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Estimating biological reference points for Largehead hairtail (*Trichiurus lepturus*) fishery in the Yellow Sea and Bohai Sea

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Abstract

It is important to find a reliable method to estimate maximum sustainable yield (MSY) or total allowable catch (TAC) for fishery management, especially when the data availability is limited which is a case in China. A recently developed method (CMSY) is a data-poor method, which requires only catch data, resilience and exploitation history at the first and final years of the catch data. CMSY was used in this study to estimate the biological reference points for Largehead hairtail (*Trichiurus lepturus*, Temminck and Schlegel) in the Yellow Sea and Bohai Sea, based on the fishery data from *China Fishery Statistical Year Books* during 1986 to 2012. Additionally, Bayesian state-space Schaefer surplus production model (BSM) and the classical surplus production models (Schaefer and Fox) performed by software CEDA and ASPIC, were also projected in this study to compare with the performance of CMSY. The estimated MSYs from all models are about 19.7×10^4–27.0×10^4 t, while CMSY and BSM yielded more reasonable population parameter estimates (the intrinsic population growth rate and the carrying capacity). The biological reference points of B/B_{MSY} smaller than 1.0, while F/F_{MSY} higher than 1.0 revealed an over-exploitation of the fishery, indicating that more conservative management strategies are required for Largehead hairtail fishery.

Key words: CMSY, surplus production models, maximum sustainable yield, Yellow Sea and Bohai Sea, *Trichiurus lepturus*

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1 Introduction

In China, fishery management methods are mainly the closure of summer season (May, June, July and August) and spawning ground, minimum mesh size regulation, and fishing power control (Wang, 2012; Shen and Heino, 2014; Yue et al., 2015). Because of the limited and poor data, maximum sustainable yield (MSY) in China fisheries are commonly unavailable, which may be one of the reasons that TAC (Total Allowable Catch) cannot be implemented in China (Wang, 2012). Therefore, it is important to find an appropriate method to estimate MSY or TAC for the fishery management in China.

Hairtail (*Trichiurus lepturus*) is widely distributed in the Yellow Sea and Bohai Sea. From 1986 to 2012 the total catches in the region for this fish species ranged from 7.38×10^4 to 32.89×10^4 t. Studies on this fish species have mostly concentrated on the effect of the Summer Fishing Moratorium Policy (Yan et al., 2007), the ecology (Wang, 2010), characteristics of reproduction and recruitment (Ling et al., 2005), the spawner-recruit model (Xu et al., 2011), the yield per recruit model (Ling et al., 2008) and surplus production models (Wang and Liu, 2013). The use of data-poor stock assessment models to analyze this fishery is not reported.

Surplus production models are among the simplest for a full fish stock assessment. Early versions of the surplus production model required equilibrium assumption, which is difficult to satisfy in practice, but it is not required by the modern production models. When the data lack contrast it means that the catch and effort data explain only a limited range of stock abundance levels. If the catch and effort data are representative for a fished stock, surplus production models may produce answers just as useful and sometimes better than those by age-structured models, at a lower cost (Haddon, 2011).

For the data-poor fisheries, some catch-based methods have been developed for estimating MSY, such as depletion-corrected average catch (DCAC) method (MacCall, 2009), stock reduction analysis (SRA, Kimura et al., 1984), and depletion-based stock reduction analysis (DB-SRA, Dick and MacCall, 2011). Martell and Froese (2013) and Froese et al. (2017) developed a Catch–MSY model (CMSY) based on catch data, resilience information, and assumptions about relative biomass of the first and last years. In comparison with the other data poor methods, an FAO workshop (Rosenberg et al., 2014) concluded that CMSY performed the best, although the other models performed similarly in many cases. CMSY was better in estimating status over short time scales and could be particularly useful in developing countries where data time series are usually short. Harvest dynamics was an important explanatory variable, which indicate the importance of having accurate data on catch and fishing effort.

Therefore, CMSY method is used in this study for stock assessment of Largehead hairtail *Trichiurus lepturus* (Temminck and Schlegel) fishery in the Yellow Sea and Bohai Sea. This study

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could be useful for determining MSY on data-limited fisheries in China. The results of CMSY are also compared with those from surplus production models, including the classical forms (Schaefer and Fox) performed by software CEDA and ASPIC, and extensions, Bayesian state-space Schaefer surplus production model. Wang and Liu (2013) and Zhang et al. (2018a, b) estimated MSY of largehead hairtail fishery in the East China Sea using surplus production models and CMSY methods, but little work has been done on the biological reference points of the species in the Yellow Sea and Bohai Sea, especially using the data-poor method of CMSY.

