ISSN 1225-827X (Print)
ISSN 2287-4623 (Online)
J. Kor. Soc. Fish. Tech., 49 (4), 432 – 439, 2013
http://dx.doi.org/10.3796/KSFT.2013.49.4.432

FISHERIES TECHNOLOGY
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Stock assessment of elkhorn sculpin (*Alcichthys alcicornis*) along the Uljin area in the East Sea of Korea

Soo-Jeong LEE°, Chang-Ik ZHANG[1], Young-Min CHOI[2], Dong-Woo LEE and Jae-Bong LEE[3]*

Fisheries Resources Management Division, NFRDI, Busan 619-705, Korea
[1]*Pukyong National University, Busan 608-737, Korea*
[2]*East Sea Fisheries Research Institute, NFRDI, Gangneung 210-861, Korea*
[3]*Dokdo Fisheries Research Center, NFRDI, Pohang 791-110, Korea*

This study was performed to assess the current stock condition of elkhorn sculpin along the Uljin area in the East Sea of Korea. To assess the state of the stock, yield-per-recruit (YPR) and spawning biomass-per-recruit (SBPR) analyses were performed. Estimates of F_{max} and $F_{0.1}$ were 2.10/year and 0.48/year, respectively, and those of $F_{35\%}$ and $F_{40\%}$ were 0.66/year and 0.54/year, respectively. Current fishing mortality was estimated at 0.63/year and the current age at first capture was 2.41years. $F_{40\%}$ was set as the target reference point of the stock. SBPR at $F_{40\%}$ and current SBPR were estimated to be 41.85g and 37.77g, respectively. Estimated F_{OTY} which is the fishing mortality for the overfished threshold yield was 0.49/year. The ratio of $SBPR/SBPR_{MSY}$ was calculated as 0.90 and that of F/F_{OTY} was 1.05. The ratio of $t_c/t_{c\ opt}$ was calculated as 1.15 and that of F/F_{OTY} was 1.17. Therefore, the current stock condition of elkhorn sculpin along the Uljin area of Korea has not been overfished, however, it indicates that a light overfishing is going on this stock.

Keywords: Elkhorn sculpin, East Sea, Stock assessment, Yield-per-recruit, Spawning biomass-per-recruit, Overfishing threshold yield

Introduction

It is known that sculpins are relatively small, demersal, and teleost fishes, consisting of 4 diverse families (Cottidae, Hemitripteridae, Psychrolutidae, and Rhamphocottidae). Sculpins are distributed throughout the Bering Sea and Aleutian Islands regions where they occupy all benthic habitats along continental shelf and slope areas (TenBrink and Aydin, 2009). Elkhorn sculpin (*Alcichthys alcicornis*) of the family Cottidae distributes from the coast of the East Sea to the Sea of Okhotsk (NFRDI, 2004).

While this species has been caught constantly along the coast of the East Sea, it was not important in the economic aspect in Korean fisheries. In recent year, however, the consumption of raw fish

*Corresponding author: leejb@korea.kr, Tel: 82-54-724-1010, Fax: 82-54-724-1088
°Current affiliation: Institute for International Fisheries Cooperation (IFIFC)

as sashimi has been increasing and this species is getting more popular than before. Nevertheless, catch is reported in aggregate as "Others" and it used not to be traded in public auction, therefore more rigid management is needed.

There are several biological studies of sculpins that not only include age and growth but also spawning and copulating behavior (Munehara, 1988; Panchenko, 2002, 2010; Shelekhov and Panchenko, 2007; TenBrink and Aydin, 2009). In Korea, however, the biology of sculpins has been poorly studied thus far. Only the studies of mesh selectivity of elkhorn sculpin (Park et al., 2004) and maturity and spawning of black edged sculpin were performed (Park et al., 2007).

Even though the catch data of elkhorn sculpin has not been collected, this species has been caught in the commercial fisheries consistently so we should know the current state of this species. The purpose of this study is to assess the current stock state of elkhorn sculpin based on population ecological data and information available along the Uljin area in the East Sea of Korea. Revised Kobe plots were suggested in this study for assessing current status of stock using the ratios of fishing intensity to spawning biomass and to size limit measure from spawning biomass- and yield-per-recruit of elkhorn sculpin, respectively.

