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Thesis for the Degree of Master of Science

Growth and reproduction of *Laternula gracilis* (Reeve, 1860) in Busan, Korea

by

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Department of Marine Biology

The Graduate School

Pukyong National University

February 2022

Growth and reproduction of *Laternula gracilis* (Reeve, 1860) in Busan, Korea

(한국 부산에 서식하는 떠조개의 성장과 생식)

Advisor: Prof. Chul-Woong Oh

by
So Yeon Nam

A thesis submitted in partial fulfillment of the requirements
for the degree of

Master of Science

in Department of Marine Biology, The Graduate School,
Pukyong National University

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Growth and reproduction of *Laternula gracilis* (Reeve, 1860) in Busan, Korea

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Growth and Reproduction of *Laternula gracilis* (Reeve, 1860) in Busan, Korea

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Abstract

Studies on the growth and reproduction of *Laternula gracilis* were conducted in Busan, Korea, from January to November 2021. A total of 1,311 samples were collected, and the month and station at which the largest number of samples were taken were March and St. 9, respectively. Shell length (SL) of the collected *L. gracilis* ranged 4.21 ~ 50.16 mm, and the relationships between shell height (SH) and shell width (SW) were shown in the following equation: $SH = 0.4765SL + 1.3829$ (r^2 = 0.9360, n = 1280, P < 0.05), $SW = 0.3051SL + 0.6689$ (r^2 = 0.9091, n = 1188, P < 0.05). Total weight (TW) ranged from 0.01 to 10.54 g, and the relationship between SL and TW followed the equation: $\ln TW = 3.2877 \ \ln SL - 10.5064$ (r^2 = 0.9110, n = 1263, P < 0.05). The age of *L. gracilis* using external ring ranged from 0 to 3 years old, and two cohort appeared during the study period. The marginal index (MI) was the lowest in February. The condition index (CI) and the proportion of mature individuals were the highest in July. The size at sexual maturity (SL_{50}) was 32.75 mm. The Von Bertalanffy growth parameters and the growth performance index (φ') were: L_∞ = 51.31 mm; K = 1.3; t_0 = 0.24 and φ' = 3.53, VBG equation as follows: $SL_t = 51.31(1 - e^{-1.3(t-0.24)})$.

Growth and Reproduction of *Laternula gracilis* (Reeve, 1860) in Busan, Korea

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요약

띠조개 (*Laternula gracilis*)의 성장과 생식에 대한 연구는 부산에서 2021년 1월부터 11월까지 이루어졌다. 총 1,311 마리의 표본이 채집되었고 가장 많은 표본이 잡힌 월과 정점은 각각 3월과 St. 9였다. 채집된 *L. gracilis*의 각장은 4.21 ~ 50.16 mm였고 각고와 각폭과의 관계는 각각 다음과 같은 식으로 나타났다: $SH = 0.4765SL + 1.3829$ ($r^2 = 0.9360$, $n = 1280$, $P < 0.05$), $SW = 0.3051SL + 0.6689$ ($r^2 = 0.9091$, $n = 1188$, $P < 0.05$). 총중량은 0.01 ~ 10.54 g 이었고 각장과 총중량의 $\ln TW = 3.2877 \ln SL - 10.5064$ ($r^2 = 0.9110$, $n = 1263$, $P < 0.05$) 와 같이 나타났다. 패각 표면의 성장륜을 이용하여 띠조개의 나이를 추정한 결과 0 ~ 3세까지 나타났으며 연구 기간 동안 2개의 연급군이 나타났다. 연변부 성장지수 (MI)는 2월에 가장 낮았고 비만도 (Condition index; CI)는 포란한 개체의 비율과 마찬가지로 7월에 가장 높았다. 군성숙체장 (SL_{50})은 32.75 mm로 나타났다. Von Bertalanffy 성장 매개변수와 성장비교지수 (φ')는 다음과 같았다: $L_\infty = 51.31$ mm, $K = 1.3$, $t_0 = 0.24$ and $\varphi' = 3.53$. 곡선의 식은 다음과 같다: $SL_t = 51.31(1 - e^{-1.3(t-0.24)})$.

1. Introduction

Laternula gracilis (Reeve, 1860), the littoral spoon clam, is distributed in India, Pacific Ocean, East China Sea, Japan, South and West sea of Korea. It inhabits the intertidal zone depth of 20-25 m with silty and sandy sediment, and usually burrows about 20 cm deep. Genetic data showed that *L. marilina* and *L. recta* are the same species with *L. gracilis* (Taylor et al., 2018).

L. gracilis has thin shells which are close to a rectangle. The surface is rough and the inner surface is milky-white, and both shells have a chondrophore below the umbo. The back edge is narrower than the front and the siphons are exposed to the outside. *L. gracilis* reported that it is a major food resource for migratory birds in various mudflats in the South Sea and the West Sea because of its fragile shells and well-developed flesh (Hong, 2006).

L. gracilis prefer salinity of 24-30 psu but can tolerate from 7-33 psu (Zhuang, 2005b). Asian *L. gracilis* can grow up to 45 mm in size, but American specimen 20 mm (Miller et al., 1999). It is suspension feeder which eats phytoplankton. Growth of shell and meat and spawning took place in late spring and summer when chlorophyll concentration is highest (Kang et al., 2006).

In the West Sea, occurrence, density, and average biomass of *L. gracilis* increased rapidly in 2017 compared to 2015-2016 (Koh et al., 2017). And in

2019, it was observed as a dominant species as it appeared at a high rate in many mudflats such as Anmyeondo Island and Muan (Ryu et al., 2020). In the South Sea, the average density and biomass decreased in 2017, and there are fewer areas where resource surveys were conducted compared to the West Sea. Therefore, it is necessary to further investigate the distribution of *L. gracilis* in the South Sea.

Studies on this species have been conducted in several fields. The relationship between sediment particles and growth in Taiwan (Hung & Hsueh, 2008), and spatial dietary variations along environmental gradients in Japan (Kanaya et al., 2008) were investigated. Metabolic rates according to body size and water temperature (Zhuang, 2005a), the influence of body size, habitat, diet concentration, salinity, diurnal rhythm and daylength on feeding were studied through laboratory breeding experiments in China (Zhuang, 2004, 2005b). In Korea, there are studies on seasonality of growth and reproduction (Kang et al., 2006), and pathways of organic matter through food webs (Choy et al., 2008). However, studies on growth and reproduction of *L. gracilis* are a little.

In China, it is cultivated to be used as a food resource (Zhuang, 2005b), but in Korea, despite its abundant population and wide distribution, *L. gracilis* is rarely used as food. The purpose of this study is 1) to evaluate the growth of *L. gracilis* over age and 2) to uncover reproductive behavior, which will be the fundamental study to use as potential fisheries resources.

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2. Materials and Methods

2-1. Sample collection

Laternula gracilis (Reeve, 1860) were sampled from January to September, 2021 in Busan, Korea (Fig. 1). Sampling station was divided into nine stations and 12.5 × 20 × 30 cm can core was used 4 times to collect whole community of each station to estimate the relationship between the inflow of land water and the distribution of *L. gracilis*. Nine stations corresponded to each part obtained by dividing the sampling area by 3 X 3. And additional *L. gracilis* were gathered by shovel. Water temperature and salinity were recorded by YSI.

