Review of Russian Marine Investigations of Juvenile Pacific Salmon

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Abstract: In the coastal waters of the far eastern seas of Russia, different gears were used for juvenile salmon surveys depending on the geomorphological and hydrological conditions of the region. In offshore waters, pelagic rope-trawls were used to collect juvenile salmon in the same areas from year to year. For the future it is recommended that monitoring in these standard areas continue, and that a new investigation on biological interactions of enhanced and wild salmonids be undertaken.

INTRODUCTION

Data on the marine biology of juvenile Pacific salmon were first collected during occasional sampling and investigation of other marine fishes, usually Pacific herring (*Clupea pallasii*), as well as during sampling directed at juvenile salmonids in coastal waters (Baranenkova 1934; Semko 1939; Gribanov 1948; Piskunov 1955, 1959). Regular studies of juvenile Pacific salmon were undertaken by I. B. Birman in the early 1960s, after a laboratory was established in Kamchatka in 1960 to investigate the marine life of salmon (Birman 1985). Originally, only the ecology of juveniles in the open sea and the North Pacific was studied, but later coastal water ecology was included.

These Russian marine investigations of juvenile Pacific salmon have addressed three topics:

1) juvenile ecology during early marine life in estuaries and coastal waters;
2) life of juvenile salmon during autumn, and assessment of their brood abundance;
3) the role of juvenile salmon in coastal and marine ecosystems of Russia's far eastern seas and the north-west Pacific Ocean.

This report reviews the results and prospects for further study of these and some other topics.

METHODS AND MATERIALS

Work reviewed in this paper was carried out by Russian scientists and their foreign colleagues in the waters of Russia's far east, and published in Russia and abroad. In addition, some data, including personal reports of investigators, were provided to the author at his request. The author acknowledges and thanks all people who have provided such data.

Various investigators used different methods of collecting data. Methods depended on geomorphological peculiarities of the survey areas as well as goals and technical requirements (Fig. 1). The sampling areas, methods and results are summarized in Table 1.

RESULTS

Early Marine Life of Pacific Salmon

Data on ecology of juvenile salmon during early marine life were first collected in the 1930s from the estuaries of some west Kamchatka rivers, from Avacha Bay, and from the Kamchatka River (Baranenkova 1934; Semko 1939; Gribanov 1948). Kamchatka scientists were the first to describe feeding and distribution patterns, and biological parameters of some salmon species in coastal waters. Later, investigations were conducted more regularly, and focussed on specific problems in the area. The results of these investigations are reviewed from south to north along the far east coast.

Primorye chum salmon

Investigations into the biology of juvenile chum salmon (*Oncorhynchus keta*) were carried out in the spring–summer seasons of 1986–1990 along the west side of Peter the Great Bay and on the Sea of Japan's coastal waters from Provotny Cape to Olga Bay (Goriaynov 1991, 1993, 1998a). The major goal of these investigations was to gather data on the food requirements of Primorye chum salmon during their

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Fig. 1. Main Investigation areas of Pacific salmon juveniles. Coastal waters: 1-Primorye, 2-Iturup Island, 3-Southeast Sakhalin, 4-Southwest Sakhalin, 5-Nyiskiy Bay, 6-Sakhalin Bay, 7-Tauy Bay, 8-Western Kamchatka, 9-Avacha Bay, 10-Karaginskii Bay; I-fall surveys TINRO-Centre; II-Winter Surveys TINRO-Centre.

