Acta Oceanol. Sin., 2018, Vol. 37, No. 2, P. 102–109
DOI: 10.1007/s13131-018-1173-9
http://www.hyxb.org.cn
E-mail: hyxbe@263.net

Application of a catch-based method for stock assessment of three important fisheries in the East China Sea

ZHANG Kui[1, 2], ZHANG Jun[1, 2], XU Youwei[1, 2], SUN Mingshuai[1, 2], CHEN Zuozhi[1, 2*], YUAN Meng[1]
[1] South China Sea Fisheries Research Institute, Chinese Academy of Fishery Sciences, Guangzhou 510300, China
[2] Key Laboratory of Open-Sea Fishery Development, Ministry of Agriculture, Guangzhou 510300, China

Received 4 May 2017; accepted 4 August 2017

Abstract

Most fisheries in China do not have maximum sustainable yield (MSY) estimates due to limited and poor data. Therefore, finding a common method to estimate MSY or total allowable catch (TAC) for fishery management is necessary. MSYs of three important fisheries in the East China Sea were evaluated through a catch-based model. Estimates for intrinsic rate of increase (r) and five levels of process error were considered. Results showed hairtail *Trichiurus japonicas* (Temminck and Schlegel) and small yellow croaker *Larimichthys polyactis* (Bleeker) fisheries experienced overfishing from the mid-1990s to the early 2000s, and the suggested TACs were 55.8×10^4 t and 9.06×10^4 t, respectively. Decades of overfishing in wintering and spawning grounds of large yellow croaker *Larimichthys crocea* (Richardson) caused the fishery's collapse in the 1980s, and it has not recovered until today. The Catch–MSY model generated similar estimated MSYs with other methods and may be a useful choice for the assessment of regional stocks in China.

Key words: Catch-MSY model, fisheries in the East China Sea, intrinsic rate of increase, maximum sustainable yield, overfishing

Citation: Zhang Kui, Zhang Jun, Xu Youwei, Sun Mingshuai, Chen Zuozhi, Yuan Meng. 2018. Application of a catch-based method for stock assessment of three important fisheries in the East China Sea. Acta Oceanologica Sinica, 37(2): 102–109, doi: 10.1007/s13131-018-1173-9

1 Introduction

Marine fisheries in China primarily span four coastal seas, of which the East China Sea (ECS) provides the highest catch, accounting for approximately 40% of the total catch (Shen and Heino, 2014). Hairtail *Trichiurus japonicas* (Temminck and Schlegel), small yellow croaker *Larimichthys polyactis* (Bleeker), and large yellow croaker *Larimichthys crocea* (Richardson) are among the most important fish species both ecologically and economically in the ECS (Lin, 2009; Liu et al., 2009; Ye, 2012). Given that a total allowable catch (TAC) system has not been implemented in China, these fisheries were operated mainly by minimum mesh size regulation, summer fishing moratorium, closure of spawning ground, and fishing power control (Wang, 2012; Shen and Heino, 2014; Yue et al., 2015). Maximum sustainable yield (MSY) for hairtail (Wang and Liu, 2013; Zhang and Chen, 2015) and small yellow croaker fisheries (Lin, 2009; Li et al., 2011) in the ECS was calculated through surplus production models. However, the catch data (1990–2003) analyzed were at high levels and did not capture the decline in the 1970s and 1980s (Ling et al., 2006; see Section "catch data"). Moreover, many fisheries in China did not have MSY estimates due to limited and poor data. This was also one of the reasons that TAC cannot be implemented in China (Wang, 2012). Therefore, finding an appropriate method to estimate MSY or TAC for fishery management is necessary.

Some catch-based methods have been developed for estimating MSY or sustainable yields on data-poor fisheries. The depletion-corrected average catch (DCAC) method (MacCall, 2009) determines sustainable yields based on catch data, natural mortality (M), and depletion in biomass. Based on DCAC and stock reduction analysis (SRA, Kimura et al., 1984), a depletion-based stock reduction analysis (DB-SRA) was proposed by Dick and MacCall (2011). DB-SRA, which is a modification of stochastic SRA (Walters et al., 2006), needs more information (e.g., age at maturity) than DCAC. However, both DB-SRA and DCAC are inappropriate for short-lived species (M>0.2 per year, MacCall, 2009), particularly at low-current biomass levels (Newman et al., 2014). Unfortunately, the compositions of the three fisheries in the ECS were dominated by one-year-old fish, and the M estimate of each species is greater than 0.2 per year (Ling et al., 2005; Lin, 2009; Ye, 2012). Martell and Froese (2013) developed a Catch-MSY model based on catch data, resilience information, and assumptions about relative biomass. This method was applied to 146 stocks and present outstanding MSY estimations, with only a few outliers due to intermediate resilience or lightly exploited levels. In this paper, the Catch-MSY method with intrinsic rate of increase (r) estimation was used for stock assessment of the three fisheries in the ECS, and management suggestions were proposed based on the results. This study will be useful for the sustainability of the three important fisheries and determining TAC on data-limited fisheries in China.

Foundation item: The National Natural Science Foundation of China under contract No. 31602157; the Special Fund for Agro-scientific Research in the Public Interest under contract No. 201403008; the Central Public-interest Scientific Institution Basal Research Fund of South China Sea Fisheries Research Institute under contract No. 2016TS06.

*Corresponding author, E-mail: zzchen2000@163.com

2 Data and modeling

2.1 *Catch data*

The catch data (1956–2013) analyzed in this paper were acquired from the China fisheries yearbook (1956–1979) and the dynamic monitoring system for fishery resources in the ECS (1980–2013). Before 1976, the three species accounted for nearly half of the total catch in the ECS; however, it declined rapidly to approximately 19%, slightly fluctuating in the past 20 years (Fig. 1).