Materials and methods

Input data

A total of 527 elkhorn sculpin (*Alcichthys alcicornis*) were collected in the Uljin-gun, Gyeongsangbuk-do, East Sea of Korea by the trammel net between March 2010 and April 2011. All specimens were measured for total length (TL, mm), total weight (TW, g), and sex and maturity stage was estimated visually. This study used the estimated input data available for stock assessment of elkhorn sculpin from Lee (2011).

Yield-per-recruit model

Yield-per-recruit (YPR) was estimated by Beverton and Holt model (1957).

$$\frac{Y}{R}=F\cdot\exp[-M\ (t_c-t_r)]\ W_\infty\sum_{n=0}^{3}\frac{U_n\exp[-nK\,(t_c-t_0)]}{F+M+nK}\cdot(1-\exp[-(F+M+nK)\,(t_L-t_c)]) \quad (1)$$

where, F is fishing mortality, M is natural mortality, t_c is age at first capture, t_r is age at first recruitment, W_∞, is asymptotic maximum total weight, t_0 is theoretical age at length is 0, t_L is maximum age and $U_0=1$, $U_1=-3$, $U_2=3$, $U_3=-1$.

Based on YPR, biological reference points, such as F_{max} and $F_{0.1}$ were estimated. F_{max} was defined as the fishing mortality that results in the highest YPR and $F_{0.1}$ was the fishing mortality where the slope of the YPR curve was 10% of the maximum slope.

Spawning biomass-per-recruit model

Spawning biomass-per-recruit (SBPR) was estimated by equations (2) and (3) as followed;

if F=0

$$\frac{SB}{R}\mid_{F=0}=\sum_{t_c=t_r}^{t_L}m_t\cdot e^{-M(t_c-t_r)}\cdot e^{-M(t-t_r)}\cdot W_\infty(1-e^{-K(t-t_0)})^3 \quad (2)$$

if $F=F_1$, i.e. F is not zero

$$\frac{SB}{R}\mid_{F=F_1}=\sum_{t_c=t_r}^{t_L}m_t\cdot e^{-M(t_c-t_r)}\cdot e^{-(M+F)(t_c-t_r)}\cdot W_\infty(1-e^{-K(t-t_0)})^3 \quad (3)$$

where, m_t is mature rate at age t, and others are same as YPR model. The mature rate at age was derived from the group maturity curve in length. It assumed that if $t<t_c$, F is 0. x% at $F_{x\%}$ is like equation (4) as followed;

$$\frac{SB/R\,|_{F=F_1}}{SB/R\,|_{F=0}} = x\% \tag{4}$$

The biological reference points, such as $F_{35\%}$ and $F_{40\%}$, were estimated from equation. (4).

Assessing current status of the stock

$F_{40\%}$ was set as a target reference point because it was adjudged that ecological factor is more important than yield for elkhorn sculpin. The current status of the stock was assessed by revised Kobe plot simply and easily. The Kobe plot is used to evaluate the status of a stock based on the fishing mortality (F) and biomass (B) associated with maximum sustainable yield (Maunder and Aires-da-Silva, 2011). In this study, Kobe plot was revised for assessing current status of stock using the ratios of fishing intensity to spawning biomass and to size limit measure from the spawning biomass- and yield-per-recruit model, respectively. In revised Kobe plot with $SBPR/SBPR_{MSY}$ on the x-axis and F/F_{OTY} on the y-axis, F_{OTY} means the fishing mortality at overfished threshold yield. F_{OTY} can calculated as below

i) When $SBPR > SBPR_{MSY}$, $F_{OTY} = F_{MSY}$
ii) When $SBPR \leq SBPR_{MSY}$,
$F_{OTY} = F_{MSY} \times (SBPR / SBPR_{MSY})$

