Thesis for the Degree of Master of Science

Stock assessment of goldeyes rockfish, *Sebastes thompsoni* in Ulleungdo area

by

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Pukyong National University

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Stock assessment of goldeyes rockfish, *Sebastes thompsoni* in Ulleungdo area

(울릉도 불볼락 (*Sebastes thompsoni*)의 자원평가 연구)

Advisor: Prof. Chang-Ik Zhang

by

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A dissertation

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요약

본 연구는 2013년 2월부터 2014년 2월까지 울릉도의 해역에서 자망에 의해 어획된 불볼락(*Sebastes thompsoni*)을 사용하여 연령과 성장, 생잔율과 사망계수 그리고 숙도지수와 50% 군성숙체장 및 가입체장 등 자원생태학적 매개변수를 추정하였다. 이석은 표면판독을 하였으며 불투명대에서 투명대로 이행하는 경계를 윤문으로 간주하여 판독하였다. 그 결과, 불볼락의 윤문형성시기는 6월경 연 1회 형성되는 것으로 추정되었고, 주산란기는 4월로 초륜의 형성시기는 1.17년(14개월)로 추정되었다. 그리고 전장에 대한 체중의 상대성장식은 $W = 0.0129L^{3.0763}$ 로 나타났다. 불볼락의 성장 매개변수는 Standard von Bertalanffy 성장식 이용하여 구하였다. Standard von Beratalanffy 성장식을 통해 구해진 이론적 최대체장 (L_∞)은 32.40cm, 성장계수 (K)는 0.244/년, 체장이 0일 때 이론적 연령(t_0)은 -0.673세 였다. 50% 군성숙체장은 22.3cm이였으며, 이는 붓스트랩방법으로 추정하였다. Pauly 방법을 이용하여 구한 생잔율(S)은 0.459/년, 순간전사망계수(Z)는 0.779/년으로 추정되었다. 순간자연사망계수(M)는 Zhang and Megrey model(2006)방법을 이용하였으며 0.461/년이 추정되었고, 순간어획사망계수(F)는 0.318/년으로 나타났다. 어획물 곡선법을 이용하여 추정된 어획개시연령(t_c)은 4.41세였다. 현재의 순간어획사망계수 0.318/년과 어획개시연령인 4.41세에서 가입당 생산량을 분석하였을 때 30.83g이 추정되었다. 그리고 F_{max}와 $F_{0.1}$은 각각 3.257/년과 0.673/년으로 나타났고, 가입당 생산량은 53.36g과 41.7g으로 추정되었다. $F_{35\%}$는 0.619/년과 가입당 산란자원량은 60.32g으로 나타났으며 $F_{current}$의 가입당 산란자원량은 90.44g으로 추정되었다. 그리고 F_{OTY} 는0.509/년으로 추정되었다. 현재 $SBPR/SBPR_{MSY}$와 F/F_{OTY}는1.313, 0.629로 추정되었다.

F/F_{OTY}는 0.629로 나타났다. 이를 수정된 Kobe plot에 적용한 결과 남획과 과도어획이 되어지지 않은 상태에 있는 것으로 평가되었다.

Introduction

Coastal area of Ulleungdo is an important zone for fisheries and submarine resources in Korea. To study characteristics and status of fishery resources in this area, a base study should be conducted for ecology. As a result, this study researched population ecological characteristics of goldeyes rockfish, *Sebastes thompsoni*, one of fishery resources in Ulleungdo area.

Goldeyes rockfish is classified in both: Order Scorpaeniformesa and Family Scorpaeridae. It is one of benthic fish and its habitation is under water depth at approximately 70~150m of all coastal areas of Korea, south of Hokkaido in Japan, East China Sea, and etc. Around the world, about 330 types of family scorpareridae are identified and 43 types are reported to inhabit in Korea.

Goldeyes rockfish is reported to inhabit in Korea and Japan only, as a result related studies mostly have been conducted in Korea and Japan. In Japan, On the determination of the age and growth of *Sebastes thompsoni* (Suzuki et al., 1978), Studies on the life histories of the rockfish (Yamada, 1980), and The early life history of the rockfish, *Sebastes thompsoni* (Nagasawa et al., 1995) were conducted. In Korea, reproductive cycle of the goldeyes rockfish (Lee et al., 1998), feeding habits of *Sebastes thompsoni* (Huh et al., 2008), and reproductive ecology of a goldeye rockfish in the coastal waters of Busan were conducted. Therefore, this study estimated research population

ecological characteristics of *Sebastes thompsoni*, and came out stock assessment to provide scientific advice to stakeholders in Ulleungdo area.

Materials and methods

1. Sampling

From February 2013 to February 2014, 731 of gold eye rock fish (*Sebastes thompsoni*) were captured by gill net in Ulleungdo areas (Fig. 1). During October to December in 2013, we couldn`t collect samples due to weather conditions (Table 1). All specimens were measured for total length (TL, mm), body weight (BW, g). Sex and degree of maturity were recorded by visual inspection.

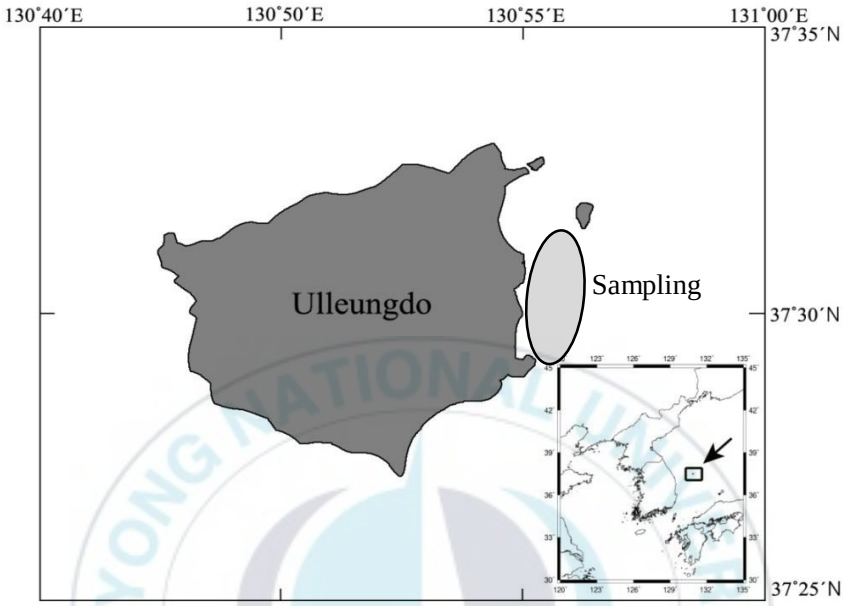

Fig. 1. Sampling site in the coastal waters of Ulleungdo, Korea, where *Sebastes thompsoni* caught by gill net.

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

Year	Month	Female		Male		Total	
		Num. of individuals	Size range (cm)	Num. of individuals	Size range (cm)	Num. of individuals	Size range (cm)
2013	Feb	9	20.2-22.7	14	19.9-24.5	23	19.9-24.5
	Mar	65	20.2-31.4	42	17.2-25.6	107	17.2-31.4
	Apr	66	19.4-28.2	51	20.0-26.5	117	19.4-28.2
	May	71	19.8-28.1	54	20.1-29.6	125	19.8-29.6
	Jun	9	18.0-21.4	-	-	9	18.0-21.4
	Jul	52	19.8-23.2	46	19.6-23.2	98	19.6-23.2
	Aug	9	15.4-25.7	1	14.8-14.8	10	14.8-25.7
	Sep	16	20.5-25.1	24	20.5-25.6	40	20.5-25.6
	Oct	2	13.6-23.6	-	-	2	13.6-23.6
2014	Jan	80	21.6-25.3	20	22.6-24.4	100	21.6-25.3
	Feb	50	22.0-24.6	50	21.6-24.6	100	21.6-24.6
Num. total & Mean size		429	22.5	302	22.3	731	22.4

2. Sexual maturity and Spawning

2.1 Gonad somatic index (GSI)

Gonad somatic index (GSI) was calculated by the following equation as an index of maturity.

$$\mathrm{GSI} = \frac{Gonad\ weight(g)}{Body\ weight(g)} \times 10^3 \quad (1)$$

2.2 Group maturity

The length, at which 50% of all specimens were sexually mature (L_{50}), was estimated by using a logistic function described as

$$\mathrm{P} = \frac{1}{1+e^{(b_1 - b_2 TL)}} \times 10^3 \quad (2)$$

where, P is the maturity fraction of mature females, TL is the total length(cm), and constant b_1 and b_2 are parameters which were to be estimated.

3. Age and growth

3.1 Age determination

To estimate age of *Sebastes thompsoni*, we used surface reading method. Collected otoliths were cleaned, using 50% ethyl alcohol and each surface was grinded. They were examined by microscope (DE/MZ-125, LEICA). The measurement software (Lampad, Zootoz) was used.