Hairtail is the most valuable and largest fishery in China, comprising 80% to 90% from the ECS (Ling et al., 2005). The hairtail fishery in the ECS began in the 1950s and had the highest catch among the commercial fish species. Before the late 1980s, the three main components of the fishery include bottom trawl fishery of state-run company fleets, inshore bottom trawling, and seine fishery (Ye and Beddington, 1996). In that period, the catch peaked at 52.8×10^4 t in 1974 and then decreased quickly until 1988. From the late 1980s, hairtail was mainly captured by canvas stow net and bottom trawl fishery. The catch rapidly increased from 1988, the peak catch was seen 91.0×10^4 t in 2000, and 66.4×10^4 t was observed in 2013 (Fig. 1).

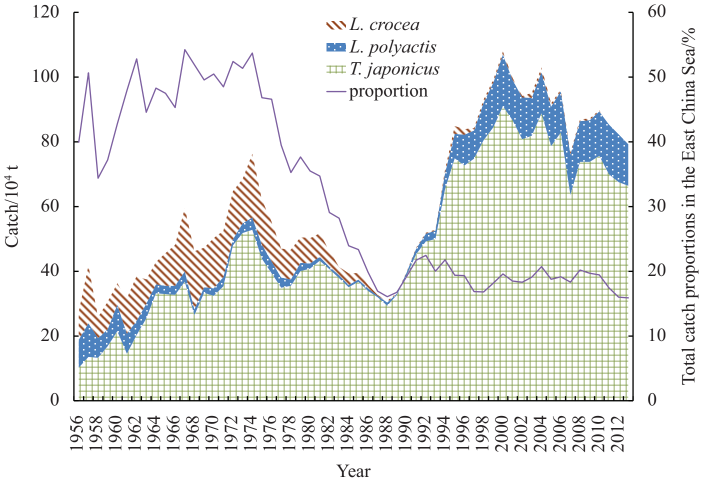

Fig. 1. Statistical catch and total catch proportions of three fish species (*T. japonicas*, *L. polyactis* and *L. crocea*) in the East China Sea from 1956 to 2013.

Small yellow croaker and large yellow croaker are both valuable Sciaenidae species native to the western Pacific. They have been exploited using various methods, including bottom trawl, canvas stow net, gill nets, and set net (Lin, 2009; Ye, 2012). The two fisheries in the ECS had the lowest catch on the same year in 1989, with approximately 4 000 t and 2 000 t. However, they exhibited different resiliencies after that. Small yellow croaker recovered gradually, and the catch stabilized at 13.0×10^4 t in the past 10 years, but large yellow croaker have an average catch of only 7 900 t since 1990 (Fig. 1).

2.2 *Catch-MSY method with r estimation*

The dynamic states are based on the Schaefer production model (Schaefer, 1991):

$$B_t = \lambda_0 k \exp v_t \quad t=1, \tag{1}$$

$$B_{t+1} = [B_t + rB_t(1-B_t/k) - C_t]\exp v_t \quad t>1, \tag{2}$$

where B_t, C_t, and k denote biomass at the start of year t, catch during the year t, and the carrying capacity of the stock habitat, respectively. Lognormal process error structure was assumed, and v_t was independent and identically distributed normal with mean 0 and variance σ^2. λ_0 is the initial depletion level (B_1/k) and is usually assumed to be λ_0=1 if it is a virgin stock.

In the Catch-MSY method, ranges of initial and current depletion levels must be specified. The levels were assigned by Martell and Froese (2013) based on a batch analysis of 98 stocks from the RAM legacy database (Ricard et al., 2012). For the first year, the range of B/k (λ_{01}, λ_{02}) is 0.5–0.9 if catch to maximum catch is below 0.5, otherwise, 0.3–0.6; for the final year, the range of B/k (λ_1, λ_2) is 0.01–0.4 if catch to maximum catch is below 0.5, otherwise, 0.3–0.7. In this study, the ranges of initial and current depletion levels were specified based on the respective exploitation state of the three fisheries in the ECS.

The prior information of r and k parameters is also needed to approximate MSY. Random samples of k were drawn from a uniform distribution where the lower and upper boundaries were the maximum catch in the data series and 50 times maximum catch. Martell and Froese (2013) suggested that the ranges for the random samples of r could be acquired from the resilience assignment in FishBase (Musick, 1999; Froese and Pauly, 2000) if no other available knowledge is available. This assignment may produce outliers of MSY estimates if the target stock has intermediate resilience. Therefore, r was estimated from an empirical equation (Sullivan, 1991) based on von Bertalanffy growth parameters k and W_∞. The estimations of k and W_∞ (Table 1) in the references (Zhou et al., 2002; Lin, 2009; Ye, 2012) were obtained using the ELEFAN method in FiSAT software (Gayanilo et al., 2003). For nongadoid stocks, the predictive equation (Sullivan, 1991) is

$$r = 0.947 + 1.189k - 0.095\ln W_\infty. \tag{3}$$

The equation suggests that faster growth and smaller body size result in a high intrinsic rate of increase. Therefore, hairtail has the smallest and small yellow croaker has the largest r values (Table 1). Moreover, in a given population, r values should be

Table 1. Natural mortality (M) and estimated intrinsic rate of increase (r) from von Bertalanffy growth parameters k and W_∞ for the three species in the East China Sea