Same as the original version, there are four sections with three colors, red, yellow and green to describe the status of stock, based on fish population biological terms, such as SBPR and fish age at the first capture, as well as fishery terms. The fundamental concept is same with the original version but it has been stricter than the original one (Fig. 1). If the value of $SBPR/SBPR_{MSY}$ is below 0.5 as minimum threshold level for a precautionary fisheries management, it means current stock is in red (danger) section regardless of F value in spirit of conservative fisheries management. When a fish stock condition is located in the red section, all fisheries targetting the fish stock should be shut down. If the value of $SBPR/SBPR_{MSY}$ is over 1.0 and F/F_{OTY} is below 1.0, it means current stock is in green (safe) section. The medium sections colored with yellow were represented as 'not overfished' - 'overfishing' condition as well as the buffer zones between 0.5 and 1.0 of the ratio of fish population biological terms (SBPR, t_c). For assessing current status of stock in terms of fisheries management measure, the ratio of fishing intensity to size limit measure, such as $t_{c\ opt}$, from the yield-per-recruit model was calculated (Fig. 1). To evaluate current t_c compared with optimum t_c ($t_{c\ opt}$) which is the t_c that has the highest YPR at F_{MSY}, the ratio of $t_c/t_{c\ opt}$ on the x-axis was replaced by $SBPR/SBPR_{MSY}$ in the revised Kobe plot.

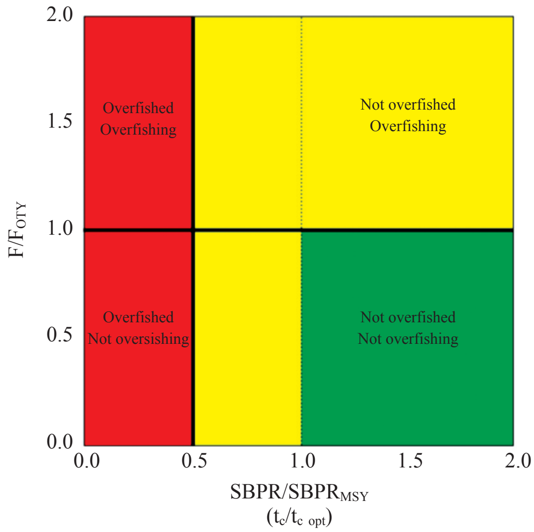

Fig. 1. Revised Kobe plot showing the overfished condition and the overfishing condition based on SBPR (t_c) and F.

Results

Input parameters

In this study, elkhorn sculpin ranged 7.4cm to 28.3cm in total length (TL) and about 60% of

Table 1. Length and weight of elkhorn sculpin collected monthly in the study area

Year	Month	Length (cm)				Weight (g)			
		Range		Mean	SD	Range		Mean	SD
2010	March	14.4	27.2	18.6	2.5	35.1	312.5	84.6	49.4
	April	12.7	25.6	19.4	3.1	21.2	204.7	91.9	45.5
	May	8.9	28.3	19.0	3.6	5.9	237.9	91.0	50.6
	June	7.7	23.7	15.9	3.4	4.8	180.0	53.8	37.1
	July	7.8	25.3	15.2	5.3	4.1	250.5	61.7	62.5
	September	7.4	23.1	13.3	3.7	4.8	202.8	37.0	36.3
	October	11.1	15.6	12.8	1.7	13.7	46.1	25.6	11.6
	November	12.8	18.4	14.7	1.3	21.9	74.0	37.5	12.8
	December	13.5	17.8	15.7	1.5	28.2	75.4	45.8	15.4
2011	January	14.2	24.6	17.5	2.4	32.9	215.5	69.7	41.5
	February	13.8	28.1	17.6	2.7	30.9	354.3	77.9	57.5
	March	13.3	25.8	18.7	2.5	25.0	203.8	85.7	40.7
	April	11.0	24.3	17.8	3.1	12.0	172.4	73.7	42.5

*No samples were collected in August due to no fishing.

