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[UCI]I804:21031-200000178309

Thesis for the Degree of Master of Fisheries Science

Age and growth of the Blackthroat seaperch, *Doederleinia berycoides* (Hilgendorf, 1879) in the Southern Sea of Korea

by

Makidul Islam Khan

The World Fisheries Graduate School

Pukyong National University

February 22, 2019

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(한국 남해산 눈볼대의 연령과 성장 분석)

Advisor: Prof. Won Gyu Park

by

Makidul Islam Khan

A thesis submitted in partial fulfillment of the requirements

for the degree of

Master of Fisheries Science

in the World Fisheries Graduate School,

Pukyong National University

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Age and growth of the Blackthroat seaperch, *Doederleinia berycoides* (Hilgendorf, 1879) in the Southern Sea of Korea

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The World Fisheries Graduate School

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Abstract

The age and growth of the blackthroat seaperch were estimated using otolith analysis. Monthly samples were collected from January to December, 2014 by using large and middle single trawl nets from the Southern Sea of Korea. The monthly changes in gonadosomatic index (*GSI)* revealed that spawning occurred between July to September with a peak spawning period in August. The monthly catch data from 2012-2017 showed that monthly fishing density increased in spawning season. The length-weight relationship (*LWR*) for both sexes were significant (p<0.05) with the coefficient of determination (r^2) 0.95 (female) and 0.89 (male). The relative growth co-efficient (b) was positive allometric, where 3.1909 for female and 3.0714 for male which revealed that growth in weight was faster than growth in length for both sexes. The marginal increment index (*MI*) was the lowest in September which indicated that otolith growth ring was formed in

September in each year. Fish age was estimated from otolith growth rings analysis and this study estimated the maximum age for females were 6 years, where males were 5 years. The relationship between otolith radius (R) and total length (L) was expressed as L = -10.325+11.881R for females and L = -6.541+9.9049R for males. From this relationship, total lengths were back-calculated for both sexes. The von Bertalanffy growth functions were expressed in the form of equation $L_t = 39.8848(1-e^{-0.2024(t+0.8726)})$ for female, $L_t = 29.2984(1-e^{-0.3245(t+0.7804)})$ for male and $L_t = 41.6011(1-e^{-0.1878(t+0.9910)})$ for both sexes, where L_t is the length at age t.

1. Introduction

1.1. Background

Fish age and growth are two of the most important prerequisites for generating basic information of biological science for fisheries management (Brunel and Piet, 2013). Fish age is an important tool for developing fish growth models, whereas, fish size is a vital indicator for understanding different year classes, length at maturity, reproduction and so forth. As a fisheries management tool, age and growth estimation provide significant insights for management plans like population structure, stock biomass, recruitment pattern, growth rate and mortality rate, longevity and age at maturity (Beamish and McFarlane, 1987; Campana and Thorrold, 2001). The von Bertalanffy growth function is most commonly used growth models for estimating fish growth parameters which indicate past history and current growth trends of the target species. These basic biological information regarding fish age and growth are obligatory for developing scientifically comprehensive fisheries management strategies.

Age and growth of fish were estimated using different methods including fish scales (Al-Absy and Carlander, 1988), otolith (Secor et al., 1995), fin rays (Cass and Beamish, 1983), opercula (Baker and Timmons, 1991) and vertebrae (Brown and Gruber, 1988). The studies of scales and otoliths are most commonly used techniques for estimating fish age and growth (Campana and Thorrold, 2001). The pros of studying scales are using samples without killing the fish, however, the cons would be difficulties in reading exact age due to scales resorption or degeneration (Vandergoot et al., 2008). Scale studies often lead to underestimate of exact age which results in incorrect estimation of growth parameters (Campana, 2001). Based on the underestimated growth parameters, the recruitment or stock biomass might be estimated incorrectly. Otoliths (known as ear stones, hard calcified carbonate structures, located in the inner part of all teleost fish brain) generally provide the most accurate ages compared to other structures as they are not subject to resorption and also due to their continued growth throughout the life (Secor et al., 1995). In the contrary, the cons would be difficulties in removing otolith, time consuming sample preparation and death of the live fish that are not be feasible in certain situations.

1.2. Rationale of the study

The blackthroat seaperch (*Doederleinia berycoides*) is one of the commercial species in the South Korean coastal and offshore fisheries (NFRDI, 2004) and widely distributed around the eastern Indian Ocean and the western Pacific Ocean from the Southern Sea of Korea and Japan to Australia (Yamanoue and Matsuura, 2007). The ecosystem of the Southern Sea was influenced by climate change (Rebstock and Kang, 2003). Species compositions and carrying capacity of the ecosystem were varied due to changing environment. The mean trophic level of fisheries showed a decreasing trend over the last four decades in the Korean waters. Consequently, the higher trophic level demersal fish decreased (e.g., small yellow croaker) and lower trophic level pelagic fish increased (e.g., anchovy and common squid) (Kim et al., 2007). In the South Sea, red tides or blooms are frequently occurred which could disrupt phytoplankton production (Jeone et al., 2017). Food availability along with sea surface temperature changes can influence recruitment pattern which could affect distribution and abundance of fish (Rijnsdorp et al., 2009). Fish growth can change depending on the environmental conditions (Kawano, 2010). For examples: growth of six fish species (including smooth oreo *Pseudocyttus maculatus*, orange roughy *Hoplostethus atlanticus*, warty oreo *Allocyttus verrucosus*) has significantly changed in the southwest Pacific due to climate change (Thresher et al., 2007). Growth rate and body size of the western blue groper (*Achoerodus gouldii*) has also changed in the southwestern coast of Western Australia (Rountrey et al., 2014). In this study, it is hypothesized that the age and growth of the blackthroat seaperch might be changed due to the changing ecosystem and environmental conditions. To test the hypothesis, it is important to study the age and growth of the blackthroat seaperch in the changing environment for updating the basic information for fisheries management.