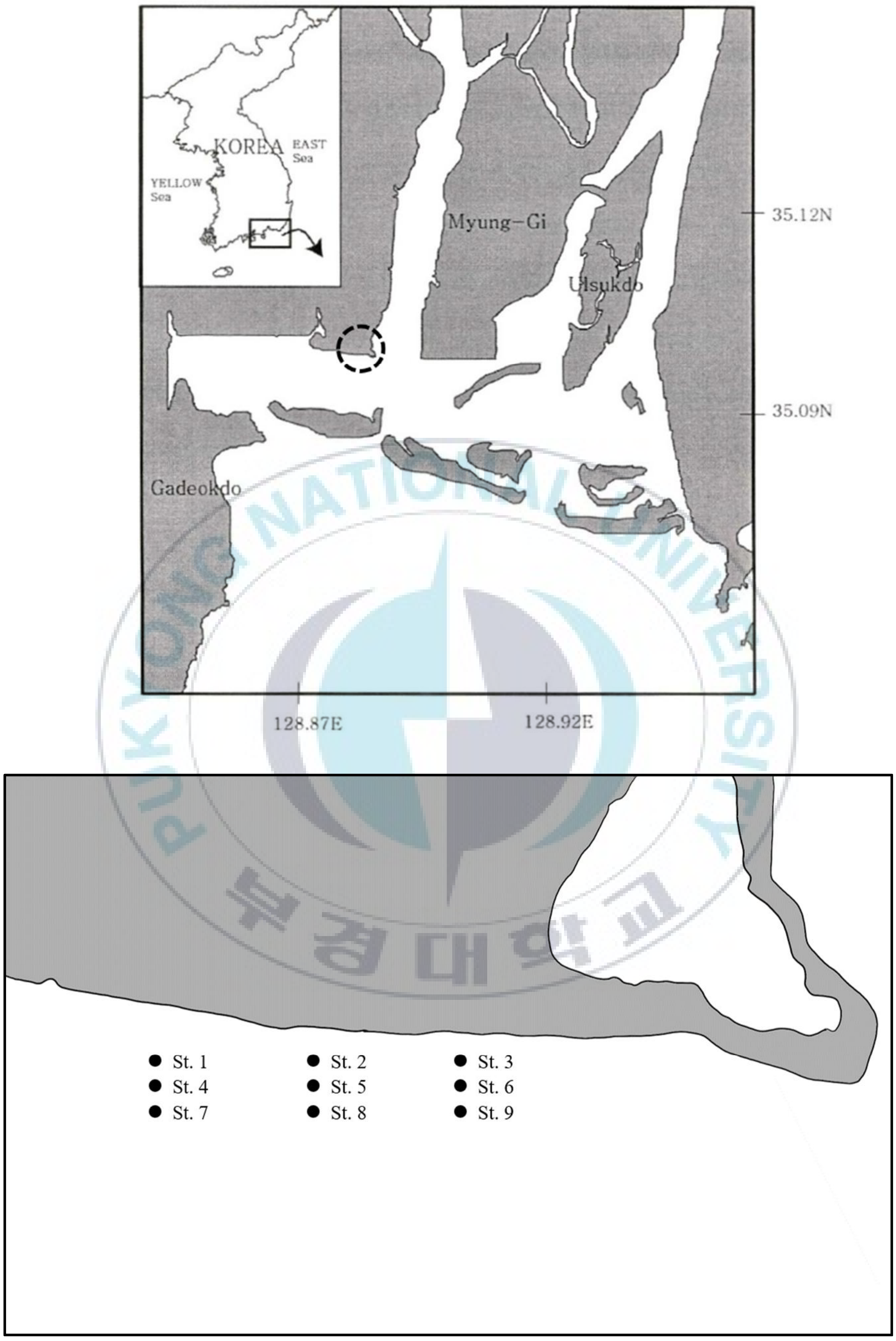

Figure 1. Map showing sampling area of *Laternula gracilis* in Busan, Korea.

2-2. Morphometric relationship

The shell length (SL), shell height (SH) and shell width (SW) of individual were measured to the nearest 0.01 mm by Vernier calipers. Morphometric relationship was examined between 1) SL and SH 2) SL and SW by using simple linear regressions. The equation is:

$$SH = a + bSL$$

$$SW = a + bSL$$

Total weight (TW) measured using an electronic balance to the nearest 0.01 g. The relationship between SL and TW was determined using natural log transformed data. The equation follows:

$$\ln TW = a + b \ln SL$$

where *a* and *b* are intercept and slope, TW is the total weight (g) and SL is the Shell length (mm).

2-3. Age determination

The age estimation is necessary for the preservation and management of fishery resources. Growth rings are known to change rapidly in temperature or before and after the spawning season (Kang & Kim, 1983; Ryu et al., 2006). Age determination using external ring was made in this study.

After separating the flesh from the shell, the surface of the shell was rubbed with a soft brush to remove dirt. Because growth increments are recorded as opaque zone and transparent zone on the surface of the shell, the shell was illuminated from the bottom, counted the number of rings and measured the shell length at each ring (Lee & Kim, 2017). To increase the accuracy of ring number determination, the assessments were checked twice. First, it was observed by lighting device under the shell and with naked eye. Second, each shell was taken picture by a video camera microscope (Zeiss DV8) and made it more visible using photoshop.

2-4. Marginal index (MI)

The external rings on the surface show the annual growth cycle pattern (Fiori & Morsán, 2004). To determine the age of the shell by using the rings on the shell surface, the rings have to represent each age. Thus, determining the period and the number of times made in a year is important.

Marginal index (MI) analysis was used to validate the annual growth pattern increment deposition (Lai et al., 1996) that was calculated by the equation:

$$MI = \frac{R - r_n}{r_n - r_{n-1}}$$

where R is the shell length, r_n is the shell length at the time of the nth transparent zone mark.

2-5. Growth parameter

Growth for the *L. gracilis* was described by the equation:

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

where L_t is the length at age *t*, L_∞ the asymptotic length, *K* the coefficient of growth and t_0 the theoretical age when predicted mean length is zero. Growth parameters were estimated using von Bertalanffy growth (VBG) by the ELEFAN program in FISAT Ⅱ.

Population structure was estimated by length-frequency distribution using the ELEFAN and NORMSEP program in FISAT Ⅱ. The intervals of SL for length-frequency distribution were 3 mm. From ELEFAN program, the growth parameters (L_∞, K) and the R_n value, an estimator of the goodness of fit, could be estimated but t_0 was not given. So t_0 was derived from the following equation which used in Walford and non-linear regression methods:

$$t_0 = \mathrm{t} + \frac{1}{K}\ln(1 - \frac{SL_t}{SL_\infty})$$

To compare with previous study of other laternulidae species, the growth performance index (φ') was calculated in each case following the formula (Munro & Pauly, 1983).

$$\text{Growth performance Index } (\varphi') = 2\log L_\infty + \log k$$

2-6. Mortality and survival rate

For the management of fishery resources, appropriate management methods can be prepared only by knowing the changes in the population over time.

The mortality rate (Z) was estimated by length-converted catch curve program in FISAT , and the growth parameters were from above. Z was computed using the linear regression:

$$\ln\frac{N}{\Delta t} = a + bt, \qquad Z = -b$$

where N is the number of *L. gracilis* in length class i, Δt is the time to grow in i^{th} length class and *t* is the age relative to median value of i^{th} class (Pauly, 1984).

The survival rate (S) was calculated by the equation:

$$S = e^{-Z}$$

2-7. Reproduction period

Condition index (*CI*) indicates the reproduction period (Massapina et al., 1999) and was calculated by the equation:

$$Condition\ \ index\ \ (CI\ \ ) = \frac{DW}{SL}\ \times 100$$

where DW is dry weight of meat (Galvao et al., 2015). In order to measure the dry weight, whole tissue separated from shell was dried for 72 h at 60 and measured to the nearest 0.0001 g using an electronic balance.

An ovarian stage observation allows to investigate the reproductive pattern. The maturity of ovary was expressed in five stages; ( ) early active stage, ( ) late active stage, ( ) ripe stage, ( ) partially spawned stage and ( ) spent and inactive stage (Kim et al., 2009).

