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Age Determination and Growth Pattern of Pacific Cod *Gadus macrocephalus* (Tilesius, 1810) in Jinhae Bay Korea

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ABSTRACT Age and growth pattern of Pacific cod *Gadus macrocephalus* were determined using samples collected in Jinhae Bay in Korea during the spawning period from 2006 to 2009. The ages of 333 specimens were estimated using their otoliths. The reliability of scales as a means of age determination was analyzed by comparing the ages estimated from otoliths and scales of 96 specimens. The scales collected from the base of the second dorsal fin or from the caudal peduncle were proved to be suitable for age determination of Pacific cod. Monthly changes in the marginal index in otoliths decreased from December showing the lowest value in February. Ages ranged from 4 to 6 years for both females and males, and most of them were 6 years old. Relationships between the otolith radius (R) and total length (TL) were $TL=10.4R+3.1$ for males, and $TL=11.5R+3.4$ for females. The growth curves in total length (L_t, cm) were expressed as $L_t=141.5\,[1-exp\{-0.089\,(t+0.209)\}]$ for males and $L_t=127.5\,[1-exp\{-0.124\,(t+0.077)\}]$ for females.

Key words : Pacific cod, *Gadus macrocephalus*, otolith, scale, age, growth

INTRODUCTION

Pacific cod *Gadus macrocephalus*, live in coldwater around the continental shelf and upper slope, and its geographical distribution ranges across vast areas of subarctic and arctic waters of the North Pacific Ocean, from the Yellow Sea and the East Sea around Korea, north through the Sea of Okhotsk as far as the Bering Sea, along the Gulf of Alaska through the North Pacific Ocean, and south to the California Coast of North America (Westrheim, 1996). Pacific cod are known to avoid horizontal movement when foraging and during the breeding season. Although there are more than 10 regional population groups of cod in the Far East Pacific Ocean, it is reported that they barely interact with one another (Moiseev, 1953).

In winter, Pacific cod immigrates for spawning to Jinhae Bay, the largest spawning ground in Korea, and emigrates to the north or into deeper waters after spawning. The spawning takes place in Jinhae Bay in Gyeongsangnam-do and Young-il Bay in Gyeongsangbuk-do, extending generally from December to April (Chyung, 1977). Age and growth data are the most important for stock management. However, only limited research has been conducted to estimate the age structure of Pacific cod in Jinhae Bay (Uchida, 1936).

According to the otolith study of Pacific cod in Pacific waters near Hokkaido (Hattori *et al*., 1992) the translucent zone was formed between October and December, and the opaque zone between March and May. This suggests that age can be determined based on the reading of translucent zones.

The aims of the present study were to (1) compare scale and otolith of Pacific cod in Jinhae Bay as age-specific traits in age determination, and (2) to determine the growth in length and compare growth patterns of Pacific cod inhabiting in other Pacific regions.

MATERIALS AND METHODS

Fish samples were collected from the Wepo Fish market (operated by Fisheries Cooperative Association in

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Table 1. Number of specimens (N), and mean total length (TL) of Pacific cod, *Gadus macrocephalus* sampled for age determination in Jinhae Bay

	Year	Month	Female		Male		Combined	Range of TL (cm)	
			N	TL ± SD (cm)	N	TL ± SD (cm)	TL ± SD (cm)	Min	Max
First year	2006	Dec.	27	66.8 ± 6.0	15	62.4 ± 5.2	65.1 ± 6.0	54.0	77.5
	2007	Jan.	28	66.1 ± 5.3	19	52.7 ± 7.0	60.9 ± 8.8	45.0	75.5
		Feb.	5	64.0 ± 3.3	2	58.0 ± 11.3	62.3 ± 6.1	50.0	69.0
		Subtotal	60	66.2 ± 5.4	36	57.0 ± 7.9	62.7 ± 7.8	–	–
Second year	2008	Dec.	34	66.8 ± 4.6	15	65.3 ± 4.4	66.0 ± 4.7	52.0	76.0
		Jan.	36	66.1 ± 5.1	14	67.2 ± 3.2	66.5 ± 4.8	58.0	77.0
		Feb.	38	62.7 ± 3.7	13	62.2 ± 2.7	62.6 ± 3.5	54.0	70.0
		Subtotal	108	65.1 ± 4.8	42	64.8 ± 4.1	65.0 ± 4.6	–	–
Third year	2009	Dec.	27	69.2 ± 3.9	–	–	69.2 ± 3.9	62.0	77.5
		Jan.	30	66.1 ± 8.1	–	–	66.1 ± 8.1	41.0	77.0
		Feb.	30	68.8 ± 4.6	–	–	68.8 ± 4.6	57.0	78.0
		Subtotal	87	68.0 ± 6.0	–	–	68.0 ± 6.0	–	–
	Total		255	66.3 ± 2.0	78	61.3 ± 5.2	65.3 ± 2.9		