Despite of having significant importance in fisheries, studies on age and growth of the blackthroat seaperch are limited in the Korean waters. Most of the studies on age and growth of the blackthroat seaperch were estimated using scale studies (Koima, 1976; Onishi, 2009; Kawano, 2010) which cannot provide accurate information as scales can be degenerated or reabsorbed (Campana and Thorrold, 2001; Vandergoot et al., 2008; Santos et al., 2017). For an example: in the Southwest Missouri, scale studies underestimated age of rainbow darter (*Etheostoma caeruleum*) when compared to otoliths studies (Beckman, 2002). Scale studies also overestimated fish age (e.g., freshwater drum *Aplodinotus grunniens*) in the Mississippi River (Goeman et al., 1984). Though otloiths studies are widely accepted for estimating age and growth of fish (Secor et al., 1995; Campana, 2001), but otolith studies for estimating age and growth of the blackthroat seaperch are very limited except Choi et al. (2012).

1.3. Objective of the study

The objective of this study was to estimate age and growth of the blackthroat seaperch (*Doederleinia berycoides*) using otoliths analysis in the Southern Sea of Korea.

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2. Materials and Methods

2.1. Sampling areas

Sampling areas were located in the Southern Sea of Korea (Figure 1) and samples were collected for 12 months from January to December, 2014 by using large single trawl and middle single trawl (one kind of bottom trawl) fishing gear.

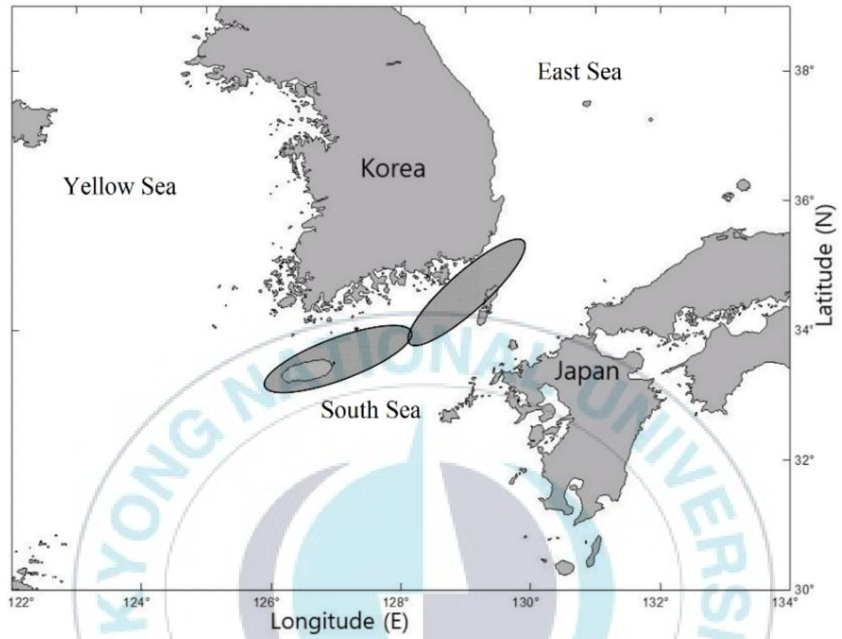

Figure 1: Sampling areas of the blackthroat seaperch (*Doederleinia berycoides*) in the Southern Sea of Korea.

2.2. Biological characteristics

Fish total length (*L*) was measured in the laboratory from the tip of the anterior to the extremity of the caudal fin to the nearest 0.1 cm using an electrical measuring board. The total body weight (*W*) and gonad weight (*GW*) were also measured in the same way to the nearest 0.1 g and 0.01 g, respectively.

2.2.1. Gonado-somatic Index (*GSI*)

In the laboratory, female and male fish were separated using the gonad morphological shape and color of individual fish. The gonado-somatic index (*GSI*) was estimated for each sex as:

$$GSI = \frac{Gonad\ weight}{Total\ body\ weight} \times 10^3$$

Or, $GSI = \frac{GW}{W} \times 10^3$ ……………………………………………..(i)

Where, *GSI* is gonado-somatic index, *GW* is gonad weight (g) and *W* is the total body weight (g).

2.2.2. Length weight relationship (LWR)

According to Le Cren (1951), the length-weight relationship was estimated by the following equation:

$W = aL^b$ ………………………………………………………..(ii)

Where, W is the total body weight (g), L is the total length (cm), a is constant and b is the relative growth coefficient.

2.3. Otolith processing and reading

Sagittal otoliths were embedded in epoxy resin and epoxy hardener in 5:1 ratio (Pace Technologies, Epoxy resin catalog number EP-3000-32 and epoxy hardener catalog number EH-3000-08). The embedded otoliths were grinded and polished carefully for further observation. Otoliths were observed under Image Analyzer (i-Solution image analyzer, model number SZX2-ILLD). Microscope magnification was (1.25x). Fish left otolith was used in the present study.

Otolith growth ring was composed of two zones: one opaque zone which is highly calcified and considered to be fast growing area and another translucent zone which is less calcified and considered to be slow growing zone. Each growth ring was counted carefully in the translucent zone of each otolith. From the center or focus of the otolith, the distance (mm) of each ring was defined as r_1, r_2, r_3,…, r_n and the total distance was represented by R (Figure 2).

