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Reproductive Biology of the Notchedfin Threadfin Bream, *Nemipterus peronii* (Nemipteridae), in Waters of Southwestern Taiwan

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Chuen-Chi Wu, Jinn-Shing Weng, Kwang-Ming Liu, and Wei-Cheng Su (2008) Reproductive biology of the notchedfin threadfin bream, *Nemipterus peronii* (Nemipteridae), in waters of southwestern Taiwan. *Zoological Studies* **47**(1): 103-113. The notchedfin threadfin bream, *Nemipterus peronii*, is an important commercial species for the trawl fishery in Taiwan. Its reproductive biology is described, based on 1273 specimens collected between Nov. 1996 and Nov. 1997 by small trawlers in southwestern Taiwanese waters. The sex ratio, 0.59, significantly differed from 0.5 by X^2 test, and females predominated when the fork length exceeded 100 mm. The combined-sex relationship between body weight (BW) and fork length (FL) was estimated as BW = 1.1 x 10^{-5} x $FL^{3.096}$ (r^2 = 0.948, n = 1213). Fecundity was estimated to range from 1.38 x 10^4 to 39.9 x 10^4. Oocytes were mature when they attained ≥ 0.5 mm in diameter. Batch fecundity was noticeably lower than fecundity, ranging from 688 to 192,437, while the relative fecundity ranged from 231 to 3981 (mean, 1487) per gram of BW. The logistic curves describing the relationship between the proportion of mature individuals (Pr) in each length interval and FL were estimated to be Pr = 1/(1 + $e^{7.3027-0.0429FL}$) (r^2 = 0.99, n = 351) for females and Pr = 1/(1 + $e^{6.2165-0.0355FL}$) (r^2 = 0.99, n = 258) for males. Sizes at 1st maturity were 96.7 and 104 mm FL for females and males, respectively. Size at 50% maturity was estimated to be 170 mm FL for females and 175 mm FL for males, corresponding to 1.72 and 1.64 yr old, respectively. The spawning season is prolonged, from Feb. to July, with a peak in Apr. to May. A seasonal closure from Apr. to May is recommended as a management measure for this species in southwestern Taiwanese waters. http://zoolstud.sinica.edu.tw/Journals/47.1/103.pdf

Key words: *Nemipterus peronii*, Reproduction, Fecundity, Sex ratio, Spawning season.

The notchedfin threadfin bream, *Nemipterus peronii* (Valenciennes, 1830) (Nemipteridae), is widely distributed in the West Pacific from Taiwan to northern Australia, and in the Indian Ocean including the Andaman Sea, the Bay of Bengal, around Sri Lanka, the Arabian Sea, the Persian Gulf, and the Red Sea. This species can be found on sand or mud bottoms at depths down to 100 m (Russell 1990 1993). The notchedfin threadfin bream is an important commercial species for the trawl fishery in Taiwan, and it is caught in substantial numbers year round by small trawlers in waters off southwestern Taiwan. Unfortunately, since the catch statistics of all *Nemipterus* species are pooled as "threadfin bream", accurate estimates of neither the yield nor fishing effort of this species are available. However, the annual yield of threadfin bream in southwestern Taiwan decreased from 510 MT in 1989 to 54 MT in 1997, suggesting that the abundances of threadfin species might have decreased over the past 2 decades. Since the notchedfin threadfin bream comprises the major proportion of the catch of threadfin bream species in southwestern Taiwanese waters, an evaluation of the stock status of this species is urgently needed.

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Some aspects of the fishery biology of *N. peronii* that have been extensively studied include its biology and reproductive behavior (Eggleston 1972, Sainsbury and Whitelaw 1984, Vivekanandan 1991); age and growth (Wu et al. 1986, Chang et al. 1988); population dynamics and stock assessment (Liu et al. 1986); and genetics (Moravec 1989, Santos and Ng 1993, Menezes et al. 2002). Lee's (1986) description of the family Nemipteridae and Russell's (1993) review of *Nemipterus* from Japan and Taiwan are the only studies of *N. peronii* in Taiwanese waters. The fishery biology, especially the reproductive biology, of this species in Taiwanese waters is still poorly known.

The Taiwanese government is promoting seasonal closure as a fishery management measure for its coastal and offshore trawl fisheries. However, this management measure needs to be based on biological evidence such as reproductive information. The objective of this study was to provide information on the reproductive biology including spawning season, fecundity, size at maturity, and sex ratio of *N. peronii* in southwestern Taiwanese waters. The results obtained in this study can be used for stock assessments and can serve as an important reference for management decision making.

MATERIALS AND METHODS

In total, 1273 specimens (755 females and 518 males) (Table 1), caught by otter trawlers in southwestern waters off Taiwan (Fig. 1), were randomly collected monthly from Nov. 1996 to Nov. 1997 at the Tongkang and Linuan fishing ports, southwestern Taiwan. Fish were weighed to the nearest 0.1 g, fork length (FL) was measured to the nearest 0.1 mm, and gonads were weighed to the nearest 0.01 g. Ovaries were macroscopically examined to determine the mature condition and then preserved in 10% formalin until processing. The relationship between body weight (BW) and FL was described by $BW = a \times FL^b$; where a and b are constants and can be estimated by the NLIN procedure in SAS (Cary, NC, USA). The difference in the BW-FL relationship between sexes was examined using the maximum-likelihood ratio test (Kimura 1980).