Species	k/a^{-1}	W_∞/g	r/a^{-1}	M/a^{-1}	Sampling years	Reference
Trichiurus japonicas	0.27	2 176	0.54	0.52	1960–1963	Zhou et al. (2002)
	0.31	2 448	0.58	0.55	1985	
	0.31	1 892	0.60	0.58	1990–1999	
Larimichthys polyactis	0.24	701	0.61	0.47	1963	Lin (2009)
	0.44	387	0.90	0.71	1983	
	0.55	261	1.00	0.87	2001	
Larimichthys crocea	0.36	629	0.76	0.69	1980	Ye (2012)
	0.29	1 837	0.58	0.56	1982	
	0.43	1 145	0.79	0.77	2010	

bigger than M (ICES, 2012). The M estimates (Table 1) are also obtained from the same references using an empirical formula (Pauly, 1980). As the M estimates are in the time span of 1960s to 2000s, the smallest estimated M multiplied by 80% was considered as the lower limits and the biggest estimated r multiplied by 120% as the upper limits to express errors. All prior information is shown in Table 2.

For r-k combinations, 0 was assigned when leading to the population exceeding k or going extinct, and 1 for those results in final depletion level between λ_1 and λ_2. Therefore, the likelihood function of the parameter vector $\varTheta=\{k, r\}$ can be expressed as

$$\begin{cases} L(\varTheta|C_t)=1 & \lambda_1 \leqslant B_{n+1}/k \leqslant \lambda_2, \\ L(\varTheta|C_t)=0 & \lambda_1 \leqslant B_{n+1}/k \leqslant \lambda_2. \end{cases} \tag{4}$$

This function ensured that each combination of r-k could result in a practicable stock in the last year of the data series. The same importance sampling procedure was used to obtain the joint distribution of parameters r and k, and 100 000 iterations were processed for each situation. Five levels of process error, namely 0, 0.01, 0.05, 0.10, and 0.20, were considered. The geometric means, which can be estimated by $0.25rk$, of r, k, and MSY (Schaefer, 1991) were obtained after the sampling. The standard deviation (SD) of logarithmic mean was used as a measure of uncertainties so approximately 95% of MSY estimates would fall in this range.

3 Results

3.1 *Hairtail*

The hairtail fishery started before 1956, but the catch was at low levels (no more than 5×10^4 t every year, Wang and Qiu, 2006); therefore, 0.6–0.9 was set as the range of initial depletion level for 1956. Although hairtail in ECS is still the largest fishery in China, obvious significant downtrend was noted starting year 2000; therefore, the range of current depletion level for 2013 was set at 0.3–0.7. For no process error situation, the estimated MSY is 77.56×10^4 t with SD 4.10×10^4 t, and estimated r is 0.64 per year with SD of 0.09 per year (Table 3). The posterior estimation of k concentrated on a narrow range, whereas r had a broad posterior estimation covering the prior range, with obvious significant inverse correlation between ln$r$ and ln$k$ (Fig. 2). The rapid increase of catch in the 1990s caused the overfishing of this fishery and the declining landings after 2000.

3.2 *Small yellow croaker*

The catches of the small yellow croaker fishery in the 1950s were at high levels (from 5×10^4 t to 10×10^4 t every year); therefore, the range of initial depletion level for 1956 was set at 0.4–0.8. As the catches were also at high levels in recent years and had a similar trend with hairtail fishery, the range of current depletion level for 2013 was set at 0.3–0.7. For no process error situation, the estimated MSY is 13.79×10^4 t and estimated r is 0.83 per year (Table 3). Although the declining stock recovered starting the 1990s, the rapid increase of catch in the 1990s caused the overfishing. The catch fluctuated around MSY after 2000 (Fig. 3). The posterior estimation of k concentrated on a narrow range, whereas r had a broad posterior estimation like the results of hairtail fishery; however, large coefficient of variations (CVs) for r and MSY was noted.

3.3 *Large yellow croaker*

Prior information did not result in effective r-k combinations

Table 2. Prior information of intrinsic rate of increase (r), carrying capacity (k), and depletion levels of first year (B_{1956}/k) and last year (B_{2013}/k) for the three species in the East China Sea

Species	r/a^{-1}	k	B_{1956}/k	B_{2013}/k
Trichiurus japonicas	(0.42, 0.72)	($C_{\max}$, $50C_{\max}$)	(0.6, 0.9)	(0.3, 0.7)
Larimichthys polyactis	(0.38, 1.20)	($C_{\max}$, $50C_{\max}$)	(0.4, 0.8)	(0.3, 0.7)
Larimichthys crocea	(0.45, 0.95)	($C_{\max}$, $50C_{\max}$)	(0.4, 0.8)	(0.01, 0.3)

Note: Numbers in brackets represent the ranges of uniform prior, and $C_{\max}$ is the maximum catch in the data series.

Table 3. Geometric mean (GM), standard deviation (SD), and coefficient of variation (CV) of posterior estimation of r, k, and MSY for the three fisheries in the East China Sea

Stock	r/a^{-1}			$k/10^4$ t			MSY/10^4 t		
	GM	GM±2SD	CV	GM	GM±2SD	CV	GM	GM±2SD	CV
Trichiurus japonicas	0.64	0.48–0.85	0.14	486.6	378.5–625.7	0.12	77.56	69.75–86.25	0.05
Larimichthys polyactis	0.83	0.45–1.53	0.30	66.4	38.3–115.1	0.26	13.79	11.33–16.78	0.10
Larimichthys crocea	0.09	0.05–0.16	0.31	289.6	218.3–332.9	0.10	6.17	4.15–9.19	0.21