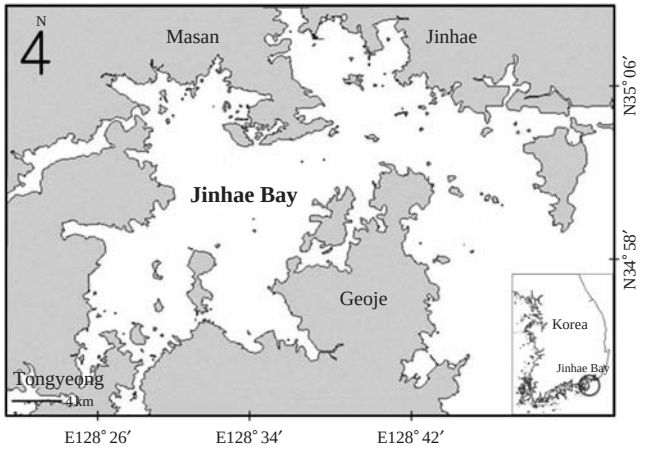

Fig. 1. Map showing the sampling site of Pacific cod, *Gadus macrocephalus* in Jinhae Bay.

Geoje) in Wepo-ri, Jangmok-myeon between December and February for 3 years (2006 ~ 2009) (Table 1). The fish were originally caught by a drift gill net in waters near Isu Island of Geoje City, Gyeongsangnam-do (Fig. 1). Once sampled, each specimen was labeled by the relevant year as 2007 Pacific cod (hereinafter referred to as the first year), 2008 Pacific cod (hereinafter referred to as the second year), or 2009 Pacific cod (hereinafter referred to as the third year). The first-, second-, and third-year sets consisted of 96, 150, and 87 individuals in total, respectively. In the third year no males were sampled.

All of the collected fish were immediately stored in an icebox and moved to the laboratory, where each individual was examined for sex, size, total length to the nearest 0.1 cm, and weight to the nearest 1 g; otolith and scales were removed to determine age. Otoliths and scales from catches in the first-year were compared to assess their suitability as age-specific traits. A comparative observation was made on the annuli from the otoliths and scales of 96 individuals. To test the scales from particular parts of the fish body for their trait relevancy for age determination, scales were taken from 4 different parts (1: behind the gill, 2: base of the first dorsal fin, 3: base of the second dorsal fin, 4: depth of caudal peduncle). The annuli of each scale were counted under the dissecting microscope. Otoliths were rinsed with distilled water for cleaning after removed from the opened skull. The right-side sagittal otoliths were used for age determination in order to provide consistency in the analysis. The molding process used polyester resins (Polycoat), promoter, and hardener as the obtained sagittae were mounted and left for 72 h at room temperature. The specimens were cut using a grinding machine (BOSCH GWS 6-100E) into sections (3 ~ 5 mm wide) from the center point and polished with sandpaper (grid 80, 400, 800, 1,200) to a thickness of 0.3 ~ 0.5 mm for growth pattern reading. Age determination was based on the adjacent line at which the annulus appeared to shift from the translucent zone to the opaque zone. The otolith radius was the length of the straight line from the center of the nucleus to the distal margin of the otolith, where the ring radius at any age was the length of the straight line from the center to the end of the opaque zone. The measurement unit was millimeter, and a stereomicroscope (OLYMPUS TOKYO, BX51) and image analysis software (OLYMPUS TOKYO, AnalySIS LS) were used. This research involved 333 specimens of Pacific cod otolith; the gender of each specimen was verified for each individual, and any sample from which a clear reading could not be obtained was excluded from the analysis.

The annual periodicity and season of band formation was verified using marginal growth index (*MI*). *MI* was

calculated using the following equation:

$$MI=(R-r_n)/(r_n-r_{n-1})$$

where R is otolith radius, r_n the distance from the focus to the last annulus and r_{n-1} is the distance from the focus to the n-1-*th* annulus.

The growth of Pacific cod in relation to age was estimated by the back-calculated total length at the time of annulus formation which was estimated using the relationship between otolith radius and the total length, providing simultaneous growth of otolith radius and the total length (Hall, 1989).

The growth to age equation was estimated using the age and the back-calculated total length. Parameter values estimated by Walford's growth transformation diagram were used as initial values for nonlinear regression for estimating parameters, and the results were presented as the von Bertalanffy growth equation (1938):

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

where L_t is the total length at age t, L_∞ is theoretical maximum total length, K is the coefficient of growth, t is the age (year), and t_0 is the theoretical age at total length of zero.

