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Spatial Heterogeneity and Long-term Changes in Bivalve *Anadara broughtoni* Population: Influence of River Run-off and Fishery

Alla V. Silina

Institute of Marine Biology, Far East Branch, Russian Academy of Science, Vladivostok 690041, Russia

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Abstract – A comparison was made of population of the economically important cockle *Anadara* (=*Scapharca*) *broughtoni* (Bivalvia, Arcidae) inhabiting different areas of the Razdolnaya River estuary at the head of Amurskii Bay (Peter the Great Gulf, East Sea). Also, changes in cockle population density and structure, as well as in cockle growth rates during the last 20 years were studied. In all years of investigation, the morphometrical parameters and growth rates of cockles were smaller at the sites located close to the River mouth than farther down-estuary. The differences can be attributed to higher concentration of suspended particulate matter, decreased salinity and water temperature, as well as a longer exposure to these unfavorable environmental factors at sites located close to the River mouth, compared to farther sites. For two decades, cockle population density had decreased by almost 30 times at some sites in the River estuary. The main reason for this population decline is commercial over-fishing of the cockle. Besides, for the last 20 years, linear parameters of the cockles in the population decreased approximately by 30% and weight parameters, almost two times. Cockle growth rates also decreased for this period. Evidently, these facts are due to the damaging effect of dredging.

Key words – benthos, trawling, mollusk, estuary, spatial distribution, age, growth

1. Introduction

The blood cockle *Anadara* (=*Scapharca*) *broughtoni* (Bivalvia, Arcidae) is a Pacific-Asiatic subtropical species (Scarlato 1981). This large suspension-feeding bivalve is common in coastal and estuarine areas of the East and Yellow Seas, and in the Philippine Islands. It is an important species in fishery and aquaculture. Cockle is a sluggish, infaunal burrower. Burial depth of mature individuals is up to 10 cm. This thermophilic mollusk inhabits pelitic, silty and silt-sandy bottom sediments at summer water temperature above +18°C (Kanno 1966; Scarlato 1981). The Peter the Great Gulf of the East Sea is the northern limit of the cockle range. In the Gulf, it forms large stocks at warm silt sites at the heads of Amurskii and Ussurijskii Bays, as well as in Possyet Bay. Here, it lives mainly between the 2 and 16 m depth, but in warm waters of Korea and Japan it occurs at a depth of 30 and 50 m, respectively (Habe 1983).

At the head of Amurskii Bay, the Razdolnaya River influences the cockle population; i. e. here, the population is exposed to riverine waters with reduced salinity, high concentrations of suspended particulate matter and pollutants (Tkalin *et al.* 1993). The mean value of river run-off water volume is 2.21 km^3/year (maximum 4.38 km^3 in 1986), whereas the water volume of Amurskii Bay is 19.2 km^3. The concentration of suspended solids in river water usually ranges from 50 to 250 mg l^{-1} (maximum 2800 mg l^{-1} in the River mouth and 136 mg l^{-1} in the marine part of the estuary, in 1989). The mean total solid runoff is 462,000 t per year (Gramm-Osipov 2005). In the estuarine zone, bottom sediments (cockle biotope) gradually accumulate contaminants, organic matter, and inorganic fine grains (Likht *et al.* 1983). Thus, the environment of cockle habitation in the Bay has been gradually changing.

Besides, from 1993 up to now, this cockle population was harvested in the Bay using a mechanical dredge. Dredging adversely affects bottom environments and benthic communities through direct mortality of benthic organisms

*Corresponding author. E-mail: allasilina@mail.ru

(Bergman and van Santbrink 2000), increased sediment resuspension and water turbidity, which inhibits filter-feeding activity and results in suppressed growth of suspention-feeding bivalves, and disruption of the benthic surface microlayer (Facca *et al.* 2002; Le Floch *et al.* 2003). These processes caused apparent changes in the cockle population during the last years.

