한국환경생태학회지 27(4): 429-436, 2013
Korean J. Environ. Ecol. 27(4): 429-436, August 2013

pISSN 1229-3857
eISSN 2288-131X

Changes in Body Size in a Land-locked Population of Sweet Smelt *Plecoglossus altivelis* (Pisces: Osmeridae), Related to the Construction of a Fishway in Lake Okjeong, Korea[1a]

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옥정호 어도 설치 후 육봉형 은어 *Plecoglossus altivelis* (Pisces: Osmeridae)의 체장변화[1a]

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ABSTRACT

Churyeong Stream flows 37km from the mouth of Lake Okjeong and is impeded by many weirs that hamper the active movement of land-locked sweet smelt fish (*Plecoglossus altivelis)* that ascend and descend between the lake and the upper stream. In late December 2006, a fishway was constructed in a weir of the lower reach of Churyeong Stream, where juveniles begin their ascent to mature upstream. At 13 sites along the stream from April to October 2007, we investigated the effects of the newly constructed fishway on sweet smelt growth. After construction of the fishway, juvenile sweet smelt were able to migrate freely upstream, something that had previously only been possible when the weir was in flood. The body size of mature sweet smelt collected during the spawning season in September 2007 was greatly increased compared to previous seasons, measuring an average of 163±21.5mm in standard length. These measurements were 13mm, 20mm, and 57mm longer than body length averages for mature sweet smelt collected in 2006, 2004, and 2005, respectively. Therefore, it is likely to be necessary for the construction of fishways on streams and rivers containing land-locked sweet smelt populations to increase average body sizes and viability.

KEY WORDS: GROWTH, MIGRATION, SPAWNING SEASON

요 약

옥정호로 유입되는 37km의 추령천에는 육봉화된 은어의 이동을 가로막는 많은 보가 설치되어 있었으나 2006년 12월 옥정호 추령천 하류에는 은어가 성숙하기 위해 추령천 상류로 이동하도록 어도가 설치되었다. 따라서 2007년 4월부터 10월까지 13개 지점에서 어도와 은어의 성장률을 조사하였다. 그 결과 어도의 설치 후, 치어들은 강수량이 풍부했던 시기에만 소상할 수 있는 상류를 새로 설치된 어도를 통해서 자유롭게 상류로 이동할 수 있었다. 2007년 9월 산란시기 동안 성숙된 은어는 163±21.5mm로 어도가 설치되기 전인 2006년에 비해 약 13mm, 2004년 약 20mm, 2005년 약 57mm정도 더 크게 나타났다. 따라서 하천에서 어도는 육봉형 은어집단의 평균 크기와 생존력에 중요한 역할을 하는 것으로 확인되었다.

주요어: 성장, 이동, 산란기

1 접수 2013년 5월 28일, 수정 (1차: 2013년 8월 29일), 게재확정 2013년 8월 30일
Received 28 May 2013; Revised (1st: 29 August 2013); Accepted 30 August 2013

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INTRODUCTION

The sweet smelt fish *Plecoglossus altivelis* is an anadromous species with a one-year life span(Kim and Park, 2002). After hatching in autumn in the upper reaches of streams, the larvae drift to sea for the winter, where they remain throughout the larval and early juvenile stages(Kim and Park, 2002; Nelson, 2006). From spring to early summer, juvenile sweet smelt ascend freshwater streams to mature while feeding on benthic algae, and then die after spawning in autumn. The sweet smelt is a commercially-important traditional food fish in Asia, particularly in Japan and Korea. However, the construction of dams on the rivers and streams in which they spawn, to provide water for agricultural purposes and to power hydroelectric generators, has led to population declines and reduced genetic diversity. Captive breeding and restocking projects have been implemented to increase sweet smelt populations in both Korea and Japan.

In Korea, large numbers of fertilized eggs have been transplanted into several lakes, including Lake Andong, Lake Jinyang, Lake Hapcheon, and Lake Okjeong, leading to the establishment of land-locked sweet smelt populations that complete their life cycles without spending any time at sea. The Lake Okjeong population has been the subject of numerous studies investigating the ecology, growth, habitat, and distribution of land-locked sweet smelt. Juveniles swim up Churyeong Stream to mature and spawn, and the resulting larvae drift back downstream to reside in the mouth of the lake or in the lake over winter(Ko *et al*., 2007a; 2007b; 2007c).

