

Reproductive biology of two sillaginid fishes, *Sillago sihama* and *S. aeolus*, in tropical coastal waters of Thailand

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Abstract: Reproduction in two co-occurring sillaginid fishes, *Sillago sihama* and *Sillago aeolus*, was investigated on the basis of 1,140 and 836 specimens, respectively, collected from Sikao Bay, Trang Province, Thailand, between May 2003 and April 2004. Histological examinations of gonads showed that the smallest mature females and males in *S. sihama* were 117 and 106 mm in standard length (SL), respectively, and 113 and 109 mm SL, respectively, in *S. aeolus*. The body size at which 50% of individuals attained maturity was estimated to be 130 mm SL for both sexes in both species. The lowest spawnable gonadosomatic indices for female and male *S. sihama* were 0.53 and 0.04, respectively, and 0.47 and 0.03, respectively, in *S. aeolus*. Spawning occurred continuously throughout the year in both species, with peaks in activity between August and November (*S. sihama*) and July and December (*S. aeolus*). Oocytes at various developmental stages, together with post-ovulatory follicles, were found in the mature ovaries of both species during their spawning periods, suggesting that they are multiple spawners.

Keywords: reproduction, *Sillago sihama*, *Sillago aeolus*, Thailand

1. Introduction

Sillaginidae has traditionally been an important fish family as a food resource in many Indo-West Pacific countries. Three genera (*Sillago*, *Sillaginodes*, and *Sillaginopsis*) are currently recognized, including thirty-one species. *Sillago sihama* and *Sillago aeolus*, widely distributed throughout tropical and subtropical waters in the west-central Pacific and Indian oceans (MCKAY, 1999), inhabit sandy and/or muddy substrates in inshore areas (SATAPOOMIN, 2005), feeding mainly on benthic invertebrates, including polychaetes, shrimps, and crabs (TONGNUNUI *et al.*, 2005).

In Thailand, these two species are the most abundant and commercially important sillaginids, although three other congeneric species are distributed around the coast (SIRIMONTAPORN and CHOONHAPRAN, 1995). In Sikao Bay, Trang Province, *S. sihama* and *S. aeolus* are both common, coexisting in shallow sandy areas where they are gill-netted year-round by local fishermen.

In spite of their abundance and popularity as food, there is a paucity of information on the reproduction of *S. sihama* and *S. aeolus*, the only previous study of the latter species having been conducted in the subtropical waters of Okinawa Island, southern Japan (RAHMAN and TACHIYAMA, 2005). Reproductive information on a commercially exploited species is crucial for an understanding of its population dynamics, such being fundamental for developing an effective management model.

The objective of the present study was to provide reproductive information on *S. sihama* and *S. aeolus* in Thailand, including the gonad

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development, spawning season, and size at maturity.

2. Materials and Methods

The study was carried out at Sikao Bay (7° 30' N, 99° 13' E) in Trang Province on the southwest coast of Thailand. The bay, approximately 40 km long with a mouth width of 30 km opening broadly to the Andaman Sea, has a relatively flat sandy substrate with several small rocky reefs along the coast. The maximum water depth was about 20 m.

Sikao Bay is subjected to relatively short dry (January to April) and long rainy (May to December) seasons, the latter being accompanied by strong winds associated with the southwest monsoon, and the former by light winds from the northeast monsoon. Water in the sampling area had an essentially marine salinity. Water temperatures (taken at Rajamangala Beach) ranged from 27.0 to 30.9°C (annual average 29.4°C), but no seasonal trends were apparent. Environmental deterioration resulting from human activities little occurred in and adjacent to the bay.

A total of 1,140 (66–224 mm in standard length, SL) and 836 (60–200 mm SL) specimens of *Sillago sihama* and *S. aeolus*, respectively, were sampled monthly from gill net fishery landings operated within Sikao Bay between May 2003 and April 2004. Gill nets (500 m wide, 1 m deep, and 25 mm × 25 mm square mesh) were set primarily on the sandy bottom in the central area of the bay (water depth about 15 m) between 05:00 and 07:00 hours, and retrieved between 09:00 and 10:00 hours. Both species were collected during the same gill net operation.

In the laboratory, SL and body weight (BW) were measured for each specimen (to the nearest 1 mm and 0.1 g, respectively) within four hours of collection. The gonads were removed, sexed macroscopically, weighed to the nearest 0.01 g, and preserved in 10% buffered formalin. The gonadosomatic index (GSI) was calculated for each fish as follows: $GSI = \text{gonad weight} \times 100 / BW$.

For histological examinations, middle portions of the right gonad were dehydrated in ethanol and embedded in paraffin wax. The

embedded gonads were serially sectioned at 6- μm thickness and stained with Mayer's hematoxylin and eosin. Developmental stages of oocytes were categorized according to WALLACE and SELMAN (1981) and MUNEHARA *et al.* (1987). The ovarian stage was defined by the developmental stage of the most advanced oocytes within an ovary. The stage of testicular development, on the other hand, was determined by the percentage of the area (> 50%) of a particular spermatogenic cell type relative to the total area of all spermatogenic cells in the entire section (RAHMAN and TACHIHARA, 2005). The terminology of spermatogenic cells mainly followed that used by GRIER (1981).

To clarify size at maturity, the stage of gonad development was recorded for each specimen. Length at first maturity was estimated by plotting GSI values with different gonadal maturity stages against SL. The size at which 50% of individuals had reached maturity was obtained by examining the proportion of fish with gonads at different maturity stages in each 10-mm SL size class.

Specimens larger than the size at 50% maturity were used to examine seasonal changes in GSI and gonad maturation. The GSIs and proportions of the various gonad developmental stages of females and males were plotted monthly to determine the seasonality of spawning. In this analysis, the proportions of spent females were used to estimate spawning frequency.

3. Results

3.1 Gonad development

The histological observations revealed that gonad developmental patterns and maturity stages in each sex were essentially similar between *Sillago sihama* and *S. aeolus*. Accordingly, the maturity stages of both species are described as follows:

Ovaries were assigned into four maturity stages: 1) The immature stage was categorized by ovaries which contained oocytes at the early perinucleolus or late perinucleolus stage (Figs. 1A, 2A). 2) The maturing stage refers to juvenile fish about to begin maturing. Their ovaries possessed early perinucleolus, late perinucleolus, and sometimes yolk vesicle stage

