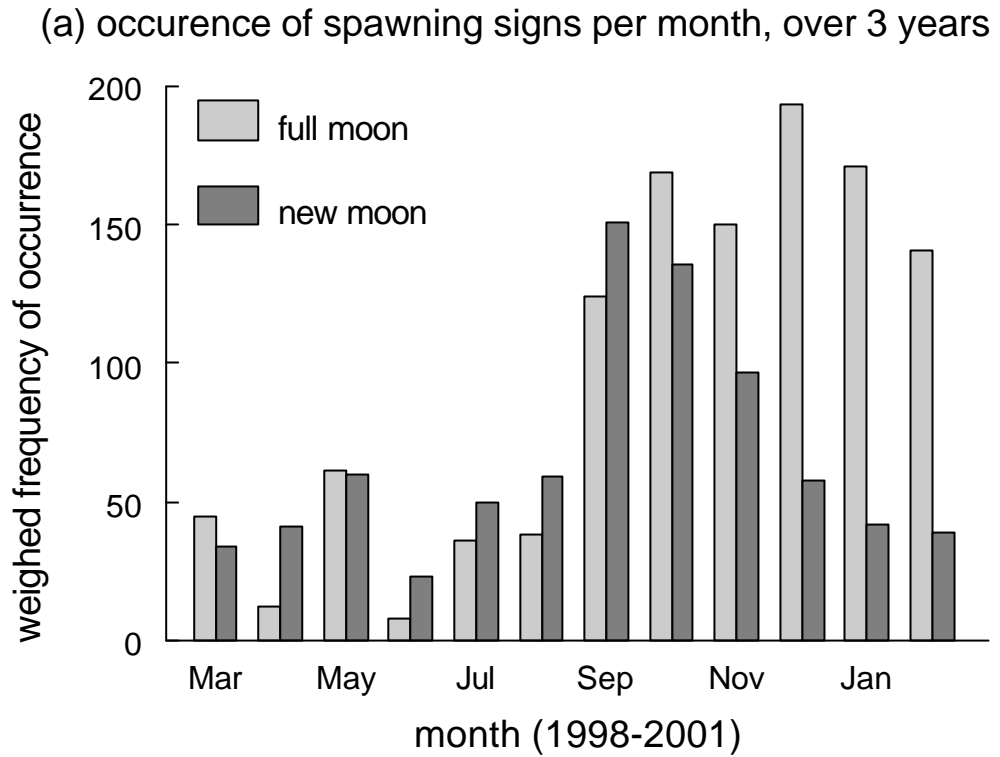


Figure 6. Annual pattern in the occurrence of spawning sites per moon phase over all monitored species (see text) and sites (a). Species-specific occurrence of spawning signs per moon phase in Komodo National Park (b).

Many (42) other species of reef fish showed spawning signs 5-7 on the 6 sites covered in the monitoring program (Table 1). Most of the spawning signs for these species were recorded in the season from October to February, which is the main spawning season for many reef fish species. Different species used the same spawning sites during different lunar phases or during the same lunar phase at overlapping but not fully coinciding patches of the sites (niche segregation). In most cases the spatial overlap was only small and species were therefore mostly spatially segregated within the sites, when they were not segregated in time. Spawning aggregations of *P. areolatus* were found on shallow coral reefs (between 5 and 20 meters) whereas *E. fuscoguttatus* were concentrated in the deeper parts (from 15 to 40 meters). Male *P. areolatus* were usually found in shallower water than females.

Length frequency distributions (LFDs) of *E. fuscoguttatus* differed monthly in shape although usually the same size range was present (Fig. 7). The LFDs show that smaller individuals of around 60 cm were commonly present next to the larger fish of around 75 cm and larger, from October through January. The aggregation contained mostly larger fish in September for the 1st and 3rd year and February in all 3 years. The same pattern of smaller fish (35-45 cm) joining larger fish (50-60 cm) mostly during the October-through-January part of the aggregations season, can be observed in the LFDs of *P. areolatus* (Fig. 8). Schools of small *P. areolatus* were observed to swim into site 8 on several occasions in the October – January period. These schools of smaller fish were mostly females since they showed to be gravid at or soon after arrival. The monthly LFDs of *P. leopardus* (Fig. 9) do not reveal any size-specific aggregation patterns.

The LFDs for *E. fuscoguttatus* show the absence of small (<45 cm) specimen of this species on the spawning aggregation sites (Fig. 7). Most fish in the aggregation of *E. fuscoguttatus* are longer than 55 cm. The monthly LFDs of *E. fuscoguttatus* and *P. areolatus* indicate changes in the aggregation structure between years. The number of large fish was reduced in the second year and the mean length in the population of this species went down, from 70.3 cm in year 1 to 64.2 cm in year 2. The number of large fish increased again after that, and the mean length went up again to 68.5 cm for the third year. The LFD of *P. areolatus* was narrow in both years and small fish of below 40 cm were rare at the aggregation site (Fig. 8). The number of larger fish in this aggregation was also reduced in the second year compared to the first one in this species. The mean length in this aggregation decreased from 54 to 49.2 cm in the same period but also went up again to 51.1 cm in the third year. *P. leopardus* was the most common grouper or coral trout in the area and can still be found throughout the area on rocky slopes and coral reefs. Small individuals of 15 to 30 cm were also observed at the sites (Fig. 9). Fish smaller than 14 cm were rarely observed during this study. The total number recorded dropped sharply from the first to the second and third year. The shape of the LFDs did not change much although the mean length in the aggregation also dropped from 44 cm in year 1 to 41 cm in year 2 and year 3.

