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Scallops of the Russian waters of northwestern Pacific. Part 1. Biology and ecology

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The review of biology and ecology of eight species of scallops (Bivalvia, Pectinidae) of the Russian Far East is given.

Морские гребешки российских вод северо-западной части Тихого океана. Часть 1. Биология и экология

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Обзор биологии и экологии 8 видов гребешков (Bivalvia, Pectinidae) Дальнего Востока России.

Scallops are the most intensively consumed and fished bivalve mollusks. The recent data on biology and ecology of eight scallops species from the Russian part of northwestern Pacific are reviewed in this part of paper.

Taxonomic status

According to recent data [Kafanov, 1991; Kafanov, Lutaenko, 1998], the Russian part of northern Pacific Ocean is inhabited by eight species of Pectinidae. Their taxonomic status is as follows:

Class **Bivalvia** Linne, 1758

Order **Pectinida**

H. Adams et A. Adams, 1857

Family **Pectinidae** Rafinesque, 1815

Genus ***Chlamys*** Röding, 1798

1. *Chlamys* (*Chlamys*) *albida* Arnold, 1906 (ex Dall, MS)

Until recently, in Pacific waters this species was confused with *Ch. islandica* (Müller, 1776).

2. *Ch.* (*Ch.*) *asiatica* Scarlato, 1981

3. *Ch.* (*Ch.*) *behringiana* (Middendorff, 1849)

4. *Ch.* (*Ch.*) *chosenica* Kuroda, 1932

Until recently, waters this species was confused with *Ch. rosealba* Scarlato, 1981.

5. *Ch.* (*Azumapecten*) *farreri* (Jones et Preston, 1904)

Until recently, this species was confused with *Ch. farreri nipponensis* Kuroda, 1932 or *Ch. nipponensis* Kuroda, 1932.

6. *Ch.* (*Swiftopecten*) *swiftii* (Bernardi, 1858)

Genus ***Delectopecten*** Stewart, 1930

7. *Delectopecten randolphi* (Dall, 1897)

Genus ***Mizuhopecten*** Masuda, 1963

8. *Mizuhopecten yessoensis* (Jay, 1857)

Biology and ecology

Chlamys albida

Common names: White scallop and Commercial scallop.

According to zonal-geographical terminology, *Ch. albida* is a Pacific widespread high-boreal species. It occurs from the middle Primorye [Lutaenko, 1999] up to the northern part of the Sea of Japan (Tatar Strait); along northern coast of the Sea of Okhotsk; near Kurile Islands (Paramushir and Iturup); Commander and Aleutian Islands. It is registered at depths of 36–398 m in muddy sand with pebbles [Scarlato, 1981]. This species occurs at a temperature range of near-bottom waters from −0.79 to 4.79°C, salinity range of 33.05–33.43‰ and oxygen abundance from 5.67 to 6.40 mg/l [Myasnikov, 1985]. In Kuriles, White scallops were more frequently inhabited by sponges *Mycale adhaerens* and *Myxilla parasitica*; and rarely by various hydrozoans, barnacles, bryozoans, algae, polychaetes, sea anemones and juveniles of bivalve mollusks [Myasnikov, 1986].

The growth rates of scallops from different regions of the Kurile Islands differ greatly from each other [Silina, Pozdnyakova, 1986]. Nevertheless, approximately equal high rates of linear growth (up to 13.5 mm/yr) are observed in all regions within the first three years (Table 1). After this age, the most intensive linear growth is observed in mollusks inhabited along the Sea of Okhotsk side of Onekotan Island, where the shell grows can amount up to 18 mm/yr. After this age, the most intensive linear growth is observed in mollusks inhabited along the Okhotsk side of Onekotan Island, where the shell growth can amount up to 18 mm/yr. The minimum shell growth was observed in Simushir Island (middle Kuriles). The annual shell growth did not exceed 13 mm/yr at this region and at Pacific Ocean waters of Onekotan Island. According to V.N. Zolotarev [1979], mollusks have three strongly pronounced stages of linear growth: juvenile, mature and senile. For *Ch. albida*, juvenile or fast growth stage finishes when the age of puberty is reached. The next stage (mature) is limited to age of 10 years. Senile stage starts at 10 years when annual shell growth does not exceed 0.5–1.5 mm. Scallops reach marketable size (60 mm) at about 5 years.

As well as in linear parameters, the weight of mollusks during their life is changed irregularly. Up to certain sizes (50–60 mm), weight increases by equal rates. Henceforward weight increase rates in scallops inhabiting the Sea of Okhotsk side of Onekotan Island are different from those of scallops from the Pacific Ocean waters. Maximum weight increases (up to 23 g/yr) is observed at the age of 5 years.

According to V.G. Myasnikov [1988], the population of *Ch. albida* from the northern part of the Sea of Okhotsk is represented by mollusks with shell height within 18–93 mm, on average 68 mm. Nevertheless, individuals with the size of 70–80 mm (about 40%) predominated. The average shell height correlates with inhabiting depths. The depth increase from 50 to 125 m result in the average shell height increase from 41 to 73 mm. In addition, at depths of over 125 m shell height decelerates markedly up to 62 mm.