2 Materials and methods

2.1 *Data sources*

Fishery statistics of Largehead hairtail *T. lepturus* fishery in the Yellow Sea and Bohai Sea of the 27 years (1986–2012) were collected from *China Fishery Statistical Year Books* (Fishery Bureau of Agriculture Ministry, China, 1986–2012), catch per unit effort (CPUE) is calculated from the catch and effort data. Catch data are in tons and CPUEs are in t/KW in each year (Table 1).

2.2 *CMSY model*

On the basis of catch data, resilience or productivity of the fish species and stock status at the beginning and the end of the time series, CMSY is a Monte-Carlo method that estimates fisheries reference point of MSY (Martell and Froese, 2013; Froese et al., 2017).

Table 1. Fishery statistics of Largehead hairtail (*Trichiurus lepturus*) fishery in the Yellow Sea and Bohai Sea (Fishery Bureau of Agriculture Ministry, China, 1986–2012)

Year	CPUE/t·kW^{-1}	Catch/t
1986	0.060 250	75 809
1987	0.055 906	74 846
1988	0.048 125	73 883
1989	0.047 409	84 442
1990	0.052 177	95 001
1991	0.055 181	107 623
1992	0.058 476	120 246
1993	0.066 224	142 246
1994	0.077 929	164 247
1995	0.070 504	168 337
1996	0.064 944	172 427
1997	0.063 675	184 304
1998	0.065 379	196 182
1999	0.064 415	206 316
2000	0.064 930	216 450
2001	0.068 425	230 883
2002	0.072 015	245 316
2003	0.080 523	274 318
2004	0.093 816	303 321
2005	0.095 082	316 124
2006	0.100 638	328 927
2007	0.089 863	274 025
2008	0.069 270	219 124
2009	0.062 679	204 377
2010	0.056 677	189 630
2011	0.051 633	178 474
2012	0.050 516	167 319

Note: CPUE is calculated from the catch and effort data.

The fish population dynamics are based on the Schaefer surplus production model (Schaefer, 1991):

$$B_t = \lambda_0 k e^{v_t} \quad \text{when} \quad t = 1, \tag{1}$$

$$B_t = \left[B_{t-1} + rB_{t-1}\left(1 - \frac{B_{t-1}}{k}\right) - C_{t-1}\right] \times e^{v_{t-1}} \quad \text{when} \quad t > 1, \tag{2}$$

where B is biomass, C is catch, r is the intrinsic population growth rate, k is the carrying capacity, t is year, and v_t is a normal error with mean 0 and variance σ^2. λ_0 is the initial depletion level (B_1/k).

For r–k combinations, if the population exceeding k or going extinct, 0 was assigned, and if the final depletion level is between the final depletion levels λ_1 and λ_2, 1 was assigned. Therefore, the likelihood function of $\Theta = \{r, k\}$ can be expressed as

$$L(\Theta|C_t) = \begin{cases} 1 & \lambda_1 \leqslant B_{n+1}/k \leqslant \lambda_2, \\ 0 & \lambda_1 > B_{n+1}/k > \lambda_2, \end{cases} \tag{3}$$

where n is the number of years in the data series, t=1, 2, ..., n. Therefore, for each pair of parameter combination (r, k) that produces a viable population at the end of the catch data, MSY can be calculated from $MSY = r \times k/4$.

CMSY requires prior information for r and k parameters. The lower and upper boundaries of k are the maximum catch in the data series and 50 times maximum catch respectively. In this study for Largehead hairtail *T. lepturus* fishery in the Yellow Sea and Bohai Sea the prior range for k is calculated by the R-code of Froese et al. (2017). According to prior ranges for parameter r based on classification of resilience (see below) in the user guide of Froese et al. (2017), we used r range of 0.2–0.8 for medium resilience:

Exploitation history at the first and final years is from the catch data. Prior initial relative biomass is 0.1–0.4, prior final relative biomass is 0.2–0.65. Prior intermediate relative biomass is 0.5–0.9 in year 2005 by default. More details of CMSY are in Martell and Froese (2013) and Froese et al. (2017).

