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Reproductive Biology of the Blue Sprat *Spratelloides gracilis* in the Waters around Penghu, Central Taiwan Strait

Jinn-Sheng Weng[1], Kwang-Ming Liu[2,*], Sin-Che Lee[3], and Wann-Sheng Tsai[4]

[1]*Coastal and Offshore Research Center, Taiwan Fisheries Research Institute, No. 1-1 North 1st Road, Chienchen Fishing Port, Kaohsiung, Taiwan 806, R.O.C.*

[2]*Institute of Marine Resource Management, National Taiwan Ocean University, No. 2 Pei-Ning Road, Keelung, Taiwan 202, R.O.C.*

[3]*Department of Biology, Tunghai University, No. 181 Chungkan Road, Sec. 3, Taichung, Taiwan 407, R.O.C.*

[4]*Pescadores Marine Biology Center, Taiwan Fisheries Research Institute, Makung, Penghu, Taiwan 880, R.O.C.*

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Jinn-Sheng Weng, Kwang-Ming Liu, Sin-Che Lee, and Wann-Sheng Tsai (2005) Reproductive biology of the blue sprat *Spratelloides gracilis* in the waters around Penghu, central Taiwan Strait. *Zoological Studies* **44**(4): 475-486. The reproductive biology of the blue sprat, *Spratelloides gracilis*, is described based on 7737 specimens collected from Mar. 2001 to Feb. 2003 in the waters off Penghu (the Pescadores), off the southwestern coast of Taiwan in the central Taiwan Strait. The spawning season was estimated to be from Feb. to Sept. based on progressive changes in the size of the ovaries, histological examination of the ovaries, oocyte diameter measurements, and gonadosomatic index calculations. The body weight (BW)-fork length (FL) relationship was estimated to be $BW = 6.06 \times 10^{-6} FL^{3.087}$ for both sexes combined ($n = 4042$, $p < 0.05$). Eight stages of oocyte development were determined based on the histological examination. Ovarian development could be divided into immature, maturing, mature, and spent stages. Mean fecundity of this species was 2606 ± 1678 eggs, and mean batch fecundity was 1204 ± 714 eggs. The sex ratio (0.45) significantly differed from 0.5 ($p < 0.05$). Relationships of fecundity (F) and batch fecundity (BF) with fork length (FL) were estimated to be $F = 0.0002 FL^{3.841}$ ($r^2 = 0.58$, $n = 62$, $p < 0.05$) and $BF = 0.001 FL^{3.806}$ ($r^2 = 0.82$, $n = 60$, $p < 0.05$), respectively. Size at 1st maturity for females estimated from the logistic model was 54 mm FL, which corresponded to an age of 120 d old. http://www.sinica.edu.tw/Journals/44.4/475.pdf

Key words: *Spratelloides gracilis*, Blue sprat, Reproductive biology, Southwestern Taiwan.

The blue sprat, *Spratelloides gracilis*, is a small, pelagic clupeoid fish that inhabits tropical and subtropical coastal waters of the Indo-Pacific region. This species is distributed from the Red Sea to French Polynesia, northward to Japan and south to Australia (Lewis et al. 1983, Whitehead 1985). In Taiwan, this species is found in the waters of Penghu (traditionally known as the Pescadores),off the southwestern Taiwanese coast in the central Taiwan Strait. It is one of the important species for the drag-net fishery in this area and is also caught by bottom gill net and hand line. The annual landings of this species in the Penghu area during the period 1991-2002 ranged from 500 tons (valued at US$3.2 x 10^6) in 1991 to 1100 tons (US$4.8 x 10^6) in 1994.

Biological information on the blue sprat is limited despite some descriptions of its reproduction in Papua New Guinea waters (Dalzell 1985), the population structure at Kashiki Is., Japan (Ozawa et al. 1989), the demersal spawning habitat (Higo and Terada 1985), reproduction, age, and growth in the Solomon Is. (Milton et al. 1990, Milton and Blabar 1991), fishery biology in Japanese waters (Abe 1995, Yamamoto 1997), and its inclusion in a study of allozyme variations of common tuna bait fish in Papua New Guinea waters (Daly and Richardson 1980). In addition, fisheries biology of

*To whom correspondence and reprint requests should be addressed. Tel: 886-2-2462-2192 ext. 5018. Fax: 886-2-2462-0291. E-mail: kmliu@mail.ntou.edu.tw

S. lewisi was reported by Dalzell (1987) and Milton and Blaber (1991). Lu and Chung's (1991) description of the optimal mesh size for drag net is the only report of the blue sprat in Taiwanese waters. Reproductive information, which is crucial for fishery management of this species in Taiwanese waters, is still unknown.

Fishery management of this species such as closure of fishing in May was initiated by fishermen and then adopted by the local government in 1995. However, this management scheme is based solely on the experience of fishermen rather than on any scientific evidence. Hence, the objective of this study was to provide information on the reproductive biology of *S. gracilis* in support of fishery management, including oocyte development, sex ratio, spawning season, fecundity, and size at maturity.

MATERIALS AND METHODS

In total, 7737 specimens, caught by drag netting in waters around Penghu, central Taiwan Strait (Fig. 1), were randomly collected on a monthly basis at the Peichen fish market, and Chikan fishing port from Mar. 2001 to Feb. 2003. Specimens were weighed to the nearest gram, fork length (FL) was measured to the nearest 0.1 mm, and the gonads were weighed to the nearest 0.001 g. The gonads of *S. gracilis* were macroscopically examined and preserved in 10% formalin until processing. The relationship between body weight (BW) and fork length can be described by $BW = a \times FL^b$, where *a* and *b* are constants. The BW-FL relationship between sexes was examined using the maximum likelihood ratio test.

