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〈Original Article〉

Stock assessment of the goldeyes rockfish *Sebasetes thompsoni* in the Ulleungdo area

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This study researched the population of ecological characteristics of the goldeyes rockfish *Sebasetes thompsoni* sampled by gill net in the Ulleungdo area from February 2013 to February 2014 in order to assess the current stock status and provide scientific advice for management implementation. The instantaneous coefficient of total mortality (Z) was 0.78/year and the survival rate (S) was 0.459. The instantaneous coefficient of natural mortality (M) was 0.461/year. Based on the estimates of Z and M, the instantaneous coefficient of fishing mortality (F) was 0.318/year. The age at first capture (t_c) was 4.41/years. Current Yield-per-recruit (YPR) was 30.83 g, and fishing mortality at maximum YPR (F_{max}) and fishing mortality corresponding to 10% of the maximum slope in YPR curve ($F_{0.1}$) were 3.257/year and 0.673/year, respectively. $F_{35\%}$ and $F_{40\%}$, indicating fishing mortalities at 35% and 40% of maximum Spawning biomass-per-recruit (SBPR), were 0.619/year and 0.509/year, respectively. Based on the biological reference points, fishing mortality at overfished threshold yield (F_{OTY}) was calculated as 0.509/year. Current $SBPR/SBPR_{MSY}$ was 1.313 above 1.0, which means 'not overfishe,' while current F/F_{OTY} was 0.629 below 1.0, which indicates 'not overfishing.' In conclusion, the current status of goldeyes rockfish was located in green zone (i.e., not overfished and not overfishing) according to the revised Kobe plot.

Keywords : *Sebastes thompsoni*, Ulleungdo, Coefficient, Mortality, YPR, SBPR

Introduction

Goldeyes rockfish is classified in the Order Scorpaeniformesa and Family Scorpaeridae. It is a benthic fish which inhabits the depth range of approximately 70 m to 150 m around all coastal areas of Korea, south of Hokkaido in Japan, East China Sea, etc. Around the world, about 418 species of family scorpareridae are identified, and 45 species are reported to inhabit in Korea (Nelson, 2006; Kim, 2011). Goldeyes rockfish is reported to inhabit in Korea and Japan, since related studies mostly have been conducted in Korea and Japan. In Japan, on the determination of the age and growth of *S. thompsoni* (Suzuki et al., 1978), studies on the life histories of the rockfish (Yamada, 1980), and

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the early life history of the rockfish, *S. thompsoni* (Nagasawa et al., 1995) were conducted. In Korea, reproductive cycle of the goldeyes rockfish (Lee et al., 1998), feeding habits of *S. thompsoni* (Huh et al., 2008), and reproductive ecology of a goldeyes rockfish in the coastal waters of Busan were conducted. Various studies of Sebastes spp. were conducted in Korea. Previous studies on the domestic research of goldeyes rockfish were based upon influence of the turbulent southern coast. But Ulleungdo area, where this study was conducted, is affected by North Korea Cold Current and East Korea Warm Current; therefore, it is considered to have a difference in ecology (Yang et al., 2016). Coastal area of Ulleungdo is an important zone for fisheries and submarine resources in Korea.

Sebastes thompsoni, *Sebastes schlegeli* and *Sebastes inermis* have high economic feasibility in Korea (Kim, 2011). These species are stationary fish and resistant to changes in water temperature (Kim and Kang, 1999). Since rockfishes can be classified into multiple species and yet they have very similar appearance to each other, the fishermen often find it difficult to distinguish them into species level. For that reason, the catch reporting is often made by the fishermen in species group rather than in single species. Furthermore, the catch reporting from coastal fishing vessels with the gross tonnage less than 5 tones were not received in the past. And except for *S. schlegeli*, the others are classified as general rockfish in the fishery production statistics. As a result, it is difficult to determine the exact amount of their catch (Song and Hong, 2009). Consequently, fisheries stock assessment studies on caught species have not been carried out yet. Hence, to study characteristics and status of fishery resources in this area, a base study should be conducted for ecology. In conclusion, this study estimated research population ecological characteristics of *S. thompsoni*, and conducted a stock assessment to provide scientific advice to stakeholders in Ulleungdo area.

Materials and methods

The survey was conducted to collect data for this study (Heo et al., 2015). From February 2013 to February 2014, 731 of goldeyes rockfish (*S. thompsoni*) were captured by gill net in Ulleungdo areas. During October to December in 2013, we could not collected samples due to bad weather conditions. All specimens were measured for total length (TL, mm), body weight (BW, g). Sex and degree of maturity were recorded by visual inspection (Table 1).