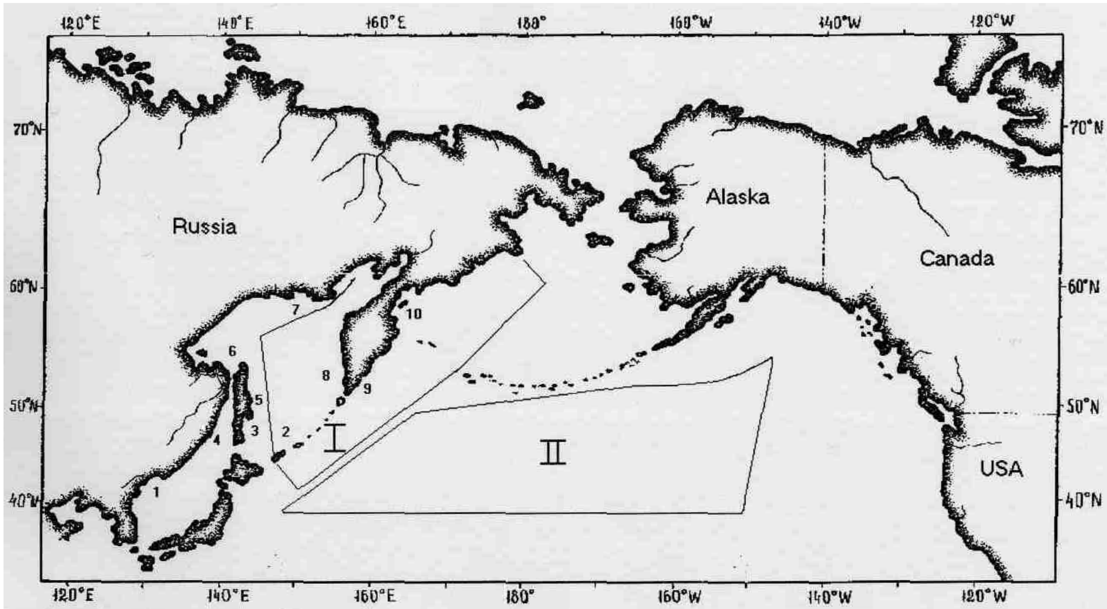


Table 1. Studies on juvenile salmon conducted in Russian waters (main cruises) and types of data collected.

Region	Investigator	Dates	Gear	Physical oceanography	Zooplankton	Food	Growth	Migration	Predators
				TINRO-Centre					
N-W Pacific	Erokhin V.G.	1985–1986	Trawl	+	+	+	+	-	-
”	Borisovskii Yu.G.	1987	”	+	+	+	+	-	-
N-W, N-E Pacific	Rassadnikov O.A.	1988–1991	”	+	+	+	+	-	-
N-W Pacific	Rassadnikov O.A.	1992	”	+	+	+	+	-	-
Bering sea	Shuntov V.P.	1986	”	+	+	+	+	-	-
”	Ozhereliev A.V.	1988	”	+	+	+	+	-	-
Bering sea, Pacific Kuril Is.	Sobolevskii E.I.	1987, 1993	”	+	+	+	+	-	-
Bering sea, Sea of Okhotsk, Pacific Kuril Is.	Boldyrev V.Z.	1990	”	+	+	+	+	-	-
”	Volkov A.F.	1990	”	+	+	+	+	-	-
Sea of Okhotsk, Pacific Kuril Is.	Rassadnikov O.A.	1990–1991	”	+	+	+	+	-	-
”	Gorbatenko K.M.	1992	”	+	+	+	+	-	-
”	Shuntov V.P.	1993	”	+	+	+	+	-	-
Sea of Okhotsk	Radchenko V.I.	1994	”	+	+	+	+	-	-
Sea of Okhotsk, Pacific Kuril Is.	Moroz I.F.	1994–1995	”	+	+	+	+	-	-
”	Gorbatenko K.M.	1995–1996	”	+	+	+	+	-	-
Sea of Okhotsk	Radchenko V.I.	1996	”	+	+	+	+	-	-
Sea of Okhotsk, Pacific Kuril Is.	Efimkin A.Ya.	1996	”	+	+	+	+	-	-
Sea of Okhotsk	Shuntov V.P.	1997	”	+	+	+	+	-	-
”	Melnikov I.V.	1998–1999	”	+	+	+	+	-	-
Sea of Japan (Peter the Great Bay)	Goriaynov A.A.	1986–1990	Trawl, beach seine, lift net	+	+	+	+	+	-

continue...

Table 1. continued.

