Growth Responses of the Scallop *Patinopecten yessoensis* (Pelecypoda: Pectinidae) to Shell Bioerosion and Bottom Sediment Type

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ABSTRACT

Data obtained from field observation revealed that the degree of shell bioerosion of the scallop, *Patinopecten* (*Mizuhopecten*) *yessoensis*, by endolithic organisms significantly higher on the muddy sand than on the sand. At the area studied, the polychaete worm, *Polydora brevipalpa* (=*Polydora ciliata brevipalpa*, *Polydora ciliata* Okuda, Not Johnston, *Polydora variegata*), which is common symbiotic species for the scallop made 95-100% of total scallop shell bioerosion at the area studied. The muddy bottom sediments enriched by organic matter create favourable conditions for development of microphytobenthos and bacteria, which are predominantly consumed by *P. brevipalpa*. Linear regressions for the degree of shell bioerosion on the scallop shell height, total wet weight and adductor muscle wet weight revealed negative relationships between them for the scallops inhabiting both sand and muddy sand. The influence of polychaetes on scallops is complex. They may be food competitors. Polychaete can directly affect the host through their boreholes. Scallop expends energy for shell regeneration to prevent the polychaete penetration into its interior cavity. It was found that the degree of shell bioerosion increased considerably with scallop age.

Keywords: Benthic ecology, Bivalves, Epibionts, Macrobenthos, Molluscs, Polychaete worms, Sediments, East Sea.

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INTRODUCTION

The species structure and the functioning of macrobenthic communities throughout the world are strongly dependent upon the sedimentary organic content related to grain size composition of the bottom sediments (Weston, 1990; Thouzeau *et al.,* 1991; Newell *et al.,* 2001). The increase of organic content and sediment silting may favour certain species over others; in one's turn, the consequences of interactions between species in community may change under such conditions. Such, in organically enriched areas, macrobenthic community tends to be dominated by annelids including the polychaete worms of *Polydora* complex (Pearson and Rosenberg, 1978; Morris and Keough, 2002). At the same time, some polychaete species are bioeroders, especially members of the family Spionidae, genus *Polydora* (Bergman *et al.,* 1982). They colonize and burrow shells of the scallops eroding them sometimes at a high degree. Bioerosion is a widespread phenomenon. However, little quantitative research has been devoted to this important process, especially, to study the influence of the polychaete bioerosion on the growth of their host scallop. Mori *et al.* (1985) suggested that heavy *Polydora variegata* infestation of the Japanese scallop shells might be the reason of the low growth rate of scallops in one of the bays of Hokkaido Island (Japan).

However, the field study of interactions between environmental factors and animals is complex, as it depends on obtaining temporal descriptions of many water and sediment parameters, which may affect benthos. Therefore, they are rarely examined in the field (Grant *et al.,* 1990). Besides, to derive growth of wild animals is usually difficult. However, for some bivalve species an estimation of actual growth in the field is possible by using their shell structure or sculpture (Clark, 1974). Such method exists for the Japanese scallop, *Patinopecten* (*Mizuhopecten*) *yessoensis* (Jay) (Silina, 1978, 1996). The external surface of the upper (left) valve of the scallop bears a thin microsculpture with detectable growth layers (bands), and their width and appearance depend on season when they are formed. This peculiarity allows determining the age of each scallop by counting the number of shell portions, for example, with summer growth layers, and reconstructing it individual linear growth in retrospect by measuring the scallop heights from the apex to each portion of the shell with summer layers. This method affords an opportunity to investigate long-term growth of wild scallops from natural environments without marking and periodical measuring of animals during many years. Besides, this method allows avoiding the mistakes connected with traumas of scallops at the moment of catching for such regular measuring.

The Japanese scallop is a common species in subtidal epibenthic communities of the East Sea (=Sea of Japan). It inhabits different bottom sediment types (from muddy sand to coarse-grained sand mixed with pebbles). In studying the Japanese scallop I have noticed that in bays with a muddy bottom its shell bioerosion is higher and growth rates are slower than in sandy areas. However, besides the bottom sediment types the environmental conditions in different bays differ in many other parameters (water temperature, salinity and others), which also may affect the scallops and their epibionts. Therefore, to minimize the influence of these additional factors on the scallops and their symbiotic endolithic organisms the present investigation was devoted to the study of parts of the scallop population in one bay where the bottom sediments vary spatially.