The maximum age of scallops does not exceed 28–30 years. The age of sexual maturity is 3–5 years at shell height of 40–70 mm. The sex ratio (male/female)

Table 1

Shell height (mm) of different ages commercial scallops in Russian waters of northwestern Pacific, M±m

Age, years	*Ch. albida*	*Ch. behringiana*	*Ch. chosenica*
	[after Silina, Pozdnyakova, 1991]		[after Silina, Pozdnyakova, 1990]
0.5	7.5±0.6	8.6±0.9	9.6±0.5
1.5	19.7±1.0	19.0±1.9	23.5±0.5
2.5	31.6±1.4	31.3±1.9	35.1±0.6
3.5	43.5±1.5	44.0±2.0	45.0±0.6
4.5	54.9±1.5	55.9±2.0	53.2±0.6
5.5	64.5±1.5	65.4±2.2	59.2±0.6
6.5	71.4±1.5	72.5±2.4	63.5±0.6
7.5	77.0±1.8	76.9±2.4	66.7±0.6
8.5	–	–	69.6±0.6
9.5	–	–	72.0±0.6
10.5	–	–	74.4±0.7
11.5	–	–	76.2±0.8
12.5	–	–	77.4±1.2

Note. «–» – data are not available.

changes in population from 0.6/1.0 to 2.0/1.0. In northern Kuriles, mass spawning in population starts in June [Myasnikov, Kochnev, 1988].

Nowadays four commercial concentrations of *Ch. albida* are known along southern and northern coast of northern Kurile Islands (Sea of Okhotsk side and Pacific Ocean side); at Simushir Island; in the northern part of the Sea of Okhotsk [Myasnikov, Hen, 1990; Myasnikov et al., 1992].

Chlamys asiatica

Common name: Asian scallop.

Ch. asiatica is a Pacific Asian high-boreal species. It occurs at Kurile Islands; at eastern coast of Kamchatka Peninsula; at the Bering Sea (the Anadyr Bay). It is registered at a depth of 80–120 m in sandy ground admixed with shingle and muddy sands [Scarlato, 1981]. It was rarely met within the limits of natural habitat.

Chlamys behringiana

Common name: Bering scallop.

Ch. behringiana is a Pacific widespread high-boreal species. It occurs in the Pacific Ocean: the Sea of Okhotsk – Sakhalin and Aniva Bays, Strait of La Perouse, southern and eastern waters of Kamchatka Peninsula, Kurile Islands (Paramushir and Shikotan); Bering Sea. In Arctic Ocean, it was found in the southern part of the Chukchi Sea and Beaufort Sea. It is registered at a depth of 24–200 m in muddy sands admixed with shingle and gravel; in gravel with pebbled grounds [Scarlato, 1981]. This species occurs at temperature range of near-bottom waters from 0.79 to 4.79°C; salinity range of 33.05–33.43‰ and oxygen abundance from 5.67 to 6.40 mg/l [Myasnikov, 1985]. Bering scallops are often inhabited by hydroids *Eunephtya* sp. and ascidians *Pyaridae* [Myasnikov, 1986].

According to recent investigations [Buyanovsky, 1999], larger scallops are observed in Karaginsky Island (72.7 mm) at the age of 10–15 years and in Olyutorsky Bay [83.3 mm] at 20–25 years. After this age, shell height is not changed. Higher growth rates in scallops from the Olyutorsky Bay are probably linked to more intensive water exchange. This is due to the fact that the main branch of Kamchatka Current is located there.

The maximum age of scallops is 35 years, but older part of population is represented mostly by mollusks of 25–28 years old. The most intensive linear growth is observed in the first two years and can amount up to 15 mm/yr. At the age of 3–6, the shell grows by 4.2–11.5 mm/yr. Then (at the age of sexual maturity), linear growth decelerates considerably and it reaches 1.6–1.2 mm/yr in 10-year-old mollusks [Silina, Pozdnyakova, 1991]. Scallops reach marketable size (60 mm) in about 6 years (Table 1). In contrast to linear parameters, the weight of mollusks increases almost in proportion to its age [Buyanovsky, 1999].

Chlamys chosenica

Common names: Pink scallop and White-pink scallop.

Ch. chosenica is a Pacific Asian low-boreal species. It occurs in the Sea of Japan – along the Primorye coastline; in western Sakhalin Island and northwestern part of Hokkaido Island; in waters of the Small Kurile Ridge and Iturup Island. It is recorded at a depth range of 13–2030 m in muddy sands admixed with shingle and gravel and sometimes in sand or shell rocky grounds [Scarlato, 1981]. It is quite eurybiontic species occuring at temperature range of near-bottom waters from −0.09 to 13.03°C; salinity range of 33.34–34.15‰ and oxygen abundance from 5.49 to 7.49 mg/l [Myasnikov, 1985]. Along the coast of northern Primorye, Pink scallops are mainly colonized by gastropod mollusk *Velutina* sp. [Myasnikov, 1986].

According to recent investigations [Silina, Pozdnyakova, 1990], the population of *Ch. chosenica* from the northern Primorye is represented by mollusks with shell height up to 90 mm, but individuals measuring 68–81 mm predominate. The size distribution of scallops is a one-peaked curve, with a maximum of 77–76 mm. The maximum age of scallops is 22 years, but the population is mostly represented by mollusks of 11–12 years old.

The most intensive linear growth is observed in the first two years and can amount up to 16 mm/yr. At the age of 3–6 years, the shell grows by 5.2–10.8 mm/yr. Then (at the age of sexual maturity), linear growth decelerates markedly and in 10-year-old mollusks comes to 2.5–1.0 mm/yr in all. Scallops reach marketable size (60 mm) in about 6 years (Table 1). In the 9–14-year-old scallops with average shell height of 70–79 mm, the muscles weight 7.4–10.4 g. In four years, from 10 to 14 years, the muscle weight increases by not more than 25% and shell weight increases at least by 50%. At the same time muscles comprise 20–25% of the total weight of the mollusk whenever shells comprise 44–52%.

