Biological Monitoring of a Key Salmon Population: Ozernaya River Sockeye Salmon of West Kamchatka

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Abundant sockeye salmon populations on the Asian and North American coasts of the Pacific Ocean are characteristically produced by river systems with lake habitat for the rearing of juveniles, and the Ozernaya River sockeye salmon population of West Kamchatka is no exception. Kurilskoye Lake is one of the principal freshwater lakes of Kamchatka and it provides important spawning and rearing habitat for sockeye salmon of the Ozernaya River basin (Fig. 1).

Kurilskoye Lake appeared in the Holocene, about 8,000 years ago after the *Il'inskoye* eruption, which ejected 18 km^3 of matter and created a caldera. About 2,000 years ago following the eruption of the *Dikiy Greben'* volcano, the lake assumed its present form. The estimated age of the extant population of *ozernovskaya* sockeye salmon might be about 1000-1500 years.

> ***"ozernovskaya"*** is the common Russian name of sockeye salmon reproducing in the Kurilskoye Lake watershed

The current lake's characteristics are 77 km^2 surface area, 15 km^3 volume, 316 m maximal depth, 195 m average depth, and it is 104 m above sea level. Ten rivers drain into the lake, and one river, the Ozernaya River, flows out of the lake to the Okhotsk Sea. The length of the Ozernaya River is about 48 km.

The total spawning area of sockeye salmon in the Ozernaya River basin is 1.055 km^2. Of this total area of sockeye salmon spawning habitat, riverine spawning areas comprise 23% and 3% are in spring-fed brooks. Most *ozernovskaya* sockeye salmon spawning habitat lies along the Kurilskoye Lake shoreline in shallow water less than 5 m deep.

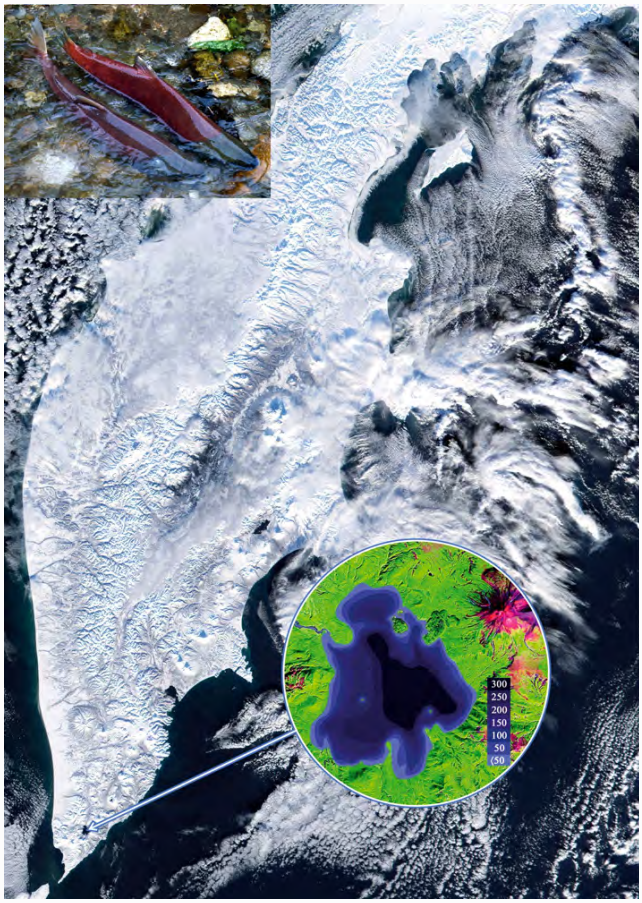


Fig. 1. A snow-bound winter view of the Kamchatka peninsula from space. Inset shows a male and female sockeye salmon on the spawning grounds (upper left) and location of Kurilskoye Lake with depth contours (m; lower right). *Photo credit: Google Maps and KamchatNIRO.*

Eugene Krohin and Phaine Krogius began biological studies of *ozernovskaya* sockeye salmon in 1932. In 1940, a fence for counting returning maturing fish was built six km from the head of the Ozernaya River. In 1941, the Kamchatka Station of VNIRO (currently KamchatNIRO) organized the Kuril Station of Fishery and Biology (currently Ozernovskiy Observatory) and sited it on the shore of Kurilskoye Lake near the head of the Ozernaya River (Fig. 2). In the mid-1970s, the fish-counting fence was also moved to the head of the river.

