Population characteristics of the bivalve *Ruditapes philippinarum* from Cheju Island coasts, Korea

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ABSTRACT

A comparative analysis of size and age structures of coastal subfossil shell assemblages of the shortnecked clam *Ruditapes philippinarum* from open and protected bays of Cheju Island (Korea) was carried out. On the whole, taking into account the damage of small fragile shells, size and age structures of the shell assemblages corresponded to the classical curve of bivalve population distribution when its mortality diminishes with age increase up to a certain threshold. It was found that shell samples from open bays of the western, southern and eastern coasts included shells of smaller and younger individuals (L ≤ 40 mm, ≤ 4 years) than samples from the eastern protected bay (L ≤ 54.5 mm, ≤ 6 years). Evidently, strong wave activity was the reason for a short life-span of the clams from the open areas. Growth was investigated retrospectively by annual growth rings on the shells. Growth rates of the clams from the various coasts of Cheju Island differed. However, growth rates of the clams from different biotopes at the same (eastern) side of the Island were similar. Shell height/length and width/length ratios statistically significantly increased with the clam age increase. Most likely, the reason for such shell shape alteration is that more conglobated individuals more survive being more energy-optimal than oblong specimens.

Key words: macrobenthos, mollusk, clam, *Ruditapes philippinarum*, population structure, size-age distribution, growth, subfossil shell assemblages.

INTRODUCTION

The shortnecked clam *Ruditapes philippinarum* (Adams et Reeve) is a dominant shellfish species at the tidal communities of the western Korea (Zhang *et al*., 1994). It is one of the common bivalve species inhabiting Cheju Island coasts (Noseworthy *et al*., 1994). This important commercial mollusk was the subject of intensive biological investigation; however, its populations living hear Cheju Island was not completely studied.

Sometimes, sampling from living animal populations is impossible or difficult. However, it is known that many population and individual characteristics of mollusks may be obtained by study of their dead subfossil shells that accumulate at site of mollusk habitat (Silina, 1990, 1996, 2003; Hallam, 1967; Shimoyama, 1984; Silina and Pozdnyakova, 1996).

Moreover, for the shortnecked clam, it is possible to determine individual age and to investigate retrospectively the growth rates of each individual by annual rings discernible on the surface of its shell (Silina and Popov, 1989). Therefore, this work is an attempt to compare size and age distributions of the clam shells in the samples from various littoral subfossil assemblages, as well as to compare growth rates of the clams from different biotopes of Cheju Island.

MATERIAL AND METHODS

Shells of the shortnecked clam were collected from

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the littoral zone of four bays of Cheju Island during low tides in October 2008. The first sampling site was situated at the western coast of the Island, on Geumneung Beach, opposite small Biyangdo Island. It was situated in open bay with the bottom sediments composed of light coarse sand between big volcanic rubbles. 53 clam shells were collected from the area of about 225 m^2 (75 m × 3 m).

The second investigated bay (also open) was situated at the southern coast of the Island near Namo Beach. The bottom sediments of this bay consisted of silt sand of grey color. Here, 201 shells were collected from the area of about 300 m^2 (100 m × 3 m).

At the eastern coast of the Island, shell assemblages of the clam were investigated in two bays. One of the bays was situated on the coast of the open bay near Ojo-ri. At the north, the bay was bounded by the cape with Sunrise Peak volcano. Subfossil shells (67 specimens) were collected from the area of about 350 m^2 (70 m × 5 m). The bottom sediments of this bay were composed of grey coarse sand and pebbles between volcanic reefs. The second eastern bay was situated near Seongsan-ri. It was protected by the cape (with Sunrise Peak volcano) from the southeastern winds, which are usual for the studied area in the summer-autumn period. Here, 147 clam shells were sampled from 10 frames, each 1 m^2, totally from the area of 10 m^2. The studied site of this bay is practically flat. The bottom sediments were consisted of silt sand, pebbles and small rubbles.

Shell length (L, mm, the longest distance between the anterior and posterior shell edges), shell height (H, mm) and shell width (D, mm, if both valves were available) were measured using sliding calipers with up to 0.1 mm accuracy. In the shell sample from the western coast, only two clams with both valves were found.