Lake Okjeong is, an artificial lake formed by construction of the Seomjin Dam in 1926 located in the Un-am, Imsil-gun, and Jeonbuk Province of Korea. Churyeong Stream is one of several streams flowing into Lake Okjeong, originating 37 km from the mouth of the lake. Churyeong Stream is impeded by a number of weirs that prevent free movement of fish between its upper reaches and the lake. Unless a weir is in flood at the appropriate time of year, which is a rare occurrence, a significant number of fish cannot migrate upstream to mature and spawn.

Fishways are hydraulic structures or systems, either natural or artificial, which enable fish to overcome obstructions in streams during their spawning, feeding, wintering, or colonizing migrations(Osborne,1987; Rowlston, 1995). In late December 2006, a pool type fishway was constructed in a weir located on the lower reach of Churyeong Stream. We collected and measured sweet smelt from April to October 2007, after construction of the fishway, and compared our data of body size from previous years, to investigate the effects of the weir and newly constructed fishway on sweet smelt growth and development.

MATERIALS AND METHODS

Sweet smelt specimens with a one-year life span were collected at all 13 sites along Churyeong Stream, which are very important one to move up and down for its growth and spawning throughout a year, as it flows into Lake Okjeong, Sannae-myeon, Jeongeup-si, Jeollabuk Province, Korea from April to October 2007 (Table 1, Figure 1). A total of 292 Individuals were captured using a cast net (5mm×5mm) and scoop nets (5mm×5mm) and preserved in 10% buffered formalin. After measuring the body weight and standard length, and particularly counting the number of the egg from a full-grown gravid female (n=18), all specimens were deposited in the Department of Biology, Chonbuk National University (CNUC), South Korea. Measurements of the stream, including width and depth, were taken using a tape measure and tachometer (Global Water Instrumentation, USA). River type and river bed structure were assessed following the methods of Kani(1944) and Cummins(1962). Data on water temperature and photoperiod were obtained from Korea Meteorological Administration (KMA) data(2009), measured monthly. Data on precipitation and water level fluctuation were obtained from Korean Water Management Information System(KWAMIS, 2009).

RESULTS AND DISCUSSION

1. Habitat and hydrological environment

1) Hydrological conditions

The length of the photoperiod changes dramatically during the year at all points along Churyeong Stream, with day lengths shortest in January (9.8 hours) and longest in

June (14.5 hours) (Figure 2A). Between April and October, when sweet smelt ascend upstream from the mouth of Lake Okjeong, the photoperiod ranges between 10.4~14.5 hours. Water temperature and air temperatures display similar trends (Figure 2B), with water temperature at its lowest in January (3.1℃) and its highest in August (27.5℃). During the period of upstream migration, water temperatures ranged between 14.0~27.5℃. Precipitation is low between April and June, reaching 35~75 m in total and increases from July to September to about 167~441mm in total during the rainy season. In October, precipitation decreases to 90.7mm (Figure 3). Water levels are low from April to June at 0.22~0.29m, rise during the rainy season, to 0.56-0.93m, and decline sharply in October to 0.34m

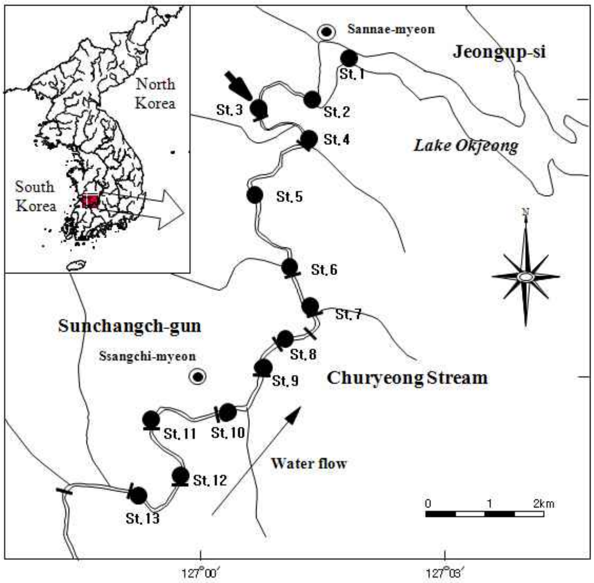

Figure 1. Collection sites (black circles) for a land-locked *Placoglossus altivelis* in Churyeong Stream and Lake Okjeong, South Korea. Black bars mean previously formed weirs without fishways. Arrow is a pool type fishway constructed on St 3 in late December 2006. The detailed localities see Table 1