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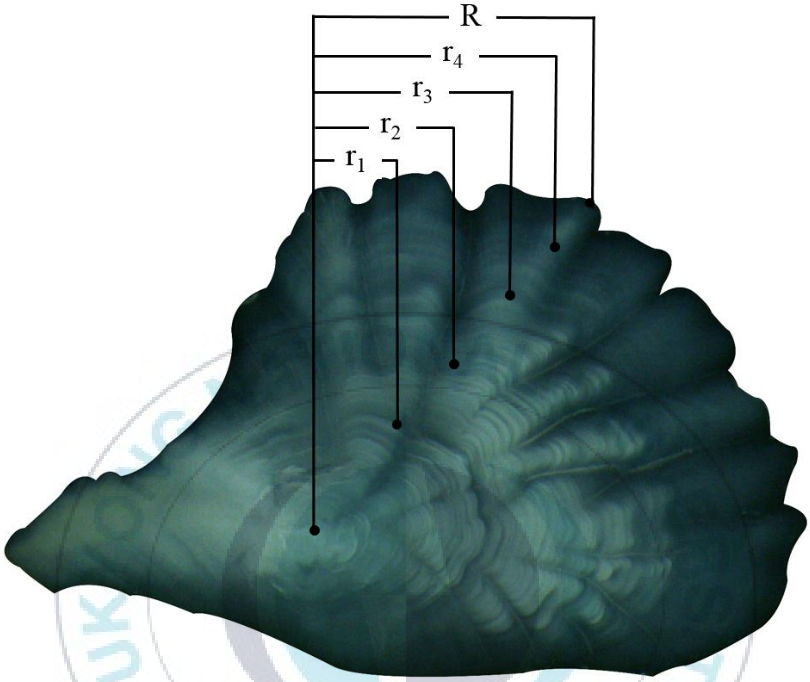

Figure 2: Otolith total radius (*R*) and individual ring radius (r_1, r_2, r_3, r_4 and r_5) of the blackthroat seaperch (*Doederleinia berycoides*) in the Southern Sea of Korea.

2.4. Age determination and periodicity

The initial otolith ring formation or age structure was determined by analyzing otolith marginal increment index (*MI*). *MI* is the ratio of the deposition of calcium carbonate ($CaCO_3$) on the otolith structure over time. *MI* also used to check the validity of the otolith growth periodicity. Based on the lowest *MI* value, the otolith ring formation time was determined. For calculating *MI*, the following equation was used:

$$MI = \frac{R - r_n}{r_n - r_{n-1}} \quad \text{.....(iii)}$$

Where, *R* is the total otolith radius (mm), r_n is the length of n^{th} ring mark from the center (mm) and r_{n-1} is the length of $(n-1)^{th}$ ring mark from the center (mm).

2.5. Growth parameters

The von Bertalanffy growth parameters were calculated by the following function:

$$L_t = L_\infty[1 - e^{-k(t-t_0)}] \quad \text{(iv)}$$

Where, L_t is the predicted length (cm) at age t, L_∞ is the asymptotic (theoretical maximum) length (cm), K is the growth co-efficient ($year^{-1}$) and t_0 is the hypothetical/theoretical age of the fish at length zero (year).

The above mentioned growth parameters were calculated from three different steps. 1st step: plotting fish total length (L) and total otolith radius (R) for back-calculating total length of the fish (Francis, 1990). 2nd step: using back-calculated total length for drawing Ford-Walford (L_t vs L_{t+1}) graph (Walford, 1946). 3rd step: L_∞ and K were determined from Ford-Walford graph's intercept and slope value.

$$L_\infty = \frac{Intercept}{1-\text{slope}} \quad \text{(v)}$$

$$K = -ln(slope) \quad \text{(vi)}$$

3. Results

3.1. Biological characteristics

Total 1209 samples were collected from January to December, 2014 (Table 1). Among the total samples, females were 827 individuals (68%) and males were 382 individuals (32%). The overall length of the blackthroat seaperch (both sexes) was ranged from 12 to 35.10 cm, where females ranged from 13.10 to 35.10 cm and males ranged from 12 to 29 cm (Figure 3). In case of females, around 46% accounted in the ranged of 27 to 31 cm but for males around 41% ranged from 22 to 24 cm. No male individual was recorded over 29 cm in the collected samples.

Table 1: The number and length (mean±sd) of the blackthroat seaperch (*Doederleinia berycoides*) samples collected from January to December in the Southern Sea of Korea in 2014.

Month	Female		Male	
	Number	*L* (mean ±sd) (cm)	Number	*L* (mean ±sd) (cm)
Jan	52	26.8±4.8	46	20.9±2.2
Feb	76	25.9±3.8	22	21.1±2.7
Mar	56	26.9±4.2	43	20.5±2.4
Apr	90	23.1±4.5	24	16.4±3.7
May	55	25.3±6.9	44	20.4±4.3
Jun	51	23.9±6.2	48	20.4±3.6
Jul	60	25.8±5.0	39	19.7±3.4
Aug	62	25.6±5.3	37	19.9±1.7
Sep	83	25.0±4.5	16	18.8±2.9
Oct	80	25.0±4.0	19	19.1±2.2
Nov	86	24.5±4.1	27	19.2±2.4
Dec	76	23.9±4.1	17	21.1±2.2
Total	827		382	

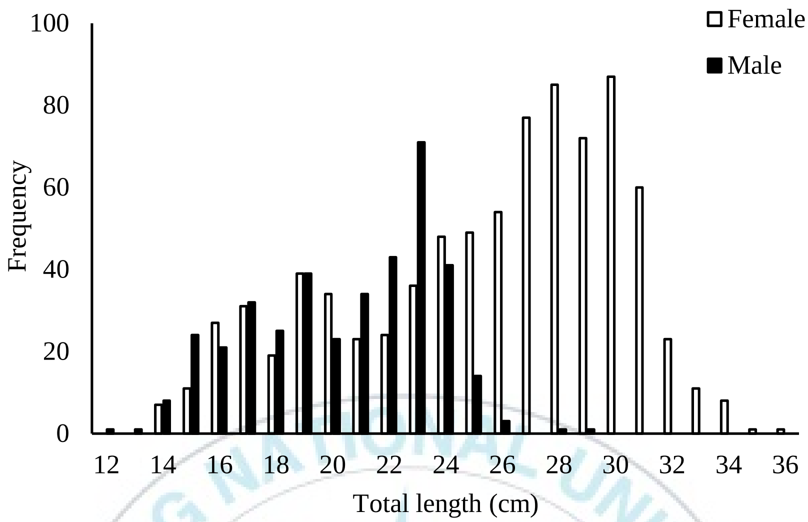

Figure 3: Length frequency distribution of the blackthroat seaperch (*Doederleinia berycoides*) in the Southern Sea of Korea in 2014.