Monthly marginal index (MI) was calculated to identify season of the ring formation.

$$\mathrm{MI} = \frac{\mathrm{R} - r_n}{r_n - r_{n-1}} \quad (3)$$

where, R is distance between the nucleus and end from the otolith. And r_n is the distance between the nucleus and n^{th} ring.

3.1.1 Statistical analysis of age data

For aging precision, two methods were used: coefficient of variation (CV) and average percent error (APE). The CV, expressed as the ratio of the standard deviation over the mean, is the most widely used measure of precision, and can be written as:

$$CV_j = 100 \times \frac{\sqrt{\sum_{i=1}^{R} \frac{(X_{ij} - \overline{X_j})^2}{R-1}}}{\overline{X_j}} \quad (4)$$

where CV_j is the age precision estimate for the jth fish. The CV is calculated across all age readings for each sample, and is usually averaged across fish to produce a mean CV. where X_{ij} is the ith age determination of the jth fish, $\overline{X_j}$ is the mean age estimate of the jth fish, and R is the number of times each fish is aged.

The average percent error (APE), is defined as:

$$APE_j = 100 \times \frac{1}{R} \sum_{i=1}^{R} \frac{|X_{ij} - X_j|}{X_j} \quad (5)$$

where X_{ij} is the ith age determination of the jth fish, X_j is the mean age estimate of the jth fish, and R is the number of times each fish is aged.

3.1.1.1 Within the reader

Reader1 read all samples twice unaffectedly from former result. As reader1 had two sets of age data respectively and read throughout them, results from comparison between 1st reading and 2nd reading identified the match rate. Therefore, the data was chosen to be compared.

3.1.1.2 Between readers

For age determination, three readers read all samples independently. All samples were aged without knowledge of previously estimated ages or the specimen lengths. Using Age data of each reader, age cross checking was conducted. After statistical analysis of age data, the data was used to estimate the growth parameters.

3.2 Growth of goldeyes rockfish

3.2.1 von Bertalanffy growth function

Length at age data was fitted with a von Bertalanffy growth function (von Bertalanffy, 1938), by non-linear method using MS EXCEL solver.

$$L_t = L_\infty(1 - e^{-K(t-t_0)}) \quad (6)$$

where, L_t is observed total length (TL, cm) at age t; L_∞ is asymptotic maximum total length (TL, cm); K is instantaneous growth coefficient; t is age (years); t_0 is theoretical age (years) when L_t is 0.

3.2.2 Growth performance index (Φ) comparison

Below growth functions are calculated by Growth performance index (Φ, Munro and Pauly, 1983) to compare with other results conducted in different areas.

The equation is as follows.

$$\emptyset = \log K + 2\log L_\infty \quad (7)$$

where, K is instantaneous growth coefficient, L_∞ is asymptotic maximum total length (TL, mm).

4. Ecological parameters

4.1 Survival rate (S) and instantaneous coefficient of total mortality (Z)

Instantaneous coefficient of total mortality (Z) of *Sebastes thompsoni* was estimated from data of Age composition data by Pauly method (1984).

Survival rate (S) estimated using Z value by following equation.

$$S = \exp(-Z) \tag{8}$$

4.2 Instantaneous coefficient of natural mortality (M)

Instantaneous coefficient of natural mortality (M) of *Sebastes thompsoni* estimated by Zhang and Megrey model (2006).

Zhang and Megrey model that is revised from Alverson and carney (1975).

$$M = \frac{\beta K}{e^{K(t_{mb}-t_0)}-1} \tag{9}$$

in $t_{mb} = C_i \times t_{max}$, C_i is the coefficient(pelagic is 0.302, demaersal is 0.440) and t_{max} is observed maximum age. β is coefficient in the length-weight relationship ($W = \alpha L^{\beta}$).

4.3 Instantaneous coefficient of fishing mortality (F)

Instantaneous coefficient of fishing mortality calculated from subtraction of total mortality and natural mortality.

$$F = Z - M \quad (10)$$

5. Age at first capture (t_c)

Age at first capture (t_c) was estimated from the length-converted catch curve as Pauly(1984). In this method, total mortality was calculated by following equation.

$$\ln\left(\frac{C}{\Delta t}\right) = c - Z(t + \frac{\Delta t}{2}) \quad (11)$$

where, C is number of catch, t is age, Δt is age gap between length classes, and c is a constant. Expected number of fish to be caught was calculated as

$$CT = \Delta t \cdot e^{(c - Z_t)} \quad (12)$$

Selectivity curve can be expressed in a linear equation

$$\ln\left(\frac{1}{S-1}\right) = T_1 - T_2 t(L_1 + L_2) \quad (13)$$

where, S is proportion of number of actual caught resource per expected number of to be caught, L_1 and L_2 are length, and T_1 and T_2 are constants. t_c estimated from T_1 and T_2.

$$t_c = \frac{T_1}{T_2} \quad (14)$$

6. Stock assessment

6.1 Yield-per-recruit model

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

$$\frac{Y}{R} = F \cdot e^{-M(t_c - t_r)} \cdot W_\infty \sum_{n=0}^{3} \frac{U_n \cdot e^{-nK(t_c - t_0)}}{F + M + nK} \cdot \left(1 - e^{\left(-(F+M+nK)(t_L - t_c)\right)}\right) \quad (15)$$

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, 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.

6.2 Spawning biomass-per-recruit model

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

$$\frac{SB}{R} = e^{-M(t_c - t_r)} \cdot W_\infty \sum_{n=0}^{3} \frac{U_n \cdot e^{-nK(t_c - t_0)}}{F + M + nK} \cdot \left(1 - e^{\left(-(F+M+nK)(t_L - t_C)\right)}\right) \cdot \frac{\sum_{t=t_c}^{t_L} e^{(-(M+F)(t-t_C)} \cdot W_\infty \left(1 - e^{-K(t-t_0)}\right)^3 \cdot m_t}{\sum_{t=t_c}^{t_L} e^{(-(M+F)(t-t_C)} \cdot W_\infty (1 - e^{-K(t-t_0)})^3} \quad (16)$$

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 is 0, F is fishing mortality, t_L is maximum age, and m_t is mature rate at age.

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.

The biological reference points $F_{35\%}$, $F_{40\%}$ were estimated.

6.3 Status of stock

This study used the revised Kobe plot (Lee, 2011). 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 $SBPR \leq SBPR_{MSY}, F_{OTY} = F_{MSY} \times (SBPR / SBPR_{MSY})$

The revised Kobe plot also has four sections with three colors (Fig. 2). If the value of SBPR/$SBPR_{MSY}$ is lower than 0.5, it indicates current stock is in danger section (red zone) regardless of F value; if the value of SBPR/$SBPR_{MSY}$ is exceeded 1.0 and F/F_{OTY} is lower than 1.0, it means current stock is in safe section (green zone).

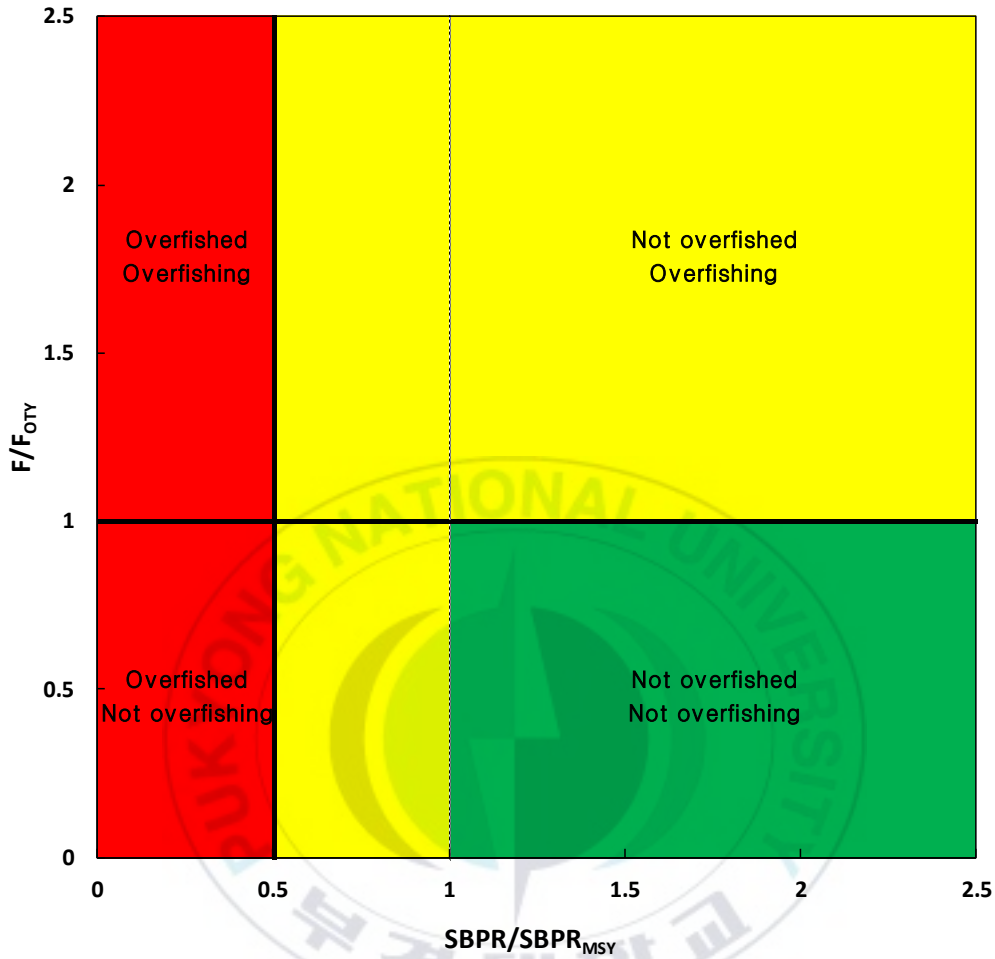

Fig. 2. Revised Kobe plot indicate status of stock by using Instantaneous coefficient of fishing mortality (F) and Spawning biomass-per-recruit (SBPR).