The number of *E. polyphkadion* remained constant from year 1 to year 3, but the mean length in the population dropped from 46.4 in year 1 to 35.8 cm in year 2, to increase again to 40.8 cm in year 3. Large fish from 50 to 60 cm disappeared in year 2 (Fig. 10). The numbers of *P. laevis* also remained stable from year 1 to year 3 and the mean length increased from 80.1 cm in year 1 to 89.6 cm in year 2 to 99.0 cm in year 3. Numbers of *P. oligocanthus* increased with 50% after year 2, while mean lengths hardly changed. LFDs of *C. altivelis* were very similar in all years. The total number of *C. undulatus* recorded on the sites dropped from year 1 to year 2, to remain stable after that. The mean length in the population of this species increased after year 2.

Table 1. Species (n = 42) showing spawning signs 5 to 7 on sites 3-8.

Site	Species	Common Name	Signs
4,6	<i>Abudefduf vagiensis</i>	Indo-Pacific Sergeant	5,6
3,5,6,8	<i>Acanthurus mata</i>	elongate tang	5,6
3,5,6,7,8	<i>Acanthurus sp.</i>	surgeonfish	6
5	<i>Anyperodon leucogrammicus</i>	white lined grouper	5
5,7,8	<i>Balistoides conspicillum</i>	clown triggerfish	5,6
6,7	<i>Bolbometopon muricatum</i>	bumphead parrotfish	6
5	<i>Caesio teres</i>	blue and gold fusilier	6
3,5,6,8	<i>Cephalopholis argus</i>	peacock grouper	5,6
5,6,7,8	<i>Cephalopholis miniata</i>	coral rockcod	5,6
5	<i>Cephalopholis sexmaculata</i>	sixspot rockcod	5
3,5,6,7	<i>Cephalopholis urodeta</i>	flagtail rockcod	5,6
8	<i>Ctenochaetus striatus</i>	lined bristletooth	5
3,4,5,7	<i>Epinephelus caeruleopunctatus</i>	white spotted grouper	5,6
3,8	<i>Epinephelus chlorostigma</i>	brown spotted grouper	5,6
6,7,8	<i>Gnathanodon speciosus</i>	golden trevally	5
4	<i>Hemitaurichthys polylepis</i>	pyramid butterflyfish	6
5	<i>Kyphosis vaigiensis</i>	long finned drummer	6
5,6,8	<i>Lethrinus erythracanthus</i>	yellow spotted emperor	5,6
8	<i>Lethrinus erythropterus</i>	longfin emperor	6
3,4,5,6	<i>Lethrinus olivaceus</i>	long nosed emperor	5,6
3,4,5,6,7,8	<i>Lutjanus bohar</i>	red bass	5,6
6	<i>Lutjanus kasmira</i>	yellow-stripe snapper	5
7	<i>Macolor macularis</i>	yellowhead snapper	6
6,7	<i>Macolor niger</i>	black & white snapper	6
3	<i>Melichthys vidua</i>	paddlefin triggerfish	5,7
6	<i>Monotaxis grandoculis</i>	bigeye bream	6
6	<i>Naso annulatus</i>	white margin unicorn	6
5,6	<i>Naso hexacanthus</i>	blue tail unicornfish	6
3,6,8	<i>Naso sp.</i>	unicornfish	5,6
3,5,6,7,8	<i>Naso vlamingii</i>	Vlaming's unicornfish	6,7
4,5	<i>Odenus niger</i>	red tooth triggerfish	6,7
7,8	<i>Platax pinnatus</i>	pinnate batfish	5,6
7	<i>Platax teira</i>	teira batfish	5,6
6	<i>Plectorhinchus gibbosus</i>	Brown sweetlip	5
5	<i>Pomacanthus emperator</i>	emperor angelfish	6
6	<i>Pomacanthus semicirulatus</i>	semicircle angelfish	6
5,8	<i>Pomacanthus sextriatus</i>	six banded angelfish	6
8	<i>Pomacanthus xanthometopon</i>	blue face angelfish	5,6
7,8	<i>Pseudanthias pleurothaenia</i>	square block anthias	5,6
4,5	<i>Pseudanthias sp.</i>	anthias	7
7,8	<i>Symphoricthys spilurus</i>	sailfin snapper	5
7	<i>Thalassoma amblycephalum</i>	bluntheaded wrasse	5,6,7

Note:

5 = Gravid (female bellies becoming highly swollen). 6 = Courtship by males. 7 = Spawning.

