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# Evidence of Flathead Mullet *Mugil cephalus* L. Spawning in Waters Northeast of Taiwan

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**Chih-Chieh Hsu, Yu-San Han, and Wann-Nian Tzeng (2007)** Evidence of flathead mullet *Mugil cephalus* L. spawning in waters northeast of Taiwan. *Zoological Studies* **46**(6): 717-725. A new spawning ground for flathead mullet (*Mugil cephalus* L.) in waters northeast (NE) of Taiwan was identified using comparisons of the maturation status of fish to that of well-known spawning grounds in waters southwest (SW) of Taiwan from 20 Nov. 2005 to 12 Jan. 2006. Similarities in hydrographical conditions between the NE and SW waters produced concurrent oceanic fronts with 20-23°C isothermal lines, temperatures which are suitable for mullet spawning in both areas. Mean fork length, body weight, the gonadosomatic index, and gonadal maturation of mullet in the NE waters were all comparable to those in the SW waters in the spawning season around the winter solstice (21 or 22 Dec.) ± 10 d. The gonadosomatic index of mullet in the NE waters significantly increased from < 0.5 at the beginning of the spawning season to greater than 21.0 for females and 19.0 for males at the peak of the spawning season. Oocytes were all either late-stage vitellogenic or post-vitellogenic from mid-Dec. to mid-Jan. In addition, a few individuals with hydrated oocytes or post-ovulatory follicles were also found. This evidence suggests that waters NE of Taiwan are a suitable spawning ground for the flathead mullet.
http://zoolstud.sinica.edu.tw/Journals/46.6/717.pdf

**Key words:** *Mugil cephalus*, Maturation, Spawning ground, Kuroshio Current, China Coastal Current.

Flathead mullet, *Mugil cephalus* L., is a cosmopolitan fish species, widely distributed in coastal waters, lagoons, and estuaries between latitudes 42°N and 42°S (Thomson 1966). This mullet is an economically important species for both aquaculture and commercial fisheries around the world. The roe industry for flathead mullet plays an important economic role in Taiwan (Su 1986). Flathead mullet migrate annually from the coastal waters of China to waters southwest (SW) of Taiwan to spawn around the time of the winter solstice (21 or 22 Dec.) ± 10 d (Chen and Su 1986, Huang and Su 1989). After spawning, larvae passively drift with the coastal currents to estuarine nursery areas along the Taiwanese west coast where they metamorphose to juveniles (Chang et al. 2000). The juveniles then migrate northward to join the adult stock in Chinese coastal waters where they feed until maturation.

In winter, the China Coastal Current (CCC) that is driven by the northeastern (NE) monsoon flows southward from the coast of China into the Taiwan Strait. Oceanic fronts form in waters NE and SW of Taiwan where the CCC meets the Kuroshio Current (Wang and Chern 1988). The coastal waters of SW Taiwan are a well-known traditional spawning ground of flathead mullet (Chen and Su 1986, Liu 1986). The optimal temperature in the spawning ground of the mullet ranges from 20.0 to 23.0°C (Huang and Su 1986 1989, Kuo 1986, Shyu and Lee 1986). Oceanic conditions in the NE area during the spawning season were similar to those in the SW. In addition, every year, large numbers of mature flathead mullet are known to appear in waters of NE Taiwan during the spawning season, with the subsequent appearance of flathead mullet fry in estuaries of NE Taiwan after the spawning season (Tzeng et

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al. 2002). All of these phenomena imply that waters NE of Taiwan may have the potential to provide suitable environmental conditions for the spawning of flathead mullet. However, no study has previously documented evidence showing that the flathead mullet spawns in waters NE of Taiwan.

In this study, we attempted to determine whether the flathead mullet spawns in waters NE of Taiwan. To test this hypothesis, the maturation status of mullet in NE waters was examined histologically along with temporal changes in the gonadosomatic index and oocyte diameter throughout the spawning season, and these were compared with similar processes in waters SW of Taiwan.

## MATERIALS AND METHODS

### Sample collection and hydrological analysis

The specimens of flathead mullet caught by hook and line gear in NE Taiwan were collected weekly during the period from 20 Nov. 2005 to 12 Jan. 2006 (Fig. 1). For comparison, specimens caught by small purse seine in the traditional spawning grounds in SW Taiwan were collected on 7 and 21 Dec. 2005. In total, 202 specimens were collected on 9 sampling dates (Table 1). Among them, a subsample of 32 individuals from NE Taiwan and 3 individuals from SW Taiwan with a gonadosomatic index (GSI) exceeding 10 were randomly selected to collect gonadal tissue to measure fecundity and oocyte diameters, and a subsample of 15 individuals was collected to examine the maturation stage of the gonads histologically.

