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Current status of small yellow croaker resources in the southern Yellow Sea and the East China Sea*

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Abstract We used data from bottom trawl surveys to study the factors influencing the abundance of small yellow croaker, *Larimichthys polyactis*, in the southern Yellow Sea (SYS) and the East China Sea (ECS). The resource density index (RDI) was generally higher in summer and autumn than in spring and winter. RDIs were also significantly greater in the SYS than in the ECS in summer and autumn. The bottom water salinity and depth of spatial distribution of small yellow croaker was similar between the two areas in summer, but different in other seasons. Regression analysis suggested that environmental factors such as bottom water temperature, salinity, and depth influenced the RDIs in summer in these areas. Growth condition factor (GCF) in the two areas varied monthly and the croaker in the SYS grew more slowly than those in the ECS. This was likely due to the low bottom temperature of the Yellow Sea Cold Water Mass in summer and autumn or to higher human fishing pressure in the ECS. To ensure sustainable utilization of the croaker stocks in these regions, we recommend reducing the fishing intensity, increasing the cod-end mesh size, and improving the protection of juveniles.

Keyword: *Larimichthys polyactis*; biology; ecology; Akaike Information Criterion (AIC)

1 INTRODUCTION

Small yellow croaker *Larimichthys polyactis* (Pisces: Sciaenidae) is a demersal warm-temperate fish species that is widely distributed in the southern Yellow Sea (SYS) and the northern East China Sea (ECS) (Hwang, 1977; Yamada et al., 1986; Zhao et al., 1987; Suam et al., 1997; Zheng et al., 2003). Due to their high commercial value, small yellow croaker constitutes one of the most important marine fisheries in China. They have been exploited for several decades using a variety of methods, including bottom trawl, canvas stow net, and gill nets (Zhao et al., 1987; Zheng et al., 2003). Since the 1950s, the small yellow croaker fishery has been defined by three significant periods: abundance (annual catches from 136.5 thousand tons in 1956 to 81.7 thousand tons in 1963), declining harvest (from 56.3 thousand tons in 1964 to 16.8 thousand tons in 1989), and recovery (from 23.5 thousand tons in 1990 to 347.9 thousand tons in 2006, more than 2.5 times higher than harvest during the early period in 1956) (Zhang et al., 2007). To protect and restore this fishery, a range of programs have been implemented in China since the 1990s, such as establishment of non-fishing regions and seasons along the coast. These measures have played a constructive role in recovering the fishery in recent years. However, in contrast to increasing catches, the population structure and eco-biological characteristics of the small yellow croaker stocks have changed considerably. These include a reduction in individual size and age, a shift

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in foraging niche and feeding ecology, early maturation, and dispersal of spawning grounds (Jin, 1996; Ren et al., 2001; Shui, 2003; Lin et al., 2004, 2007, 2008; Guo et al., 2006). These changes may subsequently affect the sustainable development of the fishery.

For effective fishery management, it is essential to have a clear understanding of the changes in recruitment mechanisms as well as the bio-ecological characteristics of the small yellow croaker populations. In particular, the primary spawning and nursery grounds of small yellow croaker in the SYS and ECS, are characterized by distinctly different oceanographic conditions (Su, 2005). The small yellow croaker populations may have developed different bio-ecological characteristics and have probably undergone drastic changes in response to the ecological regime shift in these waters in the past decades. Using the data collected from fishery monitoring and resources surveys in the SYS and the ECS from January 2006 to April 2007, we analyzed the bio-ecological characteristics of small yellow croaker populations. These included the biomass index and growth performance of the populations and their relationship with environmental factors. Our results provide information that may be used for the implementation of small yellow croaker fishery management strategies in China.