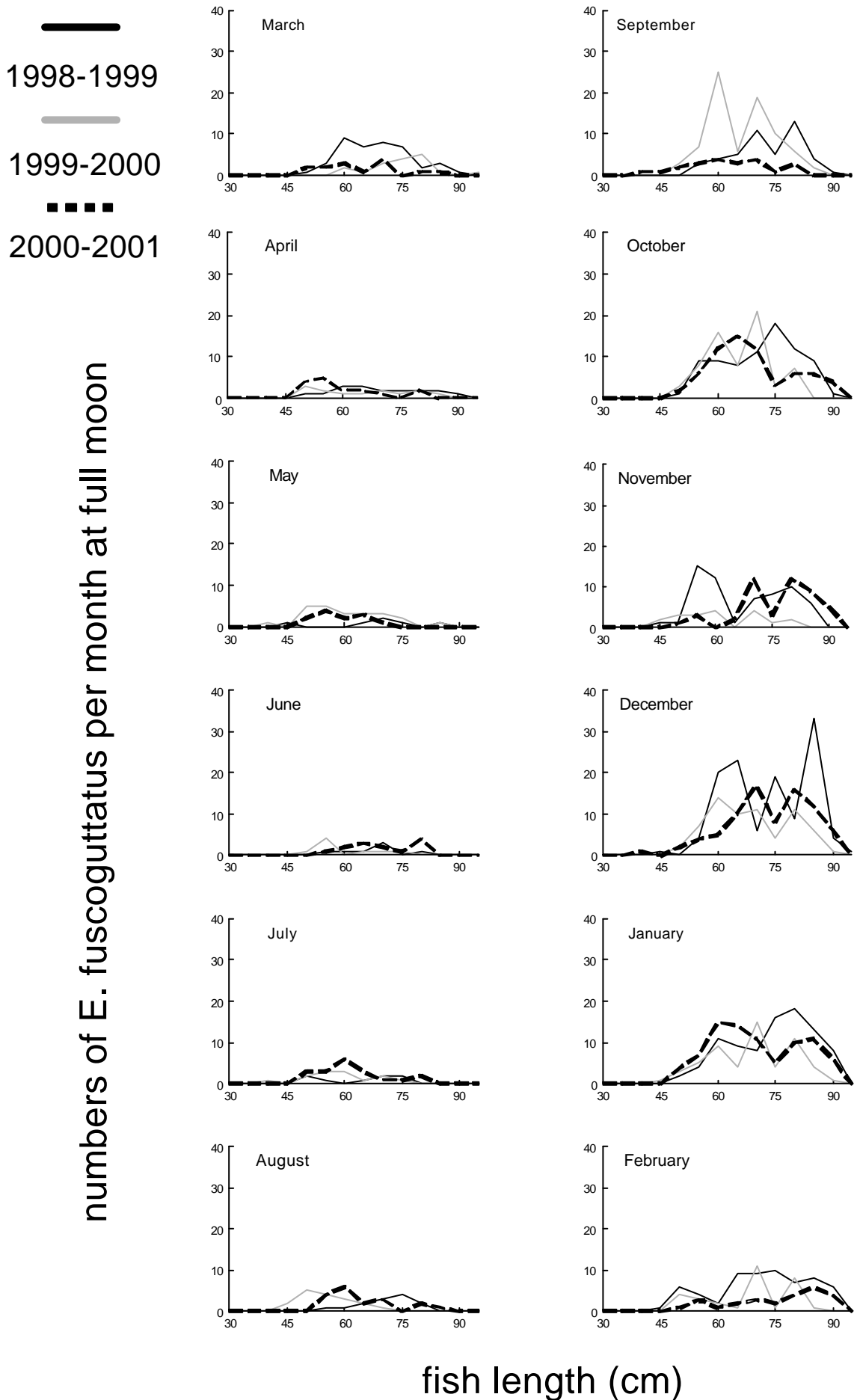


Figure 7. Monthly estimated length frequency distributions of *E. fuscoguttatus* at full moon, over all sites, from March 1998 to February 2001.