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2-8. Size at sexual maturity (SL_{50})

The proportion of mature individuals was calculated as individuals with gonad stages of 3 or higher. The proportion according to the shell length follows the logistic equation (Lee et al., 2013):

$$P = \frac{1}{1 + e^{(a+bSL)}}$$

where a and b are parameters. Size at sexual maturity (SL_{50}) is defined as the size when the proportion of mature shells reaches 50% and was calculated from the ratio between a and b:

$$SL_{50} = -\frac{a}{b}$$

2-9. Statistical analysis

Kruskal-Wallis test was performed to determine the difference between; 1) station and sample size; 2) month and sample size. The difference between station and water temperature was tested by one-way ANOVA. Relationship between sample size and water temperature was investigated by linear regression analysis. All statistical analysis was performed by SPSS with 95% confidence limit.

3. Result

3-1. Distribution

Total 181 specimens of *L. gracilis* were caught for nine months by using can core. Sample size ranged from 0 individuals in October to 45 individuals in June, and from 13 individuals in St. 1 to 39 individuals in St. 4. There was no significant difference in population among the stations (Kruskal-Wallis test, $H = 4.20$, $df = 8$, $P > 0.05$) and between station and temperature (ANOVA, $F = 0.008$, $df = 8$, $P > 0.05$). Also, there was no significant relationship between temperature and sample size in linear regression ($P > 0.05$). And there was a significant difference among the months (Kruskal-Wallis test, $H = 37.21$, $df = 10$, $P < 0.05$).

Table 1. Sample size of *L. gracilis* according to month and station and mean temperature ± deviation.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Total
St. 1	1	0	0	1	3	6	0	1	1	0	0	13
St. 2	7	2	0	1	3	8	1	0	0	0	0	22
St. 3	7	7	0	3	0	0	0	0	0	0	0	17
St. 4	0	0	2	3	2	9	5	18	0	0	0	39
St. 5	0	0	1	6	7	9	2	5	0	0	0	30
St. 6	0	0	0	0	7	5	4	0	1	0	0	17
St. 7	0	0	0	6	0	2	5	0	6	0	0	19
St. 8	2	1	0	7	2	1	3	3	1	0	0	20
St. 9	1	0	0	1	2	5	8	8	0	0	1	26
Total	18	10	3	28	26	45	28	35	9	0	1	203
Temperature (℃)	9.45 ± 0.10	12.76 ± 0.33	17.12 ± 0.25	19.85 ± 0.17	22.90 ± 0.18	24.91 ± 0.28	29.83 ± 0.20	25.48 ± 0.26	26.30 ± 0.17	21.26 ± 0.49	14.77 ± 0.18	

3-2. Morphometric relationship

The shell length (SL) of sampled *L. gracilis* ranged from 4.21 to 50.16 mm and the total weight (TW) was from 0.01 to 10.54 g, and mean shell length and total weight were 35.74 ± 7.00 mm and 3.96 ± 1.79 g, respectively.

The relationship between SL and shell height (SH), and SL and shell width (SW) were expressed in the following equations (Fig. 2):

$$SH = 0.4765SL + 1.3829 \ (r^2 = 0.9360, n = 1280, P < 0.05)$$

$$SW = 0.3051SL + 0.6689 \ (r^2 = 0.9091, n = 1188, P < 0.05).$$

The relationship between SL and total weight (TW) was expressed by the equation (Fig. 3):

$$\ln TW = 3.2877 \ \ln SL - 10.5064 \ (r^2 = 0.9110, n = 1263, P < 0.05).$$

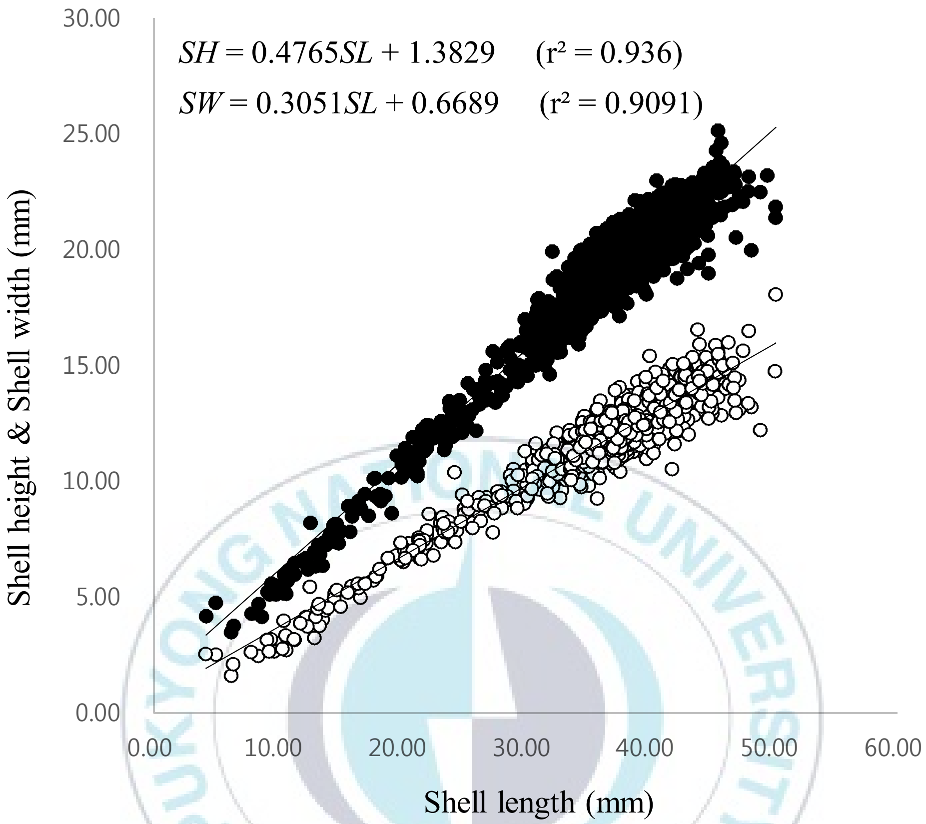

Figure 2. Relationship between shell length (SL) and shell height (SH) (●), and shell width (SW) (○) of *Laternula gracilis*.

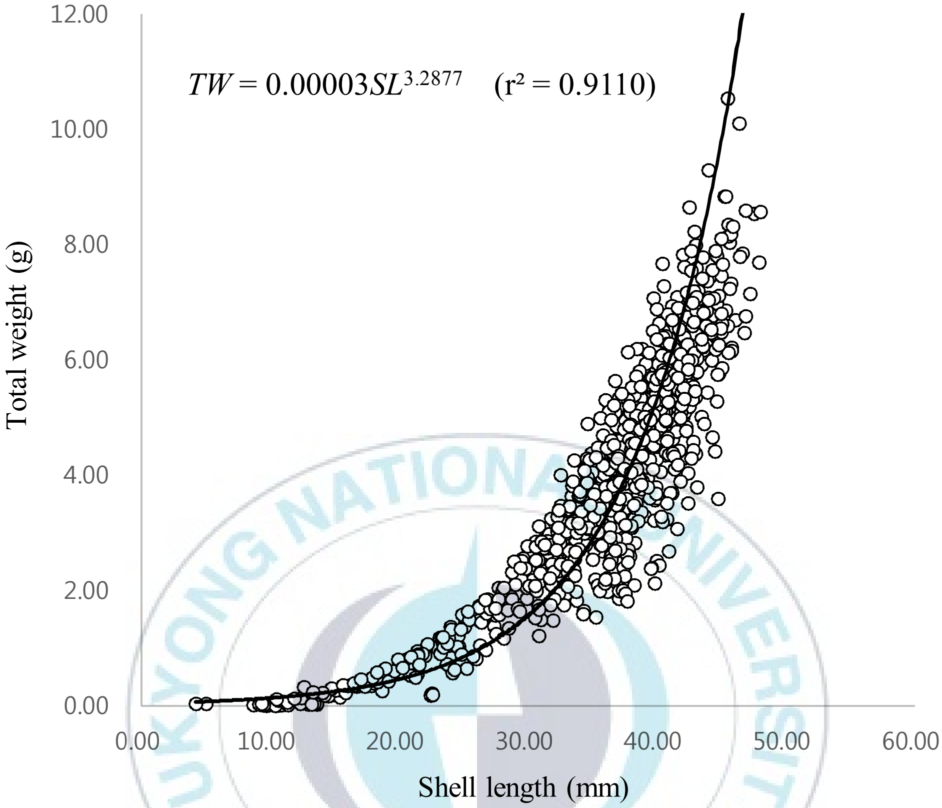

Figure 3. Relationship between shell length (SL) and total weight (TW) of *Laternula gracilis.*