RESULTS

1. Distribution of total length

Females were predominated in the 1st and 2nd year ($p<0.05$, test of population proportion), and no males were sampled in the 3rd year (Table 1). There were no significant difference between mean lengths in male and female in the 1st and 2nd year ($p<0.05$, t-test), The total length ranged from 45.0 to 74.5 cm showing a mode at the length class of 62～64 cm in male, and from 41.0 to 78.0 cm showing a mode at the length class of 64～66 cm in female (Fig. 2). The average total lengths were 61.3 cm for males and 66.3 cm for females.

2. Age distribution

The opaque and translucent zones were alternated in the sectioned otoliths and the annuli were clearly identifiable (Fig. 3). In the older fish, the annuli were stacked closely but clearly identifiable (Fig. 4). Marginal growth index decreased from December to February showing the lowest value in February (Fig. 5). The age of Pacific cod that migrated into Jinhae Bay was 5 to 6 years in males and 4 to 6 years in females, with the majority of specimens being 6 years old. The total length increased with age, and the lengths for age groups were 41.0～52.0 cm for 4-year-old, 45.0～68.0 cm for 5-year-old and 56.9～

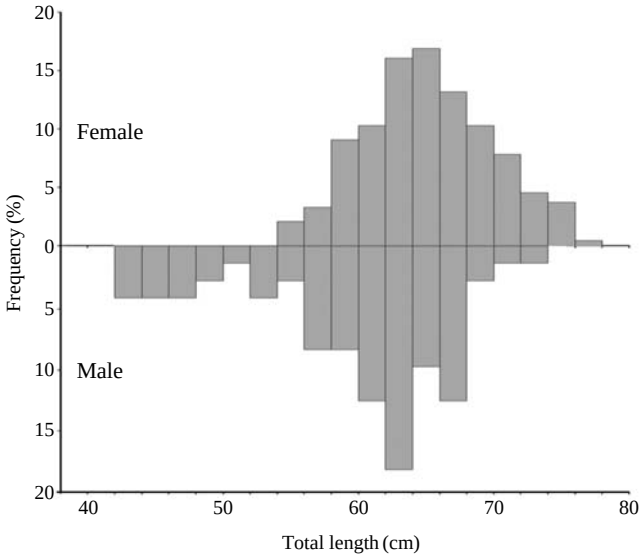

Fig. 2. Length-frequency distribution of Pacific cod, *Gadus macrocephalus* in Jinhae Bay.

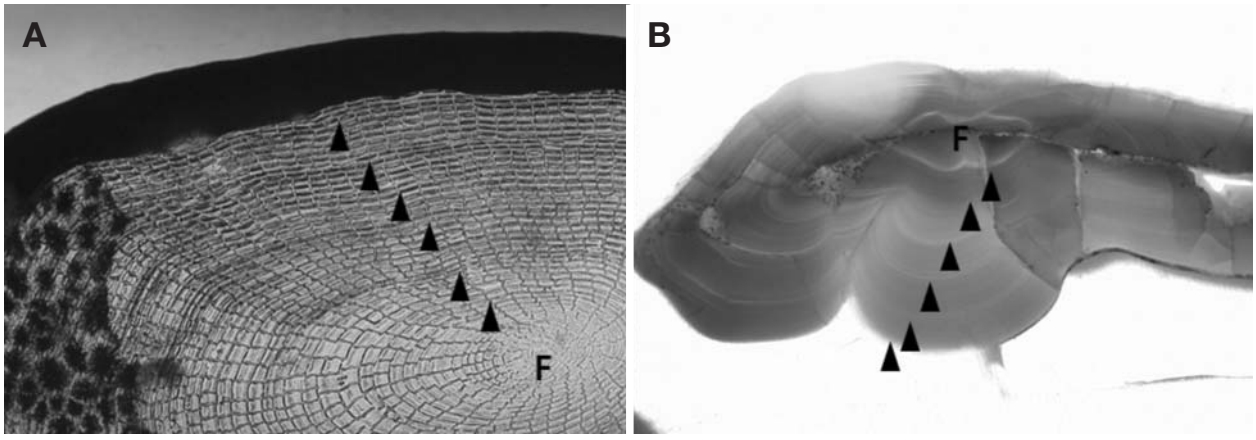

Fig. 3. Microphotograph of the scale (A) and otolith (B) of Pacific cod, *Gadus macrocephalus* under the transmitted light. F: focus; triangle: annuli.