 1998-1999
 1999-2000
 2000-2001

numbers of *P. areolatus* per month at full moon

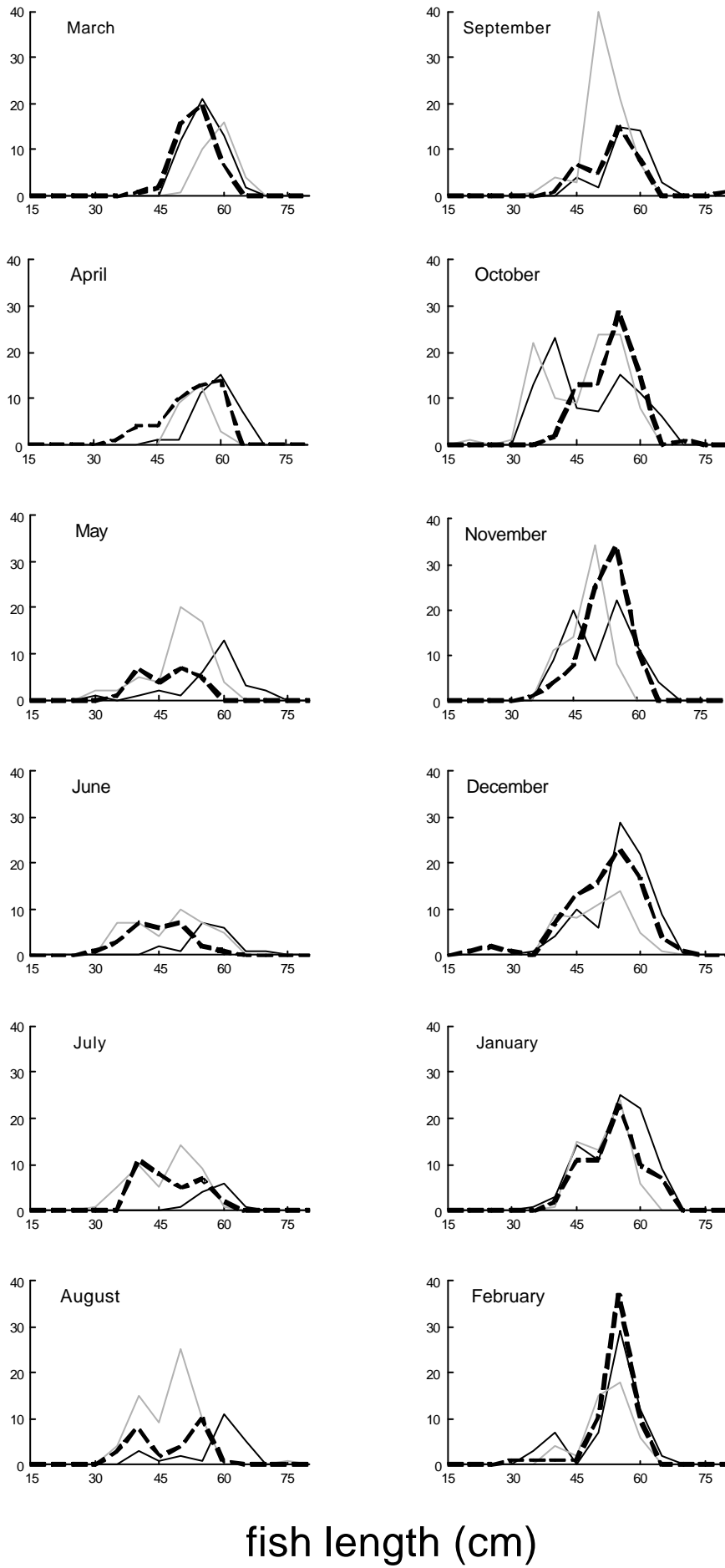


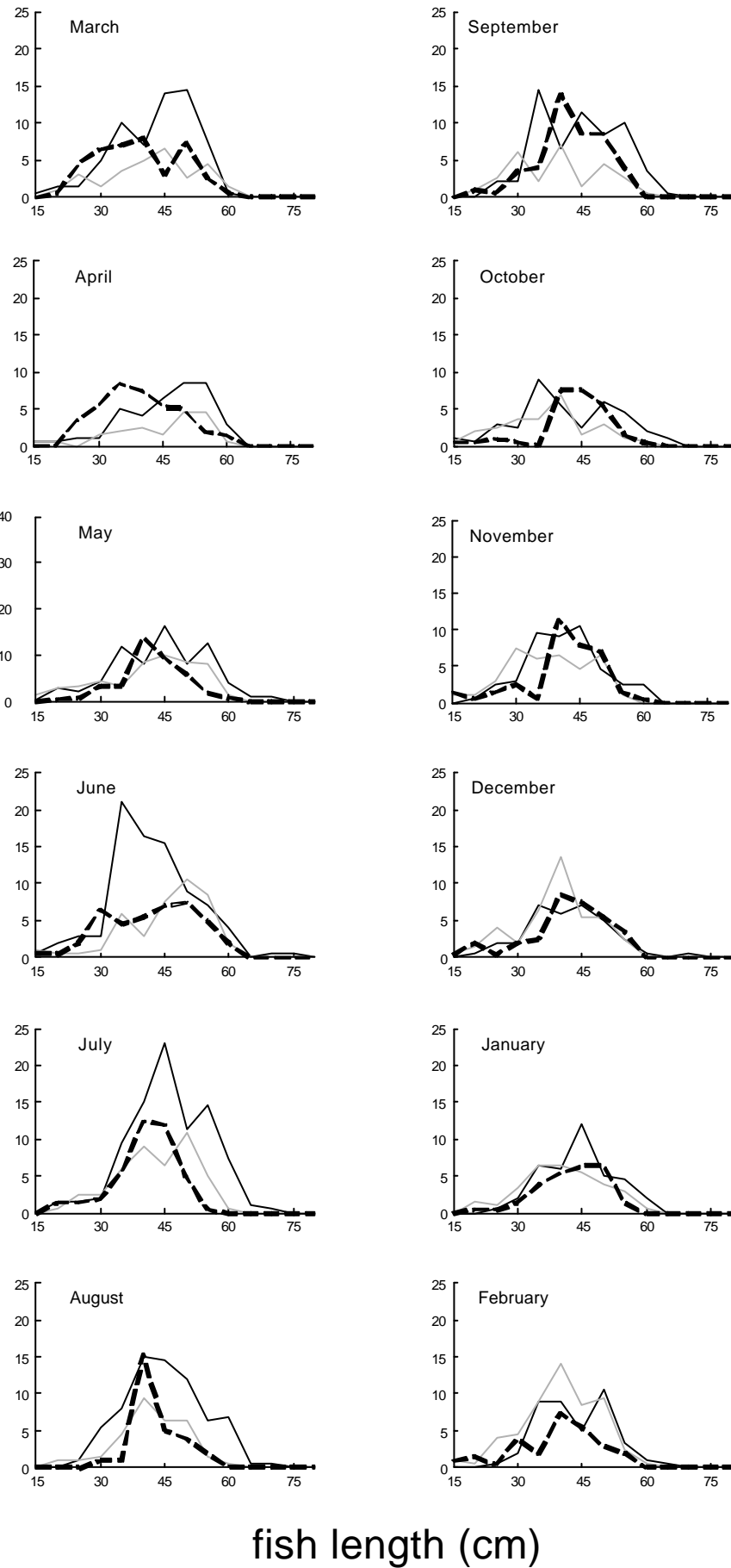


Figure 8. Monthly estimated length frequency distributions of *P. areolatus* at full moon, over all sites, from March 1998 to February 2001.

 1998-1999
 1999-2000
 2000-2001