Additionally, water salinity, especially at high tide, concentration and composition of suspended solids, concentrations of organic carbon and oxygen in water, phytoplankton productivity, and other environmental parameters differ among the various parts of the River estuary (Gramm-Osipov 2005). So, environments for various parts of cockle population differ, mainly depending on their nearness to the River mouth. Therefore, the purposes of this research were (1) comparison of cockle growth rates and population structures in different sites located either close to the Razdolnaya River mouth or farther down-estuary; (2) investigation of changes in cockle density and population structure, as well as cockle growth rates for the last 20 years.

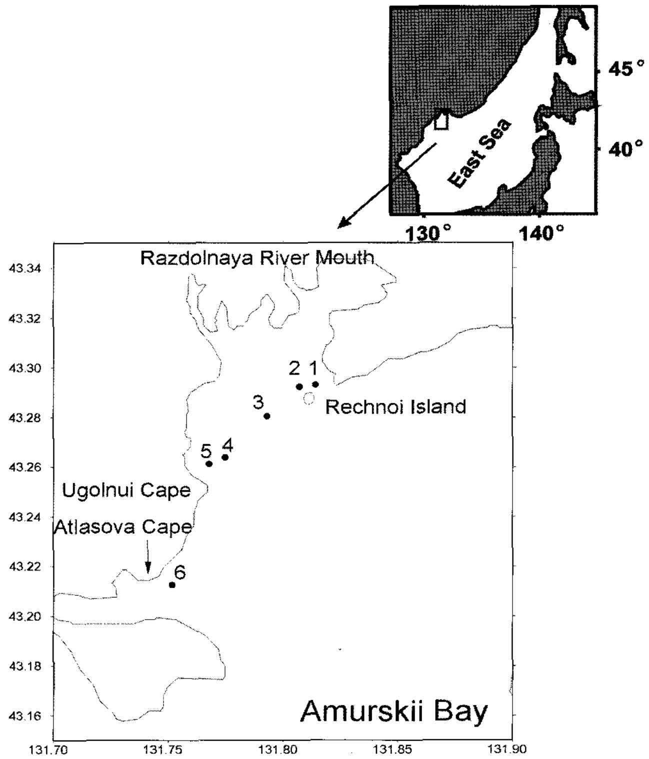

Fig. 1. Locations of *Anadara broughtoni* sampling in Razdolnaya River estuary (Sea of Japan) in 1985 (sites 1–5) and 2005 (sites 4 and 6).

2. Materials and Methods

Study sites and sampling

Cockles were sampled on 19-20 July 1985 and 3 August 2005 in the Razdolnaya River estuary at the head of Amurskii Bay (Peter the Great Gulf, East Sea). In 1985, two parts of cockle population were studied. One population part was located to the north of Ugolnui Cape (sites 4 and 5), and the other near Atlasova Cape (site 6), which is to the south of Ugolnui Cape, i. e. farther from the River mouth (Fig. 1). In 2005, three parts of cockle population were investigated. The first two sites were the nearest to the River mouth, at the northern coast of Rechnoi Island (sites 1 and 2). Site 3 was situated in the center of the section from Rechnoi Island to Ugolnui Cape. Sites 4 and 5 (the same in 1985) were located father from the River mouth than sites 1–3; they were at the western coast of Amurskii Bay, near Ugolnui Cape (Fig. 1). The coordinates of sites were established using GPS Garmin 20. At all years, sampling was made using a 1 m mechanical dredge trawl (mesh 20×20 mm). The experimental trawling way was 100 m. At each site, 2–4 parallel trawlings were carried out.

For comparison, the published data of Olifirenko (1998) and Gabaev and Olifirenko (2001) on cockle density distribution and population structure in the investigated area, which were obtained in 1996 (practically in the middle of the of author's observation period), were used.

Analysis

Total wet weight and soft tissue weight of each mollusk were determined accurate to 0.1 g using a Shimadzu electronic balance. Shell length (long side of a rectangle embracing the shell) and height (short side of this rectangle) were measured accurate to 0.1 mm with sliding calipers.

