Бюллетень Дальневосточного малакологического общества
2007, вып. 11, с. 31–48

The Bulletin of the Russian Far East Malacological Society
2007, vol. 11, pp. 31–48

Scallops of the Russian waters of northwestern Pacific. Part 2. Fishing and aquaculture

V.V. Ivin, V.Z. Kalashnikov

A.V. Zhirmunsky Institute of Marine Biology, Far East Branch, Russian Academy of Sciences, Vladivostok 690041, Russia

e-mail: ivin@hotbox.ru

The review of fishing, stock and aquaculture of commercial scallops (Bivalvia, Pectinidae) of the Russian Far East is given.

Морские гребешки российских вод северо-западной части Тихого океана. Часть 2. Промысел и аквакультура

В.В. Ивин, В.З. Калашников

Институт биологии моря им. А.В. Жирмунского ДВО РАН, Владивосток 690041, Россия

e-mail: ivin@hotbox.ru

Обзор данных по добыче, запасам и культивированию промысловых видов морских гребешков (Bivalvia, Pectinidae) Дальнего Востока России.

Scallops are the most intensively consumed and fished bivalve mollusks. Over ten scallop species are registered in the seas of the Russian Federation. The most well known of them are the Yesso scallop *Mizuhopecten yessoensis* (Jay, 1857) which is also well known as Ezo scallop, Giant scallop, Japanese scallop, Russian scallop, Primorsky scallop or Common scallop. For a long time these mollusks have been an object of traditional catching at the coastal waters of the Sea of Japan, Southern Sakhalin, and the Southern Kurile shoal. In addition to *M. yessoensis*, some scallops from the genus *Chlamys* have trade significance. The most abundant of them in north western Pacific are white scallops, *Ch. albida* Arnold, 1906, pink scallops, *Ch. chosenica* Kuroda, 1932 and Bering Sea's scallops, *Ch. behringiana* (Middendorff, 1849). The recent data on fishing, stock and aquaculture of commercial scallops from the Russian part of northwestern Pacific will be reviewed in this part of paper.

Fishing

History

Paleontological and archaeological studies reveal that the people inhabiting the coastal areas of the Far East had, from time immemorial, used marine organisms, including bivalve mollusks, to develop their national economy [Krasnov et al., 1977]. A unique Yankovsky culture of shell mounds has been found in many regions [Okladnikov, Derevyanko, 1973] dating from the Early Iron Age (2900–2300 years B.P.). Two large sites with shell middens of Early Neolithic were discovered in 1987 on the coast of Boysman Bay, western part of the Peter the Great Bay [Brodyansky et al., 1995 – cit. by: Rakov, Lutaenko, 1997]. These sites are related to the newly recognized Boysmanskaya culture. Radiocarbon dates for this culture lie between 4400 and 6300 years B.P. [Jull et al., 1994 – cit. by: Rakov, Lutaenko, 1997], which places it in the mid-Holocene age. Numerous shell concentrations suggest that the inhabitants of the coasts of Sakhalin, the Kuriles, Japan, Primorye (=Primorsky Territory) and Korea preferred gastropods, mussels, and scallops.

We still do not know how ancient people obtained the scallops. Without any suitable gear and boats they may have only been able to collect them from storm debris. The subsequent history of scallop fishing in Primorye is known from descriptions by pioneer explorers of Ussuri Region, including N.M. Przevalsky and V.K. Arseniev. Russian merchants recall that during the last century Yesso scallops *M. yessoensis* were exported as seasoned meats (muscles). Scallops were fished in Vladimir Bay and sold to China. The second half of the 19th century saw further development of scallop fishery along with the settlement of the Russian Far East. This was supported by its value and by the boundless demand on the local market. By the 1920's, the price for Yesso scallop in Vladivostok was as high as 10 rubles per 100 mollusks. During that time, they fished scallops in shallow bights using one-or-two-pronged lances and scoop nets (while watching it from the surface through a glass-bottom box), primitive dredges and cords [Razin, 1934].

Fishing gear

Dip-nets were used to fish Yesso scallops in clear water and quiet weather. The pole was 8 m long and the average haul was 50–60 specimens per day, though it could be much higher in shallower waters with excellent weather. Following rain storms the turbid water made this virtually impossible.

Initially only simple dredges (about 75 cm wide) were used for fishing scallops. They were towed by small sampans, whose prototypes were brought by members of an expedition led by N.N. Muraviev-Amursky, the first Governor-General of the Ussuri Territory, together with boats from neighboring countries. Their displacement was 1–1.5 tons, and they used sails or one oar, the so-called «yula». Industrial fishing by means of cords was unique at that time. It was performed in the following way: an anchored buoy was placed in the centre of the catching site and a cord was attached to it. The cord had length of 200 m and was 1–3 mm in diameter. The small lead loads (11–15 g each) were fixed to the cord at intervals of every 2 m. The catcher would sail in a boat to drag the cord and start making circles near the buoy. When the cord was trapped by the open scallop valves, the mollusks would abruptly close them and affix themselves. The more often the catcher would pull the cord, the tighter the bivalves would grip the gear. On even ground, a good catcher would haul several thousand scallops. In 1919–1920, Yesso scallop in Ussuri Territory was fished by professional women-divers with the ability to stay underwater for long periods of time even in the cold autumn months. At the end of 1920's when diving gear and motorboats equipped with dredges were introduced, greater scallop hauls were caught. When the Association for Exploiting Marine Resources was especially active the stocks rapidly diminished. After World War II industrial fishing was resumed for a short period of time but then totally banned in 1960.

Yesso scallops and Commercial scallops (*Ch. albida, Ch. behringiana* and *Ch. chosenica*) were fished using small seiners (about 300 tons displacement) on the coasts of northern Primorye, southern Sakhalin, Kurile Islands and the Bering Sea. This involves a steel dredge, which is 1.5–3.0 m wide. The dredge is towed for 5–30 min. In Kuriles, one such haul would yield 0.39–1.28 tons of shells [Kochnev, 1987]. In Peter the Great Bay, divers use free diving down to 5 m and SCUBA diving down to 30 m to gather Yesso scallops.

