



## Age, growth and reproduction of cutlassfishes *Trichiurus* spp. in the southern East China Sea

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### Summary

The cutlassfish is one of the most commercially important continental fishes in the East China Sea. However, the current classification of cutlassfishes is suboptimal and complicates fisheries management. This study investigated the growth and reproduction of three cutlassfish species in the southern East China Sea. Between August 2002 and September 2003, a total of 2717 specimens of *Trichiurus japonicus*, *T. sp.2* (likely synonymous for *T. nanhaiensis*) and *T. lepturus* were collected monthly from Daxi, Anping, Nanfangao, Donggang and Xingang fishing ports. The von Bertalanffy growth model in preanal length (PL) resulted in PL (mm) =  $560.79\{1 - e^{[-0.233(t+1.762)]}\}$  for *T. japonicus*, PL (mm) =  $620.38\{1 - e^{[-0.172(t+2.161)]}\}$  for *T. sp.2* and PL (mm) =  $869.53\{1 - e^{[-0.182(t+2.161)]}\}$  for *T. lepturus*. Their growths were significantly different between sexes for *T. japonicus* and *T. sp.2* and among the three species. From macroscopic examination of ovaries, histological inspection of oocytes, and analyses of gonosomatic and hepatosomatic indices, *T. japonicus* was likely to spawn all year round, with two peaks in February–July and November–December. *T. sp.2* spawned relatively later, between April and August. The length at sexual maturity of *T. japonicus* females was 264 mm PL or 746 mm total length. The sex ratios of *T. japonicus* and *T. sp.2* were significantly different from 1 : 1 whereas *T. lepturus* showed no significant difference. The three species of trichiurids have different geographical distributions in this region.

### Introduction

Cutlassfish are found throughout tropical and temperate waters of the world between latitudes 60°N and 45°S (Froese and Pauly, 2007). World harvests are approximately 1 300 000 tonnes annually, of which about 60% are caught by China (FAO, 2009). In the East China Sea, the cutlassfish is one of the most common and important commercial species and caught mainly by bottom trawling and in smaller amounts by set net, gill net and longline. The average catch size has gradually decreased, with fish reach sexual maturity at a younger age because of heavy fishing pressure in this region (Du et al., 1988).

*Trichiurus* species have long been confused taxonomically due to their similar body appearance and coloration. Overall, 29 nominal species (15 valid species) are described worldwide (Froese and Pauly, 2007; Hsu et al., 2007). Most are synonymized under *T. lepturus* (Nakamura and Parin, 1993). The taxonomic classification of *T. lepturus* was uncertain in the East China Sea (Lee et al., 1977; Lin and Shen, 1986), and had

been classified into one (Du et al., 1988) or two species (Lee et al., 1977; Chen and Lee, 1982; Jean and Lee, 1984). Recently, three species of *Trichiurus*, i.e. *T. japonicus*, *T. sp.2* and *T. lepturus* were confirmed in this region (Hsu et al., 2009).

Knowing the growth rate and breeding activity of an exploited fish species are important components for fisheries management. Over the past decades, age and growth of cutlassfish in China seas have been investigated by various methods such as using sectioned otoliths (Wu et al., 1985; Kwok and Ni, 2000), vertebral centrums (Du et al., 1988) and whole otoliths (Hong, 1980; Lin and Zhang, 1981; Chen and Lee, 1982). Cutlassfish reproductive studies have described prolonged spawning periods in the East China Sea (Li, 1982; Luo et al., 1982, 1983; Gong et al., 1984; Park et al., 1998) and the South China Sea (Kwok and Ni, 1999). Although growth and reproductive studies on cutlassfish have been conducted in China seas, these studies were based upon one or two species and may have been complicated by the confusing taxonomy.

In this study, three species of trichiurids (*T. japonicus*, *T. sp.2* and *T. lepturus*) were observed in the southern East China Sea. The specific objectives of this study were (i) to estimate age by using sectioned sagittal otoliths and to validate age estimates by employing the marginal increment method; (ii) to fit the age-length data to the von Bertalanffy growth model; (iii) to examine the reproductive cycle and spawning period; and (iv) to evaluate the size and age at sexual maturity of *Trichiurus* spp.

### Materials and methods

#### Sampling

A total of 2717 *Trichiurus* spp. was collected from five fishing ports in Taiwan between August 2002 and September 2003 (Fig. 1). A majority of the specimens were collected from Daxi and Anping, with additional samples from Nanfangao, Donggang and Xingang (Table 1). Fish were caught with bottom trawls, set nets and longlines. Fresh specimens were classified by using diagnostic keys as described by Li (1992) and Nakabo (2002) to identify *T. japonicus*, Nakabo (2002) for *T. sp.2*, and Burhanuddin (2003) for *T. lepturus*. Partial specimens were identified by using both mtDNA partial 16S ribosomal subunit and cytochrome b genes (Hsu et al., 2009). Total length (TL) and preanal length (PL) were measured to the nearest millimeter. Total body weight (BW) and gutted body weight (GW) were measured to the nearest gram. Livers and ovaries were weighed to the nearest 0.01 g. Ovaries were fixed in 10% formalin for histological inspection. Analysis of