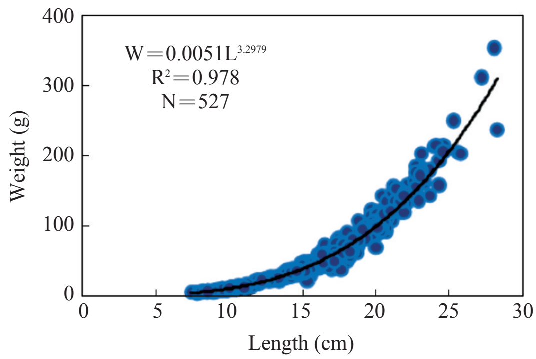

Fig. 2. Length-weight relationship for elkhorn sculpin (*Alcichthys alcicornis*) along the Uljin area of Korea.

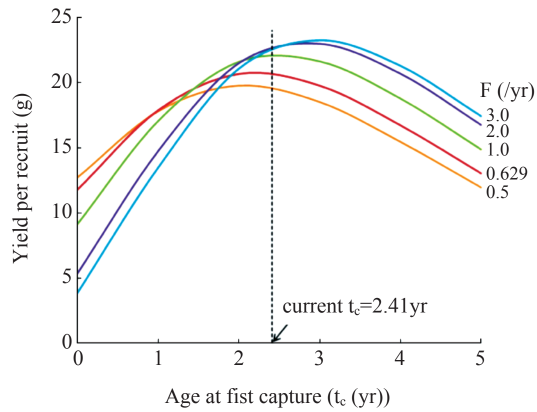

Fig. 3. YPR against the age at first capture (t_c) for various fishing mortalities (F) of elkhorn sculpin (*Alcichthys alcicornis*) along the Uljin area of Korea.

samples distributed between 14cm and 20cm (Table 1). TL class between 16cm and 17cm was the highest frequency (15.7%). Regarding monthly changes of TL and total weight (TW), both TL and TW of this species showed highest in April and lowest in October. Based on a total of 527 samples, TL-TW relationship was $TW=0.0051TL^{3.2979}$ which was used for the conversion L_{inf} to W_{inf} for YPR and SBPR models (Fig. 2).Growth parameters (L_{inf} or W_{inf}, K, t_0), instantaneous coefficients of mortalities (M, F, Z) and catch at first capture (t_c) estimated by Lee (2011) were referred as input parameters for stock assessment of elkhorn sculpin (Table 1).

Yield-per-recruit model

Based on the input data available for YPR (Table 2), the estimated current average-yield-per-recruit ($F=0.629$/year, $t_c=2.41$) was about 20.68g, which indicates that the fishery is operating below the maximum yield-per-recruit at 20.75g when t_c was 2.21years and F was 2.0/year. Fixing t_c at the current level, as F increased, YPR also increased and maximum yield-per-recruit was 22.71g when F increased to 2.103/year, which resulted in a small increase of 2.03g in yield-per-recruit (Fig. 3).Fixing F at the current level, maximum yield-per-recruit

Table 2. Input data used to yield- and spawning biomass-per-recruit models (from Lee, 2011)

W_∞ (g)	K (/yr)	t_0 (yr)	M (/yr)	F_c (/yr)	t_c (yr)	t_r (yr)	t_m (yr)
355.24	0.247	−0.609	0.467	0.629	2.41	0.564	8

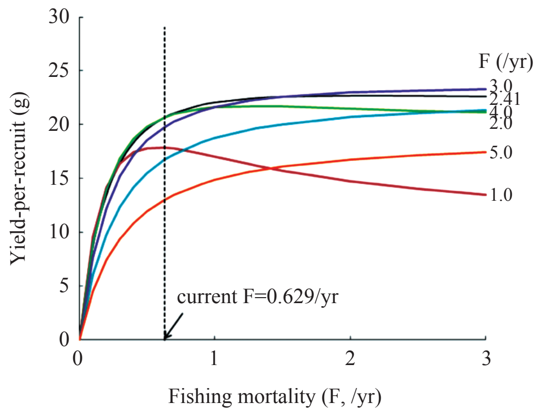

Fig. 4. YPR against fishing mortality (F) for various ages at first capture (t_c) of elkhorn sculpin (*Alcichthys alcicornis*) along the Uljin area of Korea.