Yesso scallop landings

As noted, scallops are the most intensively consumed and fished bivalve mollusks. The best known is the Yesso scallop[1] *M. yessoensis*, which also known as Ezo scallop, Giant scallop, Japanese scallop, Russian scallop, Primorsky scallop and Common scallop [Iviņ, Kalashnikov, 2005]. For a long time these mollusks were an object of traditional catching (Tables 1, 2).

Primorsky Territory. Yesso scallop landings in southern Primorye were apparently not recorded for a long period of time. Starting in 1919, when diver boats were introduced, scallop hauls reached the impressive figure of 400 tons. By 1920, industrial fishing grew threefold, but in subsequent years, it sharply declined and then almost stopped. A Trust for Marine Fisheries was organized in 1933 in Vladivostok with a network of enterprises all over the Soviet Far East. The new outfit resumed industrial fishing of the Yesso scallop to raise the average hauls for 1933–1937 up to 900 tons (Table 1). In subsequent years, the scallop was not fished and only 160 tons were landed in 1948–1949.

Sakhalin-Kurile Region. In addition to the fishing areas in southern Primorye, the Yesso scallop was harvested in Sakhalin-Kurile areas. The commercial fishing of Yesso scallops at Sakhalin and Kurile Islands by Japanese fishers occurred from the 1930's to 1945. The main fishing area at that time was Aniva Bay. Between 1933 and 1943, annual yield was 1,000–2,300 tons. At Southern Kuriles values for landings were significantly greater [Skalkin, 1966]. Commercial exploitation of scallop populations after World War II was founded by Russian fishers in 1961.

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

Table 1

Annual catch (metric tons) of Yesso scallop in Primorsky Territory in 1919–1937 [after Belogrudov, 1981]

Years	1919	1920	1923–1926	1933–1937	1948–1949
Catch	400	1,200	35	900	160

Table 2

Annual catch (metric tons) of Yesso scallop in Sakhalin and Kurile Islands in 1961–1985 [after Kochnev, 1993]

Years	Regions			
	Aniva Bay	South Kuriles	Terpenie Bay	Total catch
1961	200	–	–	200
1962	1,800	1,230	2,200	5,230
1963	260	2,010	–	2,270
1964	150	5,070	100	5,320
1965	110	2,460	Banned	2,570
1966	30	1,400	–	1,430
1967	Banned	1,220	–	1,220
1968	–	1,410	–	1,410
1969	–	1,200	–	1,200
1970	–	600	–	600
1971	–	Banned	–	Banned
1972	–	–	–	–
1973	–	–	–	–
1974	–	–	–	–
1975	–	–	–	–
1976	56	141	–	197
1977	70	102	–	172
1978	67	99	–	166
1979	169	97	16.9*	282.9
1980	114	12	–	126
1981	117	12	0.5*	129.5
1982	64	36	–	100
1983	3	6.5	–	9.5
1984	28	11	–	39
1985	Banned	Banned	Banned	Banned

* Experimental fishing.

The scallops were only fished with dredges from small seiners [Kochnev, 1993]. One year later in 1962 the catch of mollusks peaked at 5,230 tons. In the four following years, because of excessive catching, the annual yields in Aniva Bay decreased to only 30 tons (Table 2). Although it was a stable but poorly maintained population of scallops, the commercial stock of this population was evaluated at about 3,600 tons. The reason for such a decrease was the dredging method of catching scallops and in 1967 catching of scallops in Aniva Bay was banned. In 2000, after a long prohibition, commercial catching using dredging was reinstated again in Aniva Bay [Shpakova, 2001b].

Several years later commercial catching was banned at Southern Kuriles. At Terpenie Bay scallop landings endured for only one more year. As in Aniva Bay, annual yields were decreased because of excessive and irrational catching (Table 2). Between 1976 and 1984, commercial catching was reinstated and the annual yields were 9.5–282.9 tons. From 1985 to the present catching of scallops has been banned [Kochnev, 1993] in Southern Kuriles.

Yesso scallop commercial stock

Primorsky Territory. The commercial reserves of natural Yesso scallops along the coast of Primorye are presently exhausted after the last decade of irrational catching and poaching.

Sakhalin-Kurile Region. Commercial populations of Yesso scallops are known along the coast of Sakhalin Island at Aniva and Terpenie Bays. Commercial stocks at Tartar Strait have not been estimated.

In Aniva Bay, Yesso scallops are found along western and north eastern coasts at depths of 8–30 m. Their distribution has an irregular and mosaic pattern. The total stock in Aniva Bay is estimated at 16,030 tons (79.37 million scallops) with 4,970 tons (15.63 million scallops) of them being of commercial stock [Shpakova, 2001a]. Settlement densities on bottom grounds in the bathymetric range of 7–21 m average 4.33 specimens m^{-2} with an average biomass up to 0.3 kg m^{-2}. Average shell height of the commercial mollusks (14–99%) is between 139–156 mm [Shpakova, 2001a, b].

In Terpenie Bay, Yesso scallops are distributed along the north eastern coast in waters 11–20 m deep. Total stock in Terpenie Bay is estimated at 1,300 tons (2.1 million scallops) but only 600 tons of them are of commercial stock. Settlement densities on bottom grounds average 0.03 specimens m^{-2} with an average biomass of 0.008 kg m^{-2}. Average shell height of the commercial mollusks is about 167.1±6.9 mm at individual biomass of 518.7±9.8 g. Mean age of population is about 6.9 years.

In Kuriles, commercial assemblages of Yesso scallop are known in shallow waters of Kunashir Island and on the South Kuriles Shoal. Total stock is specified as 40,000 tons (200–300 million scallops) with about 18,000 tons of commercial stock [Ponurovsky et al., 2000; Ponurovsky, Brykov, 2001]. Settlement densities on bottom grounds in the bathymetric range of 5–20 m average 0.5 specimens m^{-2}. Average shell height of the commercial mollusks (44.8% of total population) is 126.8±1.1 mm. Mean age of population is 3.5 years with the maximum lifetime of 12 years.

Commercial *Chlamys* scallops

In addition to *M. yessoensis*, some scallops from the genus *Chlamys* have trade significance. These are less known because of their smaller size and their occurrence at depths greater than 50 m. The most abundant of them in northwestern Pacific are white scallops, *Ch. albida*, pink scallops, *Ch. chosenica,* and Bering Sea's scallops, *Ch. behringiana*. The Asiatic scallops, *Ch. asiatica* Scarlato, 1981*,* rarely occur here.