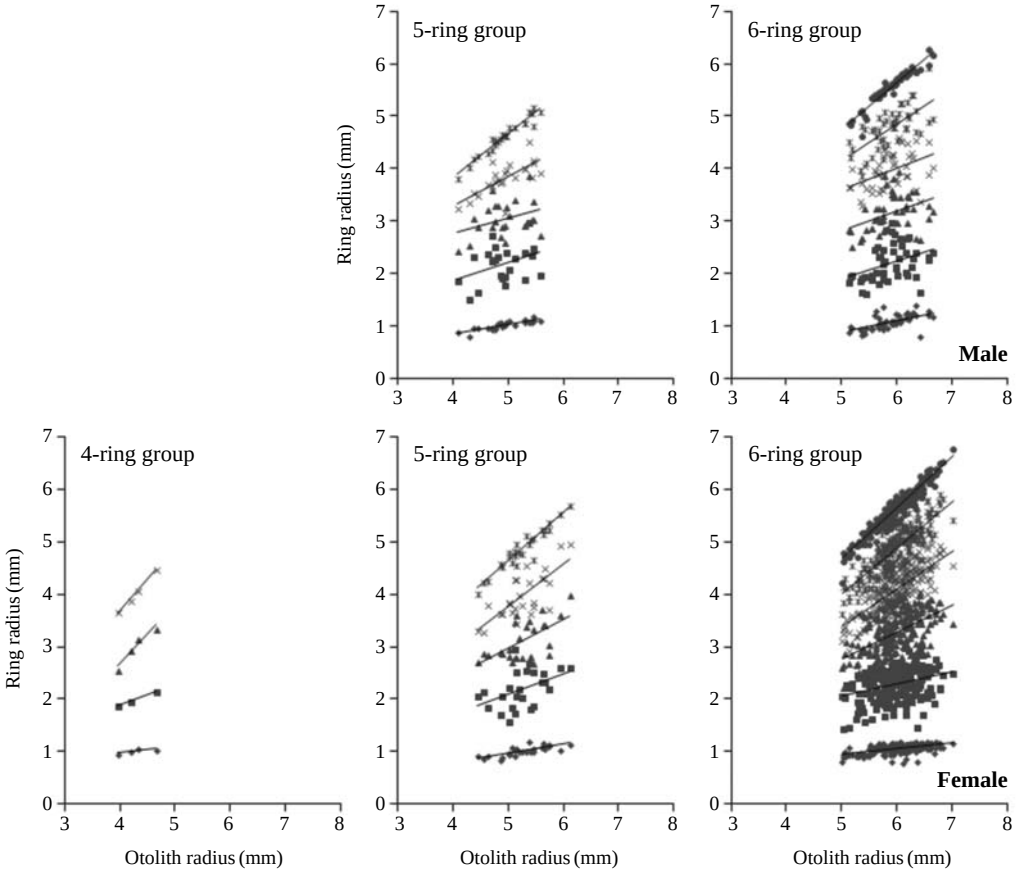

Fig. 4. Relationship between otolith radius and ring radii to each annulus of Pacific cod, *Gadus macrocephalus* in Jinhae bay.