Currently, the fish-counting fence starts operating in the first half of June and is dismantled in the beginning of September. This is the period when the great bulk of fish enters the lake for spawning and is counted. The fish pass through special windows in the fence, so people (staff of KamchatNIRO or students trainees) can count each sockeye salmon entering the lake. At the same time, all the sick and wounded sockeye and the much less abundant pink, chum and Chinook salmon are also enumerated.

Abundance data are collected based on 30-minute counts, 10-minute counts, or a combination if the run is not coming in evenly, and the totals are summed to obtain the total number of fish counted during the day (Fig. 2). Researchers have agreed that the optimal spawning ground density of sockeye salmon in Kurilskoye Lake is provided with an annual adult escapement of 1.5 to 3 million fish.

In addition to managing adult sockeye salmon spawning escapement for Kurilskoye Lake, scientists from KamchatNIRO also monitor biological characteristics of adult and juvenile sockeye salmon in the Ozernaya River basin (Figs. 2 and 3). They also monitor hydrochemical patterns in the lake, abundance of microalgae and crustaceans in the lake plankton, collect data on the water temperature of the river and lake, and conduct year-round meteorological observations.

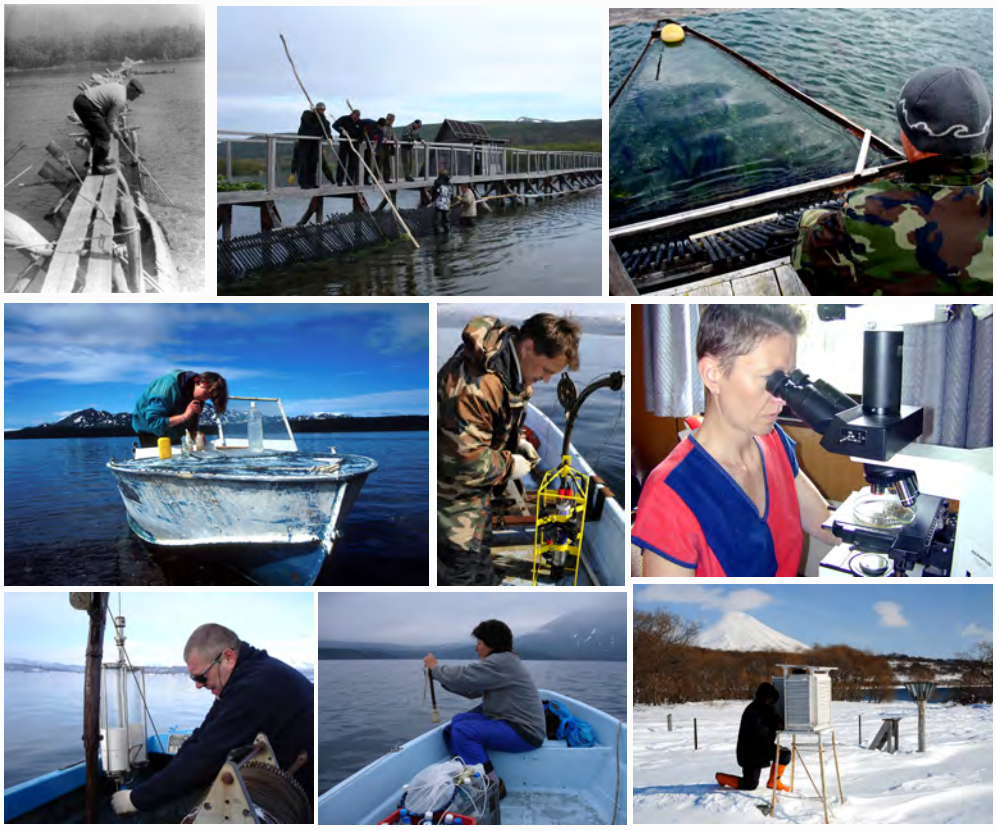
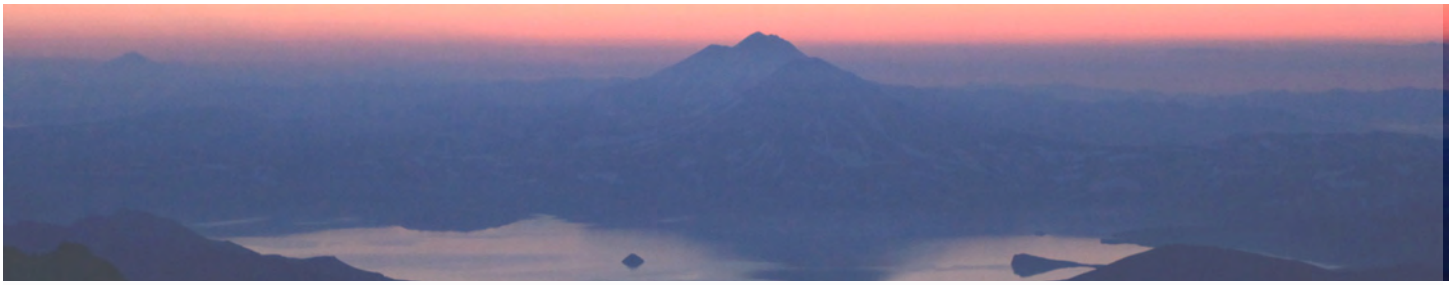