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3-3. Ring formation

A total of 815 *L. gracilis* were measured. There was a relationship between shell length and external ring radius, and followed the regression line (Fig. 4). One-ring (n = 762), two-rings (n = 52) and three-rings (n = 1) groups were observed.

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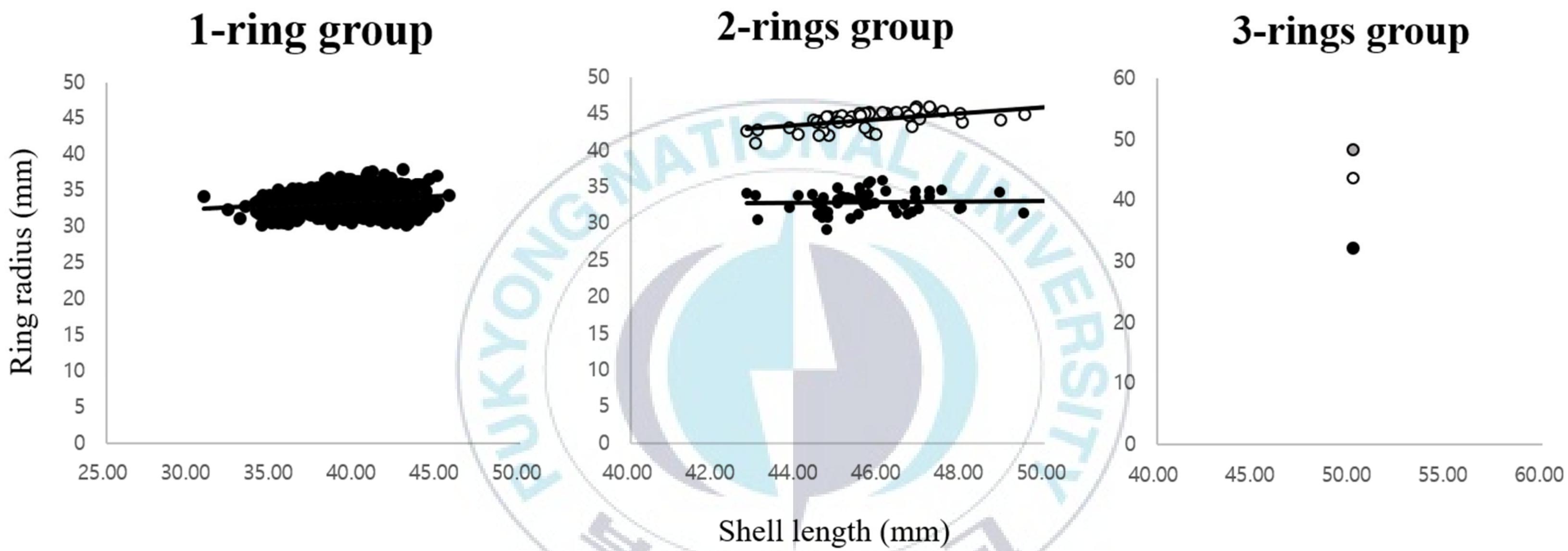

Figure 4. Relationship between shell length and ring radius of *Laternula gracilis*.

3-4. Marginal index (MI)

The mean marginal index (MI) was calculated each month and ranged from 0.1157 to 0.2218. The MI was the lowest in February (0.1157 ± 0.06), gradually increased, peaked in July (0.2218 ± 0.09), and decreased (Fig. 5).

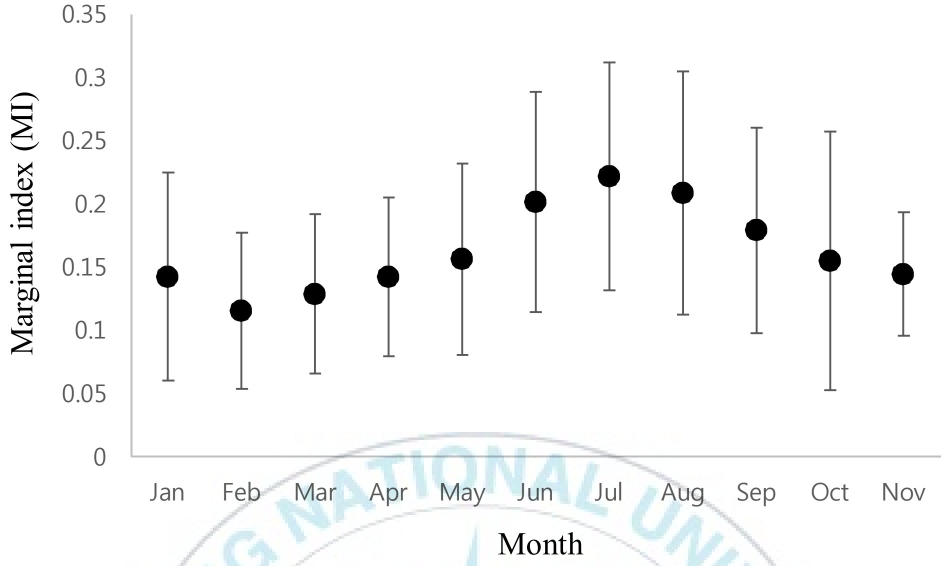

Figure 5. Monthly change of marginal index (MI) of *Laternula gracilis* during the study period.

3-5. Condition index (CI)

The monthly change in condition index (CI) to estimate the spawning period of *L. gracilis* was shown in Fig. 6. CI value had a peak in July (0.75 ± 0.22), decreased gradually and reached the minimum in September (0.45 ± 0.08).

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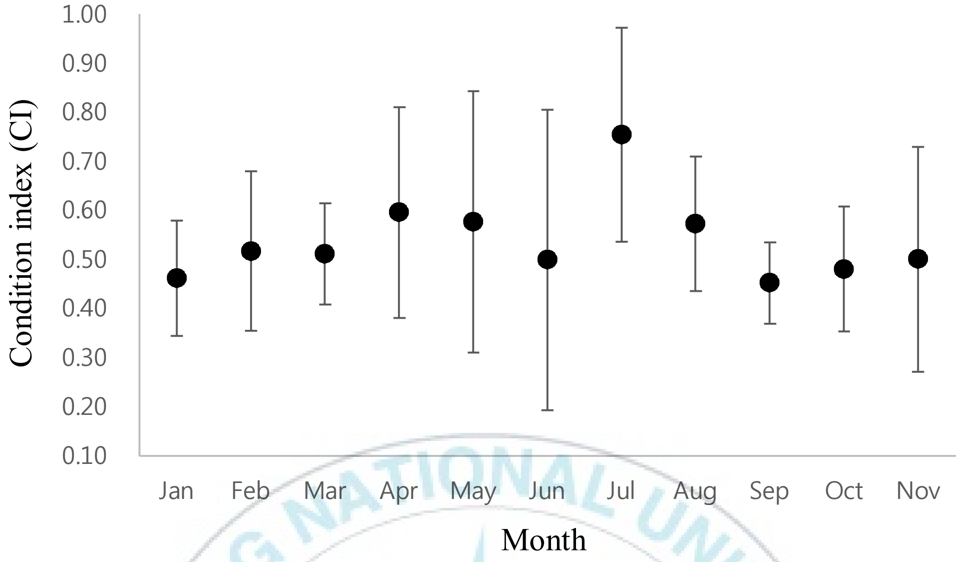

Figure 6. Monthly change of condition index (CI) of *Laternula gracilis* during the study period.

