*Zoological Studies* **55:** 53 (2016)
doi:10.6620/ZS.2016.55-53

Zoological Studies

# Growth, Diet Composition and Reproductive Biology of the Invasive Freshwater Fish Chevron snakehead *Channa striata* on a Subtropical Island

Kuan-chung Li[1], Bao-sen Shieh[2], Yuh-wen Chiu[3], Da-ji Huang[4], and Shih-hsiung Liang[1,*]

[1]*Department of Biotechnology, National Kaohsiung Normal University, Kaohsiung 824, Taiwan.*

[2]*Department of Biomedical Science and Environmental Biology, Kaohsiung Medical University, Kaohsiung 807, Taiwan.*

[3]*National Museum of Marine Biology and Aquarium, Graduate Institute of Marine Biology, National Dong Hwa University, Pingtung, 944, Taiwan*

[4]*Department of Environmental Resources Management, Chia Nan University of Pharmacy and Science, Tainan 717, Taiwan*

*(Received 9 April 2016; Accepted 30 October 2016)*

**Kuan-chung Li, Bao-sen Shieh, Yuh-wen Chiu, Da-ji Huang, and Shih-hsiung Liang (2016)** The Chevron snakehead (*Channa striata*) has been invading Taiwan for over 30 years, and it is currently widely distributed across diverse aquatic habitats within the island. Due to its strong environmental adaptability and carnivorous diet, *C. striata* has caused great negative impacts to the biodiversity of native fishes and aquatic organisms in Taiwan. To effectively restrain its spatial distribution and population, the objective of this study was to investigate the growing conditions, diet composition, and reproductive biology of *C. striata* in the field. In total, 294 individuals were collected from wetlands, irrigation canals, streams, and reservoirs in southern Taiwan from September 2008 to December 2010. Among 272 sex-identified individuals, more females (164) were collected than males (108). The morphological differences between the sexes could not be distinguished by the 10 body measurements recorded. Diverse food items, including snails, odonates, fishes, amphibians, and reptiles, were identified in the stomachs of 35 individuals. The minimum body length of sexually mature *C. striata* females exhibited at a standard length of 24.5 cm (total length 28 cm). The appearance of mature oocytes were mainly observed from July to November in 2009 and from April to October in 2010. Greater absolute fecundity (oocyte/individual) was estimated in Taiwan for *C. striata* than in its original distribution range possibly due to less water level fluctuation in the sampling habitats of Taiwan. The relative fecundity (oocyte/g) for *C. striata* was considered lower but within the documented range in Taiwan when compared with its original habitat in Malaysia. To effectively manage *C. striata* in Taiwan, regionally eradiating young and adult individuals, especially during the reproductive season and educating people to stop releasing it in the wild are possible ways to restrain and control the further spread of this exotic fish in Taiwan.

**Key words:** Snakehead, *Channa striata*, Invasive species, Reproductive biology, Taiwan.

## BACKGROUND

Snakeheads are freshwater fishes native to Asia, Indonesia, and tropical Africa (Herborg et al. 2007). All species of snakeheads are piscivorous, and they also feed on crustaceans and small vertebrates (Dasgupta 2000). Additionally, all snakeheads are characterized by either obligate or facultative breathing; thus, they can survive in moist conditions outside water over a long period of time or migrate over wet land (Liem 1987, Amilhat and Lorenzen 2005). In their native range, many snakeheads are commonly used in aquaculture and are highly valued as food fish (Courtenay and Williams 2004). The aquarium trade of young snakeheads also exists due to its bright orange body color. Because of its economic value, strong environmental tolerance and predatory nature,

*Correspondence: Tel: 886-7-7172930 ext. 7310. Fax: 886-7- 6051365. E-mail:shliang@nknucc.nknu.edu.tw

snakeheads have extensive histories of invasion and subsequent negative impacts on native biodiversity (Courtenay and Williams 2004).

The Chevron snakehead (*Channa striata*) was originally distributed in the stagnant waters of lakes, streams, swamps, rice paddies, pools, and roadside ditches in most drainages of India, southern China and Indochina (Courtenay and Williams 2004). Lee and Ng (1991) cited this species as the most economically important member of the snakeheads; hence, it is cultured throughout most of its native range. Courtenay and Williams (2004) listed *C. striata* as the most widely introduced species of snakeheads. The diet of *C. striata* includes snakes, fishes, tadpoles, frogs, shrimps, snails, and insects (Lee and Ng 1991). Tolerant of foul water and capable of moving overland, *C. striata* has been suggested to be the most adaptable snakehead (Lee and Ng 1991). Given its strong adaptability to surviving in turbid waters, predacious nature, and high economic and aquaculture values, *C. striata* has been a significant threat to many subtropical and tropical regions since its introduction. This species has currently invaded the Philippines, Indonesia, Madagascar, Taiwan, Japan and possibly Hawaii, U.S.A. (Courtenay and Williams 2004).

Few studies of *C. striata* have been centered on its life history traits in its introduced habitat despite it has currently invaded the Philippines, Indonesia, Madagascar, Taiwan, Japan and North America (Courtenay and Williams 2004, Jiao et al. 2009). Most investigations on this species were commonly found on migration and habitat use in rice field (Amilhat and Lorenzen 2005), embryonic and larval development (Marimuthu and Haniffa 2007), nutritional values (Karapanagiotidis et al. 2010), and Taxonomic and proteomic analysis (Gam et al. 2006, Vishwanath and Geetakumari 2009) due to economic value and aquaculture importance. When Jiao et al. (2009) constructed demographical models to assess the invasion impact of *Channa argus* in North America, they indicated that data on life history traits often came from a introduced species' native range, and their knowledge of *Channa argus* in North America is very limited. Thus, collecting the life history information of invasion fish in its introduced range will benefit on increasing the accuracy on their risk assessment and developing a more effective management plan.