Sea surface temperatures (SSTs) in the coastal waters of Taiwan were compiled from remote sensing data of the Fisheries Research Institute, Council of Agriculture, Executive Yuan, Taiwan, (http://www.tfrin.gov.tw/friweb/) and were analyzed to identify oceanic fronts where the Kuroshio Current and CCC meet and where the optimal temperature range for spawning occurred. This identified areas where samples of flathead mullet might be collected (Fig. 1).

### Measurement of morphometric characters

After collection, specimens were immediately preserved in ice, and their fork length (FL, mm), body weight (BW, g), and gonad weight (GW, g) were measured within 24 h. The GSI was calculated according to the method of Render et al. (1995) as follows: GSI = [GW / (BW - GW)] x 100.

The fecundity of the fish was estimated by a gravimetric method (MacGregor 1922). The total weight of the entire ovary was measured, a small gonadal tissue mass of 0.1 g was taken, and the number of oocytes in the mass was counted. Absolute fecundity, i.e., the total number of the oocytes from the entire ovary, was estimated through extrapolation. A linear regression of fecundity on the body weight of the fish was calculated.

### Gonad maturation assessment by histology and oocyte diameter

Development of the gonads of flathead mullet

**Table 1.** Mean (± SD) fork length, body weight, and gonadosomatic index (GSI) of flathead mullet collected from northeastern (NE) and southwestern (SW) waters of Taiwan, Nov. 2005 to Jan. 2006

| | | Sample size | | Fork length (mm) | | Body weight (g) | | GSI | |
|---|---|---|---|---|---|---|---|---|---|
| Site | Date | M | F | M | F | M | F | M | F |
| NE waters | 20 Nov. 2005 | 9 | 4 | 420.0 ± 17.3 | 428.3 ± 21.9 | 996.9 ± 185.8 | 996.4 ± 141.9 | 0.32 ± 0.18 | 0.11 ± 0.05 |
| | 27 Nov. | 17 | 3 | 376.8 ± 25.8 | 390.3 ± 47.2 | 664.7 ± 108.4 | 764.6 ± 221.1 | 6.33 ± 2.41 | 11.79 ± 8.55 |
| | 11 Dec. | 8 | 15 | 417.5 ± 26.1 | 468.9 ± 19.8 | 894.9 ± 161.9 | 1287.6 ± 159.2 | 8.80 ± 2.34 | 16.58 ± 3.29 |
| | 18 Dec. | 4 | 6 | 453.8 ± 23.5 | 491.0 ± 19.1 | 1320.8 ± 305.8 | 1619.0 ± 195.3 | 19.13 ± 3.29 | 21.30 ± 2.37 |
| | 29 Dec. | 9 | 11 | 460.3 ± 23.2 | 488.2 ± 50.4 | 1216.9 ± 173.3 | 1426.0 ± 320.1 | 13.88 ± 3.91 | 19.15 ± 4.84 |
| | 3 Jan. 2006 | 11 | 3 | 443.8 ± 21.8 | 518.3 ± 12.0 | 1075.9 ± 145.6 | 1675.9 ± 110.5 | 13.09 ± 4.84 | 17.63 ± 3.75 |
| | 12 Jan. | 8 | 10 | 495.0 ± 26.4 | 478.7 ± 17.9 | 1452.0 ± 192.5 | 1386.9 ± 201.0 | 10.49 ± 2.80 | 20.81 ± 3.59 |
| | Subtotal | 66 | 52 | 429.2 ± 44.7 | 472.6 ± 40.0 | 1016.9 ± 304.8 | 1344.1 ± 299.4 | | |
| SW waters | 7 Dec. 2005 | 20 | 20 | 480.1 ± 24.2 | 464.8 ± 26.1 | 1324.6 ± 181.0[a] | 1218.0 ± 215.2[a] | - | - |
| | 21 Dec. | 1 | 43 | 526 | 474.6 ± 34.1 | 1758 | 1231.7 ± 287.1 | 18.1 | 20.61 ± 0.68 |
| | Subtotal | 21 | 63 | 482.2 ± 25.6 | 471.4 ± 31.9 | 1345.2 ± 200.2[a] | 1227.3 ± 264.7[a] | | |

[a]Body weight of fish from the SW did not include gonad weight. M, male; F, female.

was reported to be synchronous and homogenous throughout the entire ovary (Shehadeh et al. 1973, Kuo et al. 1974, Greeley et al. 1987, Render et al. 1995). To validate this, the oocyte diameter frequency distribution was measured from 5 different parts of a mature mullet ovary. A small piece of gonadal tissue, weighing approximately 3 g, was removed from each of the 5 parts. The mean oocyte diameter did not significantly differ among the 5 parts (one-way ANOVA, $p > 0.05$). For convenience, the posterior portion of the gonad was used for the histological examination of maturity and examination of temporal variations in the oocyte diameter frequency distribution of the ovary.

