# Salmon Culture Based on Preservation of Biological and Ecological Conditions of Aquatic Communities

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Freshwater areas of the continental coast of the northern Sea of Okhotsk (within the Magadan region) provide spawning areas for the four main commercial species of Pacific salmon *Oncorhynchus* spp., including pink *O. gorbuscha*, chum *O. keta*, coho *O. kisutch*, and sockeye salmon *O. nerka*. In 1960-1970, increasing anthropogenic impacts in freshwater areas of the Magadan region, as well as intensive fishing of salmon at sea, resulted in decreased natural reproduction. In those years, the population of chum salmon decreased more than three times as compared to population levels in 1930-1940. In 1965-1973 pink salmon runs were at a minimum level (Volobuev et al. 2005). Decreased salmon catches provided the impetus to develop regional programs for replenishment of salmon populations by means of artificial reproduction.

In 1983 artificial salmon culture began in the Magadan region. Four federal salmon hatcheries were built with a total production capacity of 120 million downstream migrants per year. The hatcheries are located on large salmon rivers of the Taui Gulf, including the Taui, Yana, Arman, and Ola. Apart from salmon hatcheries, there are three major salmon nurseries also functioning on the northern coast of the Sea of Okhotsk. The research salmon culture facility "Kulkuty" was started in 1992 by the Research Institute for Fisheries (MagadanNIRO). Other salmon culture facilities, "Staraya Vesyolaya" and a nursery at Glukhoe Lake, were built in 1996 and 2000, respectively. These facilities are a part of the organizational subdivision of the federal agency "Okhotskrybvod".

Chum salmon has a dominate role in salmon culture of the Magadan region and constitutes more than 71% of the total salmon hatchery production. Pink salmon is 24% of the total production of salmon released. Sockeye and coho salmon are of secondary consideration and constitute 1% and 4%, respectively, of hatchery releases. Lately, there has been an increase in the amount of juvenile pink and coho released and a decrease in the amount of chum salmon released in the Magadan region.

Salmon culture activities have been conducted for many years at salmon hatcheries located on major rivers of the Taui Gulf (Taui, Yana, Arman, and Ola), and this has resulted in formation of chum salmon populations characterized by different reproduction types and consisting of fishes of wild and artificial origin. At present, reproduction in these rivers of both wild and hatchery populations has not ensured stable catches of chum salmon in fisheries. It has been noted that chum salmon runs in rivers with salmon hatcheries decreased in recent years. At the same time, obtaining a sufficient supply of fertilized eggs became a serious problem (Safronenkov and Khovanskaya, 2004). Reduction in hatchery production was due to several factors, including a consistently insufficient number of adult salmon in major rivers due to natural causes and excessive fishing, and a low biological efficiency of outdated hatcheries that were built to meet the technological requirements of the 1980s. Hatchery reconstruction and introduction of modern biotechnologies have not yet been conducted. We assume that enhancement of the resource base for the salmon fishery of the Magadan region would be impossible without complex reorganization of the region's salmon culture facilities (Safronenkov et al. 2005).

Analysis of salmon culture activities in the region shows the necessity to change from conservative methods of culturing salmon only at fish hatcheries because this method has not increased productivity in the numerous minor coastal rivers of the northern Sea of Okhotsk. About 40% of the entire salmon stock originates from minor coastal rivers. These coastal rivers are not used for salmon culture, even though they sustain quite extensive fisheries.

MagadanNIRO has developed and is now testing a full-scale biotechnology-oriented program to create artificial populations of fall-run chum salmon in minor coastal rivers that previously produced only wild pink salmon. The technology does not provide for construction of a hatchery on each minor river. "In-hatchery" operations, such as incubation of eggs and rearing of alevins, are conducted at the nearest salmon hatchery, and "out-of-hatchery" operations, such as transportation, rearing, and release of fry, are carried out directly at the river. Creation of new chum populations in rivers typical of pink salmon production preserves the biological and ecological system of the river. Such a chum salmon population was formed in 1996 by MagadanNIRO at the Kulkuty River, located in Odyan Bay of the Taui Gulf (Rogatnkykh et al. 1998). The Kulkuty River is only 19 km in length. Wild pink salmon inhabiting the Kulkuty River and the introduced fall-run chum salmon do not interact. Intensive spawning of pink salmon in rivers of the northern Sea of Okhotsk takes place in mid July and lasts until mid August. Fall-run chum salmon spawn in September (Fig. 1). Downstream migration of wild pink salmon

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in the Kulkuty River occurs in May-June, and hatchery-raised chum salmon juveniles are released into the river in early or mid July. The difference in spawning and downstream migration timing between pink and chum salmon eliminates the risks of competition on the spawning grounds, inter-specific hybridization, destruction of existing redds, possible infections, food competition among fry in the river and coastal waters, and other risks.