*Channa striata* has existed in Taiwan since 1983 (Wang et al. 2010). After being introduced into this island for over 30 years, this exotic species has become widely present in streams, reservoirs, and lakes, seriously threatening the freshwater biodiversity of Taiwan (Chen et al. 2003). To effectively manage and eradicate *C. striata* in the future, it is essential to study the life history characteristics of *C. striata* within the invaded habitat of Taiwan. Thus, this study is aimed at investigating the growth, diet composition, and reproductive biology of *C. striata* in the freshwater habitats of southern Taiwan.

## MATERIALS AND METHODS

### Study sites and Fish sampling

The study was conducted in streams, wetlands, irrigation canals, and reservoirs in the Tainan and Kaohsiung regions of southern Taiwan from September 2008 to December 2010. Samples were collected by lure fishing and fyke nets. The collected individuals were preserved in a -20°C cooler for later measurements.

### Data collection and analysis

### Morphometric measurements

Males and females were distinguished based on body weight (WT, g) and 9 morphometric characteristics, including total length (TL, cm), standard length (SL, cm), predorsal length, the length of the predorsal to caudal peduncle, body length, head length, belly width at the pectoral fin, mouth length (distance from the tip to the midpoint of a line that across the two ends of mouth in the lower jaw), and mouth width. After these 9 morphometric characteristics were recorded, the sex of each collected individual was determined by directly observing the gonads. To morphologically separate male and female individuals, a *t*-test was performed to compare the weight and 9 morphometric measurements between the sexes. Additionally, 3 body length ratios (head length, mouth length, and predorsal length divided by standard length) between sexes were compared by *t*-test. If several morphometric measurements showed significant differences between the sexes, then a discriminant analysis would be performed to identify those remaining measurements for morphologically separating the sexes. A respective correlation between SL and WT for males and females was also calculated. An analysis of covariance (ANCOVA) was used to compare the difference of the growth models between the sexes.

### Diet composition

The stomach contents of the collected individuals were collected, weighed, and preserved in a 70% alcohol solution. The food items in the stomach were examined and identified by eye and microscopic observation to the species or the possible lowest taxonomic level.

### Reproductive phenology

The gonads of sexually mature females are easier to identify and heavier than those of mature males because of enlarged oocytes. Thus, female gonads were weighed to calculate the gonadosomatic index (GSI) and determine the reproductive phenology of *C. striata* in Taiwan. The following formula was used to calculate the GSI value, and the GSI value is expected to increase as an individual reaches the reproductive season.

$$GSI = [(\text{gonad weight}) / (\text{body weight})] * 100$$

In addition to GSI, we used the systems of Holden and Raitt (1974) and Kilambi (1986) to determine the stages of oocyte development. Based on direct observation of the oocyte colors and morphology, four stages of oocyte development were categorized: the immature stage, early maturing stage, mature stage, and spent stage.

### Fecundity

Ali (1999) suggested that *C. striata* is a group-synchronous type spawner because the oocyte sizes vary during the reproductive season. Thus, following the method of Ali (1999), we estimated the fecundity using 46 individuals by first collecting three oocyte samples with a spoon from the front, middle, and lower part of either the left or right ovary. Each oocyte sample was weighed, and the absolute fecundity (no. of oocytes/female) was estimated. A gravimetric method was then applied for estimating these three oocyte samples, and these three estimates were averaged to calculate the absolute fecundity of each female.

For a comparison with the result of Ali's (1999) study, the relative fecundity (no. of oocytes/body weight, g) was also calculated. After the absolute fecundity was calculated, we also selected 50 oocytes from each individual of 27 mature females to measure the diameter of mature oocytes.

## RESULTS

In total, 294 individuals were collected. More individuals were sampled from wetlands (93, 31.6%) and irrigation canals (155, 52.7%) than from streams (37, 12.6%) and reservoirs (9, 3.1%). No clear pattern was displayed for the monthly collections, but fewer individuals were collected during January to March, and no sample was made in May 2005. Unable to conduct fish sampling because heavy rainfall caused by two typhoons in June and July 2009 decreased the fish collections in those two months.

### Sex ratio

Among the 294 individuals collected, 272 were sex-identified, including 108 males and 164 females, and 22 were sex-undetermined. The female-male sex ratio for the collected *C. striata* is 1.5:1, and no significant difference between sexes was found for the monthly collections ($\chi^2$ test, $P > 0.05$).

### Morphometric classification between sexes

The 272 sex-identified individuals (108 males and 164 females) were used for a morphometric classification between the sexes. Nine of the 10 morphometric measurements showed no significant difference between sexes; only TL exhibited significantly greater values for males than for females (Table 1). No significant difference was identified on 3 body length ratios (head length, predorsal length, and head length vs. standard length) between sexes by *t*-test.