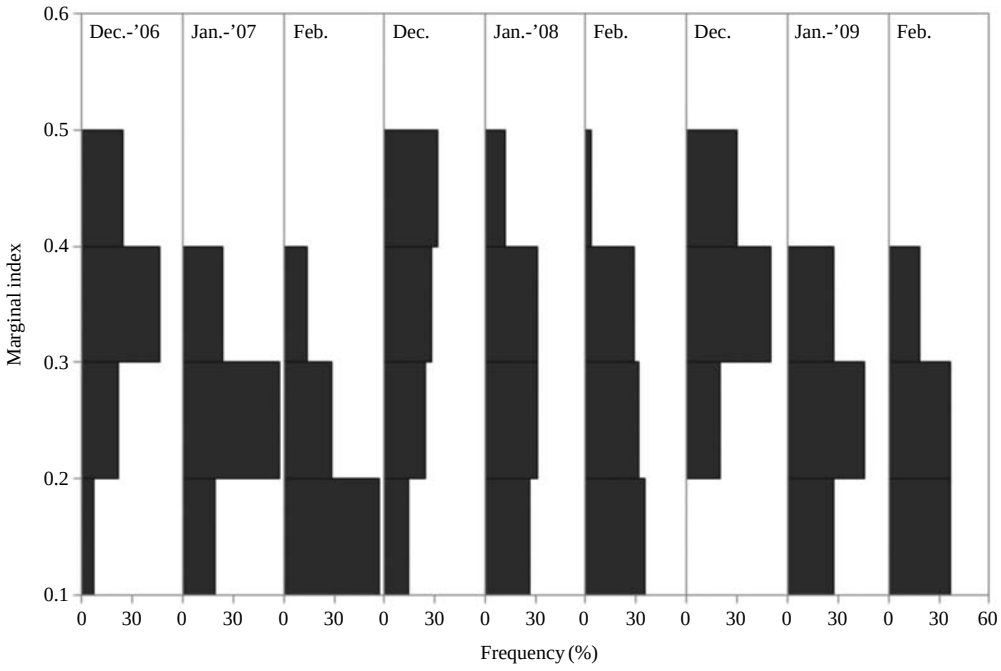

Fig. 5. Monthly changes in marginal growth index (*MI*) in otolith of Pacific cod, *Gadus macrocephalus* in Jinhae Bay from December to February, 2006～2009.

Table 2. Age and total length (TL) of females and males of Pacific cod, *Gadus macrocephalus* in Jinhae Bay

	Female			Male		
	Age	N	TL ± SD (cm)	Age	N	TL ± SD (cm)
First year	4	–	–	4	–	–
	5	1	54.0 ± 0.0	5	15	49.9 ± 4.3
	6	59	66.5 ± 5.2	6	21	63.3 ± 3.7
	Subtotal	60	66.2 ± 5.4	Subtotal	36	57.0 ± 7.9
Second year	4	1	52.0 ± 0.0	4	–	–
	5	26	60.0 ± 2.9	5	11	59.1 ± 1.9
	6	81	66.7 ± 3.9	6	31	66.4 ± 2.8
	Subtotal	108	65.1 ± 4.8	Subtotal	42	64.8 ± 4.1
Third year	4	3	44.3 ± 3.1	4	–	–
	5	2	57.8 ± 1.1	5	–	–
	6	82	69.1 ± 3.6	6	–	–
	Subtotal	87	68.0 ± 6.0	Subtotal	–	–
Total		255	66.3 ± 2.0		78	65.3 ± 2.9

N: number of specimens examined

Table 3. Mean ring radius on the otolith of Pacific cod, *Gadus macrocephalus* in Jinhae Bay

> Male

Ring group	No. of sample	Total length (cm)	Ring radius (mm)						
			R ± SD	r_1 ± SD	r_2 ± SD	r_3 ± SD	r_4 ± SD	r_5 ± SD	r_6 ± SD
5	26	52.9	4.9 ± 0.4	1.0 ± 0.1	2.2 ± 0.3	3.0 ± 0.3	3.8 ± 0.3	4.6 ± 0.3	
6	52	65.2	5.9 ± 0.4	1.1 ± 0.1	2.2 ± 0.3	3.1 ± 0.4	4.0 ± 0.3	4.8 ± 0.4	5.5 ± 0.4
			Mean	1.1 ± 0.1	2.2 ± 0.3	3.1 ± 0.4	3.9 ± 0.3	4.7 ± 0.4	5.5 ± 0.4

> Female

Ring group	No. of sample	Total length (cm)	Ring radius (mm)						
			R ± SD	r_1 ± SD	r_2 ± SD	r_3 ± SD	r_4 ± SD	r_5 ± SD	r_6 ± SD
4	4	46.3	4.3 ± 0.3	1.0 ± 0.1	2.0 ± 0.2	3.0 ± 0.3	4.0 ± 0.3		
5	29	59.6	5.3 ± 0.4	1.0 ± 0.1	2.2 ± 0.3	3.1 ± 0.4	4.0 ± 0.4	4.9 ± 0.4	
6	222	67.6	6.0 ± 0.4	1.1 ± 0.1	2.3 ± 0.3	3.3 ± 0.4	4.1 ± 0.4	4.9 ± 0.4	5.6 ± 0.4
			Mean	1.1 ± 0.1	2.3 ± 0.3	3.3 ± 0.4	4.1 ± 0.4	4.9 ± 0.4	5.6 ± 0.4

R: total radius; r_i: radius to the i-*th* annulus

Table 4. Back-calculated total length at the formation of annuli on otolith of Pacific cod, *Gadus macrocephalus* in Jinhae Bay

> Male

Ring group	No. of sample	Total length ± SD (cm)					
		L_1	L_2	L_3	L_4	L_5	L_6
5	26	13.6 ± 0.9	25.9 ± 3.6	34.7 ± 3.5	42.8 ± 3.2	51.1 ± 3.6	
6	52	14.3 ± 1.5	26.1 ± 3.6	35.8 ± 3.7	44.4 ± 3.6	52.8 ± 4.1	60.8 ± 3.7
	Mean	14.1 ± 1.4	26.0 ± 3.6	35.5 ± 3.7	43.9 ± 3.5	52.2 ± 4.0	60.8 ± 3.7