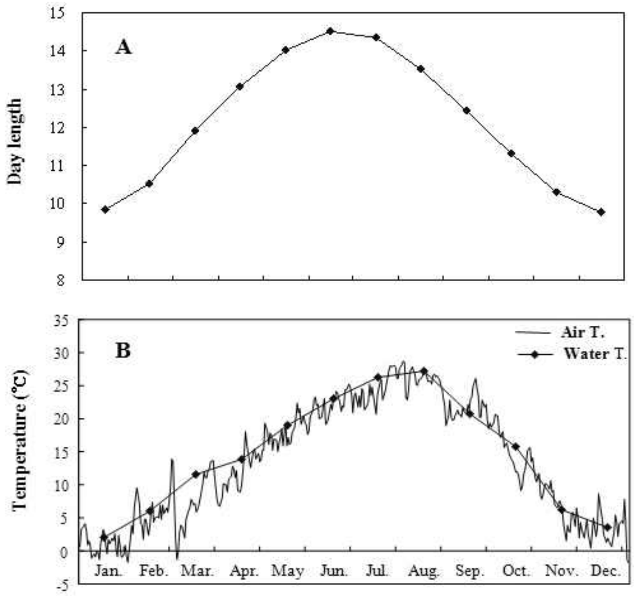

Figure 2. Monthly changes of day length (A), air temperature and water temperature (B) of the Lake Okjeong, Sannae-myeon, Jeongeup-si, Jeollabuk Province, Korea

Table 1. Observation sites of a land-locked *Placoglossus altivelis* in Churyeong Stream and Lake Okjeong, Jeollabuk Province, South Korea from April to September 2007

Sites	Localities
1	Neunggyo-ri, Sannae-myeon, Jeongeup-si, Jeollabuk Province
2	Neunggyo-ri, Sannae-myeon, Jeongeup-si, Jeollabuk Province
3	Maejuk-ri, Sannae-myeon, Jeongeup-si, Jeollabuk Province (Construction of fishway)
4	Maejuk-ri, Sannae-myeon, Jeongeup-si, Jeollabuk Province
5	Obong-ri, Ssangchi-myeon, Sunchang-gun, Jeollabuk Province
6	Yongjeon-ri, Ssangchi-myeon, Sunchang-gun, Jeollabuk Province
7	Yongjeon-ri, Ssangchi-myeon, Sunchang-gun, Jeollabuk Province
8	Ssanggye-ri, Ssangchi-myeon, Sunchang-gun, Jeollabuk Province
9	Unam-ri, Ssangchi-myeon, Sunchang-gun, Jeollabuk Province
10	Guumpyeong-ri, Ssangchi-myeon, Sunchang-gun, Jeollabuk Province
11	Guumpyeong-ri, Ssangchi-myeon, Sunchang-gun, Jeollabuk Province
12	Dogo-ri, Ssangchi-myeon, Sunchang-gun, Jeollabuk Province
13	Dogo-ri, Ssangchi-myeon, Sunchang-gun, Jeollabuk Province

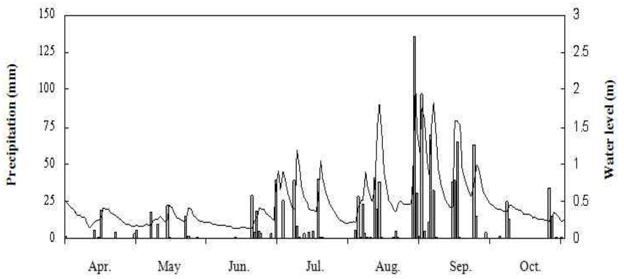

Figure 3. Precipitation and water level in Churyeong Stream, Ssangchi-myeon, Sunchang-gun, Jeollabuk Province, South Korea from April to October, 2007(cited from Korean Water Management Information System, 2009)