The input data (Heo et al., 2015) which were derived from von Bertalanffy's growth equation are as follows: L_∞=32.4 cm (i.e. asymptotic maximum total length), K=0.244/year (i.e. instantaneous growth coefficient), and t_0 (i.e. theoretical age when L_t is 0)=−0.673 year. Relationships between total length and body weight was estimated to be $W=0.0129L^{3.076}$ (Fig. 1).

Instantaneous coefficient of total mortality (Z) of *S. thompsoni* was estimated from age composition data using the Pauly method (1984). Age at first capture (t_c) was estimated from the length-converted catch curve as Pauly. In this method, total mortality was calculated by following equation.

$$ln\left(\frac{C}{\Delta t}\right) = c - Z(t + \frac{\Delta t}{2}) \quad (1)$$

Table 1. Number of individuals and size range of *S. thompsoni* collected monthly in the study area.

Year	Month	Sex combined	
		Num. of individuals	Size range (cm)
2013	Feb	23	19.9 - 24.5
	Mar	107	17.2 - 31.4
	Apr	117	19.4 - 28.2
	May	125	19.8 - 29.6
	Jun	9	18.0 - 21.4
	Jul	98	19.6 - 23.2
	Aug	10	14.8 - 25.7
	Sep	40	20.5 - 25.6
	Oct	2	13.6 - 23.6
2014	Jan	100	21.6 - 25.3
	Feb	100	21.6 - 24.6
Num. total & Mean size range		731	22.6

where, C is number of catch, t is age, △t is age gap between length classes, and c is a constant of intercept from the linear equation, expected number of fish to be caught was calculated as $CT = \Delta t \cdot e^{(c-Z_t)}$.

Selectivity curve can be expressed in a linear equation.

$$ln\left(\frac{1}{S_t - 1}\right) = T_1 - T_2 t(L_1 + L_2) \quad (2)$$

where, S_t is the proportion of number of actual caught resource per expected number to be caught, L_1 and L_2 are fish length bin in length composition and T_1 and T_2 are constants (i.e. T_1 is intercept, T_2 is slope from the linear equation). t_c was calculated as $t_c = \frac{T_1}{T_2}$.

Survival rate (S) was estimated using instantaneous coefficient of total mortality (Z) i.e. $S=exp(-Z)$.

Instantaneous coefficient of natural mortality (M) of *S. thompsoni* was estimated using Zhang and Megrey model (2006) that is revised from Alverson and Carney (1975).

$$M = \frac{\beta K}{e^{K(t_{mb} - t_0)} - 1} \quad (3)$$

where, β is coefficient in the length-weight relationship ($W=\alpha L^{\beta}$), K is instantaneous growth coefficient, in $t_{mb}=C_i \times t_{max}$, C_i is the coefficient (0.302 for pelagic fish, 0.440 for demersal fish) and t_{max} is observed maximum age (Zhang and Megrey, 2006).

Instantaneous coefficient of fishing mortality was calculated by subtracting natural mortality from total mortality (i.e. $F=Z-M$).

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

$$\frac{Y}{R} = F \cdot e^{-M(t_c - t_r)} \cdot W_\infty \sum_{n=0}^{3} \frac{U_n \cdot e^{-nK(t_c - t_0)}}{F+M+nK} \cdot \left(1 - e^{(-(F+M+nK)(t_L - t_c))}\right) \quad (4)$$

where, M is instantaneous coefficient of natural mortality, t_c is age at first capture, t_r is age at first recruitment, W_∞ is asymptotic maximum total weight, K is growth coefficient, t_0 is theoretical age at length 0, F is fishing mortality, and t_L is maximum age. U_n is summation parameter, that is, U_0= 1, U_1= −3, U_2=3, U_3=−1.

Biological reference points, such as Fmax and $F_{0.1}$, were estimated based on YPR. F_{max} means the fishing mortality that results in the highest YPR, and $F_{0.1}$ represents the fishing mortality corresponding to 10% of the maximum slope in YPR curve.