Results

1. Relationship between length and weight

Sebastes thompsoni was identified in the length range from 13.6cm to 31.4cm. And about 85% of samples distributed between 12cm and 15cm (Fig.3).

Based on a total of 731 sample, female`s equation of relationship between length-weight was $W = 0.0108L^{3.135}$ and male`s equation was $W = 0.0158L^{2.957}$ (Fig. 4).

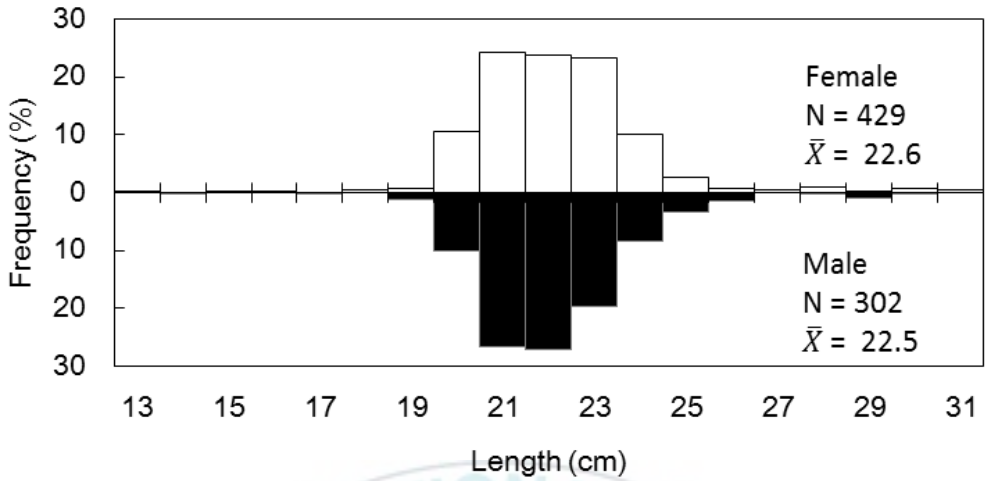

Fig. 3. Distribution of length frequency, *Sebastes thompsoni*.

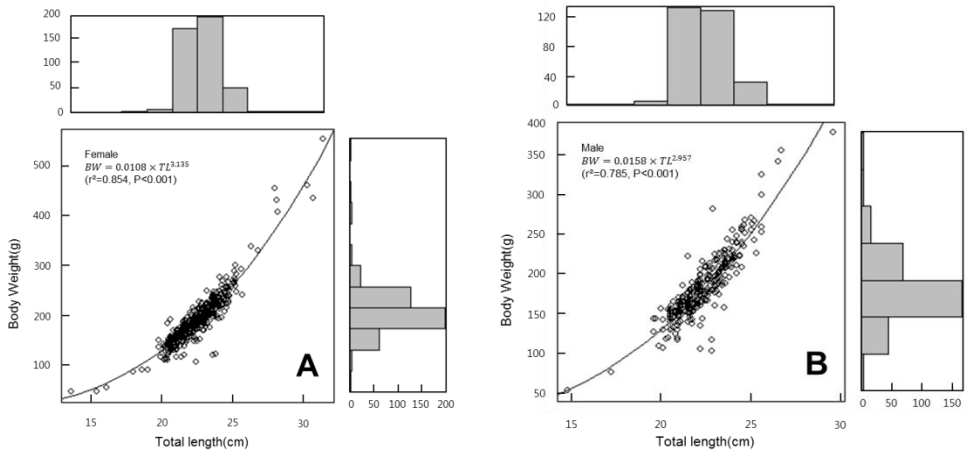

Fig. 4. Relationships between total length (L) and body weight (B) of *Sebastes thompsoni*. The side graph indicates the number of individuals. (A) Female, (B) Male.

2. Sexual maturity and spawning

2.1 Gonad somatic index (GSI)

It witnessed that GSI value increased since January (Fig. 5). The highest value of GSI was found in March throughout a year. And then the GSI value decreased in April. Therefore, spawning season of species was April.

2.2 Group maturity

The spawning season, from March to May, was used to estimate length at group maturity. Based on bootstrapped data, the length where 50% of the female had attained maturity was 22.3cm (Fig. 6).

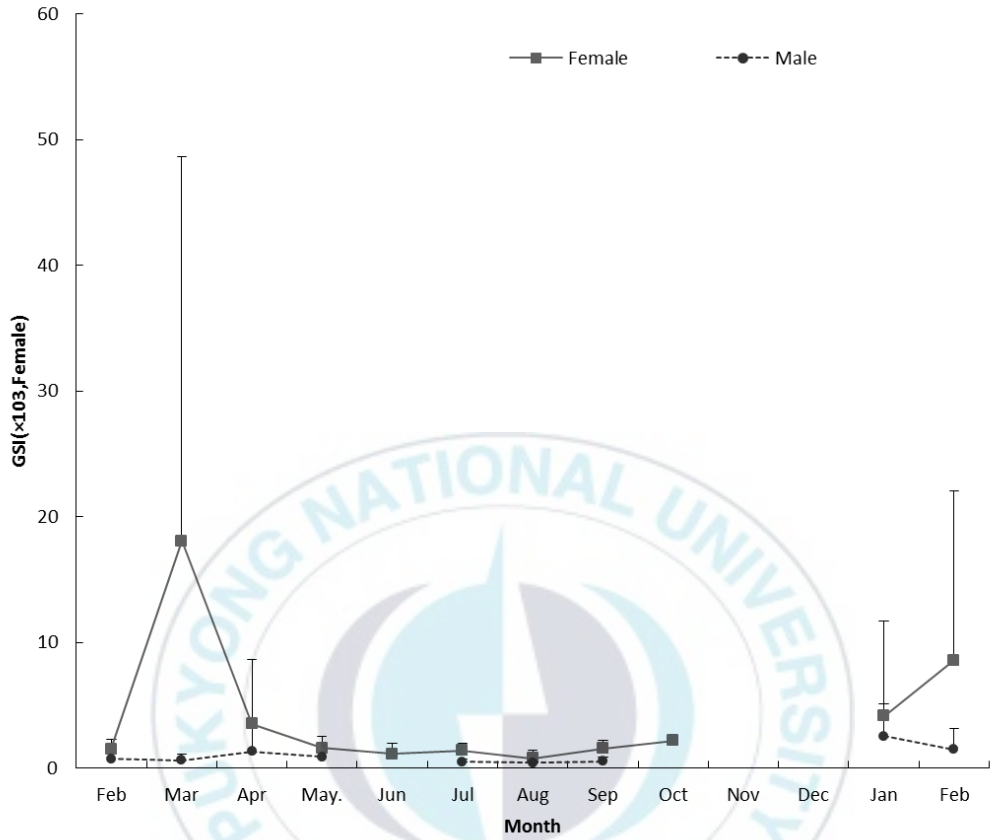

Fig. 5. Monthly changes in gonad somatic index (GSI) by sex of *Sebastes thompsoni*. And vertical bars denote maximum value.