Five ovaries taken from different individuals at

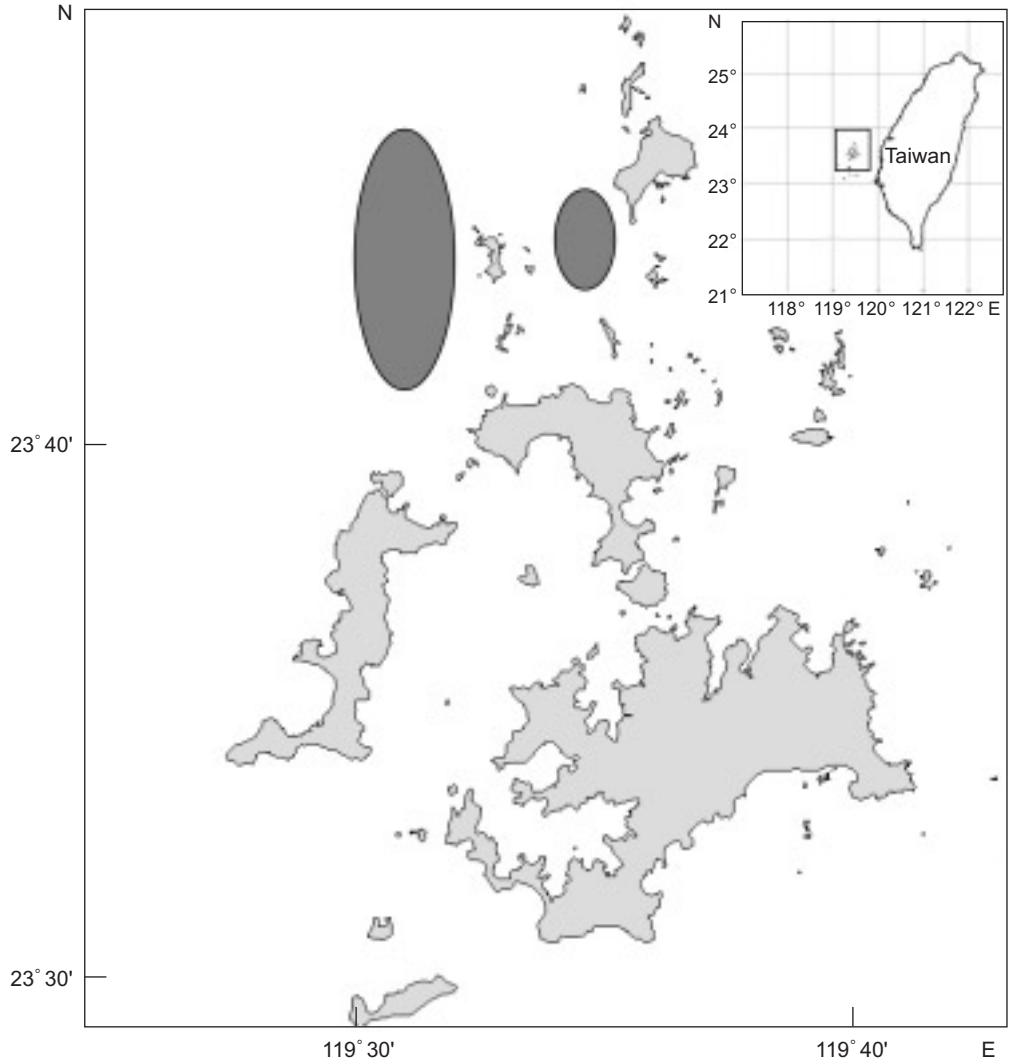

Fig. 1. Sampling area of *Spratelloides gracilis* in the waters of Penghu, central Taiwan Strait.

different development stages were examined to ensure the homogeneity of the oocyte diameter and the number of oocytes. Each ovary was divided into 6 portions (3 for each lobe), and 0.02 g was taken from each portion and placed on glass slides with a grid scale. All oocytes were measured and counted with a projector at the magnitude of 20x. A two-way analysis of variance (ANOVA) showed there to be no significant difference in the number of oocytes among portions for an individual ($p > 0.05$, $n = 30$), but a significant difference was found for the same portion among individuals ($p < 0.05$). Similar patterns of the frequency distribution of oocyte diameter for the same portion among individuals further suggested that the 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, 62 ovaries were then used to estimate the fecundity. Each ovary was placed in a Petri dish with 90% alcohol and was homogeneously distributed by stirring with an ultrasonic processor. One quarter of the oocytes, greater than 0.1 mm in diameter, were counted and measured.

The histological procedures used in this study followed Humason (1979) and Wang and Chen (1989). Ovaries were sectioned at 4-8 μm in thickness for further analysis. The gonadosomatic index (GSI), condition factor (CF), and hepatosomatic index (HSI) were calculated as follows: GSI = (gonad weight x 10^2)/(body weight - vesicular weight); CF = (BW x 10^3)/$(FL)^3$; and HSI = (liver weight x 10^2)/(body weight - vesicular weight). The sex ratio was expressed as (the number of females)/(the number of both sexes combined). Fecundity (F) was estimated from the following equation: F = (number of oocytes greater than 0.1 mm in diameter for 1/4 of the ovary) x 4. Batch fecundity (BF) was estimated by BF = (the number of oocytes greater than the diameter of mature oocytes for 1/4 of the ovary) x 4. The logistic model, $P = 1/(1 + e^{-(a+bFL)})$, was used to describe the relationship between the proportion of mature fish (P) in each length interval and fork length based on 500 specimens for females. The size at maturity was then obtained by substituting P = 0.5 in the above equation. To estimate the age of maturity and age for the maximum specimen, otoliths of 10 fish were taken, cleaned, and coated with gold. Then, the age of each blue sprat was determined based on the otolith ring count using scanning electron micrography at a magnification of 700-1000x. We assumed that rings are formed daily.

Environmental data of the fishing grounds were collected directly on the fishing grounds (119°32'-119°34'E, 23°40'-23°44'N) and on a monthly basis from Mar. 2001 to Feb. 2003 and were supplemented by satellite images for the winter season when fieldwork was not possible.

RESULTS

Weight-length relation

The length and weight frequency distributions indicated that most specimens were in the range of 50-80 mm FL with a body weight between 1.0 and 4.5 g for both sexes (Fig. 2). The relationships between body weight and fork length were estimated to be:

$BW = 5.225 \times 10^{-6} \times FL^{3.120}$ ($n = 2042$, $p < 0.05$) for females, and

$BW = 6.487 \times 10^{-6} \times FL^{3.076}$ ($n = 2000$, $p < 0.05$) for males.