The monthly changes of the gonadosomatic index (*GSI*) were significantly different for female and male blackthroat seaperch (Figure 4). The maximum value of *GSI* was found in August between the two sexes and after that it started to decrease sharply in September. The spawning season of the blackthroat seaperch was estimated to be between July to September with a peak spawning period was August to September. It was also found that male had comparatively lower *GSI* value than female throughout the whole year and the difference was very high in peak spawning time.

There was significant relationship ($p<0.05$) between the length and weight of both female and male blackthroat seaperch with the coefficient of determination (r^2) 0.95 and 0.89 respectively (Figure 5). The relative growth co-efficient (*b*) was positive allometric, where *b* value was 3.1909 for female and 3.0714 for male. In both sexes, fish grew faster in body weight than their length.

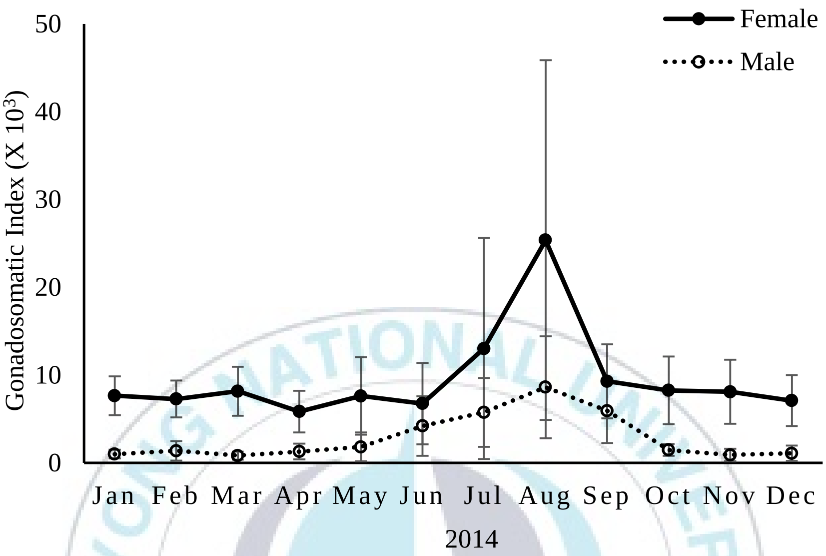

Figure 4: Monthly changes in the gonadosomatic index (*GSI*) (mean±sd) of the blackthroat seaperch (*Doederleinia berycoides*) in the Southern Sea of Korea.

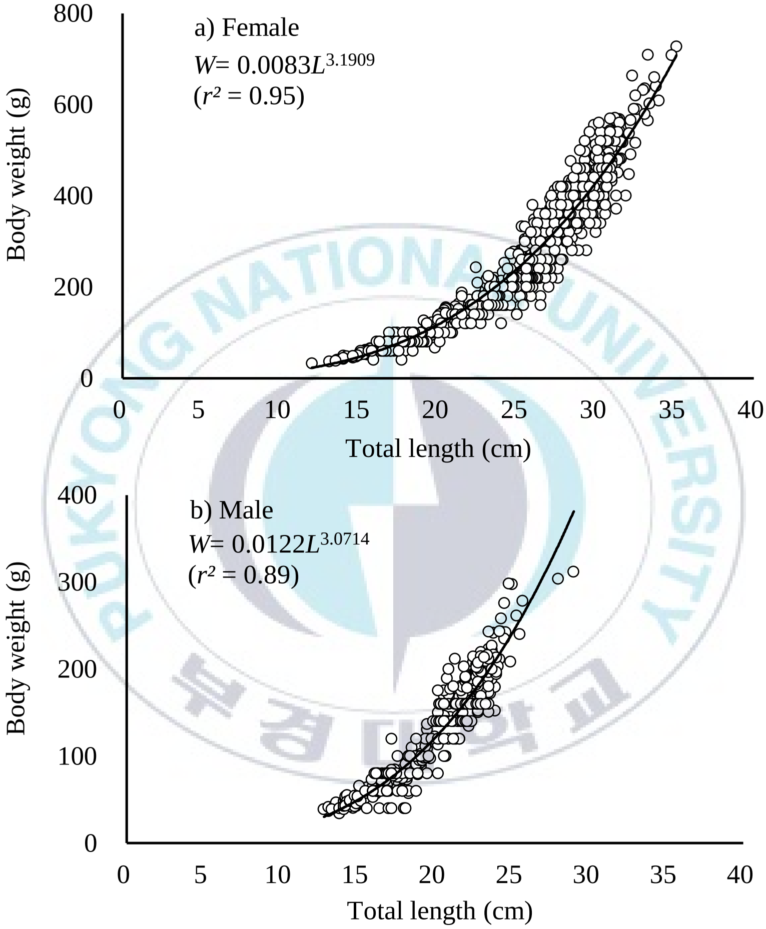

Figure 5: Relationship between total length (*L*) and body weight (*W*) of the a) female and b) male blackthroat seaperch (*Doederleinia berycoides*) in the Southern Sea of Korea.

3.2. Age determination and periodicity

The relationship between otolith radius (R) and otolith ring radius (r_1, r_2, r_3, … and r_n) was shown in Figure 6. For both female and male, each ring was separated from other rings. Only one of the 1-ring group was found in males, whereas, females were observed from 2-ring group. The maximum ring group was 6 in females, whereas, it was 5 in males. In case of females, there was no young fish caught from 0 to 1 year old. It was also found that the otolith size was increased as the number of rings increased. That's mean there was significant relationship between the otolith radius and otolith ring radius.

In Table 2, one year old fish (1^+) was practically 0 to 0.99 year old, two years old (2^+) was 1 to 1.99 years old and so on. This study estimated that females had longer live than males, where females were 6 years old and males were 5 years old.

The otolith ring formation period and periodicity were estimated by the monthly variation of the marginal increment index (MI) (Figure 7). For both sexes, MI was found at the lowest point in

September. In the present study, it was concluded that the timing of otolith ring formation was began in September in each year.