Spawning biomass-per-recruit (SBPR) was estimated as following equation (Lee et al., 2015).

$$\frac{SB}{R} = e^{-M(t_c - t_r)} \cdot W_\infty \sum_{n=0}^{3} \frac{U_n \cdot e^{-nK(t_c - t_0)}}{F+M+nK} \cdot \left(1 - e^{(-(F+M+nK)(t_L - t_c))}\right) \cdot \frac{\sum_{t=t_c}^{t_L} e^{(-(M+F)(t-t_c))} \cdot W_\infty \left(1 - e^{-K(t-t_0)}\right)^3 \cdot m_t}{\sum_{t=t_c}^{t_L} e^{(-(M+F)(t-t_c))} \cdot W_\infty \left(1 - e^{-K(t-t_0)}\right)^3} \quad (5)$$

where, m_t is mature rate at age, and other parameters are same as equation (4).

SBPR is based on yield-per-recruit (YPR) from Beverton and Holt model (1957). It is defined as multiplication of YPR and weighted average of maturity at each age of stock-per-recruits. As popular traditional biological reference points, $F_{35\%}$ and $F_{40\%}$ indicate fishing mortalities at 35% and 40% of maximum Spawning biomass-per-recruit (SBPR) and were estimated according to SBPR curve.

This study used the revised Kobe plot (Lee et al.,

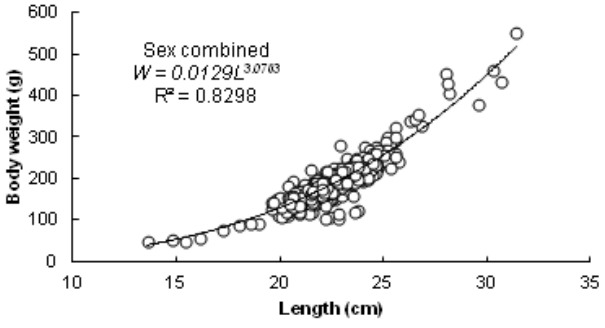

Fig. 1. Relationships between total length and body weight of *S. thompsoni*.

2013). The revised Kobe plot used $SBPR/SBPR_{MSY}$ on the x-axis and F/F_{OTY} on the y-axis. F_{MSY} was set as $F_{40\%}$. F_{OTY} means fishing mortality at overfished threshold yield. F_{OTY} was estimated as below

i) When $SBPR > SBPR_{MSY}$, $F_{OTY} = F_{MSY}$

ii) When $SBPR \leq SBPR_{MSY}$,

$F_{OTY} = F_{MSY} \times (SBPR / SBPR_{MSY})$

Results

Instantaneous coefficient of total mortality (Z) of this species was estimated to be 0.779/year using Pauly method and survival rate was estimated to be 0.459. Age at first capture, which was estimated from von Bertalanffy's equation and length composition of samples, was estimated to be 4.41 year (Fig. 2). When Zhang and Megrey (2006) method was used, instantaneous coefficient of natural mortality (M) was estimated to be 0.46/year. Current instantaneous coefficient of fishing mortality (F) was estimated to be 0.318/year. It is based on total mortality and natural mortality.

Current average Yield per recruit (YPR) was estimated based on the input data (Table 2). Current YPR was estimated to be 30.83 g, when F was 0.318/year and tc was 4.41/years. When F is the maximum value, Fmax was estimated to be 3.257/year, and YPR was estimated to be 53.36 g. And if the value of Tc remains unchanged, the value of YPR tends to increase as F increases by 3/year (Fig. 3). The value of YPR was estimated to be the highest (i.e. 46 g) when F was fixed to 0.318/year and T_c was 2 years. But if T_c is higher than 2 years, the value of YPR decreases (Fig. 4). Biological reference point F of $F_{0.1}$ was estimated to be 0.673/year and YPR was estimated to be 41.7 g (Fig. 5).

The spawning biomass-per-recruit model (SBPR) from Lee (2015) was employed, which used the weighted average mature rate (Table 3). By SBPR, $F_{35\%}$ was estimated 0.619/year and 60.32 g and $F_{40\%}$ was estimated 0.509/year and 68.88 g. SBPR by $F_{current}$ was estimated at 90.44 g (Fig. 5).

The revised Kobe plot also has four sections with three colors. If the value of $SBPR/SBPR_{MSY}$ is lower than 0.5, it indicates that current stock is in the danger section (red zone) regardless of the F value; if the value of $SBPR/SBPR_{MSY}$ exceeds 1.0 and F/F_{OTY} is less than

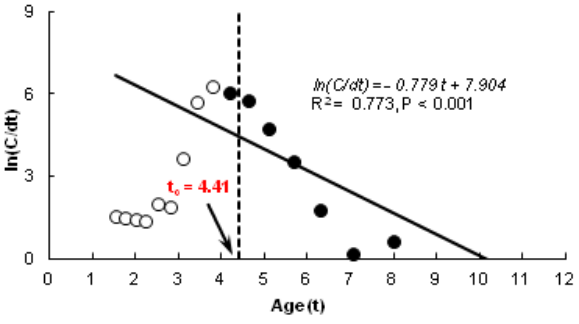

Fig. 2. Length converted catch curve of goldeyes rockfish (*S. thompsoni*) in Ulleungdo area. Closed circles used to calculate Z.