Since no significant difference between sexes was found for the weight-length relationship with the maximum likelihood ratio test ($p > 0.05$), the data were pooled, and the following equation was used to describe the BW-FL relation of blue sprat for both sexes combined (Fig. 2):

$BW = 6.06 \times 10^{-6} \times FL^{3.087}$ ($n = 4042$, $p < 0.05$).

Sex ratio

The sex ratio of all specimens was 0.45, which significantly differed from 0.5 ($p < 0.05$) (Table 1). It varied monthly, peaked in Feb. 2003 (0.62), and had the lowest value in Mar. 2001 (0.36). The X^2 test also indicated that the sex ratio significantly differed from 0.5 in Feb. and June to Sept. (Table 1).

Monthly changes in GSI, HSI, and CF

The GSI of females increased from 4.8 in Feb. to the 1st peak of 8.7 in Apr., decreased in June, increased again from July, and reached the 2nd peak of 9.5 in July (Fig. 3). A similar pattern was also found for males. The HSI of females had a similar pattern to the GSI (Fig. 3). The CF of females peaked in Feb. when the GSI and HIS were at their low values and decreased to a low level during the period of Apr. and Sept. when the GSI and HIS were high. The opposite trend sug-

gested that CF was closely related to spawning behavior (Fig. 3).

Oocyte development

Eight development stages of oocytes of the blue sprat were determined as follows, based on the histological examinations.

In stage I, or the chromatin-nucleolus stage, very small oocytes, indistinguishable to the naked eye, were generally spherical and about 0.02-0.08 mm in diameter. The large nuclei were surrounded by a thin layer of cytoplasm (Fig. 4A).

In stage II, or the peri-nucleolus stage, small

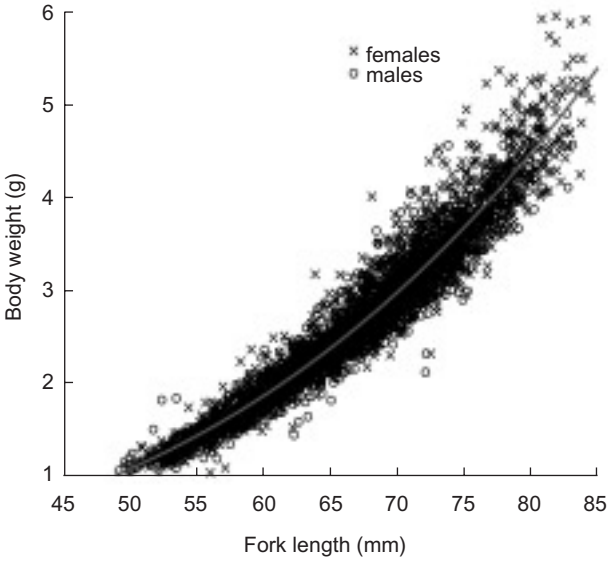

Fig. 2. Relationship between body weight and fork length of *Spratelloides gracilis*.

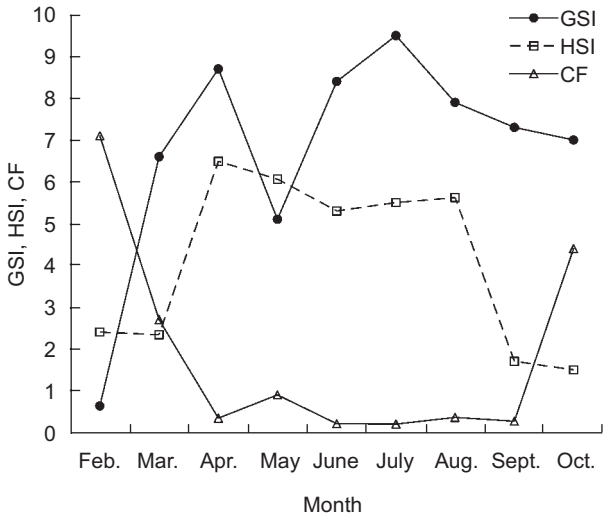

Fig. 3. Monthly variations in the gonadosomatic index (GSI), hepatosomatic index (HSI), and condition factor (CF) for females of *Spratelloides gracilis*.

Table 1. Specimens of *Spratelloides gracilis* collected during the period from Mar. 2001 to Feb. 2003

Date	Female	Male	Total	Sex ratio
Mar. 2001	93	164	257	0.36**
Apr.	185	212	397	0.47
May	107	87	194	0.55
June	152	243	395	0.38**
July	201	294	495	0.41**
Aug.	443	527	970	0.46**
Sept.	210	247	457	0.46*
Feb. 2002	29	49	78	0.37*
Mar.	184	196	380	0.48
Apr.	253	247	500	0.51
May	102	89	191	0.53
June	228	301	529	0.43**
July	222	275	497	0.45*
Aug.	163	223	386	0.42**
Sept.	156	231	387	0.40**
Oct.	44	54	98	0.45
Feb. 2003	34	21	55	0.62*
Sum	2806	3460	6266	0.45

*significant at 5% level; **significant at 1% level.

oocytes were about 0.08-0.20 mm in diameter and generally spherical, and they had a large nucleus (Fig. 4B).

In stage III, or the yolk vesicle stage, oocytes were generally spherical or elliptical and about 0.20-0.35 mm in diameter. Multiple nucleoli were located near the periphery of the nucleus. A small yolk vesicle occurred near the periphery of the cytoplasm but no yolk globule was found (Fig. 4C).

In stage IV, or the primary yolk stage, the nucleus was irregularly shaped, and nucleoli were distributed in the nucleus. Small yolk globules began to appear in the outer part of the cytoplasm. The yolk globules were densely stained by hematoxylin. Oocytes were 0.35-0.45 mm in diameter (Fig. 4D).

In stage V, or the secondary yolk stage, yolk globules and yolk vesicles rapidly increased in number and size. The nucleus was irregularly shaped, and nucleoli were distributed in the nucleus. Oocytes were 0.45-0.50 mm in diameter (Fig. 4E).