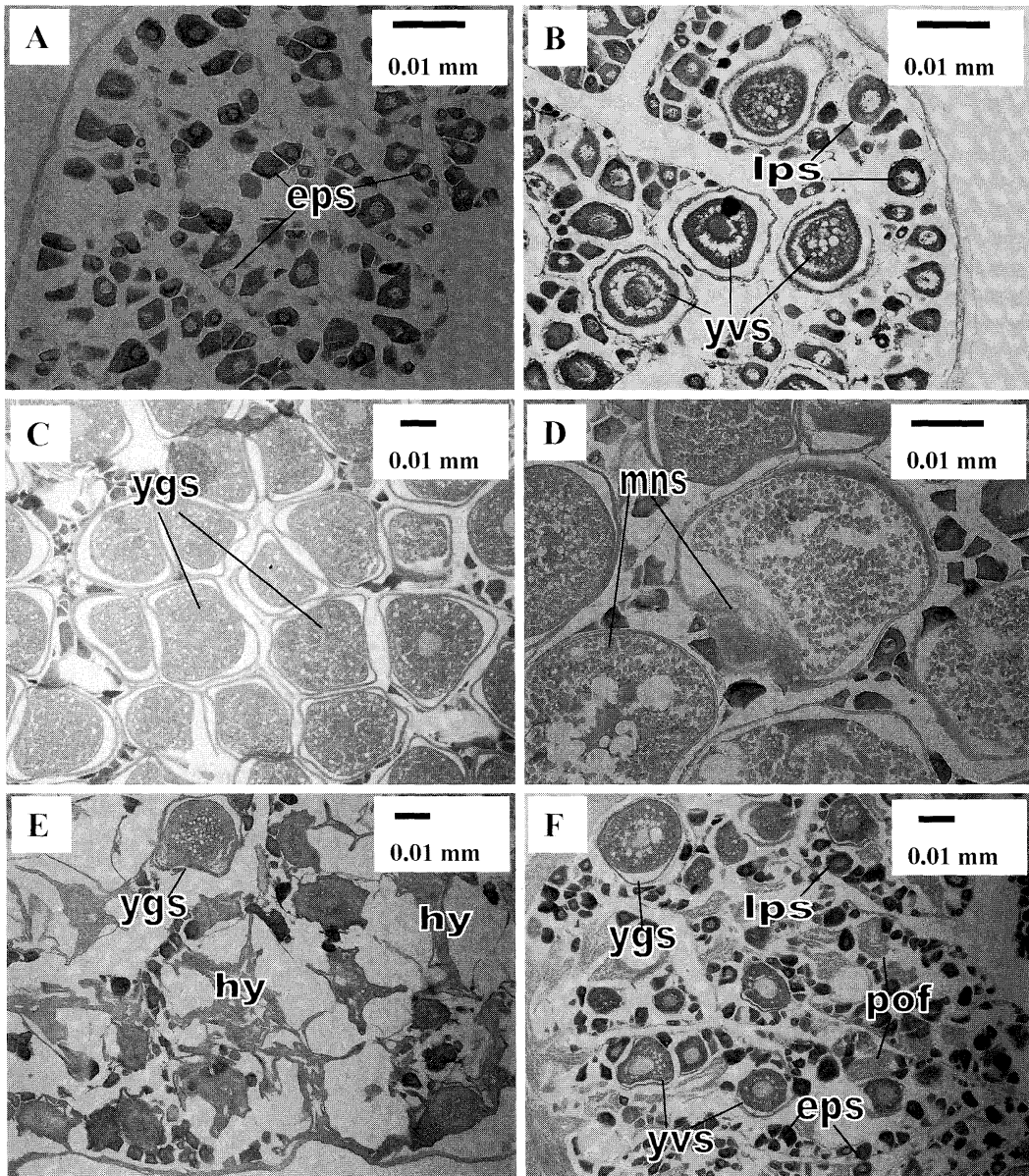


Fig. 1. Histological sections of ovaries in *Sillago sihama*. (A) Immature stage (114 mm SL). (B) Maturing stage (129 mm SL). (C) Mature active stage (156 mm SL). (D) Mature active stage (149 mm SL). (E) Mature active stage (143 mm SL). (F) Spent stage (154 mm SL). eps, early perinucleolus stage oocyte; lps, late perinucleolus stage oocyte; yvs, yolk vesicle stage oocyte; ygs, yolk globule stage oocyte; mns, migratory nucleus stage oocyte; hy, hydrated oocyte; pof, post-ovulatory follicle.

oocytes, but were dominated by late perinucleolus stage oocytes (Figs. 1B, 2B). 3) The mature active stage was defined by gonads with oocytes from the early perinucleolus to hydrated stages, but was dominated by yolk

globule, migratory nucleus, and hydrated stage oocytes (Figs. 1C-E, 2C-E). 4) The spent stage was characterized by ovaries in which all stages of oocytes, including migratory nucleus and hydrated stage oocytes, occurred along

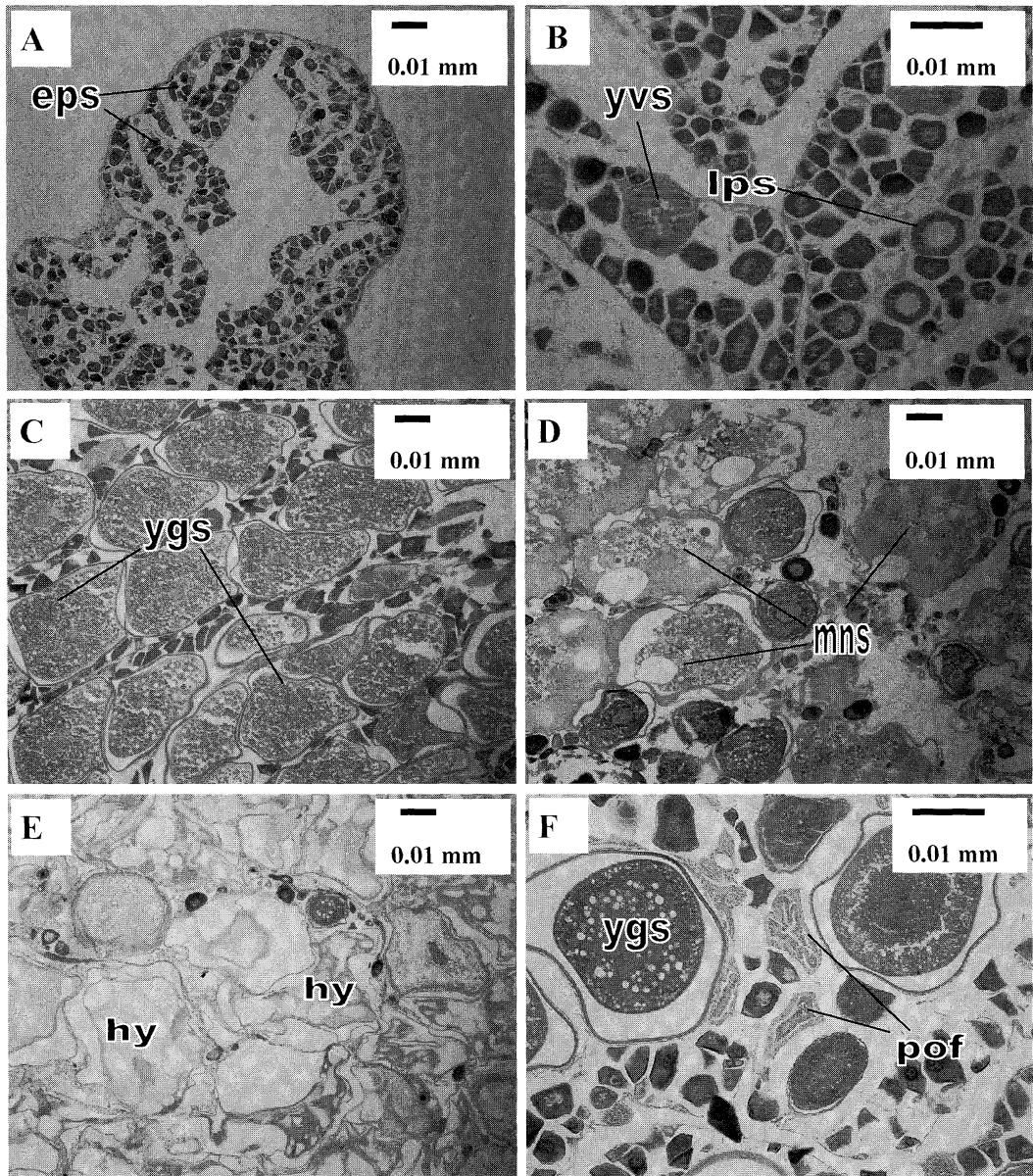


Fig. 2. Histological sections of ovaries in *Sillago aeolus*. (A) Immature stage (129 mm SL). (B) Maturing stage (130 mm SL). (C) Mature active stage (184 mm SL). (D) Mature active stage (140 mm SL). (E) Mature active stage (150 mm SL). (F) Spent stage (162 mm SL). Abbreviations as in Fig. 1.

with post-ovulatory follicles (Figs. 1F, 2F).