2 MATERIAL AND METHOD

2.1 Data

We collected data from fixed-point fishery surveys and routine fishery monitoring surveys in the SYS and ECS. The surveys were conducted by the East China Sea Fisheries Research Institute, Chinese Academy of Fishery Sciences from January 2006 to April 2007 using pair bottom trawlers and a net that was 100×4 m at the mouth and had a cod-end mesh size of 25 mm. The duration of each trawl was 1 h at a vessel speed of 2.5 knots. The trawl fishery surveys ($n=4$) were conducted in June (summer), September (autumn), and December (winter) 2006 and April (spring) 2007 (Table 1) Environmental data (e.g. water temperature, salinity, and depth) were collected at the time of each trawl survey. One hundred and twenty five stations covering the waters of 27°00′N–35°00′N and between 127°00′ E and the prohibited fishing line were surveyed in all cruises, except for the winter survey when only 67 stations were surveyed due to rough sea conditions. The location of the survey sites was based on a spatial resolution of 30′N×30′ E (Fig.1). Survey and sampling procedures followed the National Marine Survey Criteria of China (GB13763.6-91). A subsample, 20 kg of the catch was collected from each trawl, frozen, and stored on the vessel. The samples were transferred to our laboratory at the end of each survey. We measured the body length (to the nearest 0.1 cm) and body weight (to the nearest 0.1 g) of at least 30 individuals from each site. In situ measurements of water temperature, salinity, and water depth were obtained using a Seabird-37 CTD in all surveys.

Table 1 The numbers of fixed-point fishery survey sites and sampling sites (occurrence of small yellow croaker) in the southern Yellow Sea (SYS) and the East China Sea (ECS) in 2006–2007

Season	Survey sites			Sampling sites		
	Total	SYS	ECS	Total	SYS	ECS
Summer (Jun. 2006)	125	32	93	62	26	36
Autumn (Sep. 2006)	125	32	93	85	30	55
Winter (Dec. 2006)	67	9	58	47	9	38
Spring (Apr. 2007)	125	32	93	65	24	41

In addition, monthly samples were collected for routine monitoring of growth. The sampling procedures and methods were the same as those in the four seasonal fixed-point surveys. We examined a total of 4 927 individuals (2 341 and 2 586 from the SYS and the ECS, respectively).

2.2 Data analysis

2.2.1 Resource density index (RDI)

We calculated the resource density index following the method of Zheng et al. (2003):

$$D=\frac{C}{q\times A} \tag{1}$$

where D is the resource density index (number of individuals/km^2), C represents the total catch (number of ind./h) at each sampling station, q is a measure of catchability (0.5 for small yellow croaker; Zheng et al., 2003), and A is the sampling area swept by the trawl (km^2/h).

2.2.2 Relationship between RDI and environmental factors

We used multiple regression to model the relationship between the RDI and environmental factors (temperature, salinity and depth) in each seasons. Model selection was conducted using backward stepwise regression with AIC (Akaike Information Criterion; Zuur et al., 2007). The initial model was:

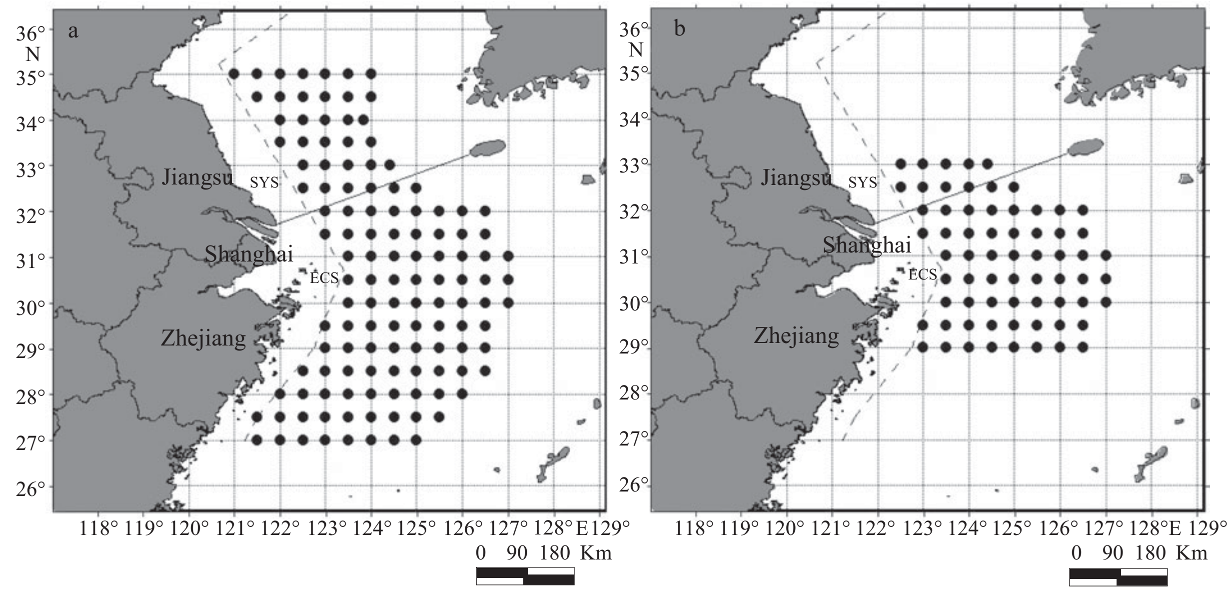

Fig.1 Map of survey sites and sampling sites (occurrence of small yellow croaker)

a. Summer (Jun. 2006) and Autumn (Sept. 2006), Spring (Apr. 2007); b. Winter (Dec. 2006). Dashed line: prohibited fishing line; solid line: border of the southern Yellow Sea and the East China Sea

$$\eta(\mu) = \alpha + \beta_i X_{i1} + \cdots + \beta_k X_{ik} + \varepsilon \tag{2}$$

where μ is the expectation of the dependent variable, α is the intercept, β_i is the regression coefficient, X_{ik} represents the design matrix of independent variables. The independent variables included bottom temperature, bottom salinity, depth, and their quadratic and interaction terms. ε represents the error term.

2.2.3 Growth condition factor (GCF)

We fitted the weight-length model, $W = a \times L^b$, to the relationship between body length (L, mm) and body weight (W, g). b is the rate at which the length of the fish increases (i.e. $b=3$, isometric growth; $b \neq 3$, allometric growth), and a is the growth condition factor (GCF). We evaluated the difference in the weight-length relationship between samples from the SYS and ECS using an F test for the residual sum of squares.

GCF is typically used as an indicator of the well-being of a fish. It can be used to describe the growth and adaptation of the fish to its environment (Ricker, 1975). GCF was calculated as follows:

$$\mathrm{GCF} = \left(W \big/ L^3 \right) \times 100 \tag{3}$$

where W is the total weight and L is the body length. The data were log transformed achieve normality. To avoid bias caused by dominant length groups, we selected representative length groups for the regression analysis. The b-parameters computed from the weight-length relationships of small yellow croaker were close to, but not exactly, 3 (Table 4). We also calculated the confidence interval for the slope to evaluate the significance of isometric growth. There was a significant difference in GCF between males and females during the spawning season (spring). Therefore, we analyzed the samples of small yellow croaker separately by sex during the spawning period (sexual maturation defined by ovary stages above stage III).

To further analyze the differences in GCF between the two areas, the samples of small yellow croaker were categorized into immature stock components (NMS) and mature stock components (MS).

2.2.4 Growth performance index (GPI)

The age groups were split using a Gaussian function and a series of iterations (Goonetilleke and Sivasubramaniam, 1987). We used a separation index (SI) as the criterion for estimating the credibility of a split into different age groups. If the SI value exceeded 2, the split was considered credible (El-Ganainy and Sabra, 2008).

We used the monthly distribution of length frequencies to obtain the growth parameters L_∞ (asymptotic length) and K (average growth rate, curvature parameter of the VBGF (von Bertalanffy, 1938). We constructed histograms of the length frequencies using a 10 mm bin size. Estimates of the growth parameters were obtained by electronic length frequency analysis (ELEFAN I; Pauly and Morgan, 1987) by FISAT (Gayanilo et al., 1995).