The sex ratio (male/female) in population is approximately 1.0 to 1.2. The domination of females (55%) implicates the stable status of the populations of *Ch. chosenica*. Spawning of population take place mostly in the first half of summer [Silina, Pozdnyakova, 1990].

Chlamys farreri

Common names: Japanese scallop, Chinese scallop, Farrer's scallop, Akazara scallop.

Ch. farreri is a Pacific Asian subtropical species. In the Sea of Japan, it is widely distributed along the southern coasts, which is the northern boundary of its natural habitat. Also, it occurs in Primorye and in Japanese Islands in total bathymetric range from 0.5 to 24 m [Scarlato, 1981]. The mollusk mainly inhabits the gravel and pebble grounds. Scallops often form many-tier reefs in rocks and oyster banks. Density of settlements can vary extremely up to 150–180 specimens/m^2 (in reefs) in depth range of 1.5–2.5 m. At other depths, their density decreases down to 5–10 specimens/m^2. This species occurs at a temperature range of near-bottom waters up to 19–22°C, and salinity range of 32–34‰.

This species is an object for mariculture and fishery in East Asian countries [Wang, Shieh, 1991]. In Russia, Japanese scallop is one of the most perspective species for fishery and mariculture [Bregman, 1982; Afeichuk, 1992a].

According to recent investigations [Afeichuk, 1992a], the population of *Ch. farreri* from the Possjet Bay is represented by mollusks with shell height up to 112 mm, but individuals measuring 70–80 mm predominate. The maximum age of scallops is 9 years, but the population is mainly represented by mollusks of three (35%) and four (27%) years old at average 3.5 years. After 6 years, natural elimination increased markedly. Therefore, only 12% of populations are older than 6 years old.

The most intensive linear growth is observed during the first three years and can amount up to 19 mm/yr. At the age of 4–7 years, the shell grows by 5.8–11.5 mm/yr. After this, linear growth decelerates markedly [Afreichuk, 1992b]. The scallops reach marketable size [72 mm] in about 3–4 years. At that time the muscles weight 5.5 g. Whenever the muscle weight of a 5-year-old scallop with average shell height of 90 mm is 11 g. In total muscles comprise 12–14% of the total weight of the mollusk and the shells amount to 63% [Afreichuk, 1990].

The age of sexual maturity is 2 years old when shell's height is 40–45 mm (Table 2). The approximate sex ratio (male/female) in population is 1 to 1.36. At the Possjet Bay spawning in population starts at the end of June when temperature of near-bottom waters approach to 16°C. The mass spawning begins in the middle of July at temperature of 18–20°C. Spawning ends at the end of August or early in September. Therefore the spawning period comprises 65 days [Afeichuk, 1992a].

Table 2

Shell height (mm) of different ages Japanese scallop *Chlamys farreri* in southern part of the Sea of Japan [after Bregman, 1982], M±m

Age, years	1	2	3	4	5
Shell height, mm	2.70±096	4.30±1.50	5.85±0.90	7.00±0.96	7.80±0.96

In Peter the Great Bay, larvae occur in plankton during the warmest season in July and August, at water temperature of 15–20°C [Kasyanov et al., 1980]. The maximum density of larvae occurs in shallow bights at a bathymetric range of 5–7 m [Afeichuk et al., 1988]. The period of settling on hard and fibrous substrate (depths to 23 m) continues from the middle of July to early August. The optimal depth for spat collection is 5–8.5 m [Gabaev, 1988]. The density of juveniles' settlements in collectors can reach up to 229 specimens/m^2, on average 48 specimens/m^2 [Afeichuk et al., 1988; Gabaev, 1990]. The morphology of larvae and larval shell structure were described by V.A. Kulikova with co-authors [1981].

Chlamys swiftii

Common name: Swift's scallop.

Ch. swifti is a Pacific Asian low-boreal species. It is distributed along the southern coasts of the Sea of Japan, and it also occurs in western Sakhalin, Hokkaido and northern part of Honshu Island. In the Okhotsk Sea, it is known from southern Sakhalin (Aniva Bay) and in shallow waters of south Kurile shoal. The mollusk mainly inhabits the gravel, pebble and shell grounds at depths of 2–143 m [Scarlato, 1981]. This species occurs at a temperature range of near-bottom waters from 9 to 22°C, and salinity range of 32–34‰.

The population of *Ch. swiftii* from the northern Primorye is represented by mollusks with shell height up to 121 mm, but individuals measuring up to 65–90 mm predominate [Ponurovsky, 1982; Ponurovsky, Silina, 1983]. The maximum age of scallops is 13 years, but the majority of the population is represented by mollusks up to five years old.

Swift's scallop grows through all life. However, the most intensive linear growth is observed during the first three years after settling on the bottom and can amount up to 21–26 mm/yr. After 4 years old, linear growth decelerates markedly and reaches only 1.0 mm/yr in 8-year-old mollusks [Ponurovsky, 1977; Ponurovsky, Silina, 1983]. The highest rates of linear growth of scallops were registered at such regions of the Sea of Japan as Petrov and Putyatin Islands, Vostok Bay (Table 3). Thus, these areas are more favorable for intensive growth of Swift's scallop [Ponurovsky, 1982].