Histological sections of gonadal tissues were prepared following McDonough et al. (2005). First, gonadal tissues were fixed in 10% neutral buffered formalin and then embedded in paraffin, cut, dried on glass slides, and stained with standard hematoxylin and eosin-Y. The maturity stage of the ovary and testis was identified at magnifications of 400x and 1000x with light microscopy and described according to protocols in tables 2 and 3, which were divided into 4 and 3 major development stages, respectively (Stenger 1959, Kuo et al. 1974, McDonough et al. 2003). The diameters of oocytes of each gonadal tissue sample were measured in a fresh condition with image-analysis computer software (SigmaScan Pro, Systat Software Inc., California, USA).

### Data analysis

Differences in mean fork length, body weight, oocyte diameters, and mean fecundity among samples were tested by one-way analysis of variance (ANOVA). Differences were considered significant at $\alpha = 0.05$.

## RESULTS

### Patterns of current systems and isothermal lines in coastal waters of Taiwan during winter

Figure 1 shows the oceanic conditions as indicated by the SST data in the coastal waters of

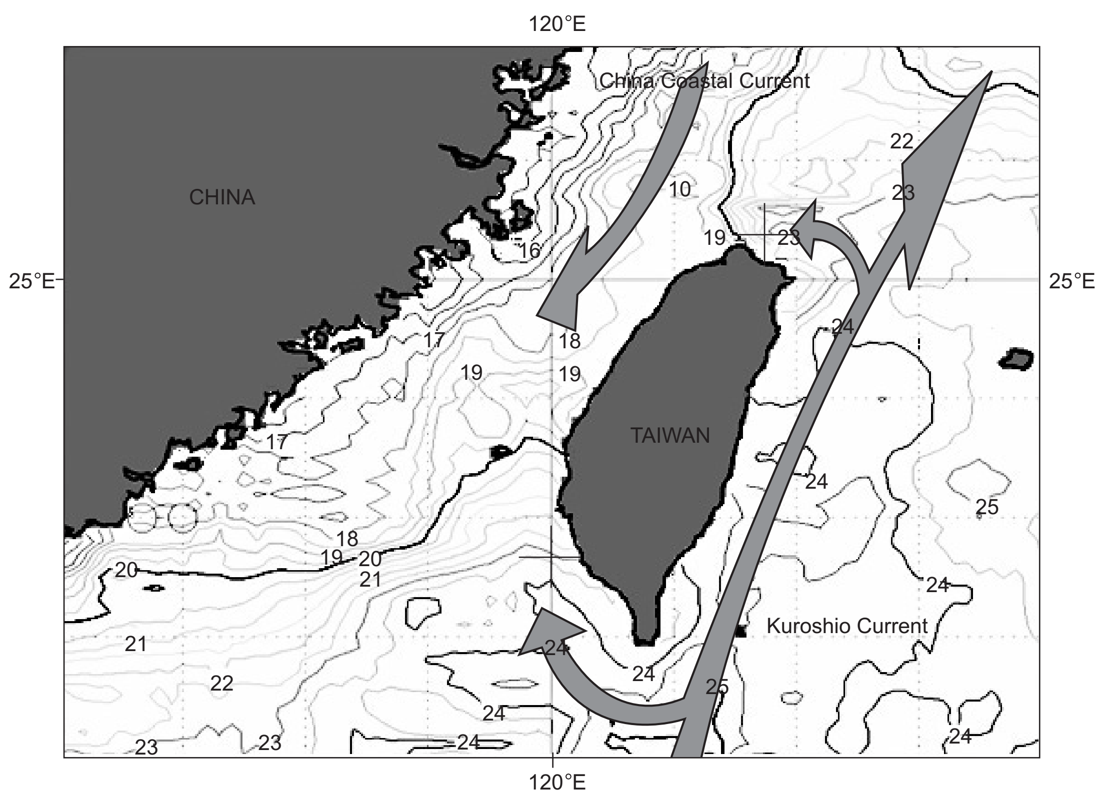


**Fig. 1.** Map showing the oceanic current system and sea surface isotherms (°C) in the waters adjacent to Taiwan on 29 Dec. 2005, reproduced from the website of the Taiwan Fisheries Research Institute, Council of Agriculture, Executive Yuan, Taiwan. Crosses indicate locations of isothermal fronts where specimens of flathead mullet were collected. Known spawning grounds in the southwestern (SW) area were located along an oceanic front of the 20-23°C isothermal lines.