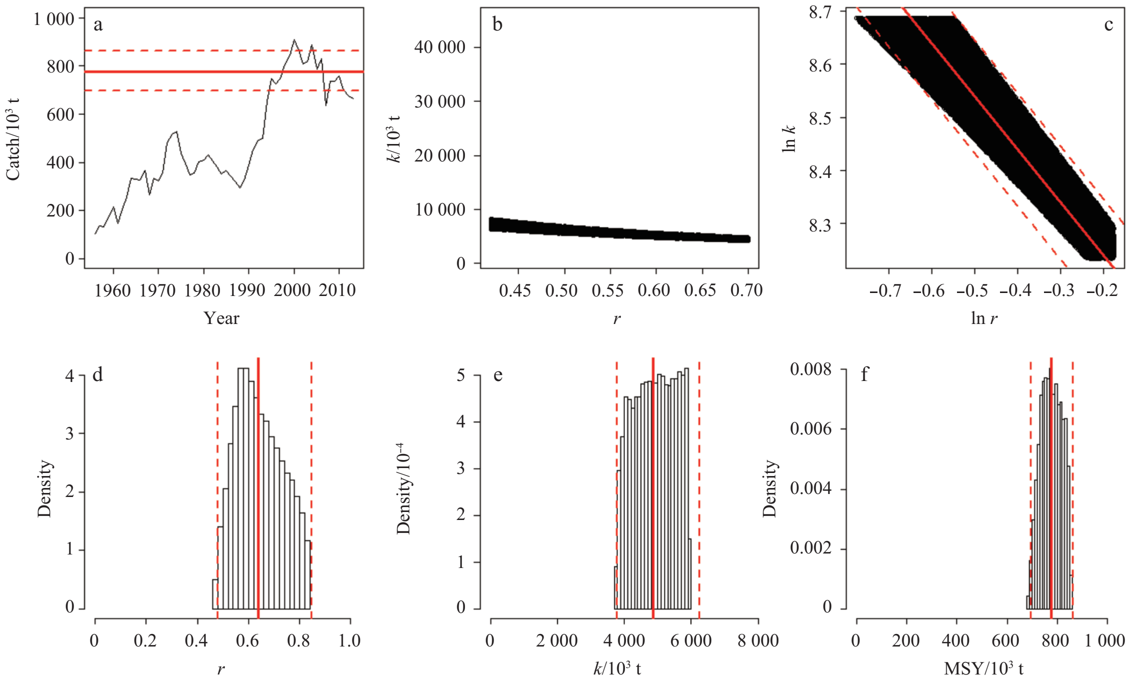

Fig. 2. Model outputs in case of no process error for hairtail fishery in the East China Sea. a. Catch history from 1956 to 2013 with the MSY estimation (solid line) ±2SD (dash line); b. prior uniform distribution of *r*-*k*, and the black dots are the posterior combinations; c. the relationship between ln*r* and ln*k* with the geometric mean MSY (solid line) ±2SD (dash line); d–f. posterior densities of *r*, *k* and MSY. The solid lines are geometric means, and the dash lines represent geometric means±2SD.

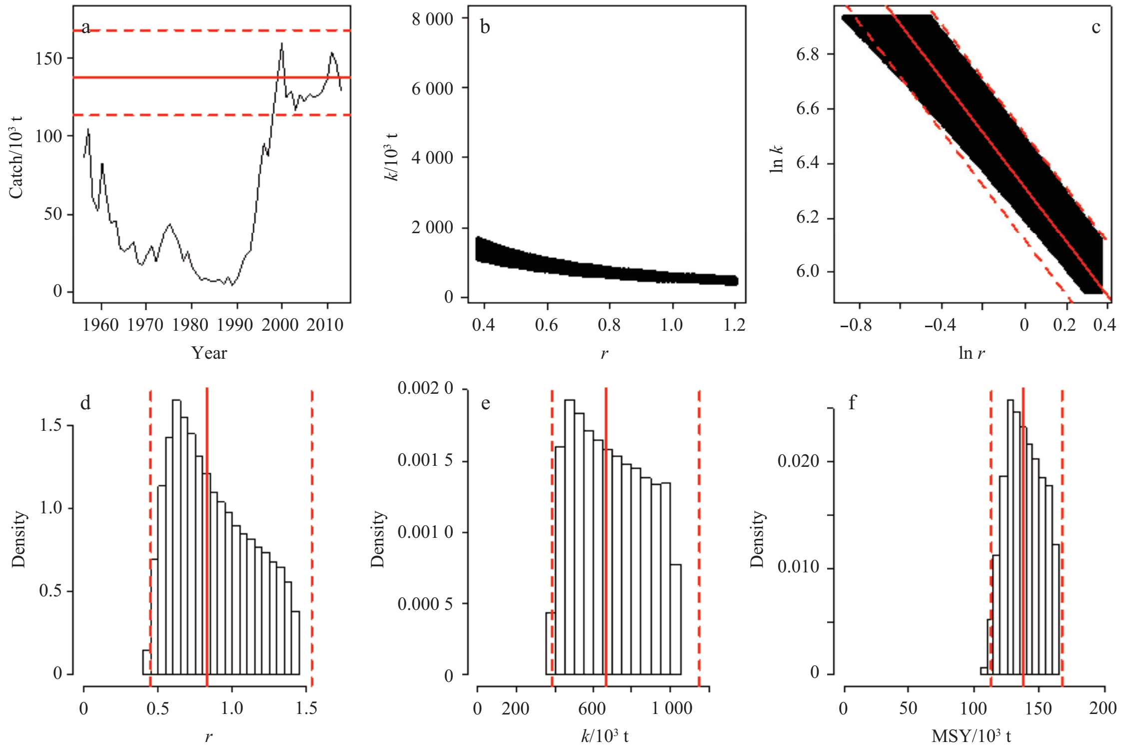

Fig. 3. Model outputs in case of no process error for small yellow croaker fishery in the East China Sea.