### Body length and weight

Body weight and SL were positively correlated for both males and females (Fig. 1). A similar growth pattern existed between the sexes, and the exponential formulas between SL and WT for males and females are listed as follows:

male: $WT = 0.0355\,(SL)^{2.75}$
($n = 108$, $R^2 = 0.89$, $P < 0.01$)
female: $WT = 0.0189\,(SL)^{2.93}$
($n = 164$, $R^2 = 0.87$, $P < 0.01$)

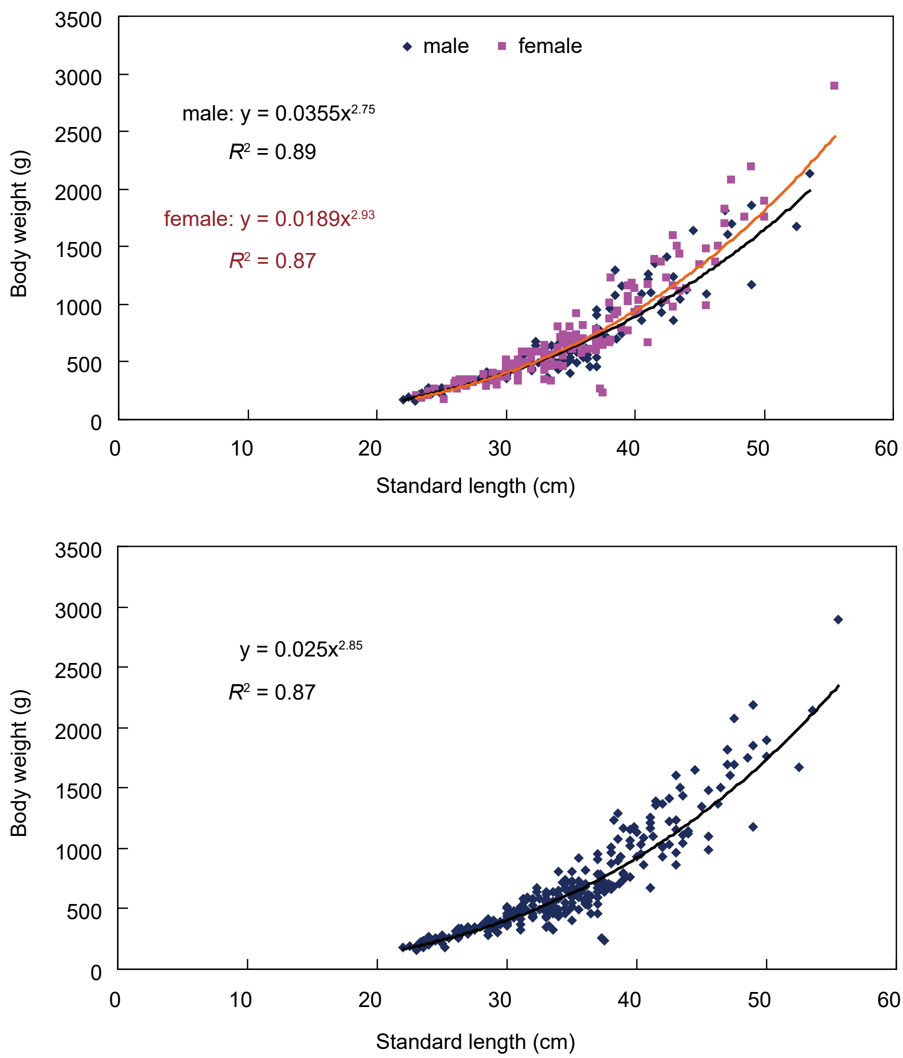


**Fig. 1.** Regression results and formulas of standard length and weight of *Channa striata*. Graphs are shown with sexes separated (top) and combined (bottom).

**Table 1.** Measurements of 10 morphometric characteristics of *Channa striata* males and females. The comparisons of 10 morphometric characteristics between the sexes were performed by a *t*-test

| Morphometric characteristics | male | | female | | $p$ value[3] |
|---|---|---|---|---|---|
| | $n$ | (mean ± SE[2]) | $n$ | (mean ± SE) | |
| WT1 | 108 | 698.8 ± 39.1 | 164 | 701.6 ± 34.2 | 0.958 |
| TL | 46 | 44.2 ± 1.0 | 88 | 40.9 ± 0.7 | 0.010* |
| SL | 108 | 35.2 ± 0.6 | 164 | 34.8 ± 0.5 | 0.579 |
| PL | 108 | 11.6 ± 0.2 | 164 | 11.6 ± 0.2 | 0.849 |
| PCP | 108 | 23.7 ± 0.5 | 164 | 23.2 ± 0.4 | 0.355 |
| BD | 108 | 5.4 ± 0.1 | 164 | 5.47 ± 0.09 | 0.608 |
| HL | 108 | 5.9 ± 0.1 | 164 | 5.87 ± 0.09 | 0.723 |
| ML | 108 | 4.22 ± 0.08 | 164 | 4.16 ± 0.06 | 0.529 |
| MW | 108 | 4.3 ± 0.1 | 164 | 4.25 ± 0.07 | 0.739 |
| BW | 108 | 5.15 ± 0.09 | 164 | 5.17 ± 0.08 | 0.866 |

[1]Acronyms: WT:Body Weight, TL: Total Length, SL: Standard Length, PL: Predorsal Length, PCP: Predorsal to Caudal Peduncle, BD: Body Depth, HL: Head Length, ML: Mouth Length, MW: Mouth Width, BW: Belly Width. [2]SE: Standard error. 3*: $p < 0.05$.

No significant difference was identified for the growth patterns between the sexes based on the ANCOVA results ($P > 0.05$). Thus, the data of the two sexes were pooled, and an exponential model was used to assess the growth pattern of *C. striata* in southern Taiwan as follows (Fig. 1):

$$WT = 0.025\ (SL)^{2.85}$$
$$(n = 272,\ R^2 = 0.87,\ P < 0.01)$$

**Diet composition**

The average weight of the stomach for the collected individuals was 7.37 ± 0.33 g ($n$ = 292). Among 290 un-decayed samples, almost half of them were empty (139, 47.9%), 116 stomachs (40%) contained milk-like and undistinguished remains, and 35 stomachs carried incompletely digested and recognizable residues.