Taiwan on 29 Dec. 2005 during the spawning season, which was compiled from remote sensing data. Water temperatures in coastal waters of Taiwan decrease when the cold China Coastal Current (CCC) moves southward from the coast of China. The CCC is induced by the NE monsoon winds. The current heads into the Kuroshio Current where oceanic fronts form in the coastal waters of both NE and SW Taiwan. The temperature of the front ranged from 20 to 23°C, which are optimal temperatures for flathead mullet spawning (Huang and Su 1986). The oceanic conditions such as the 20 to 23°C temperature gradient along an oceanic front occurred both in the traditional spawning ground in SW Taiwan and in NE Taiwan. This provided circumstantial evidence that the proper conditions occur for flathead mullet to spawn in the coastal waters of NE Taiwan.

### Comparison of fish length and weight between NE and SW Taiwan

The 202 flathead mullet collected in NE and SW Taiwan during the period from Nov. 2005 to Jan. 2006 were composed of 115 females (57%), and 87 males (43%) (Table 1). The length frequency distribution indicated that most of the fish (82%) were in the size range of 421-510 mm FL (Fig. 2). The mean FL of females in NE waters (472.6 ± 40.0 mm) was significantly (approximately 4 cm) larger than that of males (429.2 ± 44.7 FL mm) ($p < 0.01$). However, the mean FLs did not significantly differ between females (471.4 ± 31.9 mm) and males (482.2 ± 25.6 mm) in SW waters ($p > 0.05$, Table 1). The mean FLs did not significantly differ between samples of NE and SW

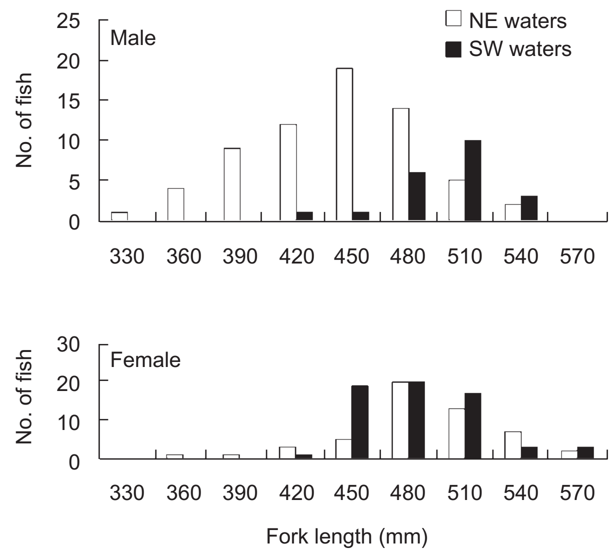


**Fig. 2.** Fork length frequency distributions of male and female flathead mullet collected in northeastern (NE) and southwestern (SW) waters of Taiwan during the spawning season.

**Table 2.** Criteria for oocyte development stage identification (modified from Stenger 1959, Kuo et al. 1974, and McDonough et al. 2003)

| Stage | Characteristics |
|---|---|
| 1 Pre-vitellogenic yolk stage | This stage was further divided into 2 sub-stages. (1) Primary growth stage: basophilic cytoplasm and a single nucleolus and/or multiple nucleoli around the periphery of the nucleus. (2) Secondary growth stage: unstained lipid droplets appear around the nucleus and migrate to the periphery of the oocyte as it grows. |
| 2 Vitellogenic yolk stage | Fast growth in weight and size occurs due to the production of yolk globules (stained red). In the early vitellogenic stage, the yolk globules are small. In the late vitellogenic stage, the entire cytoplasm is filled with large yolk globules and lipid droplets. |
| 3 Final maturation stage | The germinal vesicle (nucleus) migrates to the oocyte periphery followed by the coalescence of yolk globules and lipid droplets. Hydration of oocytes occurs just prior to spawning. Granulosa and theca cells are distinguishable for 24-48 h after ovulation and are referred to as post-ovulatory follicles (POFs). |
| 4 Atretic stage | Oocytes in the process of reabsorption. These oocytes usually lack germinal vesicles, but have vacuolated cytoplasm and are irregularly shaped. |

Taiwan collected after Dec. ($p > 0.05$ for both sexes) during the latter half of the spawning season. The mean BW, excluding gonadal weight, also did not significantly differ between samples from NE and SW Taiwan after Dec. ($p > 0.05$ for both sexes) (Table 1).

### Temporal changes in the GSI and oocyte diameter

The mean (± SD) GSI of flathead mullet in NE waters increased from 0.1 ± 0.1 (female) and 0.3 ± 0.2 (male) on 20 Nov. 2005, reached a peak of 21.3 ± 2.4 (female) and 19.1 ± 3.3 (male) on 18 Dec., and then slightly decreased thereafter (Fig. 3). The decrease in the GSI indicated that the flathead mullet had begun to spawn. Temporal changes in GSI values of mullet in NE waters corresponded with the duration of the spawning season of mullet in SW waters, which lasted for about 1 mo with a peak around Dec. 21 or 22 (the winter solstice) ± 10 d.