Resilience	Prior r range
High	0.6–1.5
Medium	0.2–0.8
Low	0.05–0.5
Very low	0.015–0.1

2.3 *Surplus production models*

Compared to other implementations of surplus production models, Bayesian state-space Schaefer surplus production model (BSM) has the focus on informative priors and the acceptance of fragmented abundance data (Millar and Meyer, 1999; Froese et al., 2017). Prior range for r and k are the same as those in CMSY. The prior range of q is calculated by the R-code of Froese et al. (2017).

Classical surplus production models (SPM) are also included in this paper for the purpose of comparison. The most commonly used model is Schaefer model, which is built on the logistic population growth model (Schaefer, 1991):

$$\frac{\mathrm{d}B}{\mathrm{d}t} = rB\left(k - B\right). \tag{4}$$

Next Fox (1970) proposed further work on a Gompertz growth equation:

$$\frac{\mathrm{d}B}{\mathrm{d}t} = rB(\ln k - \ln B)\,. \quad (5)$$

Both the two classical SPMs (Schaefer and Fox) are performed by computer software packages, CEDA (a catch effort data analysis, Hoggarth et al., 2006) and ASPIC (a surplus production model incorporating covariates, Prager, 2017). Because ASPIC does not provide the estimates of r and k, we calculated r from $2\times F_{MSY}$, and k from $2\times B_{MSY}$ for Schaefer SPM and $B_{MSY}/0.679$ for Fox SPM.

We used an R-code (CMSY_O_7q.R) from Froese et al. (2017) (downloaded from http://oceanrep.geomar.de/33076/) for CMSY and BSM. The input values for the CMSY/BSM program are in Table 2. The input values of ASPIC are in Appendix. CEDA is menu driven, it requires catch/effort data and an initial proportion (calculated as the ratio of start catch over maximum catch).

3 Results

The population parameters (r and k) and biological reference point (MSY) were estimated by these six methods for Largehead hairtail (*T. lepturus*) in the Yellow Sea and Bohai Sea (Table 3). All the methods estimated similar MSY values (in a range of 19.7×10^4–27.0×10^4 t). The parameter estimates (r and k) from CMSY and BSM were much close. However, the traditional surplus production models calculated small population growth rates (0.055–0.14) while with high carrying capacity estimates (781×10^4–$1\,372\times10^4$ t). The confidence interval of r, k and MSY estimated from the traditional surplus production models were much wider than those from CMSY and BSM. In contrast the new methods of CMSY and BSM produced reasonable values of both the above parameters.

Based on the parameters and MSY estimates, BSM provided the information for management for Largehead hairtail (*T. lepturus*) in the Yellow Sea and Bohai Sea (Fig. 1). B/B_{MSY} and F/F_{MSY} from the models are in Table 4. Except for the CMSY results, the values of B/B_{MSY} and F/F_{MSY} from all the other models showed that the biological reference points of B/B_{MSY} were mostly smaller than 1.0, while F/F_{MSY} were mostly higher than 1.0, indicating the overfishing and overfished status of this fishery.

4 Discussion

4.1 *CMSY model*

The prior information of r and k parameters is needed for methods of CMSY and BSM. Martell and Froese (2013) suggested that the prior of r could be acquired from the resilience in FishBase (Froese and Pauly, 2018). Apart from that, r may be estimated from an empirical equation (Sullivan, 1991) based on von Bertalanffy growth parameters of the exponential growth rate, K, and the asymptotic weight, W_∞. The estimations of K and W_∞ could be obtained using the ELEFAN method in FiSAT computer software package (Gayanilo et al., 2005). The predictive equation