> Female

Ring group	No. of sample	Total length ± SD (cm)					
		L_1	L_2	L_3	L_4	L_5	L_6
4	4	15.1 ± 0.5	26.8 ± 1.7	37.8 ± 3.9	49.7 ± 3.9		
5	29	15.2 ± 1.1	28.7 ± 4.0	39.2 ± 4.3	49.1 ± 5.1	59.4 ± 4.6	
6	222	15.7 ± 0.9	29.7 ± 3.3	41.0 ± 4.8	50.2 ± 4.9	59.2 ± 4.9	68.0 ± 4.7
	Mean	15.6 ± 0.9	29.6 ± 3.4	40.7 ± 4.7	50.1 ± 4.9	59.3 ± 4.9	68.0 ± 4.7

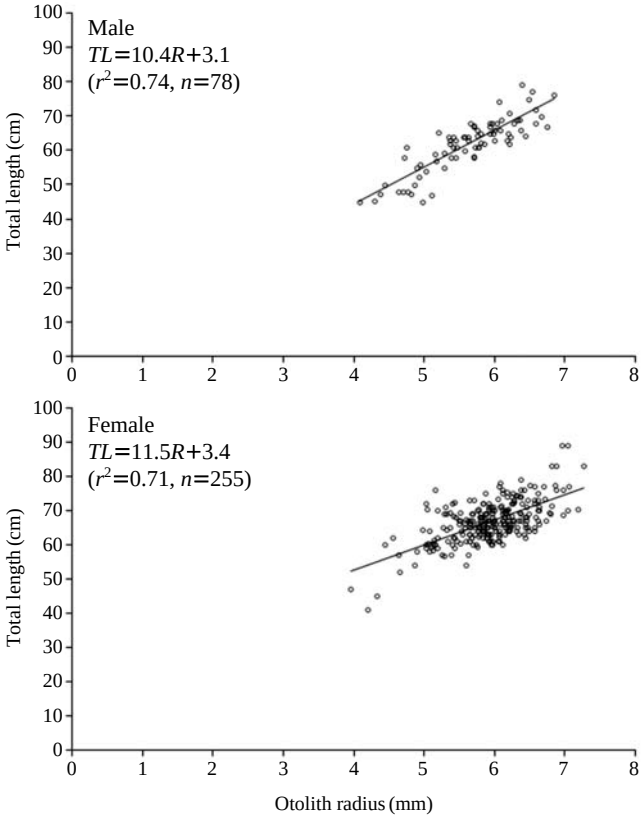

Fig. 6. Relationship between otolith radius and total length of Pacific cod, *Gadus macrocephalus* in Jinhae Bay.

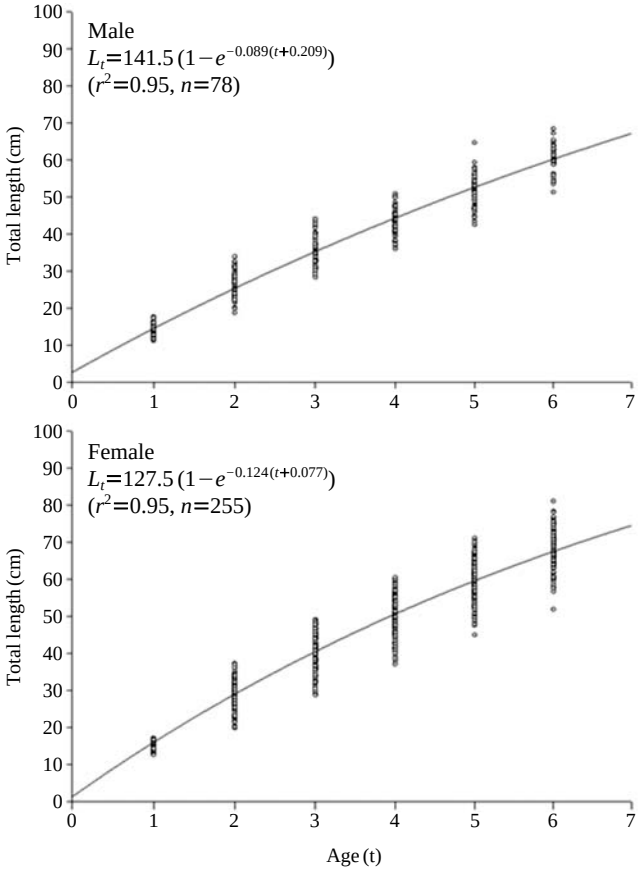

Fig. 7. Von bertalanffy growth curves of female and male of Pacific cod, *Gadus macrocephalus* in Jinhae Bay.