The frequency distribution of oocyte diameter from mullet collected in NE waters increased from 300-450 μm on 11 Dec. to 700-1050 μm on 18 Dec. and remained in that size range for the rest of the spawning season (Fig. 4a-e). The frequency distribution of oocyte diameters after Dec. in NE waters was similar to that in SW waters (Fig. 4f). A few mature females with hydrated oocytes of 900-1100 μm in diameter were found in samples from NE Taiwan after Dec. 18 (Fig. 4b-d). The hydrated oocytes were surrounded by follicle layers and connective tissue. Additionally, ovaries with post-ovulatory follicles (POFs) were also found in specimens from NE waters (Fig. 6d). The presence of POFs indicates recent spawning activity.

### Relationship between fecundity and fish weight

Fecundity of the mullet ranged (7-30) x $10^5$ oocytes per ovary. There was no significant difference in the mean fecundity between sampling dates ($p > 0.05$). However, the regression of fecundity on body weight of flathead mullet was significant ($R^2 = 0.6361$, $p < 0.01$, Fig. 5), indicating that larger females could produce more eggs.

### Comparison of maturation between NE and SW waters

Flathead mullet caught in NE Taiwan in Nov. were still immature with oocytes in the pre-vitellogenic stages (Fig. 6a). From Dec. to Jan., however, all of the oocytes developed to the late vitellogenic yolk stage (Fig. 6b). There were lots of yolk globules and lipid droplets filling the entire cytoplasm, a situation comparable to developmental stages of flathead mullet caught in SW Taiwan (Fig. 6c). Histological sections of post-spawning females with POFs were also observed in NE waters (Fig. 6d). This inferred that some flathead mullet had already spawned in the coastal waters of NE Taiwan.

In male mullet, the testes before spawning season showed signs of early development with spermatocytes and early spermatid stages (Fig. 7a). Spermatids appeared ovoid in the lumen and were surrounded by spermatocytes. Newly devel-

**Table 3.** Criteria for male germ cell development stage identification (modified from Stenger 1959, Kuo et al. 1974, and McDonough et al. 2003)

| Stage | Characteristics |
|---|---|
| 1 Spermatogonia stage | The testes are inactive and have spermatogonia and few or no spermatocytes. |
| 2 Spermatogenesis stage | Spermatogenesis begins. The stage can be divided into 3 substages. (1) First meiotic division begins and spermatocytes occur. (2) Second meiotic division begins and spermatids occur. Young spermatids appear to be ovoid cells. (3) Spermatozoa accumulate in lobules and ducts and are ready to spawn. In ripe testes, spermatozoa occur as dense and unorganized masses in ducts. |
| 3 Atretic stage | Testis size decreased by release of sperm and no spermatogenesis. Germ stem cells are present in the walls of the tubule epithelium. |

oped spermatozoa in the ducts occurred as dense, unorganized masses, and formed tails as spermatozoa before spawning (Fig. 7b). The same maturation and timing of spermatocytes were observed with flathead mullet in SW waters (Fig. 7c). This is direct evidence of spawning capability in the testes of males in both NE and SW waters at the same time.

## DISCUSSION

### Evidence of oceanic conditions for spawning in NE Taiwan

Previous studies on the spawning stocks of flathead mullet all focused on those in waters SW of Taiwan (Chen and Su 1986, Huang and Su 1986 1989, Kuo 1986, Liu 1986, Shyu and Lee 1986, Su 1986, Chang et al. 2004). Evidence of similar oceanic fronts in waters NE of Taiwan along with both indirect and direct evidence of spawning behavior has important implications for stock utilization and management of flathead mullet. Similarities in hydrographic conditions along with comparable maturation indices of flathead mullet offer strong arguments that spawning is feasible in NE waters as previously demonstrated in areas of SW Taiwan. The area of the spawning ground of flathead mullet did appear smaller in NE than in SW waters (Fig. 1). However, the explanation for this may be that the spawning ground of the mullet in NE waters has not been adequately studied. Local fishermen have harvested stocks from NE waters for many years. Although the NE

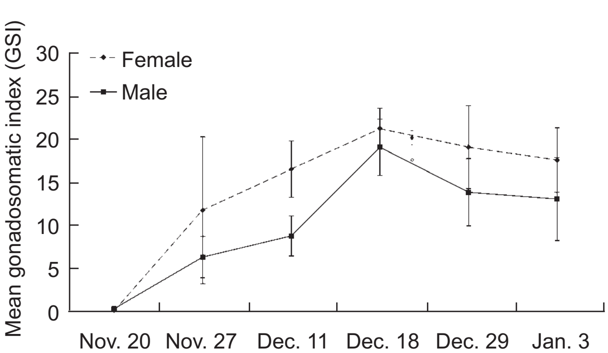


**Fig. 3.** Temporal changes in the mean (± SD) gonadosomatic index (GSI) of male and female flathead mullet collected in waters of northeastern (NE) Taiwan during the period from 20 Nov. 2005 to 12 Jan. 2006. White and black circles indicate the GSI of mullet collected from southwestern (SW) waters on 21 Dec.