Growth rates and age of each individual were retrospectively determined by annual growth rings on the outer surface of the shell. This method is based on investigation of seasonal peculiarities of formation of microlayers in the internal shell structure (Silina and Popov, 1989). As the shortnecked clam forms broad annual shell increments, especially during the first three years of its life, it was possible to determine a season of its death by the structure of shell near its edge. That is why a season of death was determined for each individual.

T-test was applied for comparison of the growth rates of the clams from the different bays. The method of linear regression was used to reveal relationships between morphometric parameters of shell, as well as changes of the H/L and D/L ratios with mollusk age.

RESULTS

1. Comparison of size and age structures of clam shell samples

Size ranges of the shortnecked clam shells from subfossil assemblages in the open bays and in the protected bay differ. The shell samples from the open bays of the western, southern and eastern coasts included smaller individuals (L_{West} = 16.5–35 mm, L_{South} = 15–36.5 mm and L_{East} open = 12.5–40 mm) as compared with the sample from the eastern protected bay (L_{East} pr = 21–54.5 mm). Small individuals with the shell length < 10 mm were not found. Mean parameters of the clam shells from the open bays were similar. Thus, on the western coast they were 24.8 ± 0.6 and 17.8 ± 0.4 mm, on the southern coast, 26.4 ± 0.4 and 18.5 ± 0.3 mm, and on the eastern coast, 27.9 ± 0.7 and 20.0 ± 0.6 mm, respectively for length and height of shell. At the eastern protected bay, mean shell length of the clams was statistically significantly ($P < 0.01$) larger, 33.1 ± 0.4 mm, and height, 24.1 ± 0.3 mm, than in the open bays.

Size structures of the shell samples from various clam populations of Cheju Island differed (Fig. 1). Shells with the length of 17–29 mm (west) and 20–35 mm (south and east) prevailed in samples from the open bays, whereas sample from the protected east bay included mainly larger individuals with the length of 26-38 mm (Fig. 1).

Shell samples from the open bays mainly consisted of young individuals (from 0.3–0.5 to 3.5–4 years old) (Fig. 2). Shells of 0.5–1.5-year-old clams prevailed in