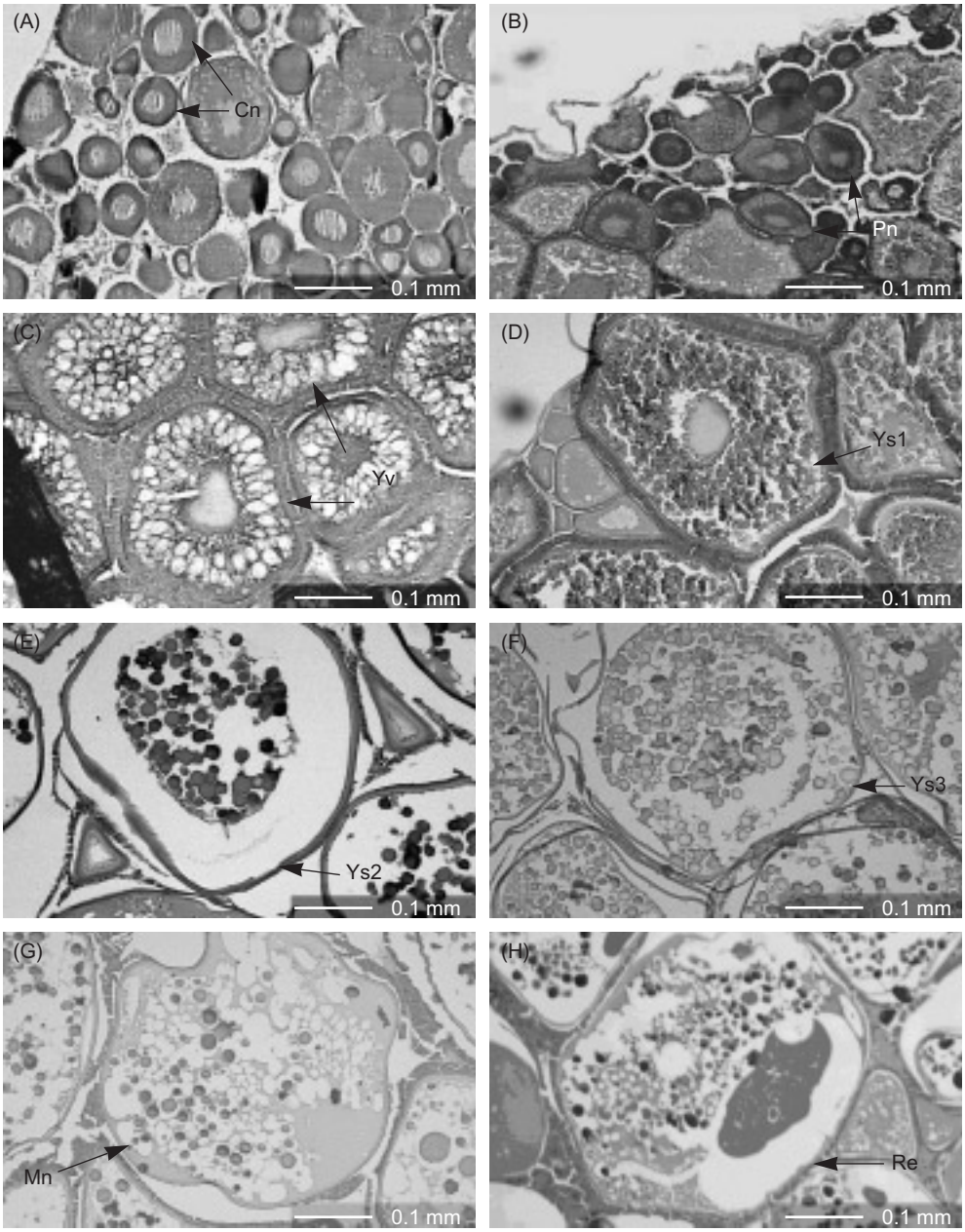

Fig. 4. Histological appearance of the ovaries of *Spratelloides gracilis*. (A) Chromatin-nucleolus (Cn); (B) peri-nucleolus (Pn); (C) yolk vesicle (Yv); (D) primary yolk (Ys1); (E) secondary yolk (Ys2); (F) tertiary yolk (Ys3); (G) migratory nucleus (Mn); (H) ripe egg (Re).

In stage VI, or the tertiary yolk stage, yolk globules increased in number and size, and fully filled the cytoplasm. Oocytes became larger, at 0.50-0.60 mm in diameter. The yolk globules began to coalesce into a yolk mass (Fig. 4F).

In stage VII, or the migratory nucleus stage, oocytes were 0.60-0.70 mm in diameter, and the yolk globules were the same size and as numerous as those in the previous stage. The yolk appeared as a homogeneous mass filling the interior of the oocytes (Fig. 4G).

In stage VIII, or the ripe stage, a single yolk mass existed, and yolk globules which had fused into larger ones were observed. Oocytes were ≥ 0.70 mm in diameter, and they were somewhat white and translucent (Fig. 4H).

Ovarian development

Based on histological examinations, oocyte development, oocyte diameter composition, maximum oocyte diameter, GSI, and macroscopic examinations, ovarian development could be divided into the following 4 stages.

In the immature stage, ovaries were small and slender, and no oocytes were visible to the