Sampling depth and near-bottom water temperature were measured at each site. Besides, water samples were taken to determine salinity and concentration of suspended particulate matter (SPM) at the sites. Replicate samples of known volume were filtered onto pre-ashed 37 mm Whatman GF/A grade filter under vacuum. Filters were washed with approximately 5 ml of distillate water to remove residual salts. Filters were then frozen on dry ice and stored in the dark until they were transported to the laboratory for processing. The concentrations of SPM in the near-bottom water were determined after drying filters at 55°C for 48 h and weighing. Two replicate samples of near-bottom water from each site were transported to the laboratory in refrigerator. After one week of precipitation, the concentration of residual SPM was determined.

For grain-size analysis, bottom sediments were excavated in the 0.09 m^2 (each) to a depth of 0–2 cm. All sediment samples were dry-sieved through 0.1, 0.25, 0.5, 1.0, 2.0 and 3.0 mm mesh screens. Grain-size distribution for sediment sample was expressed as % particle dry weight within each size category.

Growth and age of each mollusk sampled in 2005 were determined from growth rings on the outer surface of its shell. Growth rings on the cockle shell form with annual periodicity, in winter in Peter the Great Gulf (Zolotarev 1989). Thus, the age of each cockle was determined by calculation of the number of annual rings on the outer shell surface. Individual linear growth during the lifetime was estimated in retrospect by measuring the heights of cockle shell from its apex to every winter annual ring. For each cockle, its shell heights were determined for the ages of 0.5, 1.5, 2.5, etc. years. Because of the loss of cockle shells sampled in 1985, long-term changes in cockle growth rates were found by comparison of linear growth rates of young 2-8-year-old individuals (cohorts of 1997–2003) with those of old 17-24-year-olds (cohorts of 1981–1988) from the sample of 2005.

Prior to statistical analysis, all data were tested for normality of variance among the different groups by using the Kolmogorov-Smirnov test. A t-test was used to identify significant differences among mean environmental parameters and mean shell heights and wet weights for mollusks of the same age at different sites. The significance criterion for cockle morphometric parameters and environmental parameters was $P < 0.05$.

3. Results

Density distribution

In 1985, at sites 4–5, cockle population density was 2.0–3.1 ind. m^{-2}. Southward, at site 6, it was about 1.0 ind. m^{-2} (Table 1).

Later, in 1996, after commercial cockle trawling had been begun 1994, at sites 4–5, cockle population density noticeably decreased, up to 0.1–0.4 ind. m^{-2}. At site 6, population density was reduced in a lesser degree. Here, it was 0.5–0.8 ind. m^{-2} (Gabaev and Olifirenko 2001).

Table 1. Spatial and temporal dynamics of population density of bivalve *Anadara broughtoni* in Razdolnaya River estuary

Site	Population density, ind. m^{-2}		
	1985	1996	2005
1–2	–	–	0.12–0.13
3	–	–	0.01
4–5	2.0–3.1	0.1–0.4*	0.04–0.10
6	1.0	0.5–0.8*	–

Note. By * the data of Gabaev and Olifirenko (2001) are denoted; – indicates absence of data.

In 2005, cockle population density was 0.12–0.13 ind. m^{-2} at sites 1–2. At site 3, cockles occurred rarely, and population density was about 0.01 ind. m^{-2}. At sites 4–5, population density further decreased (compared to densities in 1985 and 1996) and it was only 0.04–0.10 ind. m^{-2} (Table 1), *i.e.* here cockle population density decreased 30 times for two decades.

Size structure

In 1985, at site 4, 50% of specimens from cockle sample had a shell height of 85–95 mm and 55% of individuals had a total weight from 160 to 240 g (Fig. 2).

In 1996, at the beginning of active commercial cockle fishery, individuals with a shell height of 67–71 mm prevailed (41%) (Gabaev and Olifirenko 2001).

In 2005, at sites located both close to the River mouth (sites 1–2) and farther down-estuary (sites 4–5), samples from cockle population consisted of still smaller individuals, mainly with shell height of 60–65 mm (29.7%) and total weight of 80–120 g (43.2%) (Figs 2 and 3). Thus, at sites 4-5, linear parameters of the cockles decreased approximately by 30% and weight parameters, almost two times for the last 20 years.