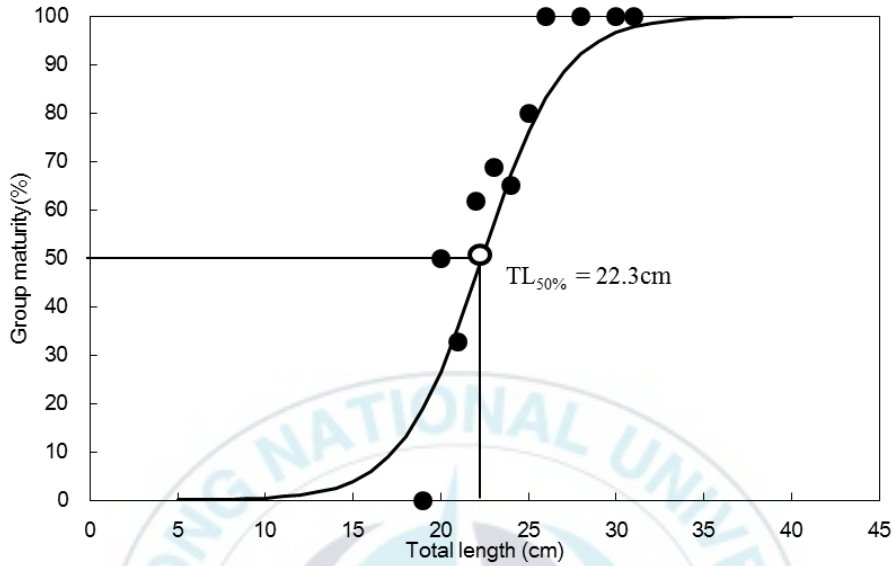

Fig. 6. Relationship between total length and group maturity of *Sebastes thompsoni* caught by gill net in the coastal waters off Ulleungdo, Korea.

3. Age and growth

3.1 Age determination

632 otoliths of all samples were used to read age. The edge of the opaque zone was measured as a year (Fig. 7). The lowest value of the marginal index was found in June throughout a year (Fig. 8). The spawning period was April. Therefore, the duration from fertilization to the complete formation of the first annual growth ring is fourteen months.

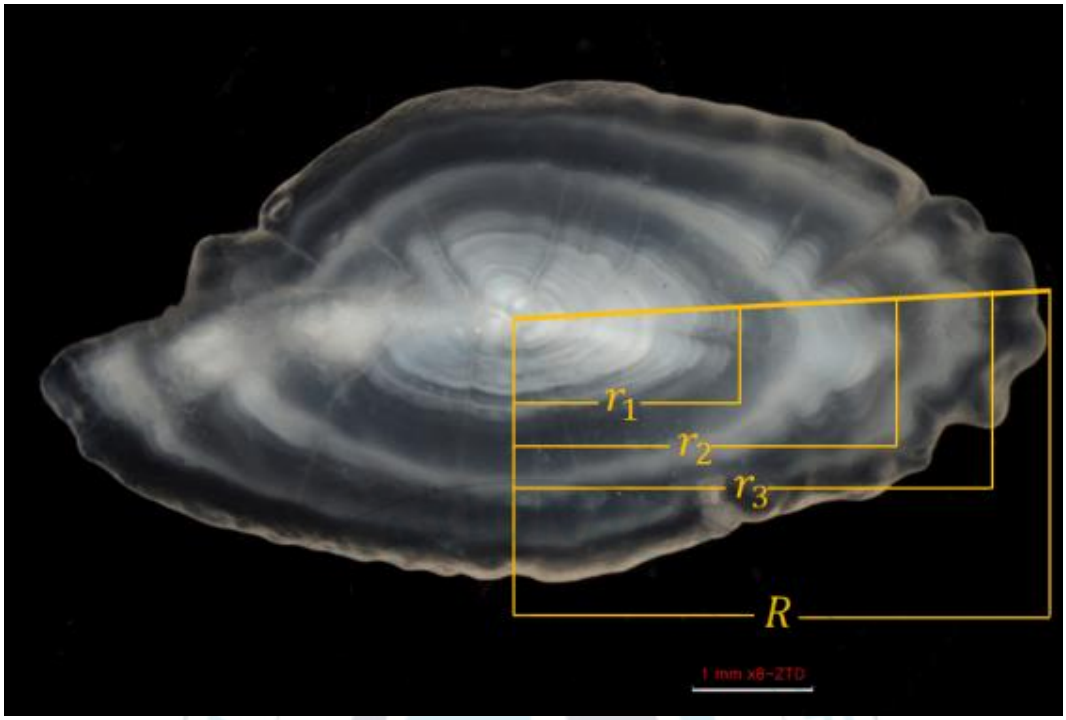

Fig. 7. The otolith of *Sebastes thompsoni*. R and r_n indicate otolith radius and ring radii, respectively

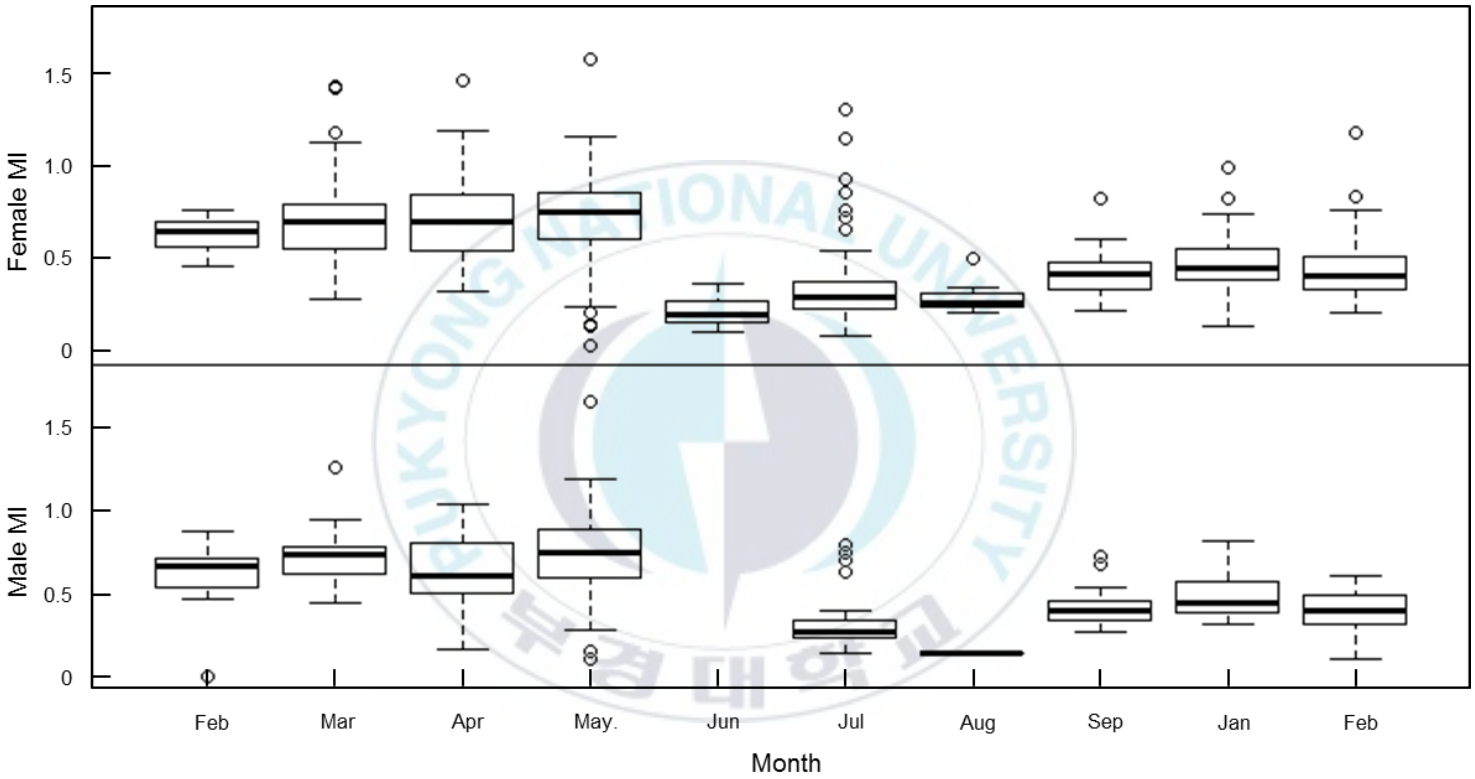

Fig. 8. Monthly changes in marginal growth increment by sex of *Sebastes thompsoni* otolith.

3.1.1 Within reader

Coefficient of variation (CV) of within reader1 as first and second reading was 4.95%.

3.1.2 Between readers

The value of CV between the first reader and second reader was 4.17%. The value of CV between reader1 and reader3 was 7.71%. The CV between reader2 and reader3 CV was 7.82% (Table 2). So this study chose the value of CV between the reader1 and reader2 (Fig. 9). The match rate between reader1 and reader2 was 79%. And between reader1 and reader2, outcome of Average Percent Error (APE) was 2.95%. Finally, age data with 100% agreement between reader1 and 2 (Fig. 10) was used for relationships between otolith radius (R) and total length (L) (Fig. 11).