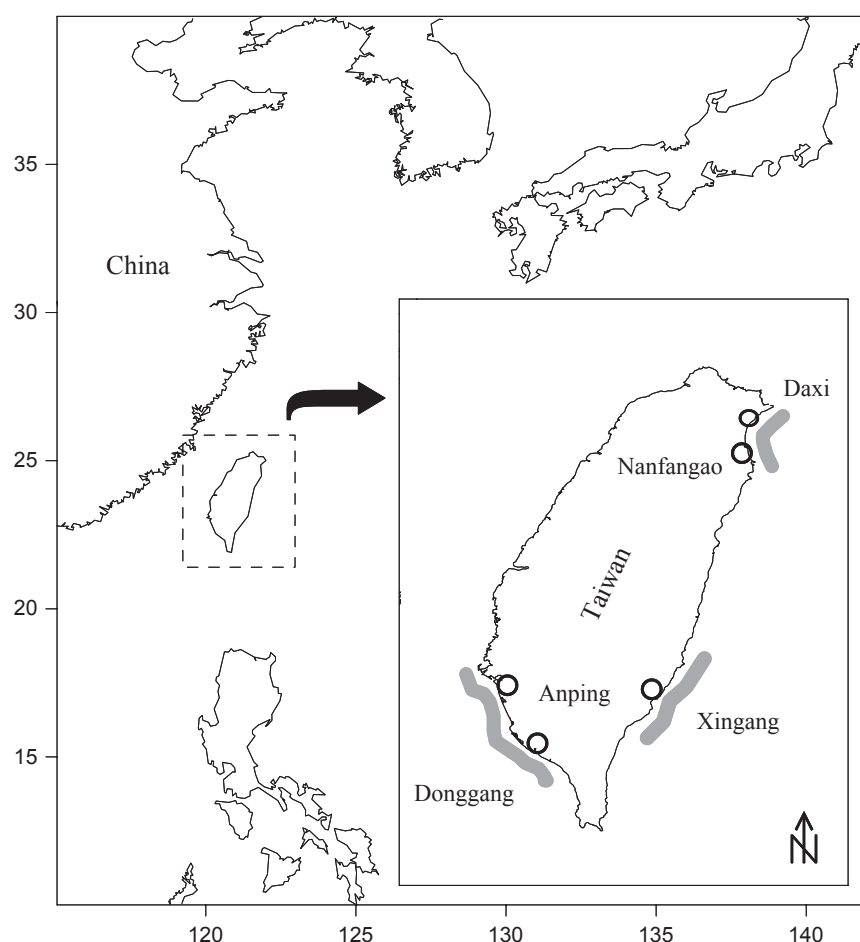


Fig. 1. Map of Taiwan showing sampling locations. Grey regions indicate extent of fishing grounds at each location. Cutlassfish specimens were caught by bottom trawls in Daxi, Anping and Donggang, by set nets in Nanfanggao, and by longlines in Xingang

covariance (ANCOVA) was used to compare the TL-PL and log-transformed BW-TL relationships between sexes and among species.

#### Ageing technique and age validation

As there is no difference in the number of growth rings between the left and right sectioned otoliths of cutlassfish, the right sagitta was used for age determination (Kwok and Ni, 2000). Sagittal otoliths were embedded in epoxy resin and sliced transversely through the edge of nucleus at about 200  $\mu\text{m}$  thickness. Sections were ground until a thin section through the nucleus remained. The sections were aged by counting the number of annual opaque growth rings under a compound microscope at 40 $\times$  magnification. Each sectioned otolith was read twice by one reader about 1 month apart without prior knowledge of fish size and sex to avoid reading bias. The precision was evaluated by the percentage of agreement between readings (Lowerre-Barbieri et al., 1994). When counts did not agree, a third reading was then taken. Only coincident readings were accepted. The marginal increment method was applied to determine the periodicity of the formation of rings and to validate the reading of annuli. The marginal increment of sectioned otolith was measured to the nearest 0.025 mm.

#### Growth equation

Estimates of the growth in length were obtained by fitting the von Bertalanffy growth equation (VBGE) to PL and TL at age

data. Having considered the reproductive period, 1 May, 1 June and 1 May (see Kwok and Ni, 1999) were assigned as the birth dates for *T. japonicus*, *T. sp.2* and *T. lepturus*, respectively. The ages of specimens were then estimated based on the birth date, date of capture, and the period of annulus formation. The growth curve  $PL_t = PL_\infty \{1 - e^{[-k(t-t_0)]}\}$  was used where  $PL_\infty$  is the asymptotic preanal length,  $k$  is the growth coefficient, and  $t_0$  is the hypothetical age at zero length. The VBGE was fitted by the PROC NLIN method using SAS (Ver. 9.1). The Chi-square tests of likelihood ratios were used to test whether growth curves were significantly different between sexes for *T. japonicus* and *T. sp.2* and between the two species (Kimura, 1980).

#### Gonad processing and reproductive period

A two-way analysis of variance showed no significant difference in oocyte diameters among six portions from three individual ovaries ( $P > 0.05$ ,  $n = 18$ ). As such, oocytes of different sizes were considered as being distributed homogeneously throughout the ovary. Only female *T. japonicus* oocytes and ovaries were examined histologically and macroscopically because mature *T. sp.2* and *T. lepturus* female specimens were limited. The central parts of 373 *T. japonicus* ovaries were embedded in paraffin, sectioned at 6–8  $\mu\text{m}$  thickness and stained subsequently with Hematoxylin-Eosin following standard histological techniques. Gonad maturation was categorized by histological inspection of oocytes following the scale modified from Bancroft and Stevens (1996) (Table 2).