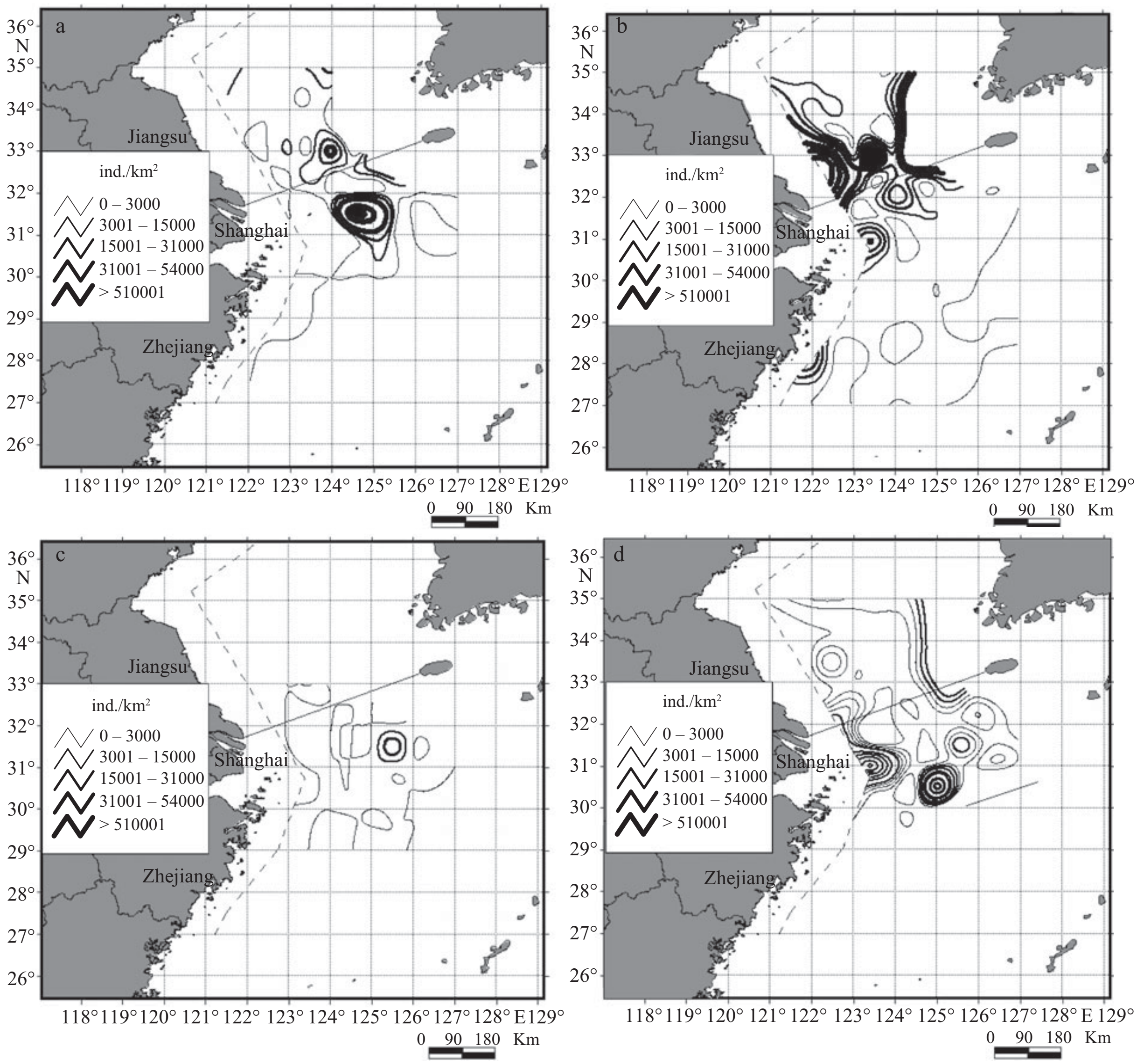

Fig.2 Spatial distribution of resource density index of small yellow croaker in the southern Yellow Sea and the East China Sea in 2006–2007

a. Summer (Jun. 2006); b. Autumn (Sept. 2006); c. Winter (Dec. 2006); d. Spring (Apr. 2007)

We used the growth performance index (GPI) to evaluate the pattern growth in small yellow croaker. The GPI was expressed by the relationship between average growth rate and asymptotic length (Gayanilo et al., 1995):

$$\mathrm{GPI}=\mathrm{Log}(K)+2\mathrm{Log}(L_{\infty}) \tag{4}$$

A P value of ≤0.05 was considered statistically significant in all analyses.