Testes were categorized into five maturity stages: 1) The immature stage was represented by testes with spermatogonia and primary spermatocytes (Figs. 3A, 4A). 2) The maturing stage was characterized by testes in which crypts containing secondary spermatocytes

predominated, but a few spermatogonia and primary spermatocytes were also found (Figs. 3B, 4B). 3) The mature stage was defined by testes in which primary and secondary spermatocytes were present, but spermatids were dominant in crypts. In addition, some crypts of spermatozoa coalesced into newly-

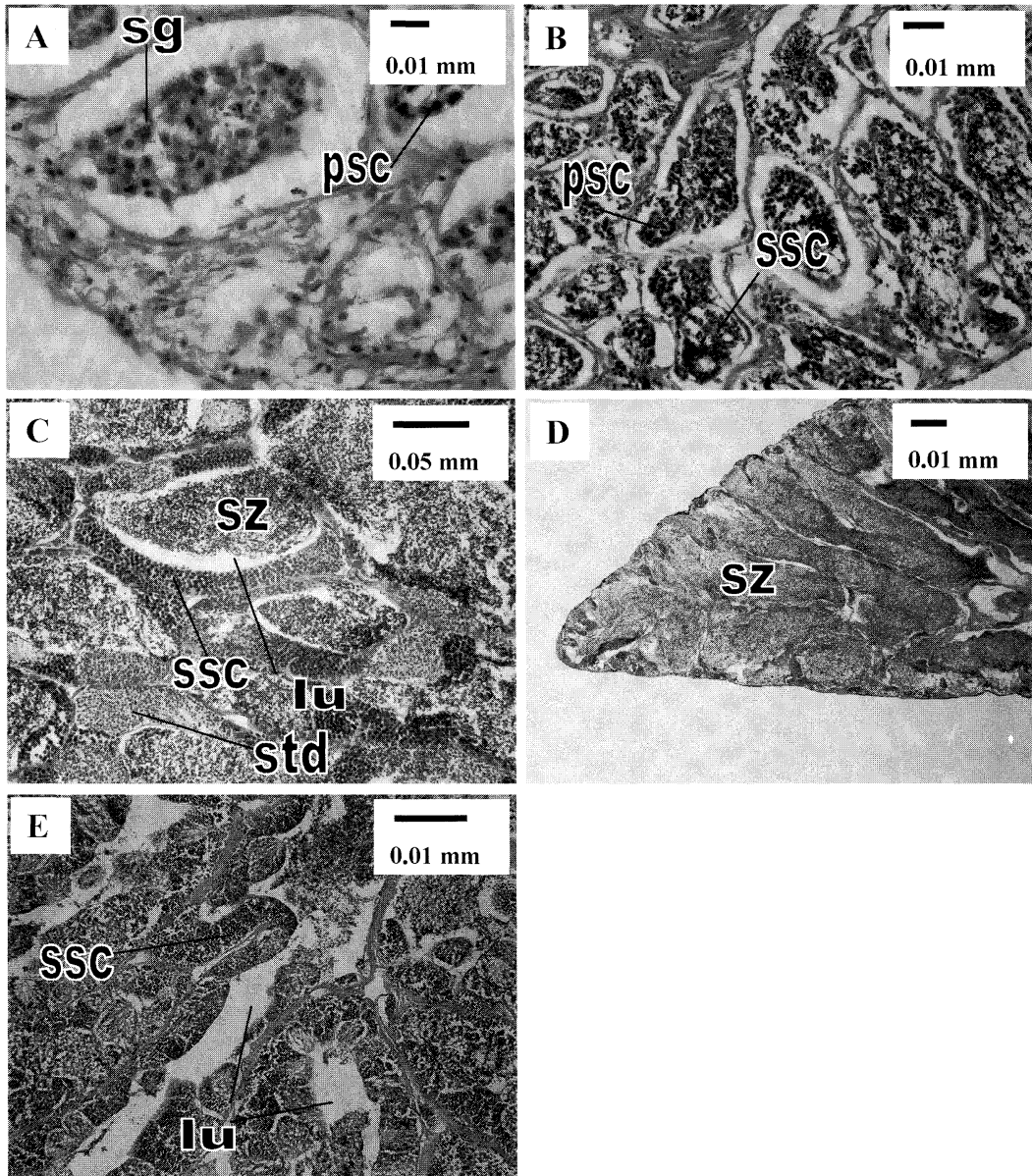


Fig. 3. Histological sections of testes in *Sillago sihama*. (A) Immature stage (119 mm SL). (B) Maturing stage (131 mm SL). (C) Mature stage (125 mm SL). (D) Ripe stage (151 mm SL). (E) Spent stage (152 mm SL). sg, spermatogonia; psc, primary spermatocyte; ssc, secondary spermatocyte; lu, lumen; sz, spermatozoa; std, spermatid.

formed sperm sinuses (Figs. 3C, 4C). 4) The ripe stage was characterized by testes dominated by spermatids and spermatozoa. Sperm sinuses were filled with spermatozoa (Figs. 3D, 4D). 5) The spent stage was categorized by testes possessing new crypts of spermatogonia

and primary spermatocytes. Moreover, testes also had empty crypts with residual spermatozoa (Figs. 3E, 4E).

Each ovary and testis could be allocated to one of the above four and five maturity stages, respectively, in both species. In this study,