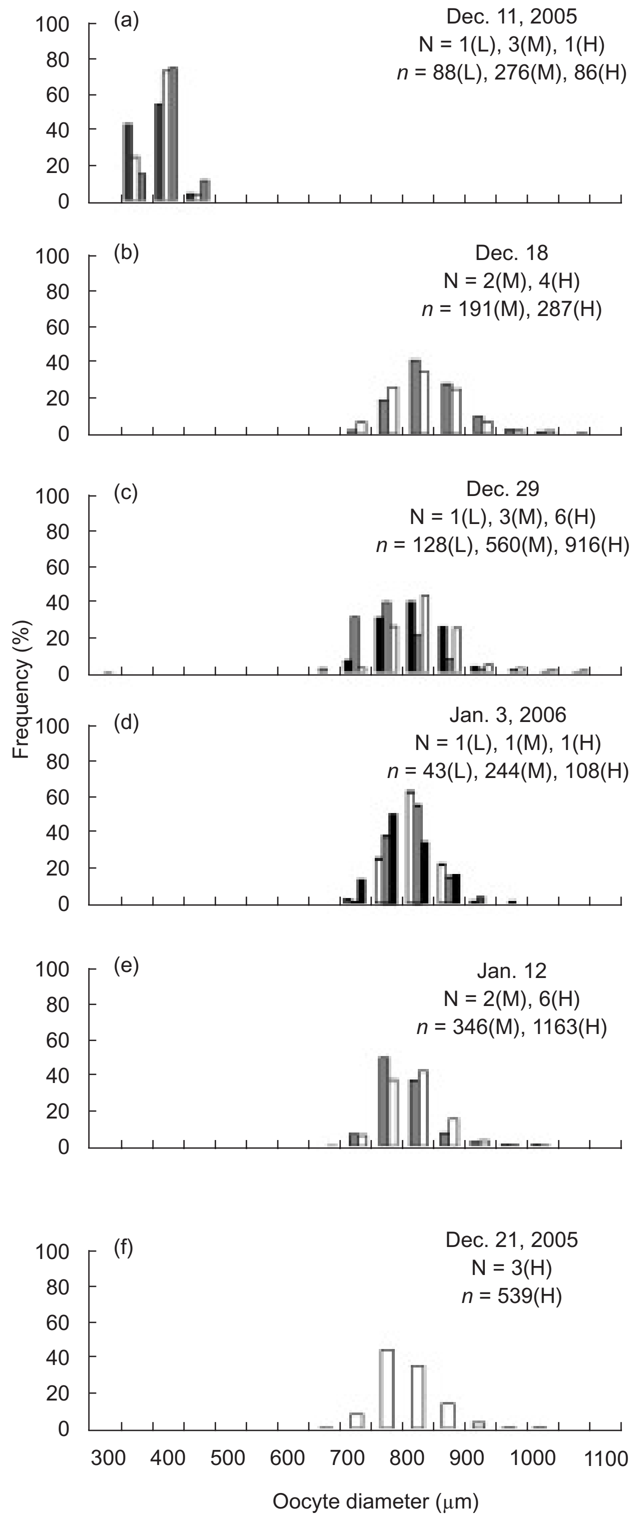


**Fig. 4.** Temporal changes in the oocyte diameter frequency distribution of flathead mullet collected from northeastern (NE) (a-e) and southwestern (SW) (f) waters of Taiwan, 11 Dec. 2005 to 12 Jan. 2006. N, number of fish; *n*, number of eggs. The fish were grouped into 3 gonadosomatic index (GSI) categories: L (■; GSI < 15), M (■; GSI 15-20), and H (□; GSI > 20).

fishery is of a smaller scale, it also affects the population dynamics of mullet, and thus has fishery management implications.

The oceanic conditions in the coastal waters of Taiwan dramatically change with the seasonal monsoons. Highly saline warm water from the South China Sea moves into the Taiwan Strait when the southwesterly monsoons prevail in summer. It is then replaced by low-salinity cold water of the China Coastal Current (CCC) driven by the northeasterly monsoon in winter. The 20-23°C isothermal lines formed in oceanic fronts between the CCC and Kuroshio Current in SW Taiwan (Fig. 1) have been shown to provide optimal temperatures for the spawning of flathead mullet (Kuo 1986, Shyu and Lee 1986, Huang and Su 1989). The same isothermal lines of 20-23°C form oceanic fronts in waters NE of Taiwan in winter (Fig. 1). These isothermal fronts allow flathead mullet to undergo reproductive development in possible spawning areas in waters NE of Taiwan.