Table 2. Input parameters of CMSY and BSM models

Parameter	Meaning	Value
Region	the catch area	West Pacific
Subregion	the subarea	YellowBohaiSeas
Stock	a unique fish stock name or identifier	HAIRTAIL_YBS
Group	optional; the functional group that a species belongs to	large predators
Name	optional; a common name of the species	Hairtail in YBS
EnglishName	optional; a common English name of the species	Hairtail
ScientificName	optional; the scientific name of the species	Trichiurus lepturus
Source	optional; the source where the data were taken from	Fishery Statistics of China
MinOfYear	the start year of the catch report	1986
MaxOfYear	the last year of the catch report	2012
StartYear	the start year to be used for the analysis (from when on the data are thought to be reliable)	1986
EndYear	the end year of the catch time series to be used	2012
Flim, Fpa, Blim, Bpa, Bmsy, FMSY, MSYBtrigger, B40, M, Fofl, SSB	optional; fisheries reference points from assessments, for comparison, not used in the analysis	NA
Resilience	prior estimate of resilience, corresponding to intrinsic growth rate (“High”, “Medium”, “Low”, “Very low”)	Medium
r.low / r.hi	Optional; to specify the range of intrinsic growth rate for the species. Set to NA to use the range specified in Resilience.	NA
stb.low / stb.hi	the prior biomass range relative to the unexploited biomass (B/k) at the beginning of the catch time series	0.1/0.4
int.yr	a year in the time series for an intermediate biomass level. Set it to NA to have it estimated by default rules.	NA
intb.low / intb.hi	intermediate relative biomass range. Set it to NA to estimate from maximum or minimum catch.	NA/NA
endb.low/ endb.hi	the prior relative biomass (B/k) range at the end of the catch time series.	0.2/0.65
q.start / q.end	the start and end year for determining the catchabilitiy coefficient. If set to NA the default is last 5 years (or last 10 years in slow growing species).	NA/NA
btype:	the type of information. Allowed values are “biomass”, “CPUE” or “None”.	CPUE
force.cmsy:	set to TRUE if the CMSY results rather than available BSM results are used. Useful when the abundance data are deemed unreliable. Default is FALSE or F	F
Comment:	a comment on the stock or the quality of the analysis or special settings.	Catch=landings from Fish Stat of China

(Sullivan, 1991) is

$$r = 0.947 + 1.189K - 0.095\ln(W_{\infty}). \quad (6)$$

Table 3. Estimates and the 95% confidence intervals of population parameters (r and k) and biological reference points (MSY) of Largehead hairtail (*Trichiurus lepturus*) in the Yellow Sea and Bohai Sea using different methods

Methods		r (1/year)	k/10⁴ t	MSY/10⁴ t
CMSY		0.566	170	24.0
		0.407–0.785	109–265	19.1–30.3
BSM		0.354	222	19.7
		0.261–0.48	165–298	15.6–24.7
CEDA	Schaefer	0.14	781	27.0
		0.005 6–0.45	221–29 251	22.8–58.2
	Fox	0.055	1 182	24.0
		0.001–0.32	288–87 652 540	15.3–73 219
ASPIC	Schaefer	0.1	1 022	26.0
		0.054–0.155	603–2 224	23.7–31.8
	Fox	0.096	1 372	24.2
		0.047–0.153	810–3 261	22.0–31.1

Note: r is the intrinsic population growth rate; k is carrying capacity; MSY is the maximum sustainable yield. See the details of the methods in Sections 2.2 and 2.3.

The above equation suggests that faster growth and smaller body size can have a high intrinsic rate of increase. Moreover, r prior values may be related to natural mortality M (r=2M) (Froese et al., 2017). The M estimates may be obtained from an empirical formula of Pauly (1980) and the natural mortality estimators for information-limited fisheries are reviewed by Kenchington (2015).

Simulation tests (ICES, 2015) suggest that CMSY analysis may be less well suited for lightly exploited stocks and/or for species with very low resilience. The Largehead hairtail (*T. lepturus*) fishery in the Yellow Sea and Bohai Sea does not fit in these two categories (Wang and Liu, 2013; Zhang et al., 2018b), so the CMSY method can provide a good fit. Therefore this model may present a useful alternative approach for the fish stock assessment in China. However in the situation where the ecological strategy of fish has changed, r estimation must be carefully considered.

The results showed that r estimates from the surplus production models of CEDA and ASPIC are lower than expected. Because a given time series of catches could be explained by a large stock size with low productivity or by a small stock size with high productivity, the estimated fish population parameters of r and k should be cautiously considered even if the estimated MSY is reasonable. The mechanisms and algorithms of CMSY and ASPIC are different in estimating parameters but should give equi-