Region	Investigator	Dates	Gear	Physical oceanography	Zooplankton	Food	Growth	Migration	Predators
				Amur branch TINRO-centre					
Sakhalin Bay	Rosly Yu.S., Novomodny G.V.	1987–1993	Trawl	+	-	+	+	-	+
				Magadan branch TINRO-centre					
Ola estuary	Frolenko L.A.	1975–1978	Beach seine	+	+	+	+	-	-
Tauy Bay	Popov S.A., Semenova N.R.	1981–1982	Beach seine	+	+	+	+	-	-
”	Kostarev N.V.	1986–1988	Pelagic trawl, Isaacs-Kidd trawl, trap, gill net	+	+	+	+	+	+
”	Afanasyev N.N. et al.	1988–1990	Pelagic trawl Isaacs-Kidd trawl	+	+	+	+	+	-
Sea of Okhotsk	Volobuyev V.V.	1986–1990	trawl	+	+	+	+	-	-
				SakhNIRO					
S-W Sakhalin	Shershnev A.P.	1964–1970	Bottom trawl, beach seine, Isaacs-Kidd trawl	+	+	+	+	+	+
”	Ivankov V.N. et al.	1985–1988	Beach seine	+	+	+	+	+	+
S-E Sakhalin	Shershnev A.P., Rudnev V.A.	1973–1976	Bottom trawl, beach seine, Isaacs-Kidd trawl	+	+	+	+	+	+
”	Shubin A.O. et al.	1988–1993	Trawl	+	+	+	+	+	+
”	Ivankov V.N. et al.	1988–1992	Beach seine	+	+	+	+	+	+
N-E Sakhalin	Churikov A.A., Gritsenko O.F.	1971–1974	Beach seine, gill net	+	-	-	+	+	+
”	Ivankov V.N. et al.	1988–1993	Beach seine	+	+	+	+	+	+
Iturup Is.	Kayev A.M., Chupakhin V.M.	1974–1987	Beach seine, landing net	+	+	+	+	+	-
				KamchatNIRO					
Karaginskii Bay	Karpenko V.I.	1975–1983, 1985–1987, 1989, 1991	Trawl, beach seine, purse seine, lift net	+	+	+	+	+	+
”	Erokhin V.G	1984	”	+	+	+	+	+	+
”	Maslov A.V.	1988	”	+	+	+	+	+	+
”	Goncharov D.V.	1992	”	+	+	+	+	+	+
”	Maximenkov V.V.	1993, 1995	”	+	+	+	+	+	+
”	Kondrashenkov E.L.	1997	”	+	+	+	+	+	+
Bering Sea	?	1965	Gill net	+	+	+	+	+	-
”	Skljarov Yu.M.	1966	”	+	+	+	+	+	-

continue…

Table 1. continued.

Region	Investigator	Dates	Gear	Physical oceanography	Zooplankton	Food	Growth	Migration	Predators
Bering Sea	Davydov I.V.	1967	Gill net	+	+	+	+	+	-
”	Karpenko V.I.	1975–1979	”	+	+	+	+	+	-
”	Shershneva V.I.	1981	”	+	+	+	+	+	-
”	Shushunov P.I.	1981–1982	Trawl	+	+	+	+	+	-
”	Kisljakov V.P.	1984, 1986, 1987	”	+	+	+	+	+	-
”	Dekshtein A.B.	1988	”	+	+	+	+	+	-
”	Sinjakov S.A.	1989–1990	”	+	+	+	+	+	-
”	Smorodin V.P.	1994, 1998, 2000	”	+	+	+	+	+	-
Avacha Bay	Karpenko V.I.	1974	Beach seine, Gill net	+	-	+	+	+	+
”	Vasilets P.M., Maximenkov V.V.	1995–2000	Beach seine	+	-	+	+	+	+
Bolshaya estu-ary	Leman V.N.	1989–1990, 1994–1999	Beach seine	+	+	+	+	+	+
”	Tokranov A.M., Maximenkov V.V.	1990–1992	Beach seine	+	+	+	+	+	+
Sea of Okhotsk (coastal waters)	Bazarkin V.N.	1987	Beach seine, purse seine, lift net	+	+	+	+	+	+
”	Grigoryev S.S.	1988	”	+	+	+	+	+	+
Sea of Okhotsk (open waters)	Grachev L.E.	1964–1967	Gill net	+	+	+	+	+	-
”	Skljarov Yu.M., Shershneva V.I.	1966	”	+	+	+	+	+	-
”	Shershneva V.I.	1968, 1973, 1981	”	+	+	+	+	+	-
”	Dguravlev V.M.	1971	”	+	+	+	+	+	-
”	Kaun A.N.	1972, 1973	”	+	+	+	+	+	-
”	Kisljakov V.P.	1975, 1977–1979	”	+	+	+	+	+	-
”	Safronov S.G.	1980	”	+	+	+	+	+	-
”	Shershneva V.I.	1982, 1986	Purse seine	+	+	+	+	+	-
“	Shushunov P.I., Sinjakov S.A.	1984	”	+	+	+	+	+	-
“	Shushunov P.I.	1981–1982	Trawl	+	+	+	+	+	-
“	Kisljakov V.P.	1983–1984	”	+	+	+	+	+	-
“	Erokhin V.G.	1985, 1986, 1989, 1991, 1993, 1995, 1997	”	+	+	+	+	+	-
”	Bezljudny A.M.	1986	”	+	+	+	+	+	-
”	Shershneva V.I.	1987	”	+	+	+	+	+	-
”	Shisterov M.V.	1990	”	+	+	+	+	+	-
”	Smorodin V.P.	1999	”	+	+	+	+	+	-
Sea of Japan	Nikolayev A.S.	1964, 1966	Gill net	+	+	+	+	+	+
”	Grachev L.E.	1965	”	+	+	+	+	+	+
”	Bezrukov A.A.	1970, 1972, 1973	”	+	+	+	+	+	+
”	Karpenko V.I.	1974	”	+	+	+	+	+	+
”	Kisljakov V.P., Shershneva V.I.	1975	”	+	+	+	+	+	+
”	Safronov S.G.	1976	”	+	+	+	+	+	+
Pacific ocean	Birman I.B.	1961	”	+	+	+	+	+	+
”	Kuznetsov A.I.	1961	”	+	+	+	+	+	+