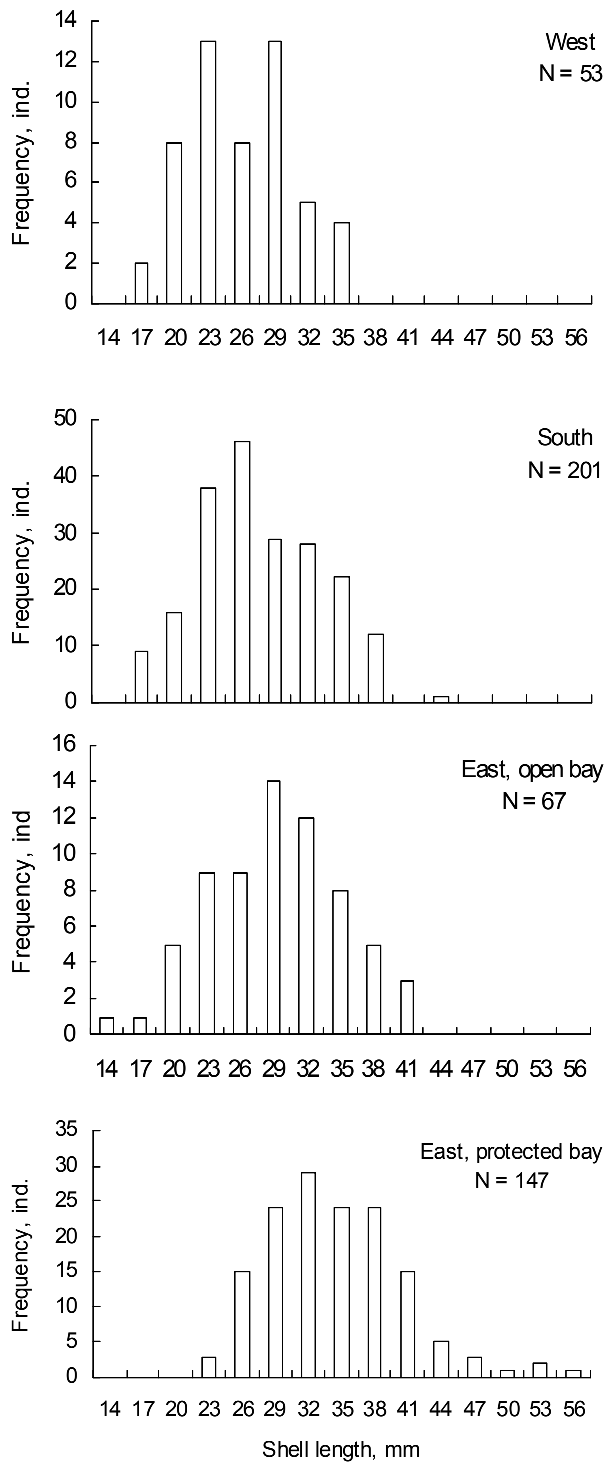

Fig. 1. Size distributions of subfossil assemblages of *Ruditapes philippinarum* shells at the western, southern, and eastern (open bay and protected bay) coasts of Cheju Island.

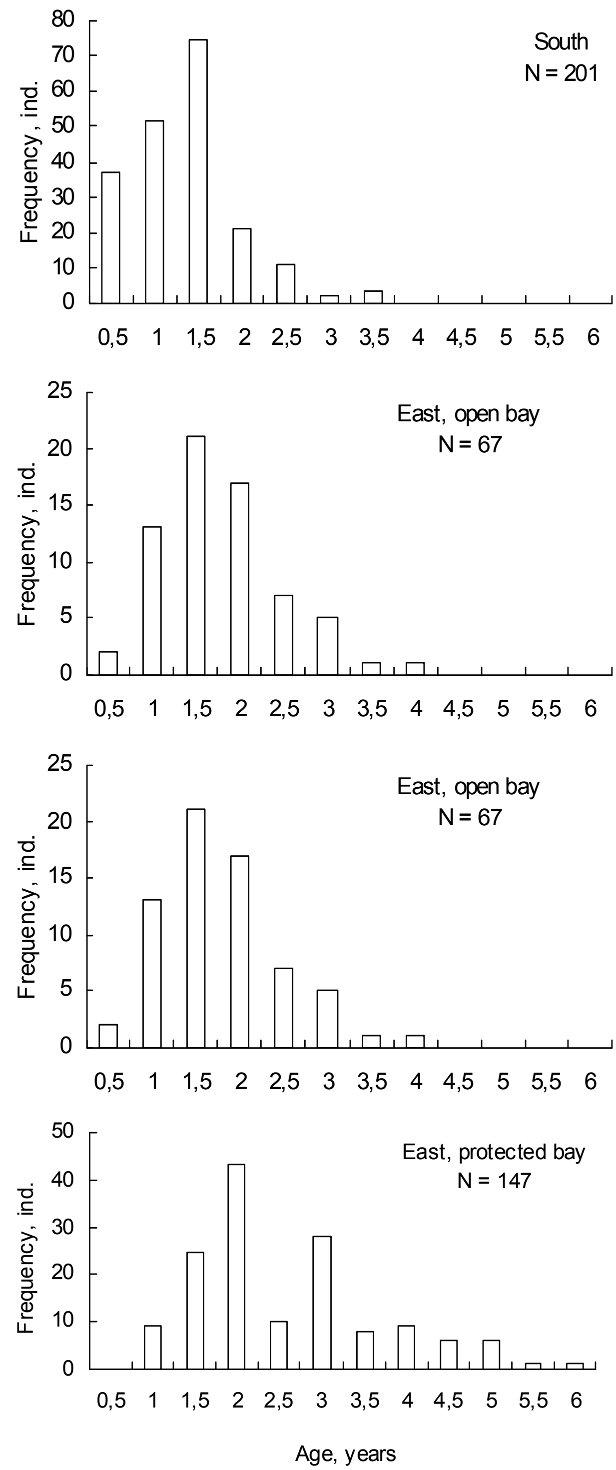

Fig. 2. Age distributions of subfossil assemblages of *Ruditapes philippinarum* shells at the western, southern, and eastern (open bay and protected bay) coasts of Cheju Island.