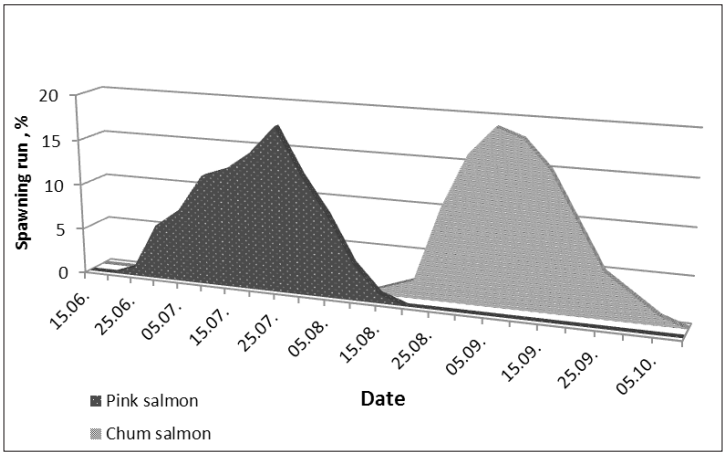


**Fig. 1.** Timing of the spawning run of wild pink salmon and hatchery-raised chum salmon in Kulkuty River. Date increments are at a 5-day interval.

There are no natural chum salmon populations in the rivers where hatchery-raised chum are introduced, and they exist in these rivers only by annual introductions. These introductions do not lead to eventual naturalization of the artificially-raised chum salmon in the river. All the adult chum salmon are caught, and natural spawning is prevented due to the unsuitable environment in small coastal rivers for natural spawning of chum salmon. As a rule, fall chum salmon spawn successfully in large rivers supplied with ground water discharge and where the water temperature does not go below 2-3 C° during winter and spring. Hydrological conditions on the spawning grounds of minor rivers do not facilitate survival of chum salmon progeny. In the Kulkuty River, for instance, the water temperature in the river channel is close to 0.2 C°, too cold for chum salmon embryos to survive, and the majority of them die. In the event that hatchery release operations end in minor rivers, the artificial fall chum salmon population will eventually disappear within several years due to the absence of adequate conditions to sustain successful reproduction.

Over 18 million chum salmon juveniles have been transported, raised, and released during the period of introductions to the Kulkuty River from 1993 to 2011. The number of juveniles released annually varied from 170 thousand up to 3.3 million individuals (average 0.99 million). Constant improvements have been observed in the size, weight, and biological parameters of chum salmon juveniles rearing in the Kulkuty River. Internal organ growth is characterized by proportional development. Over many years of study, average body weight of downstream migrants ranges from 406 to 840 mg (average 572.2 mg) and length varies from 37 to 47 mm (average 40.9 mm). Survival rates for juveniles tested for salt tolerance in sea water within 7 days approaches 100%.

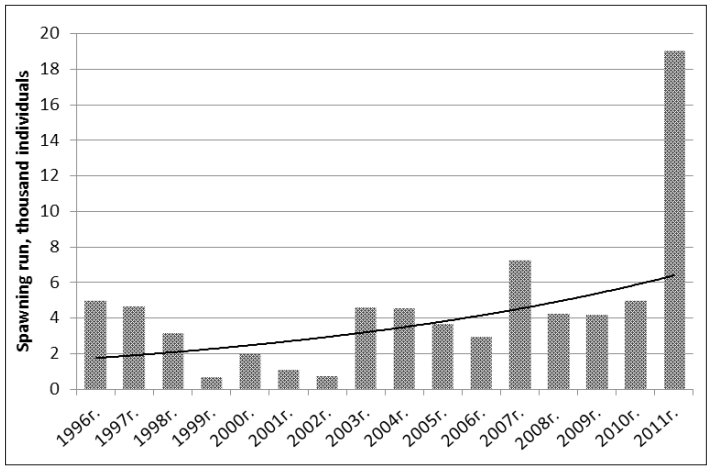


**Fig. 2.** Number of hatchery-raised chum salmon in the spawning run returning to the Kulkuty River, 1996-2011. Line indicates the long-term increase.

Adult chum salmon that were hatchery-raised and released as juveniles in the Kulkuty River began to return for spawning in 1996. Chum salmon runs varied from 0.7 to 19 thousand individuals (Fig. 2), and the maximum run was observed in 2011. During the whole period of operations (1996-2011), the total number of adults returning was more than 73 thousand (256 tons) from which more than 46 million fertilized eggs were obtained. The average rate of return was 0.7% (maximum – 1.87%) for recruits from the hatchery-raised population, which was estimated by taking into account generations that returned for spawning. This rate of return in salmon culture is considered to be quite successful, especially for areas with a climate as severe as that in the Magadan region. This means a biomass of 30 to 70 tons of chum salmon in the spawning run was obtained from release of 1 million juveniles into the feeding area of the river. Salmon returning to spawn can be used both for salmon culture and for fisheries.