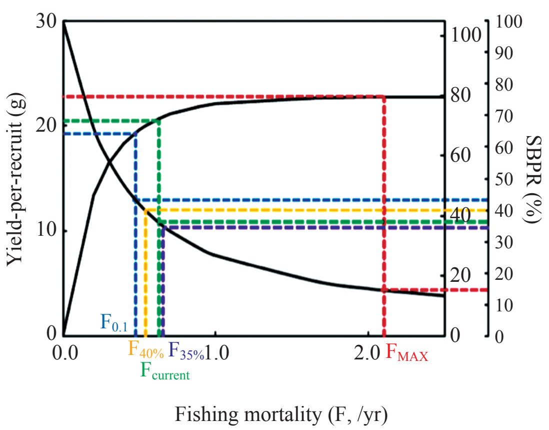

Fig. 5. YPR and SBPR against various reference points of fishing mortalities (F) of elkhorn sculpin (*Alcichthys alcicornis*) along the Uljin area of Korea.

was 20.75g when t_c decreased to age 2.0 which resulted in an increase of 0.07g in yield-per-recruit (Fig. 4).

As biological reference points, estimated F_{max} and $F_{0.1}$ were 2.103/year and 0.476/year, respectively, and estimated YPR at F_{max}, $F_{0.1}$ and $F_{current}$ were 22.71g, 19.35g and 20.68g, respectively (Fig. 5).

Spawning biomass-per-recruit model

Mature rate derived from mature length was 0 at 1-year-old group, 0.4 at 2-year-old group, 0.97 at 3-year-old group, 1 at over 4-year-old group. Estimated $F_{35\%}$ and $F_{40\%}$ were 0.658/year and 0.540/year, respectively and estimated SBPR at $F_{35\%}$, $F_{40\%}$ and $F_{current}$ were 36.62g, 41.85g and 37.77g, respectively (Fig. 5).

Current status of the stock

$F_{40\%}$ was surrogated for F_{MSY}, which was used for calculating $SBPR_{MSY}$ defined as spawning biomass at F_{MSY}. For the revised Kobe plot of the relationship between fishing intensity and spawning biomass, the ratio of $SBPR/SBPR_{MSY}$, i.e. 37.77g/41.85g was calculated as 0.90. And because SBPR is smaller than $SBPR_{MSY}$, F_{OTY} was calculated as 0.49/year= F_{MSY} of 0.54/year × $SBPR/SBPR_{MSY}$ of 0.90g, and the ratio of F/F_{OTY} was 1.05 (Fig. 6). For the revised Kobe plot of the relationship between fishing intensity and size limit measure, $t_{c\ opt}$, which has the highest YPR of 20.15g at F_{MSY}, was estimated as 2.10 years and F_{OTY} was 0.54/year. The ratio of $t_c/t_{c\ opt}$, i.e. 2.41 years/2.10 years was calculated as 1.15. And because t_c is larger than $t_{c\ opt}$, F_{OTY} was equal to F_{MSY} of 0.54/year, and the ratio of F/F_{OTY} was 1.17 (Fig. 7).

Therefore, in the case of both fishing mortality and age at first capture, the current stock condition of elkhorn sculpin along the Uljin area of Korea has

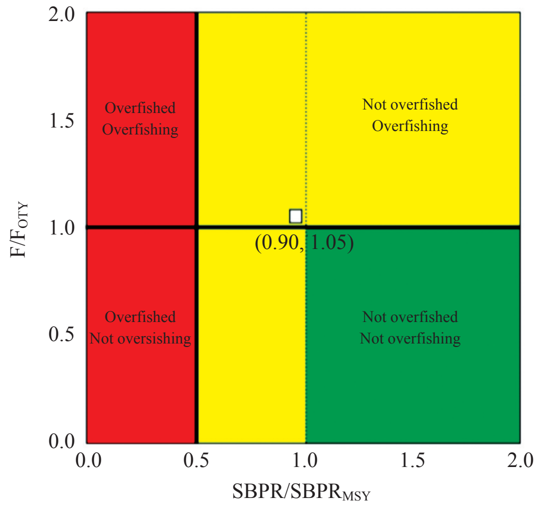

Fig. 6. Revised Kobe plot of the estimates of SBPR and F relative to $F_{40\%}$ surrogate for F_{MSY} for elkhorn sculpin (*Alcichthys alcicornis*) along the Uljin area of Korea. The white square indicates the current state of this stock.