3-6. Growth

The age of *L. gracilis* was appeared to be from 1 to 3. Total 815 *L. gracilis* was used to measure the radius of rings. The diameter of each ring was considered to be shell length at time *t*. The first ring diameter (r_1) was 32.80 mm, the second (r_2) was 43.87 mm and the third (r_3) was 48.33 mm (Table 2).

The length-frequency distribution analysis by ELEFAN showed an appropriate model of length change of each cohort (Fig. 7). In the NORMSEP graphs, a new cohort appeared in April, moved to right gradually and the existing cohort seemed to disappeared or merged with the new cohort in September (Table 3) (Fig. 8).

The Von bertalanffy growth (VBG) curve was estimated by using parameters from ELEFAN. Asymptotic length (SL_∞) was 51.31 mm, growth coefficient (K) 1.3 and calculated theoretical age (t_0) 0.24 (Table 4). The Von Bertalanffy growth equation followed (Fig. 9):

$$SL_t = 51.31(1 - e^{-1.3(t-0.24)}).$$

The growth performance index (φ') was 3.53 (Table 3).

Table 2. Relationship between shell length and ring diameter. Mean ± standard deviation.

	Ring group	Number	Ring diameter (mm)		
			r1	r2	r3
Shell length (mm)	1	762	33.42		
	2	52	32.84	44.13	
	3	1	32.14	43.61	48.33
	mean	815	32.80 ± 0.64	43.87 ± 0.37	48.33

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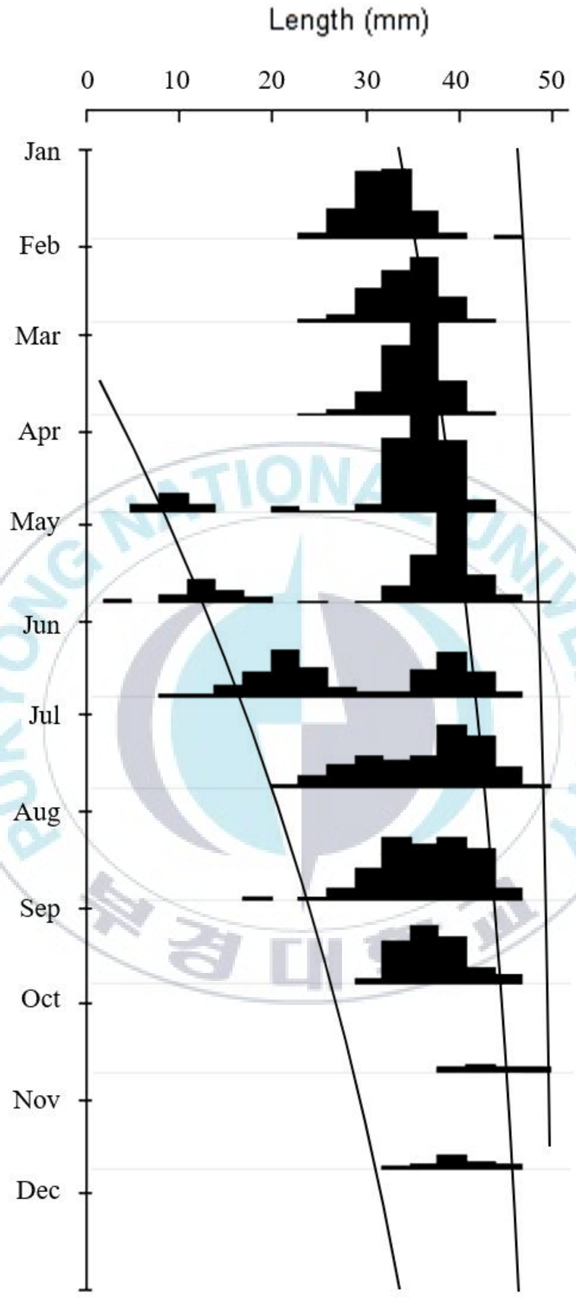

Figure 7. Length-frequency distribution of *Laternula gracilis* with Von Bertalanffy growth curves by ELEFAN.

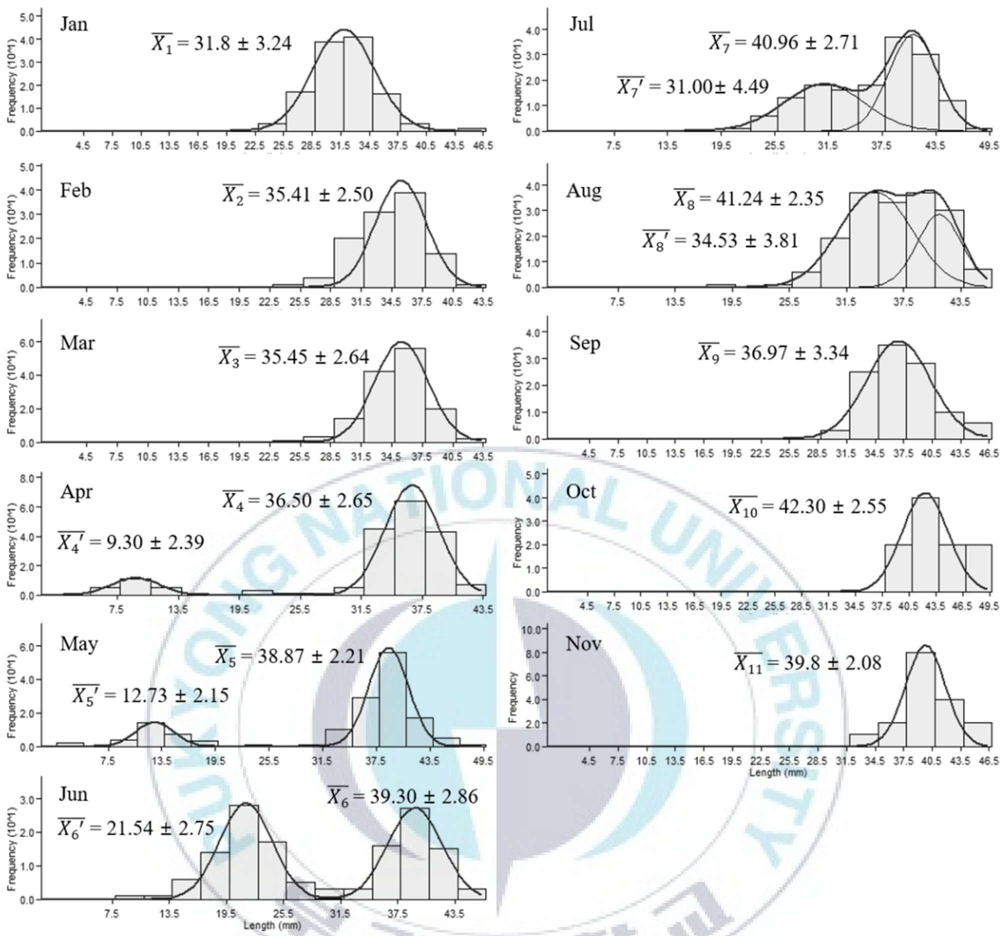

Figure 8. Length-frequency distribution of *Laternula gracilis* by NORMSEP method.