Table 2. Coefficient of variation for an age reading between readers from *Sebastes thompsoni* otoliths in Ulleungdo area

Reader	1(1st)	2	3
1(2nd)	4.94%	4.17%	7.71%
2	-	-	7.82%
3	-	-	-

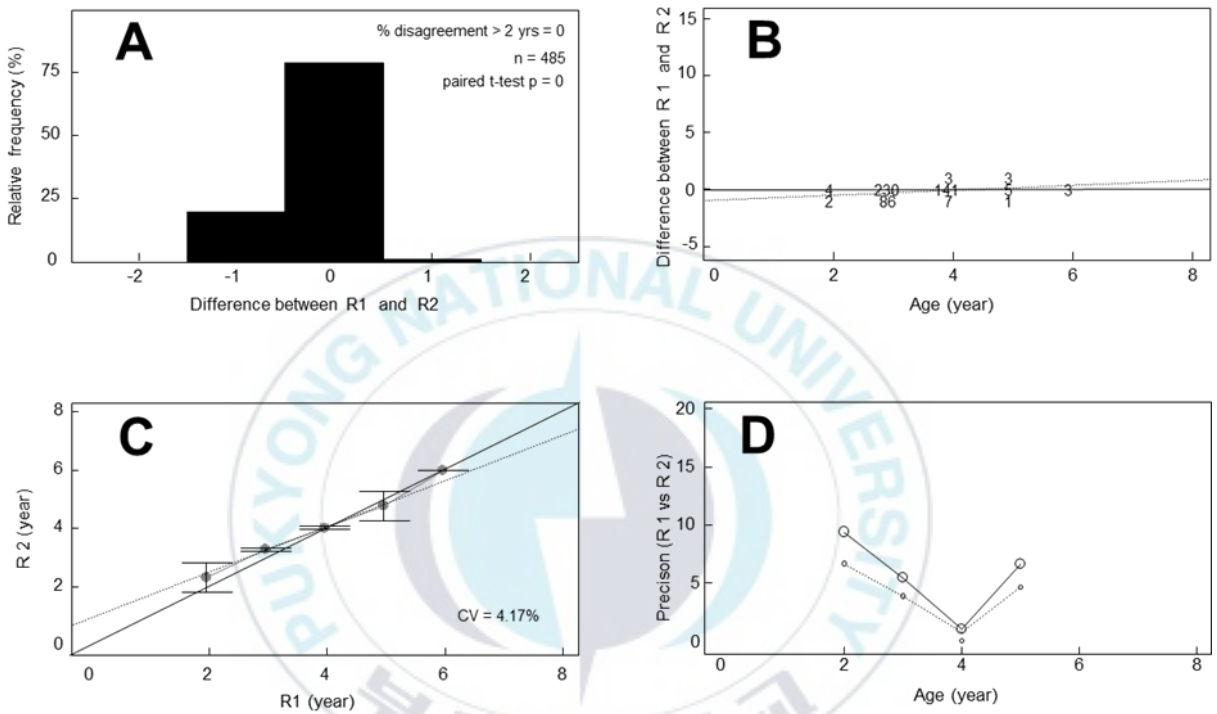

Fig. 9. Age comparison between Reader1 (R1) and Reader2 (R2) of otolith of *Sebastes thompsoni*. (A) Age difference rate, (B) Number of differences by age, (C) Range of variation by age, (D) Precision of R1 and 1st reading of R1 and R2.

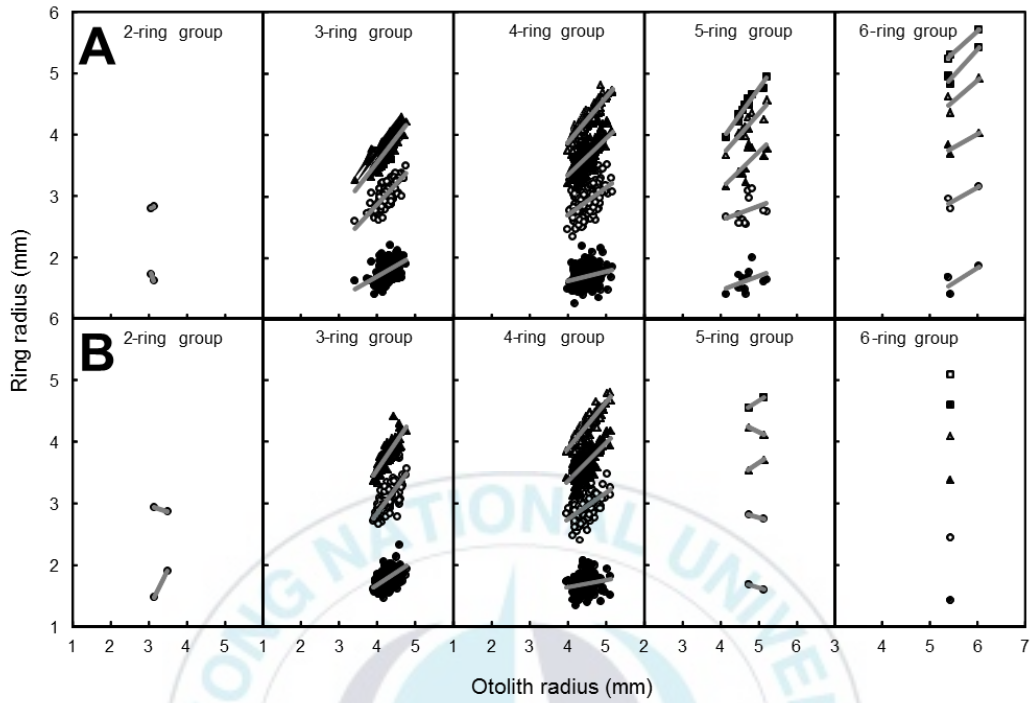

Fig. 10. Relationships between otolith radius and ring radius of *Sebastes thompsoni* by each ring group. (A) Female, (B) Male.

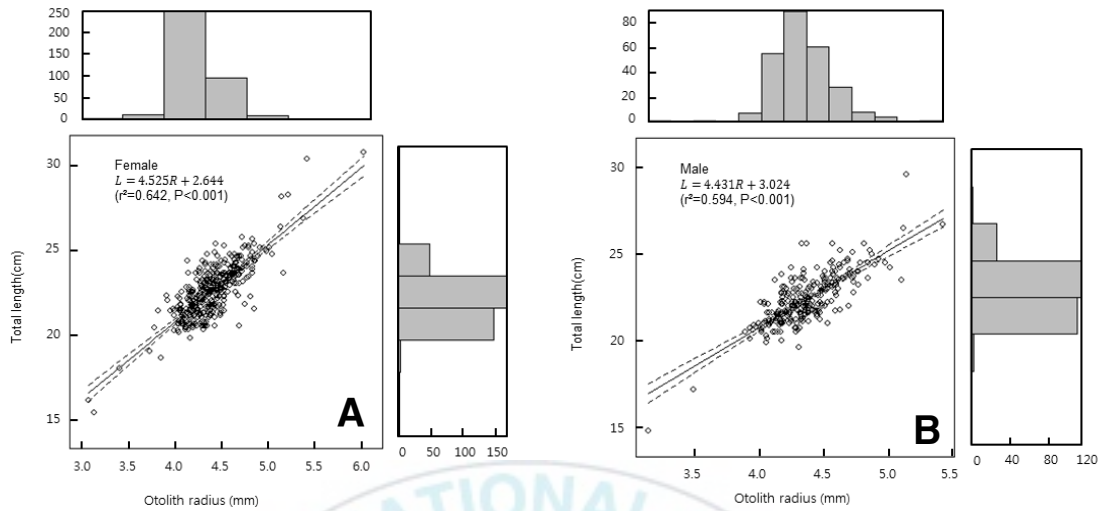

Fig. 11. Relationships between otolith radius (R) and total length (L) of *Sebastes thompsoni*. The side graph indicates the number of individuals. (A) Female (B) Male.

3.2 Growth functions

3.2.1 Standard von Bertalanffy growth function

This study used age data from ages ranged from 2 years to 6 years to estimate growth function. The Asymptotic length (L_∞) was 32.4cm, the growth coefficient (K) value was 0.2442/year, and the theoretical age at L_t=0 (t_0) was 0.6725/year (Fig. 12).

3.2.2 Compare growth functions

von Bertalanffy's growth fuction of *Sebastes thompsoni* inhabitating in Ulleungdo area. Offshore was L_∞=32.4cm, K=0.2442/year, t_0=-0.6725year. In Tong-yeong, the parameter was L_∞=29.8cm, K=0.2163/year, t_0=-1.7964year. In case of Japan, the parameter was L_∞=29.04, K=0.3032/year, t_0=-2.2305year in Aomori, and the parameter was L_∞=33.2, K=0.2241/year, t_0=-0.1564year in Niigata. Compared with growth performance index(Φ) from these 4 offshore areas, parameter of *Sebastes thompsoni* in Ulleungdo area was 2.4087, that of in Tong-yeong was 2.2835, that of in Aomori was 2.4077 and in Niigata was 2.3927 (Table 3).