Ranges of size and weight parameters differed for cockles inhabiting various estuarine sites (Table 2). Cockle morphometrical parameters were smaller at sites located close to the River mouth than at farther sites. Moreover, this regularity was observed in 2005, as well as twenty years ago (Table 2). In 2005, the majority of cockles had shell height of 50–70 and 60–80 mm, and total weight 60–160 and 80–220 g at sites 1–2 (maximal river influence) and 4–5 (lower river influence), respectively (Fig. 3).

Age structure

In 1996, 1-20-year-old cockles were sampled, and 9-12-

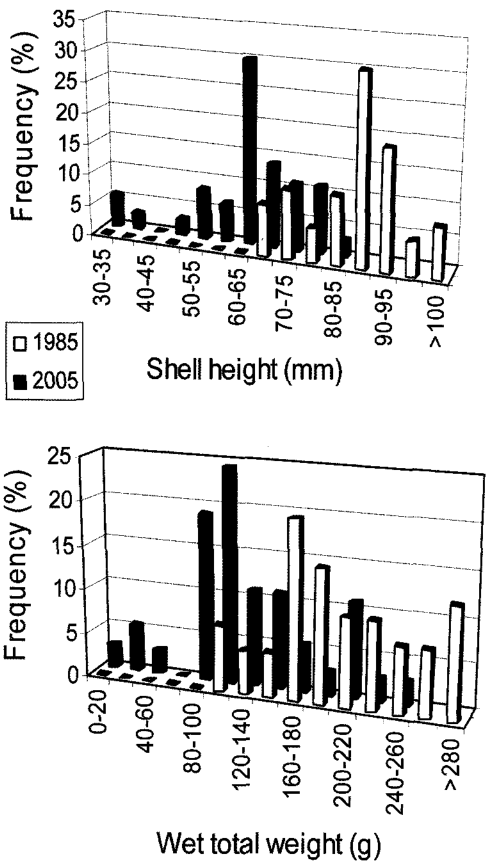

Fig. 2. Shell height and total weight distributions of *Anadara broughtoni* population at site 4 in Razdolnaya River estuary in 1985 and 2005.

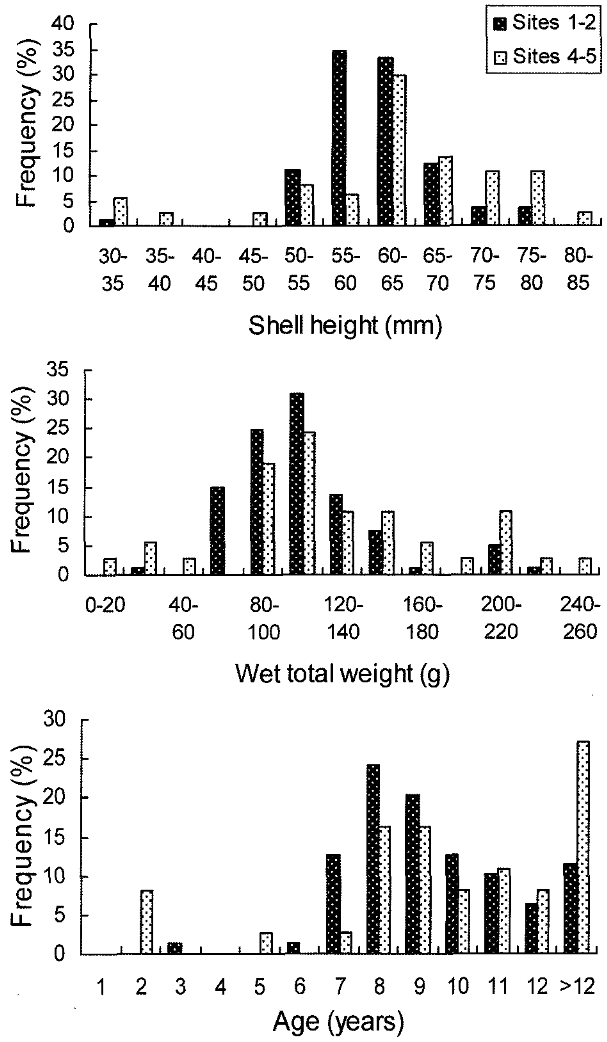

Fig. 3. *Anadara broughtoni* population structure at different sites in Razdolnaya River estuary (sites 1–2 are under maximal and sites 4–5 are under lower effect of river run-off) in 2005.

year-olds dominated (Gabaev and Olifirenko 2001).

