Abstract—Age and growth of two species of cutlassfishes, *Trichiurus* spp. (Trichiuridae), from the South China Sea were examined. Between December 1996 and November 1997, 1495 specimens were collected from coastal waters near Hong Kong. Two species, *Trichiurus lepturus* and *T. nanhaiensis,* were harvested and ages of specimens were estimated by using transverse sections of the sagittal otoliths. Opaque growth rings were verified to have formed annually during February. Lee's phenomenon was not observed for either species, although *T. lepturus* tended to display reverse Lee's phenomenon. Otolith weight was linearly related to age, and accounted for about 72% and 76% of the variation in age (t) for *T. lepturus* and *T. nanhaiensis*, respectively, comparable to the von Bertalanffy growth models in preanal length (PL). For older fish, otolith weight provided a more precise estimate of age than preanal length. Preanal length and age were fitted to the von Bertalanffy growth model by nonlinear regression, resulting in

$$PL\ (\text{mm}) = 589\{1 - e^{[-0.168\ (t\ +\ 2.682)]}\} \quad (T.\ lepturus);$$

$$PL\ (\text{mm}) = 602\{1 - e^{[-0.207\ (t\ +\ 2.044)]}\} \quad (T.\ nanhaiensis).$$

Growth in length of the two species was significantly different (ANCOVA, $F_{2,1245}$=169.69, P<0.001).

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Age and growth of cutlassfishes, *Trichiurus* spp., from the South China Sea

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The cutlassfish, *Trichiurus lepturus* Linnaeus 1758, occurs throughout tropical and temperate waters of the world, between latitude 60°N and 45°S (Froese and Pauly, 1997). World harvests are approximately 750,000 tonnes annually and China lands about 80% (600,000 tonnes) (Claus, 1995). In terms of weight, cutlassfish is the most important commercial marine fish species in China (Luo, 1991) and has accounted for about 10% to 20% of the total marine fish catch. It is caught in all Chinese seas, the Bo Hai, the Yellow Sea, the East China Sea, and the South China Sea (Jiang et al., 1991), and about 15% of the catch comes from the South China Sea (Fig. 1) (Liu, 1996). Cutlassfish is used as food fish and is caught mainly by bottom trawling (Luo, 1991) and in lower amounts by longline, hand line, gill net, drift net and purse seine (Chen and Liu, 1982).

Age and growth studies and their derived growth parameters are indispensable in determining stock dynamics (Brouard et al., 1984). Numerous age and growth studies of *T. lepturus* have been conducted over the past few decades (Table 1); however, most research has focused on northern populations in the East China Sea, the Yellow Sea, and the Bo Hai. Similar work on populations in the South China Sea has not been available.

Three species of trichiurids occur in the South China Sea, *T. lepturus, T. nanhaiensis* (Wang and Xu, 1992, in Wang et al., 1992), and *T. brevis* (Wang and You, 1992, in Wang et al., 1992), whereas only one species, *T. lepturus*, occurs in the waters of China farther north (Wang et al., 1992, 1993, 1994). Populations of *T. lepturus* in the Bo Hai, the Yellow Sea, and the East China Sea suffer from overfishing (Lin, 1985; Du et al., 1988; Ma and Xu, 1989; Luo, 1991; Ye and Rosenberg, 1991; Xu et al., 1994). It is harvested only in the Bo Hai and the Yellow Sea as bycatch in other fisheries (Lin, 1985). The condition of trichiurid stocks in the South China Sea remains unclear.

Numerous methods have been used to age trichiurids. The length-frequency method has proven useful in India (Narasimham, 1976; Chakraborty, 1990) and the Philippines (Ingles and Pauly, 1984). Yet, hard parts such as whole or sectioned otoliths and vertebral centra are most frequently used to age cutlassfish (Table 1). Measuring otolith weight or otolith size may be a cost-effective method for aging some fishes (Barbieri et al., 1994; Ferreira and Russ, 1994; Worthington et al., 1995). Although sectioned otoliths are reliable for aging fish, the method is time consuming and expensive (Beckman et al., 1991).

The aims of our study were 1) to validate age estimates by using transverse sections of sagittal otoliths; 2) to verify Lee's phenomenon; 3) to evaluate the potential of using otolith size and weight to estimate age; 4) to fit the age-length data to the von Bertalanffy growth model; and 5) to provide age-growth information for management of cutlassfish resources from the South China Sea.

Materials and methods

Between December 1996 and November 1997, 960 specimens (preanal length [PL] range:138–468 mm; PL=the tip of the lower jaw with the mouth closed to the middle of anus) of *T. lepturus*, and 535 specimens (PL range:253–551 mm) of *T. nanhaiensis* were obtained from commercial catches in the coastal waters of Hong Kong. Commercial gears included longlines, purse seines and bottom trawls. Fresh specimens were placed on ice, transported to the laboratory, and identified by using the diagnostic key of Wang et al. (1992, 1993): if the frontal bone split laterally, specimens were identified as *T. lepturus*, otherwise *T. nanhaiensis*. Preanal lengths were measured to the nearest mm. Specimens were blotted dry and weighed (whole and gutted) to the nearest 0.01 g. To estimate the relationship between PL and gutted weight (W), the variables were log-transformed to meet the assumptions of normality and homogeneous variance. A linear version of the power function: W (g) = $a\ PL^b$ (mm) was fitted to the data.