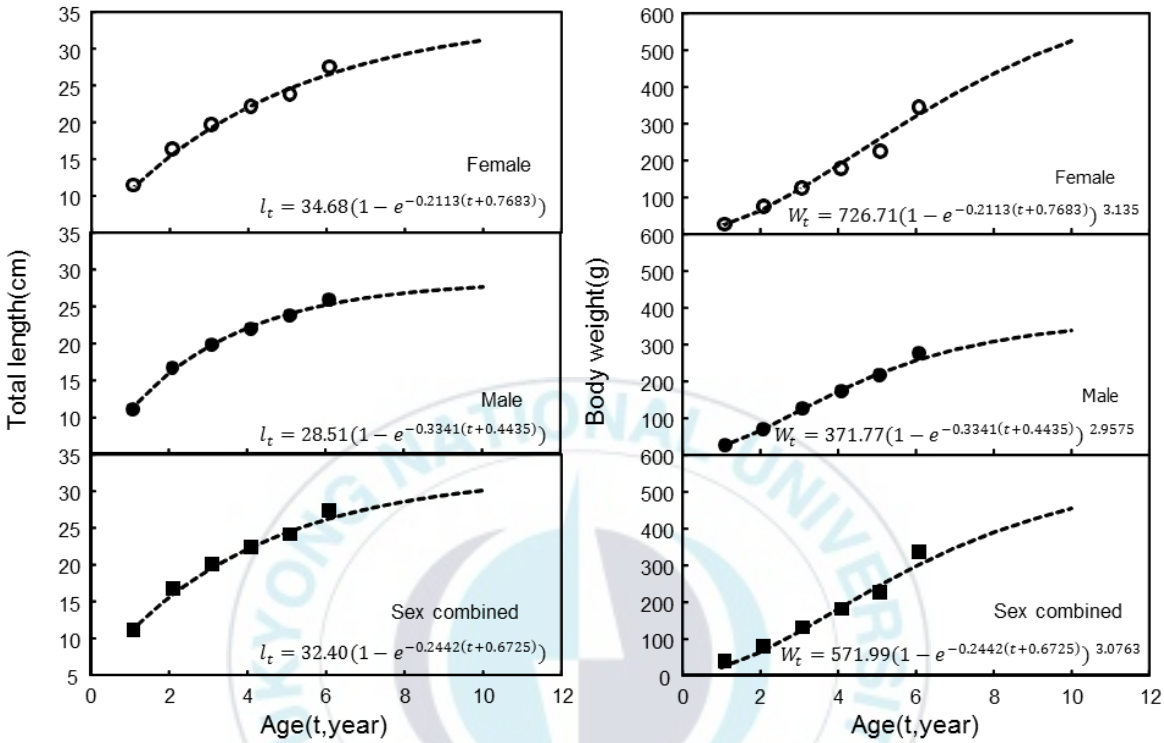

Fig. 12. von Bertalanffy growth curves (A) for the total length of *Sebastes thompsoni*, (B) the body weight of *Sebastes thompsoni.*

Table 3. Comparison in growth parameters and growth performance index of *Sebastes thompsoni* with three areas estimated by von Bertalanffy`s equation

Sex Combined	Growth parameters			
Survey area	L_∞ (cm)	K ($year^{-1}$)	t_0 (year)	Φ
Present study	32.4	0.2442	-0.6725	2.4088
Tong-yeong[1]	29.8	0.2163	-1.7964	2.2835
Aomori[2]	29.04	0.3032	2.2305	2.4077
Niigata[3]	33.2	0.2241	-0.1564	2.3927

1. Kim. (2011). The characteristics of age growth of *Sebastes inermis* and *Sebastes thompsoni*.

2. Kikuya. (2000). A study on age and growth of Usumebaru (*Sebastes thompsoni*).

3. Suzuki. (1978). On the determination of the age and growth of *Sebastes thompsoni* (Jordan et Hubbs).

4. Ecological parameters

4.1 Survival rate (S) and instantaneous coefficient of total mortality (Z)

Survival rate was 0.459 and instantaneous coefficient of total mortality of this species was 0.779/year (Table 4).

Table 4. Estimated survival rate (S) and instantaneous coefficient of total mortality (Z) for goldeyes rockfish (*Sebastes thompsoni*) in Ulleungdo area

Method	S	Z
Pauly method	0.459	0.779/year

4.2 Instantaneous coefficient of natural mortality (M) and instantaneous coefficient of fishing mortality (F)

By Zhang and Megrey (2006) method, instantaneous coefficient of natural mortality (M) was 0.461/year. Instantaneous coefficient of fishing mortality (F) was estimated as to be 0.318/year. It is based on total mortality and natural mortality.

5. Age at first capture (t_c)

Age at first capture, which was estimated from VBGF and length composition of samples, was 4.41 year (Fig.13, 14).

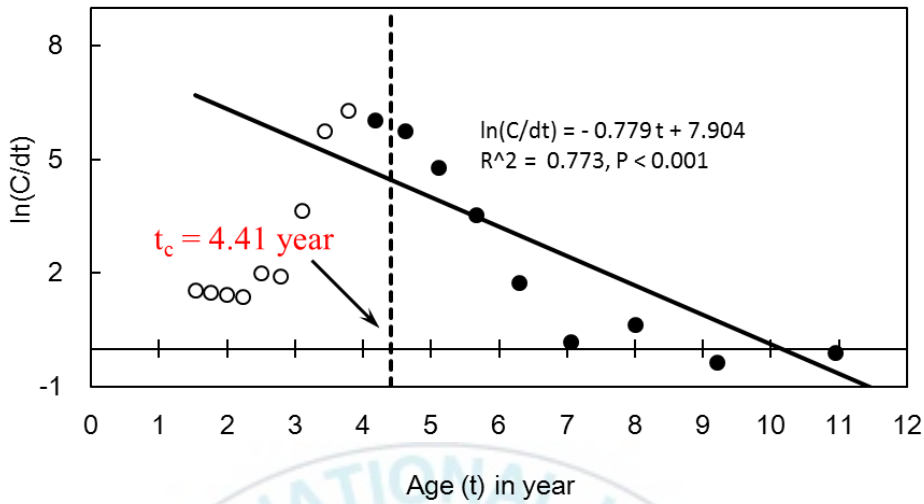

Fig. 13. Length converted catch curve of goldeyes rockfish (*Sebastes thompsoni*) in Ulleungdo area. Closed circles used to calculate Z.

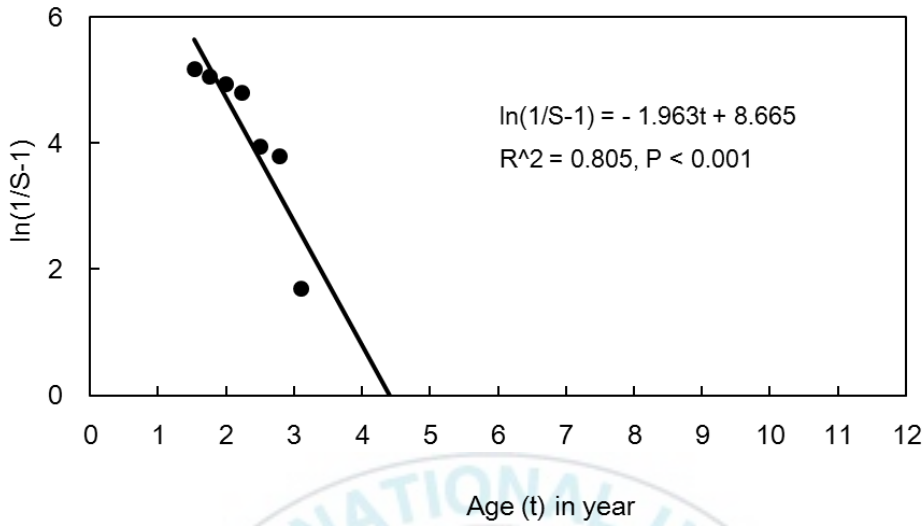

Fig. 14. Selectivity curve to estimate 50% age at first capture of goldeyes rockfish (*Sebastes thompsoni*) in Ulleungdo area.

6. Stock assessment

6.1 Yield-per-recruit model

Yield per recruit (YPR) was estimated from input data of Table 5. Current YPR was estimated 30.83g, when F = 0.318/year at t_c 4.41 years (Fig. 15, 16). And F_{max} and $F_{0.1}$ were estimated 3.257/year and 0.673/year, respectively. YPR at F_{max} and $F_{0.1}$ were 53.36g, 41.7g, respectively.