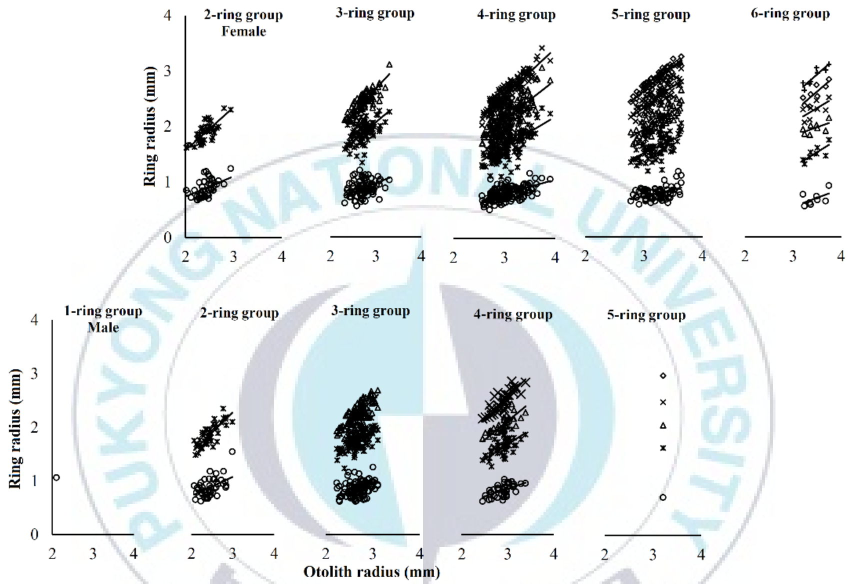

Figure 6: Relationship between otolith radius (R) and ring radius (r_1, r_2, r_3, r_4, r_5 and r_6) of the blackthroat seaperch (*Doederleinia berycoides*) in the Southern Sea of Korea.

Table 2: Age composition of the blackthroat seaperch (*Doederleinia berycoides*) caught in the Southern Sea of Korea in 2014.

Age	Female		Male	
	Number	*L* (mean±sd) (cm)	Number	*L* (mean±sd) (cm)
1^+			1	12.00
2^+	44	16.11±1.72	47	16.61±2.07
3^+	84	20.69±3.24	101	20.22±2.73
4^+	152	26.52±3.15	41	23.04±1.88
5^+	72	29.72±2.10	1	29.00
6^+	8	33.23±1.42		
Total	360		191	

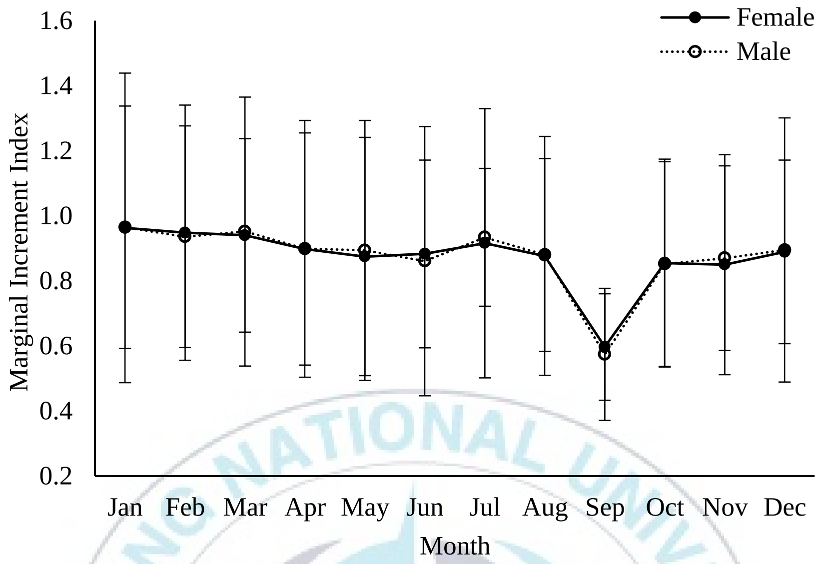

Figure 7: Monthly changes in the marginal increment index (mean±sd) of the blackthroat seaperch (*Doederleinia berycoides*) in the Southern Sea of Korea.

3.3. Growth parameters

Different ring groups along with their mean ring radius (mm) were shown in Table 3 and Table 4 for both sexes. Comparatively higher ring increment was found in the 1st and 2nd rings (i.e. r_1 and r_2) than rest of the rings (i.e. r_3, r_4, r_5 and r_6) for both sexes. The ring growth rate was slower in the larger rings than the smaller rings.

The otolith radius (R) and the total length (L) showed linear relationship for both sexes (Figure 8) and from the relation the total length at the time of ring formation was back-calculated. Back-calculated total length at age 't' (L_t) and total length at age '$t+1$' (L_{t+1}) were drawn by using Ford-Walford equation for both sexes (Figure 9). In the Ford-Walford graph, the interceptor (a) and slope (b) value were estimated 7.3069 and 0.8168 for females, and 8.1186 and 0.7229 for males.

Table 3: Otolith mean ring radius of the female blackthroat seaperch (*Doederleinia_berycoides*) in the Southern Sea of Korea.

Sex	Ring group	Number of specimens	Ring radius (mm)						
			R	r_1	r_2	r_3	r_4	r_5	r_6
Female	1								
	2	44	2.42	0.89	1.90				
	3	84	2.73	0.85	1.81	2.33			
	4	152	3.06	0.82	1.70	2.21	2.66		
	5	72	3.22	0.80	1.66	2.14	2.57	2.91	
	6	8	3.44	0.74	1.62	2.12	2.48	2.79	3.12
	Mean	360		0.82	1.74	2.20	2.57	2.85	3.12
	±sd			0.05	0.11	0.10	0.09	0.08	

Table 4: Otolith mean ring radius of the male blackthroat seaperch (*Doederleinia_berycoides*) in the Southern Sea of Korea.