The sexual maturity is reached at 3 years when shell height is 50–70 mm. The approximate sex ratio (male/female/hermaphrodite) in the population is 1.0 to 0.67 to 0.02 [Denisova, 1981]. At the age of 3 years, males predominate (86.3%) in the population. Later, males percentage decelerates considerably. At the age of 10 years, females predominate (81.2%) over all in population.

In Peter the Great Bay and Bousse Lagoon (southern Sakhalin), larvae are abundant in plankton from August to September at a water temperature of 15–20°C. The maximum density of larvae occurs in near-bottom waters in bathymetric range of 10–20 m [Kasyanov et al., 1983]. The morphology of larvae and larval shell structure were described by V.A. Kulikova with co-authors [1981]. The optimal depth for spat collection exceeds 15 m [Gabaev, 1988].

Delectopecten randolphi

Common name: Randolph's scallop.

D. randolphi is a north Pacific widespread species. It is distributed in the Sea of Japan – Possjet Bay, Peter the Great Bay,

Table 3

Shell height (mm) of different ages Swift's scallop *Chlamys swiftii* in northwestern part of the Sea of Japan [after Ponurovsky, 1982], M±m

Age, years	Region (from southern to northern) of scallops collection							
	Furugelm Island	Vityaz Inlet	Stenin Island	Klykov Island	Putyatin Island	Vostok Bay	Melkovodnaya Inlet	Petrov Island
1	29.7±0.5	26.7±0.4	21.2±0.5	24.3±0.4	29.3± 0.2	21.3±0.2	24.2± 0.4	29.8±0.3
2	44.1±1.0	37.4±0.7	32.3±1.0	34.9±0.8	45.8±0.4	45.8±0.6	40.0±0.7	47.3±0.5
3	62.3±1.7	52.8±1.5	48.9±1.6	49.4±1.4	67.2±0.6	70.3±0.7	60.6±0.7	69.8±0.6
4	87.4±1.8	70.2±20.1	67.6±2.0	69.1±1.7	90.6±0.6	88.9±0.7	81.3±0.7	90.5±0.5
5	95.1±1.4	87.5±2.0	86.1±1.9	87.9±1.7	106.4±0.4	100.3±0.7	94.7±0.6	101.6±0.5
6	101.5±1.5	97.8±1.9	96.9±1.4	99.8±1.7	112.9±0.4	105.7±0.8	98.8±0.6	105.1±0.5
7	102.3±1.8	104.4±1.7	102.1±1.2	105.3±1.3	116.8±0.5	106.7±0.9	102.0±0.6	107.5±0.6
8	104.5±2.5	107.1±1.4	105.3±1.2	109.1±1.3	118.6±0.6	108.7±1.1	104.0±0.8	109.6±0.8
9	105.6±2.7	107.4±1.6	106.5±1.3	111.3±1.5	120.6±0.7	109.0±1.5	105.6±0.9	110.8±0.9
10	–	–	107.2±1.4	112.1±1.4	121.1±1.0	–	106.2±1.7	110.5±0.8
N	22	33	30	43	243	160	51	219

Note. N – number of specimens; «–» – data are not available.

eastern Honshu Island (Sagami Bay); in Okhotsk Sea – along the eastern and western coasts; in Bering Sea – along eastern coastline. The mollusk inhabits the mud grounds at a depth of 418–3080 m [Scarlato, 1981]. This species occurs at a temperature range of near-bottom waters of 0.2–2.5°C.

The largest specimen known from the Peter the Great Bay had dimensions of 23.5 x 27.0 mm.

Mizuhopecten yessoensis

Common names: Yesso scallop[1], Ezo scallop, Giant scallop, Japanese scallop, Russian scallop, Primorsky scallop and Common scallop.

Yesso scallop *M. yessoensis* is a Pacific Asian low-boreal species of commercial value, the biggest of all pectinids. It occurs along the northern coast of the Korean Peninsula, the coastline of Primorye, near the shores of the Sakhalin, southern Kuriles and Hokkaido and on the northern coast of Honshu Island [Scarlato, 1981].

Yesso scallop was widely spread in southern and middle Primorye and occurred in bays and inlets forming aggregations at a depth of 6–30 m. These mollusks were an object of traditional catching in the region till the beginning of 1970's. But at present, commercial stock of the natural Yesso scallop along the coast of Primorye is exhausted because of irrational catching during the last ten years and its average density does not exceed 0.001 specimen/m^2.

Commercial assemblages of Yesso scallop is also known in Sakhalin Island in Aniva and Terpenye Bays. Their distribution has irregular and mosaic pattern with density up to 4.3 specimens/m^2. In Kuriles, commercial assemblages of Yesso scallop are known in shallow waters of Kunashir Island and on the south Kuriles shoal. Average density of settlements at bottom grounds is 0.5 specimens/m^2.

As Yesso scallop is not only the most known, but also is well studied pectinid species, this fact allows us to describe some aspects of its biology in more details.

Bathymetric distribution. In shallow waters, the scallop occurs at a depth of 0.5–1.0 m in small inlets inaccessible to wind and waves. Minimum depth corresponds to the winter time water level under the ice cover. Most of the scallops were found in bathymetric range of 4–10 m in closed inlets and additionally at a depth of 20–25 m in open and relatively deep-water sites of bays and inlets. Most of the mollusks were found along the coast at a depth of 20–25 m near rugged shores. In Peter the Great Bay, the scallop was recorded at a maximum depth of 82 m [Scarlato, 1981].