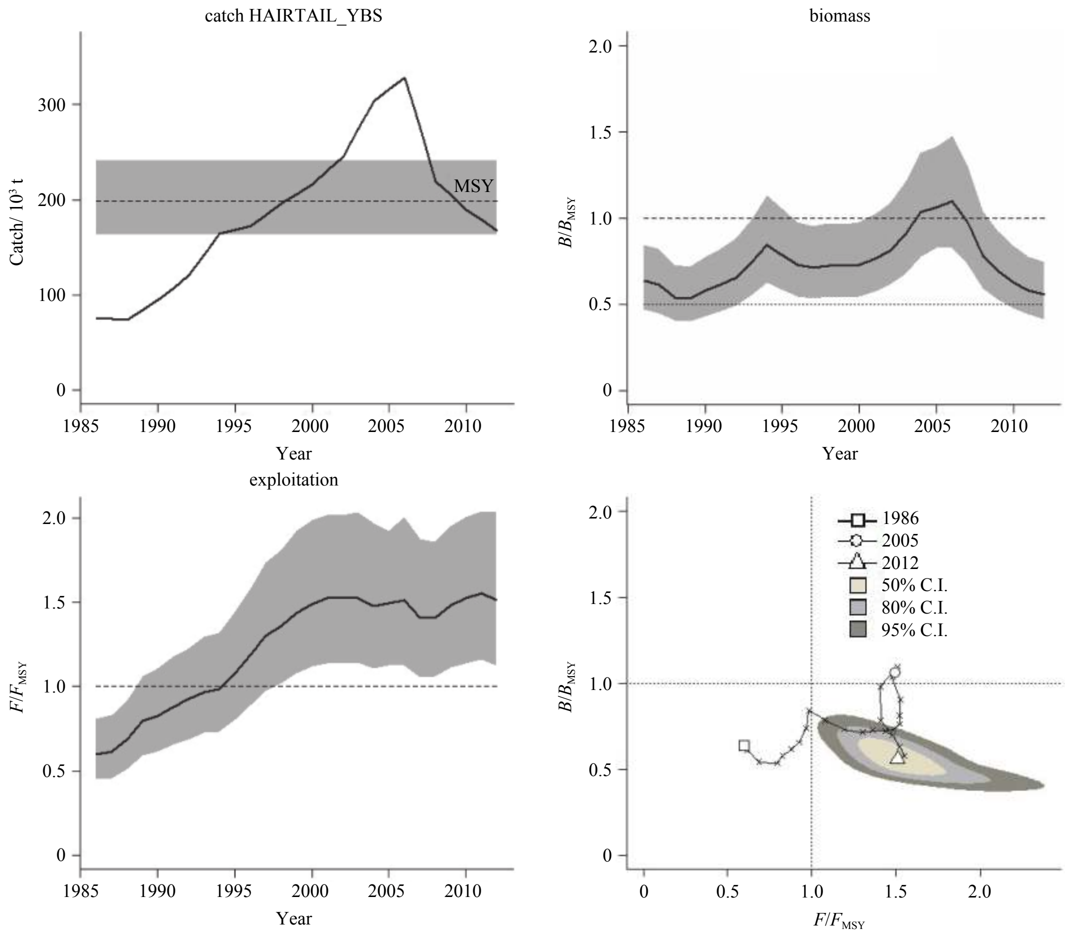

Fig. 1. Information for management for Largehead hairtail (*Trichiurus lepturus*) in the Yellow Sea and Bohai Sea. The upper-left panel shows catches, and the estimate of MSY is from BSM and the 95% confidence intervals are in grey. The upper-right panel shows the relative total biomass ($B/B_{\rm MSY}$), and the uncertainty is in grey. The lower-left graph shows the exploitation ($F/F_{\rm MSY}$), and $F_{\rm MSY}$ are corrected for the recruitment below $0.5B_{\rm MSY}$. The lower-right panel shows the relationship between stock size ($B/B_{\rm MSY}$) and exploitation ($F/F_{\rm MSY}$), and the shaded areas show the 50%, 80% and 95% confidence intervals (C.I.).

Table 4. Estimates of F/F_{MSY} and B/B_{MSY} of Largehead hairtail (*Trichiurus lepturus*) in the Yellow Sea and Bohai Sea using different methods

Methods		F/F_{MSY}	B/B_{MSY}
CMSY		0.64	1.08
BSM		1.62	0.52
CEDA	Schaefer	1.37	0.66
	Fox	2.24	0.48
ASPIC	Schaefer	1.33	0.48
	Fox	1.07	0.64

valent or similar answers unless *r* and *k* are not fully estimable given the data used. In this case, it can be diagnosed by plotting the likelihood profile or looking at the posterior MCMC (Jiao Yan, personal communication). We hope to investigate this for the Largehead hairtail fishery data in our future work.