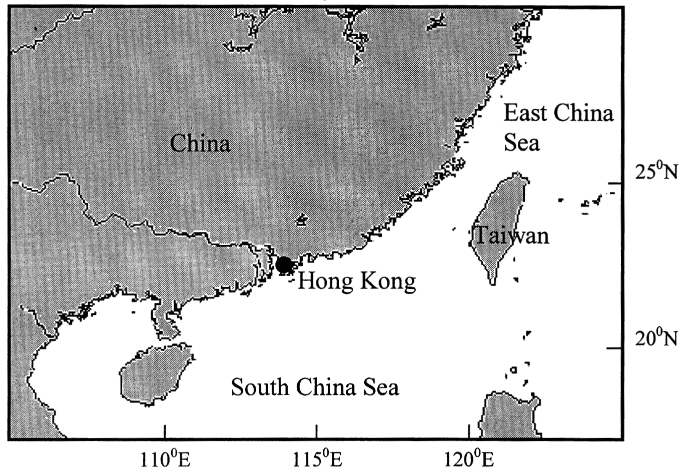

Figure 1

The South China Sea and surrounding area.

Distinct growth rings on whole otoliths and vertebral centra were ill-defined. Transverse sections of sagittal otolith yielded "readable" growth rings; the latter were chosen as aging tools. Left and right sagittae were weighed independently to the nearest 0.01 mg after being oven dried at 40°C for 30 min. Otolith length (OL) was measured to the nearest 0.05 mm with calipers. Sagittal otoliths were embedded in resin and sectioned transversely through the nucleus with a low-speed saw. Up to five sections, 0.3 to 0.5 mm thick, were made from each otolith to ensure that at least one passed through the center of the nucleus. Sections were then ground with 1000- and 1200-grit sand paper, mounted on glass slides with clear fingernail polish, and examined with a compound microscope at 40 magnification with transmitted light. The relative age in years was determined by counting the number of opaque growth rings on the dorsal side of the sectioned otoliths (Fig. 2). Thirty-five pairs of sectioned otoliths of both species were processed. No differences in the number of growth rings were found in left and right sections of each pair. Thereafter, the right sagitta was used for age determination.

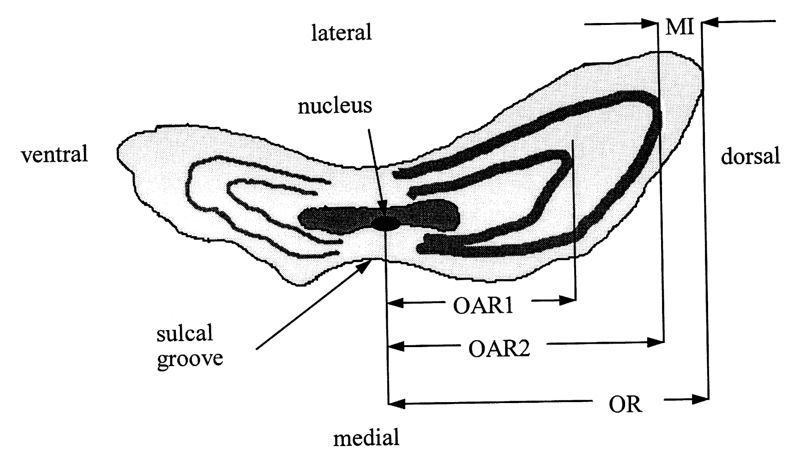

Figure 2

Schematic diagram of a transversely sectioned sagittal otolith of cutlassfishes, *Trichiurus* spp. MI = marginal increment, OAR1 = first otolith annular radius, OAR2 = second otolith annular radius, OR = otolith radius.

Otoliths were read twice (one month apart) in a random order, with no knowledge of fish length or species. Precision was measured by the percentage of agreement between readings (Lowerre-Barbieri et al., 1994). Deviations were counted a third time. Only counts with at least two agreements were used in subsequent analyses. Marginal increment method was used to validate the reading of annuli. Otolith radius (OR), otolith annular radius (OAR), and marginal increment (MI) (Fig. 2) were measured with an ocular micrometer to the nearest 0.025 mm.

The tendency for older fish to reflect smaller back-calculated length at earlier ages than measured length is known as Lee's phenomenon (Smith, 1983), and is related to size-selective mortality (Boehlert et al., 1989). To evaluate this phenomenon, the mean otolith annular radius (MOAR) for each annulus of the same age group was calculated, and the MOAR for each annulus of different age groups was plotted against the age group (Yamaguchi et al., 1990). Thus, we determined if older fish demonstrated slower growth of hard parts at younger ages, i.e. true Lee's phenomenon (Smale and Taylor, 1987). The ANOVA test was used to compare MOARs among different age groups.