Three ovaries of fish at 2 different development stages were selected to ensure the homogeneity of oocyte diameter and number of oocytes. Each ovary was divided into 6 portions (the anterior, middle, and posterior portions of each lobe), 0.05 g taken from each portion was placed on glass slides with a grid scale, and all oocytes were measured and counted with a projector (20x) (Nikon V-12B, Kanagawa, Japan). A two-way analysis of variance showed that there was no significant difference ($p > 0.05$) in the number of oocytes or oocyte diameters among portions for an individual ($n = 18$), but significant differences ($p < 0.05$) were found for the same portion among individuals which were at different development stages. Similar patterns of the frequency distribution of oocyte diameter for the same portion among individuals further suggested that oocyte diameter and number of oocytes were homogeneously distributed. For consistency, the middle portion of the right lobe of each ovary was used in this study. In total, 124 ovaries were used to estimate fecundity. In each ovary, oocytes > 0.1 mm in diameter (corresponding to the yolk vesicle

Table 1. Specimens of *Nemipterus peronii* caught in southwestern waters of Taiwan from Nov. 1996 to Nov. 1997

Month	Sex	Sample size	Range of fork length (mm)
Nov. 1996	F	43	87.1 - 190.7
	M	26	100.2 - 222.8
Dec.	F	29	139.4 - 193.1
	M	31	150.8 - 189.4
Jan. 1997	F	38	121.0 - 225.1
	M	41	113.7 - 201.2
Feb.	F	65	98.5 - 199.8
	M	57	103.7 - 210.3
Mar.	F	52	123.9 - 243.6
	M	36	144.8 - 209.9
Apr.	F	56	124.7 - 220.2
	M	30	142.5 - 186.1
May	F	68	123.7 - 214.8
	M	44	121.0 - 213.0
June	F	71	99.0 - 273.5
	M	50	99.1 - 189.9
July	F	62	96.9 - 233.2
	M	29	101.7 - 206.7
Aug.	F	80	101.7 - 227.4
	M	31	93.5 - 203.0
Sept.	F	60	120.1 - 196.4
	M	25	116.1 - 159.6
Oct.	F	91	119.9 - 210.1
	M	72	119.7 - 206.5
Nov.	F	40	109.2 - 195.1
	M	46	102.5 - 198.7
Subtotal	F	755	87.1 - 273.5
	M	518	93.5 - 222.8
Total		1273	87.1 - 273.5

stage) in the 0.05 g ovary sample were counted and measured. The maximum oocyte diameter of a mature female was obtained by averaging the measurements of at least 50 of the largest oocytes.

Histological procedures in this study followed Humason (1979) and Lee et al. (2005). In total, 220 gonads (183 females and 37 males) were sectioned at 5-8 μm in thickness for further analysis. The gonadosomatic index (GSI), condition factor (CF), and hepatosomatic index (HSI) were calculated as follows:

$GSI = (\text{gonad weight} \times 10^2)/\text{gutted BW}$,
$CF = (\text{gutted BW} \times 10^5)/FL^3$, and
$HSI = (\text{liver weight} \times 10^2)/\text{gutted BW}$.

A one-way analysis of variance (ANOVA) was used to test the homogeneity of the GSI, CF, and HSI among months.

The sex ratio was expressed as:
(number of females)/(number of both sexes combined).
A X^2 test was used to examine the homogeneity of the sex ratio.

Fecundity (F) was estimated from the following equation:
F = (number of oocytes > 0.1 mm in diameter