Fig. 2. Scientific activities of Ozernovskiy Observatory staff of KamchatNIRO on the Ozernaya River and Kurilskoye Lake. *Photo credit: KamchatNIRO*

The spawning run of *ozernovskaya* sockeye salmon starts at the end of May and finishes at the end of October or beginning of November. Fish travel from the mouth of the river to its origin in about two to seven days. The intensive portion of the run, when 1,000 to 3,000 fish and more enter the lake daily, occurs from the middle of July until the end of August. The *most* intensive portion of the run occurs around the middle of August, when 20,000 to 100,000 sockeye salmon move up to the spawning areas in just one week. This part of the run is called the main run. Spawning usually starts in the first half of July, and for a few individuals can occur as late as the end of March. On average, each female lays 3900 eggs. Both female and male fish die after spawning. Their carcasses, transformed by microbiological and chemical processes into water-soluble compounds of carbon and nitrogen and phosphorus (nutrients), fertilize the lake and its bordering ecosystems.

Ozernovskaya sockeye salmon fertilized eggs and alevins develop in the redd for five to eight months until the fry emerge from the gravel. The survival rate of the eggs averages 76%; the highest rate among Asian and North American sockeye salmon populations. This high survival rate is associated with the unique structure of the shore and the bottom of Kurilskoye Lake that consists of pervious volcanic pumice, which allows for sufficient permeability and inter-gravel flows during incubation. Emergence of fry from the gravel begins at the end of March and continues into September.



After the fry emerge from the redds, the young-of-the-year spend about 1.5 months in shallow water at the shoreline, and afterwards move into the deeper areas of the lake where they feed and grow for one to three years. Juveniles from riverine spawning areas also migrate to the lake for feeding. Most juveniles spend two years in the lake where they feed on planktonic crustaceans—cyclops and daphnia. The food for crustaceans is microscopic planktonic diatoms, which grow using the nutrients (especially phosphorus—about 3 g of phosphorus, assuming an average weight of 2.5 kg per spawner) returned to the ecosystem by the carcasses of spawned-out fish.

The juveniles that remain in the lake for another year as parr differ from smolts, which take on a silvery coloration and prepare for life in salt water. The seaward migration of smolts begins near the end of May when they gather into schools at the head of the Ozernaya River and begin migrating downstream during the night. The downstream migration to the river mouth takes five to ten days. This out-migration of smolts from the lake is generally finished by the middle of August.

Ozernovskaya sockeye salmon spend the summer and the beginning of autumn of their first year at sea in the waters near western Kamchatka, where forage plankton are abundant. The fish leave the Okhotsk Sea and migrate through the northern Kuril straits to areas off the northeastern coast of the Japanese archipelago, where they spend their first winter at sea (Fig. 4). Most fish spend the second and the third years of sea life in the western subarctic area of the North Pacific Ocean. Depending on individual fish size, sockeye salmon at sea feed on planktonic crustaceans (hyperiids, calanoids, and euphausiids), sea butterflies, young cephalopods, and small fishes. Sockeye salmon spend from one to four years at sea, with most fish spending two to three years. The bulk of sockeye salmon returning to spawn in the Ozernaya River are four to five years in total age.