Multiple linear-regression models were fitted in a stepwise manner to predict age from otolith weight and length. Variables were log-transformed to meet the assumptions of normality and homogeneous variance. A paired-sample t-test showed no significant difference between left and right sagittal otoliths in terms of weight (*T. lepturus*:

Table 1

Summary of age and growth studies of *Trichiurus lepturus*. A = Autumn brood; F = female; L_∞ = in preanal length; M = male; MI = marginal increment; otolith = sagittal otolith; S = spring brood;

Country	Study area	Study period	Sample size	Sex and brood	Aging and growth methods	Validation method	Growth parameters: k(per yr)	Growth parameters: L_∞ (mm)	Growth parameters: t_0(yr)	Authors
China	East China Sea, Yellow Sea & Bo Hai	1954–57	1472		whole otolith, Ford–Walford plot	MI	0.4083	455.7	0.4400	Misu, 1958, 1964
China	East China Sea	1968–69	869		sectioned otolith, Ford–Walford plot	MI	0.1390	766.0	–0.2660	Hamada, 1971
China	East China Sea north	1977–78	3418		sectioned otolith, Ford–Walford plot	MI	0.2928	553.2	–0.6806	Wu et al., 1985a, 1985b
China	Yellow Sea	1964			whole otolith,		0.1100	708.0	–2.8200	Lin and Zhang, 1981
China	Bo Hai	1964			Ford–Walford plot		0.1100	658.0	–2.9100	
China	Yellow Sea & Bo Hai	1962–63	492		whole otolith,	MI	0.4380	501.0	–0.0607	Hong, 1980
Japan	Kii Channel	1972–74	3739		whole otolith, ford–Walford plot	MI	0.2610	568.3	–0.6435	Sakamoto, 1976
Japan	Kumano– Nada	1978–79	213	S A	whole otolith, ford–Walford plot	MI	0.3960 0.5240	483.0 439.0	–0.4350 0.5280	Suzuki and Kimura, 1980
Japan	Suruga Bay	1965	505		whole otolith, ford–Walford plot	MI	0.2886	433.9	–0.4130	Kosaka et al., 1967
Japan	Kagoshima Bay	1993–94	292	F M	whole otolith, ford–Walford plot	MI	0.1670 0.2160	629.0 481.0	–1.7910 –1.9750	El–Haweet and Ozawa, 1996[1]
Japan	Tsushima waters	1967–87	9592	S, F S, M A, F A, M	whole otolith, ford–Walford plot	MI	0.4090 0.4810 0.4590 0.5530	502.5 438.7 465.1 400.7	–0.4910 –0.4580 –0.2200 –0.1960	Hanabuchi, 1989
China	Taiwan Strait	1962–64	3319		vertebral centrum, Ford–Walford plot	MI	0.2920	477.4	–0.6340	Du et al., 1988
Taiwan	coastal sea (E)	1976–77	154		whole otolith, Ford–Walford plot	MI	0.2710	502.0	–0.2200	Chen and Lee, 1982
Taiwan	coastal sea (SW)	1976–77	341		whole otolith, Ford–Walford plot	MI	0.2890	550.0	–0.7600	Chen and Lee, 1982

[1] Studies used species name *T. japonicus* which was a junior synonym of *T. lepturus* (after Froese and Pauly, 1997).

t=–0.097, df=917, P>0.90; *T. nanhaiensis*: t=–0.762, df=518, P>0.44) and length (*T. lepturus*: t=–0.471, df=916, P>0.45; *T. nanhaiensis*: t=–0.689, df=523, P>0.49). Therefore, average otolith length and weight were used in the analyses. For all the linear regressions mentioned above, analysis of covariance (ANCOVA) was used to compare regressions between sexes and species.

We assigned 1 May and 1 June as the birth dates for *T. lepturus* and *T. nanhaiensis*, respectively (Kwok and Ni, 1999). Relative ages derived from aging were then converted to absolute ages. Von Bertalanffy growth curves were fitted by nonlinear regression on age and preanal length data (SPSS vers. 7.5). The von Bertalanffy growth equation for length is

$$PL_t = PL_\infty \{1 - e^{[-k\,(t - t_0)]}\},$$

where PL_∞ = the asymptotic length;
k = growth coefficient; and
t_0 = the hypothetical age at zero length.

Plots of residuals from regression models were used to check the assumption of normality. ANCOVA was used to compare log-transformed age-at-length regressions between sexes and species.