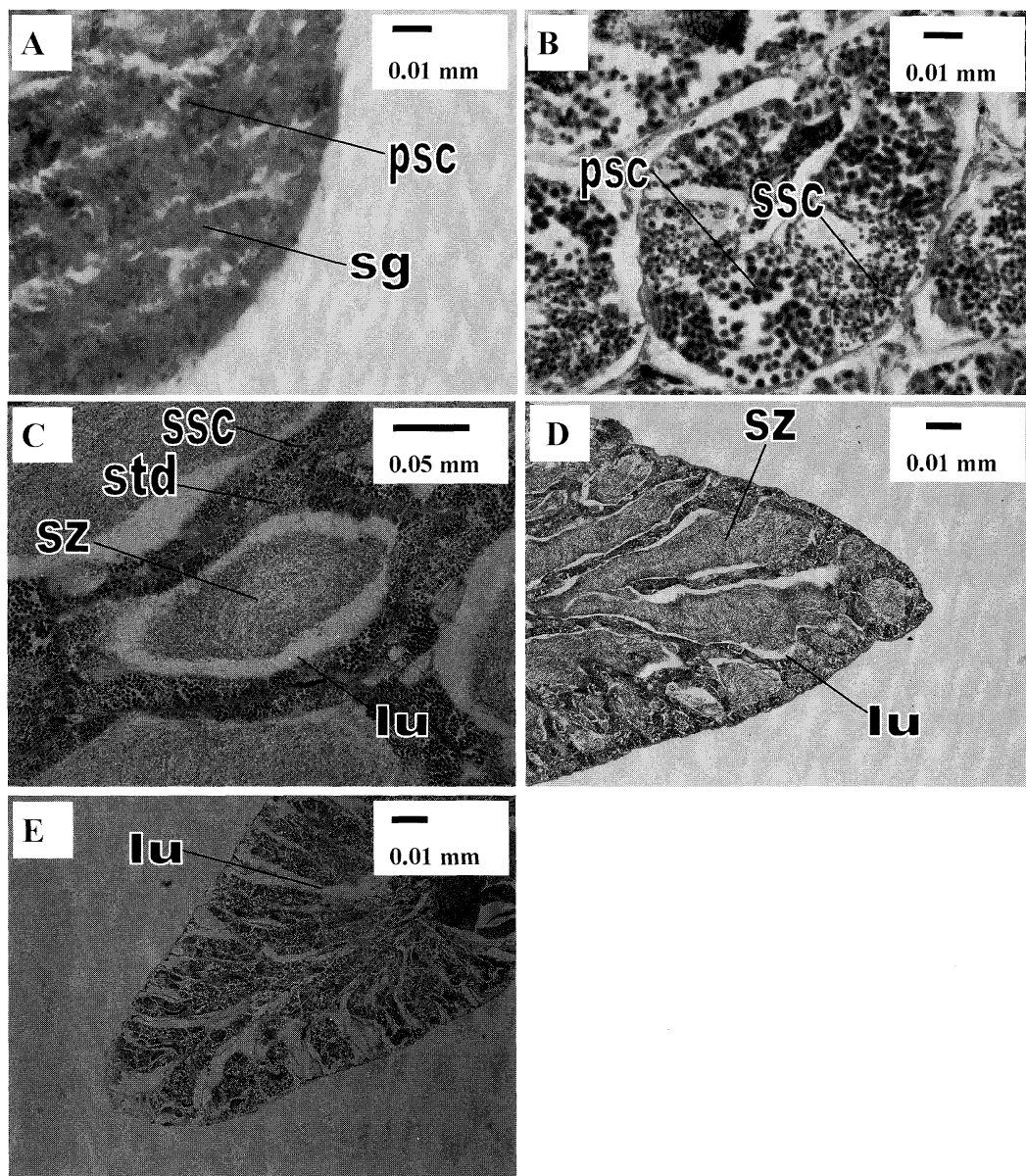


Fig. 4. Histological sections of testes in *Sillago aeolus*. (A) Immature stage (105 mm SL). (B) Maturing stage (119 mm SL). (C) Mature stage (145 mm SL). (D) Ripe stage (142 mm SL). (E) Spent stage (140 mm SL). Abbreviations as in Fig. 3.

sexually mature individuals were defined as females with ovaries at the mature active and spent stages, and males with testes at the mature, ripe, and spent stages.

3.2 Length at maturity

The relationship between SL and GSI at

different maturity stages showed that the proportions of mature females and males of the two species increased with size (Figs. 5, 6). In *S. sihama*, the smallest mature female was 117 mm SL with a GSI value of 0.80 and the largest immature female, 175 mm SL with a GSI value of 0.62. The GSI values for mature females

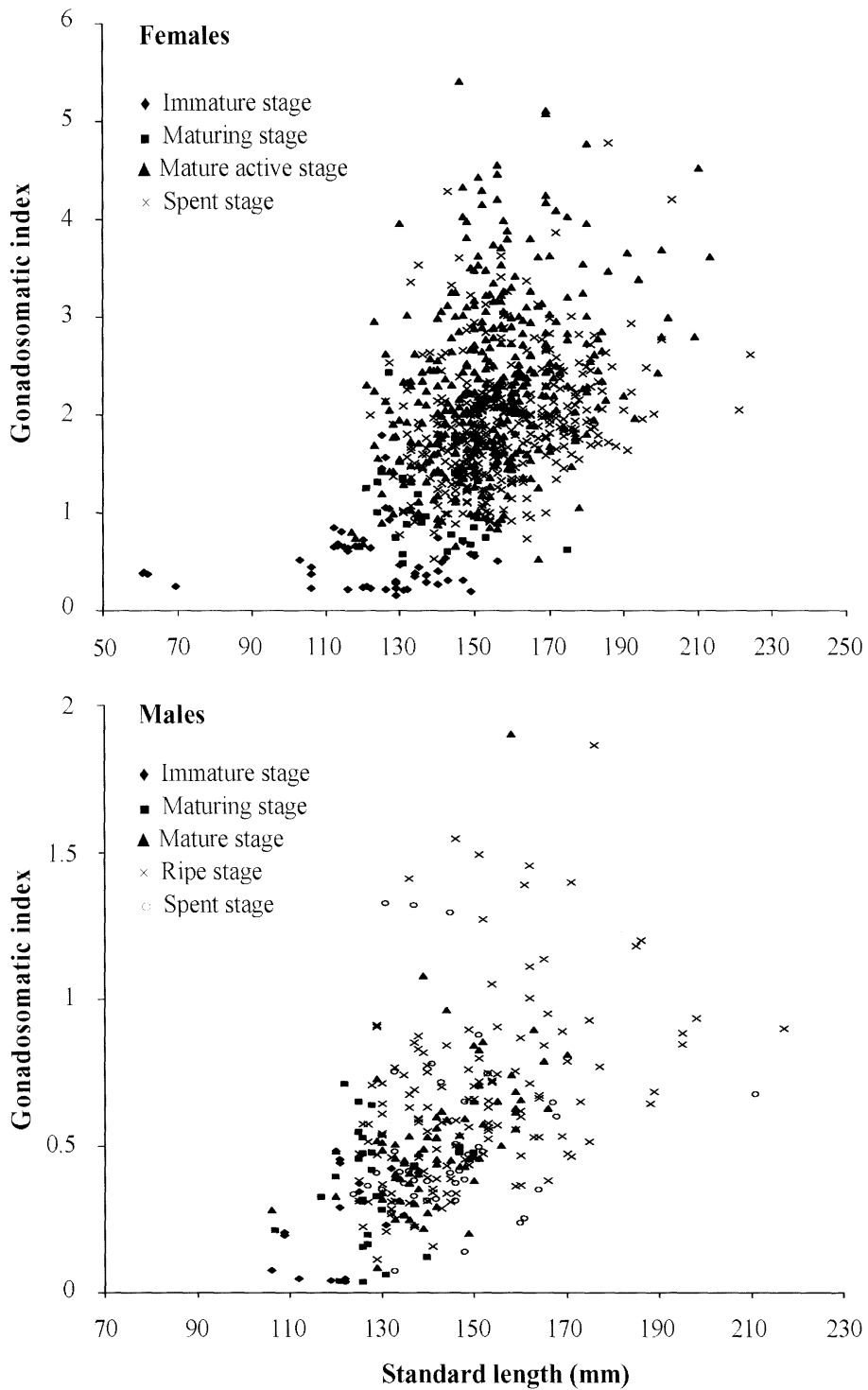


Fig. 5. Relationships among standard length, gonadosomatic index, and gonadal maturity stages for female and male *Sillago sihama* collected at Sikao Bay from May 2003 to April 2004.