for the large yellow croaker fishery; therefore, we tried to reset the prior information for this fishery in Table 2. The restrictions for *r* led to invalid results and produced a new broad range (0.05, 1) for prior *r*. The results are shown in Fig. 4. Comparing the results of the other two fisheries, the posterior *r*-*k* combinations appeared to be a different shape, in which *r* had a more narrow posterior estimation than the prior range. With no process error, the estimated MSY for the large yellow croaker fishery is 6.17×10^4 t with SD 1.21×10^4 t and estimated *r* is 0.09 per year with SD 0.02 per year (Table 3). The stock suffered from prolonged overfishing from 1956 to 1985 and had not recovered until recently (Fig. 4).

3.4 *Model uncertainty*

Different levels of process error were considered for hairtail and small yellow croaker fishery because the prior set did not generate effective results for large yellow croaker fishery. For hairtail fishery (Fig. 5), the percentage relative bias (PRB) of *r* did not vary significantly, while PRB of *k* decreased as the process error increased; PRB of MSY was the greatest when process error was 0.2. For small yellow croaker fishery (Fig. 6), PRB of *r* and *k* exhibited a larger variation than hairtail fishery; the estimated values of *r* and MSY decreased, whereas the estimated values of *k* increased as the process error increased.

4 Discussion

4.1 *Model performance*

The *r* estimation provided effective prior information for hairtail and small yellow croaker fisheries. Studies were conducted to estimate the MSY of the two fisheries by using different methods. For hairtail fishery, Xu et al. (2011) determined the estimated MSY of 7.00×10^5–7.05×10^5 t using stock-recruitment relationship. Meanwhile, an MSY of 7.16×10^5–7.99×10^5 t was obtained by Wang and Liu (2013) using surplus production models. An estim-

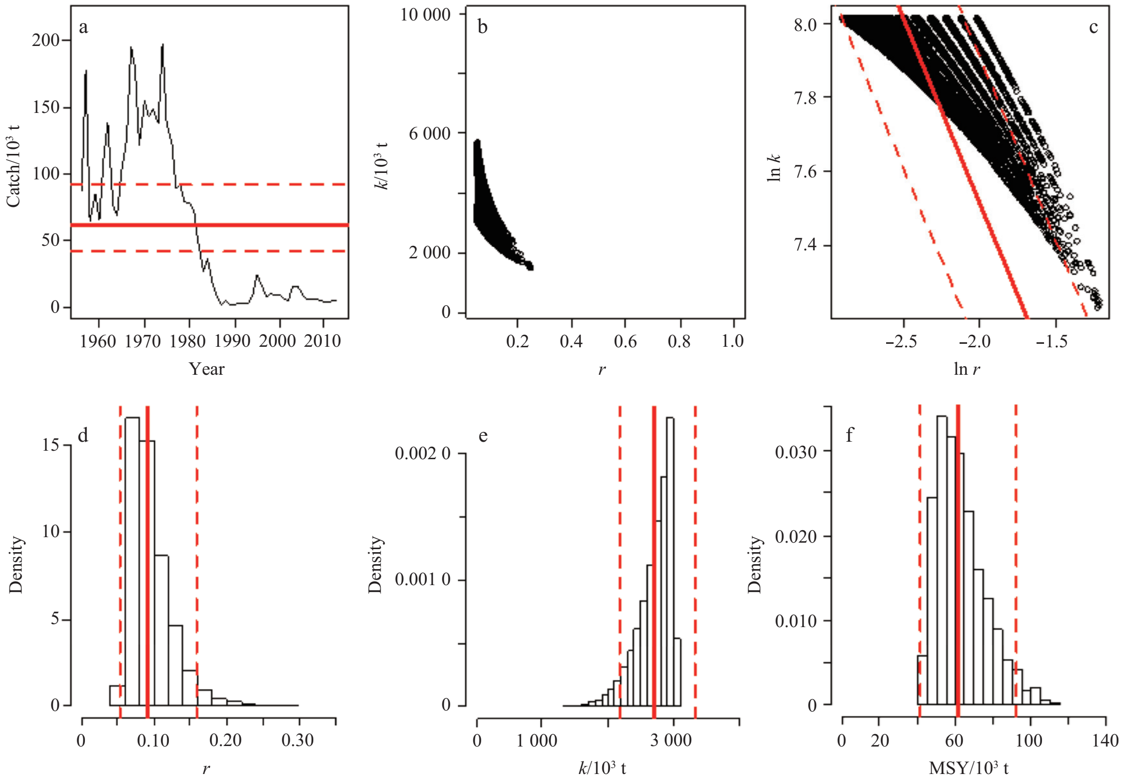

Fig. 4. Model outputs in case of no process error for large yellow croaker fishery in the East China Sea.