3 RESULT

3.1 Resource density index

Small yellow croakers were widely distributed in the SYS and the northern ECS with the highest RDI values occurring in the waters between 30.5°N and 35°N. In general, the RDI was higher in the SYS and the ECS in summer and autumn than in the spring and winter (Fig.2). In the SYS, RDI values ranged from 22–3 024 (mean: 785), 9–117 711 (11 556), 10–137 959 (23 130), and 11–3 558 (432) ind./km^2 in spring, summer, autumn, and winter, respectively. Similarly, the RDI values ranged from 11–19 708 (mean: 1 851), 11–146 868 (9 252), 11–37 916 (4583), and 11–26 717 (1936) ind./km^2 for the same seasons in the ECS.

3.2 Resources density index in relation to environmental factors

The bottom salinity and depth of habitat of small yellow croaker did not differ significantly during the summer between the SYS and the ECS (Table 2).

Table 2 Environmental indices (water temperature, salinity and depth) in the waters where small yellow croaker were caught in the southern Yellow Sea (SYS) and the East China Sea (ECS) in 2006–2007

Season	Environmental factors	Mean		Significance test	
		SYS	ECS	*t*	*P*
Summer (Jun. 2006)	Temperature	12.52±3.1	16.86±3.2	5.37	0.0001
	Salinity	33.34±1.4	33.45±1.1	0.35	0.729
	Depth	54.75±17.4	61.71±17.9	1.54	0.128
Autumn (Sep. 2006)	Temperature	15.07±6.0	21.55±2.7	5.74*	0.0001
	Salinity	32.97±1.0	34.23±0.8	6.50	0.0001
	Depth	51.94±17.4	69.69±22.5	3.82	0.0003
Winter (Dec. 2006)	Temperature	11.37±1.7	15.00±2.1	5.66	0.0001
	Salinity	32.77±0.9	33.69±0.6	3.25*	0.007
	Depth	38.34±11.2	62.74±18.0	4.24	0.0001
Spring (Apr. 2007)	Temperature	11.47±0.7	14.81±1.9	9.90*	0.0001
	Salinity	33.07±0.8	33.63±0.9	2.50	0.015
	Depth	50.58±14.6	62.66±16.	3.09	0.003

t-test, $P<0.05$; * denoting unequal variance *t*-test, otherwise equal variance *t*-test

However, we did observe significant differences for these two indices in spring, autumn, and winter. Average temperature, salinity, and depth were generally higher in the ECS than the SYS (Table 2).

The AIC analysis revealed that several environmental factors affected the RDI in summer in both water bodies (Table 3). In autumn, the RDI was positively correlated with bottom water temperature, salinity, and depth but negatively correlated with the interaction term in the SYS. In contrast, we found a negative correlation between the RDI and these three environmental indices and a positive correlation with their interaction term in the ECS. In the remaining seasons, the environmental indices and their interaction terms had less effect on the RDI in either region (Table 3). Salinity, temperature, and depth had specific effects on the RDI in both regions in these seasons.

Of the environmental factors we evaluated, bottom water temperature made the largest contribution to RDI in the models for both the SYS and the ECS.

Table 3 Regression analysis of RDI of small yellow croaker in relation to environmental indices in the southern Yellow Sea (SYS) and the East China Sea (ECS) based on Akaike Information Criterion (AIC)

Parameters	Summer (Jun. 2006)		Autumn (Sep. 2006)		Winter (Dec. 2006)		Spring (Apr. 2007)	
	SYS	ECS	SYS	ECS	SYS	ECS	SYS	ECS
α	1849.26	-51.15	-888.05	2394.06	-1.46	86.69	10.92	1639.18
$\beta1$		-28.71	57.44	-133.95	0.64	-1.42	-0.39	-32.94
$\beta2$		1.36	18.26	-39.52	0.16	-0.39	0.03	1.04
$\beta3$	-113.58	7.34	27.77	-69.89		-1.16		-85.52
$\beta4$		0.09	-1.12	2.22	-0.01	0.02		-0.07
$\beta5$			-1.79	3.93				
$\beta6$			-0.56	1.16				
$\beta7$			0.03	-0.07				
AIC models								
Null model	105.07	94.07	111.91	126.90	173.32	204.54	105.57	135.33
Full model	86.28	81.43	108.41	121.38	172.74	189.22	111.96	133.15
Selected model	77.09	76.20	107.87	122.24	167.01	179.99	99.39	130.14