Primorsky Territory. In Primorye, *Chlamys* scallops, mainly *Ch. chosenica*, form concentrations at depths between 25–250 m. Myasnikov [1982] reported three large populations of pink scallops along the northern coast of Primorye (stretching from Cape Povorotny to Cape Zolotoy). The highest density of settlements reaches up to 25 specimens m^{-2} with an average of five specimens m^{-2}. Total stock of scallops is estimated at 420,000 tons (10.6 million scallops) located at depths of 90–100 m. Since 1990 these reserves have provided annual yields of 1,000 tons [Myasnikov, Hen, 1990].

Kurile Islands. On the Kurile Islands, commercial fishing of *Chlamys* scallops by Japanese fishers occurred from the 1930's to World War II [Skalkin, 1975]. After 1972, there was a renewal of commercial fishing. From 1972 to 1975 annual yields did not exceed 140–1,170 tons. After 1976 annual yields increased up to 1,500–3,050 tons with an average of 1,990 tons. Major scallop landings (about 75% of annual yield) are derived from the Sea of Okhotsk side of Onekotan Island at depths between 50–200 m [Kochnev, 1987]. It is now the most stable scallop fishery in the Russian Far East region [Myasnikov et al., 1992]. Two species (*Ch. albida* and *Ch. chosenica*) occur in mixed settlements. Due to an intense fishing increase the annual yields was 3,462–7,198 tons with an average of 4,693 tons (Table 3).

Populations of *Chlamys* scallops on Onekotan Island are found on both the Sea of Okhotsk side and at Pacific side of the island. On the Sea of Okhotsk side of the island scallops are distributed over depths of 40–140 m. Density of settlements on the bottom grounds are 90.0 specimens m^{-2} with a biomass of 6.0 kg m^{-2}. Average density and average biomass are 2.7 specimens m^{-2} and 0.25 kg m^{-2}, respectfully. On the Pacific side of the island, the largest density of scallops was found between 40–100 m. Densities of settlements on bottom grounds on this side are as high as 175 specimens m^{-2}. Total stock of *Chlamys* scallops in the region is estimated at 64,400 tons (730.5 million scallops) with about 42,000 tons of commercial stock.

Bering Sea. In the Bering Sea, commercial concentrations of Bering Sea's scallop *Ch. behringiana* are found [Myasnikov, 1992]. Commercial stock of scallops is estimated at 3,000 tons within bathymetric range of 110–120 m.

Other *Chlamys* species

Along with the commercial importance of *Chlamys* species described above there are other potential species such as the Japanese scallop, *Ch. farreri* (Jones et Preston, 1904)*,* and the Swift's scallop, *Ch. swiftii* (Bernardi, 1858).

Table 3

Annual catch (metric tons) of *Chlamys* spp. scallops near Onekotan Island (Kurile Islands) in 1976–1997 [after Kochnev, 1993]

Year	Catch	Year	Catch
1976	1,601	1987	2,700
1977	3,050	1988	2,000
1978	2,392	1989	2,898
1979	2,317	1990	1,754
1980	1,501	1991	1,494
1981	1,625	1992	2,400
1982	1,543	1993	3,462
1983	2,101	1994	7,198
1984	1,413	1995	3,574
1985	2,370	1996	4,963
1986	2,945	1997	4,269

Chlamys farreri. The Japanese scallop, *Ch. farreri*, is the most thermophilic scallop in Russian waters. It only occurs in southern Primorye. Afreichuk [1992b] reported concentrations in Possjet Bay. The total stock is estimated at several thousand tons located at depths between 3–5 m. Commercial stock has not been estimated. This species is an object for mariculture and fishery in East Asian countries [Wang, Shieh, 1991]. In Russia, mainly in southern Primorye, the Japanese scallop is one of most promising species for fishery and mariculture [Bregman, 1982; Afreichuk, 1992a].

Chlamys swiftii. Stocks of Swift's scallop, *Ch. swiftii*, in Primorye have not been evaluated. In Aniva Bay, Swift scallops are found between 2–19 m. Average density of settlements on bottom grounds ranges from 0.04 to 5.50 specimen m^{-2} with an average of 0.17 specimen m^{-2}. Biomass ranges from 3.8 to 498.8 g m^{-2}, with an average of less than 16 g m^{-2}. Shell height ranges between 32–114 mm with an average of 86.8 mm. Individual biomass ranges from 24 to 208 g with an average of 94.1 g. Although this species is widespread in the bay it does not form commercial aggregations because of its low density.

Aquaculture

The Yesso scallop, *M. yessoensis,* is the only scallop species cultured in Russia. It is cultured in the coastal waters of Primorye in the north western part of the Sea of Japan.

History

After the ban on scallop fishing in Primorye in 1962 stocks were replenished very slowly. The first steps in the mariculture of Yesso scallops in the Russian Far East occurred after 1968. In 1971, after several years of research, the first scallop farm was organized in Possjet Bay (southern Primorye). This industry reached its greatest development in Primorye in the 1980's. In addition to the farm in southern Primorye, experimental work for spat collection was attempted in the 1970's in Sakhalin in Bousse lagoon but further cultivation was discontinued. Mariculture at this time had financial assistance from the largest fishing enterprises of region, such as «Dal'ryba» and «Primorrybprom» and from Ministry of Fisheries of the USSR.

By the mid-1980's production reached over 10 million spat a year and at least 40 million one-year-olds were settled in various sites within Possjet Bay. Since 1977, in addition to its own plantations, the Possjet farm transferred 2–10 million young scallops from other bays to other marine farms. Starting in 1983, scallop cultivators in Possjet Bay collected 30 million spat, while industrial production was only 20–50 tons. It was not until 1989 that production output exceeded 100 tons (Table 4).

In the 1990's, during the crash of the socialist system and the disintegration of the USSR, all the created farms were bankrupted or crisis-ridden. Since the end of the 1990's with the formation of the exchange relations in the Russian Federation, a new period in mariculture development has started. After the economic depression in 1997 the interest in mariculture has increased and a new period of economic expansion has started.