In 2005, 2-24-year-old cockles were caught. Eight (17–25%) and nine (12–22%) year olds, cohorts of 1996–1997, were the most frequent everywhere (Fig. 3). Evidently, years 1996 and 1997 were unusually favorable for development, settling and survival of cockle larvae. On the whole, at sites 4–5, cockles were larger and older than at sites 1–2, where River influence was maximal (Table 2, Fig. 3).

Growth

Statistical comparisons of shell heights of the same-aged cockles from various sites revealed that differences in heights were not significant for individuals from sites1, 2

Table 2. Spatial and temporal dynamics of morphometric parameters of bivalve *Anadara broughtoni* in Razdolnaya River estuary

Mollusk parameters	Sites at the River estuary				
	Maximal River effect		Lower River effect		Minimal River effect
	Sites 1–2	Site 3	Sites 4–5		Site 6
	2005 (N=81)	2005 (N=5)	1985 (N=57)	2005 (N=41)	1985 (N=30)
Shell height (mm)	61.6 (34-78)	55 (47-63)	85.0 (66-106)	62.5 (33-81)	90.5 (75-108)
Shell length (mm)	76.9 (46-95)	69 (59-79)	106.0 (84-125)	79.9 (41-102)	114.3 (100-137)
Wet total weight (g)	112.8 (21-230)	76.7 (57-96)	203.7 (102-418)	129.5 (19-261)	243.0 (170-413)
Wet weight of soft tissues (g)	28.9 (5-63)	23.7 (16-32)	51.6 (29-98)	33.8 (5-73)	–

Note. Each value represents the mean (min-max). N is number of specimens. – indicates absence of data.

Table 3. Linear growth of bivalve *Anadara broughtoni* at the different sites in Razdolnaya River estuary

Age (years)	Shell height (mm)				
	Maximal River effect			Lower River effect	
	Site 1 (N=27)	Site 2 (N=54)	Site 3 (N=5)	Site 4 (N=35)	Site 5 (N=6)
0.5	12.1±0.5[a]	11.9±0.2[a]	11.0±1.0[a]	11.5±0.3[a]	12.7±1.1[a]
1.5	23.5±0.9[a]	22.0±0.4[a]	22.1±1.5	28.5±0.7[b]	28.8±1.3[b]
2.5	34.1±0.8[a]	32.4±0.3[a]	33.5±1.2[a]	39.2±0.7[b]	39.8±1.4[b]
3.5	41.3±0.6[a]	38.6±0.4[a]	39.5±1.2[a]	45.5±0.7[b]	46.0±1.3[b]
4.5	45.7±0.6[a]	43.8±0.4	43.5±1.0	50.8±0.7[b]	51.3±1.5[b]
5.5	50.1±0.7[a]	48.9±0.4[a]	47.5±0.9[a]	55.2±0.7[b]	56.5±1.7[b]
6.5	53.6±0.7[a]	52.3±0.4[a]	52.5±1.2[a]	58.1±0.6[b]	59.0±1.7[b]
7.5	57.4±0.6[a]	55.1±0.4[a]	–	60.7±0.6[b]	61.3±1.3[b]
8.5	59.2±0.5[a]	57.7±0.3[a]	–	63.3±0.7[b]	–
9.5	61.3±0.6[a]	59.9±0.3[a]	–	66.8±0.6[b]	–
10.5	63.0±1.0[a]	61.7±0.3[a]	–	69.5±0.6[b]	–

Note. Each value represents the mean ± error of the mean. N is number of specimens; – indicates absence of specimens at the corresponding age. At each line, means sharing different letters are significantly different (t-test, P <0.01, 0.05).

and 3. The same was found for cockles from sites 4 and 5. Therefore, cockles from respective sites (1–3 on the one hand and 4–5 on the other hand) were pooled in two samples, which were compared. Starting at the age of 1.5 years, differences between these samples were statistically significant (t-test for mean shell heights of cockles from sites 1–3 and 4–5, separately for each age, P<0.05). Cockle growth rates were lower at sites 1–3 located closer to the River mouth than at farther sites 4–5 (Table 3). Differences in wet total weights between cockles from these samples were statistically significant starting at the age of 2 years (t-test for mean heights of cockles from sites 1–3 and 4–5, separately for each age, P<0.01, 0.05).