Sex	Ring group	Number of specimens	Ring radius (mm)						
			R	r_1	r_2	r_3	r_4	r_5	r_6
Male	1	1	2.10	1.06					
	2	47	2.44	0.88	1.86				
	3	101	2.69	0.85	1.74	2.23			
	4	41	2.90	0.83	1.63	2.05	2.49		
	5	1	3.21	0.69	1.59	2.00	2.42	2.90	
	Mean	191		0.86	1.71	2.09	2.45	2.90	
	±sd			0.13	0.12	0.12	0.05		

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According to the Ford-Walford relationship between L_t and L_{t+1}, the calculated von Bertalanffy growth parameters were: asymptotic length (L_∞), growth co-efficient (K) and t_0 were 39.8848 cm, 0.2024 year^{-1} and -0.8726 year for female, 29.2984 cm, 0.3245 year^{-1} and -0.7804 year for male, and 41.6011 cm, 0.1878 year^{-1} and -0.9910 year for both sexes (Figure 10).

The von Bertalanffy growth functions were:

$L_t = 39.8848(1\text{-}e^{-0.2024(t+0.8726)})$ for female

$L_t = 29.2984(1\text{-}e^{-0.3245(t+0.7804)})$ for male

$L_t = 41.6011(1\text{-}e^{-0.1878(t+0.9910)})$ for both sexes.

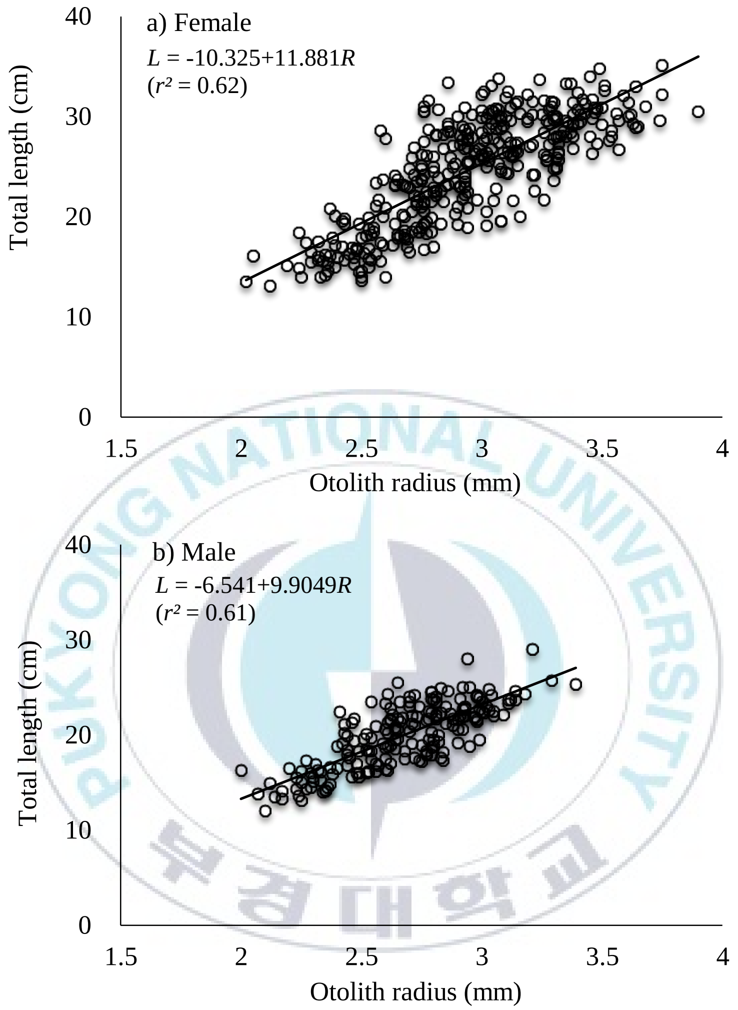

Figure 8: Relationship between otolith radius (*R*) and total length (*L*) of the a) female and b) male blackthroat seaperch (*Doederleinia berycoides*) in the Southern Sea of Korea.

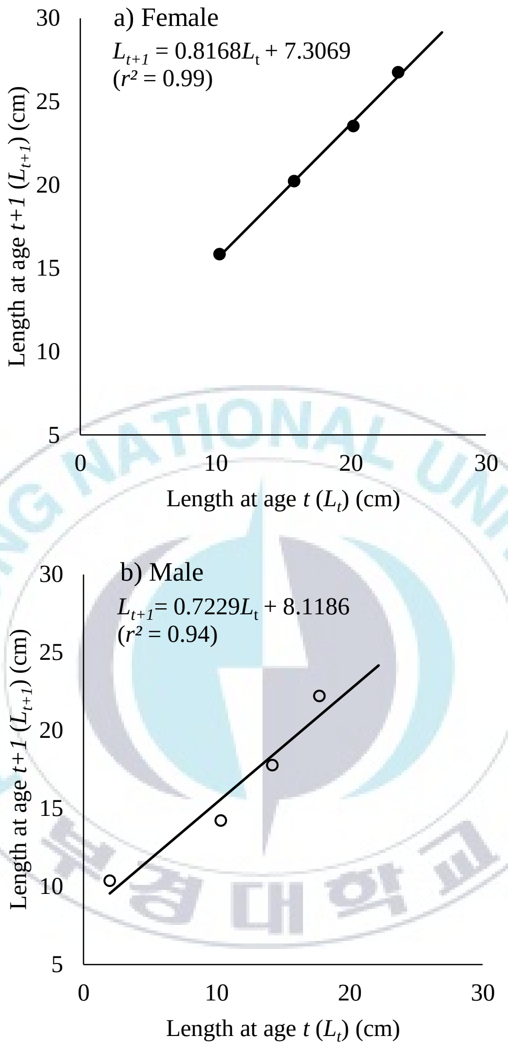

Figure 9: Ford-Walford graph for calculating von Bertalanffy growth parameters of the a) female and b) male blackthroat seaperch (*Doederleinia berycoides*) in the Southern Sea of Korea.