Table 1

Cutlassfishes, *Trichiurus* spp., used in this study. Area N (northeast) includes Daxi and Nanfangao fishing ports, S (southwest) includes Anping and Donggang fishing ports, and E (east) is the Xingang fishing port

Month	Area	<i>T. japonicus</i>		<i>T. nanhaiensis</i>		<i>T. lepturus</i>	
		n	PL (mm)	n	PL (mm)	n	PL (mm)
Jan.	N	62	225–443	57	292–344		
	S	100	214–300	65	223–345		
	E					15	257–595
Feb.	N	114	201–440				
	S	39	246–317	23	235–307		
Mar.	N	87	144–450				
	S	110	194–288	10	204–308		
Apr.	N	71	196–302				
	S	92	223–325	2	244–277		
May	N	52	87–435				
	S	99	212–334	2	278		
June	N	114	127–409	6	338–459		
	S	67	197–388	15	242–295		
July	N	49	253–431	9	263–329		
	S	53	205–307	5	188–313		
	E					23	392–761
Aug.	N	93	140–360				
	S	41	219–344	13	230–460		
	E					2	665–793
Sept.	N	257	57–400	3	224–322		
	S	29	229–353	12	264–329		
Oct.	N	81	198–410	1	270		
	S	101	170–432	80	160–432		
Nov.	N	130	140–440				
	S	237	202–435	37	193–275		
Dec.	N	87	172–447	6	195–300		
	S	132	212–295	34	223–272		
Total		2297	57–450	380	160–460	40	257–793

Monthly mean gonosomatic index (GSI = gonad weight  $\times 10^3$ /GW) and hepatosomatic index (HSI = liver weight  $\times 10^3$ /GW) were plotted separately for mature males and females of *T. japonicus* and *T. sp.2* to determine seasonal patterns of the peak spawning period and energy storage.

#### Size at sexual maturity and sex ratio

The mean length at 50% maturity was defined as size at sexual maturity and determined by a logistic model that describes the

relationship between the proportion of mature stage and body length. The function is  $Y = 1/[1 + e^{-(a+bx)}]$  (Ni and Sandeman, 1984), where  $Y$  is the proportion of sexually mature individuals in each length group;  $x$  is the PL or TL;  $a$  and  $b$  are coefficients. Sex ratios (number of males/number of females) were estimated for each month and length group (in 50 mm groups). A Chi-square test was employed to determine if the proportion of males and females was significantly different from 1 : 1.

## Results

### Length-weight relationships

*T. japonicus* ranged between 200 and 1204 mm TL, *T. sp.2* between 438 and 1094 mm TL and *T. lepturus* between 692 and 1826 mm TL. The TL and PL relationships were linear and significantly different between sexes (ANCOVA: *T. japonicus*:  $F_{2,1938} = 86.13$ ,  $P < 0.001$ ; *T. sp.2*:  $F_{2,358} = 36.40$ ,  $P < 0.001$ ; *T. lepturus*:  $F_{2,35} = 6.02$ ,  $P < 0.05$ ) and among species ( $F_{3,2333} = 591.58$ ,  $P < 0.001$ ). The TL and BW regression models were also significantly different between sexes (*T. japonicus*:  $F_{2,1937} = 66.72$ ,  $P < 0.001$ ; *T. sp.2*:  $F_{2,356} = 33.61$ ,  $P < 0.001$ ; *T. lepturus*:  $F_{2,35} = 4.80$ ,  $P < 0.05$ ) and among species ( $F_{3,2330} = 213.57$ ,  $P < 0.001$ ).

### Age estimates and growth models

The shape and annuli pattern of transversely sectioned sagittal otoliths were similar among the three cutlassfish species which presented an opaque nucleus with alternating broad translucent bands and narrow opaque bands. Annuli were more distinct on the dorsal side of the sections (Fig. 2). A total of 1 220 263 and 36 otoliths of *T. japonicus*, *T. sp.2* and *T. lepturus*, respectively, were sectioned for ageing. Of these, 43 (3.5%), 16 (6.1%) and 2 (5.6%) were unable to be aged, particularly for those of the older and larger fishes. The percentage agreement between readings for each species was 94.1, 91.2 and 91.7%, respectively.

The least marginal increment values occurred in February and December for *T. japonicus* and *T. sp.2*, respectively, suggesting that one growth ring formed on an annual basis for the two species (Fig. 3). Although there was a lack of year-round samples, it was assumed that growth rings formed each

Table 2

Macroscopic and histological criteria for assessing reproductive development stages of female *T. japonicus*

Reproductive stage		Ovary macroscopic appearance	GSI	Max. oocyte diameter (mm)	Oocyte histological characteristics
I	Immature	Ovary very small, slender and lacteous; oocytes invisible to the naked eye	< 20	< 0.45	Chromatin-nucleous, peri-nucleolus and yolk vesicle oocytes occur
II	Early maturing	Ovary about 50% length of ventral cavity; yellowish in color; oocytes gradually visible	20–45	0.42–0.85	Earlier of secondary yolk phases, the primary yolk oocytes predominant
III	Late maturing	Ovary occupying 60–80% of ventral cavity; yellowish in color; vascularization in the back of the ovaries; visible oocytes large	45–70	0.82–0.95	Oocytes predominantly of yolk stage mainly secondary and tertiary yolk oocytes
IV	Mature	Ovary swollen; pinkish in color; oocytes large, nearly transparent; vascularization heavy in the back of the ovaries	70–260	0.95–1.60	Oocytes predominantly of migratory nucleus stage and ripe egg phases
V	Spent	Ovary translucent with pale violet color. Ovary thin and flaccid, residual oocytes visible	15–60	0.90–1.20	Residual oocytes in various phases of atresia; postovulatory follicles present