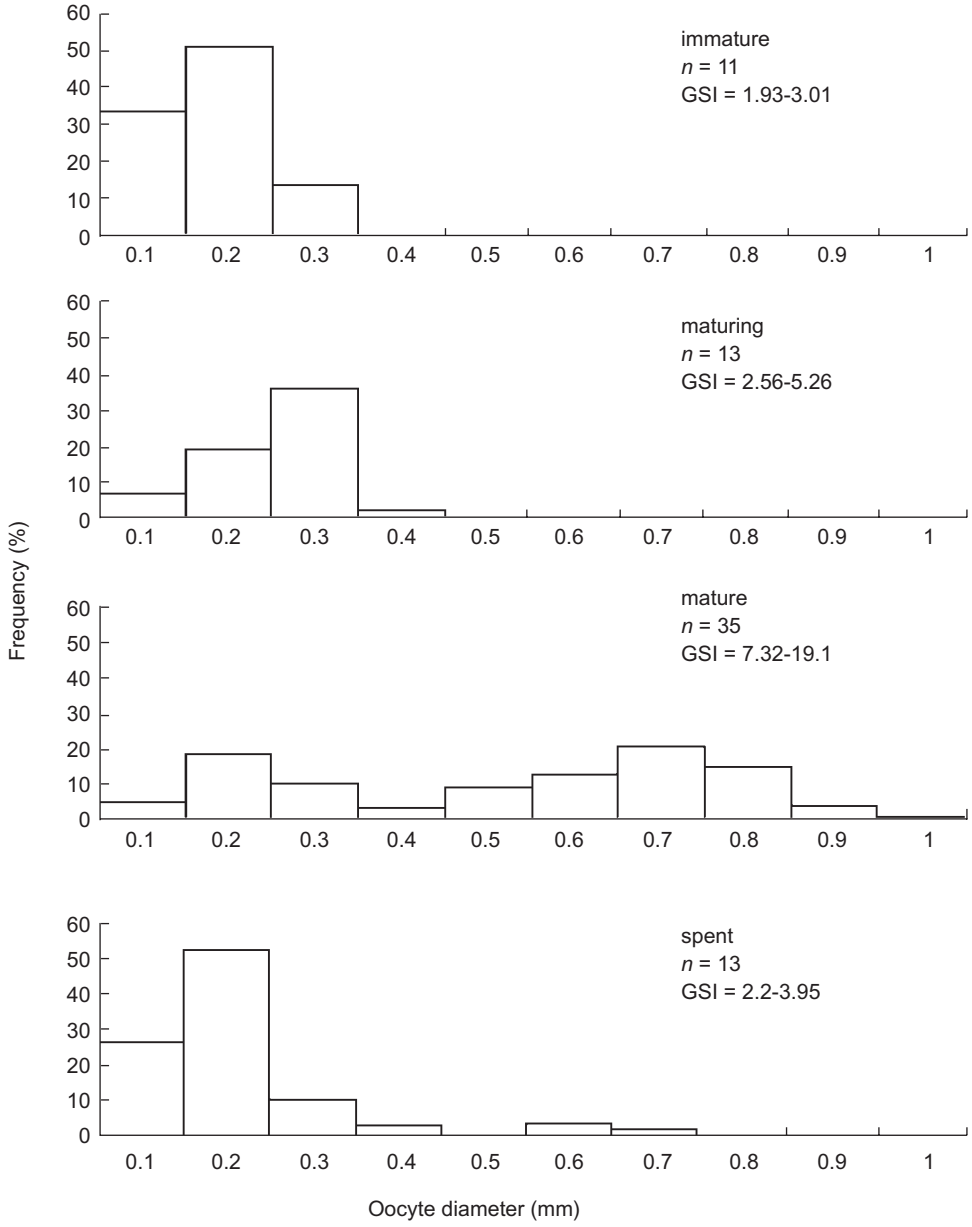

Fig. 5. Frequency distribution of mean oocyte diameter of the ovaries in different mature stages.

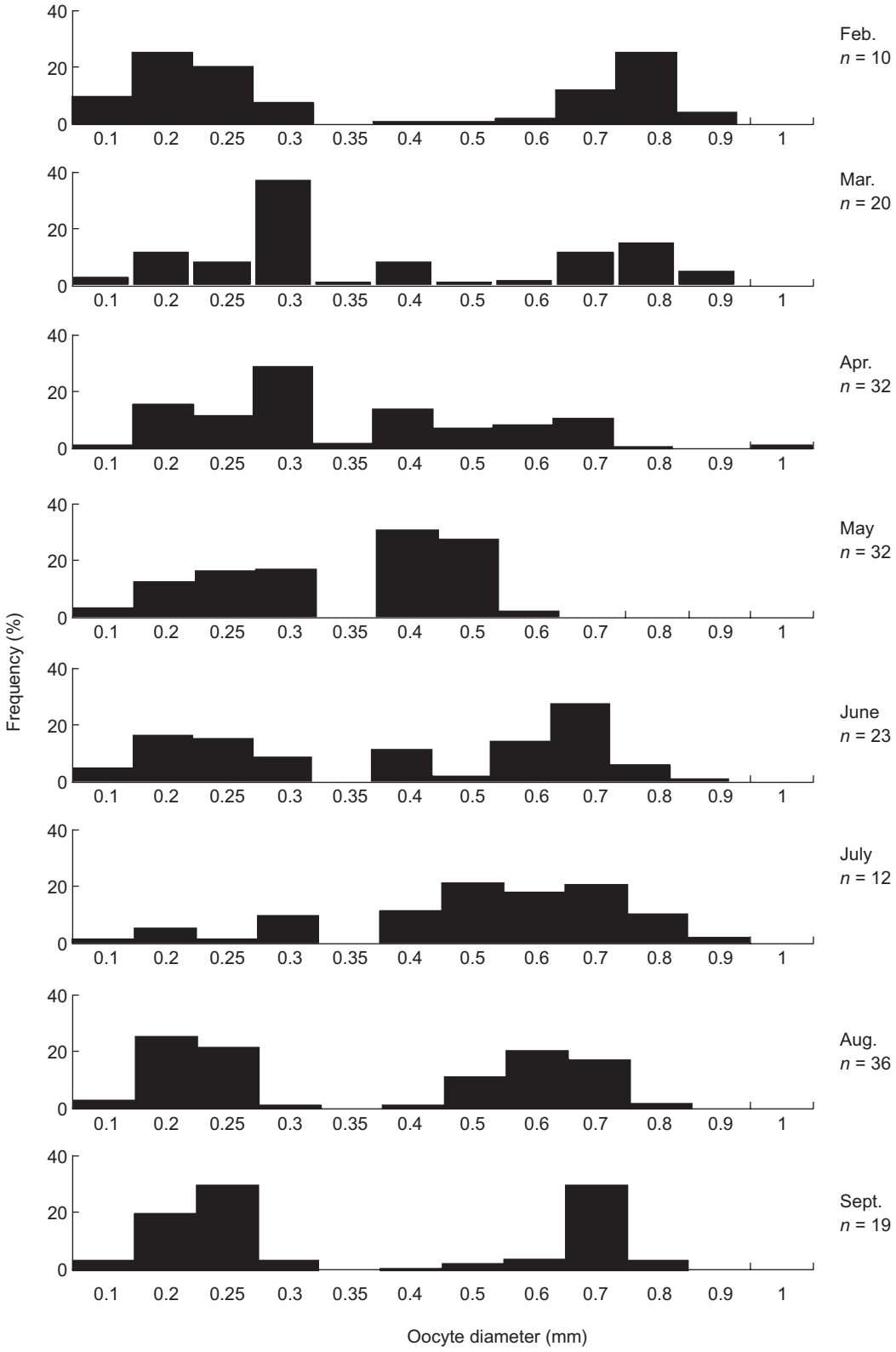

Fig. 6. Monthly changes in the frequency distribution of oocyte diameter.