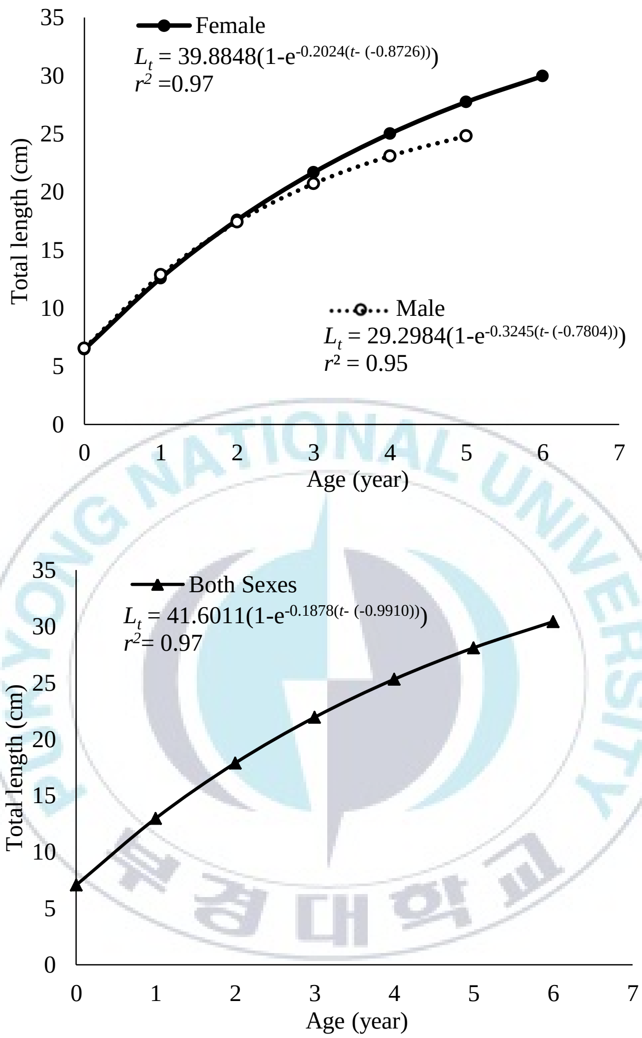

Figure 10: The von Bertalanffy growth functions for female, male and both sexes of the blackthroat seaperch (*Doederleinia berycoides*) in the Southern Sea of Korea.

4. Discussion

4.1. Biological characteristics

The onset and duration of fish spawning become one of the most important indicators for their contributions on stock recruitment. Fish species that distributed with a wide range of geographical area are prone to form different stocks which might change in their spawning time (e.g., white croaker, *Micropogonias furnieri*) (Francis, 1996). Similarly, the spawning time of the blackthroat seaperch was also reported different in different geographical areas. The spawning period of the blackthroat seaperch was between August to October with peak in September in Niigata coast of Japan (Onishi, 2009) and Waters off Eastern Taiwan (Wu et al., 2016) which are different from the present study. Besides geographical differences, various environmental factors such as changes of temperature and food availability are also accountable for altering the spawning period of different fish such as Atlantic herring *Clupea harengus* (Winters and Wheeler, 1996) and Atlantic cod *Gadus morhua* (Yoneda and Wright, 2005). Increasing temperature has shifted spawning season more than 3 weeks for European graylings (*Thymallus thymallus*) (Wedekind and Kung, 2010). Another important factor responsible for altering spawning period is related with match-mismatch hypothesis of Cushing (1990). In this case, more comprehensive studies are needed for better understanding. The estimated spawning period of the blackthroat seaperch in the present study agrees with the similar findings of Cha et al. (2010) and Choi et al. (2012) in the Southern Sea of Korean waters. Lower *GSI* value in male than female blackthroat seaperch in the spawning period was also observed by Choi et al. (2012) and Wu et al. (2016). The comparatively smaller size of testes in male than female was responsible for the lower *GSI* value of male in the spawning period.

Annual catch data of the blackthroat seaperch in Korea revealed that the percentage of catch in spawning season was continuously increased from 31% in 2012 to 46% in 2017 respectively

(MIFFAF, 2018). This increasing trend of catch in spawning season might deplete the recruitment, affect the spawning behavior and spawning ground that might ultimately affect the whole stock. Bottom contact gear like bottom trawl might destroy the spawning ground as well as feeding ground that might affect the target stocks and other non-target species. Fishing regulations like implementing spawning season closures can minimize the negative impacts of fishing during the spawning season.

The implication of length weight relationships for stock assessment and fisheries management is very important. Ricker (1975) classified fish growth types based on the relative growth coefficient b value into isometric (b=3) and allometric (b≠3). Fish growth isometric means weight and length increase equally, whereas, allometric growth shows faster increment in weight than length or vice versa. Allometric growth can be positive allometric (b>3) when weight increases faster than length or negative allometric (b<3) when length increases faster than weight (Karachle and Stergiou, 2012). The findings of the present study support Choi et al. (2012) who also reported positive allometry for both sexes of the blackthroat seaperch in the Southern Sea of Korean water.

4.2. Age determination and periodicity

Age determination is very imperative for developing dynamic population models for reliable fisheries stock assessments. Otoliths studies are widely used for estimating fish age as new rings are periodically added around the center of the otoliths each year (Campana, 2001). The formation of otolith rings depends on many factors including the changes of gonad development and environmental factors (Pannella, 1974; Beckman et al., 1990). During the period of gonad development as fish used maximum energy for reproduction, so the growth of otoliths ring increment might be slow. Despite the reproductive activity, other factors (e.g., food availability, temperature change and so forth) are also responsible for affecting otolith ring increment as annual growth rings are present in immature fish (Morales-Nin, 1992). The estimated periodicity of otoltih ring formation of the blackthroat seaperch was in September in each year (Choi et al., 2012) and the present study was also agreed with the findings.