Results

The preanal length (mm) and gutted weight (g) regression models were significantly different between sexes (ANCOVA: *T. lepturus*: $F_{2,932}$=4.00, P<0.05; *T. nanhaiensis*: $F_{2,530}$=3.34, P<0.05) and species (ANCOVA: $F_{2,1466}$=83.76, P<0.001). The regression models were

T. lepturus
males:
$W = 1.513 \quad 10^{-4}\, PL^{2.571}$ (n=212, r^2=0.9777, P<0.001);
females:
$W = 1.748 \quad 10^{-4}\, PL^{2.549}$ (n=724, r^2=0.9761, P<0.001);
sexes combined:
$W = 1.624 \quad 10^{-4}\, PL^{2.561}$ (n=936, r^2=0.9771, P<0.001);

T. nanhaiensis
males:
$W = 3.363 \quad 10^{-5}\, \mathrm{PL}^{2.846}$ (n=282, r^2=0.8506, P<0.001);
females:
$W = 6.553 \quad 10^{-5}\, \mathrm{PL}^{2.729}$ (n=252, r^2=0.9299, P<0.001);
sexes combined:
$W = 5.672 \quad 10^{-5}\, PL^{2.755}$ (n=534, r^2=0.8968, P<0.001).

Sectioned sagittae of both species had an opaque nucleus located above the sulcal groove toward the dorsum. The nucleus was surrounded by a pattern of alternating wide, translucent zones and thin, opaque zones; the latter were considered annuli (Fig. 3). Annuli were distinct on the dorsum of the sections but were usually indecipherable on the ventral side. A total of 757 and 534 otoliths were embedded in resin and sectioned for *T. lepturus* and *T. nanhaiensis,* respectively. Of these, 33 (4.3%) and 9 (1.7%) were unreadable, and the percentage agreement between the two readings for each species was 95.4% and 92.7%, respectively.

The least marginal increment values (Fig. 4) occurred in February for both species, suggesting that one growth ring (annulus) formed each year. Only specimens age 1–4 were included in the analyses because older fish were rare in our collections. The mean otolith annular radius (MOAR) of the first annulus (ANOVA: $F_{5,582}$=3.046, P<0.05) and third annulus (ANOVA: $F_{3,80}$=4.024, P<0.05) of *T. lepturus* were significantly different among different age groups (Fig. 5); MOARs increased slightly with older age groups. However, no particular trend was found with regard to the MOARs of *T. nanhaiensis* (Fig. 5). Lee's phenomenon was not evident for either species, although reverse Lee's phenomenon was possible for *T. lepturus*.

Otolith weight accounted for 68.7% and 68.9% (Table 2) of the variability in age for *T. lepturus* and *T. nanhaiensis*, respectively. A negligible amount of the remaining variability was explained by considering otolith length in addition to otolith weight. The otolith weight-age regression was improved by fitting the untreated variables (otolith weight and age) with simple linear regression models:

T. lepturus:
$OW = 6.3533 + 5.2913 Age$ (n=718, r^2=0.7168, P<0.001);
T. nanhaiensis:
$OW = 6.3921 + 3.6850 Age$ (n=515, r^2=0.7561, P<0.001).

These regression results suggest a linear relationship between otolith weight and age (Fig. 6). The regression models were significantly different between the two species (ANCOVA: $F_{2,1229}$=224.17, P<0.001). Normal probability and residual plots showed that the regressions complied with the assumptions of normality and homogeneous variance.

Von Bertalanffy growth equations for both species were

T. lepturus
males:
$PL = 755.2 \{1 - e^{[-0.116\,(t + 2.737)]}\}$ (n=146, r^2=0.684, P<0.001);
females:
$PL = 601.4 \{1 - e^{[-0.158\,(t + 2.850)]}\}$ (n=578, r^2=0.765, P<0.001);
sexes combined:
$PL = 589.1 \{1 - e^{[-0.168\,(t + 2.682)]}\}$ (n=724, r^2=0.749, P<0.001);
T. nanhaiensis
males:
$PL = 501.7 \{1 - e^{[-0.306\,(t + 1.673)]}\}$ (n=281, r^2=0.682, P<0.001);
females:
$PL = 612.6 \{1 - e^{[-0.220\,(t + 1.792)]}\}$ (n=244, r^2=0.726, P<0.001);
sexes combined:
$PL = 602.1 \{1 - e^{[-0.207\,(t + 2.044)]}\}$ (n=525, r^2=0.699, P<0.001).