It was chosen Sivuchja Bay situated in unpolluted Biosphere Marine Reserve (East Sea, Russia), where Japanese scallop population is naturally divided into some separate parts, which inhabit the different bottom sediment types (Silina, 2002). The bottom landscape of the bay is like scoop that acts as trap for particulate and dissolved organic loads (from coastal marshes), as well as fine grained mineral particles, which accumulate over years in the bottom sediments, especially in the deepest central part of the bay. There was a distinct gradient in both the content of silt fractions and the organic carbon (mainly of terrigenous origin) concentration in the bottom sediments from shorelines towards the deepest central part of the bay (Vanin *et al.,* 2000; Moshchenko *et al.,* 2001). The organic carbon content in mud bottom sediments of the central part was ten times higher than in the sand bottom sediments near shorelines of the bay (Shulkin *et al.,* 2001).

The purpose of the present study was (1) to compare both the degree of scallop shell bioerosion making by endolithic organisms and the scallop growth rates in relation to the bottom sediment types, (2) to reveal relationships between degrees of shell bioerosion and growth rates of the scallops living on the different bottom sediments, and (3) to try to define a mud content threshold of the sediment (border level) above which the mud component exerts a significant effect on shell bioerosion and scallop growth.

MATERIALS AND METHODS

1. Study sites and samples

The scallop population in Sivuchja Bay (Peter the Great Bay, northwest of the East Sea) was studied in 1999. Scallop samples were taken using scuba from sand (depth 8-10 m), site 1, and from muddy sand (depth 12-14 m), site 2, situated further from the shoreline and the top of the bay than site 1. Scallop migrations between sites 1 and 2 were not due to specific of the bottom relief between studied sites 1 and 2, which prevents from scallop migration (Silina, 2002). Samples contained 125 and 150 scallops, respectively. On the mud bottom (depth 16-18 m), situated at the deepest central part of the bay, site 3, scallops were not found.

At sites 1 and 2, environments only slightly differed in such water parameters as temperature, salinity, and direction and velocity of the water current. In 1996-1999 the water temperature ranged from -1.2 to 16.9-19.3℃ and from -1.2 to 16.5-18.7℃ during the year at sites 1 and 2, respectively (Moshchenko *et al.*, 2001; authors' data). The water salinity showed slight (from 32.4 to 33.8 $g \cdot kg^{-1}$) annual variations at both sites 1 and 2. Direction and velocity of water current caused by wind and tidal action are highly variable in the open area studied, from 3-8 to 20-30 $cm \cdot s^{-1}$ in the water column of 0-15 m depth (Vanin *et al.*, 2000; Moshchenko *et al.*, 2001).

2. Analyses

The age and individual linear growth of each scallop during its lifetime were determined retrospectively from the growth layers revealed in the microsculpture of the external surface of the upper valve according to the method suggested by Silina (1978). Winter and summer growth layers differ in their appearance and width. The scallop forms one broad elementary growth layer weekly during November-April and one narrow elementary growth layer daily during the rest of the year. The visible thickening (annual ring) of the narrowest layers annually occurs in August. This allowed me to determine both the age of each scallop by counting the number of annual shell rings and its individual linear growth rate in retrospect by measuring the heights of the scallop shell from its apex to each annual ring (Silina, 1996).

The dark-brown portion of the upper valve occupied by endolithic organisms (degree of bioerosion, % of all valve area) was determined from the inner side of the valve by light using a transparent palette with a 1 x 1 mm grid. There were the boreholes of endolithic animals on the outer surface of scallop valves and they corresponded to such dark-brown portions on the inner valve surface. For scallops from different sites studied the degree of shell bioerosion was compared only for their upper valves, as everywhere the lower valves were eroded insignificantly.