Table 4

Twenty-four years (1981–2004) annual trend in number of organizations involved in Yesso scallop culture and total production (metric tons) in Primorsky Territory. Figures have been compiled from reports of fishery organizations

Year	Number of farms	Yield	Year	Number of farms	Yield
1981	3	9.0	1993	5	155.0
1982	3	4.5	1994	5	110.0
1983	3	18.1	1995	6	113.0
1984	3	38.0	1996	8	22.0
1985	4	10.4	1997	9	60.0
1986	4	48.8	1998	10	131.0
1987	4	62.3	1999	18	99.6
1988	4	64.0	2000	20	91.2
1989	5	196.0	2001	24	84.4
1990	5	122.5	2002	26	207.2
1991	5	153.0	2003	28	301.8
1992	5	150.0	2004	32	435.6

Present situation

The number of scallop farms in Primorye is quickly growing (Table 4). There are now 32 Yesso scallop farms with a total area of more than 700 hectares of single-crop area. There are 125 hectares of hanging culture and about 600 hectares under sowing culture. The development of mariculture in the Sakhalin region has been completely terminated.

Marketing

Almost all of scallop production from scallop farms is unprocessed. Unprocessed Yesso scallops are frozen as packed meats and a very small percentage of scallops (within 1%) are cooled in the shells. As for commercial scallops (*Chlamys* spp.), in most cases they are processed by canning. In Vladivostok fish stores and supermarkets, frozen meat may be sold for 480–750 rubles per kilogram (equivalent of $19.2–30.0). Cooled whole scallops are sold for 50 rubles per shell (equivalent of $2.0). For comparison, the cost of frozen beef is equivalent to $6.5–8.0 (160–200 rubles) per kg. Canned scallops (in sauce, oil and smoked) are sold for the equivalent of $3.0–6.0 (75–150 rubles) per 8 oz. In other Russian regions prices are a little bit higher. It is profitable to cultivate scallops at this price. In Vladivostok, several dozen tons are sold every year, which is highly insufficient even for the small local market. Frozen scallop meat is in high demand in spite of a high price. Yet, the scales of cultivation do not match the levels of need.

The culture methods

All the methods used in the cultivation of Yesso scallops can be assigned to one of two categories: off-bottom cultivation or on-bottom cultivation. Experiments were conducted to harvest spat in closed and running controlled systems involving artificial spawning and larvae feeding. This technique is not popular because it is too complicated and expensive. Attempts were also made to create commercial scallop concentrations by using artificial reefs. The results concluded that this was an inefficient process.

There are two main Japanese methods for commercial cultivation [Ventilla, 1982]:

- hanging culture – cultivation of the scallop in cages;
- sowing culture – cultivation on the bottom substrates of bays and inlets.

Spat collection

Long-line structures with plates or bags as collectors are commonly used for spat collection in Primorye. Long-lines are a series of floats (Ø=240–300 mm) connected together by horizontal lines (Ø=19–22 mm) that supports a large number of vertical ropes with attached collectors. There are two types of collectors:

Conical plates of perforated plastic (Ø=250 mm) covered by mesh stockings (7–12 mm). Twenty-five collector plates are strung onto the rope (Ø=6–8 mm) as garland up to 2.5 m long.

Commercial onion bags with mesh or monofilament filling (capron or polyethylene). The bags are attached in sets of ten to the rope (Ø=6–8 mm) as garland up to 5 m long.

Prepared garlands of collectors are placed at depths between 5–10 m in semi-closed bays and inlets and at depths between 15–20 m in open waters. Mass scallop spawning in southern Primorye starts in mid-May. In order not to miss the settling peak, collectors are hung deep in the water for 15–20 days in early June, so the substrates would be covered with a bacterial-algal film. This is used to promote spat attachment prior to larvae settling [Belogrudov, 1986]. In southern Primorye settlement occurs in mid-June, 22–30 days after spawning begins. The size range of settling larvae is 250–275 mm. By the beginning of August, the spat average 3 mm in size and have growth rates of 3–4 mm per month.

There is a direct relationship between larval concentrations in the plankton and spat abundance found on the collectors. At larval concentrations in the range of 20–30 larvae m^{-3} spatfall is about 100–400 spat per collector and at 50–100 larvae m^{-3} it is up to 500–1,500 spat per collector. The long-term maximal larval concentration in plankton is 600 larvae m^{-3} [Belogrudov, 1981].

One month after settling spat size averages 10 mm. At least 200 spat have to settle in the collector in order for the result to be considered commercially profitable. In bonanza years 400–600, and even as many as 1,000 larvae can settle in a collector. In lean years, settling numbers from several to several dozen spat will make processing commercially unprofitable.

Intermediate culture

The long-line for intermediate culture is set up similar to that of spat collector lines. Horizontal lines support a large number of vertical garlands of cages.

In autumn, the collected spat (200–250 samples) are manually removed to hanging multi-tier cages (square of 0.12 m^2). Spat are collected and directly placed in cages from a raft above the plantation. The collectors are lifted from the water to remove the substrate and spat are scraped off into vats filled with water. All foreign organisms (mostly mussels) and empty shells are removed during the transfer process. The necessary numbers of scallops are poured into cages and instantly placed back into the water. When performing this work, the scallop farmer will put a tent over the raft to protect the scallops from desiccation and the sun. In wintertime, the floating structures on which the cages are hung are placed under ice to protect them from destruction by moving ice floes. All structures are preferentially placed under the water to protect from heavy waves.

By April and May, scallops grew in these cages average 25–30 mm in height. When cultivation is performed correctly the survival rate is approximately 90%. Most mortality occurs at the beginning and is due to the stress of the transfer and to the fragility of the thin shell. The viability of these scallops is dozens of times higher than in the autumn, and several methods are used to subsequently cultivate them to marketable size. At 30 mm the juveniles can be sowed in open waters. About 70% are used for sowing culture and the rest are used for hanging culture in lower density cages.

Transport of scallop seed

When scallop seed are sold to other farms, or delivered for sowing on the bottom, they are packed up in boxes (volume 20–60 l) with perforated walls and bottoms. The boxes are put under the canvas on board a transport deck and should be instantly filled with mollusks in layers of 20–30 cm. Scallop seed should be covered with moist algae or seaweed leaves after being taken out of the water. During transportation, the boxes are replenished by outboard water every 30 minutes. Transportation is preferable when the water and air temperatures are approximately the same (about 5–10°C). In this manner, the scallops can survive for 24 hours (Table 5).