Comparison of the growth rates of young 2-8-year-old cockles (cohorts of 1997–2003) and old 17-24-year-old individuals (cohorts of 1981–1988) revealed a decrease of growth rates in mollusks inhabiting both sites 1–3 and 4–5 for last 15 years (Table 4). Moreover, differences in shell heights for young and old individuals increased with their ages.

Cockle grew most intensively during the first 5–7 years, attaining 55–60 mm in shell height (Table 3). Wet total weight increased intensively, up to 105 g, at the age of 0–9 years. Wet weight of soft tissues made up about 25–26% of the wet total weight of cockles inhabiting any study site.

Spatial variations of environmental parameters

In August 2005, after prolonged (3 days) heavy rains at sites 1 and 2, which are the closest to the River mouth, water temperature was the lowest, 20°C, at the 2.5 m depth.

Table 4. Comparison of linear growth rates of young (2-8-year-olds) and old (17-24-year-olds) specimens of bivalve *Anadara broughtoni* in Razdolnaya River estuary

Age (years)	Shell height (mm)			
	Maximal River effect, Sites 1–3		Lower River effect, Sites 4–5	
	young (N=16)	old (N=5)	young (N=13)	old (N=9)
0.5	11.1±0.8[a]	10.0±0.2[b]	12.5±0.6[c]	11.6±0.5[d]
1.5	22.8±1.0[a]	21.7±0.7[b]	28.7±0.8[c]	27.9±0.9[d]
2.5	31.9±0.8[a]	33.0±0.8[b]	38.5±0.8[c]	39.2±0.9[d]
3.5	38.1±0.7[a]	42.1±0.8[b]	44.9±0.7[c]	46.4±1.0[d]
4.5	42.5±0.6[a]	47.0±0.8[b]	50.1±0.8[c]	52.7±1.0[d]
5.5	48.0±0.8[a]	52.2±1.0[b]	54.4±0.7[c]	57.4±0.9[d]
6.5	51.7±0.6[a]	56.1±1.0[b]	57.2±0.6[c]	60.6±0.9[d]
7.5	54.1±0.4[a]	58.6±0.9[b]	59.6±0.6[c]	63.1±0.8[d]

Note. Each value represents the mean ± error of the mean. N is number of specimens. At each line, means sharing different letters are significantly different (t-test, P <0.01, 0.05).

Table 5. Spatial variations of environmental parameters at the sites of the sampling of bivalve *Anadara broughtoni* in Razdolnaya River estuary, 3 August 2005

Environmental parameters	Sites	
	1–2	4–5
Near bottom water temperature, °C	20–21	22–23
Content of particles <0.1 mm in bottom sediments, %	99.8–99.9	99.3–99.4
Concentration of suspended particulate matter (SPM) in near bottom water, mg l^{-1}	419±12	334±8
SPM after one week of precipitation, mg l^{-1}	108±3	82±3

At central site 3, at the 2.2–2.5 m depth, it was 21°C. At sites 4 and 5 located farther from the mouth, water temperature was higher, 22–23°C at the 2.5 m depth (Table 5). After this downpour, salinity of near-bottom water was 0.7–2.0‰ at the study sites. This water desalination was stressful for the cockle species studied (Berger *et al.* 1982; Yaroslavtseva and Yaroslavtsev 1982; Broom 1985). At the low river flow (8–10 m^3 sec^{-1}), salinity of near-bottom water is about 21.9–32.0‰ at sites 1-3 and 28.6–32.0‰ at sites 4-5 (author's data, Condition. 2005).