Age structure of scallop settlements. Biologists believe that this species does not live more than eleven years on the average [Tibilova, Bregman, 1975] and that their real life expectancy ranges from 7 to 9 years [Makarova, 1985]. The most extensively studied populations in Primorye have no 1–2 year old specimens. Eleven–to–twelve-year-old scallops are quite frequent but older specimens are seldom.

Scallop growth. The fertilized scallop's eggs (about 60–70 μm in diameter) develop to grow into a larva, which settles onto the substrate (shell is 260–285 μm on average) in 20–40 days, depending on temperature conditions. Definitive development of scallops terminates on the substrate. The scallop detaches from the

[1] This name is used in *Yearbook of Fishery Statistics*, Rome, FAO.

substrate in 3–4 months when the shells' height is 10–30 mm. Subsequent scallop growth rate depends on temperature, feeding, water exchange and many other conditions on the sea floor.

The scallop shell grows isometrically to retain its initial form. L.G. Makarova [1985] calculated the general equation for the linear growth of Yesso scallop:

$$H_t = (160.92 \pm 18.7) \cdot (1 - e^{(-0.378 \pm 0.04)} \cdot t),$$

where $\mathbf{H_t}$ is the shell height, mm; and **t** is scallops age, years.

The scallop grows at a temperature ranging from −2°C to 26°C. The optimal growth temperature is 4–6°C. In Primorye, the temperature optimum is in May–June and in September–October [Silina, Bregman, 1986]. Within the initial three years, the scallop height reaches 90–110 mm, and then its growth slows exponentially (Table 4). The largest specimens occur in settlements on silty-sandy bottom in sites with good water exchange and relatively stable temperatures approximately at a depth of 20 m. There they become 190–195 mm height and even larger at the age of 16 and older. In the southern Kuriles, specimens older than 20 with a shell height of 220 mm were found [Skalkin, 1966]. In shallow silty inlets, scallops seldom exceed 150 mm and do not live more than 10–12 years. In Possjet Bay, we recorded the largest scallop specimen, whose dimensions were as follows: shell height 222 mm, height 202 mm, and width 37 mm. The scallop mass varies proportionally to its linear dimensions [Silina, Bregman, 1986].

The share of muscles in the scallop total mass amounts to 10–18% in various settlements of Peter the Great Bay [Belogrudov, 1981].

Sex structure of settlements. The approximate (male/female) sex ratio in population is 1.0 to 1.0 practically in all the surveyed settlements. Hermaphrodites were observed in not more than 0.3–0.4% of all cases [Bregman, 1979]. But in the same populations, males dominate in younger generation and females in elder ones. So, at the age of 1–3 years, sex ratio was approximately 2.0 to 1.0; at the age of 5–6 years, sex ratio was 1.9 to 1.0, and at the age of 7–8 years, sex ratio was 1.0 to 1.9. This could be due either to different death rate among both sexes or because of hermaphroditism.

Replenishment. Scallop populations replenish annually owing to spawning, subsequent development of larvae in plankton, their settling on substrate and juveniles' transition to free life on the seabed.

Spawning. Spawning in scallops' population starts at temperature range of 7–9°C [Belogrudov, 1981]. In waters around Primorye, spawning begins in the middle of May, and spawning ends at the end of June. Spawning begins in shallow waters of southern regions; as the seawater warm up, specimens from the deeper and more northerly settlements begin to spawn. Absolute fertility varies from 25–30 to 180 million eggs [Yamamoto, 1964] depending on age and size.

Larvae morphology. The morphology of larvae and larval shell structure of three widespread scallops: Yesso scallop *M. yessoensis,* Japanese scallop *Ch. farreri* and Swift's scallop *Ch. swifti* were described by V.A. Kulikova with co-authors [1981]. All of the larvae are of triangular form and the anterior end is the apex of the triangle. The larvae are inequivalve. The umbos are low, rounded and poorly defined. The

Table 4

Linear growth of Yesso scallop *Mizuhopecten yessoensis* from various regions of natural habitat in Russian waters of northwestern Pacific [after Silina, Bregman, 1986]