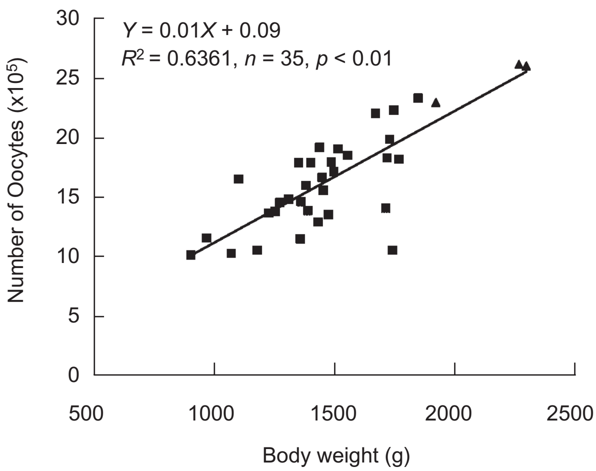


**Fig. 5.** Regression of the absolute fecundity (eggs per female) on body weight of flathead mullet collected from northeastern (NE) (■; 32 specimens) and southwestern (SW) (▲; 3 specimens) waters of Taiwan from 11 Dec. 2005 to 12 Jan. 2006.

## Evidence of gonadal maturation and larval occurrence for spawning in NE Taiwan

Additional evidence of flathead mullet spawning in NE waters was found in the maturation stages and degree of ovarian development. Mullet

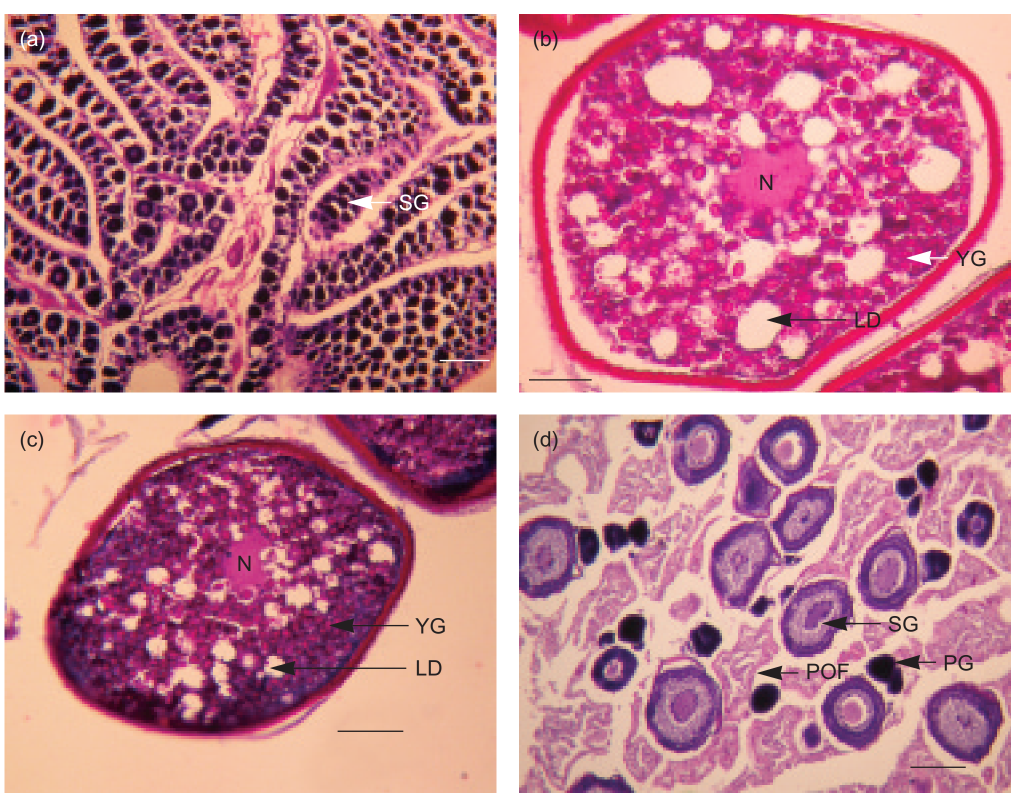


**Fig. 6.** Maturation stages of the ovaries of flathead mullet collected from northeastern (NE) (a, b, d) and southwestern (SW) (c) waters of Taiwan. (a) Premature in the pre-vitellogenic yolk stage; (b, c) mature in the late vitellogenic yolk stage, (d) after spawning. SG, secondary growth oocyte; POF, post-ovulatory follicle; PG, primary growth oocytes; LD, lipid droplet; N, nucleus; YG, yolk globule. Scale bar = 100 μm.