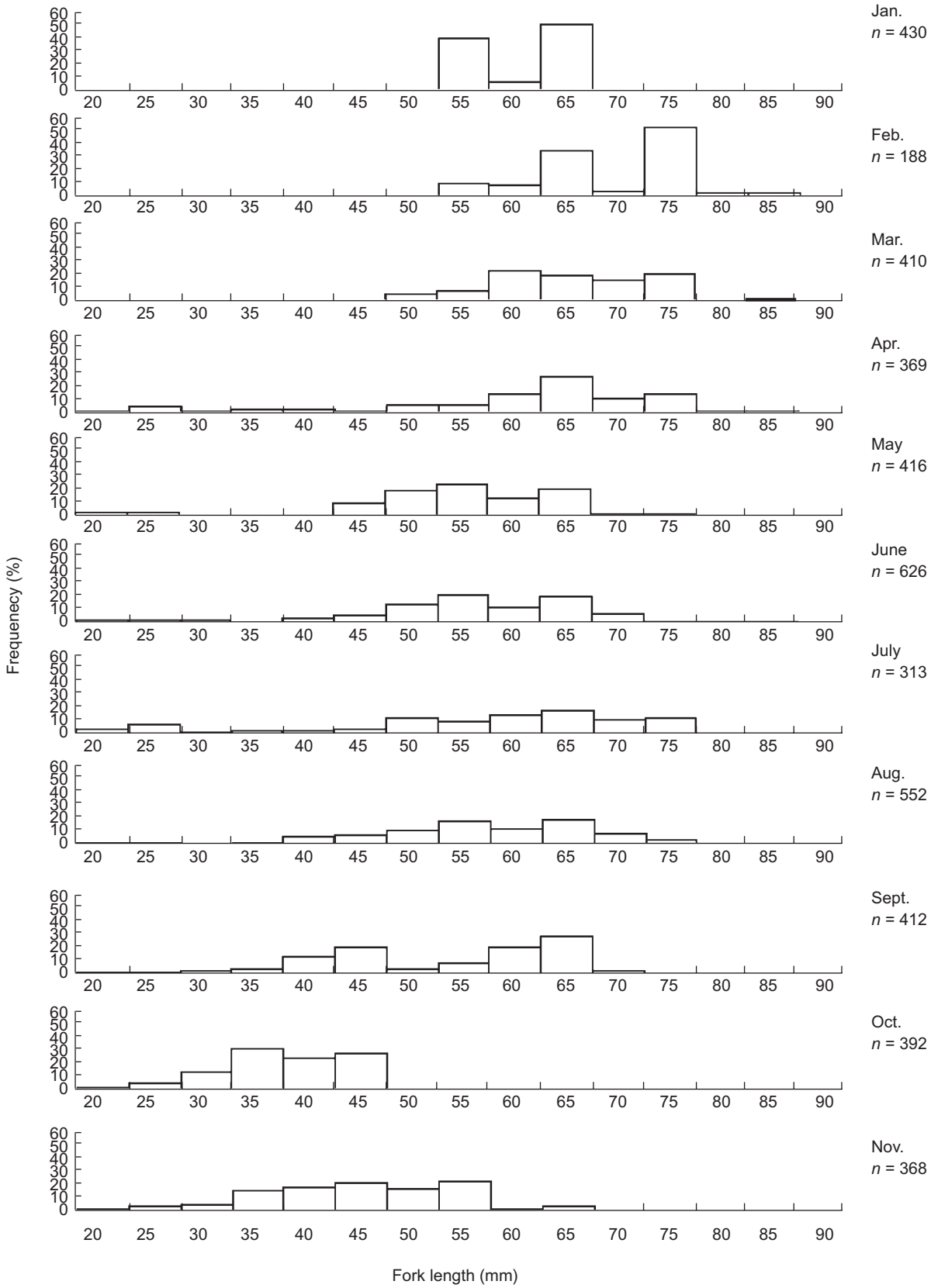

Fig. 7. Monthly changes in the frequency distribution of fork length.

naked eye. Oocyte diameter was < 0.2 mm, and a single mode was found for the ovum diameter frequency distribution. This stage corresponded to the time before the yolk stage in the histological examination. Undeveloped oocytes were randomly distributed, and oogonia were rarely found.

In the maturing stage, ovaries became larger and yellowish; the mean oocyte diameter was < 0.4 mm, and this stage corresponded to the secondary yolk stage or earlier in the histological examination. A single mode was also found in the oocyte diameter frequency distribution.

In the mature stage, ovaries were very swollen and yellowish, and the eggs were translucent. Vascularization was heavy in the back of the ovaries, and the diameter of the oocytes had significantly increased. Most oocyte diameters were 0.6-0.9 mm, corresponding to the migratory to ripe stages in the histological examination. There were 2 modes in the frequency distribution of oocyte diameter, a smaller one at 0.2 mm and a distinct one at 0.7 mm (Fig. 5).

In the spent stage, ovaries were small and flaccid. Several unshed large oocytes, at > 0.6 mm in diameter, were found near the cloaca. These oocytes will normally be reabsorbed. The GSI was 2.2-3.95.

Spawning season

The macroscopic appearance of the gonads indicated that they could readily be observed between Feb. and Sept. but were absent from Oct. to Jan. The histological examination showed that mature oocytes were present from Feb. to Sept. The oocyte diameter measurements showed that 2 modes of oocyte diameter were present between Feb. and Sept. (Fig. 6). Monthly changes in the frequency distribution of FL indicated that new recruits appeared in Apr. (Fig. 7). The GSI showed peaks in Apr. and July. These 4 methods showed that the blue sprat in the waters around Penghu spawned between Feb. and Sept. with peaks in Apr. and July.