2) Physical characteristics of sites

Habitat conditions on 13 sites between the mouth of Lake Okjeong and the upper reaches of Churyeong Stream were seen Table 2. At Site 1, located at the mouth of the lake, the stream ranges from 150~200m wide and 5~10m deep, and its bottom consists mostly of mud and boulders. Drastic changes in water level occurred at this site. Upstream, between Sites 2 and 5, the stream ranges from 60~100m in width and is characterized by boulder and rock beds. This area conforms to an Aa or Aa-Bb river type with a gentle stream slope of 0 to 48 degrees, making it possible for sweet smelt to migrate easily upstream. Further upstream, between Sites 6 and 13, the stream ranges from 60-140m in width, conforms to the Bb river type, and is characterized by gravel, cobbles, and boulders.

3) Weirs

Along Churyeong Stream, a total of 11 weirs were built during the 1960s and 1970s to provide water for irrigation (Table 2). Weirs are located close to the lower reaches of the stream at Sites 3 and 4, where the stream is about 60m in width, 3.4 to 18.7m in length, and flows at a 10 to 48 degree slope. Nine weirs are located further upstream at Sites 8, 10, 11, and 13. These ranges between 1.5 to 1.7m in height and 50 to 60 degree in slope, and all are high enough to impede the progress of migrating sweet smelt. The problem is exacerbated by low water levels caused by agricultural overuse and frequent shortages of precipitation throughout the year except during the rainy season. Floods are necessary to raise water levels high enough for migrating sweet smelt to cross these weirs, but such floods rarely occur.

4) Fishways

Three fishways were constructed at Sites 6, 8, and 9 during the 1990s (Table 2), but they had little impact on the movement of sweet smelt or other fish. In December 2006, a new fishway was constructed on the right side of the weir at Site 3, which was already a favorite feeding site for fish as the weir there is narrow and has a low slope. The new fishway is a pool type fishway, 1.2 m wide and 9 m in length (Figure 4). Unlike the previously constructed fishways, this new fishway was designed to be lower than the weir's height and remain mostly under water, even during drought season. Active movement of sweet smelt through this fishway was observed immediately after its construction.

The land-locked sweet smelt showed a variety on growth according to the length and water volume of the streams or rivers, the size of its territory, and environments surrounding the habitats, reaching 70 to 300m in body size(Korea' inland fishes association, 1987; Iguchi and Hino, 1996; Katano and Iguchi, 1996; Kim and Park, 2002; Iguchi and Abe, 2002; Katano *et al*., 2004; Shimada *et al*., 2006; Lee *et al*., 2008). About one million fertilized sweet smelt eggs were discharged into Lake Okjeong (Kwater, 2001). The land-locked population that resulted maintained more or less stable life cycle in the lake and associated stream, spawning and growing normally, but many weirs constructed along Churyeong Stream prevented the upstream movement of juvenile sweet smelt necessary for growth and feeding(Ko *et al.*, 2007a). The weir located at Site 3, close to the mouth of the lake, constitutes the first major obstacle to upstream migration (Table 2). As a result, a large number of sweet smelt remained immature, and subject to slow growth and strong competition for territory and food in a small, contained area(Ko *et al.*, 2007a; 2007b).

To alleviate the situation, the provincial office was required to construct a fishway at this Site, which was completed in December 2006. After construction of the Pool type fishway at Site 3, the average body sizes of sweet smelt collected from Lake Okjeong and Churyeong Stream increased despite water levels and rainfall that were deficient compared to previous years (Table 4) In April and May 2007, when juvenile sweet smelt were ascending upstream, the rainfall was reduced by half or

Table 2. Physical characteristics of the observed sites in Lake Okjeong, Jeollabuk Province, South Korea