in SW waters spawn around the winter solstice ± 10 d (Kuo 1986, Shyu and Lee 1986, Huang and Su 1989). The GSI of the mullet in NE waters showed a significant increase during the same time period in Dec., which was comparable to that which occurred in the SW (Fig. 3). Seasonal similarities in GSI levels and oocyte sizes (Fig. 4) indicated that mullet were likely capable of spawning in NE Taiwan under the right conditions. Temporal changes in oocyte diameters indicated that oocytes were either at or close to hydration, while the presence of POFs in NE waters was direct evidence of recent spawning activity (Fig. 6d). Oocytes of most females cannot stay hydrated for more than a few hours, and the size of the POFs found in this study were probably less than 24 h old. In addition, the 2 spawning areas are too far apart; thus, it is highly unlikely that a female with hydrated oocytes or POFs traveled more than 200 km from the SW spawning area to the NE area in 2 d or less. It is believed that the NE and SW waters contain 2 independent spawning grounds for flathead mullet.

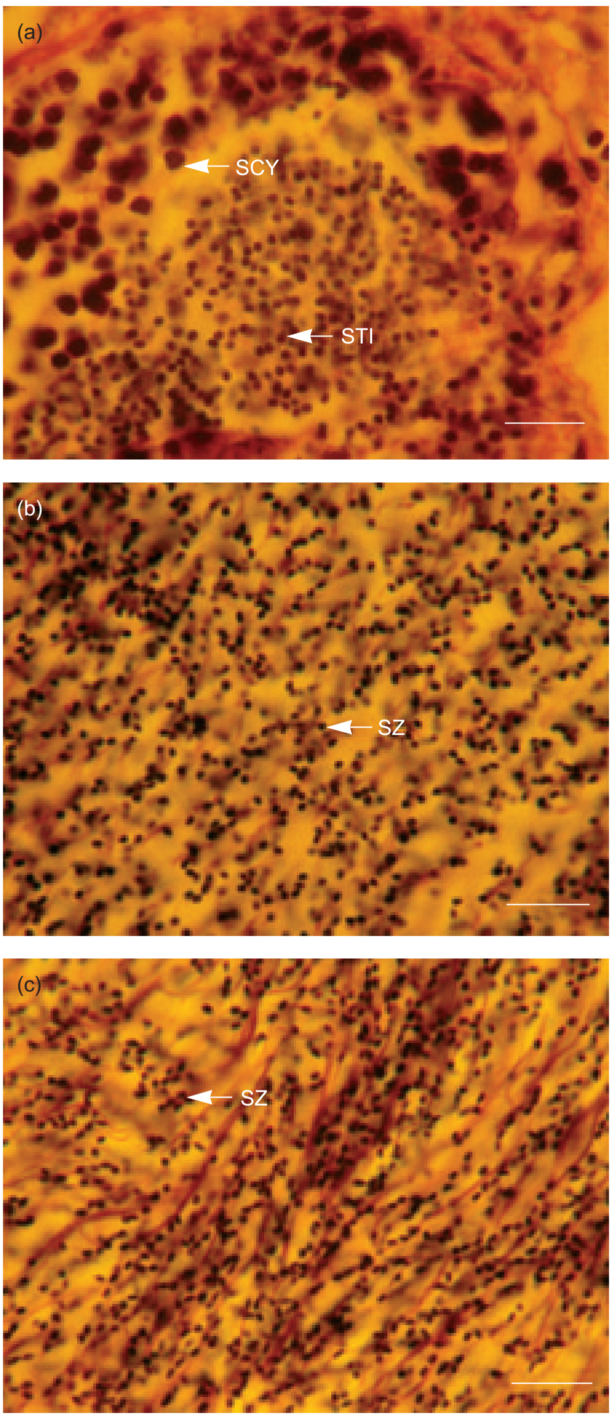


**Fig. 7.** Maturation of testes of flathead mullet collected from northeastern (NE) (a, b) and southwestern (SW) (c) waters of Taiwan. SCY, spermatocyte; STI, spermatid; SZ, spermatozoon. Scale bar = 10 µm.

Additional indirect evidence comes from the recruitment of juvenile flathead mullet to estuaries of NE Taiwan in winter. Approximately 1 month after the spawning season, abundant flathead mullet juveniles simultaneously occurred in estuaries along NE to SW Taiwan (Chang et al. 2000). Although juveniles which spawn in SW Taiwan may swim along the west coast of Taiwan to the estuaries of the NE coast, the prevailing CCC is moving strongly southward at this time, and a northerly migration along the coast would require active migration against the current which would be energetically costly. Accordingly, juveniles caught in estuaries of the NE coast likely come from spawners in NE waters.

The information on oceanic current systems, adult maturation cycles, and the occurrence of juveniles all points toward previously undefined spawning grounds for flathead mullet in coastal waters of NE Taiwan. The results suggest that further work is needed to study the stocks of flathead mullet in NE and SW spawning grounds including population identification by genetic methods.

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