Table 5. Input data for yield –per-recruit model of goldeyes rockfish (*Sebastes thompsoni*) in Ulleungdo area

K (/yr^{-1})	t_0 (yr)	W_∞ (g)	M (/yr^{-1})	t_c (yr)	t_r (yr)	t_m (yr)*
0.244	-0.672	584.08	0.460	4.41	1.556	13

* Kim. (2011). The characteristics of age growth of *Sebastes inermis* and *Sebastes thompsoni*.

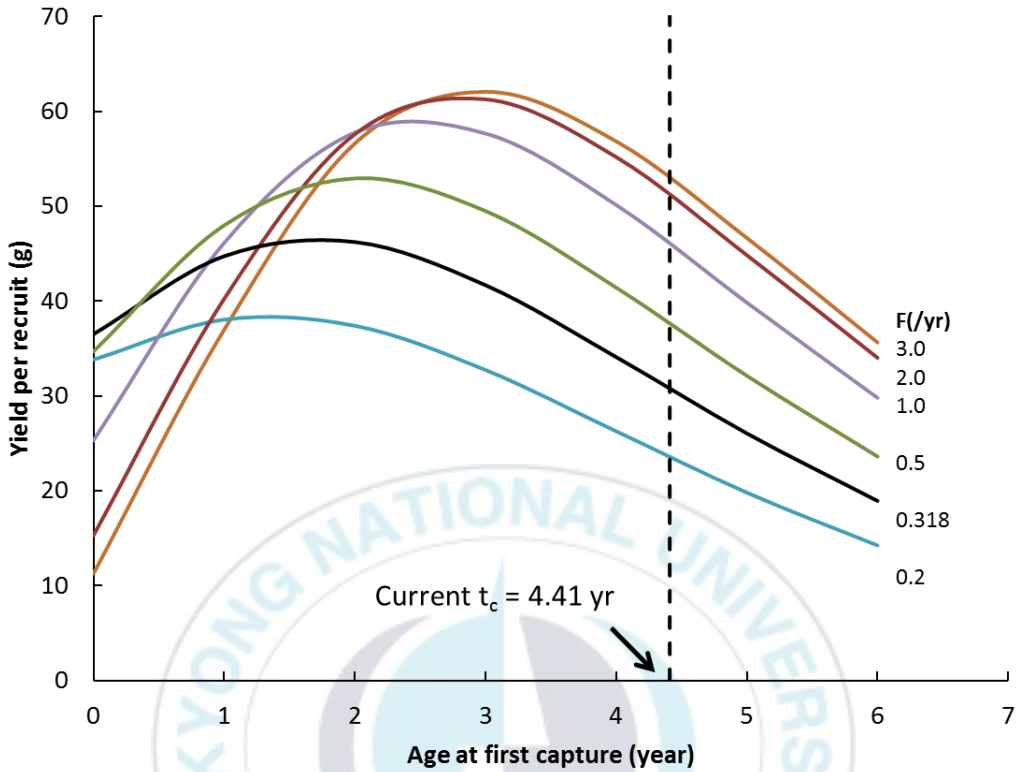

Fig. 15. Yield per recruit against the age at first capture (t_c) for various fishing mortalities (F) of goldeyes rockfish (*Sebastes thompsoni*) in Ulleungdo area.

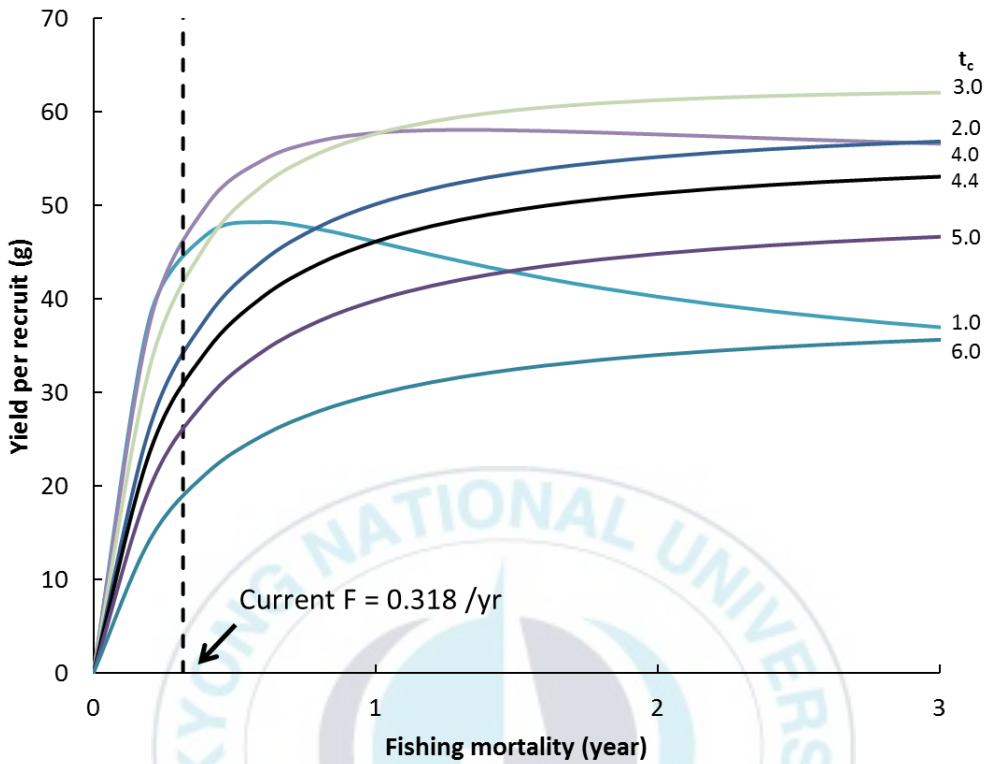

Fig. 16. Yield per recruit against fishing mortalities (F) for various ages at first capture (t_c) of goldeyes rockfish (*Sebastes thompsoni*) in Ulleungdo area.

6.2 Spawning biomass-per-recruit model

The spawning biomass-per-recruit model (SBPR) from Lee (2015) was employed, which used the weighted average mature rate (Table 6). By SBPR, $F_{35\%}$ was estimated 0.619/year and 60.32g and $F_{40\%}$ was estimated 0.509/year and 68.88g. $F_{current}$ was estimated at 90.44g (Fig. 17).

Table 6. Weighted average mature rate of goldeyes rockfish (*Sebastes thompsoni*) in Ulleungdo area

Age	0	1	2	3	4	5	6	7
Weighted average maturity	0.73	0.73	0.81	0.87	0.95	1.00	1.00	1.00

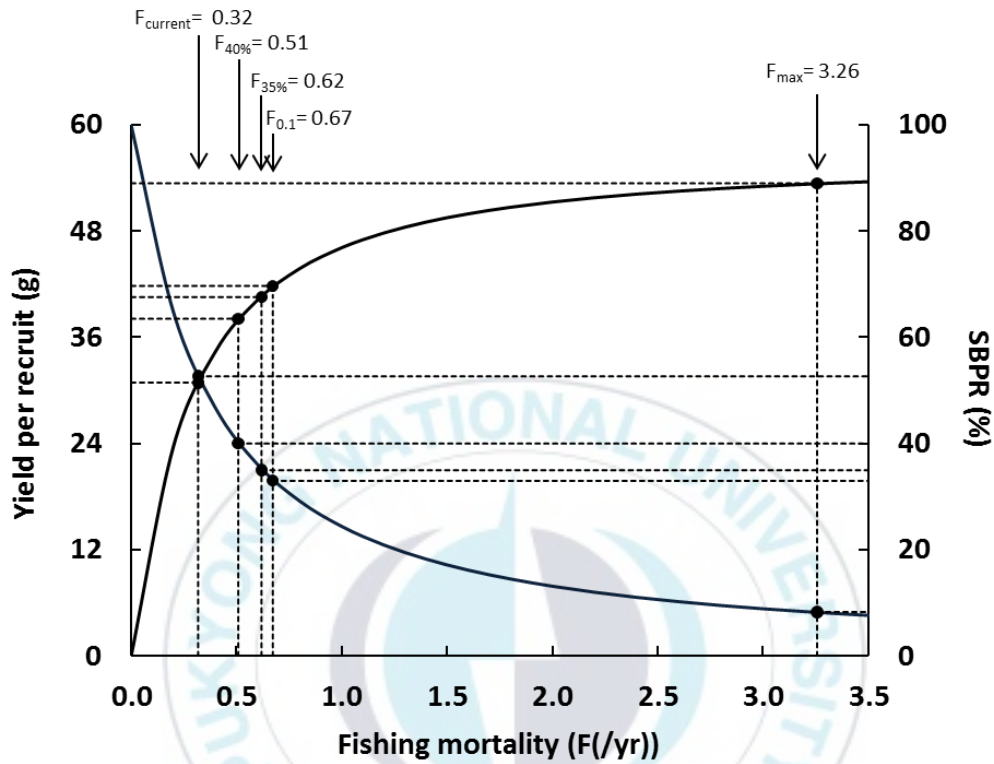

Fig. 17. Yield per recruit (YPR) and Spawning biomass-per-recruit model (SBPR) against various reference points of fishing mortalities (F) of goldeyes rockfish (*Sebastes thompsoni*) in Ulleungdo area.