Site	River width (m)	Water width (m)	Water depth (cm)	River type	Bottom structure[a](%)						Weir				Fishway				
					M	S	G	P	C	B	Length (m)	Width (m)	Height (m)	Slope (°)	No.	Width (m)	Length (m)	H:L[b]	Type[c]
1	150-200	150-180	100-500	Bc	90					10									
2	60-80	30-40	50-100	Aa				20	30	50									
3	70-80	50-60	50-100	Aa					20	80	60	3.4	1.2	45	1	1.2	9	1:10	Pool
4	70-80	50-60	50-100	Aa-Bb				10	20	70	60	18.7	1.5	10					
5	80-100	60-70	50-70	Aa-Bb		5	20	50	15	10									
6	80-100	70-80	30-50	Bb			10	30	40	20	80	11.2	1.1	75	1	2.0	27	1:25	Pool
7	70-80	50-60	30-70	Bb			10	20	50	20									
8	80-100	70-80	30-50	Bb				30	50	20	80	12.0	1.5	50	1	2.0	27	1:18	Pool
9	80-90	70-70	30-50	Bb				30	50	20	70	11.3	1.2	67	1	2.0	27	1:23	Pool
10	70-80	50-60	50-100	Bb		10	20	30	30	20	60	10.3	1.7	60			-		
11	60-70	30-40	30-40	Bb				10	30	60	40	3.8	1.5	43			-		
12	60-70	40-50	20-50	Bb					20	80	45	2.7	1.0	53			-		
13	100-140	100-120	20-30	Bb			10	30	50	10	120	3.7	1.7	55			-		

[a] M: Mud(~0.1 ㎜), S: Sand(0.1~2 ㎜), G: Gravel(2~16 ㎜), P: Pebble(16~64 ㎜), C: Cobble(64~256 ㎜), B: Bolder(256 ㎜<) by Cummins(1962),
[b] Height: Length, [c] Pool type fishway(Kwater, 2001)(some modification from Ko *et al*., 2007b)

more from 2004 to 2006. The average water level in 2007 was also lower than in 2004 or 2006, and was lower than or similar to 2005. Previous studies have shown that these environmental factors have major effects on the growth and fecundity of sweet smelt(Tachihara and Kimura, 1992; Shimada *et al*., 2006; Ko *et al*., 2007b).

2. Changes of body size

1) Seasonal variation in body size

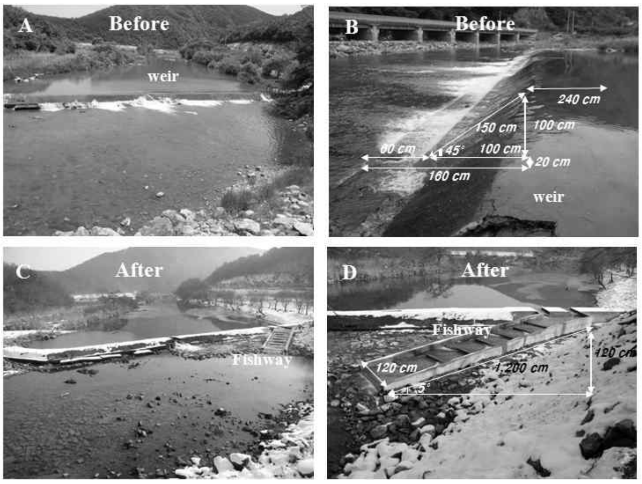

Figure 4. Weirs and a Pool type fishway feature at Site 3 of Churyeong Stream, Maejuk-ri, Sannae-myeon, Jeongeup-si, Jeollabuk Province, South Korea. A and B, before construction of the fishway; C and D, After construction of the fishway in late December, 2006(some modification from Ko *et al*., 2007b)

Juvenile sweet smelt, having overwintered in Lake Okjeong, began to ascend Chhuryeong Stream in early April 2007 (Table 3). During this period, they were a mean length of 60.3±5.71mm (n=11) (Figure 5). The juvenile sweet smelt traveled rapidly upstream, reaching Site 10 in May, with a mean length of 103±12.7mm (n=63). By July, the sweet smelt reached Site 13, showing rapid growth, growing by a mean length of 138±20.2mm (n=123). We did not collect individuals above Site 13 due to the height of the weir there. In September, the sweet smelt returned downstream near Sites 2 and 3 to spawn. Some individuals began to spawn in mid-September, and reached a size of 163±21.5mm (n=93) by late September. After hatching, the larvae to the lake and continued to develop during mid-September and early October. After mid-October no individuals remained to be collected in the stream.