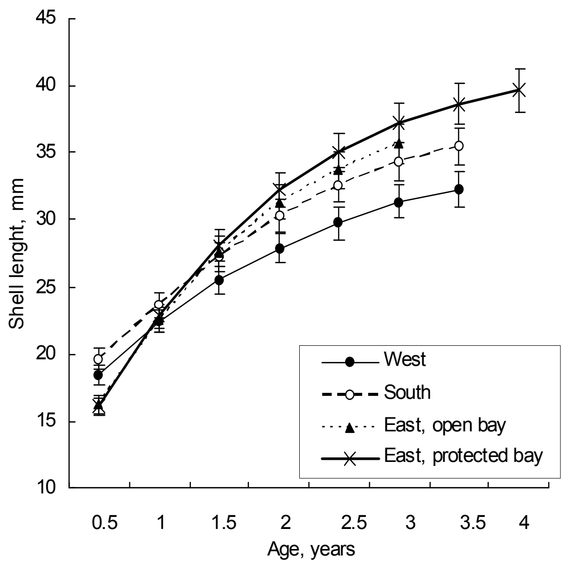

Fig. 3. Growth rates of *Ruditapes philippinarum* near the western, southern, and eastern (open bay and protected bay) coasts of Cheju Island. Vertical lines are SE.

the samples from the western and southern populations, whereas shells of 1–2-year-olds dominated in the eastern population (Fig. 2). At the eastern protected bay, the clam shell sample mainly consisted of 1.5–3-year-old individuals. Maximal life span of the studied bivalve species was substantially higher in the protected bay, 6 years, than in the open biotopes, even in the neighboring eastern open bay, there it was equal to 4 years (Fig. 2).

The highest mortality of the clams from the western bay of Cheju Island occurred in summer period at the age of about 1 year. Maximal mortality of the clams from the eastern protected bay was also registered in the hottest period (July-September) at the age of about 2, 3 and 4 years. However, the clams from the eastern open bay had maximal mortality in cold period (from the second half of autumn to the first half of spring), at the age of about 1.5 years. Summer (when the clams reached the ages of 1 and 2 years) is the second season of high clam mortality in this bay. In the southern population the highest mortality was observed in autumn-winter period, at the age of about 1.5 years.

2. Comparison of growth of the clams from different populations

Growth rates of the shortnecked clam from different coasts of Cheju Island substantially differed (Fig. 3). However, the clam growth rates in different biotopes of the eastern coast were statistically indistinguishable. At the western and southern coasts the clams reached statistically significantly ($P < 0.01$) greater sizes by its first winter as compared to the individuals from the eastern coast. But the growth rates of the clams from the western and southern bays were lower than those of individuals from the eastern bays, and already at the 1-year-old age their parameters became less than the latter of the clams from the eastern coast (Fig. 3). By the age of 1.5 year, the clams from the western population become significantly smaller than the individuals from the other coasts of Cheju Island ($P < 0.01$–0.001). The highest growth rates were found for the clams from both eastern bays.

3. Relationships between morphometric parameters of clam

At various studied sites, it was found that the clam shell height and length were positively linearly associated with a high reliability (Table 1). The shapes of the shortnecked clam shells varied significantly among the sites. Calculations of the shell heights of standard 20 and 30 mm long clams for each site (equations in Table 1) showed that at the western coast on the coarse sand clams tended to be more oblong than at the other sites especially apparent in comparison with clams from the eastern protected bay, where the bottom sediments were silt sand with pebbles and rubbles. Thus, standard 20 (and 30) mm long clams had shell height 12.9 (and 19.7) mm at the western coast, 13.8 (and 21.1) mm at the southern coast, and 13.8 (21.7) and 14.3 (21.8) mm in the open and protected bays at the eastern coast of the Island.