α: intercept; $\beta1$: temperature; $\beta2$: depth; $\beta3$: salinity; $\beta4$: temperature×depth; $\beta5$: temperature×salinity; $\beta6$: salinity×depth; $\beta7$: temperature×salinity×depth

Table 4 Parameters of the length-weight equations for small yellow croaker in the southern Yellow Sea and the East China Sea, with 95% confidence interval indicated for the parameters ln *a* and *b*

Parameters	ln *a*			*b*			R^2
	Value	Se	CI95%	Value	Se	CI95%	
SYS	-10.96	0.10	(-11.2, -10.7)	2.9968	0.02	(2.950, 3.040)	0.999
ECS	-11.60	0.26	(-12.2, -11.0)	3.0213	0.05	(3.004, 3.038)	0.997

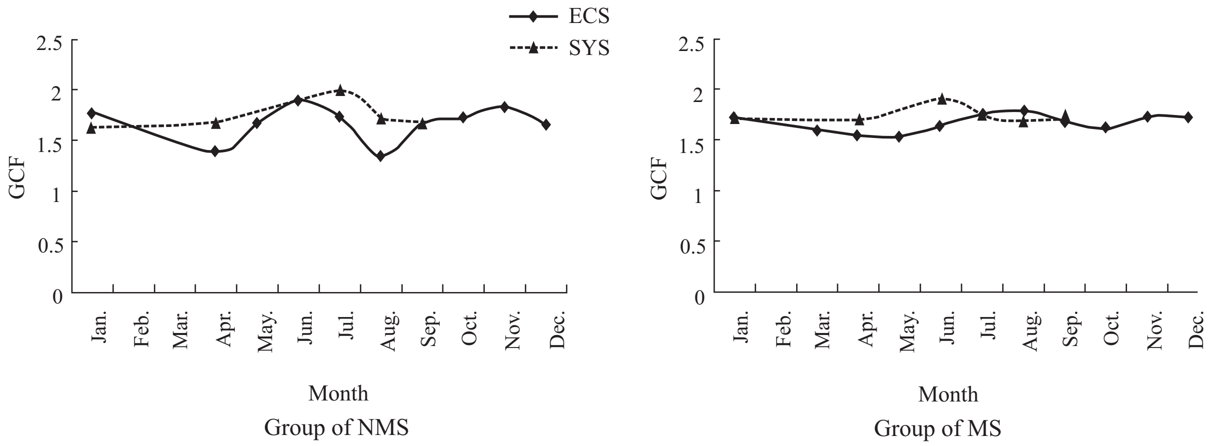

Fig.3 Monthly variation in the mean condition factor of groups of immature (NMS) and mature (MS) *Larimichthys polyactis* in the southern Yellow Sea and the East China Sea from January to December 2006

We found a positive relationship between RDI and bottom water temperature in summer and autumn in the SYS and a negative relationship between these indices in spring in the SYS and in all seasons in the ECS.

3.3 Growth condition factor (GCF)

We compared the monthly changes in the GCF of immature (NMS) and mature (MS) stock components in each region (Fig.3). There was no difference in the mean monthly GCF of the NMS (mean: 1.78, range: 1.6–2.0) and MS (mean: 1.75, range: 1.7–1.9) groups in the SYS. Similarly, there was no significant difference in GCF between the NMS (1.68, range 1.4–1.9) and MS (1.67, 1.5–1.8) groups in the ECS. GCF declined sharply in the NMS group in the ECS during two periods (December-April and June-August) then peaked in June (Fig.3). The pattern was similar in the SYS, but was delayed by ca. 1 month. The pattern of monthly changes in the GCF of the MS group was similar in both regions although the peak in the SYS was ca. 1 month earlier than in the ECS. There was no significant difference in the mean GCF of either group between the two areas (NMS: t=1.77, df=13, P>0.05; MS: t=1.75, df=15, P>0.05). The mean GCF of the MS group was higher between January-April than in the NMS group in both areas. However, the mean GCF of the MS group was lower than in the NMS group between late June and August in the SYS.