4.2 *Surplus production models*

Surplus production models are among the classic fish stock assessment models which require catch and effort/CPUE data. Even though the concept of MSY had been criticized in the history of fishery science, it remains still an important biological reference point (ICES, 2015). Recent advances of mathematics and computer science enabled extensions of surplus production models, such as BSM, which can consider the priori and posteriori fish population parameters (Froese et al., 2017).

4.3 *Largehead hairtail (T. lepturus) fishery*

The Largehead hairtail (*T. lepturus*) is one of the most important fisheries in China. In the Yellow Sea and Bohai Sea the fishery started in 1960s, whose catch peaked at 328 927 t in 2006 and then declined to 167 319 t in 2012 (Table 1). Recently the age composition of the catch is largely 1 year, and there are clear evidences of early maturation, prolonged spawning season and increased young fish. Even though these biological characteristics can compensate the effects from heavy fishing, but they are not limitless. There are signs that the over-exploitation has exceeded the carrying capacity of the species, the fishery is still in declining. Apart from the effects of over-exploitation from excess fishing effort, the climate change may also affect the fish population dynamics of this species①.

In the past decades the mean anal length and mean anal length at maturity of Largehead hairtail had decreased, while the growth coefficient and exploitation rate of Largehead hairtail had increased (Table 5). This indicates that the ecological strategy of this fish has changed. Therefore the application of CMSY method (as well as any other fish stock assessment models) should be carefully considered.

In conclusions, the population of Largehead hairtail in the Yellow Sea and Bohai Sea was overfished and overfishing, indicating that more conservative management strategy is required for the fishery of this important species. The biological reference points estimated in this study could provide scientific background for the management of the Largehead hairtail fishery. Compared with the classical surplus production models performed by software CEDA and ASPIC, CMSY and BSM provided more reasonable estimates for the population parameters and biological reference points for the Largehead hairtail, which can

Table 5. Variations in biological characteristics of Largehead hairtail *Trichiurus lepturus* (Zhang et al., 2018b)

Period	Mean anal length/mm	Mean anal length at maturity/mm	Growth coefficient	Exploitation rate
1960s	239	264	0.27	0.70
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

be applied to the stock assessment and fishery management of many other fishery species, especially for those species with limited data in China.

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References

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, doi: 10.1016/j.fishres.2011.05.007

Fishery Bureau of Agriculture Ministry, China. 1986–2012. China Fishery Statistical Yearbook. Beijing: Agriculture Press

Fox W W Jr. 1970. An exponential surplus-yield model for optimizing exploited fish populations. Transactions of the American Fisheries Society, 99(1): 80–88, doi: 10.1577/1548-8659(1970)99<80:AESMFO>2.0.CO;2

Froese R, Demirel N, Coro G, et al. 2017. Estimating fisheries reference points from catch and resilience. Fish and Fisheries, 18(3): 506–526, doi: 10.1111/faf.12190

Froese R, Pauly D. 2018. FishBase. World Wide Web electronic publication. www.fishbase.org [2018-06-01]

Gayanilo F C, Sparre P, Pauly D. 2005. FAO-ICLARM Stock Assessment Tool (FiSAT II) User's Guide. FAO Computerized Information Series (Fisheries) No. 8. Rome, Itlay: FAO, 1–168

Haddon M. 2011. Modelling and Quantitative Methods in Fisheries. 2nd ed. London: CRC Press, 449

Hoggarth D D, Abeyasekera S, Arthur R I, et al. 2006. Stock assessment for fishery management. A framework guide to the stock assessment tools of the fisheries management science program. FAO Fish Tech Pap 487. Rome, Italy: FAO, 261

ICES. 2015. Report of the fifth workshop on the development of quantitative assessment methodologies based on life-history traits. In: Exploitation Characteristics and Other Relevant Parameters for Data-limited Stocks (WKLIFE V), Lisbon, Portugal, 2015

Kenchington T J. 2015. Natural mortality estimators for information-limited fisheries. Fish and Fisheries, 15(4): 533–562

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, doi: 10.1139/f84-162

Ling Jianzhong, Li Shengfa, Yan Liping, et al. 2008. Utilization and management of *Trichiurus japonicus* resources in East China Sea based on Beverton-Holt model. Chinese Journal of Applied Ecology (in Chinese), 19(1): 178–182

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

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, doi:

① Zu Kaiwei, Cheng Jiahua, Liu Yang, et al. Distribution of fishing ground of Japanese Spanish mackerel (*Scomberomorus niphonius*) during spawning and overwintering period and its relation with sea surface temperature in China sea. Transaction of Oceanology and Liminology, in press.