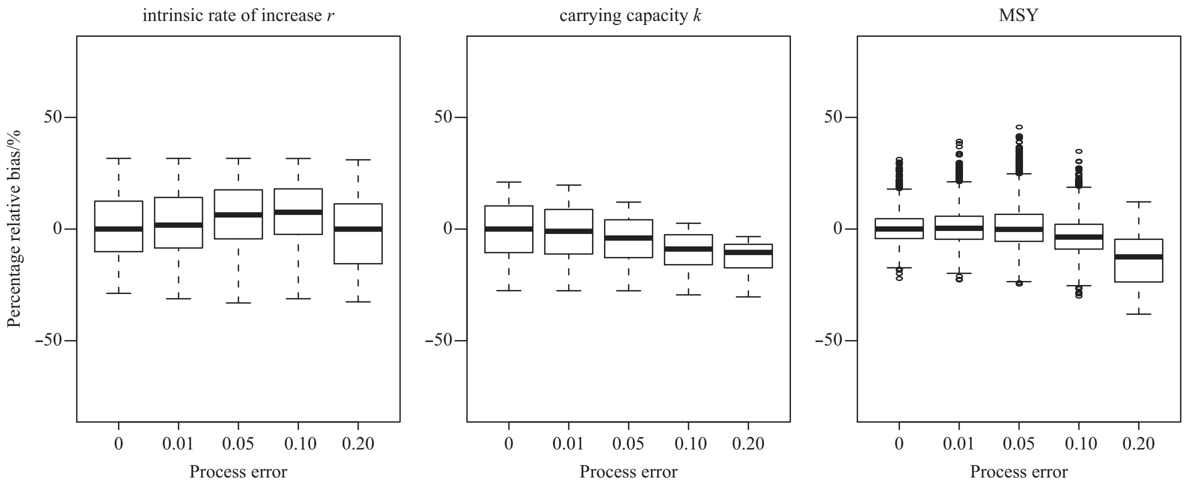

Fig. 5. Boxplots of the percentage relative bias of intrinsic rate of increase (*r*), carrying capacity (*k*), and MSY estimated at different levels of process error for hairtail fishery in the East China Sea.

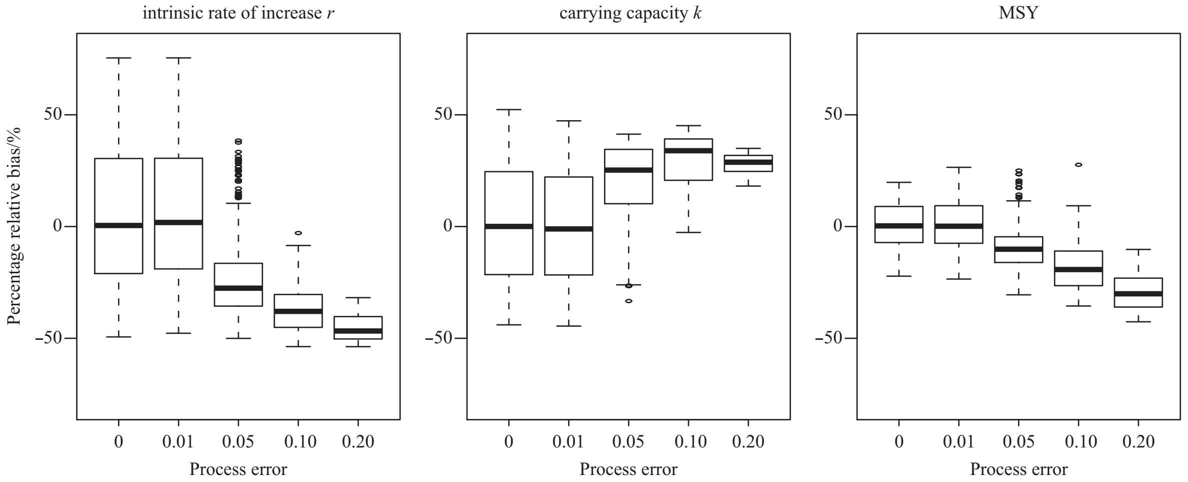

Fig. 6. Boxplots of the percentage relative bias of intrinsic rate of increase (r), carrying capacity (k), and MSY estimated at different levels of process error for small yellow croaker fishery in the East China Sea.

ated MSY of 7.55×10^5 t was provided by Zhang and Chen (2015) based on Bayesian state-space modeling. In the present study, an estimated MSY of 7.76×10^5 t was obtained using the Catch-MSY method. For small yellow croaker fishery, an estimated MSY of 11.0×10^4 t was provided by Li et al. (2011) using Bayes-based Pella-Tomlinson model. An MSY of 13.6×10^4 t was obtained by Lin (2009) based on the Schaefer production model and 11.7×10^4 t based on the Fox model. In the present study, an estimated MSY of 13.79×10^4 t was obtained using the Catch-MSY method. Our results for the two fisheries were similar to that using the Schaefer production model and were higher than the other studies because the Catch-MSY method was transformed by the Schaefer production model. However, the Catch-MSY method uses lesser data compared with other methods.

Process error exhibited a different influence on the estimated values of parameters and MSY in different fisheries. Results of the hairtail fishery presented a lesser change than that of the small yellow croaker fishery while the process error varied from 0 to 0.2. Therefore, the process needs to be set cautiously for a specific fishery.

4.2 *Overfishing of the three fisheries*

Estimated MSY and catch trajectories (Figs 2 and 3) indicated the hairtail and small yellow croaker fisheries were overfished from the mid-1990s to the early 2000s. The catches were near MSY during these years and had a downward trend. In fact, the fishing effort in the ECS increased rapidly from the 1980s. In the last two decades of the 20th century, the number of marine engine-powered fishing vessels and their total engine power increased by 420% and 284% (Fig. 7). Given the rapid increase of fishing effort and catches, the long-lived, high-trophic-level fishes were replaced by small-sized species with high growth rate and may also lead to changes in the biological characteristics of the three species (Zhu et al., 2009). The mean body or anal length of the the small yellow croaker and the large yellow croaker tapered from the 1960s (Table 4) decreased by 42.4% and 58.9%, respectively. In addition, they also tend to mature earlier, grow faster, and be exploited more excessively in recent years than in the 1960s (Table 4).

