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SEXUAL MATURITY AND SEASONAL SPAWNING OF HAPUUPUU, *EPINEPHELUS QUERNUS*, IN HAWAII

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INTRODUCTION

Hapuupuu, *Epinephelus quernus* (Serranidae), is an endemic grouper of considerable importance in terms of total landings and value to the deep-sea handline fishery in Hawaii (Ralston and Kawamoto 1987). It ranked third in average bottom fish landings in 1984-88 (Somerton et. al. 1989) and is the only serranid that contributes significantly to the commercial landings in Hawaii (Seki 1986). The majority of the catch (88% in 1988) is taken in the Northwestern Hawaiian Islands (NWHI) between Necker Island and Kure Atoll at depths ranging from 18 to 230 m.

The reproductive biology of hapuupuu is previously undescribed in the literature, although such information is important as a biological basis of management for the bottomfish resources in Hawaii (Western Pacific Regional Fishery Management Council 1986). The goal of this study is to determine the spawning season and size at sexual maturity of hapuupuu. Size at sexual maturity is a particularly important parameter used to assess and evaluate the impact of fishing mortality on spawning stock biomass and to determine levels of optimum fishery yield (Polovina 1987). Evidence exists that indicate hapuupuu, like many other serranid species (Smith 1965), may be hermaphroditic. A secondary goal of the study is to substantiate and characterize the pattern of hermaphroditism.

METHODS

A total of 131 hapuupuu gonads, collected between 1978 to 1981 at various locations throughout the NWHI, were examined for sex and stage of maturation. Most were from fish caught with deep-sea handline gear. The entire gonad was preserved in 10% formalin usually within an hour of the time of capture. Most gonads (102) were histologically sectioned at 4-5 μm, stained with hematoxylin and counterstained with eosin. They were staged and sexed using criteria established by Moe (1969) for *E. morio*. The remainder of the gonads were macroscopically determined to be ovaries in an advanced stage of vitellogenesis. They were staged by a subsample being taken through the ovary with a cork borer and then examined under a dissecting microscope (Everson et. al. 1989). The average diameter of the largest oocyte mode was determined, and the percentage of each maturity stage present was noted.

Gonadosomatic index (GSI) values [(gonad weight/somatic weight) x 100] were calculated to provide a preliminary indication of developmental stage. These values were compared with those obtained from the microscopic staging techniques.

Size at sexual maturity (L_{50}) of females was defined as the smallest 50 mm total length (TL) category in which at least 50% of the individuals had reached the yolked (vitellogenic) stage of development during the spawning season. A logistic equation was fitted to the weighted percentage of individuals in each 50 mm size class (Px) and TL (Gunderson et al. 1980; Ni and Sandeman 1984); that is

$$P_x = \frac{100}{1+\exp(aFL+b)},$$

where a and b are fitted parameters and $L_{50} = -b/a$.

Sex ratio was examined for significant deviation from unity and to assess hermaphroditism.

RESULTS

Spawning Season

Samples were obtained in all months except October. Unfortunately, less than five fish each were obtained for January, February, March, September, and December (Table 1). Also, the state of preservation for many samples (especially November) made it difficult to accurately characterize ovarian atresia. This was probably due to the lack of immediate infiltration of preservative upon capture and to prolonged preservation in formalin. Although cytological detail was obscure in these samples, it was still possible to determine sex and stage of sexual development. April and June represented peak spawning months: A total of 68% (April) and 62% (June) of the females had vitellogenic oocytes (Table 1). The GSI also were elevated (Fig. 1) during this time. Limited spawning activity occurred from January to March and in May. Spawning activity seemed to decrease sharply in July (0% mature, 0.288 mean GSI) and then increase again in August (50% mature, 0.596 mean GSI). Negligible spawning activity occurred in September and November, when only 4-25% of the females were classified as mature and mean GSIs were generally lowest. In addition, a large percentage (64-75%) of the females were classified as post-spawning during these months.

Size at Sexual Maturity

Fifty percent of the female hapuupuu attained sexual maturity by 575-625 mm TL, as indicated by elevated mean GSIs (Fig. 2) and the percentage of fish judged mature by microscopic staging methods (Table 2). The smallest mature female caught during the spawning season was 564 mm TL (2.79 kg). All of the females were judged mature by the time they reached 750 mm TL (Table 2). The predicted value of L_{50} obtained from the logistic fit of percentage mature on TL was 570 mm TL (a = -0.89185; b = 3.04070) (Fig. 3).