78.0 cm for 6-year-old cods (Table 2). There were significant difference between mean ages in female among the 1st, 2nd and 3rd year ($p<0.05$, t-test). But, there were no significant difference mean ages in male between in the 1st and in the 2nd year ($p>0.05$, t-test).

3. Scales as the age-specific trait

The radii to each annulus correlated with the size of the otoliths, suggesting that the otolith can be used for age determination (Fig. 3). The age determined using scales collected from the base of the second dorsal fin and from the caudal peduncle was highly correlated with that determined by the otoliths, suggesting that scales were also appropriate traits for age determination.

4. Back-calculation of total length for each age

Since the ages and total lengths were not significantly different among sampling years, the data of 3 years were combined. Table 3 presents the average ring radius from the otolith center to each annulus. Mean ring radii at each age did not showed any significant difference among age groups ($p<0.01$, t-test).

Relationships between the otolith radius and the total length were expressed as follows (Fig. 6).

TL=10.4R+3.1 (r^2=0.74, n=78) for males
TL=11.5R+3.4 (r^2=0.71, n=255) for females

There were no significant differences ($p<0.05$, ANCOVA) in the slopes of the otolith radius/total length relationships for males and females. The back-calculated values of the average total length using the above relationships at the time of annulus formation were given in Table 4.

5. Growth in total length

Based on the back-calculated total length to age, von Bertalanffy growth equations were derived (Fig. 7).

L_t=141.5 (1−$e^{-0.089\,(t+0.209)}$) for males
L_t=127.5 (1−$e^{-0.124\,(t+0.077)}$) for females

Females apparently grow fast than the males.

DISCUSSION

Age of Pacific cod has been determined by otoliths, scales, and dorsal fins Lai *et al.* (1987) showed that all 3 sources presented similar results. Regarding Pacific cod

Table 5. Comparison of lengths at age and growth parameters of Pacific cod reported from the various regions

Region	Body length (cm) at age											Growth parameters	
	1	2	3	4	5	6	7	8	9	10	11	K	L_∞
Jinhae Bay (this study)	12.5	25.0	35.0	43.6	52.1	60.4	–	–	–	–	–	0.106	127.4
East coast of Korea	23.5	39.0	57.5	69.0	80.0	90.0	–	–	–	–	–	0.141	155.0
off Southern Coast of Hokkaido	–	40.3	53.2	63.1	70.7	76.3	–	–	–	–	–	0.259	96.6
off Kamchatka Peninsula	–	–	38.3	48.0	55.4	61.0	65.2	68.4	70.8	–	–	0.278	78.4
West Bering Sea	18.0	29.5	35.5	45.7	54.2	64.2	77.4	79.8	83.6	87.0	91.0	0.106	130.0
East Bering Sea	23.9	34.1	39.9	48.7	56.8	62.1	67.4	72.0	76.8	82.1	83.1	0.175	123.0
Gulf of Alaska	29.9	41.5	50.4	56.7	62.7	68.7	74.1	78.9	83.9	88.3	93.7	0.122	120.0
Sea of Okhotsk	22.8	34.6	44.8	53.4	60.8	67.7	75.1	84.0	84.1	85.5	87.5	0.168	103.0

Source: Jinhae Bay (this study); East coast of Korea (Ketchen, 1961); off Southern Coast of Hokkaido (Hattori *et al*., 1992); off Kamchatka Peninsula (Hattori *et al*., 1992); West Bering Sea (Ketchen, 1961), East Bering Sea (Foucher *et al*., 1984); Gulf of Alaska (Foucher *et al*., 1984); Sea of Okhotsk (Ketchen, 1961)

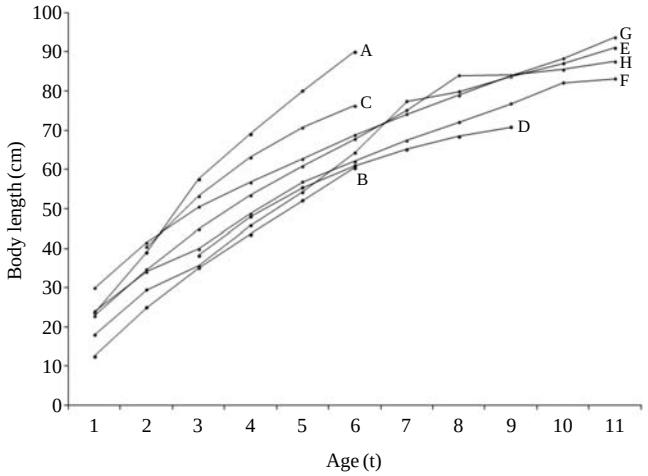

Fig. 8. Age-length relationships for the Pacific cod collected from various regions. A: East coast of Korea (Ketchen, 1961), B: Jinhae Bay (this study), C: off Southern Coast of Hokkaido (Hattori *et al*., 1992), D: off Kamchatka Peninsula (Hattori *et al*., 1992), E: West Bering Sea (Ketchen, 1961), F: East Bering Sea (Foucher *et al*., 1984), G: Gulf of Alaska (Foucher *et al*., 1984), H: Sea of Okhotsk (Ketchen, 1961).