Size at 1st maturity

The logistic curve describing the relationship between the proportion of mature fish (P) at each length interval and fork length was estimated to be $P = 1/(1 + e^{5.222-0.964FL})$ ($r^2 = 0.99$, $n = 2799$) for females. The size at 1st maturity was estimated to be 54 mm for females by substituting 0.5 into the left-hand side of the equation. This age was estimated to be 120 d based on the length versus the presumed daily rings of otoliths.

Fecundity and batch fecundity

In total, 62 ovaries with distinct oocyte size-frequency modes were used to estimate the fecundity. The fecundity was estimated to range from 514 to 7336 eggs with a mean (±SE) of 2060±1678 and increased with fork length and body weight as follows:

$F = 0.0002\ FL^{3.841}$ ($r^2 = 0.58$, $n = 62$, $p < 0.05$), and

$F = -583.4 + 1031.7\ BW$ ($r^2 = 0.63$, $n = 62$, $p < 0.05$).

Batch fecundity was estimated based on 60 ovaries of gravid females in the spawning season. The number of oocytes with a diameter exceeding 0.6 mm was defined as the batch fecundity (Fig. 8). The mean batch fecundity (± SE) was estimated to be 1204 ± 714 eggs. Batch fecundity also increased with fork length and body weight as follows:

$BF = 0.001 \times FL^{3.806}$ ($r^2 = 0.82$, $n = 60$, $p < 0.05$), and

$BF = 47.30 + 398.89\ BW$ ($r^2 = 0.43$, $n = 60$, $p < 0.05$).

The sea surface temperature (SST) around Penghu ranged from a low of 22.0°C in Jan. (Fig. 9) to a peak of 26.5°C in Aug. Figure 9 shows the seasonal trend in SST with temperatures remaining around or above 25°C between May and Oct. The onset of the spawning season of the blue sprat was in Feb. when the SST begins to rise and ended in Sept. when the SST begins to drop.

DISCUSSION

In this study, the spawning season determined by the methods of the macroscopic appearance of the ovaries, the gonadosomatic index, the oocyte diameter frequency distribution, and histological examinations showed good agreement, which suggests that our estimate of the spawning season (Feb. to Sept.) is reasonable. Larvae of 20 mm TL were found in Apr., and a large quantity of larvae occurred in May which we thought had likely hatched in Mar. and Apr., further supporting our estimation of the onset of the spawning season.

The spawning season of the blue sprat began in Feb., corresponding to the time when water temperatures begin to increase and ended in Sept. when water temperatures begin to decrease (Fig.

9). This indicates that the development of the ovaries in the blue sprat is closely related to changes in water temperature. Dalzell and Wankowski (1980) showed that the spawning peaks of 2 anchovies, *Stolephorus heterolobus* and *Sto. devisi*, coincided with changes in the monsoon. However, there was no correlation between the amount of rainfall and the intensity of spawning of *S. gracilis* in this study. A similar finding for *S. gracilis* in Papua New Guinea was also given by Dalzell (1985), who found no correlation between spawning intensity and environmental stimuli such as temperature or salinity.

In Feb., the specimens were dominated by large adults (70-80 mm FL), and the gonads were indistinct for specimens of < 70 mm FL. The small adults (50-60 mm FL) found in Apr. were suspected of being new recruits (Fig. 7). A similar result was reported for the Japanese anchovy, *Engraulis japonicus*, by Takeshita and Tsukahara (1971), who concluded that the peak of the spawning season of *E. japonicus* is due to the recruitment of small adults. The new recruits in this study were estimated to be about 120 d old, which if true would mean they would have hatched in Dec. However, all of the gonads of specimens collected in Nov. or Dec. were indistinct. Hence, we suspect that these new recruits might have immigrated from other waters. However, further analyses of stock identification with molecular techniques are required to test this hypothesis.

Fish may store the energy required for spawning in the liver or viscera. In the present study, an opposite trend between the GSI and CF (Fig. 3) suggests that the required energy for spawning by the blue sprat might be derived from their fat reserves.

Two distinct modes of oocyte diameter distribution for mature fish (Fig. 8) indicate that the blue sprat in Penghu waters may undergo multiple spawnings per season. However, the secondary ovarian mode was not synchronously developed with the mode of maturing oocytes. Leary et al. (1975) and Struhsaker and Uchiyama (1976) suggested that *Stolphorus purpureus* spawns only once due to its short life span (< 180 d) and high mortality. However, Dalzell (1985) found no conclusive evidence on the number of times that an individual of *S. gracilis* can spawn in its life span. A similar situation was found in this study. Thus, even though we suspect that this species can only spawn once in its life span, we have no solid evidence to support this point.

Species with multiple spawnings per year have longer spawning seasons. For example, the spawning seasons of *Stolephorus zollingeri* and *Sto. heterolobus* extend for 6 mo (Chen 1984 1986), and of *E. japonicus* for 11 mo (Okada and Wada 2000). The blue sprat has a similar life history with those species and a long spawning season, but multiple spawning behavior was not found in this study.

In addition to the larvae (20 mm), we found ovary samples containing hydrated or running ripe oocytes. This suggests that Penghu waters comprise the spawning ground for the blue sprat. The fecundity for the blue sprat at Penghu ranged from 514 to 7336 eggs, which was similar to the estimate by Dalzell (1985) on the same species in Papua New Guinea waters of 594-5973 eggs. The fecundity of the blue sprat increased with length in both Papua New Guinea and Penghu waters, but the fecundity for the same size fish slightly differed between the 2 areas.

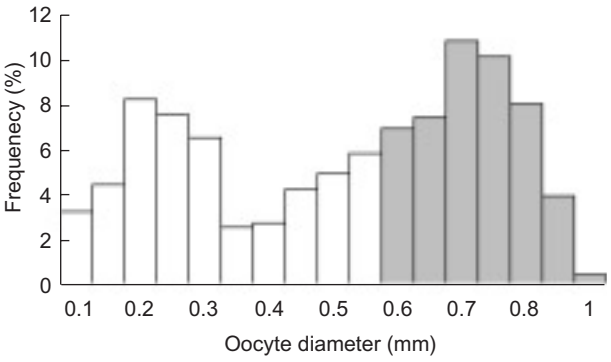

Fig. 8. Frequency distribution of oocyte diameter of mature ovaries of *Spratelloides gracilis*.