Sex Ratio and Hermaphroditism

Of the 131 hapuupuu that were examined, there were 120 females and 10 males. Only one individual appeared to be transitional. The overall sex ratio of females to males was 12:1 (92% females). Females accounted for 100% of the 450-700 mm TL fish; the smallest transitional fish and the smallest male fish were encountered at 750 mm TL (Table 3). Males comprised 22-33% of the total from 800 to 950 mm TL and 100% above 950 mm TL. Most (33%) males and the only transitional individual were caught in July, about a month after spawning activity had peaked.

Histological examination of males revealed several important characteristics. All of the testes examined contained atretic bodies, apparently the remnants of vitellogenic oocytes from a previous spawning. The actual number and condition of these atretic bodies varied between individuals. In addition, several testes also contained early developing (unyolked) and vitellogenic oocytes in the process of atresia. Postmortem histolysis and poor preservation prevented a more accurate description of the actual degenerative process. Developing spermatogenic crypts were observed within the existing ovarian lamellae.

DISCUSSION

Hapuupuu have a protracted spawning season that extends from January through June; a high percentage of mature individuals with elevated GSIs was observed during these months. Limited spawning activity occurred during January-March and in May. Spawning reached a peak in April and again in June. Most of the females caught in July were in post-spawning condition, although a few individuals may have spawned as late as August. Interestingly, the largest percentage of males and the only transitional individual were also caught in July, following the June peak in spawning activity. By November, nearly 100% of the females had spawned out. Protracted spawning has been reported for other serranid species. The spawning season of several

epinephaline species from New Caledonia extends from September to February (Loubens 1980). In Curacao, *Cephalopholis fulva* spawns from May to October (Nagelkerken 1979), but in Tahiti spawns from November to July, with peaks in January-March and in June-July (Thompson and Munro 1978). Unlike most of the other deep-sea bottomfish in Hawaii, which are strictly summer spawners, hapuupuu also spawn in winter and spring. Apparently there is considerable variability in spawning seasonality among the serranids (Sadovy and Shapiro 1987), and no factor or combination of factors clearly explains this variability.

Female hapuupuu in the present study began maturing at around 565 mm TL, with over 50% mature by the 575-624 mm TL size class. Size at sexual maturity examined by logistic fit demonstrated that 50% of the hapuupuu matured by 570 mm TL (3.5 kg), which was 52% of the maximum size encountered in the sample population. A related species, *E. tauvina* matures at 412-500 mm standard length (SL) (Chen et al. 1977), while *E. morio* from the Eastern Gulf of Mexico (Moe 1969) attains maturity at 425-500 mm SL (50% of maximum length). Since only one individual was identified as a transitional, it is premature to speculate regarding actual size or age at sex change.

Hapuupuu appear to be protogynous hermaphrodites. They are functional females first and later transform into males. Several lines of evidence support this conclusion. Sadovy and Shapiro (1987) summarize the important indicative features for the diagnosis of protogyny. These include the presence of membrane-lined central cavity (lamellae) within the testes, presence of transitional individuals, and the presence of atretic bodies in various stages of oocyte atresia located within testes. Hapuupuu possess all of these diagnostic features to some degree. A less reliable indicator is the presence of unequal sex ratios biased toward females at small and intermediate sizes, then shifting to a bias for males at the largest sizes (Moe 1969; Nagelkerken 1979; Sadovy and Shapiro 1987). Gear selectivity must be evaluated before interpreting this type of information, however (Sadovy and Shapiro 1987).

Since males tend to be larger, older, less numerous, and thereby more vulnerable to selective fishing methods than females (Smith 1982; Sadovy and Shapiro 1987), protogyny in groupers presents unique problems for fishery managers. The effect of sex change and skewed sex ratios on population dynamics, production, and yield must be understood as predictive models are conceived for these species.

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Table 1.--Percentage of sexually mature female hapuupuu caught during 1979-81, examined by month (I = immature, M = mature, PS = post-spawning).