The surface bottom sediments were excavated in a 0.09 m^2 quadrate to a depth of 3 cm. At each site studied, for covering the area of scallop sampling, five sediment samples were taken. All sediment samples were dry-sieved through 0.1, 0.25, 0.5, 1.0, 5.0 mm mesh screens. The particle-size distribution for sediment samples was expressed as % particle weight within each size category. The particle?size distribution for each site was calculated as the mean of five samples (in each size category separately). Additionally, the surface bottom sediments were sampled at site 3, where no scallops were found.

Prior to statistical analysis, all data were tested for normality of variance among the different groups by using a Kolmogorov-Smirnov test. The degrees of shell bioerosion were percentage data; therefore, the percentages were arcsine-square root transformed in order to ensure homogeneity and normality of variances. A t-test was used to identify significant differences among mean degrees of shell bioerosion, mean shell heights and mean wet weights (total and adductor muscle) for scallops of the same age at different sites. The significance criterion was $p < 0.05$. Linear regressions for the degree of bioerosion of the upper valves on shell height and both total and adductor muscle wet weights were calculated for 7-years-old (as the most numerous age class with wide range of the shell bioerosion degree) scallops inhabiting sand site 1 and muddy sand site 2. Differences in shell height, total weight and muscle weight of scallops between two lines of regression (for sand and muddy sand sites) were tested by ANCOVA.

RESULTS

At site 1, the bottom sediments consisted of fine-medium-grained sand as it contained 91.7% of the fractions 0.1-0.5 mm and 6.0% of the fractions < 0.1 mm size. At site 2, the bottom sediments consisted of muddy fine-grained sand. It contained 25.5% and 66.2% of fractions < 0.1 mm and 0.1-0.25 mm, respectively (Table 1). At the central part of the bay, where scallops did not live (site 3), the bottom sediments contained 52.3% of the fraction < 0.1 mm size.

1. Scallop shell bioerosion

Scallops from sites 1 and 2 significantly differed in the degree of shell bioerosion by endolithic organisms. The polychaete worms that inhabit only the shells of

Table 1. Percentage (on a dry weight basis; mean ± SE) of particle size distribution for the bottom sediments at the sites of scallop sampling in Sivuchja Bay (Peter the Great Bay, East Sea).

Size of sediment particles (mm)	Grain-size weight proportion (%)		
	Site 1	Site 2	Site 3
< 0.1	6.0 ± 1.0	25.5 ± 2.4	52.3 ± 3.2
0.1-0.25	60.2 ± 3.2	66.2 ± 3.8	38.2 ± 2.3
0.25-0.5	31.5 ± 2.8	7.7 ± 1.1	9.0 ± 1.0
0.5-1.0	2.1 ± 0.4	0.4 ± 0.1	0.3 ± 0.1
> 1.0	1.2 ± 0.3	0.2 ± 0.0	0.2 ± 0.0

Table 2. Changes of the degree of bioerosion (mean ± SE) by endolithic organisms of the upper valve of the scallop (*Patinopecten yessonsis*) with its age at the different bottom sediments in Sivuchja Bay (Peter the Great Bay, East Sea). Some age classes were absent in scallop samples.

Age (years)	Portion of the valve area eroded by endolithic organisms (%)			
	Sand		Muddy sand	
	N	Degree of bioerosion	N	Degree of bioerosion
1	1	-	5	1 ± 0
2	12	1 ± 0	18	4 ± 1
3	18	5 ± 1	15	11 ± 2
4	19	15 ± 2	10	22 ± 2
5	0	-	0	-
6	12	37 ± 3	5	44 ± 3
7	21	45 ± 3	18	53 ± 4
8	10	54 ± 4	28	63 ± 4

bivalves, gastropods, barnacles and some other carbonate substrates constituted the bulk of these endolithic organisms. At the bay studied, the polychaete worm, *Polydora brevipalpa* Zachs (=*Polydora ciliata brevipalpa*, *Polydora ciliate* Okuda, Not Johnston, *P. variegata* (Radashevsky, 1993)), which is common symbiotic species for the Japanese scallop made 95-100% of total scallop shell bioerosion. It was found that the degree of shell bioerosion increased considerably with scallop age (Table 2).