continue…

Table 1. continued.

Region	Investigator	Dates	Gear	Physical oceanography	Zooplankton	Food	Growth	Migration	Predators
Pacific Ocean	Grachev L.E.	1963, 1966	Gill net	+	+	+	+	+	+
"	Davydov I.V.	1965	"	+	+	+	+	+	+
"	Shershneva V.I.	1966, 1967, 1970, 1972	"	+	+	+	+	+	+
"	Piskunova L.V.	1972	"	+	+	+	+	+	+
"	Kaun A.N.	1973	"	+	+	+	+	+	+

early marine life in coastal waters. To obtain these data, investigators assessed the productivity of coastal waters in areas where fish hatcheries were located and operated. The results permitted the evaluation of possible increases in hatchery production, and provided management recommendations for chum salmon produced at hatcheries in the south Primorye. The results led to technological improvements in chum salmon hatchery production, specifically regarding the timing, quantity, and frequency of releases. Release success was correlated with the development and production of the main crustacean forage species. Implementation of the recommendations increased hatchery production efficiency.

Sampling of zooplankton in 1991 (April 19–June 18) documented the presence of 32 species, but only 3–4 of these were abundant: *Acartia clausi, Oithona similis, Paracalanus minutus,* and *Calanus plumchrus.* Zooplankton biomass varied from 50 to 437 mg/m^3, the maximum occurring in the Barabashevka River estuary and Narva Bay in mid May. The food composition of juvenile chum salmon included 26 taxa, of which copepods (*P. minutus, Tortanus discaudatus*) and euphasiids (*Euphausia pacifica*) were the main groups. Stomach fullness reached 133–446 $^0/_{000}$ (Puschina and Goriaynov 1994). Young mysids, decapod larvae and fish larvae were minor components of the diet of juvenile chum salmon.

Although the main downstream migration of juvenile chum salmon occurs in April, a high growth rate is observed later in May: fork lengths increase from 32–42 to 48–60 mm, and weights from 460–590 to 850–2100 mg, daily growth rate in length was from 0.17 to 0.65 mm. At Iturup Island and southwestern Sakhalin Island, daily growth rate was 0.26–0.6 mm (Ivankov and Shershnev 1968; Shershnev 1968). For comparison, in southern Alaska daily growth rate was 0.4 mm (Murphy et al. 1988), and at Hokkaido Island, 0.21–0.39 mm (Irie 1990).

Juvenile chum salmon begin their seaward migration at fork lengths of 55–65 mm, and the duration of coastal habitation in Peter the Great Bay is 0.5–1.5 months. The number of circuli on the scales reaches six, though when migrating to sea most juveniles have no scales. A new circulus appears approximately at each 4–5 mm increment in fork length (Goriaynov 1993).