Sowing or on-bottom culture

Sowing cultivation is based on the principle of transferring scallop juveniles from areas where they settled in great abundance, to bottom grounds, where they can be spread at lower density in order to obtain better growth rates and weights. Sowing culture is practiced more widely in Primorye.

Scallops are usually transferred after intermediate culture to bottom grounds in May and June when they are about one year old. Specific sites should be preselected before the sowing on sandy-silty sediments or on shingle-shell mixtures and should be without starfish (or at most 0.5 specimens m^{-2}). The content of finely dispersed silt (particles smaller than 130 mm) shall not exceed 30%. Bottom grounds shall be at least 3 m deep in inlets protected from wave action. They should be over 10 m deep in open waters, partially protected from prevailing winds and over 20 m deep at bays opened to all winds, so that storms will not ruin the benthic habitat. Areas with natural scallop accumulations (past or present) are preferable for sowing culture. The selected sites should be established by taking bearings on shore to reference marks and then mapped. Prior to sowing the water space should be marked with buoys. The vessel should sail between the buoys at low speeds, and the one-year-old scallops will be evenly scattered all along the bottom grounds with a density of 10–20 specimens m^{-2}. Sowed scallops usually weigh less and are 10–15 mm smaller in shell height than native scallops [Silina, 1994]. This difference usually continues throughout the lifetime of scallops. It is thought that the slower growth of sowed scallops from collectors or cages unfavorably affects the growth during winter and spring when the densities are high. Additionally, some

Table 5

Survival rates (%) of Yesso scallops juveniles during transportation depending on temperature [after Bregman, 1987]

Duration of transportation, h	Temperature, °C			
	5	10	15	20
3	98	98	95	90
5	97	96	93	88
10	95	94	91	85
15	93	92	85	80
20	92	91	83	75
25	90	88	80	70

of the growth inhibition results from shell breakage during transportation and sowing on the bottom. Growth of sowed scallops is further reduced while the animals adapt to their new habitat and generate new shell at the ventral margins. Depending on the temperature and other ground conditions, the scallops will grow to marketable sizes in two to four years. Survival on the sea floor will depend on predation and wave intensity and may vary from 5 to 20% within the same grounds during different cultivation cycles.

In two to four years after sowing, SCUBA divers collect marketable scallops. Their productivity on shallow grounds (3–5 m deep) with densities over 10 samples m^{-2} amounts to 1,500–3,000 scallops hr^{-1}. In cases of lower densities or larger depths and in turbid waters divers' productivity will progressively decline down to only 300 scallops hr^{-1}.

Hanging or off-bottom culture

Hanging cultivation adds a third dimension to the essentially two-dimensional sowing culture. The crop is spread over and can utilize a much greater proportion of the water column. The long-line for intermediate culture is set up in the same manner as that for the intermediate culture. They are usually set deep (5–15 m from the surface) to escape wave action and the thermocline in the summer months. There are two schemes for hanging culture:

Young scallops with shell heights of 10–15 mm are placed into cages of 200–250 specimens. One-year old scallops (20–30 mm) are transferred into cages of 20–25 individuals and two-year-olds (50–70 mm) scallops of 5–7 individuals. In three years the scallops will reach the marketable size of 100 mm in height.

Young scallops with shell heights of 10–15 mm are placed into cages of 20–30 individuals and in 1.5 years are transferred to cages of 5–7 specimens. The number of transfers in the second case is smaller, but there is strong fouling on cages due to the longer period of time between operations. Fouling has a negative effect on scallop growth and survival.

All scallop transfer operations are performed in the spring and autumn at relatively low temperatures (about 10°C). When the work is performed correctly, survival rates average 90%. Most mortality occurs at the beginning since it is due to the stress of the transfer and to the fragility of the thin shell.

Harvesting methods require lifting of cages and collecting the scallops of marketable size. Manual harvesting is time-consuming and labor intensive. It is assisted by mechanical winches for lifting lines.

Obstacles to mariculture development

There are several obstacles to the development of mariculture in Russia:

• Financial problems of protracted payback periods in mariculture and the necessity of a huge investment in equipment. Lump-sum investments for the creation of mariculture farms exceed $500,000. It is often very difficult to find investors for such a long-term project.

• Ethnic and gastronomic problems because shellfish are not a traditional nourishment of the Russian people.

• Legal problems arise from the absence of the laws regulating sea farming.

• Socio-economic problems concerned with undeveloped infrastructure of inshore population centers.

Ecological constraints associated with cultivation

Predation. As mentioned earlier, young scallops are often preyed upon by various starfish species. In mariculture, when their bipinnaria larvae reach concentrations of 20 specimens m^{-3} in plankton or when inside collectors they develop twice as fast as the scallop spat they may cause 100% mortality [Belogrudov, 1981; Gabaev, 1981]. During settling starfish larvae attach to the same collectors as the scallop juveniles. The average abundance of starfishes and scallops on spat collectors is shown in Table 6. The relationship between the abundance dynamics of scallops and starfishes can be described by following equation [Gabaev, 1990]:

$$A_{scallops} = 128.7 + 39.4 \cdot A_{starfishes}$$
$$(r=0.82;\ p<0.05),$$

where $A_{scallops}$ is the abundance of scallops (specimens m^{-2}) and $A_{starfishes}$ is the abundance of starfishes (specimens m^{-2}).

The relationship between the number of attached scallop juveniles and number of scallops consumed by starfish can be described by the following equation [Gabaev, 1990]:

$$N_{eating} = 175.0 + 2.3 \cdot A_{scallops}$$
$$(r=0.74;\ p<0.05),$$

where N_{eating} is the amount of eaten scallops (specimens) and $A_{scallops}$ is the abundance of scallops on spat collectors (specimens m^{-2}). In other words the larger

Table 6

Average abundance (mean±s.d.; specimens m^{-2}) of starfish and scallop juveniles on spat collectors at a scallop farm in Possjet Bay, Sea of Japan [after Gabaev, 1990]

Year	Species			
	Yesso scallop *Mizuhopecten yessoensis*	Japanese scallop *Chlamys farreri*	Swift's scallop *C. swiftii*	Starfish *Asterias amurensis*
1977	479±49	13±1	0	9.5±3.1
1978	69±3.0	16±8	0	0.9±0.7
1979	327±89	2±1	2±1	2.0±0.3
1980	22±0.4	103±25	3±1	0.2±0.1
1981	259±56	84±43	16±9	1.1±0.6
1982	160±18	229±65	1	0.1±0.0
1983	1,060±232	16±11	29±5	0.8±0.1
1984	193±16	66±40	9±7	0.0
1985	109±1	74±62	5±2	0.0
1986	541±337	0	5±3	0.2±0.1
1987	176±36	1±0.5	0.3	0.1±0.05
1988	458±165	0	0.4	0.02

the abundance of scallop juveniles, the faster it decreases.