mean numbers of *P. leopardus* per month



fish length (cm)

Figure 9. Monthly estimated mean length frequency distributions of *P. leopardus*, over all sites, from March 1998 to February 2001.

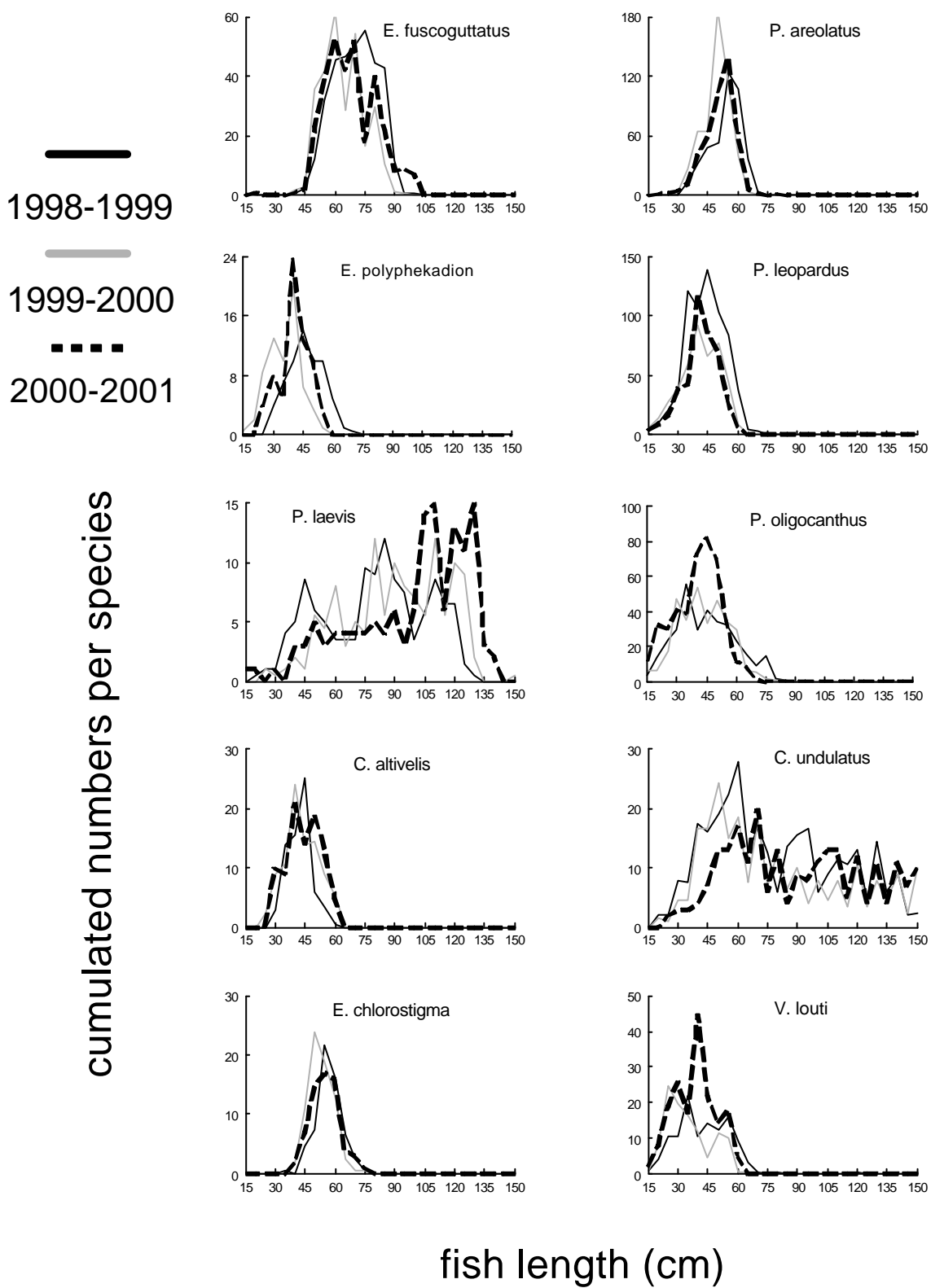


Figure 10. Cumulated length frequency distributions per species over all sites, from March 1998 to February 2001.