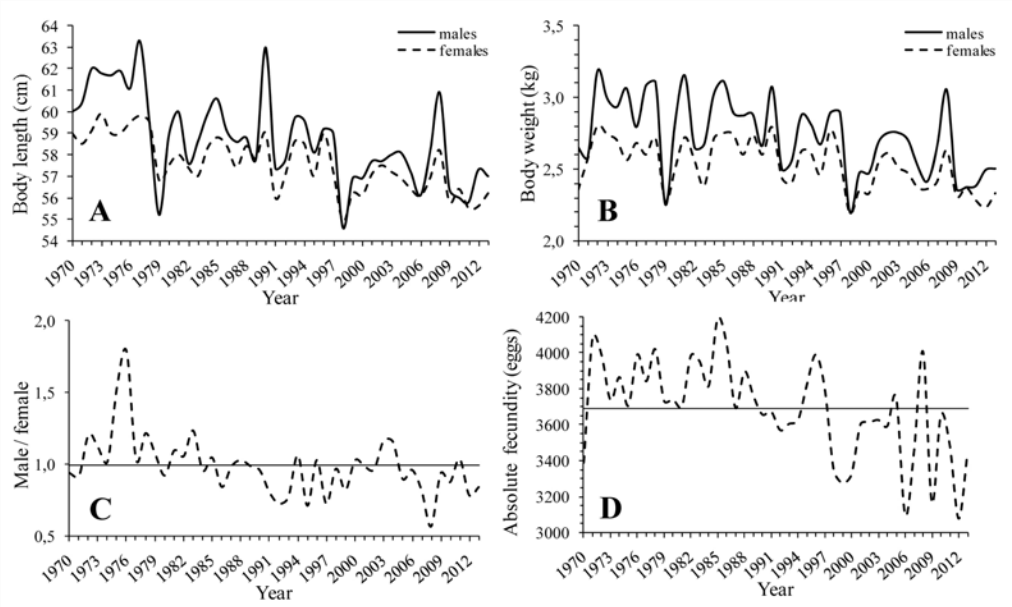


Fig. 3. Biological characteristics of Ozernaya River adult sockeye salmon obtained from coastal commercial catches, 1970-2013. A. Average body length of males and females (cm). B. Average body weight of males and females (kg). C. Ratio of males to females. D. Fecundity of females (number of eggs).

The spawning migration of sockeye salmon from the sea to native rivers begins in early spring. *Ozernovskaya* sockeye salmon migrate from oceanic feeding areas to the eastern coast of Kamchatka along the Aleutian Islands, and then move down the southern tip of the peninsula. During this migration, sockeye salmon build their strength for the last spurt of movement to the native river. Passing the northern Kuril straits, the maturing sockeye salmon retrace the pathway they took as juveniles (Fig. 4). By the beginning of July, considerable concentrations of maturing fish appear near the Ozernaya River, and these fish are the source of commercial catches of *ozernovskaya* sockeye salmon.

Ozernaya River sockeye salmon are monitored throughout their lifespan. Observations are obtained from the downstream migration of smolts from Kurilskoye Lake to the Okhotsk Sea, the early marine period of life in the inshore water of West Kamchatka, the anadromous migration of mature salmon returning to the river and lake for spawning, and the period that fish are on the spawning grounds (Fig. 5). Monitoring the complete life cycle over many years has resulted in a rich biological and ecological data set that provides a strong basis for thoughtful and rational use of the *ozernovskaya* sockeye salmon resource.

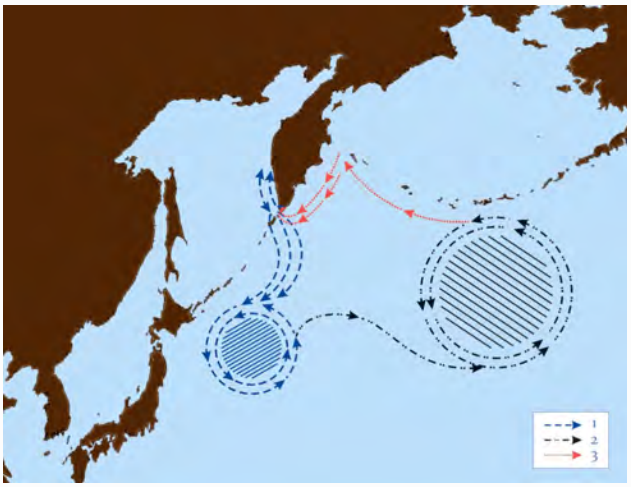


Fig. 4. General migration route of Ozernaya River sockeye salmon during their marine movements in the northwest and central North Pacific. Number and arrow patterns indicate the movement of fish having spent one, two, or three winters at sea.