In a previous study of the sweet smelt of Churyeong Stream, Ko *et al*.(2007b) reported that at least an average of 0.5 m in daily water level is necessary to maintain water levels high enough to allow fish to ascend upstream past the weir at Site 3. From 2004 to 2006, before construction of the fishway, water levels exceeded 0.5m for spans of time ranging from 6 to 13 days. In 2007 water levels exceeded 0.5m for only one day (Table 4). Nevertheless, average body sizes of sweet smelt increased greatly in 2007. During migration upstream, from April to August, average body size was 20mm to 25mm larger than in 2004 and 2006 (Figure 7). During the spawning season in September, it was about 57mm larger than in 2005 (Figure

Table 3. Number of individuals of *Plecoglossus altivelis* at the surveyed sites in Lake Okjeong, Jeollabuk Province, South Korea from April to September 2007

Station Date / Month		1	2	3	4	5	6	7	8	9	10	11	12	13	Total	Life style
4	Apr.		9	2											11	Juvenile
24	May	9	18	6	10	5	7	1	3	3	1				63	Immature
28	Jul.	30	16	8	4	14	6	10	6	1	4	20	4	2	125	Immature
30	Sep.		85	8											93	Adult
Total		39	128	24	14	19	13	11	9	4	5	20	4	2	292	

7). The largest fish collected in 2005 were anywhere from 40mm to 80mm longer than the smallest fish, double the disparities observed in fish collected from May to July 2007. The greater uniformity in size observed in 2007 may

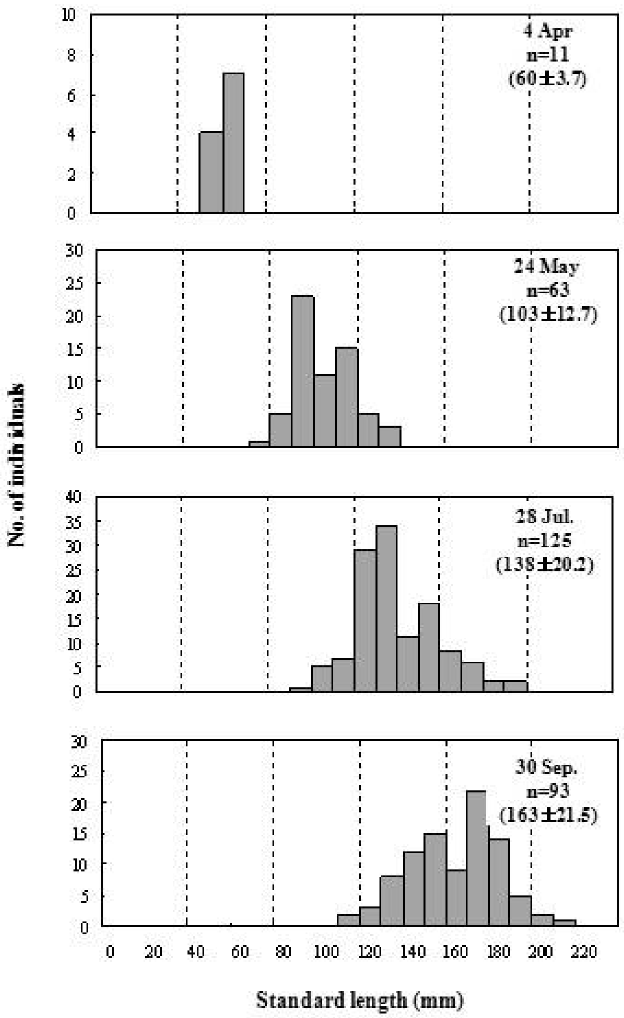

Figure 5. Standard length frequency of Plecoglossus altivelis in Lake Okjeong, South Korea from April to September, 2007