Region	Shell height (mm) at corresponding age (in numerator) and annual shell gain (in denominator), M±m									
	1	2	3	4	5	6	7	8	9	10
Furugel'm Island	50.2±1.2 / 50.2±1.2	101.4±1.2 / 51.2±0.9	125.9±1.3 / 24.5±1.0	141.4±1.9 / 15.5±1.0	151.8±1.8 / 10.4±0.8	156.4±2.5 / 4.6±0.8	–	–	–	–
Bol'shoi Pelis Island	–	89.8±4.2 / no data	120.4±3.2 / 30.5±1.0	139.1±2.1 / 18.7±2.0	147.8±2.4 / 8.7±1.8	151.5±2.6 / no data	151.8±2.8 / no data	–	–	–
Andreev Inlet	46.9±0.8 / 46.9±0.8	85.8±1.0 / 38.9±1.0	107.0±1.0 / 21.2±1.0	118.8±1.1 / 11.8±1.0	124.7±1.3 / 5.6±0.9	128.3±1.1 / 3.6±0.8	130.4±1.5 / 2.4±0.6	133.5±1.7 / 3.0±0.8	–	–
Putyatin Island	50.7±1.6 / 50.7±1.6	90.8±1.2 / 40.2±1.4	115.3±1.0 / 24.5±1.2	128.5±1.1 / 13.2±1.1	135.7±1.8 / 7.3±1.2	141.1±1.0 / no data	–	–	–	–
Olga Bay	36.6±1.1 / 36.6±1.1	83.2±1.4 / 43.8±2.2	114.6±1.4 / 30.4±2.0	133.8±1.0 / 14.0±1.6	145.4±0.9 / 11.0±1.3	152.0±1.1 / no data	154.5±1.1 / no data	155.4±1.5 / no data	158.8±1.7 / no data	–
Vladimir Bay	33.6±2.6 / 33.6±2.6	77.4±2.8 / 43.8±2.2	107.8±2.4 / 30.4±2.0	121.8±2.8 / 14.0±1.6	132.8±2.8 / 11.0±1.3	–	–	–	–	–
Aniva Bay	26.1±2.4 / 26.1±2.0	56.2±2.1 / 30.1±2.0	86.9±2.0 / 30.7±1.8	110.9±1.4 / 24.0±1.6	125.5±1.6 / 14.6±1.4	134.2±2.1 / 8.7±1.0	143.6±2.2 / 9.4±0.8	148.4±2.3 / 4.8±0.6	156.2±2.3 / no data	160.8±2.5 / no data
Izmena Strait	24.9±5.8 / 24.9	75.2±8.4 / 50.3	97.9±10.4 / 22.7	119.9±8.2 / 22.0	130.7±8.4 / 10.8	138.4±5.2 / 7.7	141.2±3.9 / 2.8	143.0±4.8 / 1.8	–	–
South Kuril Strait	20.7±5.5 / 20.7	56.9±6.8 / 36.2	89.0±11.5 / 32.1	119.1±12.2 / 30.1	141.3±11.1 / 22.2	150.3±8.7 / 9.0	155.3±7.7 / 5.0	158.4±7.5 / 3.1	161.3±8.0 / 2.9	–

N o t e . «–» – data are not available.

taxodont hinge has several teeth at each side of the hinge line. The central hinge area is undifferentiated. However some specific characteristics were distinguished among the scallop larvae of Peter the Great Bay. Their main differences are in the shell form, umbo form, shell size, number of teeth at each side of the hinge line [Kulikova et al., 1981].

Development in plankton. Duration of larvae growth in plankton lasts from 20 to 40 days [Kasyanov et al., 1980]. Larvae disseminating current-induced distribution mechanism create new local settlements. Plankton surveys [Belogrudov, 1981] showed that larvae can form dense distributions in Possjet and Peter the Great Bays over several square kilometers. In that case, higher densities are noted in areas with abounding adult mollusks. In bonanza years, larval density reached 200–300 specimens per cubic meter in the closed inlets; at the same time, it did not exceed 20–30 specimens per cubic meter in the adjacent open inlets and bays. Long-term researches in Possjet Bay showed the absence of direct spatial relations between parents and new scallops generations.

Migration behavior. It is well-known fact that the Yesso scallops can freely move along the sea bottom. The mechanism of reactive movement of freely living scallop is widely known (for example: Dautov, Karpenko, 1983). As a rule, researchers note random movement in natural conditions, or individual scallop behavior in aquarium. Such evidence generally helps to form an idea that the scallop is a migrating species. But the fact that populations have been present for many years in specific sites clearly showed that scallops ability to migrate is limited.

Risk factors. Abiotic factors. Survival rates of the pelagic larvae at metamorphosis depends on water temperature (ranges for survival is 5–20°C, with an optimum of 10–15°C), salinity (30–40‰, optimum of 33‰), density (optimum 8 specimens/ml), quantity and composition of food and on abundance of predators [Belogrudov, 1973; Bregman, Guida, 1983; Chan, 1989]. In addition to that, mortality is caused mainly by the absence of suitable substrate and intolerance to changing environments [Yamamoto, 1964; Belogrudov, 1973]. Yu.E. Bregman and G.M. Guida [1983] reported that the number of attached juveniles made only 5–8% of all fertilized eggs. Settling on the bottom is the next critical period in the life history of the scallop, and the mortality increases sharply. According to G. Yamamoto [1964], only 5–10% or sometimes none of the settled juveniles survive. A.N. Golikov and O.A. Scarlato [1970] reported that only 4% of the settled juveniles survived as long as 6 months. Only A.N. Golikov and O.A. Scarlato [1970] have reported on the mortality of older scallops; these researchers conjectured that after 6 months the quantity of survived mollusks decreased gradually. Moreover, they noted that winter was the period when the highest mortality of scallops occurred off the northwestern coastline of the Sea of Japan. In contrast, in Honshu Island, the most difficult season for scallop survival is summer and early autumn when water temperature increases above 15°C [Yamamoto, 1960].

Recent investigation [Silina, 1996] also shows the highest mortality when scallop were less than 2 years while the mortality from 2 to 5 years of age is minimal. And quite the contrary, at the age of 6–7 years (probably, the beginning of the senile period of scallop development) and upwards to 9–10 years (transition to the old-aged stage), scallops mortality increased sharply.