The LFDs for *P. leopardus* per site (Fig. 11) show small fish of below 30 cm were only recorded at one of the sites, site number 8. Small specimen of *P. oligocanthus* were also recorded only at this site. The section of this site where small coral trout were present is separated from the section where spawning by *P. areolatus* takes place. This section of the reef is characterized as a high relief coral reef slope which flattens out to a sandy bottom at about 25 meters depth. The current at this section is much less than in the section (promontory) where *P. areolatus* aggregates and presumably spawns and there were large numbers and many species of fish present. These sites with high relief in combination with abundant fish life are currently few in KNP. The central section of site 8 has many *P. leopardus* and *P. oligocanthus* between 30 and 46 cm. Larger fish of these species partly overlap on site 8 with *P. areolatus* on the deeper part of their spawning site. The largest *P. leopardus* seem to prefer deeper rocky slopes, a type of habitat which is available throughout the park, and where spawning presumably takes place on various sites. The decline in the numbers of *P. leopardus* after year 1 seems to be mostly explained by the removal of larger (> 30 cm) animals from sites 3, 5, 6 and 8.

Conclusions and Discussion

Spawning locations, seasons and lunar phases were identified in Komodo National Park, for several of the most important target species in the fishery for life reef food fish (Table 2). The overall main spawning season for target species was from September to February, with small differences between species. This spawning season overlaps with the one recorded for *P. leopardus* on the Great Barrier Reef (Samoilys and Squire, 1994) but is quite different with what has been observed for *E. fuscoguttatus* and *P. areolatus* in Palau (Johannes *et al.*, 1999) and Pohnpei (Rhodes, 1999). The aggregation of *P. areolatus* in Komodo is occasionally also forming outside the spawning season but increased occurrence of spawning signs was not recorded outside this period. A prolonged season of aggregation was also observed for *P. areolatus* at one site in Palau where this was perceived to be related to high fishing pressure and abnormal sex ratios (Johannes *et al.*, 1999). Aggregations of the same species at lightly fished sites in Palau were strongly seasonal.

Table 2. Peak spawning seasons, lunar phases and spawning sites per species.

Species	Spawning Season	Lunar Phase	Sites
<i>E. fuscoguttatus</i>	September - February	full moon	6, 7
<i>P. areolatus</i>	September - February	full moon	4, 7, 8
<i>E. polyphekadion</i>	September - February	full moon	6, 7, 8
<i>P. leopardus</i>	September – December	new moon	3, 5, 8, multiple
<i>P. laevis</i>	September - December	new moon	3, 7
<i>P. oligocanthus</i>	September - December	new moon	3, 6, 8, multiple
<i>C. altivelis</i>	? <- October -> ?	n.a.	n.a.
<i>C. undulatus</i>	September - December	new moon	6, 7