Table 3. Mean shell length (SL) of cohort from NORMSEP. SD: Standard deviation; n: Sample size; SI: Separate index

Month	Mean SL (mm)	SD (mm)	n	SI
January	31.8	3.24	120	-
February	35.41	2.5	92	-
March	35.45	2.64	132	-
April	9.3	2.39	23	-
	36.5	2.65	166	10.79
May	12.73	2.15	26	-
	38.87	2.21	109	11.99
June	21.54	2.75	66	-
	39.3	2.86	65	6.33
July	31	4.49	69	-
	40.96	2.71	86	2.77
August	34.53	3.81	119	-
	41.24	2.35	56	2.18
September	36.97	3.34	102	-
October	42.3	2.55	9	-
November	39.8	2.08	15	-

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Table 4. Parameters from the length-frequency distribution analysis by ELEFAN. SL_∞: Asymptotic shell length (mm); K: Growth coefficient (yr^{-1}); t_0: the theoretical age of size 0; φ': Growth performance index; R_n: Score function.

Parameter	Value
SL_∞	51.31
K	1.3
t_0	0.24
φ'	3.53
R_n	0.35

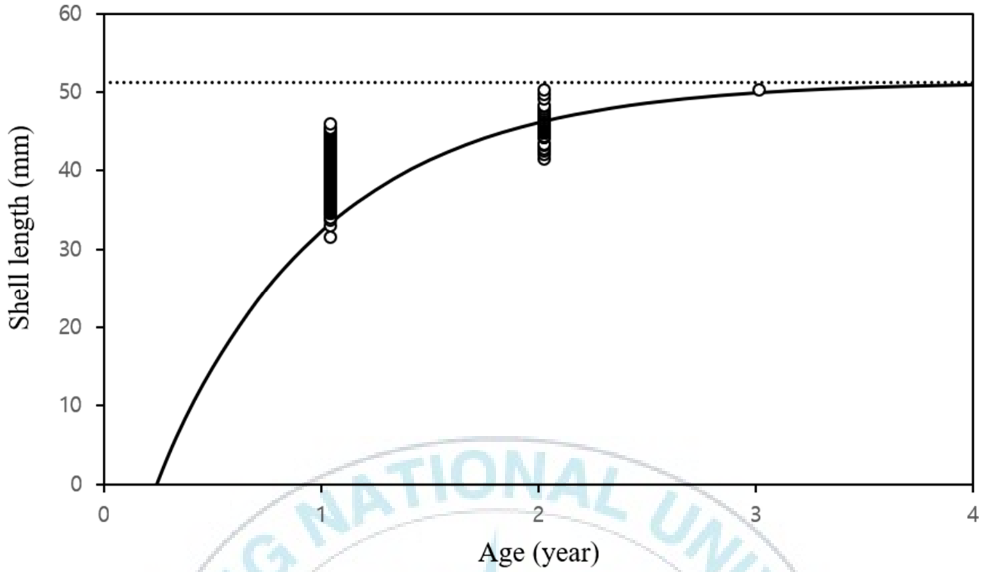

Figure 9. The Von Bertalanffy growth curve of *Laternula gracilis*.

3-7. Mortality and survival rate

The mortality rate (Z) was 5.46 ± 2.13 $year^{-1}$ (r^2 = 0.9991) and the regression analysis result followed:

$$\ln\frac{N}{\Delta t} = -\ 5.46t + 13.50$$

(Fig. 10).

The survival rate (S) estimated from external rings was 0.004 $year^{-1}$.

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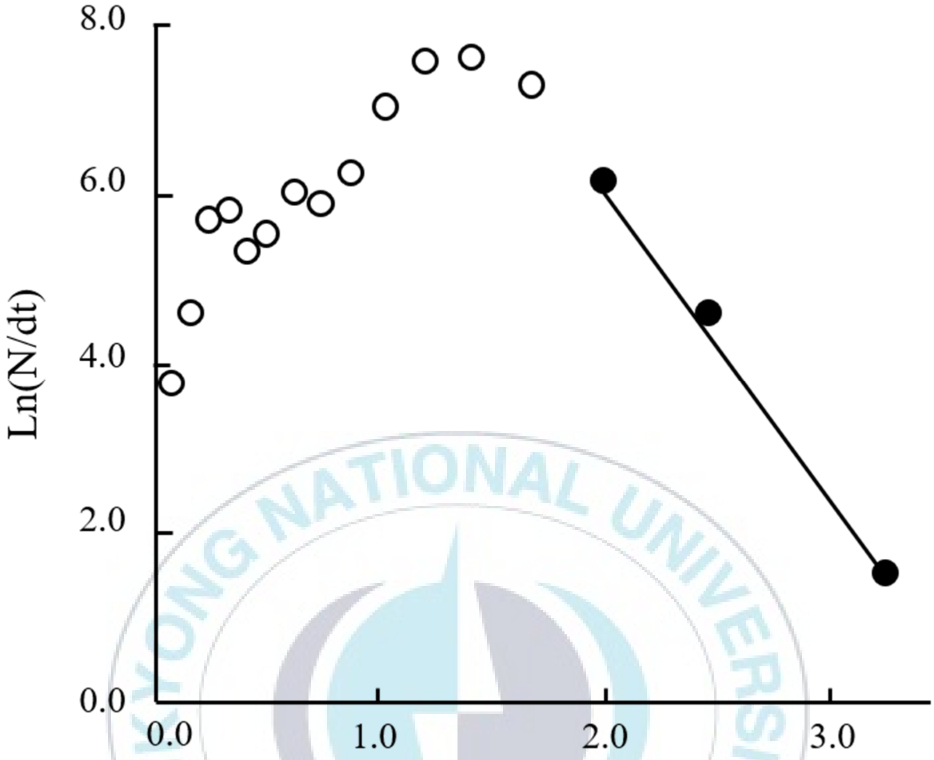

Figure 10. Length-converted catch curve of *Laternula gracilis* based on length-frequency distribution.

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3-8. Reproduction period

The spawning period was estimated by the ovarian stages of *L. gracilis*. Individuals with eggs were observed from April to October (Fig. 11). The proportion of mature specimen peaked in July and declined gradually (Fig. 12).

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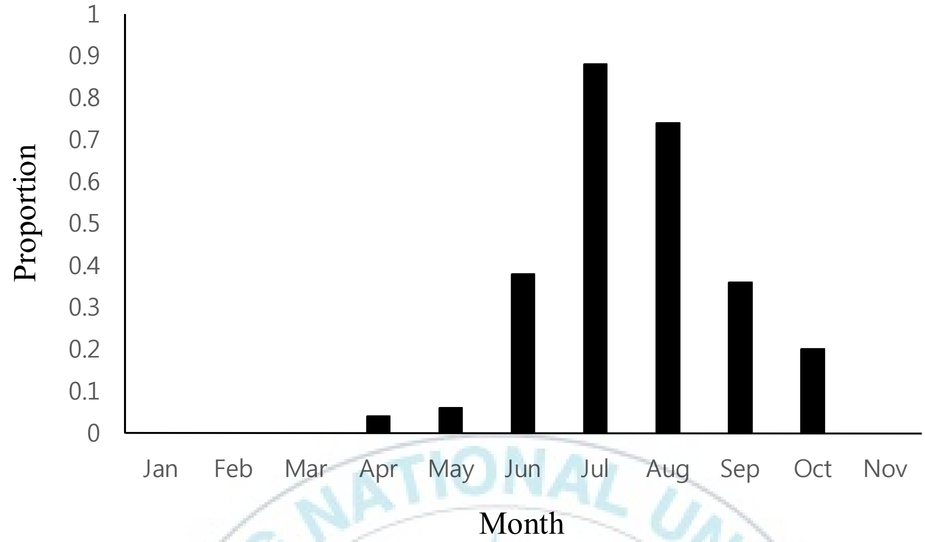

Figure 11. Proportion of ovigerous *Laternula gracilis* in each month.