6.3 Current status of stock of goldeyes rockfish (*Sebastes thompsoni*)

F_{OTY} was estimated 0.509/year. Current $SBPR/SBPR_{MSY}$ and F/F_{OTY} were estimated 1.313, 0.629 respectively. And F/F_{OTY} was estimated 0.629. Current status of stock of goldeyes rockfish (*Sebastes thompsoni*) in Ulleungdo area was located in green zone by the revised Kobe plot (Fig. 18). It means goldeyes rockfish has not been overfished.

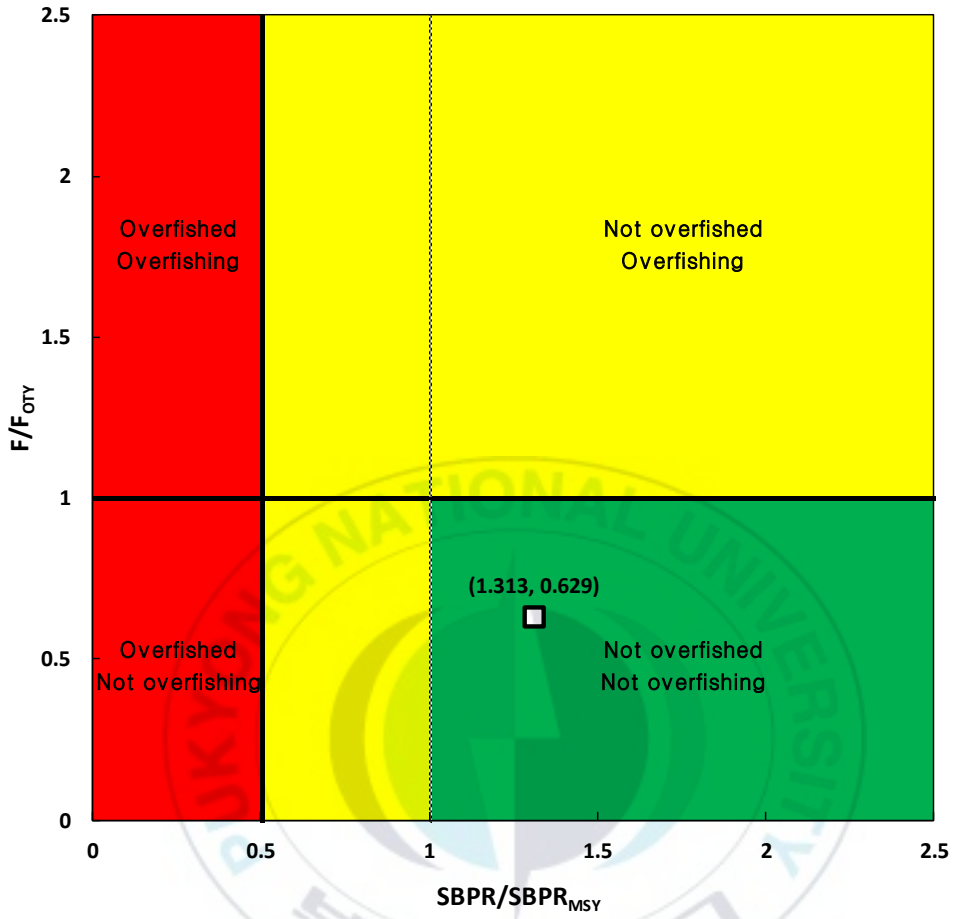

Fig. 18. Revised Kobe plot of the estimate of SBPR and F relative to $F_{40\%}$ for goldeyes rockfish (*Sebastes thompsoni*) in Ulleungdo area. and the white square indicates the current state of this stock.

Discussion

In this study, otolith was used to estimate age. And annual rings defined edge of opaque zone. Generally cross-section reading was used to read age of sagittal otolith because edges of annual rings in the older age can be overlapped. To avoid this error, the reader compared data from surface read and cross-section read. As a result, otolith used in this study was demonstrated no difference from results between surface read and cross-section read. In a similar study, age of *Sebastes alutus* (Beamish, 1979) age read results between surface read and cross-section read showed no difference from 22 to 24-year-old, however over the age of 24, it showed some differences. In short, the result of this study drew conclusion with same results between 2 read methods as the age of *Sebastes thompsoni* used in this study was ranged from 2 to 6-year-old.

To read year ring, results of reader 1, reader 2, reader 3 were compared by average coefficient of variation (CV). CV of reader 1's 1st read result and 2nd read result was 4.95%. CV of reader 1 and reader 3 was 7.71%. Reader 2 and reader 3's CV was 7.82%. CV from reader 1's 2nd read and reader 2's read verified the highest reliability. The CV with the highest reliability, again, compared by Average Percent Error (APE) to raise accuracy of results from readers. Outcome of APE was 2.95% within confidence range, so results of

reader 1 and reader 2 were finally used.

Age at first annual ring was revised to be 14 months by using difference between 2 months from April, spawning season, to June, when MI value decreased. This is estimated due to ovoviviparity of *Sebastes thompsoni*.

Prior to estimating growth function, year ring, back-calculated length, and average weight were calculated by applying weighted value to minimize error, occurred in arithmetic mean, due to different quantity of samples of each age.

To compare regional difference of growth function of *Sebastes thompsoni*, inhabiting in Ulleungdo area, the reader studied results of studies conducted in Tong-yeong in Korea, Aomori, and Niigata in Japan.

The growth function of *Sebastes thompsoni* in Ulleungdo area showed the highest parameter. The lowest parameter was witnessed in Tong-yeong, located at the far south offshore among studied areas. Also, *Sebastes thompsoni* in Aomori showed high growth function compared with Niigata which indicates speed of growth function gets faster as the temperature of sea gets lower in high latitude. However, distinctive parameter was found in *Sebastes thompsoni* in Ulleungdo area located in similar latitude with Niigata. The growth function of *Sebastes thompsoni* in Ulleungdo area was higher than that of Niigata or Aomori. The reason of this distinctive parameter was proved

due to more favorable environment for growth, but more studies on ecosystem and its function such as feeding organisms and trophic level, should be conducted.

The level of resource *Sebastes thompsoni* in Ulleungdo area is considered to be not overfished as t_c was 4.41 year when F was 0.318/year, which means $F_{53\%}$. If t_c is set to be 2 years from 4 years when F was 0.318/year, yield per recruit (YPR) would increase (Figs.15 and 16). However, as YPR increase, spawning biomass-per-recruit (SBPR) would decrease (Fig.17). As a result, considering current level F is $F_{53\%}$, the value can be raised to $F_{40\%}$. But *Sebastes thompsoni* in Ulleungdo area is not one of commercial fish and they are only caught for locals in the island. Also, *Sebastes thompsoni*'s fishing authority is only allowed for Dodong fishing village cooperatives. Accordingly current level of F was expected to maintain. As well as, Ulleungdo area's habitation environment is not violated by dragged net and its environment is maintained well.

Summary

This study estimated the characteristics of age growth and population ecological parameters of goldeyes rockfish, *Sebasetes thompsoni* in the Dokdo and Ulleungdo areas by using 731 samples from February 2013 to February 2014. The lowest value of the marginal index was witnessed in June once a year. The spawning period was estimated as April. Therefore, the duration from fertilization to the complete formation of the annual growth ring was fourteen months. Using the weighted average length of annual ring, the growth of *Sebastes thompsoni* was demonstrated by the von Bertalanffy growth equation as $L_t = 32.40(1 - e^{-0.2442(t+0.6725)})$ for combined sex. The instantaneous coefficient of total mortality (Z) was 0.78/year and the survival rate (S) was estimated 0.459 by Pauly method. The instantaneous coefficient of natural mortality (M) was estimated by Zhang and Megrey model (2006) to be 0.461/year. Based on the estimates of Z and M, the instantaneous coefficient of fishing mortality (F) was calculated to be 0.318/year (F = Z – M). In addition, the age at first capture (t_c) was estimated to be 4.41 years. And current YPR was estimated 30.83g. F_{max} and $F_{0.1}$ were estimated 3.257/year and 0.673/year, respectively. YPR at F_{max} and $F_{0.1}$ were 53.36g, 41.7g, respectively. $F_{35\%}$ and $F_{40\%}$ were estimated 0.619/year, 0.509/year and 60.32g and 68.88g by SBPR, respectively. SBPR at $F_{current}$ was estimated 86.45g. F_{OTY} was estimated 0.509/year. Current SBPR/$SBPR_{MSY}$

and F/F_{OTY} were estimated 1.313, 0.629 respectively. And F/F_{OTY} was estimated 0.629.

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