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
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).

\[
\frac{Y}{R} = F \cdot \exp[-M(t_c-t_0)] \cdot \frac{\sum_{n=0}^{\infty} U_n \cdot e^{-nK(t_c-t_0)}}{F+M+nK} \cdot (1 - e^{-[F+M+nK](t_c-t_0)})
\]

where, \(F\) is fishing mortality, \(M\) is natural mortality, \(t_c\) is age at first capture, \(t_0\) is age at first recruitment, \(W_\infty\), is asymptotic maximum total weight, \(t_0\) is theoretical age at length is 0, \(t_i\) 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 \(F = 0\)

\[
\frac{SB}{R} \bigg|_{F=0} = \sum_{t=t_0}^{\infty} m_{t} \cdot e^{-(M\cdot(t-t_0))} \cdot e^{-(U\cdot(t-t_0))} \cdot W_\infty \cdot (1 - e^{-K\cdot(t-t_0)})^3
\]

If \(F = F_1\), i.e. \(F\) is not zero

\[
\frac{SB}{R} \bigg|_{F=F_1} = \sum_{t=t_0}^{\infty} m_{t} \cdot e^{-(M\cdot(t-t_0))} \cdot e^{-(M+F\cdot(t-t_0))} \cdot W_\infty \cdot (1 - e^{-K\cdot(t-t_0)})^3
\]

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 \(t < t_c\), \(F = 0\). x% at \(F_{F_0}\) is like equation (4) as followed;
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 be 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 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 targeting 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 $t_c / t_{c_{opt}}$, 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.

Results

Input parameters

In this study, elkhorn sculpin ranged 7.4 cm to 28.3 cm in total length (TL) and about 60% of...
samples distributed between 14 cm and 20 cm (Table 1). TL class between 16 cm and 17 cm 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 $W = 0.0051L^{3.2979}$ 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 2.21 years 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

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

<table>
<thead>
<tr>
<th>Year</th>
<th>Month</th>
<th>Length (cm)</th>
<th>Weight (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Range</td>
<td>Mean</td>
</tr>
<tr>
<td>2010</td>
<td>March</td>
<td>14.4</td>
<td>27.2</td>
</tr>
<tr>
<td></td>
<td>April</td>
<td>12.7</td>
<td>25.6</td>
</tr>
<tr>
<td></td>
<td>May</td>
<td>8.9</td>
<td>28.3</td>
</tr>
<tr>
<td></td>
<td>June</td>
<td>7.7</td>
<td>23.7</td>
</tr>
<tr>
<td></td>
<td>July</td>
<td>7.8</td>
<td>25.3</td>
</tr>
<tr>
<td></td>
<td>September</td>
<td>7.4</td>
<td>23.1</td>
</tr>
<tr>
<td></td>
<td>October</td>
<td>11.1</td>
<td>15.6</td>
</tr>
<tr>
<td></td>
<td>November</td>
<td>12.8</td>
<td>18.4</td>
</tr>
<tr>
<td></td>
<td>December</td>
<td>13.5</td>
<td>17.8</td>
</tr>
<tr>
<td>2011</td>
<td>January</td>
<td>14.2</td>
<td>24.6</td>
</tr>
<tr>
<td></td>
<td>February</td>
<td>13.8</td>
<td>28.1</td>
</tr>
<tr>
<td></td>
<td>March</td>
<td>13.3</td>
<td>25.8</td>
</tr>
<tr>
<td></td>
<td>April</td>
<td>11.0</td>
<td>24.3</td>
</tr>
</tbody>
</table>

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

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

As biological reference points, estimated $F_{\text{max}}$ and $F_{0.1}$ were 2.103/year and 0.476/year, respectively, and estimated YPR at $F_{\text{max}}$, $F_{0.1}$ and $F_{\text{current}}$ were 22.71 g, 19.35 g and 20.68 g, 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 $F_{\text{current}}$ were 36.62 g, 41.85 g and 37.77 g, respectively (Fig. 5).

### Current status of the stock

$F_{40\%}$ was surrogated for $F_{\text{MSY}}$, which was used for calculating SBPR$_{\text{MSY}}$ defined as spawning biomass at $F_{\text{MSY}}$. For the revised Kobe plot of the relationship between fishing intensity and spawning biomass, the ratio of SBPR/SBPR$_{\text{MSY}}$, i.e. 37.77g/41.85g was calculated as 0.90. And because SBPR is smaller than SBPR$_{\text{MSY}}$, $F_{\text{OTY}}$ was calculated as 0.49/year = $F_{\text{MSY}}$ of 0.54/year × SBPR/SBPR$_{\text{MSY}}$ of 0.90g, and the ratio of $F/F_{\text{OTY}}$ 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 20.15 g at $F_{\text{MSY}}$, was estimated as 2.10 years and $F_{\text{OTY}}$ was 0.54/year. The ratio of $t_c/t_c \text{ opt}$, i.e. 2.41 years/2.10 years was calculated as 1.15. And because $t_c$ is larger than $t_c \text{ opt}$, $F_{\text{OTY}}$ was equal to $F_{\text{MSY}}$ of 0.54/year, and the ratio of $F/F_{\text{OTY}}$ 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

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

<table>
<thead>
<tr>
<th>$W_\infty$ (g)</th>
<th>$K$ (/yr)</th>
<th>$t_0$ (yr)</th>
<th>$M$</th>
<th>$F_c$ (/yr)</th>
<th>$t_c$ (yr)</th>
<th>$t_r$ (yr)</th>
<th>$t_m$ (yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>355.24</td>
<td>0.247</td>
<td>-0.609</td>
<td>0.467</td>
<td>0.629</td>
<td>2.41</td>
<td>0.564</td>
<td>8</td>
</tr>
</tbody>
</table>

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Soo-Jeong LEE, Chang-Ik ZHANG, Young-Min CHOI, Dong-Woo LEE and Jae-Bong LEE
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

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Stock assessment of elkhorn sculpin (Alcichthys alcicornis) along the Uijin area in the East Sea of Korea

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