Thirty-five stomachs of the collected *C. striata* specimens were dissected and analyzed for diet composition (Table 2). The SL of these individuals ranged from 24.0 to 55.5 cm. Based on the SL, we divided the collected individuals into three groups for diet analysis; the first group includes the minimum mature body length (24 cm) to the mean SL of the collected *C. striata* (34 cm), and the other two groups were established with 10 cm intervals of 35 to 45 cm and greater than 45 cm.

For the SL of 24-to-34 cm group, 11 food items, including snails, Chironomids, Odonata, fishes, geckos, insects, and fish baits, were identified within 17 stomachs of the collected individuals (Table 2). Ten food items, including snails, fishes, turtles, frogs, shrimps, insects, and fish baits, were present in the stomachs of 15 *C. striata* with the SL ranging from 35 to 45 cm. For SLs greater than 45 cm, only fish and frog were found in the stomachs of 3 individuals.

**Reproductive biology**

**Reproductive phenology**

During the sampling period, 162 female *C. striata* were collected. The GSI value of *C. striata* females began to increase at a SL of 24.5 cm (TL 28 cm) (Fig. 2).

Based on the development stage of the ovaries, no ovary was categorized as mature in January to March in both 2009 and 2010 despite a few higher GSI values appearing in February 2010

**Table 2.** Diet composition of *Channa striata* in 3 body-size groups based on standard length

| Organisms | Items | Standard length | | |
|---|---|---|---|---|
| | | 24 - 34 cm | 35 - 45 cm | > 45 cm |
| | | $n$ = 17 | $n$ = 15 | $n$ = 3 |
| Aquatic invertebrate | *Pomacea canaliculata* | 1 | 2 | |
| | *Tarebia granifera* | 1 | | |
| | *Physa* spp. | 2 | | |
| | Gastropoda | 1 | 1 | |
| | Chironomidae | 1 | | |
| | Odonata | 1 | | |
| Fish | Fish bone | 6 | 4 | 2 |
| | *Trichogaster trichopterus* | 1 | | |
| | *Monopterus albus* | | 1 | |
| | *Channa striata* | | 1 | |
| Reptiles | Gecko | 1 | | |
| | Turtle | | 1 | |
| Amphibians | Frog | | 1 | 1 |
| Others | Shrimp | | 1 | |
| | Insect | 1 | 2 | |
| | Fish bait | 1 | 1 | |

(Fig. 3). The appearances of mature oocytes were mainly observed from July to November in 2009 and from April to October in 2010. The GSI values also showed a trend similar to that observed in the development stage of the ovaries in both years. Few females with mature oocytes in their ovaries were found in April 2009 and December 2010 (Fig. 4).

The monthly medians GSI values did not show a significant correlation with the monthly mean air temperatures in either year, whereas a significant correlation was present with the monthly total precipitation for 2010 (Spellman correlation, $p < 0.05$) but not for 2009.

**Oocyte count and oocyte diameter**

Forty-six females with mature ovaries were selected to assess fecundity. The absolute fecundity of the females ranged from 4,484 to 96,498, mainly between 4,484 to 40.641 (89.1%, 41 of 46 individuals), with a mean absolute fecundity of 24,479 ± 2,666 oocytes/female ($n$ = 46). The ovaries of 27 out of 46 females were used to measure oocyte diameter. The diameter of mature oocytes of *C. striata* ranged from 1.05 to 1.26 cm with a mean diameter of 1.16 ± 0.01 mm ($n$ = 27).

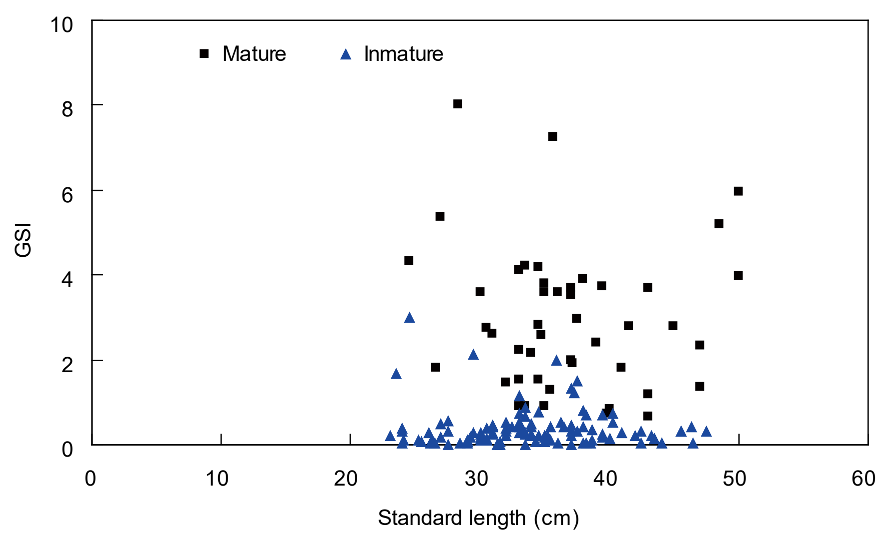


**Fig. 2.** Standard length plotted against the gonadosomatic index (GSI) for collected *Channa striata* females from southern Taiwan ($n$ = 162). The mature gonads of females first appeared at a standard length of 24.5 cm (arrow).