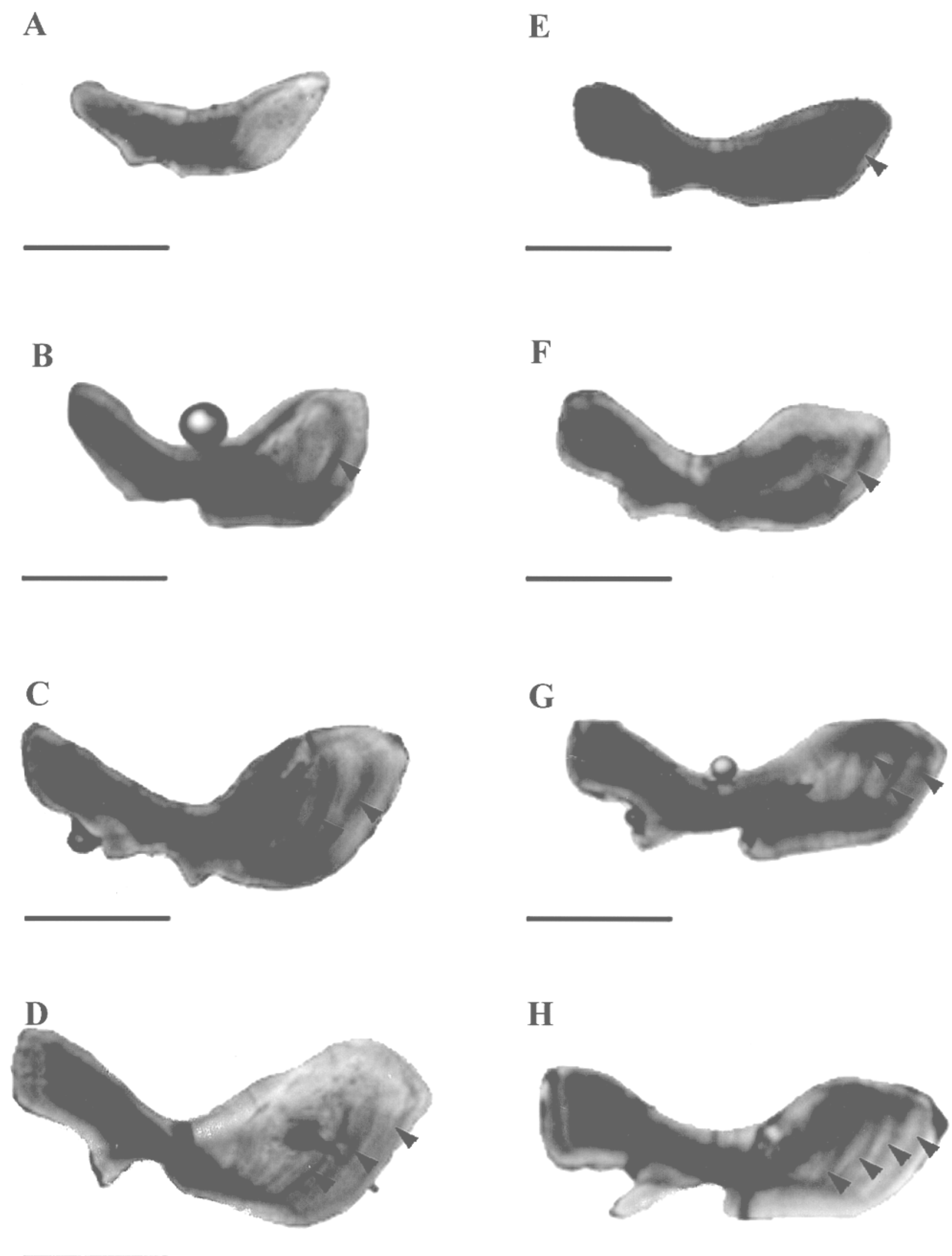

Figure 3

Sectioned sagittal otoliths of cutlassfishes, *Trichiurus* spp. in transmitted light. (**A–D**) *T. lepturus*, (**E–H**) *T. nanhaiensis*. A: age: 0+, PL = 237 mm; B: age: 1+, PL = 296 mm; C: age: 2+, PL = 361 mm; D: age: 3+, PL = 384 mm; E: age: 1+, PL = 299 mm; F: age: 2+, PL = 340 mm; G: age: 3+, PL = 404 mm; H: age: 4+, PL = 421 mm. Magnification = 30 , Ar = artifact, arrow indicates growth ring, scale bar = 1 mm.

Von Bertalanffy growth curves for sexes combined are depicted in Figure 7. No systematic trend was found in the residual plots for all regressions. The t_{max} (age at 95% of asymptotic length) of *T. lepturus* and *T. nanhaiensis* were 15.1 and 12.4 years, respectively. The W_∞ (asymptotic weight: estimated by substituting PL_∞ to the preanal length-weight equations) of *T. lepturus* and *T. nanhaiensis* were 2025 g and 2585 g, respectively. Log-transformed age-at-length regressions were significantly different between sexes (ANCOVA: *T. lepturus*:

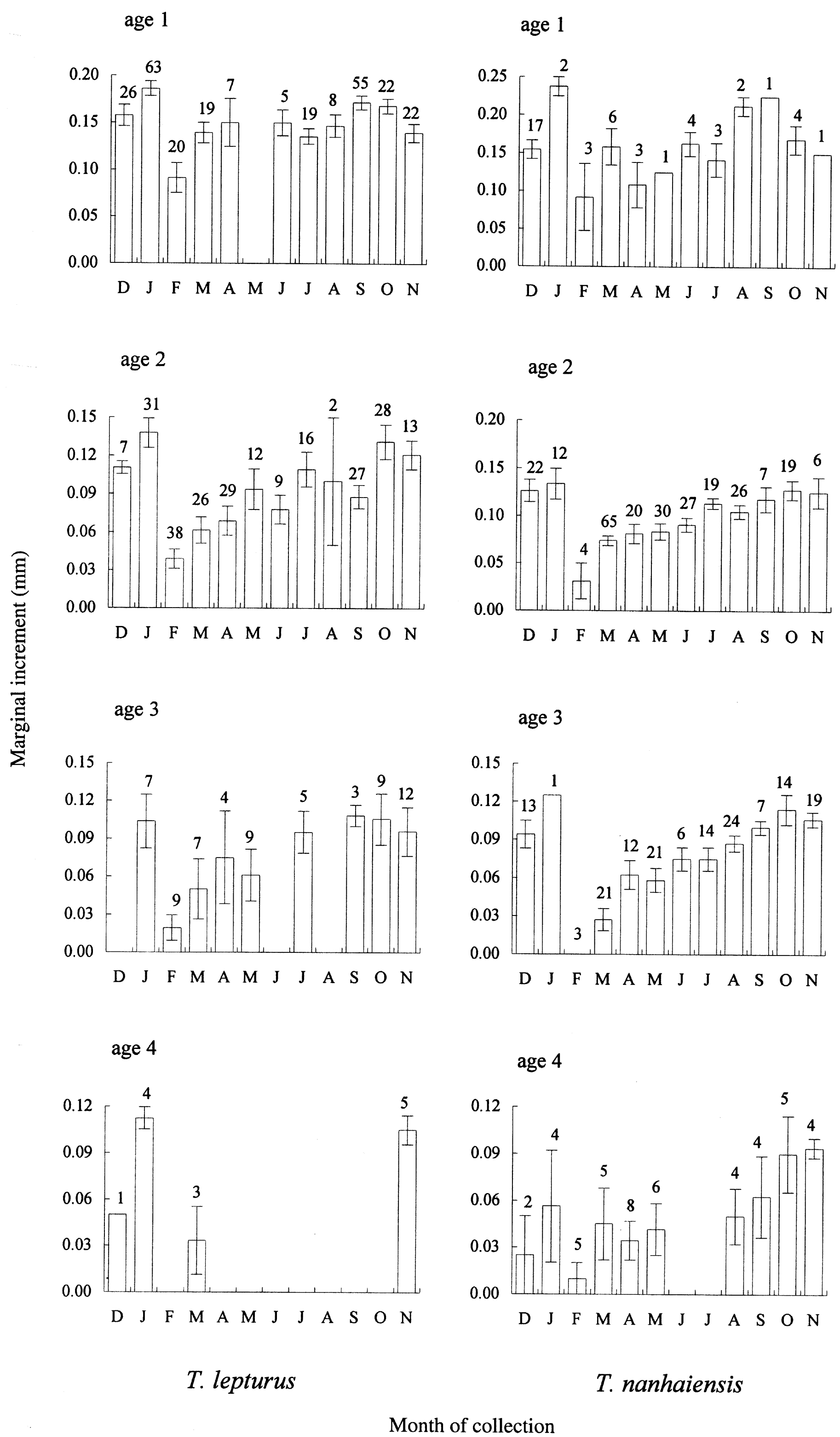

Figure 4

Mean monthly otolith marginal increment for *T. lepturus* (left panel) and *T. nanhaiensis* (right panel). Vertical bars are 1 SE, numbers on the top of vertical bars are sample sizes.