The prior information did not result in effective r-k combinations for the large yellow croaker fishery mainly because the r estimation used data of the 1980s and the 2000s, and the ecological strategy of this fishery changed from k strategy to r strategy (Xu and Liu, 2007; Zhu et al., 2009). The age composition of catches changed from 2–25 in 1958 to 1–3 in 1993 (Xu and Liu, 2007). Therefore, as shown in Table 1, the estimated r using catch data from 1956 to 2013 was lower than that using data after the 1980s. This fishery had been overfished since the mid-1950s, and the overfishing lasted for nearly 30 years (Fig. 4). The catch maintained low levels since the mid-1980s and, unlike the small yellow croaker fishery, did not recover. The large yellow croaker was highly clustered in overwintering and spawning grounds. The severe overfishing in overwintering and spawning grounds (e.g., Zhoushan Islands, the coastal area of Fujian) during the 1970s, especially 1974–1976, caused the collapse of this fishery (Xu and Liu, 2007). Although several conservation measures have been implemented, this fishery has not recovered.

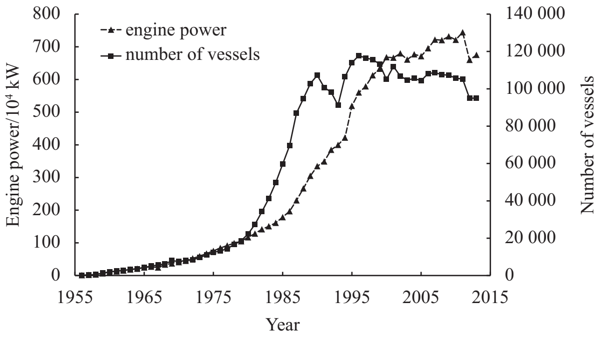

Fig. 7. The number of marine engine-powered fishing vessels and their total engine power in the East China Sea from 1956 to 2013.

4.3 *Management advice*

Based on the principles of MSY-based management suggested by Martell and Froese (2013), the lower margin of error of MSY (geometric mean MSY-2SD) should be used as a target for TAC if stock size were above 0.5 k. Unfortunately, the hairtail and small yellow croaker fisheries were overfished in the 1990s, the mean length of the catch has declined (Table 4), and the proportion of large fish is less than 20% at the beginning of the fishery (Zhou et al., 2002; Lin, 2009). Therefore, stock sizes of the two

Table 4. Variations in biological characteristics and exploitation rates of the three fisheries in the East China Sea

Species	Period	Mean body (anal) length/mm	Mean body (anal) length at maturity/mm	Growth coefficient	Exploitation rate	Reference
Trichiurus japonicas	1960s	239	264	0.27	0.7	Zhou et al. (2002) Wang (2010) Chen et al. (2013)
	1970s	227	235	–	0.83	
	1980s	215	242	0.31	0.84	
	1990s	189	221	0.31	0.87	
	2000s	183	–	0.34	0.86	
Larimichthys polyactis	1960s	224	246	0.24	–	Lin (2009)
	1980s	152	174	0.44	–	
	2000s	129	123	0.55	–	
Larimichthys crocea	1960s	321	–	–	–	Zhu et al. (2009) Ye (2012)
	1970s	342	–	–	–	
	1980s	222	–	0.33	0.82	
	2010s	132	–	0.43	0.86	

Note: Anal length was used for *T. japonicas*, whereas body length was used for *L. polyactis* and *L. crocea*. The mean value was applied when one decade included separate data of more than one year or reference.

fisheries may be below 0.5 k (Froese, 2004). TACs of the two fisheries should be less than the lower margin of error of MSY, and 80% of it should be appropriate when TAC management is implemented for the two fisheries for the first time. That is, 55.8×10^4 t for hairtail fishery and 9.06×10^4 t for small yellow croaker fishery. In addition, minimum mesh size regulation should be more stringent as several immature individuals were included in the catches of the two species (Lin, 2009; Wang, 2010). For the large yellow croaker, the estimated TAC is 3.32×10^4 t. It had been overfished for nearly 30 years, and recovery is difficult. Therefore, we suggest that the overwintering and spawning grounds should be closed so that stock enhancement could continue. Artificial breeding of this species started in 1986 in Fujian Province and has become one of the main mariculture fishes in China.

In summary, the Catch-MSY method with r estimation provides a good fit for fisheries in the ECS. This model may also present a useful choice for the assessment of regional stocks in China. However, r estimation must be carefully dealt with because the ecological strategy of fish has changed.

References

Chen Yunlong, Shan Xiujuan, Dai Fangqun, et al. 2013. Relative stock density and distribution of hairtail *Trichiurus lepturus* and its spawning stock structure in coastal waters of the East China Sea. Progress in Fishery Sciences (in Chinese), 34(4): 8–15

Dick E J, MacCall A D. 2011. Depletion-based stock reduction analysis: a catch-based method for determining sustainable yields for data-poor fish stocks. Fisheries Research, 110(2): 331–341

Froese R. 2004. Keep it simple: three indicators to deal with overfishing. Fisheries Research, 5(1): 86–91

Froese R, Pauly D. 2000. FishBase 2000: Concepts, Design and Data Sources. Los Baños, Laguna, Philippines: ICLARM, 167

Gayanilo F C, Sparre P, Pauly D. 2003. FAO-ICLARM Stock Assessment Tool (FiSAT II) User's Guide. FAO Computerized Information Series (Fisheries) No.8. Rome, Italy: FAO, 1–168

ICES. 2012. Report of the Workshop on the Development of Assessments based on LIFE history traits and Exploitation Characteristics (WKLIFE). Copenhagen, Denmark: ICES, 36