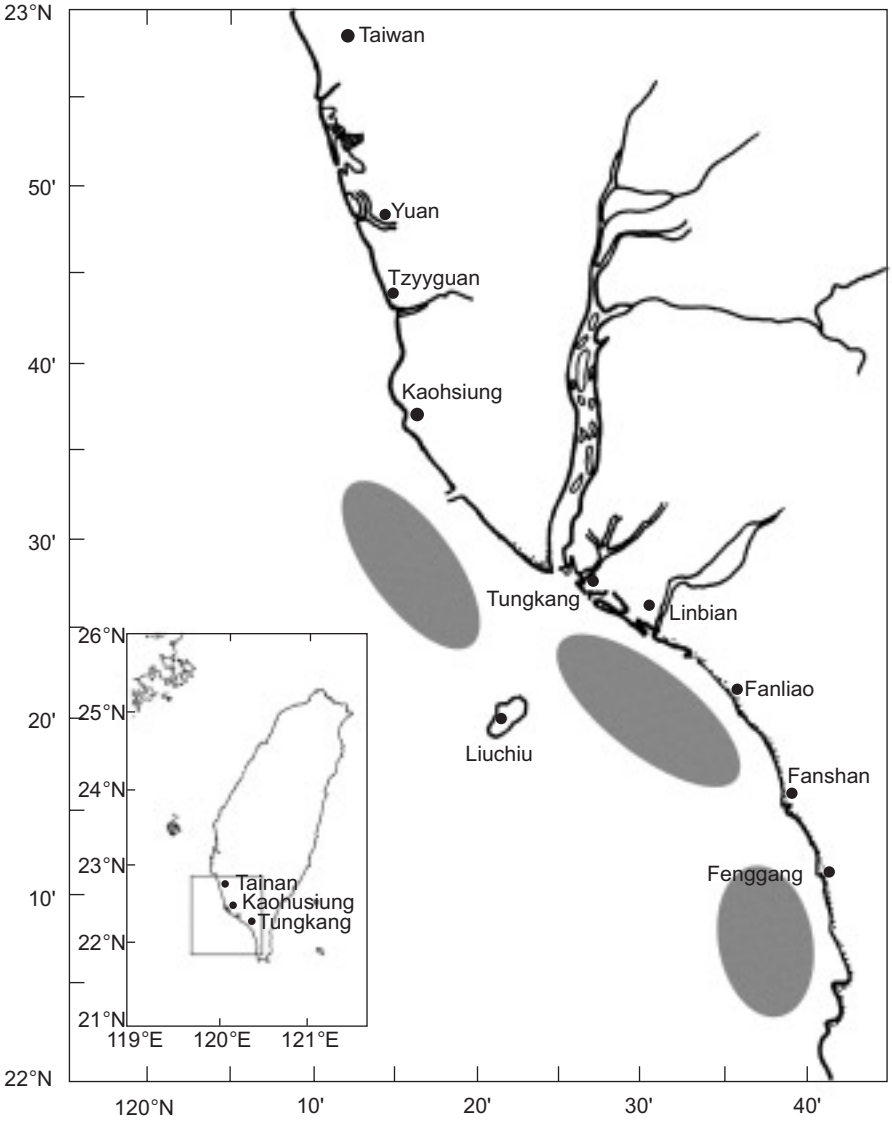

Fig. 1. Sampling area of *Nemipterus peronii* in this study.

in 0.05 g of ovary tissue) x (weight of the ovary preserved in formalin)/(0.05 g ovary).

The relationships of fecundity with gonad weight (GW) and F with fork length were described by the allometric equations $F = a \times GW^b$ and $F = a \times FL^b$, respectively.

Batch fecundity (BF) was estimated from:

BF = (number of oocytes > 0.5 mm in diameter in 0.05 g of ovary tissue) x (weight of the ovary preserved in formalin)/(0.05 g ovary).

The logistic model, $Pr = 1/(1 + e^{(a+bFL)})$, where a and b are constants, was used to describe the relationship between the proportion of mature fish (Pr) in each length interval and fork length (FL) based on 351 female and 259 male specimens. Size at 50% maturity was then obtained by substituting Y = 0.5 in the above equation. A significance level of 0.05 was used throughout this study for statistical tests.

RESULTS

Length-weight relationship

The length and weight frequency distributions indicated that females were in the range of 87.1-273.5 mm FL at body weights of 10-289 g; while males were 93-222.8 mm FL at body weights of 11-208 g. Relationships between BW and FL were estimated as:

$BW = 1.2 \times 10^{-5} \times FL^{3.090}$ ($r^2 = 0.954$; $n = 714$, $p < 0.01$) for females and

$BW = 1.1 \times 10^{-5} \times FL^{3.107}$ ($r^2 = 0.947$; $n = 499$, $p < 0.01$) for males.

Since no significant difference between sexes was found for the length-weight relationship with the maximum likelihood ratio test ($X^2 = 1.056$, $p = 0.59$), the data were pooled, and the following equation was used to describe the BW-FL relationship for both sexes combined (Fig. 2):

$BW = 1.1 \times 10^{-5} \times FL^{3.096}$ ($r^2 = 0.948$, $n = 1213$, $p < 0.01$).

Sex ratio

The sex ratio of all specimens was 0.59 (755/1273), which significantly differed from 0.5 ($X^2 = 44.1$, $p < 0.01$). Females outnumbered males throughout the year except in Dec. and Jan. The monthly sex ratio ranged from the lowest at 0.47 in Nov. 1998 to the highest at 0.72 in Aug. 1997. The X^2 test indicated that females outnumbered males from 100 mm FL onward, except at 170-190 mm FL (Fig. 3).

Monthly changes in the GSI, CF, and HSI

The GSI of females increased from 0.75 in Aug. to a peak of 3.47 in Mar., decreased thereafter to the lowest value of 0.75 in Aug., and then gradually increased again (Fig. 4). A similar pattern, with a peak at 0.33 in Mar. and the lowest at 0.11 in Sept., was found for males (Fig. 5). Significant differences in GSI among months were

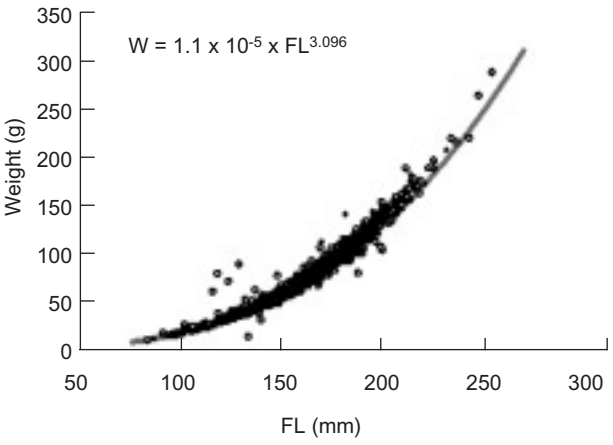

Fig. 2. Relationship between body weight (BW) and fork length (FL) of *Nemipterus peronii* (sexes combined).