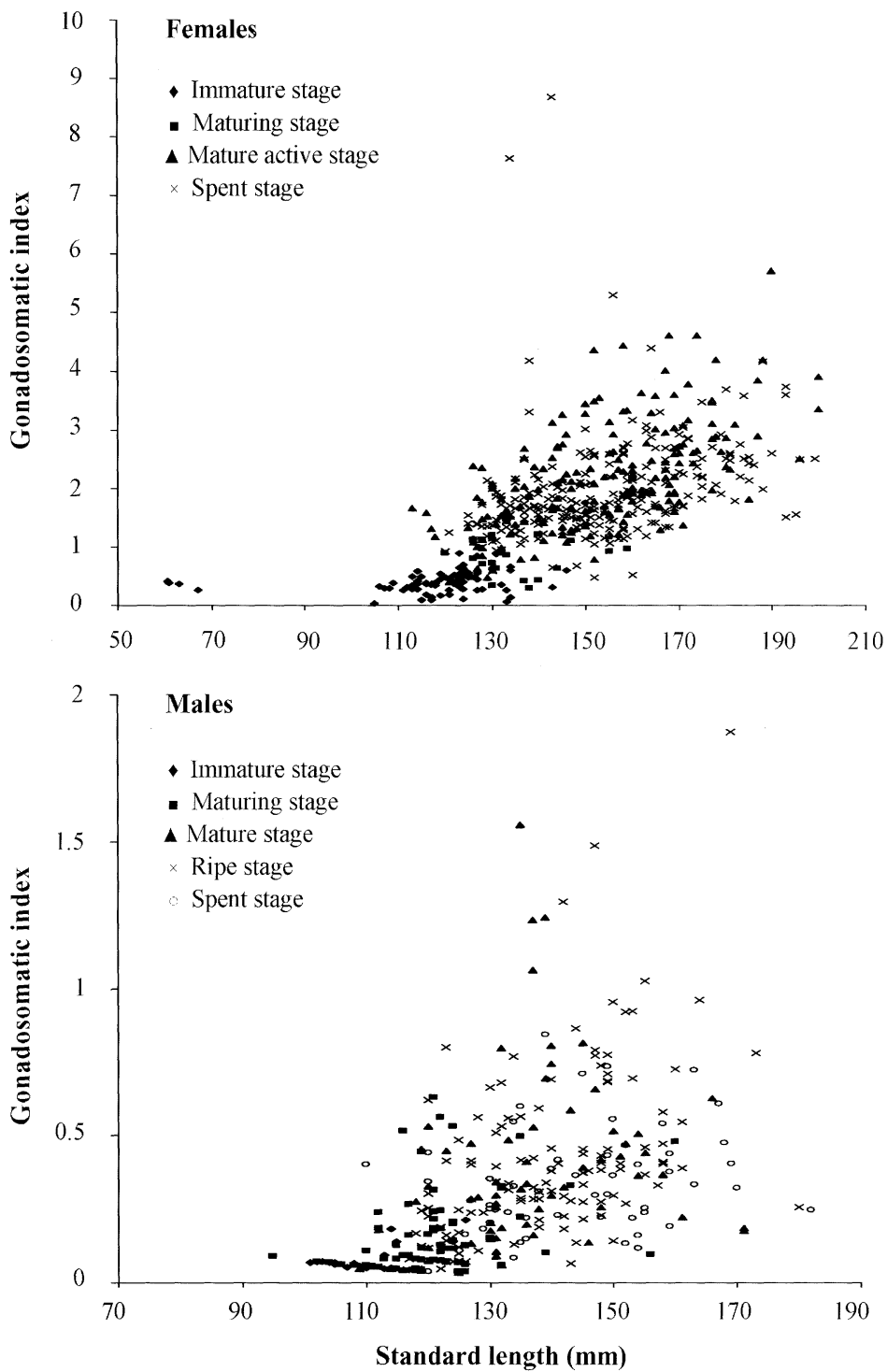


Fig. 6. Relationships among standard length, gonadosomatic index, and gonadal maturity stages for female and male *Sillago aeolus* collected at Sikao Bay from May 2003 to April 2004.

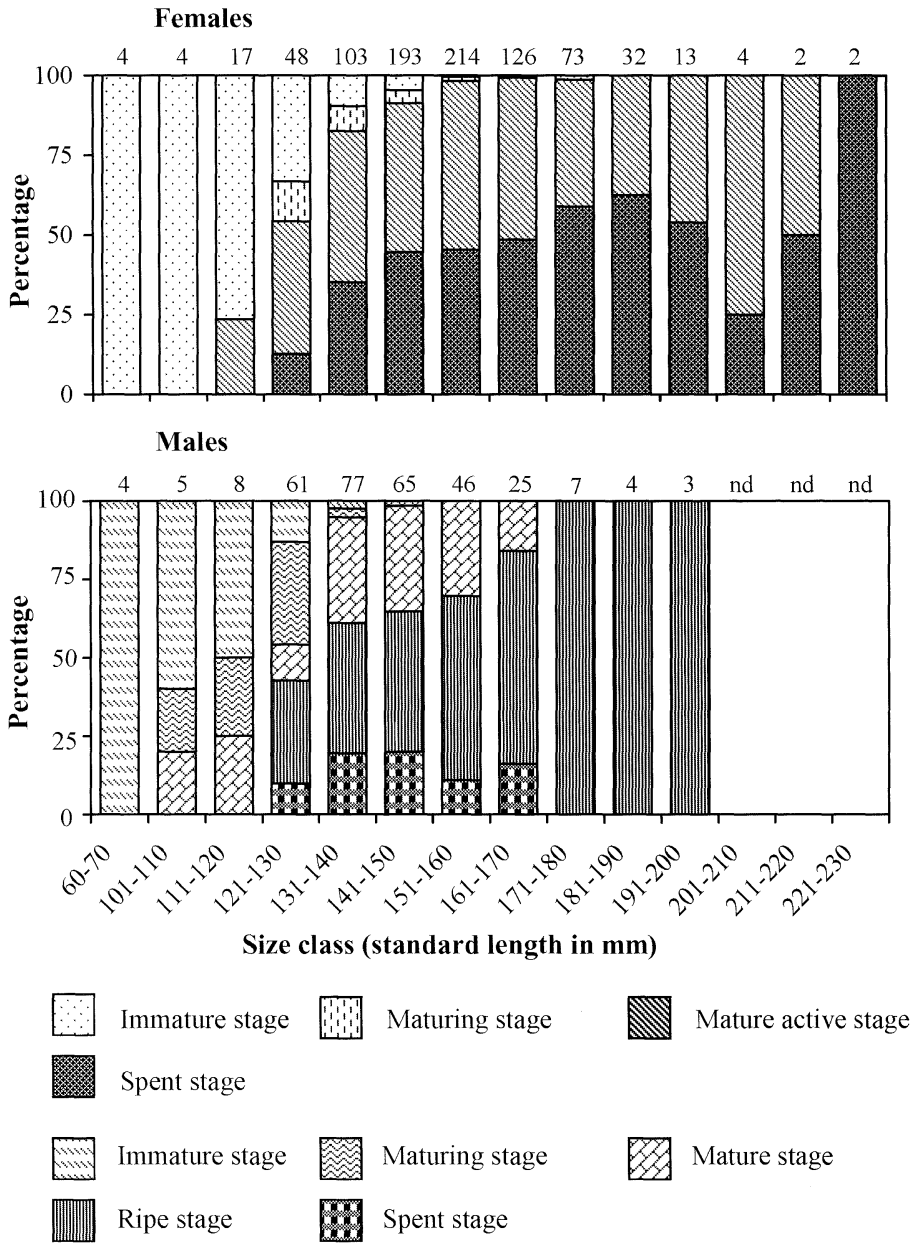


Fig. 7. Percentage frequencies of occurrence of various gonadal maturity stages in different size classes for female and male *Sillago sihama* collected at Sikao Bay from May 2003 to April 2004. Number of specimens sampled given above each column. nd, no data.

ranged from 0.53 to 5.41 (Fig. 5A). The smallest mature male was 106 mm SL with a GSI value of 0.28 and the largest immature male, 150 mm SL with a GSI value of 0.47. The GSI values for mature males ranged from 0.04 to

1.90 (Fig. 5B).