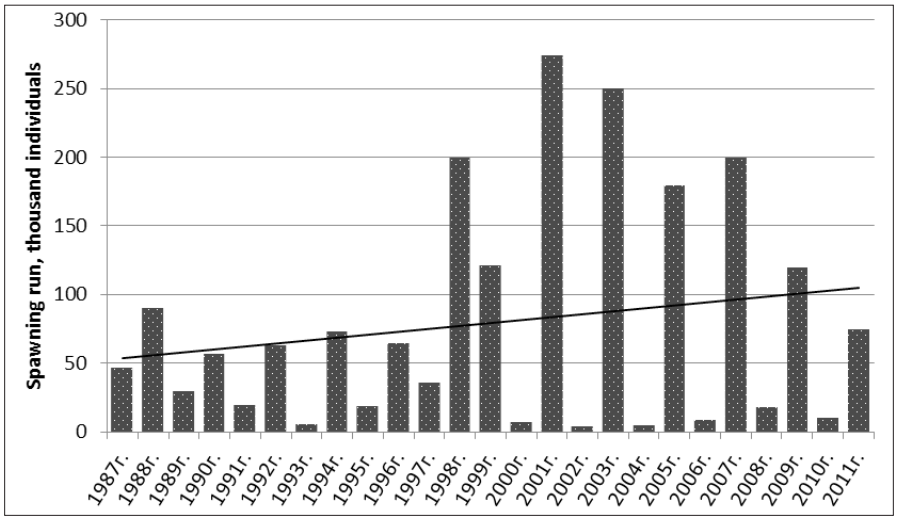


**Fig. 3.** Number of wild pink salmon returning to the Kulkuty River, 1987-2011. Line indicates the long-term increase.

Over the 1987-2011 period, the population of wild pink salmon in the Kulkuty River has remained at a stable high level. Spawning runs of wild pink salmon in odd-numbered (high-yield) years approached 270 thousand fish (Fig. 3). Where hatchery-raised fall-run chum salmon have been introduced, the abundance dynamics of wild pink salmon spawning runs comply with the general tendencies and common factors affecting the entire aggregate stock of pink salmon originating on the continental coast of the northern Sea of Okhotsk.


**Fig. 4.** Locations of small coastal rivers in the Odyan Gulf of the Magadan region that produce wild pink salmon and that are under consideration for future introductions of hatchery-raised chum salmon juveniles.

Formation of artificial populations of chum salmon in rivers typical of wild pink salmon production allows for significant increases in total salmon production capacity without causing damage to the biological and ecological conditions in rivers, providing that minimum inter-specific interaction is allowed. For example, in 1999-2011 the average cumulative wild pink salmon run for odd-numbered years in the Kulkuty River was 174 thousand individuals. The annual recommended commercial catch did not exceed 52,000 pink salmon, or 67 tons. Pink salmon are harvested from late June until late July. The spawning run of introduced fall chum salmon in the Kulkuty River begins in mid August. Run strength depends on the number of artificially-reared and released juveniles. The ecological capacity of the Kulkuty River is not less than 5 million chum salmon juveniles, given the density of fry on the feeding grounds is 0.4 thousand fish per $m^2$. Consequently, this number of juveniles can produce an adult return ranging from 40 to 90 thousand fish, from which approximately 8-10 thousand individuals are used for egg-taking, and another 32-80 thousand fish (120-290 tons) are available for commercial purposes. Given the above conditions, the potential production capacity of particular rivers can be increased 2 to 5 times, without causing any damage to the existing ecological structure and natural abundance dynamics of the wild salmon populations. By replicating this methodology in other minor coastal rivers of the northern Sea of Okhotsk, a whole network of environmentally-safe salmon populations can be created over time (Fig. 4). Provided that advanced technological principles of salmon culture are observed, such populations can produce an additional 1-1.5 thousand tons of salmon for fisheries. Formation of new salmon populations using biotechnology that is based on the peculiarities of the stock's temporal structure combined with both "in-hatchery" and "out-of-hatchery" culturing methods has proven in practice to be efficient and within the tolerance of natural river systems. The use of these methods on a large-scale basis will help resolve the problem of obtaining sufficient fertilized eggs for incubation at hatcheries and increase salmon harvest in the Magadan region.

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