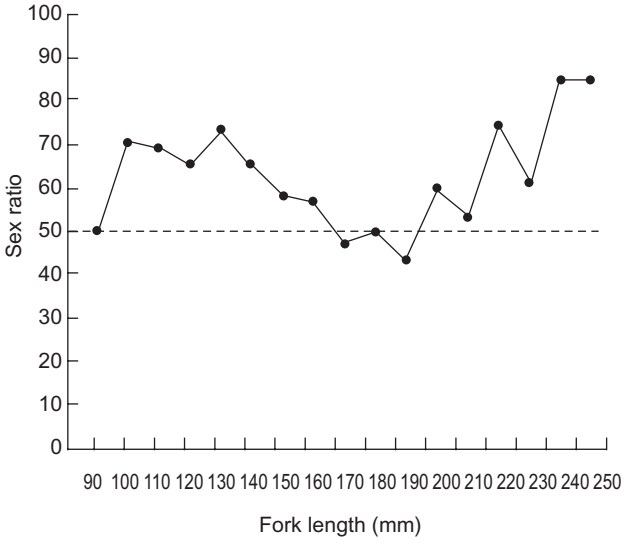

Fig. 3. Sex ratio of *Nemipterus peronii* by size.

found ($p < 0.05$) for both sexes with ANOVA.

Values of CF of females reached a peak after the spawning season. Values for males, however, were stable throughout the year (Fig. 5). CF values did not significantly differ among months for either sex ($p > 0.05$) by ANOVA suggesting that CF has little relation to maturation.

In parallel with changes in the GSI, the HSI of females showed a slight fluctuation (Fig. 4). The mean HSI of females rose from 0.96 in Nov. and peaked at 1.71 in Mar., while that of males increased from Nov. (0.89) continuously toward a peak in May (1.35) (Fig. 5). Similar trends for with HSI and GSI for females suggest that liver development is closely related to gonadal maturation.

Size of oocytes

Figure 6 shows year-round changes in the oocyte diameter distribution, having 1 or 2 peaks at 0.1-1.0 mm. Large-sized groups over 0.5 mm were observed mainly during Feb. and July, and had decreased by Aug.

Frequency distributions of oocyte diameter were highly correlated with the GSI. The oocyte diameter from ovaries with a GSI of < 2.49 was almost always smaller than 0.5 mm, with some exceptions. Once oocytes attained ≥ 0.5 mm in diameter, they were mature (Fig. 6).

Size at 50% maturity

The logistic curves describing the relationship between the proportion of mature individuals (Pr) in each length interval and FL were estimated to be $Pr = 1/(1 + e^{7.3027-0.0429FL})$ ($r^2 = 0.99$, $n = 351$) for females (Fig. 7a) and $Pr = 1/(1 + e^{6.2165-0.0355FL})$ ($r^2 = 0.99$, $n = 258$) for males (Fig. 7b). Sizes at 50% maturity were estimated to be 170 and 175 mm FL for females and males, respectively; which corresponded to 1.72 and 1.64 yr old based on the von Bertalanffy growth equation documented by

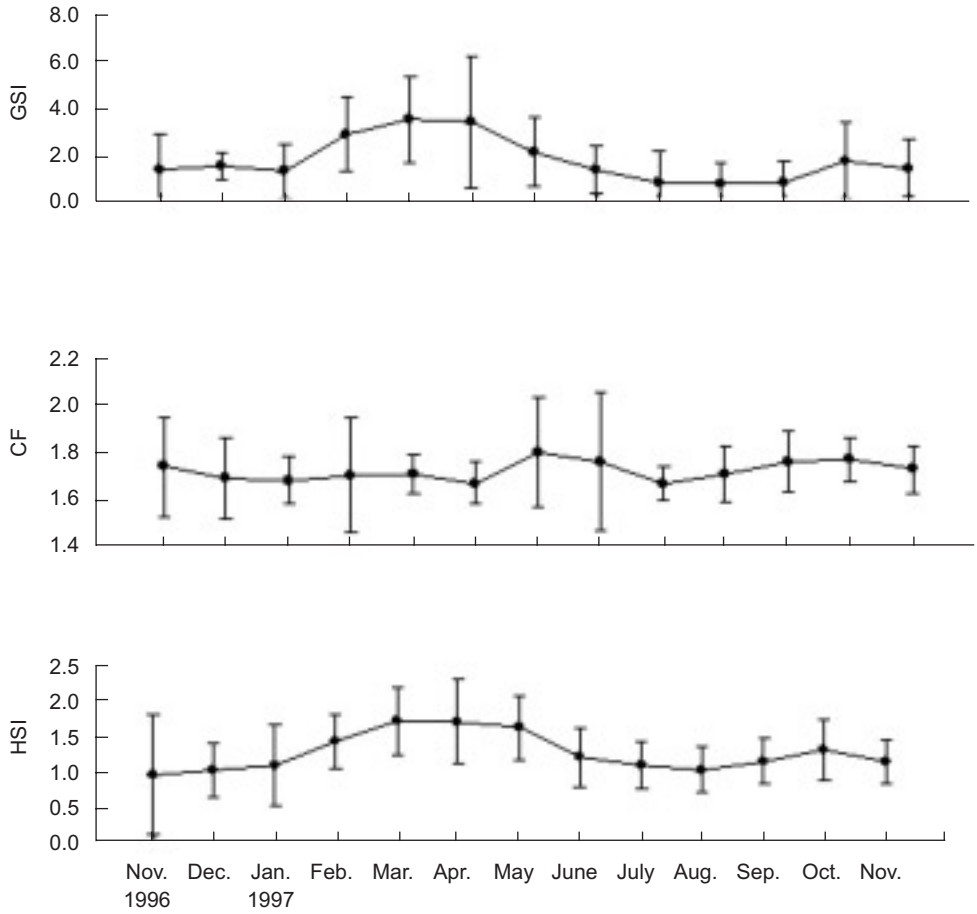

Fig. 4. Monthly variations in the gonadosomatic index (GSI), hepatosomatic index (HSI), and condition factor (CF) of females. Circles and vertical bars denote means and standard deviations, respectively. Numbers denote the sample size.