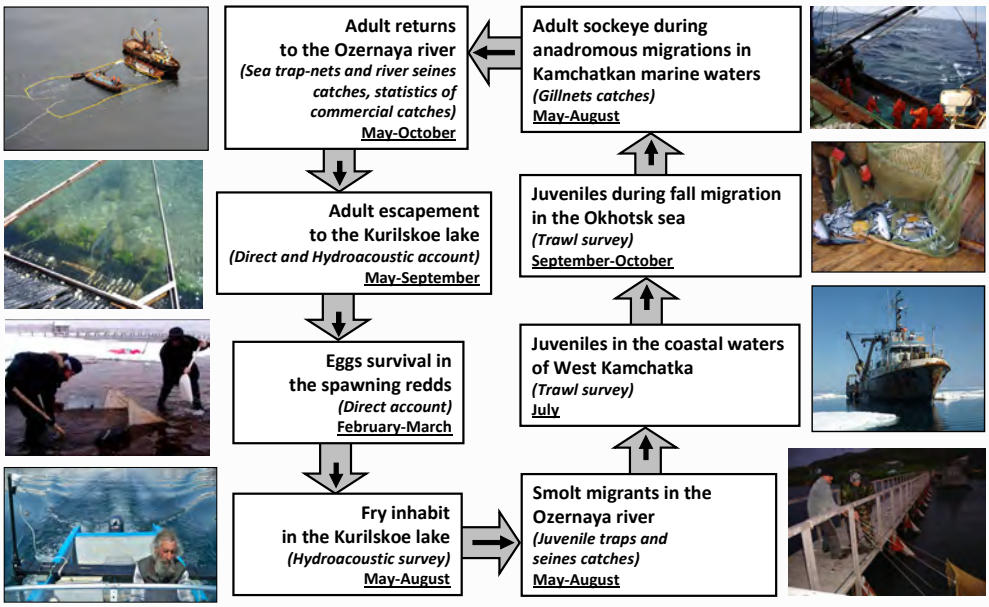


Fig. 5. Ozernaya River sockeye salmon life history stages and the timing of annual biological monitoring conducted by KamchatNIRO scientists.

The current abundance of *ozernovskaya* sockeye salmon can be estimated based on three indices: adult escapement, nearshore catches, and catches at sea (Fig. 6). These data sources are important to fisheries management in order to control escapement to Kurilskoye Lake, potentially at the expense of fisheries at sea, nearshore, and in the river.

Aware of the great importance of *ozernovskaya* sockeye salmon to the health and high productivity of the lake and its bordering ecosystems, KamchatNIRO scientists campaigned for creation of a regional preserve. They achieved that goal with establishment of the Kurilskoye Lake Regional Reserve in 1965. To further strengthen protection of this unique place, the South Kamchatka Preserve of federal importance was organized in 1983. At the present time, this exceptional place is strongly protected, owing to a new generation of dedicated people living in the area.

Due to a strong system of management and protection, catch and escapement of the *ozernovskaya* sockeye salmon stock have demonstrated visible growth since 2000 and remained at a stable high level until now (Fig. 6). For example, nearshore catches averaged 18,200 tons a year in 2001-2013, providing some 73% of the total sockeye salmon catch in Kamchatka. In 2013, the total catch of Ozernaya River sockeye salmon (plus the ocean catch off western Kamchatka) was the highest in 100 years of observations: 29,700 tons, or more than 15 million fish.

Nevertheless, trends in data collected for decades indicate recent population transformations. There has been a significant decrease in the average body weight of mature Ozernaya River sockeye salmon (Fig. 3). Moreover, data in recent years indicate an increase in the duration of the marine period of life because the portion of older age groups among mature individuals has increased. Other trends indicate a switch from a higher prevalence of males in the spawning stock in the 1970s-1980s to a higher prevalence of females in the 1990s-2000s. The females in the recent period also have a lower mean fecundity (average number of eggs). These transformations can be related to growth in the total population abundance and to some environmental factors, including possible effects of climate changes in the North Pacific.