In *S. aeolus*, the smallest mature female was 113 mm SL with a GSI value of 1.66 and the largest immature female, 159 mm SL with a GSI value of 0.97. The GSI values for mature

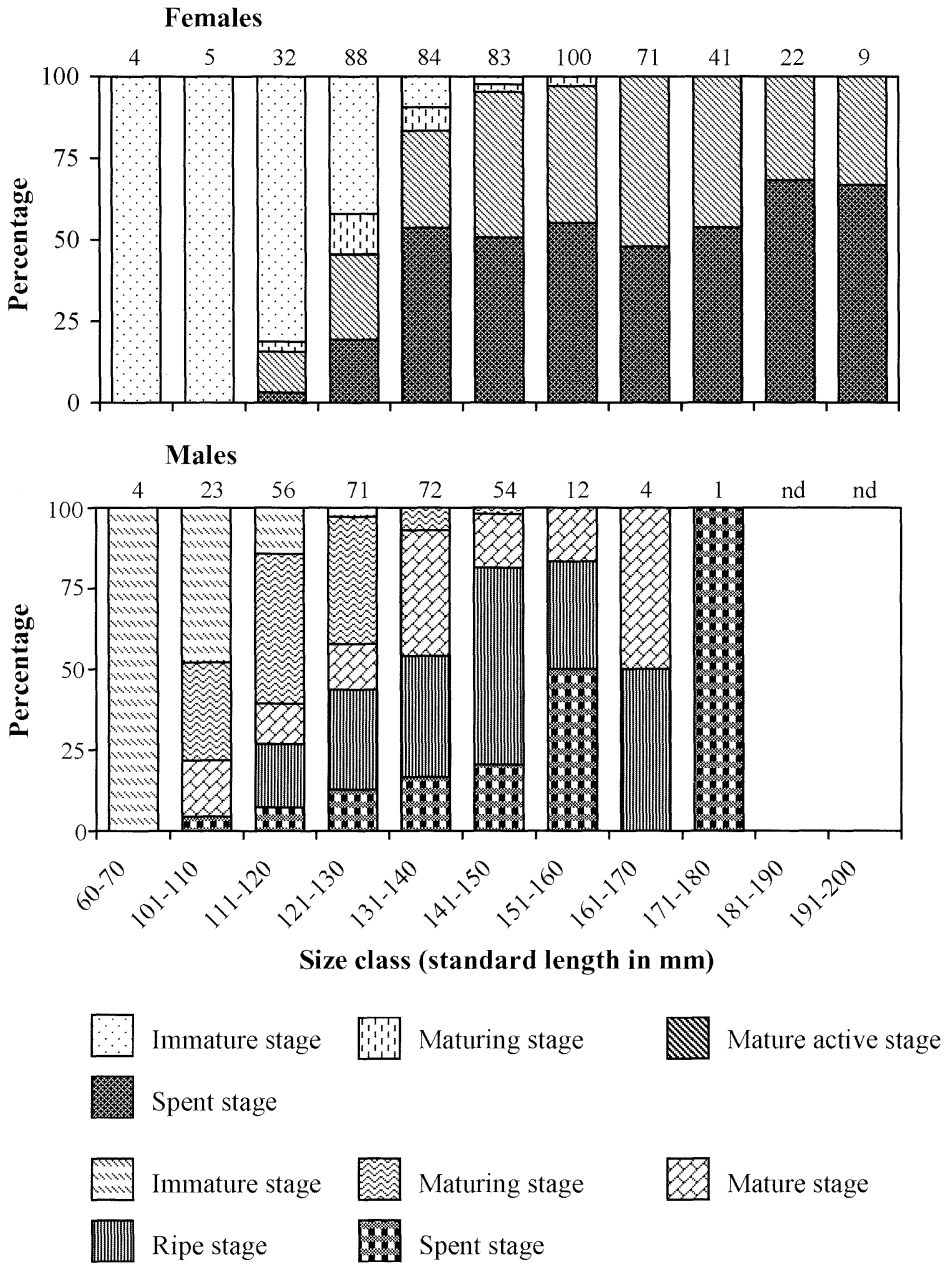


Fig. 8. Percentage frequencies of occurrence of various gonadal maturity stages in different size classes for female and male *Sillago aeolus* collected at Sikao Bay from May 2003 to April 2004. Number of specimens sampled given above each column. nd, no data.

females ranged from 0.47 to 8.69 (Fig. 6A). For males, the smallest mature specimen was 109 mm SL with a GSI value of 0.04 and the largest immature male, 160 mm SL with a GSI value of 0.47. The GSI values for mature males ranged

from 0.03 to 1.87 (Fig. 6B).

The relationship between SL and the proportions of various gonadal maturity stages indicated that body size at 50% maturity occurred in the 121-130 mm SL size class for both sexes

of both species (Figs. 7, 8). Therefore, the size at 50% maturity was determined as 130 mm SL for both species and sexes. Virtually all females and males larger than 150 mm SL possessed mature gonads in both species (Figs. 7, 8).

3.3 Spawning season

The monthly mean GSIs varied little from month to month for females and males of 130 mm SL or more in both species (Figs. 9, 10). The mean GSIs in *S. sihama* fluctuated between 0.80 in May to 2.77 in January for females, and between 0.39 in May and 0.70 in October for males (Fig. 9). Those for *S. aeolus* ranged from 1.41 in September to 3.47 in May for females, and from 0.21 in May to 0.96 in January for males (Fig. 10).

The monthly percentages of gonadal maturity stages indicated that in both species, females with ovaries at the mature active and

spent stages, and males with testes at the ripe and/or spent stages occurred every month (Figs. 11, 12). However, these histological observations showed that there was a seasonal change in the proportion of spawning females in each species, although such a change was not found in males. The proportions of spent females were relatively high between August and November in *S. sihama* (Fig. 11A), and between July and December in *S. aeolus* (Fig. 12A).

4. Discussion

The lowest possible spawning GSI values of females of *Sillago sihama* and *S. aeolus* at Sikao Bay were determined as 0.53 and 0.47, respectively, because their ovaries contained yolk globule stage oocytes with post-ovulatory follicles. In males, the lowest spawnable GSI values were defined as 0.04 for *S. sihama* and 0.03 for

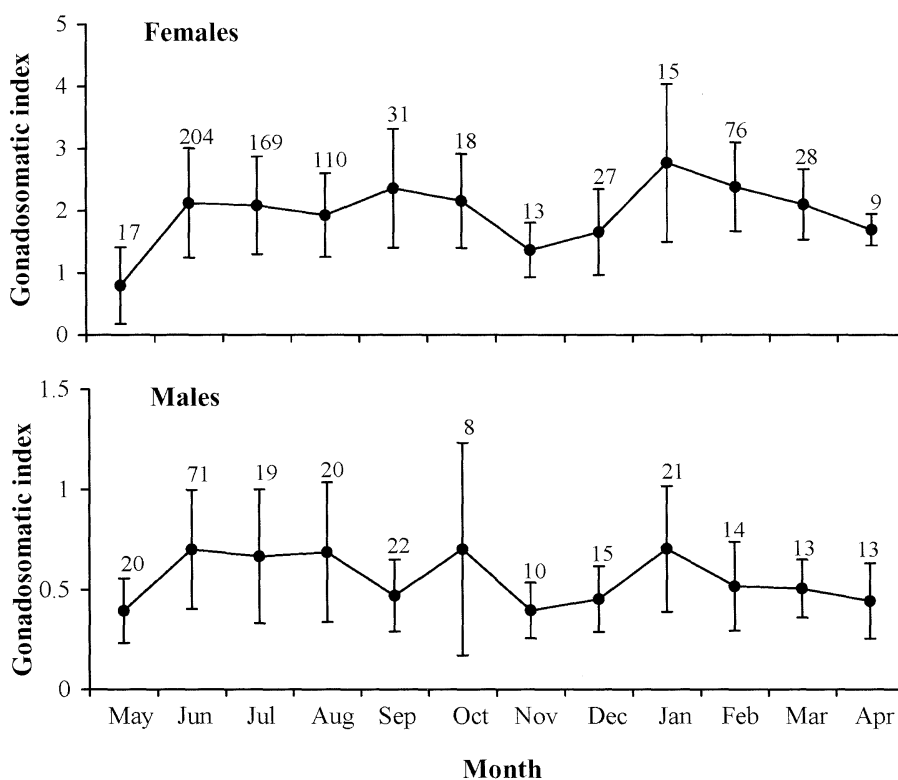


Fig. 9. Monthly mean gonadosomatic indices for adult females and males (≥ 130 mm in standard length) of *Sillago sihama* collected at Sikao Bay from May 2003 to April 2004. Bars indicate standard deviation. Number of specimens examined given above each bar.