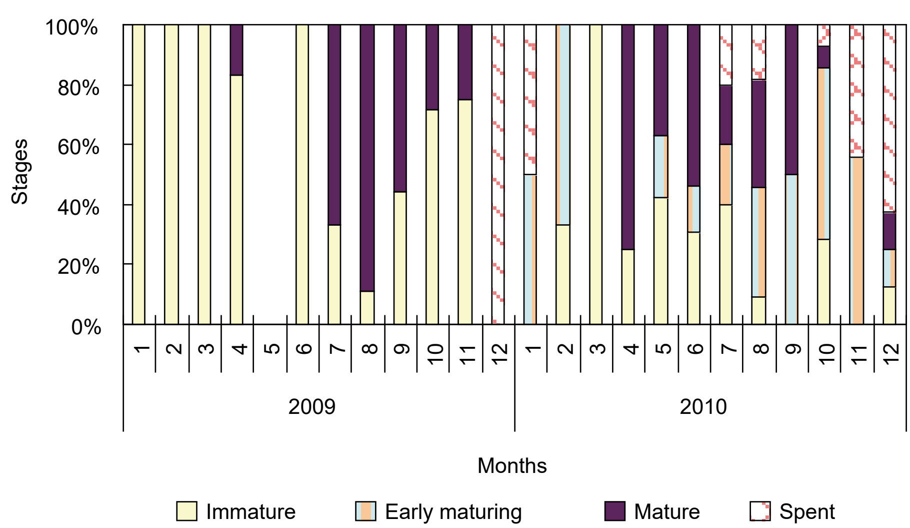


**Fig. 3.** Monthly variations of the proportional numerical abundance of the ovarian developmental stages of *Channa striata* females from 2009 to 2010.

## DISCUSSION

### Morphometric comparisons and growth

It is difficult to separate individuals of *C. striata* between sexes through morphometric measurements and growth patterns based on the results of this study. The comparisons of 10 morphometric measurements, including WT, SL, predorsal length, length of the predorsal to caudal peduncle, body depth, head length, mouth length, mouth width, and belly width, and 3 body length ratios between the two sexes of *C. striata* were unsatisfactory, and only the TL of the males was significantly greater than that of the females.

Greater growth coefficients were recorded in southern Taiwan than in Malaysia for *C. striata* males and females. Ali (1999) estimated the length-weight exponential power coefficient for males only (2.72), for females only (2.76), and pooled (2.75) from the rice fields of Malaysia. In Taiwan, the exponential power parameters of the growth model were estimated for males only (2.75), females only (2.93), and the two sexes together (2.85) for *C. striata.* Moreover, these exponential power parameters were not significantly different from the cubic relationship, indicating an isometric growth for this alien fish in Taiwan (Nielsen and Johnson 1983). This finding suggested that the body shape of *C. striata* becomes more rotund as the body length increases in the invaded habitat of southern Taiwan (Wang et al. 2010) compared with its original distribution range in Malaysia (Courtenay and Williams 2004). The lower sensitivity and ability of its prey of native fishes and aquatic organisms to escape predation by *C. striata* in Taiwan may have contributed to this observation.

### Diet composition

In Taiwan, the diet composition of smaller *C. striata* (SL smaller than 34 cm) included mainly aquatic invertebrates, such as gastropods and insects, and fishes, while larger individuals (SL greater than 34 cm) prey more intensively on shrimps, aquatic vertebrates, such as reptiles and amphibians, and fishes. This observation indicated that the predation of *C. striata* would possibly cause negative impacts on abundance and biodiversity in both the population and community level of stream organisms in Taiwan.

The predatory effect of *C. striata* would decrease abundance, restrict spatial distribution, and alter the age structure of the population level of native fishes. Carnivorous invasive fishes have been extensively documented to decrease the abundance of aquatic vertebrates and invertebrates, such as the Nile perch, *Lates niloticus*, in Lake Victoria (Balirwa et al. 2003) and the brown trout, *Salmo trutta*, in New Zealand (Townsend 1996). Predation by invasive

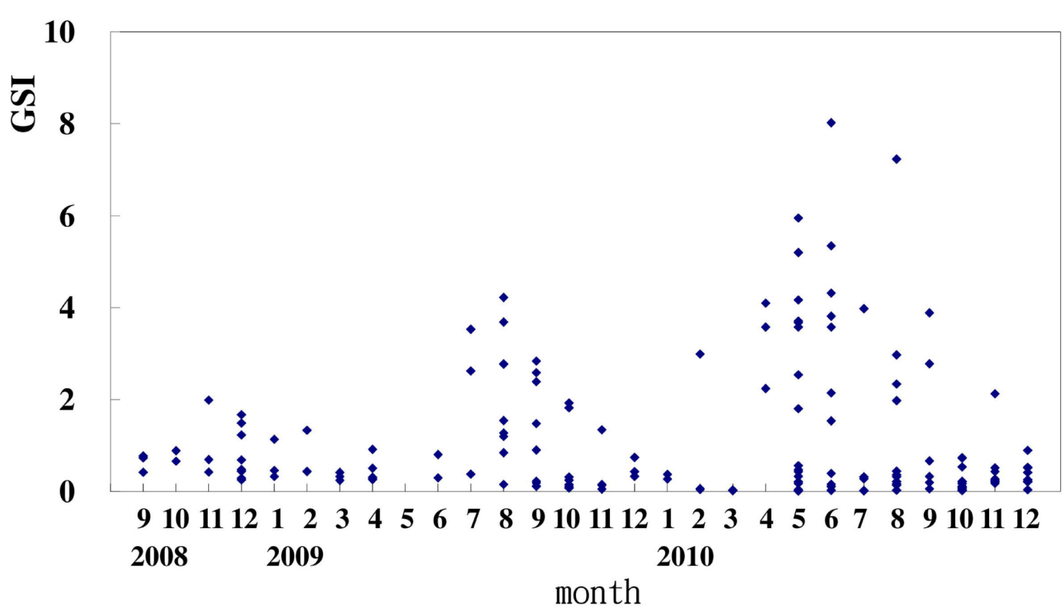


**Fig. 4.** Temporal variations of the gonadosomatic index (GSI) of *Channa striata* females in southern Taiwan from September 2008 to December 2010.

fishes can also affect the distribution of native species by decreasing their abundance, such as the largemouth bass in South Korea (Jang et al. 2006), and by displacing them from optimal habitat through competitive exclusion, such as the brook trout in the small headwater tributaries of Northern Europe (Korsu et al. 2009). An example from a stream of northern Taiwan also showed that the predatory effect of *Culter alburnus,* which was originally distributed in central Taiwan, could change the age structure of *Candidia barbata* through preying more heavily on younger individuals (Chiu et al. 2012).