3.4 Growth performance index (GPI)

The body length frequency data were divided into different age groups using Bhattacharya's method (Goonetilleke and Sivasubramaniam, 1987). Small yellow croakers in the SYS were categorized into a one-year (body length: mean±SD, 113.1±15.1 mm) and 2-year-old group (151.3±16.2 mm). The catches of one-year-old fish accounted for 79.8% of the total catch. The SI value for the two groups was 2.11, thus, the split was considered credible. Similarly, small yellow croakers in the ECS were also categorized into a one-year (128.6±14.6 mm) and 2-year-old group (149.2±17.9 mm) with the younger group accounting for 82.8% of the total catch. The SI value for the two groups was 2.01, slightly lower than in the SYS. This was due to the fact that there was an excessive overlap of the normal distribution curves between the two groups (Fig.4).

The L_∞ and K were 250.5 mm and 0.4 respectively, in the SYS and 257.3 mm and 0.4 for small yellow croaker in the ECS. The estimated GPI in the SYS and in the ECS were 2.39 and 2.45 respectively.

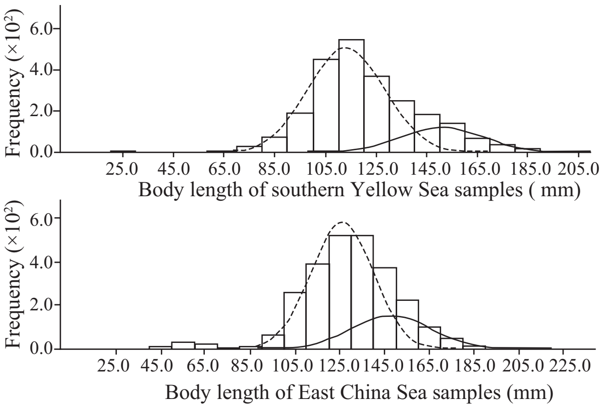

Fig.4 Age group divisions based on length distribution data using the Bhattacharya method

Dashed line: 1-year-old group; solid line: 2-year-old group

4 DISCUSSION

We observed significant seasonal differences in the spatial distribution of small yellow croaker in the SYS and the ECS. These differences may reflect the migration of small yellow croaker. In spring (March–May), small yellow croaker in both regions migrated towards the coastal waters of Jiangsu (northern waters of Yangtze estuary) and Zhejiang Provinces (north Zhejiang coast and Yangtze estuary waters), respectively, to spawn. After spawning, the spent fish remained in these areas to feed whereas the juveniles dispersed to the nursery grounds in both the SYS and the ECS until autumn (Yamada et al., 1986; Hwang, 1977; Zhao et al., 1987). Thus, small yellow croakers were widely distributed in the coastal waters and the adjacent waters (30°00′–35°00′N, 122°00′–127°00′E) during this period, evidenced by the high RDI in these areas. As the water temperature decreased in late autumn (October), the small yellow croaker population mixed with recruits and migrated offshore to deeper waters in the ECS (28°00′–32°00′N, 123°00′–124°00′E) and SYS (west off Cheju Island) for overwintering (Zheng et al., 2003).

Hydrological parameters (water temperature, salinity, and depth) were generally different in each season in the areas of the SYS and the ECS containing small yellow croaker, with the exception of salinity and depth in summer. The distribution of small yellow croaker in the SYS was primarily regulated by the SYS water masses with low temperature and medium salinity. Similarly, their distribution in the ECS was primarily influenced by the surface water mass of the Taiwan Warm Current and the Zhejiang Coastal Water Mass (Su, 2005). Particularly in summer and winter, water temperature was the most important environmental factor influencing the spatial distribution of small yellow croaker and was associated with high RDI values. During this period, RDI increased as water temperature increased in the SYS. In contrast, the values decreased with the increase in water temperature in the ECS suggesting that the distribution of small yellow croaker is a function of the environmental characteristics of the two areas.