The gastropod *Nucella heyseana* is also a predator of scallops, which can cause similar problems [Gabaev, Kolotukhina, 1999].

Epibionts. Farmed scallops constitute an excellent substrate for the settlement of many epifaunal and epifloral organisms. Almost 60 species of algae and invertebrates were noted on the shells of cultured scallops. In hanging culture, scallops are most frequently inhabited by other bivalve mollusks and barnacles [Silina, Ovsyannikova, 2000]. The dominant epibiotic species are mussels *Mytilus trossulus* (abundances up to 110 individuals per shell and biomass estimates of up to 46 g $shell^{-1}$), *Modiolus kurilensis* (up to 32 specimens) and *Hiatella arctica* (up to 27 specimens). Subdominants of epibiotic communities include barnacles, *Balanus improvisus* (up to 268 specimens per shell), *B. crenatus* (up to 189 specimens) and *Hesperibalanus hesperius* (up to 27 specimens). Scallops from wild populations have epibionts only on the upper valve. But in cultured scallops the fouling is presented on both valves and in cage culture epibionts are more abundant on the lower valve than on the upper valve. Because of cage overcrowding and immobility, epibionts in hanging culture are more extensive than in sowing culture.

In sowing culture, epibionts on scallop shells are mainly the barnacle *H. hesperius*. Their abundance can reach up to 77 specimens per a shell on two-year scallops and up to 337 specimens on three-year scallops [Silina et al., 2000; Silina, Ovsyannikova, 2000].

Excessive fouling is a scallop-farming problem mainly by virtue of the extra effort required to clean the crop for marketing. It may also have some influence on growth rate and productivity through competition for space and reduction of water circulation. Again, farm management provides the best means of alleviating this problem, i.e., using optimal techniques for cultivation tending to sustain less fouling.

Biofouling of cultivation structures. According to the techniques of hanging culture existing in Russia, the cages are placed at depths of 5–15 m. These depths teem with the larvae of various organisms, many of which may form abundant fouling communities on all the parts of the structures. Maslennikov and Kashin [1993] reported strong fouling occurs on cages during cultivation. The fouling biomass reached 5.7 kg m^{-2} at a depth of 5–7 m. The dominant species, accounting for more than 84% of the total biomass, is *M. trossulus* (4.9 kg m^{-2} at a population density of over 10,000 specimens m^{-2}). The fouling biomass on collectors at this depth horizon was 6.5 kg m^{-2}, of which *M. trossulus* and *B. improvisus* contributed 61.2 and 36.4%, respectively.

Fouling causes the weight of the structures to sharply increase and their storm resistance to decrease. This reduces the life span of these structures [Bregman, Kalashnikov, 1983]. When strong, fouling may also make the collectors and cages an inhospitable environment by restricting water flow through the bags, depleting nutrients, and hindering the growth of scallops within the collectors and cages. The rate of growth of the scallops (height and mass) is also strongly affected by fouling organisms.

Many ways of removing fouling organisms on sea farms (mechanical, physical, chemical and biological) are now known.

Chemical methods are not suitable for scallop cultivation because they use toxic substances. The application of physical and mechanical methods is considerably limited because they damage cultivated mollusks or are very labor consuming.

Future prospects

The future of Yesso scallop farming is very promising. The market is constantly growing as demand continues to exceed supply. There is some potential for increased farming. Production of scallop farms might be increased through better scallop farm management and the application of technological innovations for mariculture.

There are prerequisites for future mariculture development in Primorye and the northern part of the Russian Far East including historical, organizational, market opportunities, resource environment and socio-economic [Arzamastsev, 2000]. According to experts, the inshore water suitable for development of maricultural farms includes approximately 6,000–10,000 hectares in Primorye alone. This provides commercial output of 700,000 tons [Mokretsova, 1996]. In coastal waters of the Sakhalin and Kurile Islands, natural resources and environmental conditions are also favorable. The optimum place for mariculture development was found in shoaling waters of southern Sakhalin [Kochnev, 2000] and South Kurile Shoal [Ponurovsky et al., 2000].

One of the promising trends of mariculture is polyculture. Scallop populations that spontaneously developed under kelp plantations at kelp farms, are well known in practice [Shaldybin, 1983]. Moreover, joint cultivation of kelps and scallops will help protect against excessive eutrophication, which often occurs at mollusk and kelp farms from overcrowding [Arakawa et al., 1971; Ventilla, 1982; Rosenthal et al., 1988; Ivin, 1999].

Not long ago a project on the joint cultivation of Yesso scallops *M. yessoensis*, Japanese kelp *Laminaria japonica* and common sea cucumbers *Apostichopus japonicus* was conducted [Ivin, Maslennikov, 2000, 2001]. This project started in 2000 by one of the biggest joint stock companies of aquaculture and recently about 100 million spat were collected and more than 40 million scallop seed and 30,000 juvenile sea cucumbers were sowed. The methods for cultivation and construction of structures applied in the project were originally developed and protected by a patent of the Russian Federation No. 2149541 [Maslennikov, Kashin, 2000]. One hectare of sea farms can yield up to 400,000 market-sized scallops. This is equal to 8 tons of scallop meat. Kelp productivity is not less than 50 tons in wet weight or about 10 tons in dry weight. Technology of sea cucumber cultivation can yield up to 10,000 market-sized individuals. The projected profitability of the sea farms is about 15–18%.

World experiences with mariculture are driving sea farms transferred from closed bays to open waters. The technology uses open seawaters with depths of more than 30 m which are unsuitable for traditional mariculture. The shallow bays with depths of 10–15 m are used only during a short period (not longer than 6 months) for the collection of scallop spat and sea cucumber juveniles. Areas which are occupied by maricultural structures will cover no more than 33% of the general area for sea farms. The remaining water space is used as a reserve for the rotation of areas occupied by the cultivation of sea organisms. After termination of each culture cycle, the plantations will be relocated to a new area. This allows areas that are used in mariculture to be maintained in a natural state. Turnover of used areas allows long-term usage of sea farms without negative environmental impact. This rotational scheme has long been applied in agriculture.