The predation of *C. striata* on lotic organisms would also cause alterations in community levels such as species composition and food webs. Studies on farm ponds in Japan showed that the top-down control of predatory largemouth bass (*Micropterus salmoides*) and bluegill (*Lepomis macrochirus*) could cause a trophic cascade effect of indirectly increasing the numbers of benthic organisms by directly decreasing the number and body size of fish, crustaceans, and odonate nymphs (Maezono and Miyashita 2003). Recently, in South Africa, Shelton et al. (2015) reported that introduced trout have induced a trophic cascade by releasing herbivorous invertebrates from predation and consequently indirectly decreasing the biomass of benthic algae by increasing grazing pressure.

## Reproduction biology

### Mature minimum body length

The minimum mature body length of *C. striata* is slightly greater in Taiwan than in its original distribution area. In southern Taiwan, the GSI value of 162 collected *C. striata* females began to increase at 24.5 cm SL (TL 28 cm). In the irrigated rice fields of Malaysia, the smallest mature *C. striata* female had a TL of 25.5 cm (Ali 1999). In India, Alikunhi (1953) found that the smallest mature body length of *C. striata* females was 23.4 cm TL. The TL for the smallest mature *C. striata* female in Sri Lanka was 23.2 cm (Kilambi 1986). Because *C. striata* requires 2 years to reach its minimum mature body length under the growing conditions in Sri Lanka and similar climate conditions exist between northern Malaysia and Sri Lanka, Kilambi (1986) suggested that *C. striata* females in Malaysia begin to spawn when they are 2 years old. Taiwan is located at a higher latitude than Malaysia and Sri Lanka, and a greater minimum mature body length of the females was recorded in this study; thus, it may also be reasonable to assume that *C. striata* females require at least 2 years to grow before they are able to reproduce within the island.

### Oocyte diameter

*C. striata* females in Taiwan are currently able to produce mature oocytes similar in size to those in their original region. We measured the oocyte diameters of 27 mature females in this study and found that the oocyte diameter ranged from 1,050 μm to 1260 μm with a mean of 1,160 ± 10 μm. In Sri Lanka, Kilambi (1986) suggested that the diameter of mature oocytes ranged from 1,000 to 1,530 μm. Wan Yaakob and Ali (1992) recorded the size of spawned oocytes as approximately 1,390 μm. They also reported that the size of mature oocytes was between 1,000-1,200 μm. Based on these findings, Ali (1999) proposed that oocyte diameters of 1,000 μm and above could be used as a maturity criterion for *C. striata* females.

### Fecundity

A greater absolute fecundity was recorded in Taiwan for *C. striata* females than in their original distribution range, which includes India (Alikunhi 1953, Parameswaran and Murugesan 1976), Sri Lanka (Kilambi 1986), and Malaysia (Ali 1999). This study measured 46 mature ovaries and recorded an absolute fecundity of *C. striata* females in Taiwan ranging from 4,484 to 96,498 oocytes, mainly between 4,484 to 40,641 oocytes (89.1%. 41/46), with a mean of 24,479 ± 2,666 oocytes. However, in India, a maximum absolute fecundity of 11,811 of 4 females was estimated by Alikunhi (1953), while a brood of developing oocytes not exceeding 5500 was also reported (Parameswaran and Murugesan 1976). A later study by Kilambi (1986) in Sri Lanka assessed absolute fecundity for *C. striata* as between the two studies above conducted in India. Ali (1999) estimated a range of 4,326 to 9,017 oocytes based on 77 *C. striata* specimens collected from an irrigated rice field in Malaysia. However, Jhingran (1984) cited fecundity as 3000 - 30000 oocytes/ovary.

The greater absolute fecundity of *C. striata* in Taiwan compared with its original distribution range may have resulted from the sampled habitat. Tropical fishes have been documented to deposit their oocytes over several instances rather than spawning at one time (Ali and Kadir 1996). The increase in water levels has been suggested to provide a stimulus for the fish to attain gonad maturation and to spawn, such as for *C. striata* in Malaysia (Ali 1999) and *Varicorhinus alticorpus* in Taiwan (Han et al. 2000). Ali (1999) conducted his study mainly in a rice field, a sump pond, and irrigation and drainage canals where the water levels may be shallow and frequently fluctuate, thus causing repeated spawnings and lower absolute fecundity in *C. striata*. Although half of the samples in this study were collected from irrigation canals, the other half of the samples were collected in southern Taiwan mainly from wetlands and reservoirs which may maintain a more stable water level than in irrigated rice agroecosystems.

The relative fecundity was considered lower in Taiwan when compared with its original habitat in Malaysia for *C. striata*. The mean relative fecundity (oocyte/g) of *C. striata* in Taiwan was calculated as 28.9 ± 16.8 oocytes/g, ranging from 4.9 to 88.4 oocytes/g. In Malaysia, more than 35 oocytes/g can be produced by mature females with a range from 10.5 to 36.3 oocytes/g WT (Ali 1999). However, closer to the recorded relative fecundity in Taiwan was also found, Ali (1999) stated that mature *C. striata* females would commonly produce between 15 to 30 oocytes/g WT.