Wu et al. (1986). Sizes at first maturity were 96.7 and 104 mm FL for females and males, respectively.

Oocyte development

Nine development stages of oocytes for the notchedfin threadfin bream were determined based on histological examinations as follows (Weng et al. 2005). In stage I, the chromatin-nucleolus stage, very small oocytes, generally spherical and about 0.01-0.05 mm in diameter, were found (Fig. 8A). In stage II, the peri-nucleolus stage, small oocytes, about 0.05-0.10 mm in diameter and generally spherical, were found. They had a large nucleus of 0.01-0.03 mm in diameter (Fig. 8B). In stage III, the yolk vesicle stage, oocytes were generally spherical or elliptical and about 0.10-0.20 mm in diameter (Fig. 8C). In stage IV, the primary yolk stage, the nucleus was irregularly shaped and nucleoli were distributed in the nucleus. Oocytes were 0.20-0.30 mm in diameter (Fig. 8D). In stage V, the secondary yolk stage, yolk globules and yolk vesicles increased rapidly in number and size, and fully filled the cytoplasm. Oocytes were 0.30-0.40 mm in diameter (Fig. 8E). In stage VI, the tertiary yolk stage, as yolk globules increased in number and size, oocytes became larger, at 0.40-0.45 mm in diameter. The yolk globules began to coalesce into a yolk mass (Fig. 8F). In stage VII, the migratory nucleus stage, oocytes were 0.45-0.50 mm in diameter. The yolk appeared as a homogeneous mass filling the interior of the oocytes (Fig. 8G). In stage VIII, the ripe stage, a single yolk mass existed and yolk globules which had fused into larger ones were observed. Oocytes were ≥ 0.50 mm in diameter. The eggs were somewhat white and translucent (Fig. 8H). In stage IX, the translucent egg stage, oocytes were translucent and ranged ≥ 0.50-0.55 mm in diameter.(Fig. 8I).

Gonadal development

Based on oocyte development, the oocyte diameter composition, the maximum oocyte diameter, the GSI, and macroscopic examinations, gonadal development could be divided into the fol-

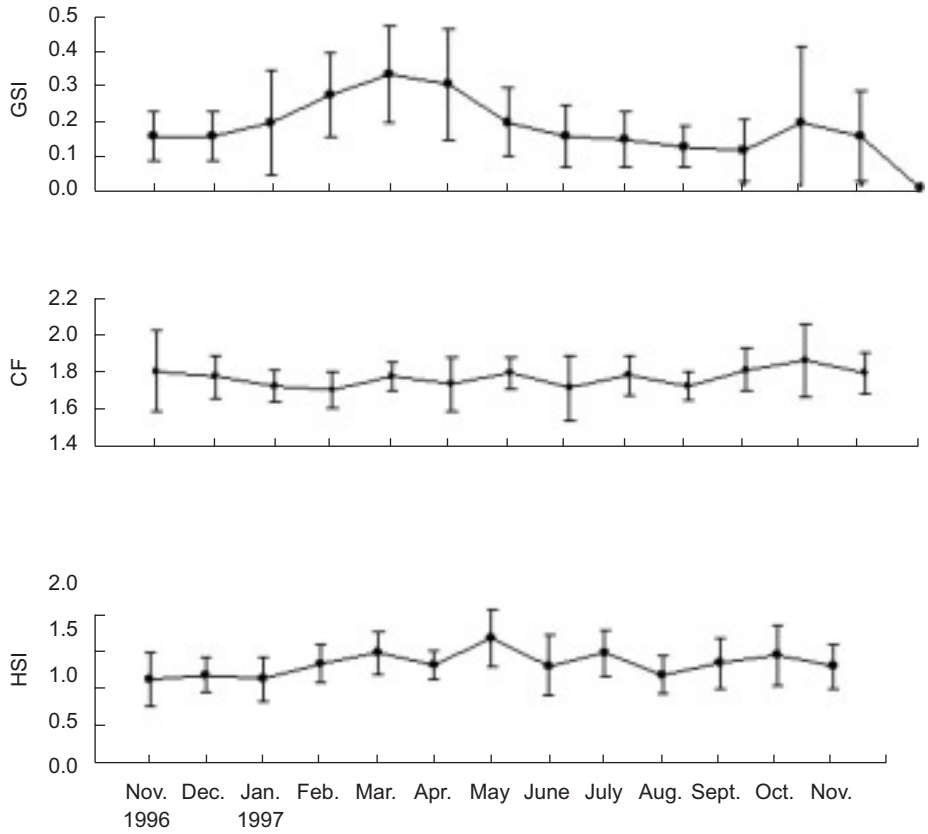

Fig. 5. Monthly variations in the gonadosomatic index (GSI), hepatosomatic index (HSI), and condition factor (CF) of males. Circles and vertical bars denote means and standard deviations, respectively. Numbers denote the sample size.

lowing 4 stages.