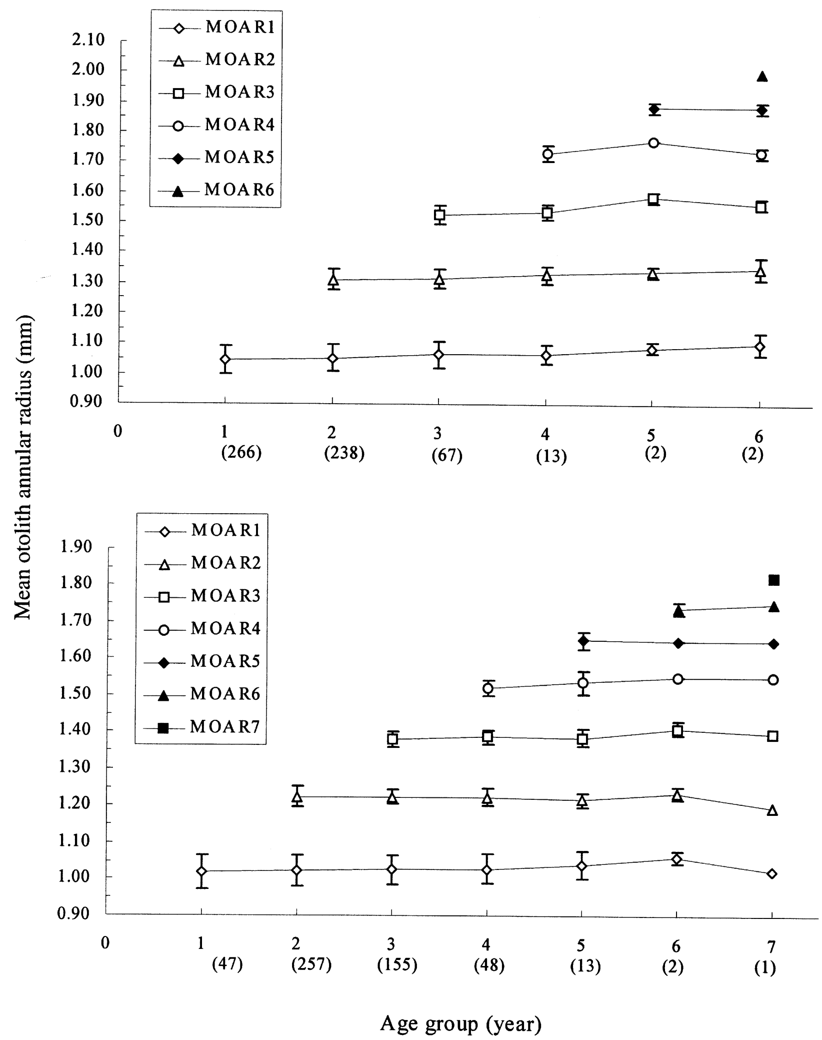

Figure 5

The relationship between mean otolith annular radius (MOAR) and age group for *Trichiurus lepturus* (top panel) and *T. nanhaiensis* (bottom panel). Vertical bars are 1 SE, numbers in parentheses are sample sizes.

$F_{2,720}$=4.39, P<0.05; *T. nanhaiensis*: $F_{2,521}$=23.78, P<0.001) and species (ANCOVA: $F_{2,1245}$=169.69, P<0.001).

Discussion

Our aging study of cutlassfishes from the South China Sea was successful in that we 1) found distinct growth rings on sectional sagittal otolith, 2) had excellent precision in independent ring counts, and 3) used marginal increment analyses to validate our aging method. In general, cutlassfishes from the northern seas of China (Misu, 1958, 1964; Hamada, 1971; Sakamoto, 1976; Hong, 1980; Wu et al., 1985a; Du et al., 1988; Hanabuchi, 1989; El-Haweet and Ozawa, 1996) and the South China Sea (our study) deposit annuli in late winter or early spring, suggesting that ring formation likely occurs in response to reduced water temperatures and is not correlated with peak spawning as indicated in Chen and Lee (1982). Summer is the peak spawning period of *T. lepturus* and *T. nanhaiensis* in the South China Sea (Kwok and Ni, 1999).

El-Haweet and Ozawa (1996) questioned whether Lee's phenomenon existed in a trichiurid population from Japan, having found no indication of Lee's or reverse Lee's phenomenon. We found that *T. lepturus* may exhibit reverse Lee's phenomenon, which suggests that *T. lepturus* are not overfished in the South China Sea or that fishing mortality is not size-selective, or that both situations may apply. Alternatively, fast growing individuals in the *T. lepturus* population may have greater chances of survival and attain older ages.

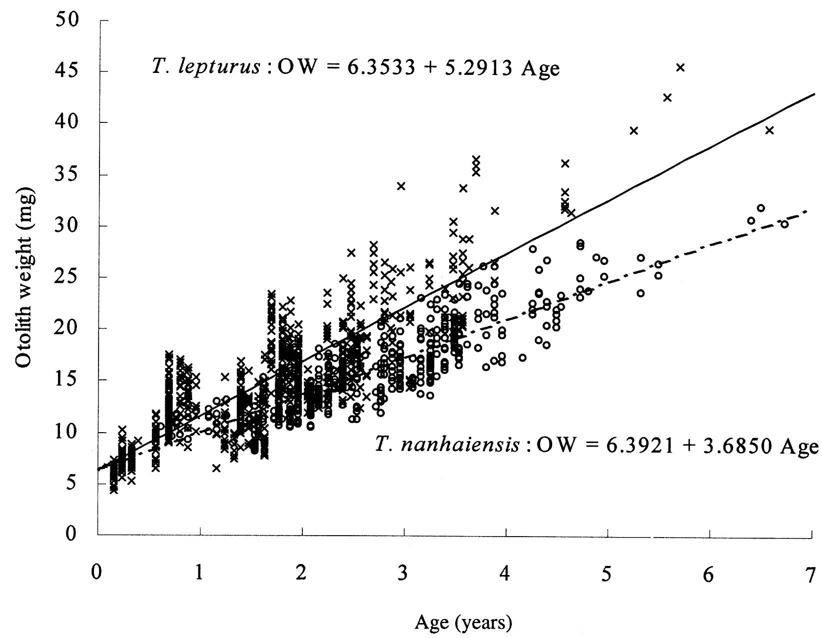

Figure 6

Regression model between otolith weight and age for *Trichiurus* spp. Solid line (regression line) and crosses (raw data): *T. lepturus*. Dotted line (regression line) and circles (raw data): *T. nanhaiensis*.