Acknowledgements

The authors wish to thank Dr. Sandra E. Shumway, President of the US National Shellfisheries Association for the basic idea of this paper and Dr. Konstantin A. Lutaenko, President of the Russian Far East Malacological Society for the censorious remarks and discussion of the manuscript.

References

Afreichuk L.S. 1992a. Growth pattern of the Japanese scallop (*Chlamys farreri*) in Possjet Bay // Ecology of the Sea Organisms: Sea Ecosystems. Abstracts of the Conference, 19–21 May 1992, TINRO-Center, Vladivostok. S.Yu. Shershenkov (Ed.). P. 61–62. [In Russian].

Afreichuk L.S. 1992b. Reproduction of the Japanese scallop (*Chlamys farreri*) in Possjet Bay // Ecology of the Sea Organisms: Sea Ecosystems. Abstracts of the Conference, 19–21 May 1992, TINRO-Center, Vladivostok. S.Yu. Shershenkov (Ed.). P. 62–64. [In Russian].

Arakawa K.Y., Kusuki Y., Kamigaki M. 1971. Studies on biodeposition in oyster beds. I. Economic density for ouster culture // Venus (Japan Journal of Malacology). V. 30, N 3. P. 113–128.

Arzamastsev I.S. 2000. Mariculture in Primorye // Ecological Bulletin of Primorye N 4. P. 3–6. [In Russian].

Belogrudov E.A. 1981. Biological bases of cultivation of the Japanese scallop *Patinopecten yessoensis* (Jay) (Mollusca, Bivalvia) in Possjet Bay, Sea of Japan. Dissertation, Candidate of Science in Biology (Ph.D. Thesis). Vladivostok: Inst. Mar. Biol., Far East Center, Acad. Sci. USSR. 134 p. [In Russian].

Belogrudov E.A. 1986. Scallops cultivation. 1. Settling of larvae on collectors // Japanese Scallop *Mizuhopecten yessoensis* (Jay). P.A. Motavkin (Ed.).Vladivostok: FESC Acad. Sci. USSR. P. 201–203. [In Russian].

Bregman Yu.E. 1982. Biology and cultivation of scallop *Chlamys farreri nipponensis* // Biology of Shelf Zones of the World Ocean: Abstracts of the 2nd All-Union Conference on Marine Biology, September 1982, Vladivostok. A.I. Kafanov (Ed.). Vladivostok: Inst. Mar. Biol., FESC USSR Acad. Sci. Part 3. P. 58–60. [In Russian].

Bregman Yu.E., Kalashnikov V.Z. 1983. State, problems and prospects of culturing of bivalve mollusks in Primorye // IV All-Union Conference on Scientific-Technological Problems of Mariculture: Abstracts of Papers, 23–28 October 1983. V.G. Markovtsev (Ed.). Vladivostok: TINRO. P. 144–145. [In Russian].

Gabaev D.D. 1981. Settling of the larvae of bivalve mollusks and starfishes on suspended collectors in Possjet Bay (Sea of Japan) // Biologiya Morya (Marine Biology, Vladivostok). N 4. P. 59–65. [In Russian with English abstract].

Gabaev D.D. 1990. The biological substantiation of new methods for cultivation of some commercial bivalves mollusks in Primorye. Abstract of Dissertation, Candidate of Science in Biology (Ph.D. Thesis). Vladivostok: Inst. Mar. Biol., Far East Branch, Acad. Sci. USSR. 30 p. [In Russian].

Gabaev D.D., Kolotukhina N.K. 1999. Influence of predatory gastropod *Nucella* (*Thais*) *heyseana* on population of scallop *Mizuhopecten yessoensis* (Jay) // Russian Journal of Ecology. N 2. P. 153–156. [In Russian].

Ivin V.V. 1999. Present situation, problems and perspective in Japanese kelp cultivation in Russia // Earth – Water – Humans: Proceedings of the International Symposium, 30 May – 1 June 1999, Kanazawa University, Kanazawa, Japan. K. Tazaki and H. Ikariyama (Eds.). P. 109–114.

Ivin V.V., Kalashnikov V.Z. 2005. Scallops of the Russian waters of northwestern Pacific. Part 1. Biology and ecology // Bulletin of the Russian Far East Malacological Society. V. 9. P. 27–45.

Ivin V.V., Maslennikov S.I. 2000. Seafarms for joint cultivation of invertebrates and seaweeds // Ocean and Business: Pacific Business Herald. N 4–5. P. 44–45. [In Russian].

Ivin V.V., Maslennikov S.I. 2001. Commercial technology of polyculture at the open waters of Russian Far East seas // Proceedings of the 8th Meeting of the Hydrobiological Society of the Russian Academy of Sciences, 16–23 September 2001, Kaliningrad, Part 2. E.N. Naumenko (Ed.). P. 37–38. [In Russian].

Kochnev Yu.R. 1987. Dynamics of resources and fishery of white scallop at the Onekotan Island // Results of Investigations of Rational Using and Preservation of the Environment at Sakhalin and Kurile Isles: Abstracts of the 3rd Scientific Conference, 27–28 March 1987, Yuzhno-Sakhalinsk. A.V. Ivanov (Ed.). Yuzhno-Sakhalinsk: Geographic Society of the USSR. P. 130–131. [In Russian].

Kochnev Yu.R. 1993. Sea scallops // Commercial Fishes, Invertebrates and Algae of Seawaters of Sakhalin and Kurile Islands. V. Semenchik (Ed.). Yuzhno-Sakhalinsk: SakhNIRO. P. 49–60. [In Russian].

Kochnev Yu.R. 2000. Distribution of *Mizuhopecten yessoensis* in the Izmenchivoe Lake (South Sakhalin) // Bulletin of the Russian Ear East Malacological Society. N 4. P. 82–84. [In Russian].

Krasnov E.V., Evseev G.A., Tatarnikov V.A., Shavkunov E.V., Besednov K.N., Diyakova O.V. 1977. Sea organisms and their using by the human // Biologiya Morya (Marine Biology, Vladivostok). N 1. P. 81–90. [In Russian with English abstract].