Scale studies were previously used for estimating age of the blackthroat seaperch (Kojima, 1976; Onishi, 2009; Kawano, 2010), but there were no consistency among the different studies for the estimated age of the blackthroat seaperch. Scale studies could not estimate the accurate age of the blackthroat seaperch. Scales studies overestimated younger fish age (McBride et al., 2005) and underestimated older fish age (McBride et al., 2005; Gunn et al., 2008). For an example: scales studies underestimated fish age 1 or 2 years than otolith studies in round whitefish (*Prosopium cylindraceum*) in the Leaf River, Quebec (Jessop, 1972). The otoliths based study for estimating age of the blackthroat seaperch for both sexes by Choi et al. (2012) agrees with the findings of the present study. In the present study, only 1 male fish was caught in 1^+ age because of fish small size that makes them difficult to catch by the sampling gear.

4.3. Growth parameters

Fish growth parameters have become one of the cornerstones in fisheries management as they are widely used for describing fish life histories. Growth parameters are species specific, but they might also differ within the same species depending on the geographical distributions, environmental conditions and sex (Sparre and Venema, 1998). The von Bertalanffy growth functions are commonly used for estimating fish growth parameters. Female blackthroat seaperch had higher asymptotic length (L_∞) than male blackthroat seaperch (Onishi, 2009; Kawano, 2010; Choi et al., 2012) and the present study agrees with the findings. The larger L_∞ of female might be induced by the longer lifespans of female than male or lack of having small samples of male fish at the oldest age. The difference might also related with sexual dimorphism as reported for Southern Bluefin Tuna (*Thunnus maccoyii*) (Farley et al., 2014). But the present study reported higher L_∞ for female than the reported value of Choi et al. (2012) in the Southern Sea of Korea. The disagreement might because of having larger female individuals (35.10 cm) in the present study over the estimated value of L_∞ by Choi et al. (2012) (Figure 3). The reported value of L_∞ (41.20 cm) for both sexes by Park (1971) supports the present study. The asymptotic length was estimated from the back-calculated total length through otolith reading which might related with Lee's Phenomenon when the back calculated total length at age decreases with increasing fish age (Francis, 1990).

Fish growth co-efficient or growth rate (*K*) is related with size at maturity, reproduction activity, foods availability, environmental factors and so forth (Jennings et al., 2001). The energy budget or requirement during the period of gonad development is varied between the sexes which can cause different growth rate for the male and female blackthroat seaperch. Moreover, changes of environmental factors like temperature increase and metabolic activities of fish might result in different growth rate (Santos et al., 2017). The growth rate of the male and female black scabbard fish (*Aphanopus carbo*) was reported different in the Southern Northeast Atlantic (Vieira et al., 2009). Food availability can also affect growth rate (e.g., Atlantic cod, *Gadus morhua*) (Yoneda and

Wright, 2005) Higher growth rate for male than female blackthroat seaperch was reported by Onishi (2009) and Choi et al. (2012) and the preset study agrees with their findings. The different growth rate between male and female might be associated with reproductive activities and environmental factors that might induced higher growth rate for male than female blackthroat seaperch. The present study reported lower growth rate for male (0.324) and female (0.202) than the estimated value for male (0.339) and female (0.256) by Choi et al. (2012) in the Southern Sea of Korea. As the blackthroat seaperch shows ontogenetic feeding variations (changes feed types from phytoplankton to fish throughout the whole life) (Huh et al., 2011) like Atlantic cod, so disruption in phytoplankton productivity or availability of food along with climatic change might affect the growth rate of the blackthroat seaperch. But the present study suggests that comprehensive studies are needed for better understanding of the cause of the growth rate change.

The value of t_0 indicated fish growth pattern in whole life cycle (i.e. how fish grow in early ages comparing in old ages). The value of t_0 can be negative or positive, where negative t_0 value shows faster growth in early life stages than older ages or vice versa (King, 1995). The blackthroat seaperch grew faster in the first two years comparing older ages (Onishi, 2009; Kawano, 2010; Choi et al., 2012) and the present study agrees with the previous studies.

Overall, in the present study, the spawning period, length-weight relationship, age and growth parameters of the blackthroat seaperch were estimated in the Southern Sea of Korea. This study updated the basic data like age and growth parameters of the blackthroat seaperch for fisheries management. Based on the findings of this study, population structure, stock recruitment, growth and mortality rates, and so forth might be estimated for developing proper management strategies of the blackthroat seaperch in the Southern Sea of Korea. The management strategies should be developed based on the different growth patterns of females and males blackthroat seaperch. The estimated von Bertanlanffy growth parameters are key for many age and growth modeling management. Management regulations should be implemented on fishing during spawning season for sustainable production of the stock. But more studies need to be conducted on the impacts of fishing during spawning season of the blackthroat seaperch for better understanding. This study suggests that otolith chemistry and microstructure should be analysis for assessing the impacts of environmental factors on the growth rate of the blackthroat seaperch in future. One of the simplified suggestions would be to develop otolith based growth model for estimating fish age rather than back-calculation methods.

5. Acknowledgements

First of all, I would like to express my heartfelt gratitude to my respected supervisor, Professor Dr Won Gyu Park, Department of Marine Biology, Pukyong National University. Without his continuous supports, enduring guidance and encouragement, it would not be possible for me to complete the thesis. It is a great pleasure to express my gratitude and sincere appreciation to Dr Choi Jung Hwa, Senior Scientist, National Institute of Fisheries Science (NIFS), Fisheries Resources Research Center, Tongyeong-si, South Korea, who gave me the opportunity to work in the center. Again special thanks to Mrs Jeon Bok-Soon and other otolith laboratory members' in the center for their warm cooperation. In addition, special thanks to Professor Dr Chul Woong Oh for allowing me to use the Marine Ecology Lab, Pukyong National University. I would like to thank all of the World Fisheries University staffs for their kind co-operation and supports during this study. I also expressed my special thanks to

Dr Dale Marsden, Professor, The World Fisheries Graduate School, Busan and Mr. Goutam Kumar Kundu Assistant Professor, University of Dhaka, Bangladesh for their enormous mental support and guidelines. Last but not least, I would like to say a big thank you to all those who have contributed in diverse ways to the successful completion of this thesis, but whose names have not been mentioned.

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