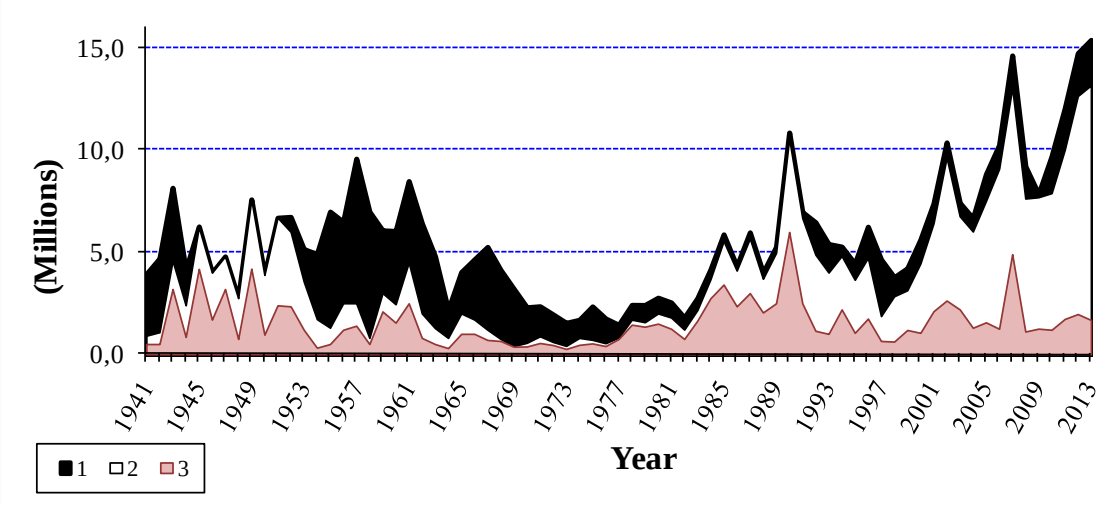
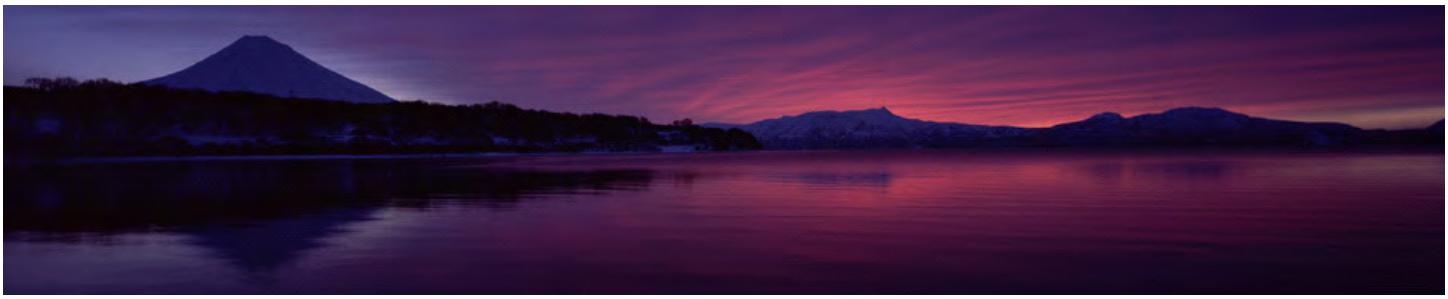


Fig. 6. Total abundance of Ozernaya River sockeye salmon from 1941-2013 in millions of fish. Shaded areas show different components of the total number.
1: Number of fish caught in marine fisheries. Before 1993 this number includes Japanese high-seas catches that may be immature and maturing fish. Since 1993 the number includes Japanese and Russian catches of maturing fish caught in the Russian exclusive economic zone.
2: Number of maturing fish caught in commercial fisheries in the river and river mouth.
3: Number of adult fish on the spawning grounds.



Despite the current status of a high stock abundance of Ozernaya River sockeye salmon, we conclude that the following efforts are necessary key conditions to promote population stability.

1. Overall scientific research (KamchatNIRO)
   - study population dynamics and productivity
   - investigate the lacustrine period of life
   - examine the marine period of life
   - determine the role of the terrestrial ecosystem in maintenance of productivity of the Kurilskoye Lake ecosystem
   - provide environmental education to the general public

2. Efficient fisheries management (Fishery industry and KamchatNIRO)
   - manage escapement for optimum spawning levels
   - monitor escapement for maintenance of genetic biodiversity of spawners
   - enforce fisheries rules in adjacent marine areas

3. Overall protection (South Kamchatka Preserve)
   - protect spawning areas
   - protect the Kurilskoye Lake basin including terrestrial ecosystems
   - provide environmental education to the general public

The unique, rich resource of the Ozernaya River sockeye salmon population can be protected in the long-term for fruitful use only by the mutual efforts of scientists, stakeholders, local society, and environmental organizations.

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