At the investigated sites, <0.1 mm particles prevailed in bottom sediments. This particle size category was 99.9% at site 1, 99.8% at site 2, and 98.1% at site 3. Bottom sediments contained 99.4% and 99.3% of silt particles at sites 4 and 5, respectively (Table 5). Thus, bottom sediments at the investigated sites of the estuary were identical and consisted practically of silt.

Difference in concentration of SPM in near-bottom water was statistically significant (t-test, $P < 0.01$) for sites 1–3 and 4–5. Such as, at sites 1–3, SPM concentration was 419±12 mg/L; and at sites 4–5 located farther down-estuary, it was 334±8 mg l^{-1}. After one week of precipitation, water was still turbid in all water samples. Residuary concentrations of SPM were 108±3 and 82±3 mg l^{-1} for samples from sites 1–3 and 4–5, respectively (Table 5).

4. Discussion

In Razdolnaya River estuary, the cockle population density has decreased practically 30 times for the last two decades. The main reason for this reduction is commercial over-fishing. Moreover, in Amurskii Bay, about 5% of dead shells have damage (author's data), and in Ussuriyskii Bay, such shells are about 8% (Afeichuk 2005). Therefore, another reason for decrease of cockle population density is mortality due to damaging effect of trawling equipment. With the beginning of fishery, the population density decreased about 5 times over the three years, and during the following 10 years of regular catch of the cockle, its population density decreased practically 6 times. Now, the cockle population density is low throughout the Razdolnaya River estuary. Besides, cockle size parameters are also reduced; linear parameters of the bulk of cockle population decreased about 30%, and weight parameters decreased almost two times for the two decades.

Moreover, despite reduction of cockle population density and thus decrease in competition for food, cockle growth rates also decreased for the period of study. Besides, from the middle of the 1990s, anthropogenic pollution of Amurskii Bay, including Razdolnaya River estuary, decreases due to the reduction of industrial production and agricultural activity in the Primorsky Krai of Russia (Razdolnaya River basin) (Dulepov *et al.* 2002). This would seem to enhance growth rates of cockles. Thus, during the last 12 years, estuarine biocenosis was exposed to only one unfavorable factor, that is, bottom dredging. It is well known that trawling (dredging) adversely affects benthic community inhabiting the area of trawling due to physical damage of organisms, increase in water turbidity, mixing of edible and inedible particles, etc. (Jennings *et al.* 2001; Piersma *et al.* 2001; Thrush *et al.* 2001; Talman *et al.* 2004; Trimmer *et al.* 2005). At the cockle fishery in Peter the Great Bay, only individuals with shell length 70–95 mm (shell height 56–72 mm, respectively) are selected, and specimens of other sizes are thrown overboard, so, they experience stress. Besides, there is damaging effect of trawling equipment on cockles. Evidently, the reason for reduction of cockle growth rates is the disturbing effect of trawling on cockle population and its biotope.

It should be noted that few cockles with a shell height <55 mm were found, though dredge mesh was 20×20 mm (with diagonal about 28.5 mm; cockles with shell width <28.5 mm have shell height <36 mm). Moreover, there were lumps of bottom sediments in a trawling net (not sifted through the teeth and meshes of dredge), in which small individuals could certainly have been found, if they had been available at the depth of dredging. Such peculiarity of cockle *A. broughtoni* samples was also reported by other researchers (Gabaev and Olifirenko 2001). Size frequency distributions with relatively few small individuals have often been described for other mollusk species including burrowing bivalves (Shimoyama 1984; Peharda *et al.* 2003) and species of *Anadara* genus (Benavides and Carrion 2001). Very likely, this size distribution pattern in cockle population is due to the non-coincidence of locations of young and full-grown cockles at the area occupied by population, as well as different burying depths for young and full-grown individuals. Such as, it is known that young cockles inhabit mainly shoaling waters. Moreover, mature individuals aggregate during the spawning period (Gabaev and Olifirenko 2001; Afeichuk 2005). In Peter the Great Gulf, spawning takes place from the middle of July to the end of August (Dziuba and Maslennikova 1982), i.e. all investigations (in 1985 and 2005) were conducted during the spawning period of cockle. Besides, using the layer-to-layer dredging at the same place Gabaev and Olifirenko (2001) revealed that old *A. broughtoni* individuals live close to the surface or practically on the surface of the bottom. So, these peculiarities of different-aged cockle distributions and trawling method of sampling may explain the rare catch of small specimens.