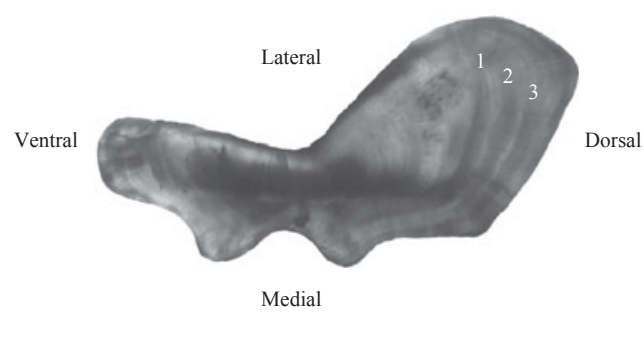


Fig. 2. Photomicrograph of sectioned *Trichiurus japonicus* otolith in transmitted light. Numbers show position of opaque bands (scale bar = 1 mm)

year for *T. lepturus* (Kwok and Ni, 2000). VBGEs were expressed for male, female and sexes combined in preanal length and total length for the three species (Table 3). The VBGEs were significantly different between sexes for *T. japonicus* (PL:  $\chi^2 = 45.2$ ,  $P < 0.01$ ; TL:  $\chi^2 = 90.8$ ,  $P < 0.01$ ) and *T. sp.2* (PL:  $\chi^2 = 23.0$ ,  $P < 0.01$ ; TL:  $\chi^2 = 10.58$ ,  $P < 0.05$ ) as well as between species for sexes combined (PL:  $\chi^2 = 83.9$ ,  $P < 0.01$ ; TL:  $\chi^2 = 70.3$ ,  $P < 0.01$ ). Von Bertalanffy growth curves in preanal length for sexes combined are depicted in Fig. 4. Most samples ranged from age 0 to 6 for all species. Estimated  $L_{\infty}$  of *T. japonicus* was smaller than those of the other two species. The  $t_{\max}$  (age at 95% of asymptotic length) were 11.1, 15.3 and 16.1 years for *T. japonicus*, *T. sp.2* and *T. lepturus*, respectively.

#### Gonad development and spawning period

Both sexes of *T. japonicus* had two peaks in GSI and HSI. GSI of *T. japonicus* females and males increased from January to the first peak in March and April, respectively, then declined

significantly to a trough in September, and finally increased again to a minor peak in November and October, respectively (Fig. 5a,b). Similar patterns were observed for the HSI of *T. japonicus* females and males (Fig. 5a,b). Despite the fact that specimens of both sexes of *T. sp.2* were limited in April, May and July, relatively high values of GSI and HSI of *T. sp.2* females occurred in April and August (Fig. 5c). Similar patterns were also found in GSI and HSI of *T. sp.2* males (Fig. 5d).

Oocytes of *T. japonicus* females were divided into eight developmental phases based on histological inspection: (i) chromatin-nucleous phase: basophilic oocytes with one larger nucleus and several smaller nucleoli (Fig. 6a); (ii) peri-nucleolus phase: oocytes with several small nucleoli in the periphery of the nucleus (Fig. 6b); (iii) yolk vesicle phase: the cytoplasm full of yolk vesicles and oil globules (Fig. 6c); (iv) primary yolk phase: acidophilic yolk globules appeared at the circumference of the cytoplasm (Fig. 6d); (v) secondary yolk phase: yolk globules occupied the cytoplasm completely (Fig. 6e); (vi) tertiary yolk phase: yolk globules filled the cytoplasm and began to integrate into the yolk mass (Fig. 6f); (vii) migratory nucleus phase: the yolk appeared as a homogeneous mass filling the interior of the oocytes and the nucleus moved to the periphery of the oocyte (Fig. 6g); (viii) ripe egg phase: oocytes were irregular in shape and had a large oil droplet (Fig. 6h). Finally, postovulatory follicles from a spawned female are illustrated in Fig. 6i.

Five gonadal stages of *T. japonicus* were defined by macroscopic examination of ovaries, oocyte diameter composition, GSI and histological inspection (Table 2). Of note is that more than one developmental phase might occur in one particular gonadal maturation stage (e.g. maturing stages). According to the monthly variation in ovary maturity stages, the spawning period of *T. japonicus* occurred throughout the year with two peaks, i.e. from March to July and November to December (Fig. 7). The spawning period of *T. sp.2* was from April to August, inferred by the monthly variation in GSI and HIS.