It was found that the H/L ratios significantly statistically increased with clam age increase. The only exception occurred at the western bay, where H/L did not change with clam age (Table 1). The

Table 1. Relationships between morphometric parameters of shells of the shortnecked clam *Ruditapes philippinarumin* different habitats near Cheju Island

Habitat	Equation	R	N	F	P
West bay	H = 0.6801L + 0.7093	0.9527	53	501.13	0.0000
South bay	H = 0.7283L - 0.7658	0.9846	201	6313.70	0.0000
East protected bay	H = 0.7515L - 0.7793	0.9831	146	4138.17	0.0000
East protected bay	D = 0.6118L - 4.4174	0.9679	17	222.47	0.0000
West bay	H/L = -0.0028× + 0.7134	0.0583	53	0.17	0.68
East protected bay	H/L= 0.0071× + 0.7093	0.3000	146	14.24	0.0002
South bay	D/L = 0.0149× + 0.402	0.2693	13	0.8602	0.37
East open bay	D/L = 0.0373× + 0.3411	0.6855	16	12.41	0.0034
East protected bay	D/L = 0.0424× + 0.3974	0.7670	17	21.43	0.0003

R – coefficient of correlation, F – coefficient of significance, P – level of significance, x – age, years, L, H and D, mm.

mean values of H/L ratios were 0.70 ± 0.00, 0.71 ± 0.00, 0.71 ± 0.00 and 0.72 ± 0.00 for the clams from the western, southern, eastern open and eastern protected bays, correspondingly. The regressions describing the relationships between height/length ratio and clam age at the various sites differed at their slopes. The most appreciable H/L increase (shell became less elongated) with clam age was found for the eastern open population (Table 1, coefficient was equal to 0.0232), which was exposed to the summer monsoon effect in high degree.

The clam shell width was positively associated with its shell length at a high degree of reliability (Table 1). However, the slopes of regression lines were different. Thus, standard 20 mm long clams had similar shell widths among the sites, 8.2 mm, 7.6 mm and 7.8 mm at the southern coast, in the open and protected bays at the eastern coast of the Island, but 30 mm long individuals were wider on silt sand in the eastern protected bay (13.9 mm) than on the coarse sand at the southern coast (12.9 mm) and on the sand in the eastern open bay (12.3 mm). A tendency to the increase of width/length ratio with the increase of clam age was revealed (Table 1). It was statistically significant with a high reliability for populations lived in the eastern bays.

DISCUSSION

Cheju Island is situated at the distance of about 80 km to the south from the Korean Peninsula. It is an oval-shaped volcanic island with rocky shore and sand beaches with a few sand tidal flats (Noseworthy, 2007). It is known that sand and gravel bottom sediments are the most favorable for the shortnecked clam (Cigarria and Fernandez, 2000). Thus, concerning this environmental factor, all investigated populations live in favorable conditions. At the studied area, the water salinity is normal, usually oceanic (Lee and Hyan, 1992; Lee and Kim, 1993). The optimal salinity for the euryhaline shortnecked clam is 32-34 ‰ (Scarlato, 1981) therefore this environmental parameter is also optimal for the studied bivalve species.

However, the sampling sites differ by the degree of wave activity. The three studied sites are situated on the open coasts of the Island and are influenced by strong wave activity of ocean waters. But one clam population inhabits protected tidal flat. Most likely, just this environmental factor is the reason for short life span of the clams in open bays, < 3.5-4 years, mainly < 1.5-2 years, in comparison with the clams from the protected bay where large quantity of the individuals live up to 3 years, and some of them survive up to 6 years. In other protected areas of the southern part of the continental Korea the maximal life span of the shortnecked clam is also 6 years (Cho and Jeong, 2007; Cho *et al*., 2008). This difference in life spans of the clams from the protected and open areas causes a considerable difference in the size structures of the shell samples.