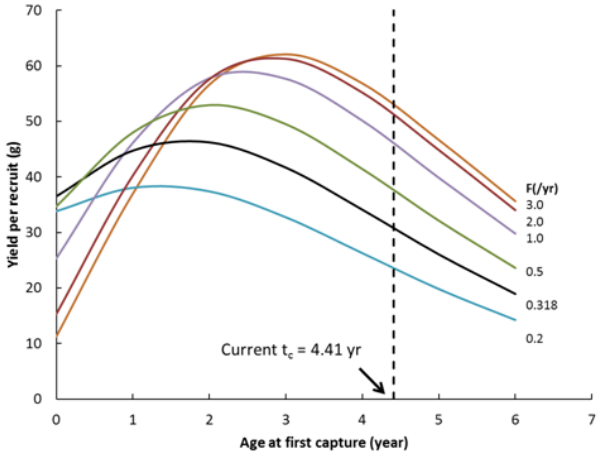

Fig. 3. Yield per recruit against the age at first capture (t_c) for various fishing mortalities (F) of goldeyes rockfish (*S. thompsoni*) in Ulleungdo area.

Table 2. Input data for yield-per-recruit model of goldeyes rockfish (*S. thompsoni*) in Ulleungdo area.

K (/yr)	t_0(yr)	W_∞ (g)	M (/yr)	t_c (yr)	t_r (yr)	t_m (yr)*
0.24	-0.67	584.08	0.46	4.41	1.56	13

* t_m was referred from Kim (2011)

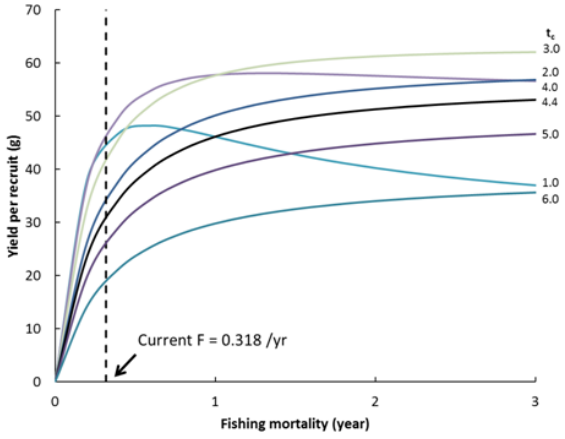

Fig. 4. Yield per recruit against fishing mortalities (F) for various ages at first capture (tc) of goldeyes rockfish (*S. thompsoni*) in Ulleungdo area.

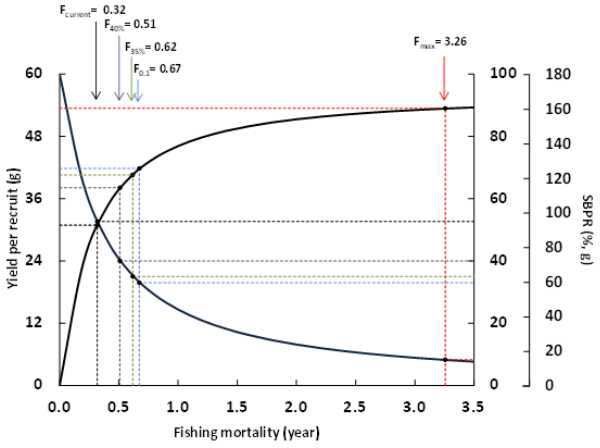

Fig. 5. Yield per recruit (YPR) and Spawning biomass-per-recruit model (SBPR) against various reference points of fishing mortalities (F) of goldeyes rockfish (*S. thompsoni*) in Ulleungdo area.