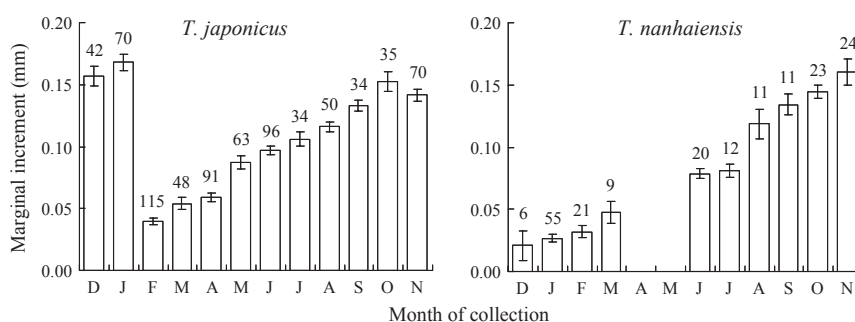


Fig. 3. Mean monthly otolith marginal increment for *T. japonicus* and *T. nanhaiensis*. Vertical bars are 1 SE, numbers on top of vertical bars are sample sizes

Table 3

Growth parameters of von Bertalanffy model of *Trichiurus* spp. in preanal length (PL) and total length (TL)

Species	Sex	PL <sub>∞</sub>	k	t <sub>0</sub>	TL <sub>∞</sub>	k	t <sub>0</sub>	n
<i>T. japonicus</i>	M	577.34	0.221	-1.823	1381	0.215	-2.773	216
	F	543.10	0.253	-1.654	1408	0.253	-2.226	931
	M + F	560.79	0.233	-1.762	1435	0.234	-2.316	1147
<i>T. nanhaiensis</i>	M	621.12	0.169	-2.264	1446	0.184	-2.596	56
	F	621.70	0.166	-2.195	1418	0.183	-2.692	167
	M + F	620.38	0.172	-2.161	1439	0.179	-2.703	223
<i>T. lepturus</i>	M + F	869.53	0.182	-0.416	1986	0.182	-1.127	34



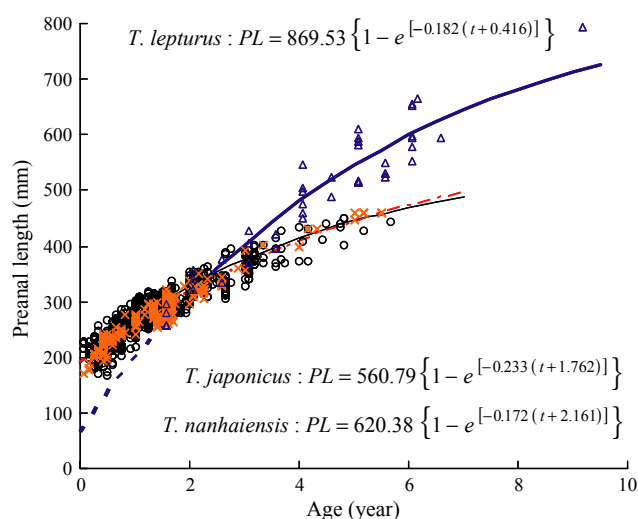


Fig. 4. Von Bertalanffy growth curve in preanal length of *Trichiurus* spp. Solid line and circles: *T. japonicus*; dotted line and crosses: *T. nanhaiensis*. Solid thick line and triangle: *T. lepturus*

#### Size at sexual maturity and sex ratio

*T. japonicus* females with ovaries in the mature and spent phases were categorized as mature. The regression results between the proportion of mature *T. japonicus* females and preanal length was as follows:

$$P = 1/(1 + e^{6.7694 - 0.0256 PL}), r^2 = 0.945, n = 232$$

Size at 50% of sexual maturity of *T. japonicus* females was calculated as 264 mm PL. This size corresponded to 746 mm TL and 11.6 months of age (estimated by using VBGE derived above).

Sex ratios were 0.22 for *T. japonicus* (388/1796), 0.43 (111/259) for *T. sp.2*, and 1.5 (24/16) for *T. lepturus*. A chi-square analysis indicated significant deviation from a 1 : 1 sex ratio for *T. japonicus* and *T. sp.2* among different size ranges (*T. japonicus*:  $\chi^2_7 = 491.76$ ,  $n = 2184$ ,  $P < 0.01$ ; *T. sp.2*:  $\chi^2_6 = 43.89$ ,  $n = 370$ ,  $P < 0.01$ ; Fig. 8a) and different months

(*T. japonicus*:  $\chi^2_{11} = 1091.00$ ,  $n = 2297$ ,  $P < 0.01$ ; *T. sp.2*:  $\chi^2_{11} = 93.37$ ,  $n = 380$ ,  $P < 0.01$ ; Fig. 8b). The sex ratio of *T. lepturus* did not differ significantly from 1 : 1 among the three sampling months ( $\chi^2_2 = 5.92$ ,  $n = 40$ ,  $P < 0.05$ ).

#### Discussion

##### Cutlassfish species distribute differently

*T. japonicus* and *T. sp.2* are the most frequently caught hairtails in the East Asian Shelf (Nakabo, 2002), but the barriers between *T. japonicus* and *T. sp.2* are inferred to lie along the southeastern coast of Taiwan (Hsu et al., 2009). The predominant trichiurid species in the waters adjacent to Taiwan was *T. japonicus*, which was caught year round (Table 1). About 80% of *T. sp.2* samples were collected from southern waters, which corroborates with previous distribution studies (Hsu et al., 2009). Only a limited number of *T. sp.2* and *T. lepturus* mature females were collected from the sampling areas, inferring that either the mature individuals of these two species might migrate to different and/or deeper waters for reproductive purposes, or that these two species have a different geographical distribution. Kwok and Ni (1999, 2000) report two dominant cutlassfishes, *T. lepturus* and *T. nanhaiensis* in the South China Sea, and Hsu et al. (2009) suggest that *T. nanhaiensis* is likely synonymous with our *T. sp.2*. Additionally, our results disagree with previous studies, which reported either only one (Du et al., 1988) or two species of Trichiuridae (Lee et al., 1977; Chen and Lee, 1982; Jean and Lee, 1984) occurring in the southern East China Sea.