Table 2

Regression coefficients and statistics on multiple-regression models of age for cutlassfishes, *Trichiurus* spp. Variables were log-transformed for analyses.

Variable	Coefficient	SE	P	Partial r^2
T. lepturus (n=718)				
one-variable model (r^2=0.687)				
intercept	–4.404	0.108	<0.0001	
otolith weight	1.629	0.041	<0.0001	0.687
two-variable model (r^2=0.696)				
intercept	–5.922	0.430	<0.0001	
otolith weight	0.966	0.153	<0.0001	0.053
otolith length	2.076	0.461	<0.0001	0.028
T. nanhaiensis (n=515)				
one-variable model (r^2=0.689)				
intercept	–2.692	0.107	<0.0001	
otolith weight	1.305	0.039	<0.0001	0.689
two-variable model (r^2=0.690)				
intercept	–3.068	0.227	<0.0001	
otolith weight	1.123	0.105	<0.0001	0.183
otolith length	0.476	0.255	>0.05	0.007

The linear relation between otolith weight and age (Fig. 6) indicates that cutlassfish otoliths continuously increase in weight with age. The regression models explain 72% and 76% of the variance for *T. lepturus* and *T. nanhaiensis*, respectively, comparable to the von Bertalanffy growth model in preanal length. Thus, otolith weight pro-

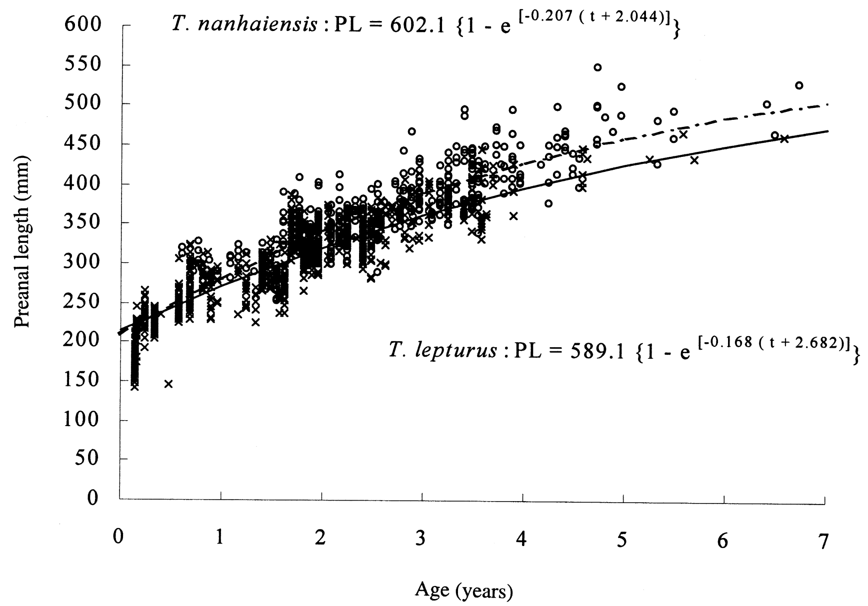

Figure 7

The von Bertalanffy growth curve for *Trichiurus* spp. Solid line (regression line) and crosses (raw data): *T. lepturus*. Dotted line (regression line) and circles (raw data): *T. nanhaiensis*.

vides a more precise estimate of age in older fish. Use of otolith weight to estimate age should be done with caution because these relationships have been shown to be population specific (Worthington et al., 1995).

This study is the first application of nonlinear regression in deriving a von Bertalanffy growth model for the cutlassfish; previously Ford-Walford plots were the most common method. The shortcomings associated with that method include 1) weighing problems due to different sample sizes of each age group; 2) a failure in providing variance-covariance for comparisons; 3) none of the raw data are used (Liu and Yeh, 1991); and 4) a reliance on back-calculated body length, which is usually estimated from the linear regression between hardpart dimension (e.g. otolith radius) and body length. Unfortunately, the growth of otoliths has been shown to be independent of somatic growth (Beckman et al., 1991; Barbieri et al., 1994), i.e. growth of body length ceases with age, while growth of hard parts continue. In comparison, our application of nonlinear regression analysis can avoid all these problems.

Basic growth parameters for these two populations of trichiurids in the South China Sea showed lower growth coefficients and higher asymptotic length, i.e. specimens reached maximum size at a slower pace than other trichiurids from the western Pacific Ocean (Table 1). This finding may be real or may reflect different methods employed for estimating growth.

In our comparison of the two species, *T. nanhaiensis* possessed a higher growth coefficient (k) than *T. lepturus*. Male *T. lepturus* had a lower growth coefficient but attained larger asymptotic size (PL_∞) than did female *T. lepturus*, whereas the opposite held true for *T. nanhaiensis*.

We provide basic growth parameters for use in the study of stock dynamics of trichiurids in the South China Sea. A formal stock assessment should be conducted with special emphasis on establishing an ecologically sustainable cutlassfish fishery in the South China Sea to prevent overfishing, or even fishery collapse, as has occurred in the northern populations of trichiurids.

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