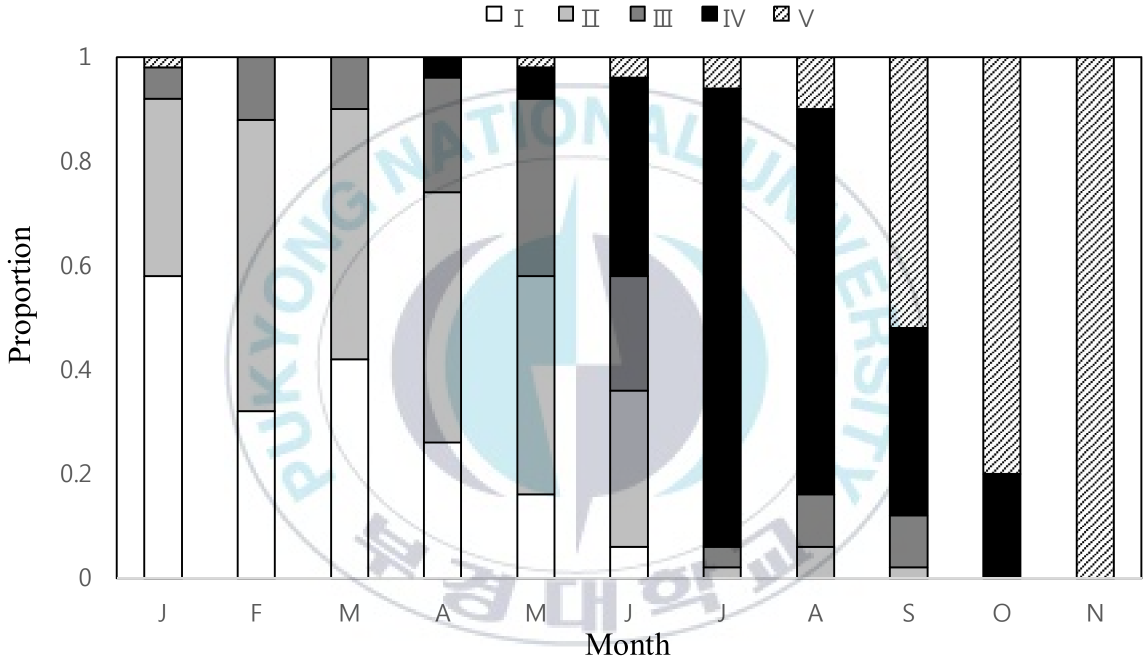

Figure 12. Variation in proportion of *Laternula gracilis* according to five ovarian stages.

3-9. Size at sexual maturity (SL_{50})

The shell length of *L. gracilis* used in the analysis was from 18.5 to 49.5 mm (n = 499). The size at sexual maturity (SL_{50}) was estimated as 32.75 mm. The proportion of mature *L. gracilis* by shell length was calculated by the equation (Fig. 13):

$$P = \frac{1}{1 + e^{(12.48 - 0.38SL)}}$$

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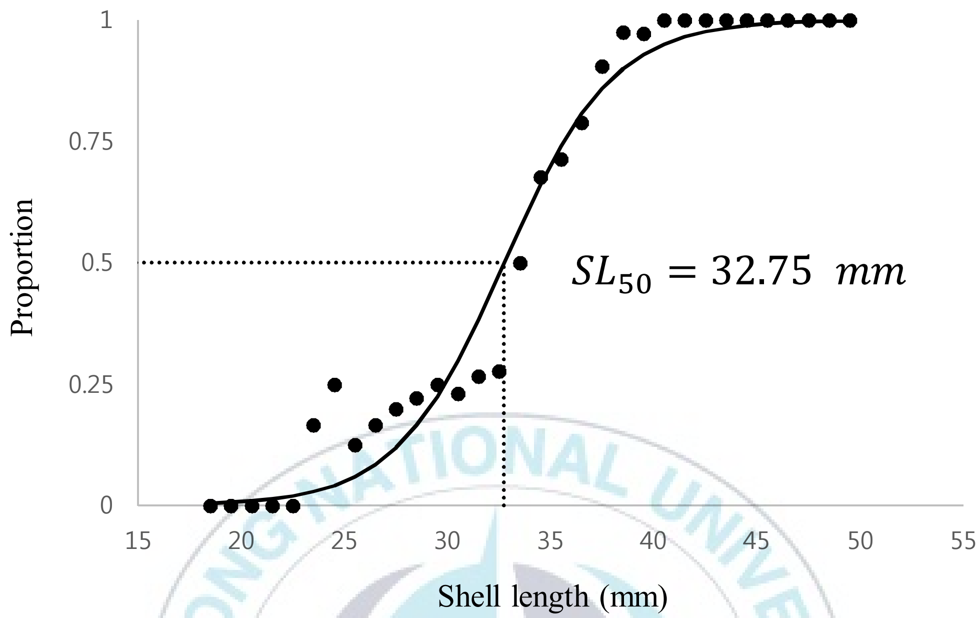

Figure 13. The logistic function fitting proportion of mature *Laternula gracilis* to shell length. The shell length at 50% of mature *L. gracilis* (SL_{50}) was 32.75 mm.

4. Discussion

4-1. Growth

In October and November, there was no or only one *L. gracilis* were caught, respectively. The reason is presumed to be the failure to adapt to the rapidly decreasing water temperature around the sampling site from October. Zhuang (2005) found that for all sizes of clams, metabolic rated had positive relationship with water temperature. Also, migratory birds such as *Cygnus columbianus*, *Anser fabalis,* and *Platalea leucorodia* stay approximately from October to March at the estuary of the Nakdong River (Kim et al., 2015), and it is also presumed that the population has decreased as they are used as food for these migratory birds. In order to find out the exact reason for the decline, more investigations of environment and diet of birds are needed.

It was found that the spawning period of *L. gracilis* was from July to August, but the smallest complex individual was collected in April. It was different with the study of Kang et al. (2006) in which individuals less than 5 mm appeared from January to April. It is difficult to say that the settlement of juveniles was delayed due to environmental factors such as water temperature. Because of its small size, it might have been pushed out with low tide or sampled due to extreme patch distribution (Miller et al., 1999). Therefore, it is necessary to collect small-sized specimens using a net with small mesh size.

In this study, only up to the age of 2 was observed and two cohorts were appeared for *L. gracilis*. On the other hand, in previous study conducted in Gwangyang Bay, there was only one cohort (0+) (Kang et al., 2006). Also, the largest *L. gracilis* in this study was 49.50 mm but the mean size did not exceed 30 mm in Gwangyang Bay. The small specimens were caught at stations far away from the land in Busan, but the sampling stations in Gwangyang were relatively farther. Therefore, it is presumed that smaller *L. gracilis* were collected and no large ones were caught in Gwangyang.

Cyclina sinensis, inhabits in the same area, is known to live until the age of 7 (Jeong, 2021). The growth parameters (L_∞, K, t_0) were 79.93 mm, 0.114 and -0.947, and the growth performance (φ') was 2.86. Also, in the similar area, the lifespan, the growth parameters, and the growth performance of *Mactra chinensis* were 5-6 years, 90.03 mm, 0.20, -0.50 and 3.21 (using chondrophore) (Kim et al., 2016) (Table 4) (Fig. 14). *L. gracilis* has thin shells relatively, it may need less energy and resources for growth and therefore, *L. gracilis* showed fast growth.