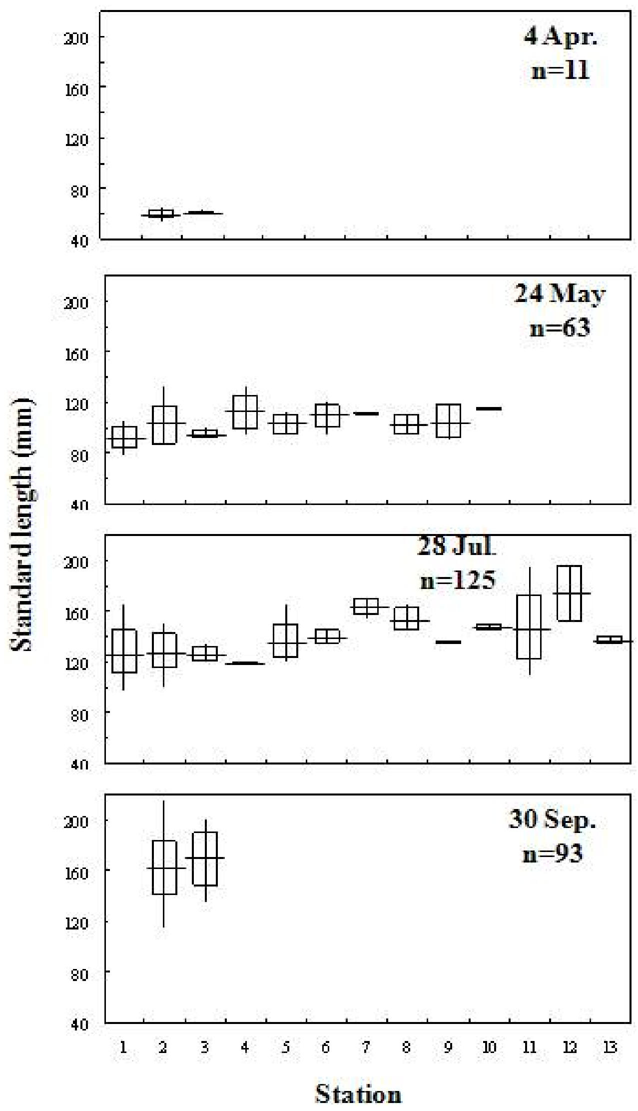

Figure 6. Histograms showing standard length frequency distribution of *Plecoglossus altivelis* at Lake Okjeong, South Korea from April to September 2007. The diagrams indicate the mean (horizontal line), standard deviation (empty rectangle) and range (vertical line)

Table 4. Precipitation and water level in Churyeong Stream, Ssangchi-myeon, Sunchang-gun, Jeollabuk Province, South Korea from April to October 2004 to 2007

Month	2004			2005			2006			2007		
	Precipi. (mm)[a]	Water level (m)	Days[b]	Precipi. (mm)[a]	Water level (m)	Days[b]	Precipi. (mm)[a]	Water level (m)	Days[b]	Precipi. (mm)[a]	Water level (m)	Days[b]
Apr.	70	0.26	0	68	0.30	2	84	0.36	4	35	0.29	0
May	121	0.40	7	88	0.22	1	163	0.53	11	74	0.26	0
Jun.	222	0.47	5	182	0.29	3	172	0.42	9	63	0.22	1
Jul.	255	0.60	14	335	0.67	17	448	0.11	28	167	0.56	14
Aug.	454	0.65	12	358	0.76	17	106	0.33	3	374	0.70	17
Sep.	258	0.62	13	59	0.47	8	29	0.27	0	441	0.93	26
Oct.	11	0.20	0	16	0.24	0	12	0.15	0	91	0.34	0
Total	1,391	-	51	1,106	-	48	1,014	-	55	1,245	-	58

[a]: Precipi.: Precipitation; [b]: days exceeding 0.5 m in water levels a month(by Korean Water Management Information System, 2009)

be explained by juveniles growing rapidly while feeding and actively migrating upstream via the fishway. Conversely, the large size difference observed in 2005 was likely due to the fact that the sweet smelt had little opportunity to climb upstream except during the rainy season, and therefore grew more slowly. This tendency was similar to reports regarding the size of sweet smelt(Shiraish and Suzuki, 1962; Tachihara and Kimura, 1992; Shimada *et al.*, 2006). These results suggest that vigorous upstream migration is necessary for sweet smelt to maintain normal development and life cycles.

2) Variation in body size by Site

On April 4, juvenile sweet smelt ascending Churyeong Stream were mean body sizes 60.4±4.0 and 61.0±0.9mm, respectively (Figure 6). On May 24, 2007, juvenile sweet smelt were distributed widely between Sites 1 and 10, but most were collected between Sites 1 and 6. 63 juveniles averaged 90-110mm in length. The body sizes of fish collected at Site 1 and Site 3 were smallest, with mean lengths of 92.8±9.0mm (n=9) and 94.5±3.3mm (n=6), respectively, whereas those of 4, 7, and 10 exceeded more or less 110mm, mean 108mm±9.9mm (n=12).