##### Ring formation, age estimation and growth model

High precision in independent ring counts on sectioned otoliths provides accurate age estimates for fishes. The alternating translucent and opaque bands on sagittal otoliths have been attributed to various factors such as seasonal temperature variations (Wu et al., 1985; Du et al., 1988; Gonzalez Castro et al., 2009) or reproductive cycles (Chen and Lee, 1982; Pérez and Fabr , 2009). From the observation of

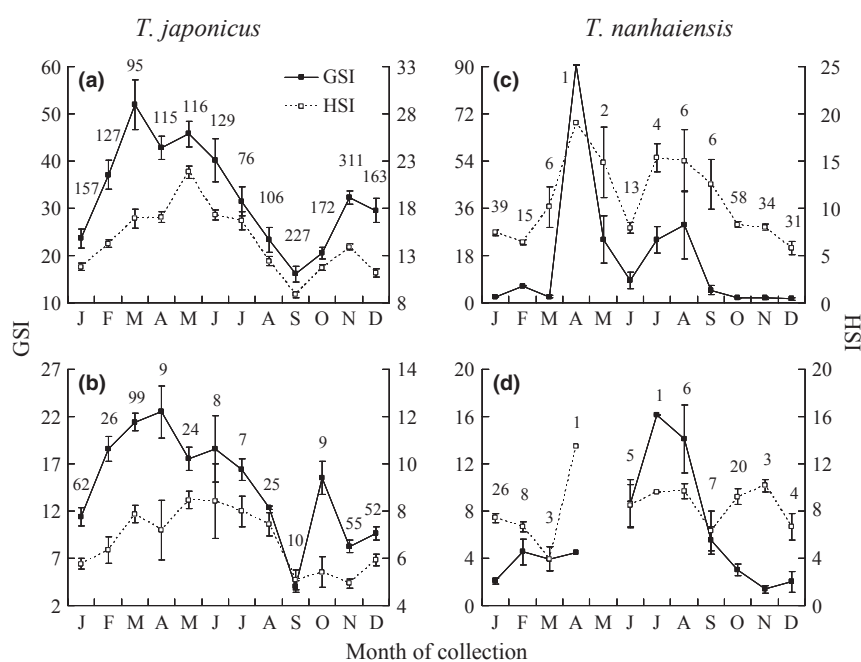


Fig. 5. Monthly variation in gonosomatic index and hepatosomatic index of *T. japonicus* (a) females, (b) males, and *T. nanhaiensis* (c) females, (d) males. Black line: GSI  $\pm$  SE. Dotted line: HSI  $\pm$  SE. Numbers are sample sizes