## Reproduction phenology

The monthly distribution of female GSI values and the mature ovarian stage reflected the reproductive period of female *C. striata* as appearing in April and July - November in 2009, whereas it lasted from April to October and December in 2010.

These observations suggested that the reproductive period of *C. striata* females in Taiwan may last for 9 months from April to December but appear for at least 4 months from July to October. Herre (1924) indicated that *C. striata* spawns throughout the year, and many individuals may breed twice annually. Ali (1999) also documented and confirmed that spawning occurred all year round in an irrigated rice field and in irrigation systems in northwestern Malaysia with the main spawning season in February, March, June-September, and November - February due to the increase in irrigation water levels and rainfall. In Sri Lanka, Kilambi (1986) stated that the peak spawning season of *C. striata* occurs between May and September with a secondary spawning season from October to December. In India, *C. striata* breed most months of the year with a peak spawning time coinciding with the peak rainfall season (Parameswaran and Murugesan 1976). This spatial disparity in the reproductive times of *C. striata* may arise from the rainy seasons among regions. In Taiwan, the rainy season mainly lasts from April to October, and the monthly GSI scores also significantly positively correlate with the amount of monthly rainfall in 2010. Nevertheless, despite its spatial distribution, the reproductive period of *C. striata* peaked from June to October. Moreover, judging from the multiple peaks of the reproductive period in both years, fractional spawning may exist in *C. striata* in Taiwan as cited in its original distribution region of Malaysia (Ali 1999), India (Parameswaran and Murugesan 1976), and Sri Lanka (Kilambi 1986).

Due to limited samples were collected from wetlands, reservoirs, and irrigation canals, collected females were grouped to investigate the reproductive phenology of invasive *C. striata* in southern Taiwan. The yearly difference of 2009 and 2010 in reproductive phenology of *C. striata* may partially attributed to water fluctuation were varied in the lotic (irrigation canal) and semi-lotic (reservoir and wetlands) habitats (Ali 1999). Further studies in recording reproductive phenology of *C. striata* in Taiwan or other invaded area, lotic and lentic habitats are suggested to be separately documented.

## Environmental impact and Management suggestions

*Channa striata* has exhibited a strong diet and reproduction adaptability, including a diet of diverse food items, greater absolute fecundity, similar relative fecundity, and comparable reproductive phenology, in lotic and lentic habitats of southern Taiwan.

In addition, its carnivorous feeding habit could cause severe and negative impacts on the population, community, and biodiversity level of native fishes and organisms in Taiwan.

Given that this species has invaded the island for over 30 years and is currently present throughout the whole island, completely removing it from Taiwan is impractical; a more realistic goal should be focused on gradually limiting its spatial distribution through extirpating regional populations. Recently, some researchers in Taiwan have proposed that it is futile to eradicate *C. striata* from polluted urbanized wetlands because other alien fishes may repeatedly invade from adjoined waters (Yam et al. 2015). However, the presence of *C. strata* will continuously impact and decrease the biodiversity of local and endemic fish species despite water quality conditions. To maintain the remaining sources of local and endemic fishes in the field for future restoration, we believe that it is essential to eliminate *C. striata* from its invaded habitat to restrain its spatial distribution.

Based on the findings from this study, we strongly suggest the removal of *C. striata* from aquatic systems in Taiwan by all possible means, such as by holding fishing contests and providing financial incentives. The removal activities should last all year, especially in the reproductive period of April - December, and juveniles with an amber color should also be eliminated after the reproductive period. For the water bodies with limited surface areas, the release of all water to extirpate all individuals of *C. striata* should be considered as an option. After action begins, educating the general public to not introduce this species back to any aquatic ecosystems is also critical for effectively controlling the wild population of *C. striata*.

## CONCLUSIONS

After it was introduced into Taiwan over 30 years, *Channa striata* has displayed great environmental adaptability by showing carnivorous diet and compatible reproductive traits with its original distribution ranges. Moreover, its wide distribution and predatory feeding habit has generated seriously threat to decrease the aquatic biodiversity in Taiwan. For restraining further expansion of spatial distribution and population size of *C. striata*, to remove young and adult individuals with all possible means all years long, especially during its reproductive season from April-December, were recommended. Other than extirpate the wild population, educating general public not to introduce *C. striata* into any local waters is also critical for protecting the endemic aquatic organisms from the negative impacts of this exotic species in Taiwan.

**Acknowledgment:** This study was supported by the Council of Agriculture (104- Foresty-07.1-C-28) and Ministry of Science and Technology (99-2621-B-017-001-MY3), Taiwan through research grants awarded to Liang, Shih-hsiung and Shieh, Bao-sen.

## REFERENCES

Ali AB. 1999. Aspects of the reproductive biology of female snakehead (Channa striata Bloch) obtained from irrigated rice agroecosystem, Malaysia. Hydrobiologia **411:**71-77.

Ali AB, Kadir BKA. 1996. The reproductive biology of the cyprinid, *Thynnichthys thynnoides* (Bleeker), in the Chenderoh Reservoir - a small tropical reservoir in Malaysia. Hydrobiologia **318:**139-151.

Alikunhi KH. 1953. Notes on the bionomics, breeding and growth of the murrel, *Ophiocephalus striatus* Bloch. Proc Indian Acad Sci **38:**10-20.

Amilhat E, Lorenzen K. 2005. Habitat use, migration pattern, and population dynamics of chevron snakehead *Channa striata* in a rainfed rice farming landscape. J of Fish Biol **67(supplement B):**23-34.