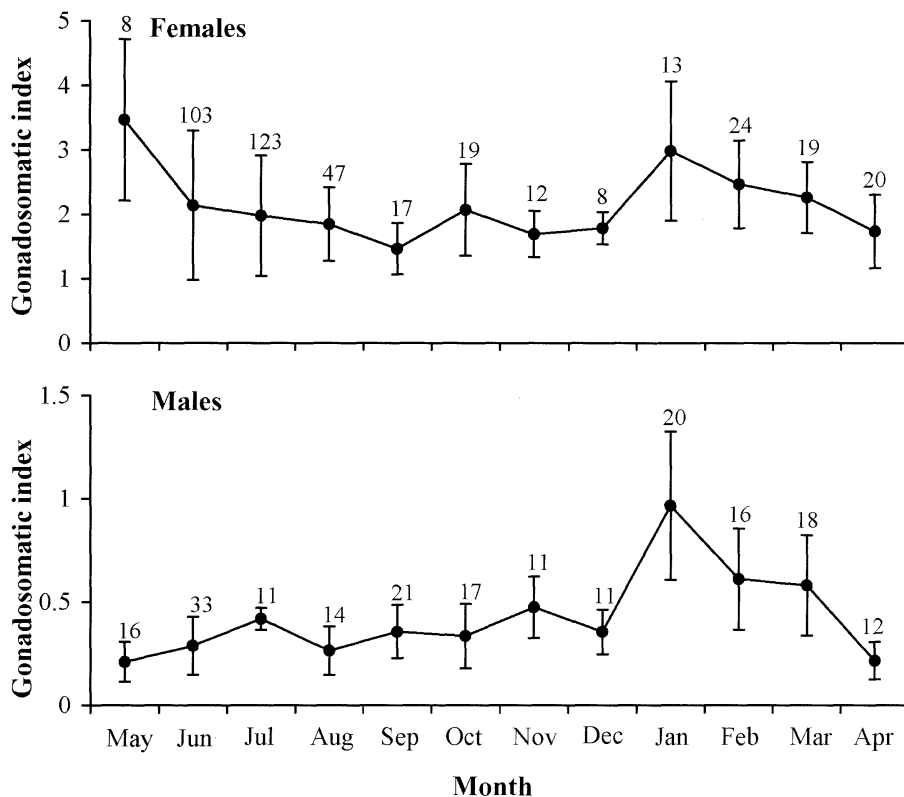


Fig. 10. Monthly mean gonadosomatic indices for adult females and males (≥ 130 mm in standard length) of *Sillago aeolus* collected at Sikao Bay from May 2003 to April 2004. Bars indicate standard deviation. Number of specimens examined given above each bar.

S. aeolus, because most crypts in their testes contained numerous spermatids and/or residual sperms. These findings indicated that possible spawning GSI values in each sex are very similar between the two species at Sikao Bay. However, such GSI values of *S. aeolus* at the study site were lower than those (1 for females and 0.05 for males) of conspecifics at Okinawa Island (RAHMAN and TACHIYARA, 2005). Furthermore, the minimum GSI values of mature individuals for each sex of the two species were lower than those described for other temperate *Sillago* species, such as *S. robusta* and *S. bassensis* (HYNDES and POTTER, 1996).

At Sikao Bay, the lengths (130 mm SL) at 50% maturity for *S. sihama* females and males were the same as in *S. aeolus*. According to their age and growth information (TONGNUNUI, 2006), most females and males of both species in the bay attain this length at the end of their

first year of life. Such a small size at 50% maturity has been recognized in some congeneric species, including *S. burrus* (130 mm SL in both sexes) and *S. robusta* (123 and 120 mm SL in females and males, respectively), in temperate, shallow inshore waters (HYNDES and POTTER, 1996; HYNDES *et al.*, 1996). In addition, the smallest mature fish were reported to be 120 and 113 mm SL for female and male *S. aeolus*, respectively, from subtropical, nearshore waters of Okinawa Island (RAHMAN and TACHIYARA, 2005). Several studies have indicated that such rapid attainment of small-sized maturity in inshore species may be due partly to benefits derived from feeding in highly productive shallow waters (HYNDES *et al.*, 1996; HYNDES and POTTER, 1997; RAHMAN and TACHIYARA, 2005).

In the present study, mature individuals of *S. sihama* and *S. aeolus* were observed to have

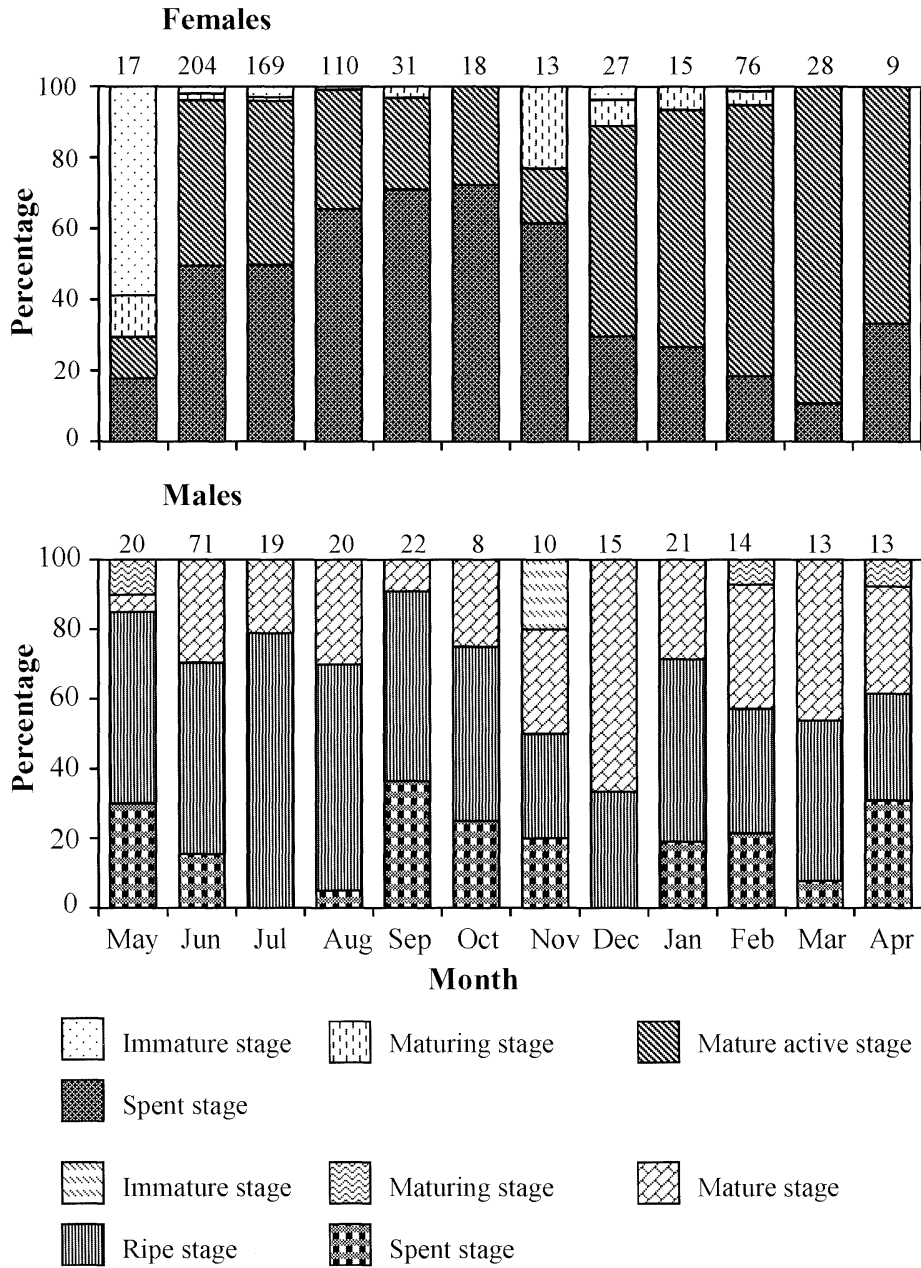


Fig. 11. Monthly percentage frequencies of occurrence of gonadal maturity stages for adult females and males (≥ 130 mm in standard length) of *Sillago sihama* collected at Sikao Bay from May 2003 to April 2004. Number of specimens examined given above each column.