In the immature stage, ovaries were small and slender, and no oocytes were visible to the naked eye. Oocyte diameter was < 0.2 mm, the GSI was below 0.8, and undeveloped oocytes were randomly distributed. In the early maturing

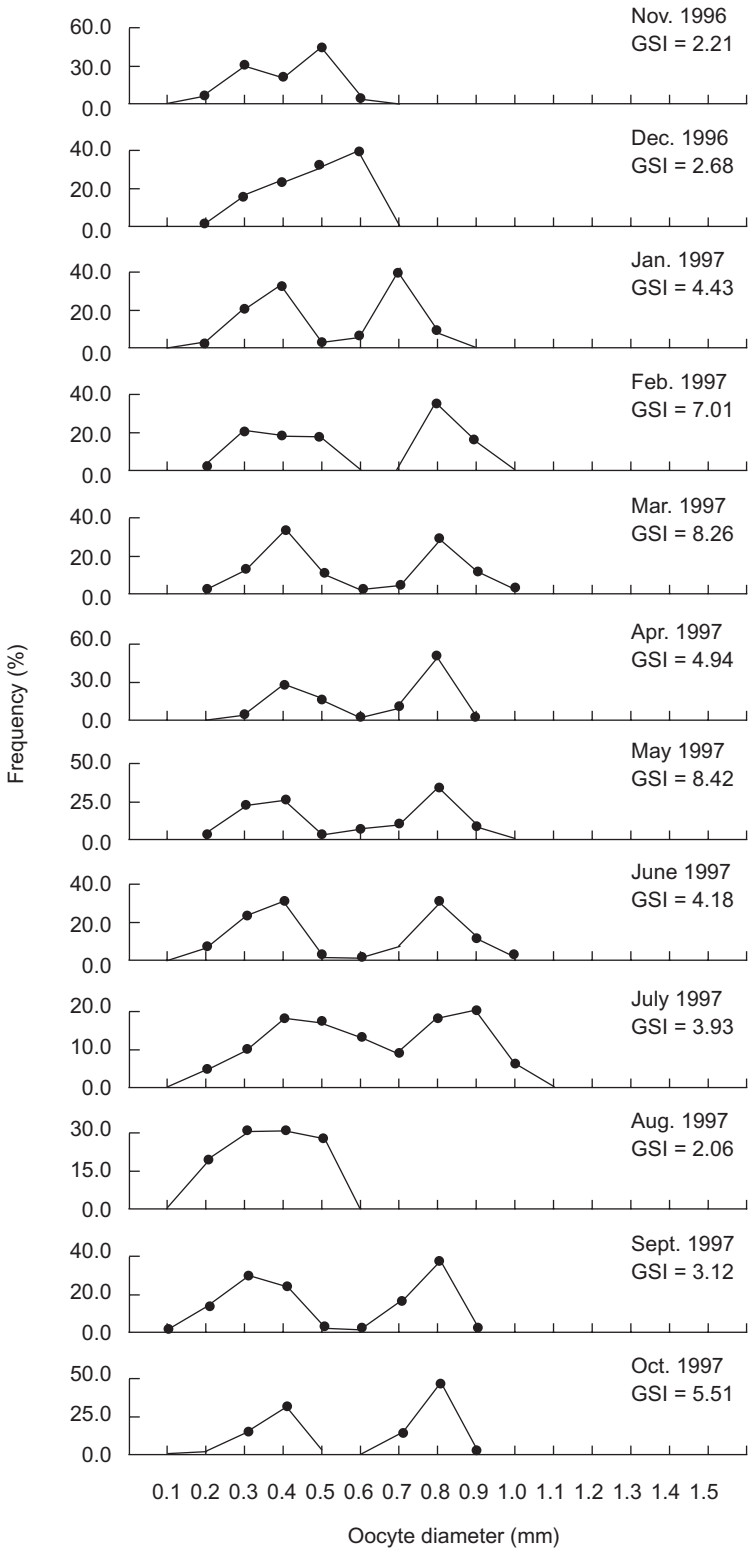

Fig. 6. Monthly changes in the frequency distribution of oocyte diameter.

stage, ovaries were larger and yellowish, the mean oocyte diameter was 0.28-0.35 mm, and the GSI was 0.8-2.5. In the late maturing stage, ovaries were very swollen, yellowish, and translucent. Vascularization was heavy in the back of ovaries, and the diameter of oocytes had significantly increased. Most oocyte diameters were about 0.4 mm and the GSI ranged 2.5-4.0. In the mature stage, ovaries were enlarged and opaque, oocytes were distinguishable, with diameters of 0.4-0.8 mm, and the GSI was > 4.0.

Spawning season

The macroscopic appearance of the ovaries indicated that most immature ovaries presented from Sept. to Jan., and mature ovaries appeared from Feb. to July. Histological examinations showed that mature oocytes presented from Feb. to July. Oocyte diameter measurements showed that 2 modes of oocyte diameter appeared from Feb. to July, and hydrated oocytes were also found in this period (Fig. 6). The GSI in Feb. to May was higher than values of other months. Based on the results from the above 4 methods, the spawning season of the notchedfin threadfin bream appears to be from Feb. to July, with a peak in Apr. to May.