Survival of juvenile chum salmon depends on their growth in coastal waters, which in turn is determined by the abundance and availability of their food. The coefficient of return of chum salmon to the Narva River decreased more than three times (from 5.2% to 1.6%) when juvenile numbers increased by six times. In addition, return coefficients depend on the average daily growth rate in weight of different generations of juveniles. Release of juvenile chum salmon from hatcheries increases their abundance in coastal areas, and high densities create competition for food because of a limitation in coastal food resources. This is exacerbated in Southern Primorye waters by a relatively short favorable feeding period, associated with a rapid warming of water, leading to the migration of juveniles offshore. This does not occur in more northern areas of salmon production.

Growth rate of juvenile chum salmon may therefore be a reliable indicator of feeding conditions. It affects the number of generations of maturing salmon present at one time, their sizes which affects reproductive effectiveness, and the potential salmon production capacity of this area (Goriaynov 1998b).

Iturup Island chum and pink salmon

In this area, wild and hatchery salmon reproduction are of nearly equal importance. However, very high hydrological activity and such indicators as temperature, salinity, upwelling, and high productivity mean that food availability is likely not crucial to survival of juvenile salmon during their first weeks of marine life. The major objectives of the study on juvenile pink salmon (*O. gorbuscha*) and chum salmon during early marine life in this area were to assess the biological parameters affecting their condition and abundance. Knowledge of these factors is essential for stock assessment and management (Chupakhin and Kayev 1980; Kayev and Chupakhin 1980, 1982, 1986). Investigations were begun in 1974, and continued regularly until the late 1980s. After that, data were collected only occasionally. Some recent data have not yet been published. The specifics of downstream migration, feeding and migration of juvenile pink and chum salmon have received most attention, including formation and growth of scales in the spring-summer season. Ecological groups have been identified in juvenile chum salmon under different feeding conditions, and patterns of individual growth and survival (Kayev 1992). Thus growth patterns in some juvenile broods were used to forecast commercial escapement (Kayev 1979, 1983, 1986, 1999). In addition, juvenile condition while feeding in coastal waters of Iturup Island allows prediction of further growth, and of the numbers and age composition of adults returning to spawn.

Research in this area was begun in the 1960s by V.N. Ivankov (Ivankov and Shershnev 1968), and was continued through the 1970s and 1980s by A.M. Kayev and V.M. Chupakhin (Chupakhin and Kayev 1980; Kayev and Chupakhin 1980). Juvenile salmon were caught in shallow coastal waters and in the zone of stationary trap nets located more then 2 km from the home-river estuary.

Juvenile salmon biology was studied in Kurilsky and Kuybyshevsky bays where both wild and hatchery fish intermingled. The bays have similar geomorphological and physical and hydrological characteristics where juveniles enter from rivers and are released from hatcheries in May and June. In recent years about 50 million pink fry were released annually from the Kurilsky hatchery into Kurilsky Bay, whereas natural spawning grounds in the Kurilka and Rybatskaya rivers produce only 20–30 million fry (O.A. Shubin, SakhNIRO, Komsomolskaya Str. 196, Yuzhno-Sakhalinsk, personal communication). Juveniles in coastal waters are generally observed around the beginning of May, and by the end of May and in June their numbers have considerably increased. By mid-June, offshore migration begins, as at this time temperatures in shallow water increase noticeably, promoting juvenile migration offshore. During this period, the diet of juvenile pink and chum salmon changes, pink salmon in particular switching to more pelagic organisms. Feeding of juvenile salmon may therefore be divided into three stages: 1) feeding in warm, shallow coastal waters, 2) feeding in open bays, and 3) feeding during migration from bays to the open waters of Kurilsky and Kuybyshevsky bays (Chupakhin and Kayev 1980).

The open waters of Kurilsky and Kuybyshevsky bays are influenced by the warm Soya Current and the cold Oyashio Current, which are prominent oceanographic features of the coastal waters determining the seasonal appearance of food organisms here. As a result of the interaction of these two currents at Iturup Island in the coastal waters of the Sea of Okhotsk, three bioproductive zones can be identified. Annually in coastal waters, about 40 species of zooplankton appear belonging to 18 taxonomic groups (Efanov et al. 1990). From small rivers of Iturup Island, pink and chum salmon migrate downstream to the sea where they inhabit coastal waters for 2–3 months. This period may be divided into two, the first being in shallow waters, and the second in open areas and bays. Water temperatures and juvenile growth determine the time juveniles remain to feed in these zones. The optimal temperature is from 6° to 14°C, and salinity from 20 to $32.5^{0}/_{00}$.