spawnable GSI values throughout the year, histological examinations showing also that their ovaries and testes were functional for spawning each month. These results demonstrate that in the two species, spawning

occurred continuously throughout the year, although histological observations revealed that spawning activity peaks occurred between August and November in *S. sihama*, and between July and December in *S. aeolus*.

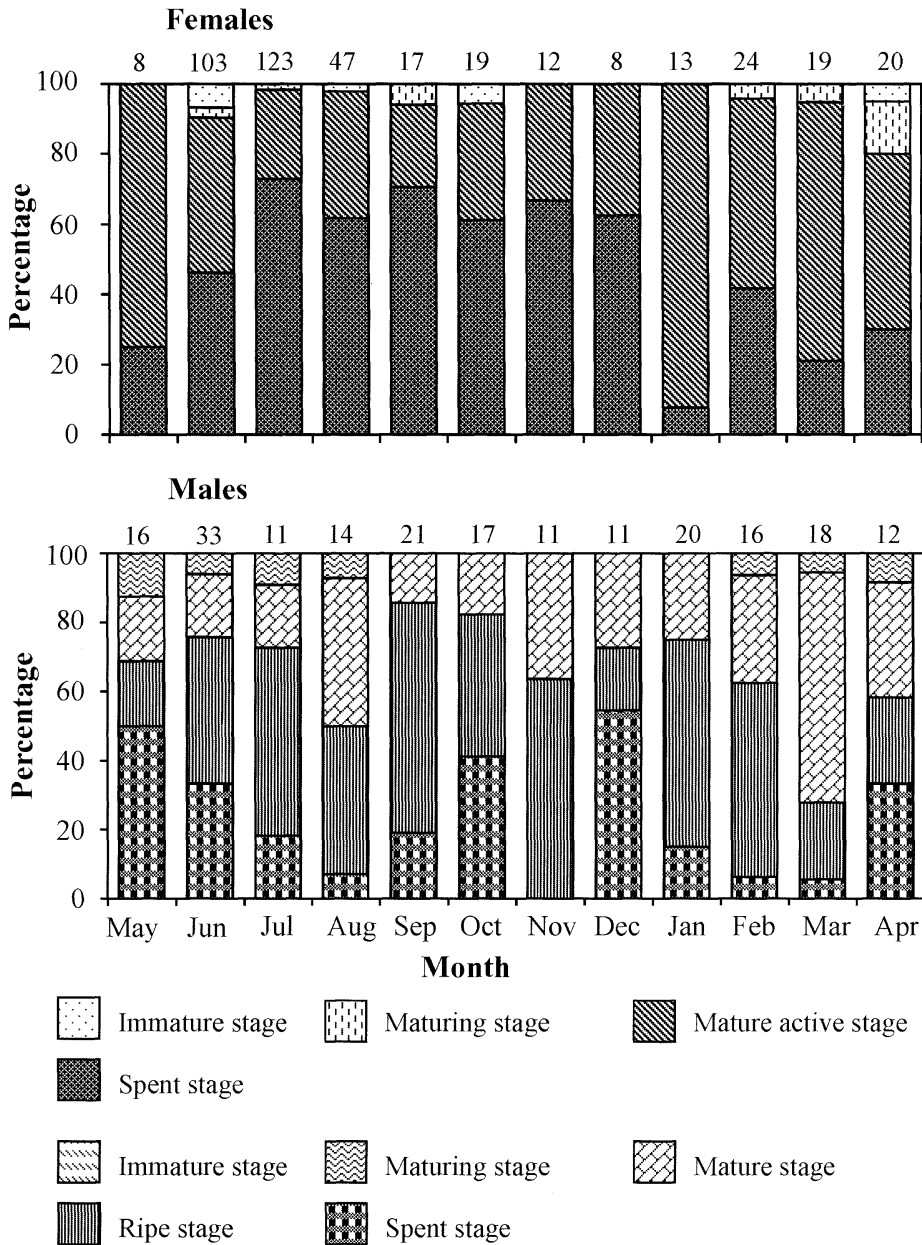


Fig. 12. Monthly percentage frequencies of occurrence of gonadal maturity stages for adult females and males (≥ 130 mm in standard length) of *Sillago aeolus* collected at Sikao Bay from May 2003 to April 2004. Number of specimens examined given above each column.

However, such spawning patterns of the two species at Sikao Bay contrasted with a conspecific (*S. aeolus*) and other sillaginids studied in temperate and subtropical coastal waters of Australia (HYNDES and POTTER,

1996, 1997; HYNDES *et al.*, 1996) and Japan (SULISTIONO *et al.*, 1999; RAHMAN and TACHIYARA, 2005), the latter fishes spawning during a short period in spring or summer. COULSON *et al.* (2005) reported that the

spawning period of *Sillago schomburgkii* in subtropical environments commenced earlier and continued for longer than in temperate waters, suggesting that water temperature plays a crucial role in stimulating spawning activity in sillaginids. The year-round spawning of *S. sihama* and *S. aeolus* at Sikao Bay may, therefore, be a reflection of the higher water temperatures at that locality.

Histological examinations revealed that oocytes at various developmental stages, in addition to post-ovulatory follicles, were found in the mature ovaries of *S. sihama* and *S. aeolus* during their spawning periods (Figs. 1F, 2F). These facts provide strong circumstantial evidence that the two species are multiple spawners, i.e. spawning on several occasions during the breeding period (CAILLIET *et al.*, 1986). Since similar phenomena have been documented in several other species of *Sillago*, as well as in *Sillaginodes* (HYNDES and POTTER, 1996, 1997; HYNDES *et al.*, 1996; FOWLER *et al.*, 1999; COULSON *et al.*, 2005; RAHMAN and TACHIHARA, 2005), multiple spawning may be a common life-history trait of sillaginids in tropical and temperate waters.

Acknowledgments

We are grateful to Ruangrit PANTONG, Suwat TANYAROS, Kou IKEJIMA, Masahiro HORINOCHI, Takashi INOUE, Tadaomi NAKAI, Pisut KAOBATH, Viwat SAETON, and the staff and students of the Department of Marine Science, Faculty of Science and Fisheries Technology, Rajamangala University of Technology Srivijaya, for providing invaluable advice and assistance with field work. Constructive comments on the manuscript from Ichiro AOKI, Kazuhiko KOBAYASHI, Takashi YAMAKAWA, Iain McTAGART, Graham HARDY, and an anonymous reviewer were much appreciated. This study was supported by a Grant-in-Aid for Scientific Research (A) from the Japan Society for the Promotion of Science (No. 15255017).

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Received March 16, 2006

Accepted May 12, 2006