Month	Stage	*N*	Percent
Jan.	I	1	33.3
	M	2	66.7
Feb.	I	2	50.0
	M	2	50.0
Mar.	I	1	33.3
	M	1	33.3
	PS	1	33.3
Apr.	I	8	21.1
	M	26	68.4
	PS	4	10.5
May	I	2	25.0
	M	5	62.5
	PS	1	12.5
Jun.	I	2	12.5
	M	12	75.0
	PS	2	12.5
Jul.	I	4	80.0
	PS	1	20.0
Aug.	I	1	8.3
	M	6	50.0
	PS	5	41.7
Sept.	M	1	25.0
	PS	3	75.0
Nov.	I	7	31.8
	M	1	4.5
	PS	14	63.6
Dec.	I	3	75.0
	M	1	25.0

Table 2.--Stage of maturity, compared by 50 mm total length (TL) size classes for female hapuupuu sampled during the spawning season.

TL (mm)	Percentage	
	N	mature
425-474	1	0
525-574	2	33.3
575-624	6	66.7
625-674	14	87.5
675-724	7	58.3
725-774	14	100.0
775-824	12	92.3
825-874	4	100.0
875-924	6	100.0
925-974	3	100.0

Table 3.--Sex ratio of hapuupuu caught during the spawning season in the Northwestern Hawaiian Islands (F = female, M = male, T = transitional).

TL(mm)	Sex	N	Percent
450	F	1	100.0
500	F	2	100.0
550	F	7	100.0
600	F	14	100.0
650	F	23	100.0
700	F	18	100.0
750	F	19	90.5
	M	1	4.8
	T	1	4.8
800	F	18	85.7
	M	3	14.3
850	F	7	77.8
	M	2	22.2
900	F	6	100.0
950	F	4	66.7
	M	2	33.3
1,050	M	1	100.0
1,100	M	1	100.0