In all years of survey, the same regularity was revealed. At sites located close to Razdolnaya River mouth, both linear and weight parameters of cockles were smaller than at farther sites. Thus, cockles were larger and their growth rates were higher at site 6 (farthest down-estuary) than at sites 4–5, whereas at sites 4–5 they grew better than at sites 1–2 (nearest to the mouth). Evidently, this difference is a result of the unfavorable effect of the River run-off on cockle. There are several reasons for the reduction of cockle growth rates under the influence of the River.

It is known that cockle tolerance to low water salinity is due to its capability to tightly close the valves and its great internal volume relative to the shell surface. However, prolonged periods of low salinity, which are likely to occur in sites located close to the River mouth, especially after heavy rains, are unfavorable for cockle. Long duration of water salinity within the range of 4–14 ‰ can result in considerable cockle mortality (Berger *et al.* 1982; Yaroslavtseva and Yaroslavtsev 1982; Broom 1985). In 1993, after the rainy summer, high cockle mortality was recorded. In that year, from site 6 to sites 1–3, the number of dead cockles increased from 10 to 50% of the total cockle number in a dredge (Gabaev and Olifirenko 2001). Moreover, after heavy rains in August 2005, water temperature near the mouth (sites 1–2) was 3°C lower than at sites 4–5. *A. broughtoni* is a thermophilic subtropical mollusk (Scarlato 1981; Kanno 1966); that is why temperature decrease can also reduce its growth rates.

Besides, the concentration of SPM in water increases when approaching the River mouth. During strong wind or/ and heavy rains, it exceeds (especially at sites close to the River mouth) the theoretical threshold of disturbance of the physiological processes in organisms, which is 100 mg l^{-1} at chronic exposure and 200 mg l^{-1} at short-term (<5 days) exposure in the estuarine zone (Robinson *et al.* 1984; Patin 2000; Archambault *et al.* 2004). The mollusks stop feeding because of the disturbance of gill function at this SPM concentration in water (Archambault *et al.* 2004). At sites located close to the River mouth (sites 1–2), the threshold was exceeded after a week of period of stress concentration of SPM in water. Though *A. broughtoni* is tolerant to silty bottom sediments and high water turbidity because of the ability to survive periods of unfavorable conditions by tight closure of its valves (Scarlato 1981; Kanno 1966; Broom 1985), frequent or long-lasting transition to anaerobic life conditions can reduce cockle growth rates. Additionally, according to the data of Patin (2000), in the estuarine zone, SPM includes mainly inorganic terrigenous materials; that is why mixing of edible particles with inedible inorganic fine-grained particles reduces food potential for suspension-feeding cockle, especially during the periods of increased terrigenous run-off (e.g. related to heavy or/and steady rain). Grant *et al.* (1990) concluded that high mixing of suspended edible and inorganic particles is one of the main reasons for the decreased growth rates of the oyster *Ostrea edulis.* The highest SPM concentration in the water was observed at sites which are the closest to the River mouth.

Thus, in the estuarine zone, the commercial cockle *A. broughtoni* is affected by a variety of unfavorable factors operating either for short periods of time or permanently. The unfavorable anthropogenic factors are ecological disturbances in the cockle population (removal of a considerable portion of cockles from their population, mechanical damage of shells and stress due to dredging) and cockle biotope (mixing of bottom sediments, increase in water turbidity, etc. during dredging). Unfavorable natural factors are low water salinity and high concentration of suspended particulate matter (mainly of terrigenous origin); and these adverse conditions are more frequent and prolonged at sites located closer to the river mouth than at farther sites. Therefore, these factors lead to spatial heterogeneity and temporal changes in cockle population.

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