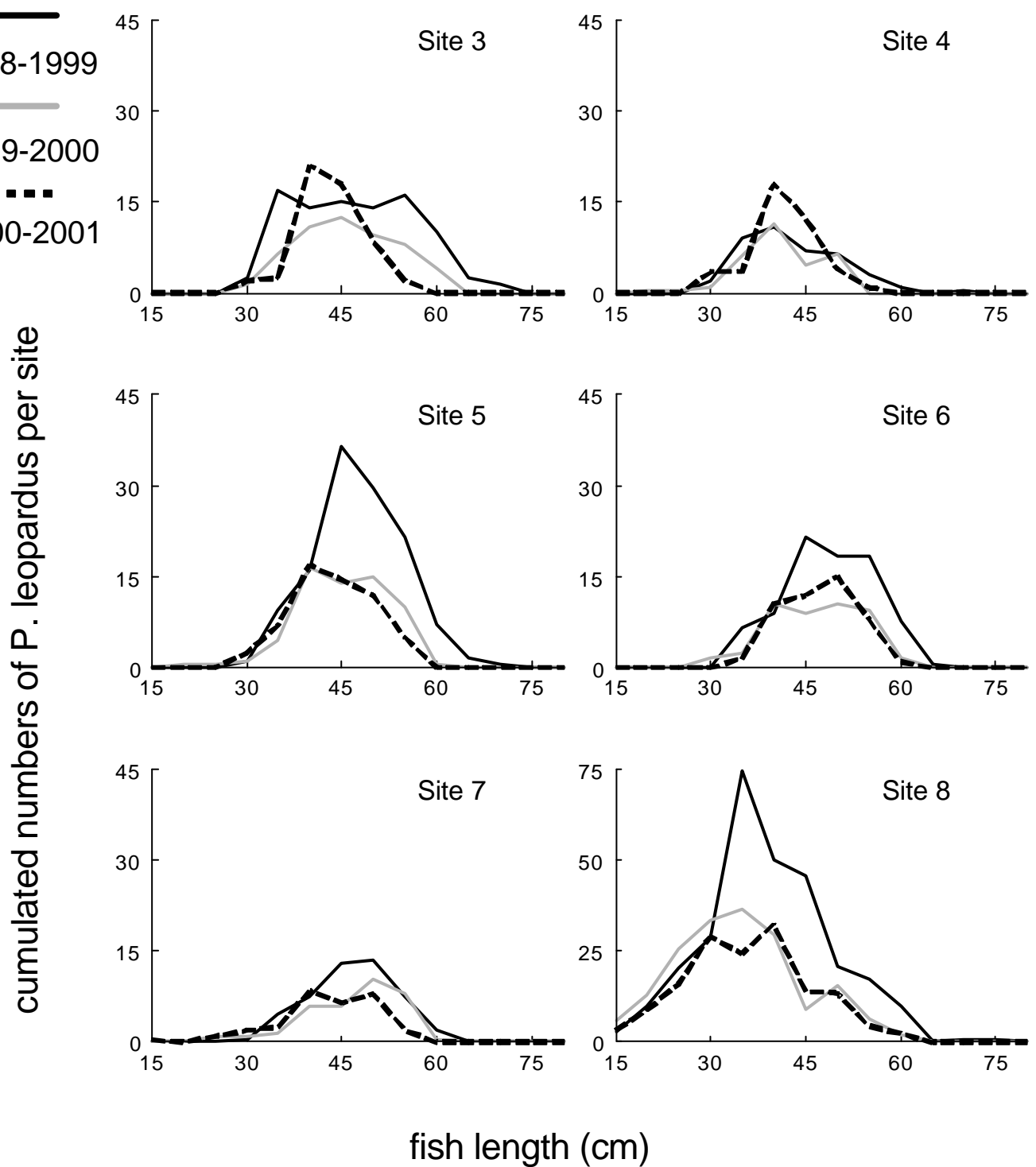


Figure 11. Cumulated estimated length frequency distributions of *P. leopardus*, for sites 3 to 8, from March 1998 to February 2001.

The spawning aggregations of *E. fuscoguttatus* and *P. areolatus* formed around the new moon in Palau (Johannes et al., 1999) whereas they formed around the full moon in both in Komodo, Indonesia, and in Pohnpei (Rhodes, 1999; Pet *et al.*, 2001). This indicates that these species can choose different lunar phases for spawning. Within the Komodo area it was shown that although most species were reproductively active at certain lunar phases, they did also aggregate and/or show signs of imminent spawning at other lunar phases on occasion. Signs of spawning were less frequently observed in aggregations forming during other than preferred lunar phases (e.g. *P. areolatus* aggregation during new moon of September 1999). The fact that the spawning signs with lower weight factors, such as grouping, fighting, color and wounds, were typically recorded during the aggregations and at the same time as the signs with higher weight factors, does indicate that these signs can also be used to determine spawning times and locations.

LFDs of *P. areolatus* and *E. fuscoguttatus* were bimodal on the spawning aggregation sites during the months of peak spawning activity. The two peaks in the LFDs are assumed to represent the two sexes. Sex ratios on the grouper spawning aggregation sites were different from month to month based on the observed LFDs and the assumption that the smaller fish are females and the larger ones are males. Sex-change was completed at around 50 cm in *P. areolatus* and at around 70-80 cm in *E. fuscoguttatus* in Palau (Johannes et al., 1999). LFDs of female *P. areolatus* and *E. fuscoguttatus* changed during the spawning season, with smaller fish being present in the first month and larger ones in the last months of the season. The differences in shapes of LFDs from month to month do suggest that different fish visit the sites in consecutive months. Based on the identification of several individual males, it seems that at least in some grouper aggregations the males are present each month and possibly spawn with different females each time. It is unclear if and how many times individual females return to the aggregations site.

All spawning sites identified during this study had strong currents directed away from the reef on both tides. This feature would have resulted in eggs to be taken away from the reef and from predators immediately after spawning. Most sites were reef promontories, but channels, rocky outcrops of steep-sloped islands were also used. The spawning aggregation site of *P. areolatus* described in this study was a channel and the aggregation site of *E. fuscoguttatus* was a reef promontory. As was observed earlier in Palau (Johannes *et al.*, 1999), many reef fish species make use of the same spawning sites, of which there are only a limited number. These sites are therefore very important, from a management point of view, for the target species in the monitoring program (groupers and Napoleon wrasse).