Many factors influence the growth and condition of fish species. Fish living under marginal environmental conditions will theoretically weigh less at any particular body length than those living under more optimal circumstances. Body condition may also vary between geographically isolated stocks due to genetic inequality of stocks or geographic variation in habitat quality (Doyon et al., 1988). The GCF was highest in summer in both areas (Zheng et al., 2003), then declined to its lowest values in autumn. During their spawning migration from the overwintering grounds in deeper waters in the ECS towards the coastal waters in spring (April), the small yellow croaker generally feed with low intensity. This is likely a function of low prey abundance in spring and higher abundance in summer in both waters (Zheng et al., 2003). As a result, the stomach fullness index of small yellow croaker is low in spring but high in summer (Hong, 2004). The combination of expending large amounts of energy during the migration and limited prey availability likely explains the slowing of growth in migrating small yellow croaker, leading to a slight decrease in individual GCF values. After arriving at the spawning grounds, the fish forage intensively for a short period during which the GCF of the spawners increases rapidly because of ovary and testis development. After spawning, the GCF decreases somewhat in autumn but remains relatively stable until the overwintering period. The young-of-the-year (YOY) small yellow croaker had high GCF values in spring because of their intensive foraging and abundant supply of food in the nursery grounds, However, their GCF declined drastically in summer, possibly due to limited prey availability. Thereafter, the GCF began to increase in autumn and was relatively high and stable during the overwintering period. It is thought that small yellow croaker may conserve energy, via an unknown mechanism, for survival through the winter when the fish do not forage as actively (Hong, 2004).

Teleostean growth parameters are closely related to environmental conditions such as habitat type, prey diversity and availability, exploitation, and interspecific competition (Getabu, 1992; Salvanes et al., 2004). For example, fish live a relatively long time and have low growth rates due to the lower temperatures (Gordon et al., 2004). Therefore, the differences in growth parameters among different areas are likely a direct reflection of the quality of the habitat. Thus, these parameters could be used to compare the differences among habitats for different populations (Treer et al., 2000). We found that small yellow croaker grew faster in the ECS than in the SYS. We speculate that this difference is related to the environmental characteristics of the two regions, which differed in several ways. First, the bottom temperature was generally low in the SYS compared with the ECS, particularly in summer and autumn because of the effect of the Yellow Sea Cold Water Mass. Thus, small yellow croaker in this region is likely to grow relatively slowly during this time. Second, prey availability differed significantly in the two areas. The prey species and biomass were more abundant in the ECS, and more favorable for small yellow croaker growth (Getabu, 1992; Zhang et al., 2007). Hong (2004) noted that similar prey species were found in the stomach contents of the small yellow croaker in both areas, but the frequency of occurrence of the principal prey items differed remarkably. Crustacean plankton, which is highly nutritional and easily digested, accounted for a predominant proportion of the food contents in the small yellow croaker in the ECS. The abundance of high quality prey may explain the higher growth rate in this region. Third, feeding intensity is closely related to water temperature. The low temperatures in the SYS resulted in retarded growth as well as low feeding intensity.

Commercial fishery exploitation may be another factor influencing growth parameters. Fisheries in the ECS have been heavily exploited for several decades, leading to a decline in the abundance of fish populations and oversupply of prey populations (Lin et al., 2004). The recently recovered fisheries, including the small yellow croaker fishery, may have experienced environmental changes that are favorable for survival and growth (e.g. expansion of available habitat and niche space). Furthermore, intense fishing pressure can result in changes in life history strategies. This may have caused an increase in growth rates and early maturation in small yellow croaker in the ECS.

In summary, we showed that small yellow croaker in the SYS and ECS exhibited different biological and ecological characteristics due to the differences in environmental conditions of the two regions. These differences should be incorporated into the management strategies for the fisheries in these two regions. First, YOY and 1-year-old small yellow croaker dominated the catch in both areas. Second, the life history characteristics differed between the two stocks, particularly during the spawning season. The time of spawning depended largely on water temperature. When the temperature in the spawning grounds reaches a certain level, small yellow croaker begin spawning. Generally, the ECS stock of small yellow croaker began spawning in early April. This timing should be considered when setting the closed seasons for fishing in summer. We suggest an earlier time for the closure of fishing in summer in the ECS. Last, we noted that one-year-old small yellow croaker accounted for a high proportion of the catch in the ECS. These fish grew faster and had a shorter life than those in the SYS suggesting that this region contains important nurseries. To ensure the sustainable utilization of the small yellow croaker stocks, methods should be implemented to protect the ECS small yellow croaker, such as enlargement of the mesh size, and greater protection for the juvenile year classes.

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