Juvenile salmon are much smaller in shallow coastal waters than in open areas and bays. Lengths differ on average by 1.5 to 1.8 times, weight by 5 to 9 times, and the sea zone variability (salinity gradients) is higher. Stomach fullness is almost the same in the two areas, but variability is higher in coastal waters. The stomach fullness of chum salmon is usually 1.5 times higher than that of pink salmon, and on average exceeds $200^{0}/_{000}$. Nevertheless, interannual differences in size and fullness of stomachs are significant, and are used to estimate survival and return rates of different generations.

As in other coastal areas, the food spectrum of juvenile salmon in shallow waters is usually narrower than in open areas or small bays. The diet of chum salmon narrows after their seaward migration. This defines lower indicators of the food overlap of the two species of juveniles in the first zone near beaches after seaward migration, 50%, in comparison with those in the second zone, bays, 80%. While in the first zone (May–June) the main food components are representatives from river insect drift and small coastal crustaceans, in the second zone and period (June–July, early August) they are calanoida, amphipoda and euphausiacea. Chum salmon in the first period usually consume benthic and epibenthic organisms (gammaridae, polychaeta and fish eggs as well as aerial insects); pink salmon prefer crustaceans that inhabit the water mass (Kayev and Chupakhin 1980, 1986). Chum salmon change their predominant food from harpacticoida to calanoida and euphausiids as they grow (Kayev 1983). In pink salmon, this change in diet is not so obvious, but prey sizes increase as the fish grow.

By mid-August most juvenile salmon have migrated from the bays to the open Sea of Okhotsk, and only a few remain in the zone of stationary trap nets. In some years this migration begins earlier, in July; nevertheless, juveniles are seldom caught in the open sea, and then only in small numbers.

Food availability (food supply per fish) in coastal waters as estimated from growth parameters can be used to predict the rate of return of mature fish. For characterizing growth features of chum of different generations Kayev (1979) used asymetries in the size compositions of juveniles. The coefficient of asymetry of fork length for juveniles was used to estimate the return rate of mature salmon: right asymetry (a predominance of small fish) suggested a low return rate, and left asymetry (predominance of larger fish) a high rate of return (Poljakov 1975). In the case of juvenile pink salmon, the rate of scale formation was used as an index of feeding conditions and growth. For this purpose, annually at the end of the first 10 days of July the proportion of juveniles with fully formed scales was identified. This index was significantly correlated ($r = 0.87$; $p < 0.01$) with brood year survival of pink salmon during their life at sea (Chupakhin 1986).

As the example of wild populations of fall chum salmon of Iturup and Sakhalin islands showed (Kayev 1983, 1985), when fish with a limited population adaptability are exposed to highly variable thermal conditions and low temperature shock, mortality is high. Unfavorable environmental conditions can cause a change in the size structure of fish populations (Kayev 1983). Chum salmon mortality is highest in coastal waters when water temperatures change rapidly. This mortality is both direct and indirect; indirect salmon mortality results from thermally induced reduction in abundance and availability of their prey. Food availability is estimated from the growth rate of juvenile salmon in different brood generations (Kayev 1989a, 1989b). The survival rate of brood year-classes is well correlated with variations in this indicator; survival shows an exponential relation to food abundance. This method of predicting survival has permitted a five-fold increase in precision in estimates of numbers of salmon in general, and a 2.5-fold increase in the precision of predicted spawning escapement numbers.

With water temperatures down to 1–3°C during stormy weather, stomach fullness indices of older juvenile salmon differed from those of recent downstream migrants; older fish fed better than recently arrived migrants. At low temperatures, yolk-sac fry fed poorly compared with fish at other stages (Kayev 1992). Fork length (FL) perfectly corresponded with condition factor and stomach fullness in all groups including those migrating downstream and those in coastal waters. The analysis of the condition factor variability of juveniles also supports the assumption of a critical situation among juveniles at this early marine stage and particularly juveniles with remnants of yolk sac. Critical condition threatening survival can therefore arise both from poor food availability and from low temperatures resulting in poor feeding.