in Jinhae Bay, Uchida (1936) conducted scale reading for age determination of 430 individuals collected during spawning migrations to Jinhae Bay for 3 years (1929～1931). The ages determined from both scales and otoliths from 96 individuals in our study did not show a significant difference, and therefore the data obtained from otoliths in our study can be compared with the data obtained from scales by Uchida 80 years ago. The ages and average total lengths of 1929～1931 Pacific cod in Jinhae Bay were 1～6 years and 20.4～81.5 cm, respectively (Uchida, 1936), whereas the 2006～2009 batches were smaller in size when compared by age, given as 46.3～67.6 cm for 4～6 years for females and 53.0～65.3 cm for 5～6 years for males. The back-calculated length at 1～6 years was 14.8～64.4 cm, smaller than the sizes at each age reported by Uchida (1936).

The growth pattern of Pacific cod varies by region, particularly in the Northern Pacific (Fig. 8) (Ketchen, 1961; Foucher *et al*., 1984; Hattori *et al*., 1992). The growth rate is faster in lower latitudes than in higher latitudes excluding Jinhae Bay. Comparing the results of present study that estimated growth parameters for each Pacific regions, the value of theoretical maximum body length (L_∞) was highest in East coast of Korea (155.0) and lowest in off Kamchatka Peninsula (78.4); and the value of coefficient of growth (K) was highest in off Kamchatka Peninsula (0.278) and lowest in Jinhae Bay (0.106) (Table 5). The life span of Pacific cod also varied by region. It was reported as over 11 years in the northern Pacific waters in contrast to 6～8 years in the southern region (Foucher and Westrheim, 1984; Cohen *et al*., 1990; Hattori *et al*., 1992). Resultantly, the growth rate tended to be slow in the northern region, and the life span increased. Such a phenomenon is considered to reflect that, although the distribution of Pacific cod ranges across the high and low latitudes of the North Pacific Ocean, factors such as high independency of individual population, as well as changes in water temperature and seasons to the different latitude, still influence the growth patterns of cod including the life span (Hattori *et al*., 1992). Regarding Pacific cod in Jinhae Bay, unlike other parts of the southern region, the growth rate was relatively low. An mtDNA and msDNA analysis of Pacific cod populations suggested the 2 genetically distinguishable populations in Korean waters (Gong *et al*., 1991; Gwak and Nakayama, 2011) and noted that the cod population that migrates into Jinhae Bay is an independent population (Gwak and Nakayama, 2011). In this regard, Korean cod populations in the East Sea and in Jinhae Bay were genetically separated and showed a different growth pattern.

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진해만에 산란회유하는 대구(*Gadus macrocephalus*)의 연령과 성장패턴

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요 약 : 대구의 연령과 성장패턴에 대하여 조사하기 위해 진해만에서 2006～2009년 산란기간 동안 채집되었다. 조사된 총 333미의 대구 연령은 이석을 이용하여 추정하였고, 비늘이 연령형질에 있어 적합성을 보기 위하여 96미의 대구에서 채집한 비늘의 결과와 비교하였다. 비늘을 이용한 연령사정에서 제2등지느러미 기저 부분과 미병고 부분에서 채집한 비늘이 이석연령과 높은 상관성을 나타내어 연령사정에 가장 적합한 것으로 나타났다. 이석의 연변부지수는 12월부터 감소하여 2월에 가장 낮았다. 연령은 암컷과 수컷 모두 4～6세 범위였으며, 6세어가 대부분을 차지하였다. 전장(*TL*)은 이석경(*R*)에 1차 비례하여 수컷이 $TL=10.4R+3.1$, 암컷이 $TL=11.5R+3.4$의 관계식을 보였다. 역계산된 연령별 전장으로부터 추정된 대구의 von Bertalanffy 성장식은 수컷 $L_t=141.5\,[1-exp\{-0.089\,(t+0.209)\}]$, 암컷 $L_t=127.5\,[1-exp\{-0.124\,(t+0.077)\}]$였다.

찾아보기 낱말 : 대구, *Gadus macrocephalus*, 이석, 비늘, 연령, 성장