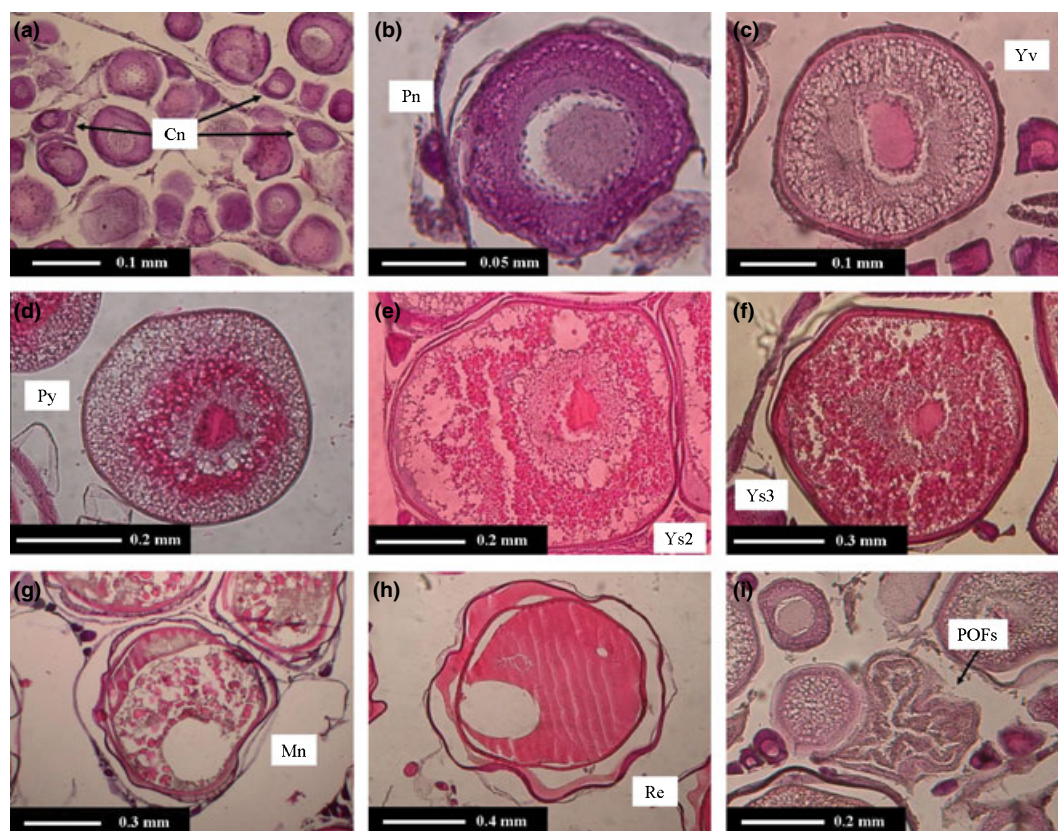


Fig. 6. Histological appearance of *T. japonicus* oocyte development (a) Cn: Chromatin-nucleous phase, (b) Pn: Peri-nucleolus phase, (c) Yv: Yolk vesicle phase, (d) Py: Primary yolk phase, (e) Ys2: Secondary yolk phase, (f) Ys3: Tertiary yolk phase, (g) Mn: Migratory nucleus phase, (h) Re: Ripe egg phase, and (i) POFs: postovulatory follicles

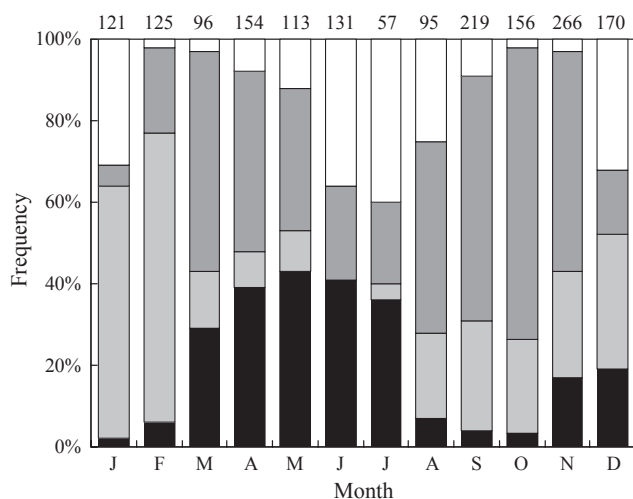


Fig. 7. Monthly variations of female *T. japonicus* ovary maturity stage. Sample size at top of each column. Maturity phases as explained in Table 2: black = mature, light grey = immature and early maturing, dark grey = late maturing, white = spent

marginal increment in *T. japonicus* and *T. sp.2*, the annuli were confirmed as being deposited annually, occurring during late winter to early spring. The growth rings on sagittal otoliths of *T. lepturus* were also formed annually between November and January for the East China Sea population (Hamada, 1971) or in February for the South China Sea population (Kwok and Ni, 2000). Therefore, the low water temperature in winter was probably the most important factor controlling opaque band formation of cutlassfishes. No clear

association between spawning season and timing of ring formation has been found.

In comparing the von Bertalanffy growth coefficients for *T. japonicus* in the East China Sea derived from different studies (Table 4), the results of this study had a lower growth coefficient than previous studies. This discrepancy was likely due to different ageing methods that had been employed or might reflect that the current cutlassfish resource had increased significantly (Yan et al., 2007) as the result of an enforced closed fishing for three summer months in the East China Sea. *T. sp.2* and *T. lepturus* possessed lower growth coefficients than *T. japonicus*. In this connection, exploitation of these two trichiurids species should be more cautious in order to avoid population collapse. An evident discrepancy in growth coefficient and asymptotic PL for *T. lepturus* in China seas can likely be ascribed to taxonomic confusion. Furthermore, male *T. japonicus* and *T. sp.2* attained larger sizes than did females in this study, indicating that females might expend more energy on reproduction than males or that the larger females were not captured by the fishery.

#### Cutlassfish had a prolonged spawning period

In general, the gonosomatic index is an objective indicator of seasonal trends for gonad development (West, 1990). This is supported by the fact that GSI values correlated well with histological findings in *T. japonicus* females (Fig. 5a,b). As fishes may store the energy required for spawning inside the liver, the high correlation between HSI and GSI values in both sexes of *T. japonicus* and *T. sp.2* females were observed (Fig. 5a,b,c). Jons and Miranda (1997) emphasized that using

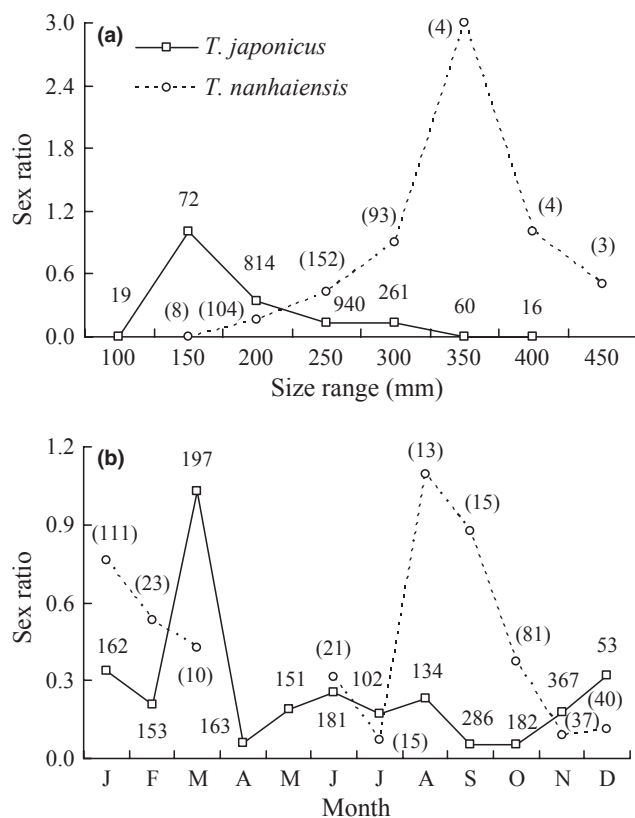


Fig. 8. Variation of sex ratios (a) among different size ranges and (b) months for *T. japonicus* and *T. nanhaiensis*. Numbers without parentheses = sample sizes of *T. japonicus*, with parentheses = sample sizes of *T. nanhaiensis*