Maslennikov S.I., Kashin I.A. 1993. Fouling of constructions for mariculture of *Mizuhopecten yessoensis* // Biologiya Morya (Marine Biology, Vladivostok). N 4. P. 90–97. [In Russian with English abstract].

Maslennikov S.I., Kashin I.A. 2000. Technique for cultivation of aquatic organisms in polyculture. The patent for an Invention of Russian Federation registered on 27 May 2000, No. 2149541 // Invention Bulletin. N 15. P. 1–18. [In Russian].

Mokretsova N.D. 1996. Present situation and perspectives of mariculture development in Far East Seas // The Status and Perspective of Scientific and Practical Works in Mariculture of Russia: Proceedings of Conference, August 1996, Rostov-on-Don. L.A. Dushkina (Ed.). Moscow: VNIRO. P. 203–209. [In Russian].

Myasnikov V.G. 1982. Distribution of the scallop *Chlamys rosealbus* (Scarlato) along the north coastline of Primorye (Sea of Japan) // Izvestiya TINRO V. 106. P. 70–73. [In Russian].

Myasnikov V.G. 1992. Commercial scallops of the genera *Chlamys* (Bivalvia, Pectinidae) from temperate waters of northwestern Pacific: distribution, growth and resources. Abstract of Dissertation, Candidate of Science in Biology (Ph.D. Thesis). St. Petersburg: Zool. Inst., Russ. Acad. Sci. 22 p. [In Russian].

Myasnikov V.G., Hen G.V. 1990. Conditions for the forming of commercial aggregations of *Chlamys* scallops in the northwestern Pacific // Abstracts of the 5th All-Union Conference on Commercial Invertebrates, 9–13 October 1990, Minsk-Naroch. B.G. Ivanov (Ed.). Moscow: VNIRO. P. 122–123. [In Russian].

Myasnikov V.G., Zgurovsky K.A., Temnych O.S. 1992. Morphological differentiation of commercial scallops of the genus *Chlamys* (Bivalvia, Pectinidae) in the northwestern Pacific Ocean // Zoologichesky Zhurnal (Zoological Journal). V. 71, N 9. P. 22–31. [In Russian with English abstract].

Okladnikov A.R, Derevyanko A.P. 1973. Distant Past of Primorye and Priamurye. Vladivostok. 439 p. [In Russian].

Ponurovsky S.K., Brykov V.A. 2001. Present state in population of scallops *Mizuhopecten yessoensis* at South Kuriles Shoal // Nearshore Fishery – XXI Century: Abstracts of the International Scientific and Practical Conference, 19–21 September 2001, Yuzhno-Sakhalinsk, Russia. Yuzhno-Sakhalinsk: SakhNIRO. P. 97–98. [In Russian].

Ponurovsky S.K., Brykov V.A., Evseev G.A. 2000. Population structure and growth of the scallop *Mizuhopecten yessoensis* in shallow waters of Kunashir Island South Kurile Shoal (Kurile Islands) // Bulletin of the Russian Ear East Malacological Society. N 4. P. 93–94. [In Russian].

Rakov V.A., Lutaenko K.A. 1997. The Holocene molluscan fauna from shell middens on the coast of Peter the Great Bay (Sea of Japan): paleoenvironmental and biogeographical significance // The Western Society of Malacologists, Annual Report. V. 29. P. 18–23.

Razin A.I. 1934. Marine commercial mollusks of the Southern Primorye // Izvestiya TIRKh. V. 8. P. 48– 63. [In Russian].
Rosenthal H., Weston D., Lowen R., Black E. (Eds.) 1988. Environmental impact of mariculture. Report of the ad hoc study group // Cooperative Research Report. N 154. P. 1–83.
Shaldybin S.L. 1983. Growth of the Japanese scallop in Kit Inlet // IV All-Union Conference on Scientific-Technological Problems of Mariculture: Abstracts of Papers, 23–28 October 1983. V.G. Markovtsev (Ed.). Vladivostok: TINRO. P. 201–202. [In Russian].
Shpakova T.A. 2001a. Distribution and resources of scallop *Mizuhopecten yessoensis* (Jay) in Aniva Bay (Eastern Sakhalin) // Abstracts of the Conference, 19–21 September 2001, Yuzhno-Sakhalinsk, SakhNIRO. P. 125–126. [In Russian].
Shpakova T.A. 2001b. Dynamics of size composition in populations of scallop *Mizuhopecten yessoensis* (Jay) in Aniva Bay (Eastern Sakhalin) // Abstracts of the Conference, 19–21 September 2001, Yuzhno-Sakhalinsk, SakhNIRO. P. 126–127. [In Russian].
Silina A.V. 1994. Growth of the scallop *Mizuhopecten yessoensis* cultured in the coastal waters of Primorye Province, Russia // Proceedings of the 9th International Pectinid Workshop, B.C., Canada, 22–27 April 1993. V. 2. N.F. Bourne (Ed.). P. 99–103.
Silina A.V., Ovsyannikova I.I. 2000. Yesso scallop and its epibioses in cage and bottom cultures in the Alekseeva Bight (Sea of Japan) // Bulletin of the Russian Far East Malacological Society. N 4. P. 103–105. [In Russian].
Silina A.V., Pozdnyakova L.A., Ovsyannikova I.I. 2000. Population conditions of Japanese scallop in southwest part of the Peter the Great Bay // Ecological Conditions and Biota of Southwest Part of the Peter the Great Bay and Mouth of the Tumannaya River. V.L. Kasyanov (Ed.). Vladivostok: Dalnauka. P. 168–185. [In Russian].
Skalkin V.A. 1966. Biology and Fishing of the Sea Scallop. Vladivostok: Far East State Publisher. 30 p. [In Russian].
Skalkin V.A. 1975. White scallops *Chlamys albidus* (Dall) (Molluska, Bivalvia, Pectinidae) at Onekotan Island (Kurile Ridge) // Izvestiya TINRO. V. 95. P. 69–77. [In Russian].
Ventilla R.F. 1982. The scallop industry in Japan // Advances in Marine Biology. N 20. P. 309–382.
Wang R., Shieh L.C. 1991. Culture of Farrer's scallops *Chlamys farreri* (Jones and Preston) in China // Estuarine and Marine Bivalve Mollusks Culture. W. Menzel (Ed.). Boston: CRC Press. P. 277–281.