10.1093/icesjms/fsp209

Martell S, Froese R. 2013. A simple method for estimating MSY from catch and resilience. Fish and Fisheries, 14(4): 504–514, doi: 10.1111/j.1467-2979.2012.00485.x

Millar R B, Meyer R. 1999. Nonlinear state-space modeling of fisheries biomass dynamics using metropolis-Hastings within Gibbs sampling. Technical Report STAT9901. Auckland, New Zealand: Department of Statistics, University of Auckland, 33

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, doi: 10.1093/icesjms/39.2.175

Prager M H. 2017. A stock-production model incorporating covariates and auxiliary programs, ASPIC, version 7. www.mhprager.com [2017–07–15]

Rosenberg A A, Fogarty M J, Cooper A B, et al. 2014. Developing new approaches to global stock status assessment and fishery production potential of the seas. FAO Fisheries and Aquaculture Circular No. 1086. Rome: FAO

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, doi: 10.1007/BF02464432

Shen Gongming, Heino M. 2014. An overview of marine fisheries management in China. Marine Policy, 44: 265–272, doi: 10.1016/j.marpol.2013.09.012

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

Wang Yao. 2010. The resource evaluation of Trichiurus Japonicus on East China Sea in Summer Close Season (in Chinese) [dissertation]. Hangzhou: Zhejiang Ocean University, 12–17

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, doi: 10.1007/s00343-013-2073-7

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

Yan Liping, Hu Fen, Li Shengfa, et al. 2007. The effect of summer closed fishing and the reasonable utilization on hairtail (*Trichiurus japonicus*) resources in the East China Sea region. Journal of Natural Resources (in Chinese), 22(4): 606–612

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, Liu Qun, Liao Baochao, et al. 2018a. Comparative effects of distorted fishery data on assessment results of two non-equilibrium surplus production models. Journal of Fisheries of China (in Chinese), 42(9): 1378–1389

Zhang Kui, Zhang Jun, Xu Youwei, et al. 2018b. 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

Appendix: Input file for ASPIC

ASPIC-V7
File generated by aspic5to7 v.0.59, at 2014-05-14 16:54:24
"Hairtail Yellow and Bo Seas"
Program mode (FIT/BOT), verbosity, N bootstraps, [opt] user percentile:
BOT 2 2000
Model shape, conditioning (YLD/EFT), obj. fn. (SSE/LAV/MLE/MAP):
FOX YLD SSE
N years, N series:
27 1
Monte Carlo mode (0/1/2), N trials:
1 20000
Convergence criteria (3 values):
1.00E-08 3.00E-08 3.00E-05
Maximum F, N restarts, [gen. model] N steps/yr:
6.0d0 6 6
Random seed (large integer):
567931
Initial guesses and bounds follow:
B1K 0.23 0 0.1 5.0 penalty 0
MSY 2.2E+05 1 7.0E+04 2.6E+07
Fmsy 2.00E-01 1 1.00E-02 1.50E+00
q 3.00E-08 1 1.00E+00 5.00E-09 3.00E-05
DATA
"Biomass index, Total yield"
CC
1986 0.060249545 75809
1987 0.055905706 74846
1988 0.04812509 73883
1989 0.047409094 84442
1990 0.052177374 95001
1991 0.05518087 107623.5
1992 0.05847625 120246
1993 0.066223875 142246.5
1994 0.077928529 164247
1995 0.070504189 168337
1996 0.064944476 172427
1997 0.063675137 184304.5
1998 0.065379464 196182
1999 0.064415293 206316
2000 0.064930137 216450
2001 0.068424902 230883
2002 0.072014936 245316
2003 0.080522855 274318.5
2004 0.093816025 303321
2005 0.095081521 316124
2006 0.100638077 328927
2007 0.089862929 274025.5
2008 0.069269932 219124
2009 0.062678757 204377
2010 0.056676689 189630
2011 0.051632619 178474.5
2012 0.050515681 167319