Spawning aggregations of groupers in Komodo National Park contained relatively low numbers of fish, compared to aggregations of the same species in other locations such as Palau (Johannes *et al.*, 1999), Pohnpei (Rhodes, 1999; Pet *et al.*, 2001) and the Great Barrier Reef (Samoilys, 1997). The aggregation sites identified in Komodo were also smaller than the ones in Palau and Pohnpei (Johannes *et al.*, 1999, Pet *et al.*, 2001). Only two grouper aggregation sites, one with mainly *E. fuscoguttatus* and one with mainly *P. areolatus*, have been identified within the Park's 17 km² of reef slopes, although hundreds of sites have been surveyed repeatedly, between 1995 and 2000. The total number of spawning sites and individual animals is presently concluded to be very low in the Komodo area. The most important species in the life reef food fish trade, *P. leopardus*, aggregated only in small groups in Komodo. This occurrence of multiple (and unpredictable) small spawning aggregations was also observed on the Great Barrier Reef (Samoilys & Squire, 1994; Samoilys 1997) but the lack of larger aggregations may well be a result of over-fishing.

Species-specific behavior determines the vulnerability of groupers to diving cyanide fishers and other perturbations. Species not swimming away but hiding in caves will fall victim more easily than species escaping by swimming away. This is why *E. polyphkadion* is the most vulnerable species. Within the coral trout, shallow living *P. laevis* juveniles (45 cm) and small *P. areolatus* are the most vulnerable whereas *P. oligocanthus* is often saved by its reaction to swim away fast from approaching divers. All species are vulnerable to habitat loss by coral reef degradation but some seem to be more dependent on pristine reefs than others. Where *P. areolatus* is only observed near shallow high quality coral reefs, *P. leopardus* seems to be tolerant of a variety of habitats (although juvenile *P. leopardus* do seem to prefer high rugosity). *E. fuscoguttatus* prefers holes as hiding places but where coral is not available, holes in rocks are readily occupied (as on site 7 which consists mostly of rocks).

Monitoring of resource utilization by the Park authorities has shown that all spawning sites in Komodo National Park were targeted heavily by fishermen supplying the live reef food fish trade (Pet, 1999), and that these fishermen were especially active during the spawning season. Both of the aggregation sites of *E. fuscoguttatus* and *P. areolatus*, sites 7 and 8, were heavily fished during the aggregation seasons at least until late 2000. Before 2001, all grouper species and *C. undulatus* were always heavily fished wherever they occurred abundantly. Fishing at the spawning aggregation sites was reduced by Park Authorities since late 2000 and was officially banned in the no-take zones, which contain all the known grouper spawning aggregations and other sites where target species had been observed to spawn, since mid 2001.

Before 2001, daytime hook and line fishermen mostly targeted coral trout but nighttime activity of diving fishermen would have targeted many other species as well. All survey sites had large quantities of line and hooks tangled in coral and among rocks, showing that hook and line is an important method and that cyanide fishing is certainly not the only threat to these sites. It is believed that if the remaining spawning aggregations are not protected effectively and immediately, they will disappear like so many others before them. Also the numbers observed of the larger grouper species such as *E. tukula* and *E. malabaricus* were lower during the study than in 1996, before monitoring started (Pet, pers. obs.) and these species have been heavily fished mostly by longlines which catch both sharks and groupers (Pet, 1999). The shark fins are kept and the shark meat is the preferred bait for groupers.

Changes in length frequency distributions per species are important indicators of the impact of the fisheries and management over the years. Impact can be caused both directly, by fishing or protecting, or indirectly by destruction or rehabilitation of habitat. Year to year variance in abundance will partly be caused by variation in recruitment and therefore the length-estimation is of major importance. Consistently and strongly reduced numbers of large fish across target species, resulting in reduced mean lengths in the populations, indicated heavy fishing pressure in Komodo during the first year of this study. This heavy fishing pressure could have lead to local depletion if spawning aggregation sites were not protected from fishing since late 2000.

Spawning aggregations are present in Komodo National Park, but if the park is to serve as an area where spawning stocks of commercial species are protected, all known fish spawning sites should be closed to fisheries. In June 2000, a management plan for Komodo National Park was signed by the Park Authority and the local and central governments, and herewith officially adopted (Pet and Yeager, 2000). This plan is based on the current knowledge of high biodiversity areas in the Park, reef quality, spawning aggregations and resource utilization patterns. All known spawning sites have been embedded well within the no-take zones of the Park. These no-take areas do not conflict with traditional use areas for Park inhabitants. Total

effort, licenses and fishing methods in traditional use zones will be strictly controlled, since limited fishing by inhabitants needs to be sustained. No-take zones are extending 500 meters from most of the Park reefs into open water. All areas of Komodo National Park are closed for fishing groupers and Napoleon wrasse, from September 1st to March 1st. During this period it is prohibited to capture or keep any grouper species or specimen of *C. undulatus* anywhere in the Park, also in traditional use zones. This regulation will enable the Park managers to keep live reef fish traders out of the Park during the entire spawning season and will result in many reef fish species being better protected. Local communities will still be able to engage in limited reef fishing activities year round in the multiple use zones, as long as they do not collect, keep or sell groupers or Napoleon wrasse during the closed season. The spawning sites will eventually be accessible only for very limited numbers of recreational divers under guidance of specially trained Park rangers, to prevent disturbances to the spawning fish. Since the spawning aggregation sites are also among the most interesting dive sites, the sites can contribute significantly to tourism revenues and since Park financing will become more and more dependent on tourism revenues, these sites will not be closed altogether. Strict tourism management however will be implemented according to the long-term management plan.

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