GSI or HSI values to compare the maturity of gonads in fishes should be treated with more caution, particularly in multiple spawning fishes. However, there was no evidence of the coexistence of postovulatory follicles and migratory oocytes of histological sections. These indicated that *T. japonicus* practiced synchronous group spawning (Nagahama, 1983) and spawned once per season. The same conclusion was also made for *T. japonicus* in the waters off Taiwan (Jean and Lee, 1984), and for *T. nanhaiensis* and *T. lepturus* in the South China Sea (Kwok and Ni, 1999).

The spawning period of *T. japonicus* obtained in this study did not agree with Jean and Lee (1984), who reported that the spawning period is from October to June. This discrepancy is because the spawning season of *T. japonicus* may vary among

years (El-Hawet and Ozawa, 1996) and populations in the East China Sea are composed of two brood stocks, i.e. spring–summer spawners and autumn spawners (Li, 1982; Gong et al., 1984). Despite the fact that the spawning period of *T. sp.2* was only inferred by GSI and HSI values, the results, i.e. from April to August still agreed with *T. nanhaiensis* in the South China Sea (Kwok and Ni, 1999). The southern East China Sea might not be the major spawning grounds for *T. sp.2* and *T. lepturus* due to limited mature specimens.

#### Sex ratio and size at sexual maturity

Unequal sex ratios in the larger fish could likely be caused by different rates of growth and mortality. The growth studies indicated that the *T. japonicus* and *T. sp.2* females had a greater growth rate and a smaller maximum size than males (Table 3). Therefore, the growth rate could not explain skewed sex ratios for the two species. The deviation in sex ratios among different size ranges might be related to other factors such as spatial variation. In Fig. 8b, the sex ratios for *T. japonicus* were similar between sexes in samples in March, indicating that *T. japonicus* males might arrive at the spawning grounds with females during the beginning of the spawning period. However, the reverse phenomenon in the sex ratio of *T. sp.2* during the end of the spawning season remains a question for further investigation.

Previous studies in the 1960s documented the size at sexual maturity of *T. japonicus* females in the East China Sea as about 230–240 mm PL at age 1 year (Luo et al., 1982), which decreased to about 200 mm PL at the age of 7 months in 1979–1980 (Luo et al., 1983). The decline in size and age at sexual maturity for *T. japonicus* was possibly due to serious overfishing in this area since size selective fishing would favor early maturity (Du et al., 1988). In the present study the size at sexual maturity was 264 mm PL for *T. japonicus* females, which was larger than those of their counterparts in the northern East China Sea. This might indicate that *T. japonicus* off Taiwan was either subject to less fishing pressure than their counterparts or attributable to seasonal change, spatial change, or gear change in fishing effort of the fishery.

#### Management suggestions

The collapse of fishery resources is an increasingly common phenomenon (Pauly et al., 2003). Concern in this issue has led to extensive interest in the management of available fish resources. In this study, three *Trichiurus* species, i.e. *T. japo-*

Table 4  
Summary of age and growth studies of *Trichiurus* spp., East China Sea and South China Sea

Species	Locality	Growth parameters			Authors
		<i>k</i>	PL <sub>∞</sub>	<i>t</i> <sub>0</sub>	
<i>T. japonicus</i>	East China Sea	0.293	553	−0.681	Wu et al., 1985
	East China Sea	0.289	550	−0.760	Chen and Lee, 1982
	East China Sea	0.292	477	−0.634	Du et al., 1988
	East China Sea	0.233	561	−1.762	This study
<i>T. nanhaiensis</i>	East China Sea	0.177	620	−2.043	This study
<i>T. lepturus</i>	East China Sea	0.182	869	−0.416	This study
	East China Sea	0.408	456	0.440	Misu, 1964
	East China Sea	0.139	766	−0.266	Hamada, 1971
(Male)	South China Sea	0.116	755	−2.737	Kwok and Ni, 2000
(Female)	South China Sea	0.158	601	−2.850	Kwok and Ni, 2000



*nicus*, *T. sp.2* and *T. lepturus* had diversified geographic distributions (Table 1) and different growth rates (Table 3). Therefore, proper management strategies for cutlassfishes in waters off Taiwan should be developed based upon the vital statistics of the three species instead of only one as at present, and the spatial variation required should consider providing feasible management scenarios. Furthermore, *T. japonicus* was the most common and dominant species of trichiurids in the southern East China Sea, where it possessed a high growth rate and was capable of spawning in the same year after hatching. The feasible approach in the management of *T. japonicus* fisheries would probably be to implement a closed fishing season during the spawning season so as to protect the recruitments (Shih et al., 2009). However, management of only this species would result in the overfishing of the other two species. We strongly suggest that to exploit these two species with their lower growth rates should be treated with caution.

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