It is known that water temperature is one of the principal factors for development and growth of poikilothermic invertebrates including shortnecked clam (Mann, 1979). Optimal temperature for the shortnecked clam is 20℃ (Han *et al*., 2008). Under increase of the water temperature up to 20–25℃ the growth rates of the clams increase, but at the temperature > 25℃ a thermal stress can occur (Isono *et al*., 1998; Kanazawa and Sato, 2008). The optimal temperature for the clam growth is 18–23℃ (Fan *et al*., 2007). At Cheju Island, the climate is subtropical. In summer, the water temperature is about 22–26℃ with maximum in August. Minimum temperature, 13–14℃, is observed in January–February. However, Cheju Island is washed by variously directed water currents, which results in different water temperature regimes at the different Island coasts. Thus, the southern coast is washed by warm Kuroshio Current giving this area somewhat warmer water temperature (Noseworthy, 2007). Besides, at the studied site of the western coast of Cheju Island, opposite to Biyangdo Island, the water temperature is slightly higher than at the eastern coast (Lee and Hyan, 1992; Lee and Kim, 1993). Most likely, the differences in water temperature regimes cause the differences in the clam growth. Thus, near the western coast, the water temperature exceeds the threshold of 25℃ in August (Lee and Kim, 1993), and this can unfavorably affect growth of the clam. Possibly, too high summer water temperature is the main reason for high mortality of the clams at the western coast in summer period. Moreover, during this period the clams undergo such stress as spawning. At the coasts of Korea the spawning period of the shortnecked clam is between early June and early October, and the main spawning occurs between July and August (Son and Kim, 2006). Besides, it is possible, that the clams begin to spawn somewhat earlier at the western and southern coasts due to earlier water warming than at the eastern coast. This can explain the larger sizes of the clams in their first winter at the western and southern coasts due to a longer time for growth before winter comes. Generally, growth of the shortnecked clam at the coasts of Cheju Island is approximate to those of the clams from the southern coasts of continental Korea (Shin and Shin, 1999; Cho and Jeong, 2007; Cho *et al*., 2008).

Most likely, the main reason of the highest mortality of the shortnecked clams at the open eastern bay in autumn was ejection of the clams on the seashore during storms which are typical for this region. In contrast, the reasons of high summer mortality of clams in the eastern protected bay are high energy expenses and stress during spawning (Mann, 1979), as well as high temperature of environment caused by bay landscape. It is practically flat shallow area, where the shell sample was taken from the drained site in the population habitat. During low-tide the dark bottom sediments actively absorb solar energy, wherewith the temperature of the sediments (clam biotope) increases.

Usually, acurve of bivalve mortality rates has a maximum for the settled young individuals, and further it gradually declines with bivalve age (Yanin, 1983). In accordance with such theoretical conception the age structure of ideally intact clam shells should have a maximum for the age < 0.5 years. In the studied clam shell samples, the number of shells of such young individuals was less than the number of 1–1.5-year-olds. This may be explained by the fact that thin fragile shells of young individuals are easily destroyed by tidal water motion during their transportation along the bottom and at their cast ashore during storms, i. e. they rarely remain in subfossil accumulations of dead shells. On the whole, taking into account the loss of small shells, the size structures of studied shell accumulations correspond to the classical curve of bivalve size-age distribution.

Evidently, shell length values 54.5 mm and 40 mm are close to the maximal parameters of the shortnecked clam that inhabits, correspondingly, sheltered and exposed biotopes of Cheju Island. Thus, local environmental conditions substantially affect life span of clam, its growth rates, as well as the season of the greatest vulnerability.

It was found that the shortnecked clam shell gradually becomes more round (increase of H/L and D/L ratios) with age increase. Hence, gradual reduction of body surface area relative to body volume (for a sphere this ratio is minimal) is characteristic for the majority populations of the shortnecked clam. This testifies to the reduction of energy waste, which is positively correlated with the body surface area. Probably, the shell shape does not change with the clam age, but more round individuals, which are energetically more efficient, better survive then more oblong specimens. Besides, a greater inner volume relative to body surface area permits to keep body temperature of invertebrate for a longer time. Increases of H/L and D/L ratios are also typical for other populations of the shortnecked clam, which inhabit the coasts of continental Korea, for example, Kamak and Chinhae Bays (Kang *et al*., 2000), and Taean and Gochang (Choi *et al*., 2000).

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