The Antarctic species, *L. elliptica*, had similar thin shells, but the asymptotic length was 105.4 mm, survived for 13 years but grew slower than *L. gracilis* (K = 0.16 year^{-1}) (Ralph & Maxwell, 1977)(Table 5) (Fig. 13). It may be just a species difference, but it can also be seen as an example of polar gigantism. In many taxonomic groups, Antarctic species are larger than relatives (Moran & Woods, 2012). Low temperatures depress metabolic demand for oxygen (Woods & Moran, 2020), then organism grows slowly and gets long lifespan. And there was a negative relationship between growth coefficient (K) and lifespan among several bivalves (Moss et al., 2016). Also, there was a positive relationship between water temperature and growth rate (Tomaru et al., 2002). Adjei-Boateng and Wilson (2012) showed the differences in the population parameters (L_∞, K, Z) of *Galatea paradoxa* depending on the region. The specimen with longer asymptotic length had smaller K value and larger Z, and this result can fully explain the relationship among parameters.

There are several methods to estimate the age of shell; 1) external rings, 2) internal lines of chondrophore, 3) chemical analysis. To observe the transparent and opaque zone of the shells, dye with such as Alizarin red after cutting it, or corrode it using hydrochloric acid (Lee & Kim, 2017). The shell of *L. gracilis* was too thin, thus illuminated directly. In the study of *Mactra chinensis* (Kim et al., 2016), the method with chondrophore was more suitable than using surface rings, and there was a difference in the maximum age observed. And the lines in the chondrophore connects to the line in the shell, the cross sectioned shell can be observed to estimate the age (MacDonald & Thomas, 2021). The methods using the rings or lines have the risk of reading a fake one as a growth index. Beaver et al. (2017) analyzed the elemental composition of *Glycymeris grayana*; the ratios of Sr/Ca, B/Ca and Mg/Ca. Each low point coincided with the translucent zone. Bivalves with a lifespan of less than two years can be judged relatively easily using mark-and-recapture field studies (Abele et al., 2009). It is a method of fluorescent labeling and measuring them by capturing them over time, and although it has the advantage of showing accurate growth indicators, the number of objects being captured is uncertain.

Table 5. The growth parameters and the growth performances of four species.

	L_∞	K	t_0	φ'	Sampling area	Authors
Laternula elliptica	105.4	0.16	-0.62	3.25	Antarctica	Ralph and Maxwell (1977)
Mactra chinensis	91.79	0.19	-0.56	3.21	Busan, Korea	Kim et al. (2016)
Cyclina sinensis	79.93	0.114	-0.947	2.86	Busan, Korea	Jeong (2021)
Laternula gracilis	50.81	1.0	-0.1	3.41	Busan, Korea	Present study

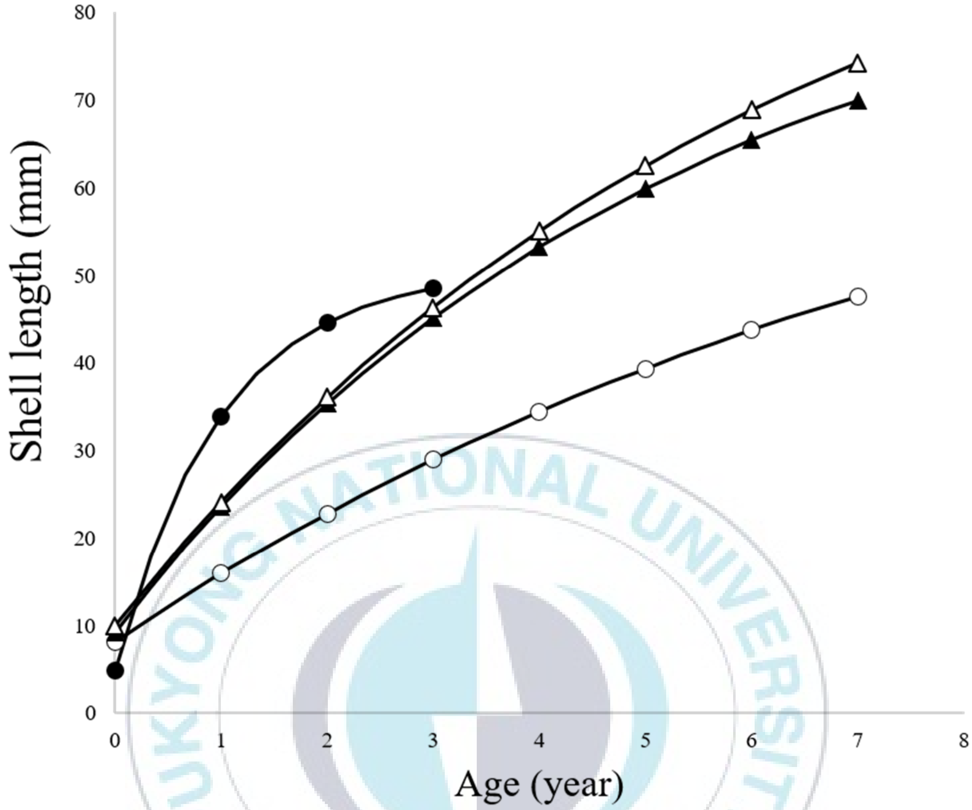

Figure 14. Von Bertalanffy growth curves of four species; *Laternula gracilis* (●), *Cyclina sinensis* (○), *Mactra chinensis* (△), *Laternula elliptica* (▲)

4-2. Reproduction

In this study, spawning period was July as indicated by condition index (CI). The CI of spawning *Crassostrea rhizophorae* and were also significantly higher than post-spawning period, dropped after spawning and then recovering (Li et al., 2009; Nascimento & Pereira, 1980). The fatness index, equals to CI, is strongly correlated with the gonad development and generally increased with maturity of the gonad and decreased during/after spawning (Kim et al., 2005). In general, during the period of reproductive development, the weight of the meat excluding gonad will decrease because it does not spend much energy on growth. But as the ovaries develop and become heavier, the overall weight also seems to increase. Thus, to estimate the change of meat weight except gonad, it needs to weigh that and gonad. In order to determine a more accurate spawning period, not only CI value, but also indices such as Gonadosomatic index (GSI) or Gonad index (GI) should be analyzed together.

This study showed that CI value in July which is consistent with Gwangyang Bay (Kang et al., 2006). These results suggest that spawning period using CI was similar in Busan and Gwangyang Bay. In the previous study, gonadal maturity index (GMI) increased from April, reached the maximum in November. But in this study, the proportion of mature individuals peaked in September. Differences in GMI between the two studies could be accounted for difference in water temperature, amount of prey and salinity change.

Studies have shown that *Laternula elliptica* and *L. truncata* are hermaphrodites (Kang et al., 2008; MORTON, 1973). Hermaphrodite bivalves function both sex at least once during life cycle and this can be achieved at the same time or different times (Breton et al., 2018). In simultaneous hermaphrodites, female and male gametes may be arranged in different ways (Coe, 1943). Sex changers show only one type during the different sexual phases and change at specific size, or lose female functions when the resources is insufficient (Coe, 1943). There are several reasons of sex change; 1) Exogenous steroids: *Mulinia lateralis*, *Placopecten magellanicus* (Moss, 1989; Wang & Croll, 2004); 2) Temperature: *Crassostrea corteziensis* (Chávez-Villalba et al., 2008); 3) Food availability: *Mytella charruana* (Stenyakina et al., 2010); 4) Pollution: *Mya arenaria* (Gagné et al., 2003). *Crassostrea gigas* was affected by 1, 2 and 3 (Mori et al., 1969; Fabioux et al., 2005; Lango-Reynoso 1999). Through observations of gonad of *L. gracilis* with naked eyes and microscope, this species also has both ovary and testis. During the spawning period, most of *L. gracilis* seemed to have developed both the testis and the ovary. Further study will be focusing on the type of hermaphrodite and reasons why *L. gracilis* changes sex.

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