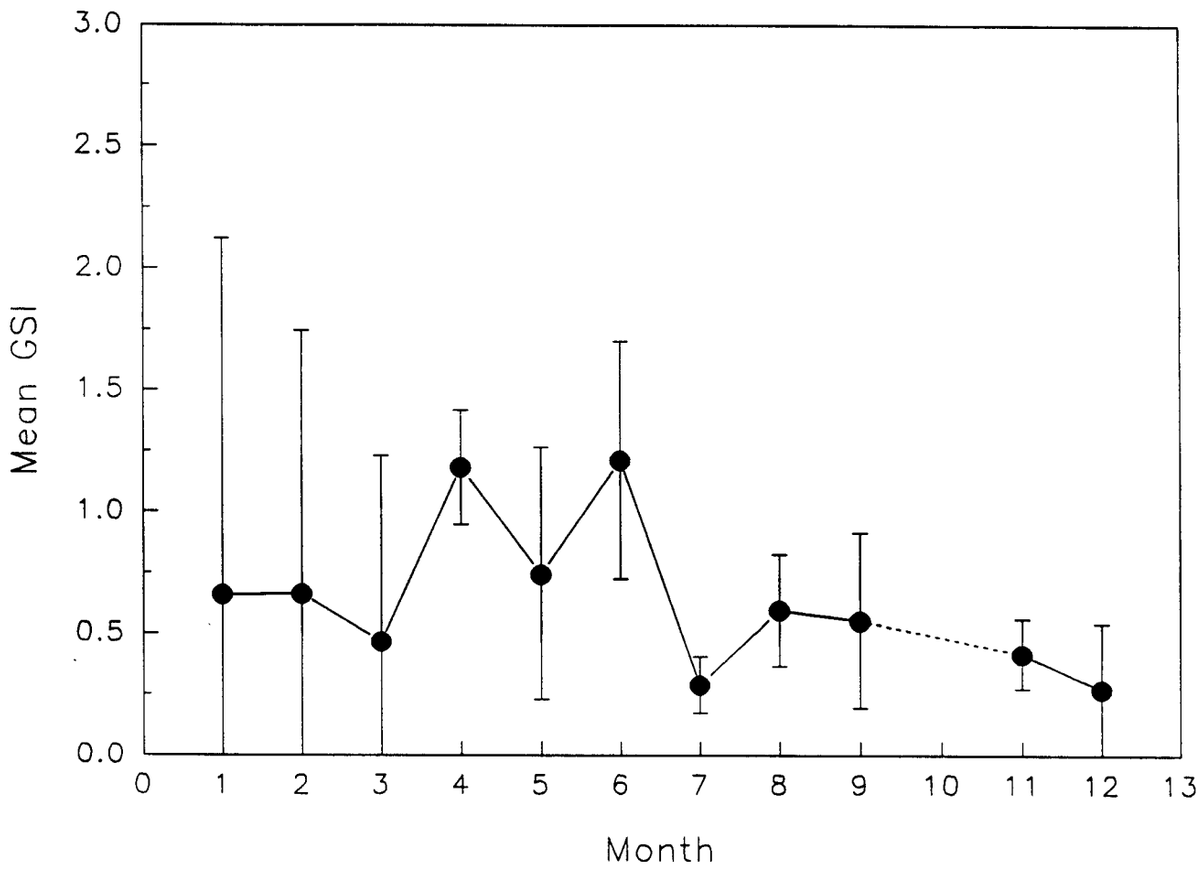

Figure 1.--Mean gonadosomatic indexes plotted by month for female hapuupuu caught in the Northwestern Hawaiian Islands, 1978-81. Vertical bars indicate 95% confidence limits.

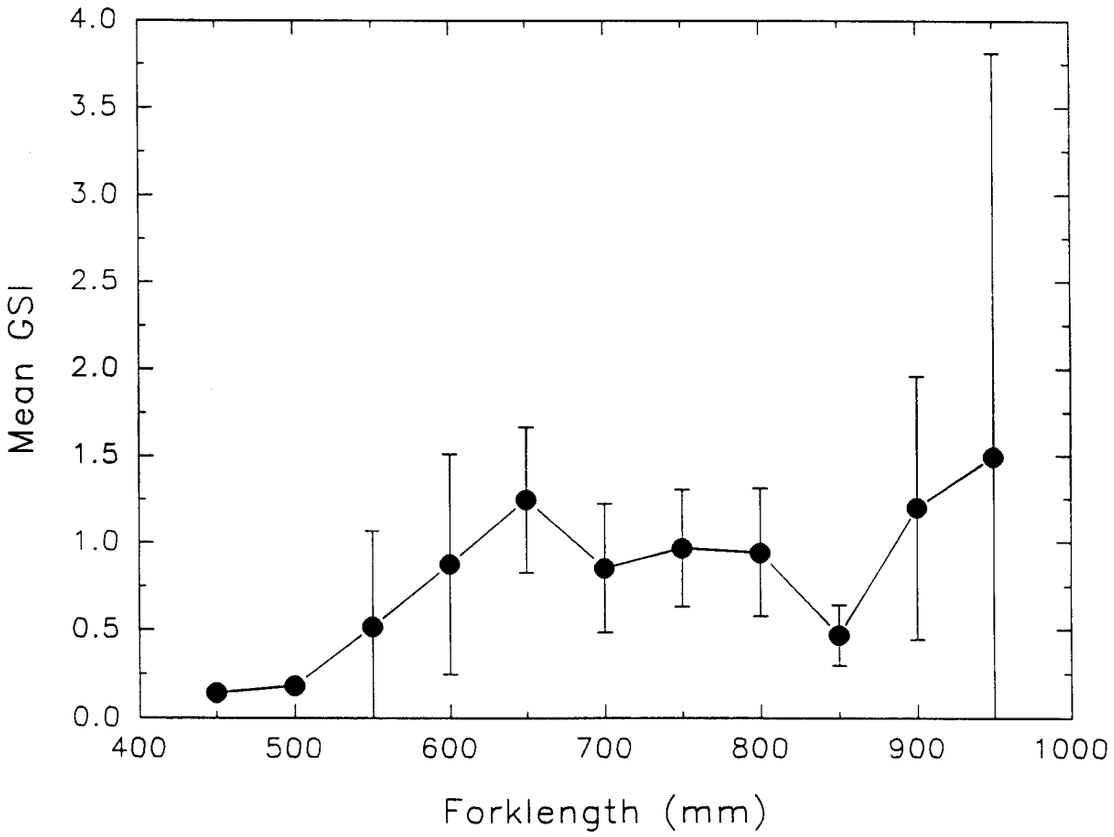

Figure 2.--Mean gonadosomatic indexes plotted by 50 mm total length intervals for female hapuupuu caught during the spawning season. Vertical bars indicate 95% confidence limits.