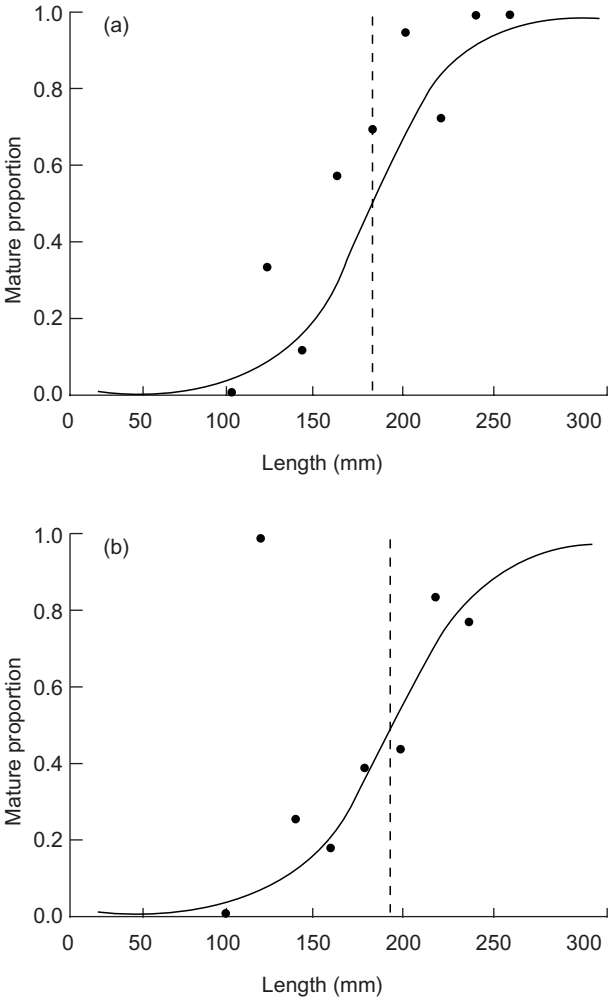

Fig. 7. Relationship between the mature percentage and fork length (FL) of *Nemipterus peronii*. (A) Female, (B) male.

Fecundity and batch fecundity

In total, 132 ovaries with distinct modes of size-frequency distributions of oocytes were used to estimate fecundity. The number of oocytes with a diameter > 0.10 mm was defined as fecundity, which was estimated to range from 13,758 to 398,859 with a mean of 149,429. Fecundity increased with GW and FL:

$F = 4.5 \times 10^4 \times GW_{0.917}$ ($r^2 = 0.79$, $n = 132$, $p < 0.05$) and

$F = 5 \times 10^{-5} \times FL^{3.747}$ ($r^2 = 0.69$, $n = 132$, $p < 0.05$).

Batch fecundity was estimated based on 124 ovaries of gravid females ranging from 96.7 to 237.5 mm FL in the spawning season. The number of oocytes with a diameter of > 0.5 mm was defined as batch fecundity. The batch fecundity was estimated to range from 688 to 192,437 with a mean of 51,766. No significant relation between batch fecundity and GW or FL was found. Relative fecundity, expressed as the number of oocytes per gram of gutted body weight, was estimated to be 231-3981 (mean, 1487), and there was no significant relation between relative fecundity and FL.

DISCUSSION

The largest specimen collected in this study was 273.5 mm FL, which is close to the maximum size of 260 mm standard length recorded by Russel (1990). However, specimens smaller than 90 mm FL were rarely collected. It is likely that these fish are regarded as trash fish because of their low economic value and are discarded at sea.

The sex ratio during the spawning season may be related to fecundity and batch fecundity. Other studies have found that for those species with high fecundity such as the white croaker, *Argyrosomus argentatus* (Tzeng and Liu 1972), mullet, *Mugil cephalus* (Su 1989), and white-tongued crevalle, *Uraspis helvolus* (Chiou and

Chen 1993), the sex ratio in the spawning season is low. On the other hand, the sex ratio in the spawning season is high for those species with low batch fecundity such as the Indian drift fish, *Ariomma indica* (Lin and Chen 1991) and notchedfin threadfin bream in the present study.

An increase in the sex ratio with body size has been documented for other species, and is possibly due to the high mortality of males and greater longevity of females (Fumio 1960). In addition, differences in growth among sexes, sexual dimorphism, and migration may also be contributing factors (Fumio 1960). In the present study, no sexual dimorphism was found. Therefore, the increase in the sex ratio with size might be related to different growth and longevity characteristics between the sexes.

In this study, large variations in the GSI and HSI were found in the spawning season from Feb. to Aug. Similar results have also been documented for the dolphin fish, *Corphaena hippurus* (Wu et al. 2001), and bigeye, *Priacanthus macracanthus* (Liu et al. 2001). The large proportion (70.9%-86.0%) of immature specimens (< 170 mm for females and < 175 mm for males) in this period may account for these results.

Fish can store the energy required for spawning in the liver or viscera. In the present study, similar trends of the HSI and GSI, but constant CF, for females (Fig. 4) suggest that the energy required for spawning of females might be derived from their energy reserves instead of from the diet. A similar finding was also reported for the common ponyfish, *Leiognathus equulus* (Lee et al. 2005).

The spawning seasons for females and males were very consistent. The maturation period of gonads was between Jan. and Mar. The spawning season is very prolonged, from Feb. to July, with a peak in reproductive activity extending from Apr. to May.

Nagahama (1983) classified the developmental patterns of fish oocytes into 3 types: (1) total synchronism, (2) group synchronism, and (3) asynchronism. The developing form of *N. peronii*