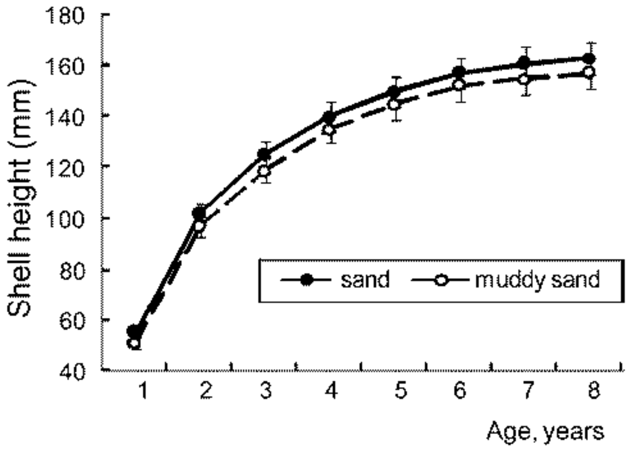

Fig. 1. Linear growth rates of the scallops (*Patinopecten yessonsis*) living on sand and muddy sand at Sivuchja Bay (Peter the Great Bay, East Sea). Vertical bars are SE.

From t-test (for mean values of degrees bioerosion for each age of scallops from sites 1 and 2), significant differences in the degree of bioerosion were observed between the scallops living on sand (lower) and the individuals living on muddy sand (higher).

2. Scallop growth rates

Significant statistical differences in the growth of the scallops were observed between sites 1 and 2. The scallops grew slower (t-test for mean heights and weights for each age of scallops from sites 1 and 2) on muddy sand than on sand (Fig. 1, 2).

Linear regressions for the degree of shell bioerosion on the shell height and weight of scallop revealed that bioerosion negatively affects size and weight of the scallops inhabiting both sand (site 1) and muddy sand (site 2) (Fig. 3). At the same time, regression lines for scallops inhabiting muddy sand were situated under similar line for scallops living on sand. The regressions for sand and muddy sand sites gave significant differences between regression coefficients (ANCOVA) (for shell height, $p < 0.02$; for total weight, $p < 0.001$; for muscle weight, $p < 0.01$).

DISCUSSION

The greater shell bioerosion of scallops inhabiting site 2 compared to individuals from site 1 is, most probably, due to the fact that organic carbon content in muddy sand is higher than in sand. Thus, total organic carbon is about 0.14 and 1.09% of dried weight for sand (site 1) and muddy sand (site 2), respectively (Vanin *et al.,* 2000; Moshchenko *et al.*, 2001; Shulkin *et al.,* 2001). As known, quantity and quality of food is the main factor for successful growth of the most animal species. The organic matter of the bottom sediments creates favourable conditions for the development of bacteria and bottom microphytobenthos predominantly (mainly diatoms and bacteria) consumed by polychaetes of the genus *Polydora* (Fauchald and Jumars, 1979; Sato-Okoshi and Nomura, 1990; Zhukova and Radashevsky, 1995), which constitute the bulk of endolithic organisms burrowing in the shells of the scallop species studied. In one's turn, the increase of the degree of shell bioerosion leads to the decrease of shell height and both total and muscle weights of scallops. Earlier, the data of Kojima and Imajima (1982) indicated that the flesh weight of abalone *Haliotis diversicolor aquatilis* decreased significantly by the infestation with more than ten individuals of *Polydora* per shell. Mori *et al.* (1985) suggested that heavy *P. variegata* infestation of