By July 28, immature sweet smelt had become more widespread between Sites 1 and 13.These fish measured between 125 and 160mm in length, with the smallest mean size of 119±1.2mm (n=14) measured at Site 4 and the largest, 175.0±22.5mm (n=4), at Site 12. These data indicate that fish increase in body size as they move upstream and mature in boulder-cobble riffles. On September 30, mature individuals that were either spawning or had finished spawning appeared at Sites 2 and 3 for the first

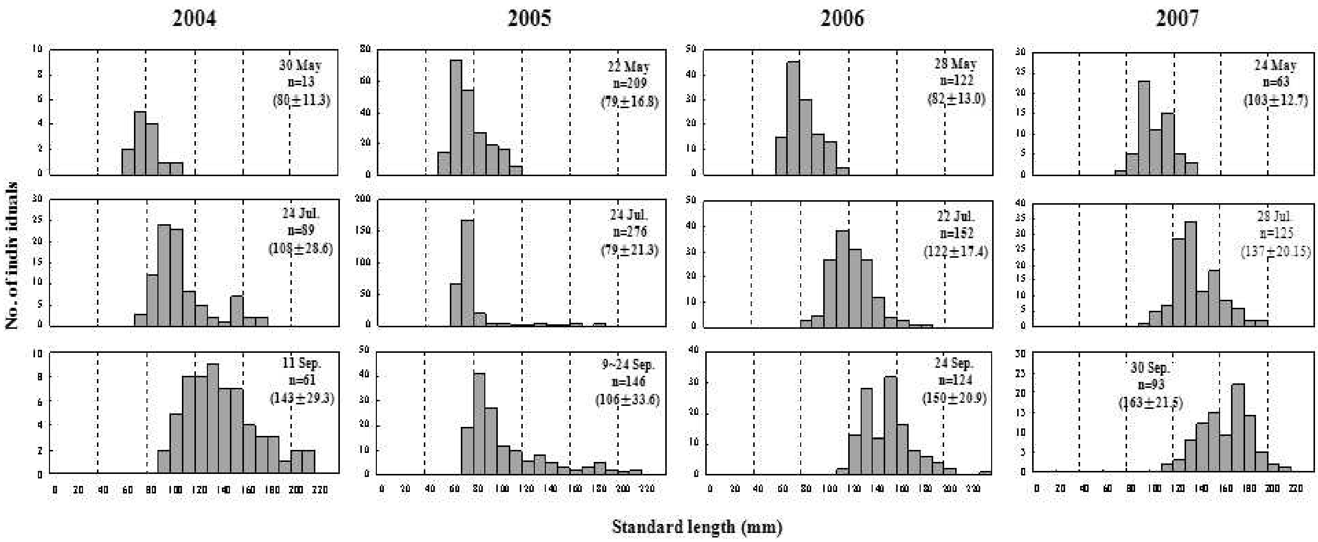

Figure 7. Standard length frequency of *Plecoglossus altivelis* in Lake Okjeong, South Korea from 2004 to 2007

time. The mean sizes of these mature fish were 162±21. 8mm and 169±20.9mm, respectively. Many more fish were collected at Site 2 (n=85) than at Site 3 (n=8). We observed a large number of sweet smelt that had died after spawning.

Previous studies of sexually mature sweet smelt suggest that body size is related to fecundity(Shimada *et al*., 2006; Ko *et al*., 2007a). The relationship between fecundity (y) and body length (x) may be calculated as y=617.71x-54192 (R^2= 0.9003)(Ko *et al*., 2007a). Following this formula, a 10mm increase in body size allows a female to produce 6,167 more viable eggs per ovary. Therefore, the 20~57mm increase in body size observed in 2007 may have major effects on fecundity of the study population, with the number of eggs per female in 2007 averaging 40,119±22.5 (n=18).

Our results suggest that the construction of well-designed fishways is beneficial to foster the growth and fecundity of land-locked sweet smelt populations. We recommend that established weirs be removed or, at minimum, more appropriate fishways be constructed, in Churyeong Stream.

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