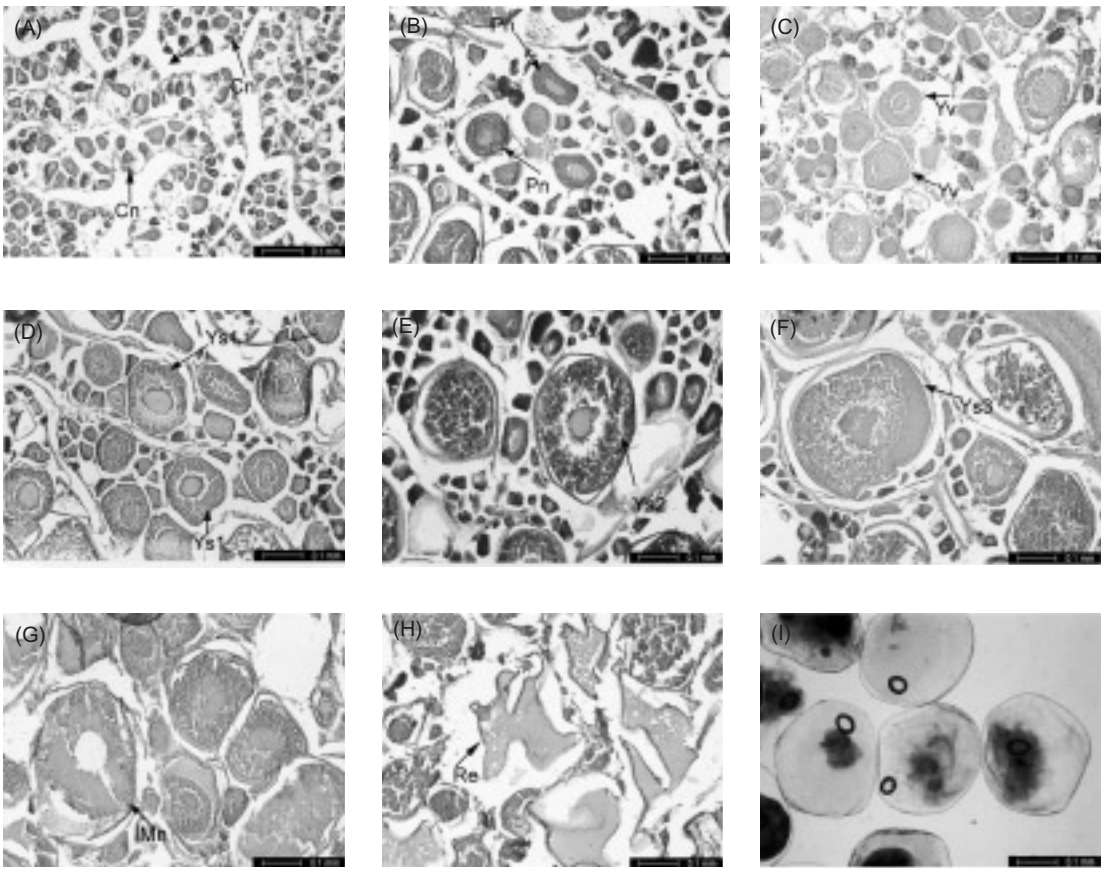

Fig. 8. Histological appearance of oocyte development of *Nemipterus peronii*. (A) Chromatin-nucleolus stage (Cn); (B) peri-nucleolus stage (Pn); (C) yolk vesicle stage (Yv); (D) primary yolk stage (Ys1); (E) secondary yolk stage (Ys2); (F) tertiary yolk stage (Ys3); (G) migratory nucleus stage (Mn); (H) ripe egg stage (Re); (I) translucent egg stage.

oocytes suggests that *N. peronii* may spawn once or more over the prolonged spawning season, and it is considered to belong to the group synchronism oocyte development type.

Macroscopic identification of ovarian developmental stages was easier than with other methods, and large samples could be routinely examined. However, this method may lead to erroneous classifications (Erickson et al. 1985). Variations in the GSI have been used for a number of species as a measurement of reproductive maturity (Kaya 1973, Brewer 1978), but DeVlaming et al. (1982) suggested that the GSI is not an accurate indicator of gonadal activity. In this study, all 4 methods (the macroscopic appearance of the ovaries, the GSI, oocyte frequency distribution, and histological examination) showed good agreement, which suggests that our estimate of the spawning season (Feb. to July) is reasonable. A similar method was successfully applied to the Japanese barracuda, *Sphyraena japonica* (Chen et al. 1993), and bigeye, *Pricanthus macracanthus* (Liu et al. 2001).

From oocyte development and histological examinations, we concluded that the notchedfin threadfin bream belongs to the synchronous oocyte development group. Two distinct modes of oocyte diameter distribution for mature fish (Fig. 6) suggest that the notchedfin threadfin bream in the southwestern waters off Taiwan might release multiple batches per season. However, we did not find the coexistence of postovulatory oocytes and ripe-stage oocytes. Future work is needed to estimate the time of release of these batches.

Hunter and Macewice (1985) reported that spawning of the northern anchovy, *Engraulis mordax*, may be a rapid process, and hydration in other teleosts may occur as early as 12 h before spawning. Therefore, the chance of capturing fish with running ripe oocytes is very small. In the present study, although larvae were not found, we found ovary samples which had hydrated or running ripe oocytes. This finding suggests that southwestern Taiwan waters are one of the spawning grounds for the notchedfin threadfin bream.

The logistic curve has been successfully used to estimate the size at 50% maturity for many species (DeMartini and Lau 1999, Liu et al. 2001, Wu et al. 2001). Based on this method, we estimated the sizes at 50% maturity in southwestern Taiwan waters to be 170 and 175 mm for females and males, respectively. However, Sainsbury and Whitelaw (1984) documented a smaller size at maturity for females (150 mm) in Australian waters. Tormosova (1983) suggested that stock density, food, and water temperatures may influence the growth of fish and affect the age at maturity. However, the factors affecting size at maturity of *Nemipterus peronii* could not be clearly identified in this study.

The spawning season of *Nemipterus peronii* in southwestern Taiwanese waters extends from Feb. to July and peaks in Apr. and May. To ensure sustainable utilization of this species, we recommend protecting adults during the major spawning season. A seasonal closure from Apr. to May can provide better breeding opportunities for adults and is believed to be a good fishery management measure for this species.

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