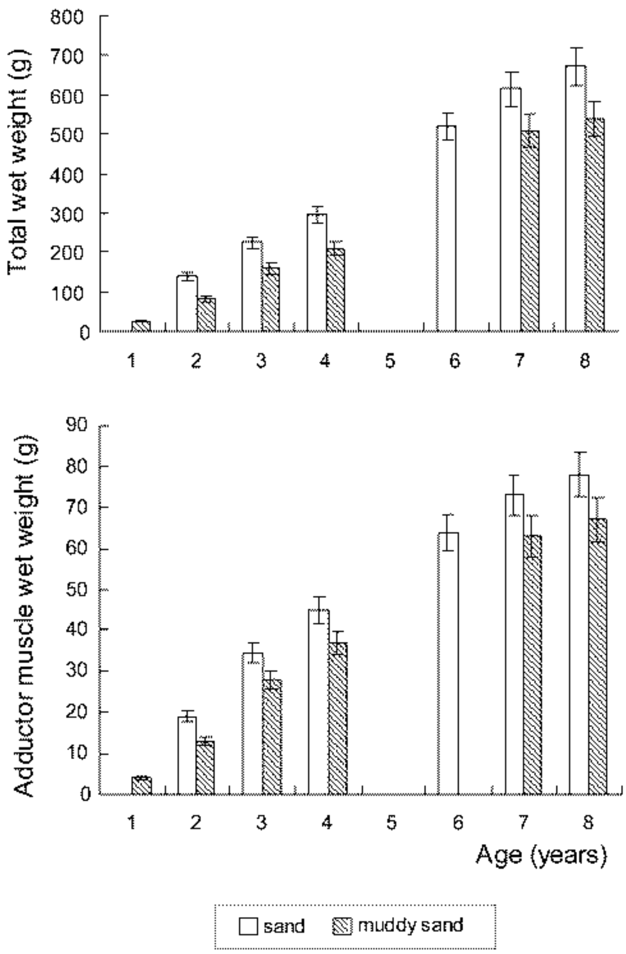

Fig. 2. Weight growth rates of the scallops (*Patinopecten yessonsis*) living on sand and muddy sand at Sivuchja Bay (Peter the Great Bay, East Sea). Vertical bars are SE.

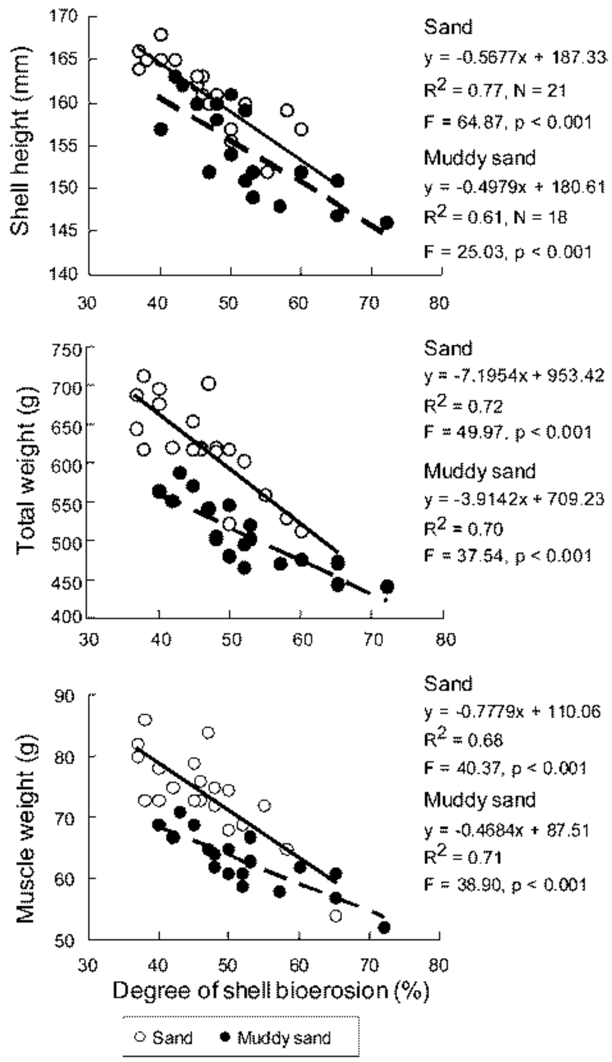

Fig. 3. Linear regressions for the degree of bioerosion of the upper valves on shell height, total wet weight and adductor muscle wet weight of 7-years-old scallops (*Patinopecten yessonsis*) inhabiting sand (white circles) and muddy sand (black circles) at Sivuchja Bay (Peter the Great Bay, East Sea).

the Japanese scallop shells might be the reason of low growth rates of the scallops in Abashiri Bay (Hokkaido Island, Japan), where 38.0% of shell area of 4-year-old scallops was infested by *Polydora* spesies. In other bays of Hokkaido Island the shells of 4-year-old scallops were infested only at 1.5-5.8%.