Storms. Storms are another factor, which causes mass deaths of scallops in coastal shallow settlements. Depending on the floor relief, they can increase settlement dispersity over vast flat areas or make them more dense at the foothills of cliffs. In either case, a considerable number of mollusks are buried under moving sediments. Near shallow coasts, particularly beaches, the majority of scallops die in storm drift. Trivial storms deform settlements; however, the loss is compensated by annual replenishment. While the impact of typhoons (annual frequency is about 50%) are natural calamities for the floor near-shore population, including the scallop, for they destroy most of the species around open waters at about 20 m deep [Kalashnikov, 1984; 1985].

Predators. The first hours and days of life on the sea floor till the moment the mollusks become one year old (shell height is about 30 mm) appeared to be the most dangerous ones. During this period, natural death is maximal and young scallops are preyed upon by various starfish species such as *Asterias amurensis*, which can grow up to 165 mm in a radius and weigh 450 g. Another species, *Distolasterias nipon* is even larger growing up to 250 mm with a weight of 1000 g. These species attack the scallops, age of which is less or the same as that of starfish. One-time ration of one starfish changed from 1 up to 8.5 g of fish and annually amounts 400–450 g [Biryulina, 1972]. In view of great abundance of these predators (density can amount up to 15 specimens/m^2), the damage of population can be considerable. The death rate of young scallops in super-dense aggregations (over 100 specimens/m^2), in which predators temporarily eat only scallop, is especially high.

When storms are so strong that they influence the sea floor, scallops become weaker and readily accessible to predators. Joint effects of storms and starfishes have destroyed an artificial scallop settlement (about two hectares) with a population of over 200000 specimens for several weeks. In stable conditions, starfish and scallops were noted to co-exist peacefully when they occupied a single habitat for several years in succession. However, generally the number of cultivated mollusks declines more in sites where starfish are more abundant.

After the sowing, spat are preyed upon by various benthophagous fishes such as flounders and bullheads. It is quite possible that in this period scallops are preyed by fishes more than by starfishes. There are other predators of sown seed and adult scallops, which are less important but nevertheless, pose a threat to small seed and juveniles. These include the octopuses, some crabs, first of all King crabs *Paralithodes camtschatica*, and hermit crabs [Kalashnikov, 1986]. Crabs predate mainly on seed scallops especially if present in large numbers, for example, during seasonal migration, they can greatly denude newly seeded grounds. Some predatory gastropod mollusks pose a threat to both juveniles and adult scallops. Drilling muricid gastropod *Boreotrophon candelabrum* and *Tritonia japonica* could attack and eat the scallops [Belogrudov, 1973. In natural populations, about 14–27% of adult scallops had drilling marks on the shells. D.D. Gabaev and N.K. Kolotukhina [1999] reported that two-year scallops (shell height up to 73 mm) in the cages were preyed upon gastropod *Nucella heyseana*.

Parasites. In comparison to other bivalves, such as oysters and mussels, the parasites and diseases of scallops are little known about. Also epizootic diseases, like those that have devastated the oyster culture industry in parts of the world, have not been encountered by the scallop culture industry. The relative lack of information on parasites and diseases in scallop may be attributed to the shorter period of intensive culture, and comparatively fewer investigations. Moreover, insufficient data on scallop parasites indicate the poorness of parasitic fauna and the low vulnerability of the scallop. Infectiousness of scallop by parasites is quite low, as parasitic fauna is scanty and is presented only by potentially pathogenic species. Nor was mass scallop death caused by parasites ever recorded. Now it is known about 17 parasites and commensales in scallops [Kurochkin et al., 1986; Kovalenko, 1990; Plyusnin, 1990; Rakov, 1990; Didenko, 1996]:

1. *Sirolpidium zoophthorum* Vishniac, 1955 (Lagenidiales)
This fungus was found in 1972 in juveniles in scallop farm in Possjet Bay.

2. *Myxosporidia* gen. sp. (Myxosporea)
Local pestholes, which probably were caused by unknown Myxosporidia, were noted in scallop farm in Minonosok Inlet (Possjet Bay) in April 1996.

3. *Perkinsus* sp. (Sporozoa)
It was unknown until 1979 when a spherical cyst (0.2–0.3 mm in diameter) of *Perkinsus* sp. was found in 86% of discovered scallops (intensity of invasion by 1–2 cysts). Occasionally this species can pose serious threat for scallops' spat. Conceivably it was introduced with scallop seed from Aomori prefecture, Japan.

4. *Pectenita golikowi* Jankowski, 1973 (Ciliophora)
Approximately all scallops are affected by this endoparasitic infusoria. Intensity of invasion is several tens specimens in scallop intestines. Any kind of pathogenous action on the host is unknown.

5. *Trichodina pectenis* Stein, 1974 (Ciliophora).
See below.

6. *Trichodina* sp. (Ciliophora)
These two species of endoparasitic infusoria were described out of mantle of Yesso scallop. Extensity of invasion is 20–100% and intensity by several tens specimens. Any kind of pathogenous action on the host is unknown, but probably it can be caused by a secondary parasite.

7. *Cliona* sp. (Porifera)
This drilling parasitic sponge affected more often the lower (right) valve and less often upper (left) one. Extensities of invasion are up to 70% on lower valve and up to 10% on upper one.

8. *Hirudinea* gen. sp. (Hirudinea).
Leeches were found in mantle as isolated instances.

9. *Podocotype* spp. (Trematoda)
Approximately 1% of all scallops are affected by trematode metacercaria, which were found in various tissues (including adductor). Intensity of invasion is only one specimen in scallop body.