1.0, it means that current stock is in the safe section (green zone). The ratio of current SBPR to $SBPR_{MSY}$ ($SBPR/SBPR_{MSY}$) was estimated to be 1.313, and that of F/F_{OTY} was estimated to be 0.629. Current status of this fish stock in Ulleungdo area was located in green zone in the revised Kobe plot (Fig. 6). The result

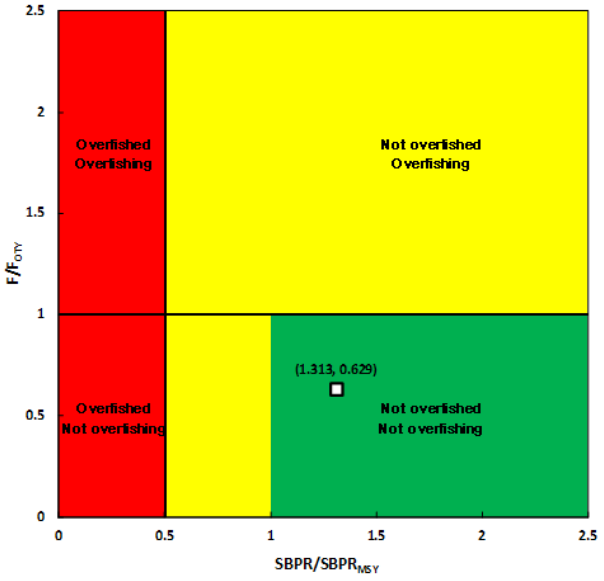

Fig. 6. Revised Kobe plot for goldeyes rockfish (*S. thompsoni*) in Ulleungdo area. White square indicates the current state of this fish stock in terms of SBPR and F.

indicates that goldeyes rockfish has not been overfished.

Discussion

It is ideal to evenly collect as many samples as one can in all age groups in order to secure samples to study characteristics of fisheries ecology. Nevertheless, the dominant case would be to have practical limitations impeding the collection of even number of samples for each age. For that reason, von Bertalanffy's equation was estimated by applying weighted average method to reflect number of samples.

If there is precise data of mature rate with all ages, traditional spawning biomass-per-recruit is good to use. On the other hand, if the data was not enough, alternative method was needed. Therefore, modified spawning biomass-per-recruit (Lee et al., 2015) was applied. Traditional spawning biomass-per-recruit was estimated to multiply only mature rate. But the modified spawning

Table 3. Weighted average mature rate of goldeyes rockfish (*S. thompsoni*) in Ulleungdo area

Age	1	2	3	4	5	6	7
Weighted average maturity	0.73	0.81	0.87	0.95	1.00	1.00	1.00

biomass-per-recruit was estimated to multiply mature rate with all ages after age at first capture to reduce errors. As a result, comparing the traditional spawning biomass-per-recruit to modified spawning biomass-per-recruit, the difference was witnessed in the range of 6.35 g to 101.89 g. And value of spawning biomass-per-recruit also showed difference between the two methods under 5 year-old, when mature rate reaches 1.0.

The difference increases as fishing mortality (F) and age at first capture (t_c) decrease. The level of resource *S. thompsoni* in Ulleungdo area is not considered to be overfished as t_c was 4.41 year when F was 0.318/year (i.e. when F is $F_{53\%}$). And if t_c is set to be 2 years from 4 years when F was 0.318/year, yield per recruit (YPR) would increase. However, as YPR increase, spawning biomass-per-recruit (SBPR) would decrease. As a result, considering that the current level F is $F_{53\%}$, the value can be raised to $F_{40\%}$. But *S. thompsoni* in Ulleungdo area is not one of commercial fish, and they are only caught by locals in the island. Also, fishing *S. thompsoni* is authorized only to Dodong fishing village cooperatives. Accordingly, current level of F was expected to be maintained. $SBPR/SBPR_{MSY}$ and F/F_{OTY} were estimated to be 1.313 and 0.629, respectively. In conclusion, current status of stock was located in green zone by the revised Kobe plot. Based on the results, we determined that the coastal fishing was sustainable and the current status of this fish stock was still stable in Ulleungdo area.

Stock assessments generally require data on catch, relative abundance and the life history of the species in question (Cooper, 2006). And this study was an attempt to fishery-independent data. This study still has some more space for development. To achieve better accurate results, more data should be collected by scientific vessels and commercial fishing vessels. Moreover, data of trawl for various water levels also should be investigated in the future. Also considering the geographical characteristics of Ulleungdo area, it is necessary to conduct studies on the function of feed organisms affecting growth and the structure of ecosystems such as nutritional stages. Lastly, it is necessary to study the stock assessment of goldeyes rockfish in the southern coast and the western sea and to compare the results in each area for management of goldeyes rockfish in Korea.

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