The influence of polychaetes on scallops is complex. The polychaete *Polydora brevipalpa* consumes the particles < 30-50 μm (Fauchald and Jumars, 1979). At the same time, its Japanese scallop host consumes suspended particles of 9-950 μm in diameter, but the bulk of large particles pass intact through the scallop alimentary canal (Mikulich and Tsikhon-Lukanina, 1981). Therefore, a competition for food is potentially occurring. In addition, Zhukova and Radashevsky (1995) using fatty acids as biological indicators in study the food sources of symbiotic polychaetes and their scallop hosts revealed that fatty acid components of *P. brevipalpa,* boring into scallop shell, are similar to those of its host, that is, *P. brevipalpa* and scallop may be food competitors. More over, at the water column of Sivuchja Bay, a phytoplankton is not too abundant, from 200,000 to 800,000 (usually 300,000-400,000) cells/liter in May-September, with diatoms being dominant group (Orlova *et al.,* 2001).

Additionally, polychaetes are likely to cause particle resuspension and, therefore, modify a composition of the water layer over the host scallop, and a competition for oxygen could also be occurring (Ropert and Goulletquer, 2000).

Day *et al.* (2000) counted for limpets that the cost of shell erosion is about 8-12% of the total energy devoted to “production” (somatic growth, shell production and gonadial output). Besides, they determined that the compensation for shell erosion is an ongoing process involving a long-term cost. Therefore, it is evidently, that the higher the degree of scallop shell bioerosion, the greater the energy expenses for regeneration of scallop shell and the lower the efficiency of scallop growth.

Sato-Okoshi and Okoshi (1993) argued that, in case of penetration in scallop soft body, *Polydora* could directly affects the host through boreholes by some substance secreted for dissolution of scallop shell and by constant mechanical stimulation of the soft body of the host.

Hence, the results that scallop height and weight decrease with an increase of the degree of shell bioerosion are explicable. However, for the same values of the degree of shell bioerosion the shell height, total weight and adductor muscle weight were lower for scallops from muddy sand than from sand (Fig. 1). Therefore, it is obviously, that the higher shell bioerosion is not the only reason for reduction of growth rates of the scallops living on muddy bottom. Earlier, Weston (1990) found that the mean of animal size decreased with increasing organic enrichment of the bottom sediments. He indicated that the relationship between enrichment and body size is complex, and suggested that one of the principle reasons is the fact that organic enrichment alters the types and amounts of food resources available to the macrobenthos. Perhaps, unfavourable influence of high content of organic matter in the muddy bottom sediments on the Japanese scallop also can be explained by following reason. It is known that the Japanese scallop is sensitive to oxygen deficiency in the water (Yamamoto, 1957). A decomposition of organic matter requires oxygen; therefore, this process reduces the oxygen concentration in the water layer near the bottom. Actually, at the moment of scallop sampling (in August) the oxygen concentrations were 6.14 and 7.37 $ml \cdot l^{-1}$ in the water layers under muddy sand site 2 (organically enriched) and sand site 1, respectively (Chernova, E., personal communication).

The present study deals with environments that are favourable for the Japanese scallop. Actually, the scallop growth rates are high for the population studied in comparison to other Japanese scallop populations (Silina and Pozdnyakova, 1986). At the same time, growth rates were lower for the scallops from substrata containing 25.5% of the particles < 0.1 mm (site 2) than from substrata containing 6.0% of such particles (site 1) under many other equal environment parameters. In contrast, differences in Japanese scallop growth rates were not significant at two sites in Zapadnaya Bay (Peter the Great Bay, northwest of the East Sea) where the mud contents in the bottom sediments were 0.2% and 10.2%, respectively (Silina, 2003). Therefore, in the bottom sediments a mud content threshold, above which the mud component noticeably adversely affects scallop growth rates, most probably, lies within the range of 10.2-25.5%. At the same time, significant increase of the degree of Japanese scallop shell bioerosion was found when the mud content in the bottom sediments of Zapadnaya Bay increased from 0.2 to 10.2% (Silina, 2003).

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