10. *Anisakidae* gen. sp. (Nematoda).
Larvae of these nematodes were found in digestive system as isolated instances.

11. *Ohridiidae* gen. sp. (Nematoda).
Ohridiidae affects approximately 73% of scallop. Their larvae were found in mantle with intensity of invasion up to 17 specmens.

Table 5

Known bacteria of Yesso scallop *Mizuhopecten yessoensis* cultivated in Peter the Great Bay (Sea of Japan) in cages and bottom ground [compiled from: Avdeeva and Filipchuk, 1988; Kovalenko, 1989; Plyusnin, 1990; Avdeeva et al., 1991; Plyusnin, Cherkashin, 1991; Kovalenko, 1994]

Species	1987	1988		1989		1990		1991	
	Cages	Ground	Cages	Ground	Cages	Ground	Cages	Ground	Cages
Gram-negative									
Pseudomonas sp.	+	+	–	+	+	+	+	–	–
P. putida	–	–	–	–	+	–	–	+	–
Yersinia ruckeri	–	–	+	+	+	–	–	+	–
Vibrio sp.	+	+	+	+	+	+	+	–	+
V. anguillarium	–	–	–	–	–	–	–	+	–
V. parahaemolyticus	–	–	–	+	–	+	+	+	+
Aeromonas hydrophila	+	–	–	–	–	+	–	+	+
A. punctata	–	–	–	–	–	–	–	+	–
A. salmonicida	–	–	–	+	–	–	–	–	–
A. s. achromogenes	–	+	+	+	+	+	–	–	–
A. s. masoucida	–	–	–	+	+	–	–	–	–
A. dourgesii	–	–	–	+	+	+	–	+	+
Aeromonas sp.	+	+	+	+	+	+	+	–	–
Plesiomonas sp.	+	+	–	–	+	–	–	+	–
Bacteroides sp.	+	+	–	–	–	+	–	–	–
Moraxella sp.	–	–	–	–	–	+	–	–	–
Acinetobacter sp.	–	+	–	–	–	–	–	–	–
Alcaligenes sp.	+	+	+	+	–	+	+	+	+
Chromobacterium sp.	–	+	–	+	–	–	–	–	–
Flavobacterium breve	+	+	+	+	–	+	–	+	+
F. halmephilum	+	–	–	–	–	–	–	–	–
Enterobacteriaceae g. sp.	+	–	–	+	–	–	–	–	–
Gram-positive									
Micrococcus sp.	–	+	+	+	–	+	+	–	+
Leuconosfoe sp.	–	+	+	–	–	+	–	+	–
Streptococcus sp.	–	+	–	+	+	+	–	–	–
Listeria sp.	–	+	+	–	+	+	+	–	–
Corynebacterium sp.	+	–	–	–	+	–	–	+	–
Artrobacter sp.	+	–	–	+	–	+	–	+	–
Lactobacter sp.	–	–	–	+	–	–	–	–	–

12. *Polydora ciliata* (Johnston, 1838) (Polychaeta)
This widespread and well-known drilling polychaete is responsible for loss of market quality among cultivated and natural Yesso scallops. It affected more often the upper (left) valve. The burrows made by *Polydora* in scallop shell cause unsightly blisters containing compacted mud. Approximately 75% of scallops have wormholes and blisters. Since 1974 infestation of scallop shells by the boring polychaetes is increasing as siltation of the bottom increases [Silina et al., 2000].

13. *Polydora websteri* Hartmann, 1943 (Polychaeta)
Burrows and blisters of this species are indistinguishable from ones of *P. ciliata*.

14. *Dodecaceria concharum* Oersted (Polychaeta)
This drilling polychaete has wormholes similar with ones of *Polydora*. They can use old holes, created by other polychaetes and sponges.

15. *Herrmannella longicaudata* G. Avdeev, 1975 (Copepoda)
These small (maximal length up to 2.2 mm) cyclopoid copepods were found approximately at 73% of Yesso and Swift scallops. Any kind of pathogenous action on the host is unknown, even in the case of great abundance. Average intensity of invasion by commensales is nine specimens in mantle.

16. *Odostomia fujitanii* Yokogawa, 1927 (Gastropoda)

17. *O.* (*Evalea*) *culta* Dall et Bartsch, 1906 (Gastropoda)
These small (maximal shell height up to 5 mm) littoral gastropods often prey on various bivalves as temporary parasite. Gastropods feed with using a long proboscis, which they introduce between shell valves.

Four of 17 pathogens found in scallop are shell drillers. Other twelve species may be true parasites. Only three species of them such as *Sirolpidium zoophthorum*, *Myxosporidia* gen. sp. and *Perkinsus* sp. can pose the serious threat for scallops; however, they were found only once. In addition, others caused no noticeable pathology in normal conditions. The scallop has no parasites that could endanger humans.

<u>Bacterial contamination.</u> According to recent investigations [Avdeeva, Filipchuk, 1988; Kovalenko, 1989; Plyusnin, 1990; Avdeeva et al., 1991; Plyusnin, Cherkashin, 1991; Kovalenko, 1994], except of these 17 pathogens, numerous species of bacterial contaminants have been identified from cultivated scallops (Table 5). Totally 29 species of contaminants were identified on scallop farms. Gram-negative bacteria present in the most part of them (22 species). Some of them, as specimens of *Aeromonas*, *Vibrio* and *Pseudomonas*, can be conditionally pathogenous. These bacteria may be pathogenic in situations where environmental conditions are poor.

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