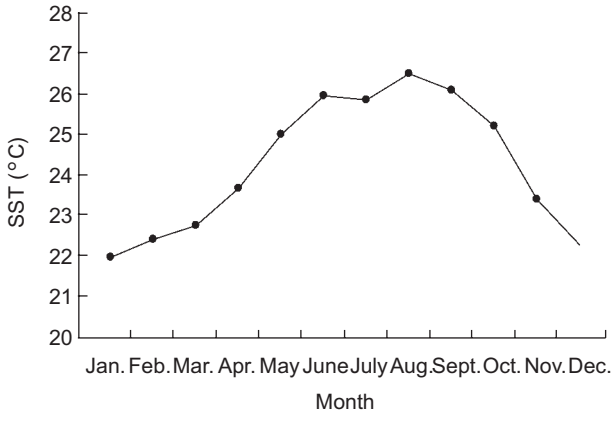

Fig. 9. Monthly changes in the mean sea surface temperature (SST) in Penghu waters.

In the present study, we estimated the size at maturity to be 54 mm for female blue sprat which is larger than that in Papua New Guinea at 45 mm (Dalzell 1985) and that in the Solomon Is. of 35 mm (Milton and Blabar 1991). Tormosova (1983) suggested that stock density, food, and water temperature may influence the growth of fish and further affect the age at 1st maturity. The optimal water temperature for the spawning of blue sprat is 22.5-27.3°C in Penghu waters but is 28-30.5°C in Papua New Guinea. Since the size at maturity is inversely related to the water temperature of the habitat, we believe that water temperature should be an important factor affecting the size at maturity for the blue sprat. Dalzell (1985) and Maliton and Blaber (1991) reported the smallest sizes that mature females were observed as the size at 1st maturity, which might have resulted in smaller sizes at maturity.

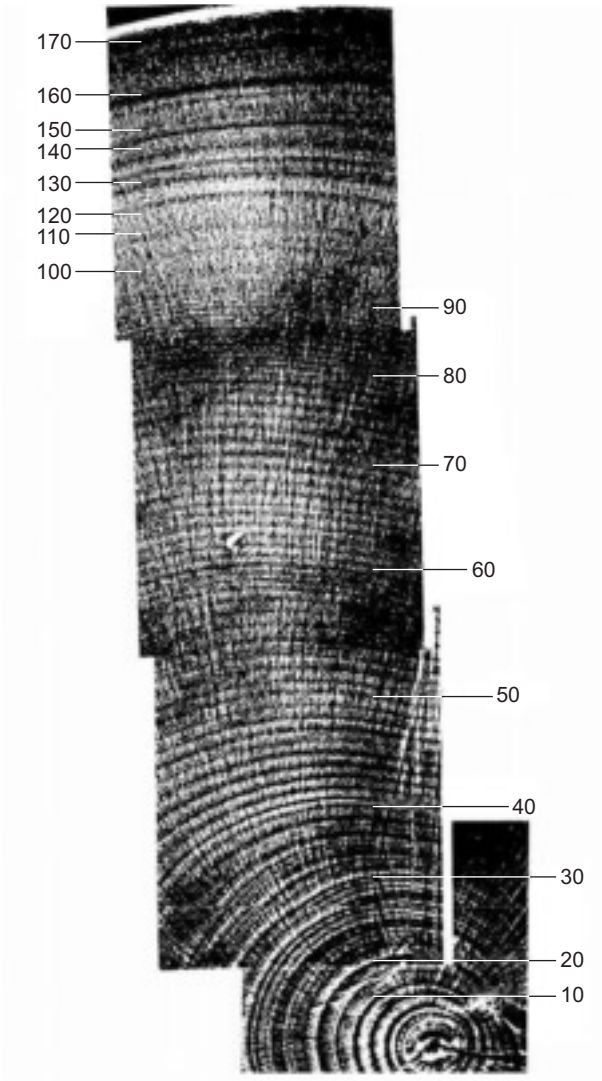

Fig. 10. Scanning electron micrograph of a sagittal otolith showing daily increments. The numbers denote the number of rings. This otolith is from a female specimen of 66 mm FL collected on 23 Mar. 2001.

Dalzell and Wankowski (1980) documented that the maximum size of this species in Papua New Guinea is 68 mm and the life span is 180 d. In the present study, we estimated the ages to be 170-180 d for specimens of 66-71 mm based on otolith ring counts by scanning electron micrography (Fig. 10). This result indicates that the growth rate of the blue sprat in Penghu waters is similar to that in Papua New Guinea waters. However, the longevity of the blue sprat was estimated to be at least 210 d in this study as maximum size of specimens of 86.7 mm, and the age of an 81 mm individual was estimated to be 200 d based on the otolith ring count. Abe (1995) and Yamamoto (1997) suggested that the blue sprat in Japanese waters does not exceed 110 mm, and its life span is 1-2 y. The difference in longevity among the above 3 waters might be related to the habitat. Usually, fish grow faster and have shorter longevities in warmer environments, while they grow more slowly and have longer longevities in cooler waters.

In the present study, no validation was carried out on the otolith ring counts. However, Milton et al. (1991) found that otolith rings form daily in the blue sprat, and the daily increment of body length is 0.97-1.19 mm/d for the first 30 d after hatching, decreasing to 0.19-0.037 mm/d after 90 d. Their findings support our assumption of using daily rings for age determination.

The spawning season of the blue sprat in Penghu waters extends from Feb. to Nov. and peaks in Mar. to Apr. and July to Aug. However, fishing is closed in May under the current management scheme. This management measure does not account for the reproductive behavior of this species and cannot reduce the fishing pressure on spawners. As the blue sprat is a short-lived species, we recommend protecting the adults during the major spawning season. We believe that fishing closure in Mar.-Apr. and July-Aug. can provide better breeding opportunities for adults and is a better management strategy for this species.

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