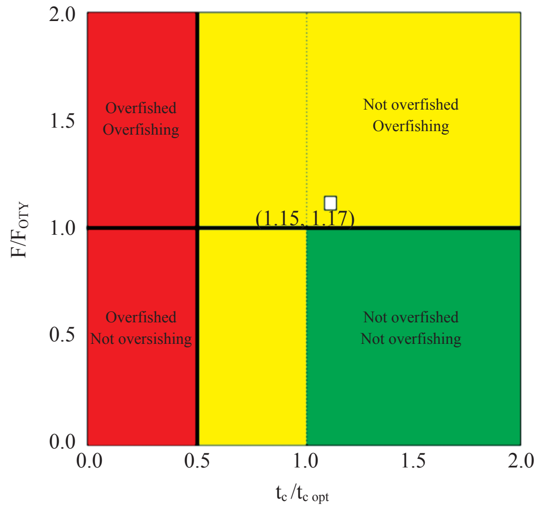

Fig. 7. Revised Kobe plot of the estimates of t_c and F relative to $F_{40\%}$ surrogate for F_{MSY} for elkhorn sculpin (*Alcichthys alcicornis*) along the Uljin area of Korea. The white square indicates the current state of this stock.

not been overfished, however, it indicates that a light overfishing is going on this stock (Fig. 6 and 7).

Discussion

In this study, no samples were collected in August, because this species moves to the deep sea bottom (below 200m) during the summer season (NFRDI, 2004). This characteristic feature is like as other sculpins in previous study (Park *et al*., 2007). Furthermore, big size specimens were inferior in number. It is considered that the main fishing gear was trammel net (mesh size 7.6～12.1cm) so the length selectivity was limited.

Population ecological data and fishery information of elkhorn sculpin were very limited, even though this species, in fact, has been caught in the commercial fisheries consistently. Based on the definition of Haddon et al. (2005), the situations of elkhorn sculpin arise where information for an assessment are not sufficient are when a fishery is new or developing and a time series of information has yet to be collected, and when data collection tends to focus on the target species thus bycatch fisheries constitute another common data poor category. So far no full stock assessments of elkhorn sculpin are performed in Korea, therefore there is no prior knowledge of population size, exploitation rates, safe harvest levels, and food web relationships. Without these critical pieces of information, biological reference points cannot be developed. Data-limited situations create challenges for fishery managers responding to societal demands to develop new fisheries while striving for precaution under the Code of Conduct for Responsible Fisheries (FAO, 1995). Under fishery-dependent data-limited situations of elkhorn sculpin in the coast of the East Sea, the current stock state of the species was assessed using population ecological data and information available and revised Kobe plots were suggested using the ratios of fishing intensity to management strategies, such as spawning biomass conservation and size limit measure. This paper contributed to new applications of tried-and-true modeling in terms of precautionary approach and motivated the development of new assessment techniques that rely on meager data requirements for the assessment of underutilized fisheries.

The current state of this stock was assessed to be not overfished but it tends to be a light overfishing. However, the catch data has not been reported at all even though this species has been caught continually. Thus, measures to manage this stock are urgently needed and the first step of management should be an accurate observation of catch. Catch data collection system should be improved for all fish species so as to accumulate catch data of even bycatch species including elkhorn sculpin in Korea.

This study represents the first documented attempt at assessing the stock condition of elkhorn sculpin along the Uljin area of Korea. Results from this study have contributed to our knowledge on the biology of this species that hopefully will lead to improvements in management of sculpins in Korea.

Acknowledgement

The authors would like to thank three anonymous reviewers for their thoughtful comments of this paper. This research was supported by the National Fisheries Research and Development Institute (RP-2013-FR-100).

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2013년 11월 11일 접수
2013년 11월 14일 1차 수정
2013년 11월 15일 수리