Kimura D K, Balsinger J W, Ito D H. 1984. Generalized stock reduction analysis. Canadian Journal of Fisheries and Aquatic Sciences, 41(9): 1325–1333

Li Jiuqi, Ye Changchen, Wang Wenbo, et al. 2011. A stock assessment of small yellow croaker by Bayes-based Pella-Tomlinson model in the East China Sea. Journal of Shanghai Ocean University (in Chinese), 20(6): 873–882

Lin Longshan. 2009. Study on the fishery biology and management strategy of *Larimichthys polyactis* in the southern Yellow Sea and the East China Sea (in Chinese)[dissertation]. Qingdao: Ocean University of China

Ling Jianzhong, Li Shengfa, Yan Liping. 2006. Analysis on the utilization of main fishery resources in the East China Sea. Marine Fisheries (in Chinese), 28(2): 111–116

Ling Jianzhong, Yan Liping, Lin Longshan, et al. 2005. Reasonable utilization of hairtail *Trichiurus japonicus* resource in the East China Sea based on its fecundity. Journal of Fishery Sciences of China (in Chinese), 12(6): 726–730

Liu Yong, Cheng Jiahua, Chen Yong. 2009. A spatial analysis of trophic composition: a case study of hairtail (*Trichiurus japonicus*) in the East China Sea. Hydrobiologia, 632(1): 79–90

MacCall A D. 2009. Depletion-corrected average catch: a simple formula for estimating sustainable yields in data-poor situations. ICES Journal of Marine Science, 66(10): 2267–2271

Martell S. Froese R 2013. A simple method for estimating MSY from catch and resilience. Fish and Fisheries, 14(4): 504–514

Musick J A. 1999. Criteria to define extinction risk in marine fishes: the American fisheries society initiative. Fisheries, 24(12): 6–14

Newman D, Carruthers T, MacCall A, et al. 2014. Improving the science and management of data-limited fisheries: an evaluation of current methods and recommended approaches. New York, USA: NRDC, 1–36

Pauly D. 1980. On the interrelationships between natural mortality, growth parameters, and mean environmental temperature in 175 fish stocks. ICES Journal of Marine Science, 39(2): 175–192

Ricard D, Minto C, Jensen O P, et al. 2012. Examining the knowledge base and status of commercially exploited marine species with the RAM Legacy Stock Assessment Database. Fish and Fisheries, 13(4): 380–398

Schaefer M B. 1991. Some aspects of the dynamics of populations important to the management of the commercial marine fisheries. Bulletin of Mathematical Biology, 53(1-2): 253–279

Shen Gongming, Heino M. 2014. An overview of marine fisheries management in China. Marine Policy, 44: 265–272

Sullivan K J. 1991. The estimation of parameters of the multispecies production model. ICES Marine Science Symposium, 193(1): 185–193

Walters C J, Martell S J D, Korman J. 2006. A stochastic approach to stock reduction analysis. Canadian Journal of Fisheries and Aquatic Sciences, 63(1): 212–223

Wang Yao. 2010. The resource evaluation of *Trichiurus Japonicus* on East China Sea in Summer Close Season (in Chinese) [dissertation]. Zhoushan: Zhejiang Ocean University

Wang Yun. 2012. Study on marine fishing quota system of China (in Chinese) [dissertation]. Qingdao: Ocean University of China

Wang Yu, Liu Qun. 2013. Application of CEDA and ASPIC computer packages to the hairtail (*Trichiurus japonicus*) fishery in the East China Sea. Chinese Journal of Oceanology and Limnology, 31(1): 92–96

Wang Yuezhong, Qiu Yongsong. 2006. An analysis of interannual variations of hairtail catches in East China Sea. South China Fisheries Science (in Chinese), 2(3): 16–24

Xu Kaida, Liu Zifan. 2007. The current stock of large yellow croaker *Pseudosciaena crocea* in the East China sea with respects of its stock decline. Journal of Dalian Fisheries University (in Chinese), 22(5): 392–396

Xu Hanxiang, Liu Zifan, Zhou Yongdong, et al. 2011. The relation between parents and recruitment of hairtail on status of summer closed fishing in East China Sea. Fishery Modernization (in Chinese), 38(1): 64–69

Ye Jinqing. 2012. Resource and biological characteristics of large yellow croaker (*Larimichthys crocea*) in Guanjing Yang (in Chinese) [dissertation]. Shanghai: Shanghai Ocean University

Ye Yimin, Beddington J. 1996. Modelling interactions between inshore and offshore fisheries: the case of the East China Sea hairtail (*Trichiurus haumela*) fishery. Fisheries Research, 27(4): 153–177

Yue Dongdong, Wang Lumin, Zhang Xun, et al. 2015. Status and reflections of the summer closed fishing in the East China Sea. Journal of Agricultural Science and Technology (in Chinese), 17(4): 122–128

Zhang Kui, Chen Zuozhi. 2015. Using Bayesian state-space modelling to assess *Trichiurus japonicus* stock in the East China Sea. Journal of Fishery Sciences of China (in Chinese), 22(5): 1015–1026

Zhou Yongdong, Xu Hanxiang, Liu Zifan, et al. 2002. A study on variation of stock structure of hairtall, *Trichiurus haumela* in the East China Sea. Journal of Zhejiang Ocean University (Natural Science) (in Chinese), 21(4): 314–320

Zhu Xiaoguang, Fang Yuanyong, Yan Lijiao, et al. 2009. The ecological strategy evolution of marine fishes under high intensity fishing environment. Bulletin of Science and Technology (in Chinese), 25(1): 51–55