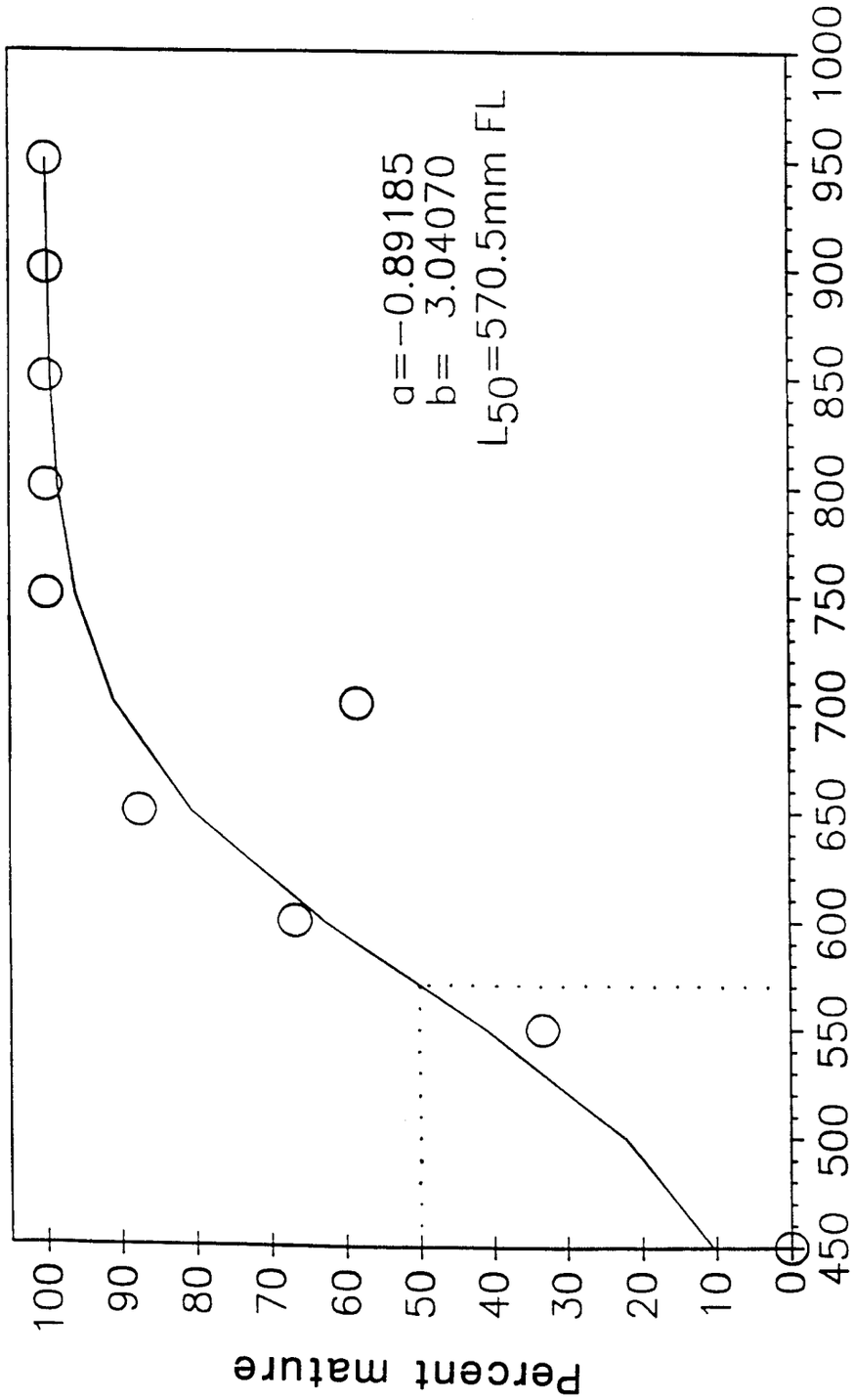

Figure 3.--Predicted 50% maturity value obtained form the logistic fit of percentage mature by 50 mm total length intervals for female hapuupuu caught during the spawning season.