Balirwa, JS, Chapman CA, Chapman LJ, Cowx IG, Geheb K, Kaufman L, Lowe-McConnell RH, Seehausen O, Wanink JH, Welcomme RJ, Witte F. 2003. Biodiversity and fishery sustainability in the Lake Victoria Basin: an unexpected marriage? BioScience **53:**703-715.

Chen RT, Ho PH, Lee HH. 2003. Distribution of exotic freshwater fishes and shrimps in Taiwan. Endem Sp Res **5:**33-46. (in Chinese).

Chiu YW, Tso CW, Shieh BS, Liu CC, Lin YS, Liang SH. 2012. Evaluation of the predatory effect on fish community by an introduced fish, *Culter alburnus*, in a small stream of northern Taiwan. Zool Stud **51(8):**1438-1445.

Courtenay WR, Williams JD. 2004. Snakeheads (Pisces, Channidae) – A biological synopsis and risk assessment. US Geological Survey, Gainesville.

Dasgupta M. 2000. Adaptation of the alimentary tract to feeding habitat in four species of fish of the genus *Channa*. Indian J Fish **47(2):**100-109.

Gam L-H, Leow C-Y, Baie S. 2006. Proteomic analysis and snakehead fish (*Channa striata*) muscle tissue. Malaysian Journal of Biochemistry and Molecular Biology **14:**25-32.

Han CC, Tew KS, Chen IS, Su LY, Fang LS. 2000. Environmental biology of an endemic cyprinid, *Varicorhinus alticorpus,* in a subtropical mountain stream of Taiwan. Env Biol Fish **59:**153-161.

Herborg LM, Mandrak NE, Cudmore BC, MacIsaac HJ. 2007. Comparative distribution and invasion risk of snakehead (Channidae) and Asian Carp (Cyprinidae) species in North America. Can J Fish Aquat Sci **64:**1723-1735.

Herre AWCT. 1924, Distribution of the true fresh-water fishes in the Philippines, Vol. II of The Philippine Labyrinthici, Clariidae, and Siluridae. Philipp J of Sci **24(6):**683-709.

Holden MJ, Raitt DFS. 1974. Manual of fisheries science. Part 2. Methods of resource investigation and their application. FAO Fish Tech Rep 115.

Jang MH, Joo G-J, Lucas MC. 2006. Diet of introduced largemouth bass in Korean rivers and potential interactions with native fishes. Ecol Freshw Fish **15(3):**315-320.

Jhingran AG. 1984. The fish genetic resources of India. Bureau of Fish Genetic Resources, Allahabad. India.

Jiao Y, Lapointe NWR, Angermeier PL, Murphy BR. 2009. Hierarchical dempgraphic approaches for assessing invasion dynamics of non-indigenous species: an example using northern snakehead (*Channa argus*). Ecol Model **220:**1681-1689.

Karapanagiotidis LT, Yakupitiyage A, Little DC, Bell MV, Mente E. 2010. The nutritional value of lipid in various tropical aquatic animals from rice-fish farming systems in northeast Thailand. Journal of Food Composition and Analysis **23:**1-8.

Kilambi RV. 1986. Age, Growth, and reproductive strategy of the snakehead, *Ophiocephalus striatus* Bloch, from Sri Lanka. J Fish Biol **29:**13-22.

Korsu K, Huusko A, Muotka T. 2009. Does the introduced brook trout (*Salvelinus fontinalis*) affect growth of the native brown trout (*Salmo trutta*)? Naturwissenschaften **96(3):**347-353.

Marimuthu K, Haniffa MA. 2007. Embryonic and larval development of the striped snakehead *Channa Striataus*. Taiwania **52:**84-92.

Maezono Y, Miyashita T. 2003. Community-level impacts induced by introduced largemouth bass and bluegill in farm ponds in Japan. Biol Conserv **109:**111-121.

Lee PG, Ng PKL. 1991. The snakehead fishes of the Indo-Malaysia region. Nature Malaysia **16(4):**113-129.

Liem KF. 1987. Functional design of the air ventilation apparatus and overhand excursions of teleosts. Fieldiana Zoology **37:**1-29.

Nielsen LA, Johnson DL.(eds.) 1983. Fisheries techniques. American Fisheries Society, Bethesda.

Parameswaran S, Murugesan VK. 1976. Observations on the hypophysation of murrels (Ophiocephalidae). Hydrobiologia **50:**81-87.

Shelton JM, Samways MJ, Day JA. 2015. Non-native rainbow trout change the structure of benthic communities in headwater streams of the Cape Floristic Region, South Africa. Hydrobiologia **745:**1-15.

Townsend CR. 1996. Invasion biology and ecological impacts of brown trout *Salmo trutta* in New Zealand. Biol Conserv **78:**13-22.

Vishwanath W, Geetakumari KH. 2009. Diagnosis and interrelationships of fishes of the genus *Channa* Scopoli (Teleostei: Channidae) of northeastern India. Journal of Threatened Taxa **1:**97-105.

Wan Yaakob WAA, Ali AB. 1992. Simple method for backyard production of snakehead (*Channa striata* Bloch) fry. NAGA the ICLARM Quarterly **15:**22-23.

Wang GS, Sha ML, Chang ST. 2010. A Key to the Species of the Genus *Channa* (Channidae: Teleostei) of Taiwan with Description of a Ventral Fin Abnormal Specimen of *Channa Striata* (Bloch, 1793) Taiwan Journal of Biodiversity **12(4):**419-426. (in Chinese)

Yam RSW, Huang KP, Hsieh HL, Lin HJ, Huang SC. 2015. An ecosystem service approach to evaluate the role of non-native species in urbanized wetlands. Int J Environ Res Publ Health **12(4):**3926-3943.