Juvenile salmon in coastal waters feed selectively, especially immediately after switching to exogenous feeding. This was concluded from analysis of food composition both in different coastal locations and at different times of day. The stage of tide also influenced food composition (Karpenko 1979, 1981; Kayev et al. 1993). As juveniles grow they observe both total coincidence of the food composition and plankton composition and their differences. Food selectivity depends first on improved swimming and hunting abilities as juveniles grow, and is reflected not only in the plankton composition of their diet, but also the variety of species consumed other species than plankton. The influence of broadened ocean diet is apparent from higher fat content. Scale growth can also be used to successfully estimate abundance of various brood years, and the numbers returning to spawn (Kayev 1989a, 1994). Research into the ecology of juvenile salmon during early marine life reduced the error in spawning escapement estimates of chum salmon to Iturup Island by a factor of 1.7. A similar improvement in estimates was realized for Iturup Island pink salmon (Chupakhin 1986).

Sakhalin Island chum and pink salmon

Investigations have been conducted in three coastal areas of the Island; the south-west, the south-east including Terpeniya Bay, and the north-east. Hatchery salmon production has been developed more intensively at Sakhalin Island than in any other region of Russia, and a major objective of work on the ecology of juvenile salmon has been to assess the survival of both wild and hatchery produced salmon in shelf waters. A second objective was to assess the productivity of coastal waters to determine the carrying capacity for and distribution of salmon in various areas of the Sakhalin region. Chum and pink salmon have been the major species of investigation.

The first systematic investigations of chum and pink salmon biology in south-west Sakhalin were carried out by Shershnev (1971a) from 1964 to 1970. The goal was to study habitat requirements, migration, behaviour, growth and development patterns, and causes of mortality in the coastal waters of the area. Studies were conducted not only in areas of natural reproduction, but in areas near hatcheries. Results have been published in a number of articles in journals on the ecology, early marine life and limiting factors of chum and pink juvenile salmon. The investigations have also provided specific values on juvenile mortality, particularly mortality from predation, at various life stages in coastal waters (Shershnev 1968, 1970, 1971b, 1973, 1974, 1975).

Juvenile salmon inhabit coastal waters of south-western Sakhalin Island during May and July, in some years remaining until mid-August. During that time, zooplankton reach high biomass densities of 300–530 mg/m^3 both in shallow coastal waters and in bays (Shershnev 1971a). Harpacticoida are the most abundant zooplankters during the first weeks after juvenile salmon arrive, and make up the bulk of their diet. Later these juveniles begin to consume mysids, gammarids, and fish larvae, primarily in bays. Immediately after downstream migration, more than half the juvenile chum salmons' food by weight is insects, and these also make up 23.3% of the juvenile pink salmon diet (Shershnev 1975). Stomach fullness of the fish is also high, reaching $450^0/_{000}$. Favorable temperature during spring and summer, and good food availability promote growth, development and survival of juveniles in that brood year. As juvenile chum and pink salmon grow, they migrate to bays and begin to prey on larger organisms (mysids, euphausiids), smaller prey (harpacticoida) becoming less significant. At the same time, however, competition for food both within and among species intensifies.

Juvenile pink and chum salmon migrating downstream in April and May at a size of 30–40 mm double their fork length and increase their weight 8–9 times by mid-August. The highest growth rates occur after their migration to bays and open coastal waters (Shershnev 1973). By this time chum salmon have 8–9 scale circuli, and pink salmon 6–8 circuli, the fastest rate of circuli formation coinciding with the fastest growth from July to August. During this feeding period, the condition factor of juvenile chum salmon in coastal waters increases from 1.04 in May to 1.15 in August (Shershnev 1975).

As these juvenile salmon grow, predation by their chief predators, immature white spotted char (*Salvelinus leucomaenis*), saffron cod (*Eleginus gracilis*) and sculpins (*Cottidae*), decreases. These predators consume more than 11% of a year class present in shallow waters, and about 31% in bays; white spotted char are responsible for about 80% of this predation (Shershnev 1975). In offshore waters, juvenile chum salmon are found in the stomachs of greenlings (Hexagrammidae) and rockfishes.

In the late 1980s, with the reconstruction of the majority of Sakhalin Island's salmon hatcheries, investigations into the early marine life of salmon in the area resumed (Ivankov et al. 1999), particularly in areas with hatcheries. The major goal of the investigations was to assess the carrying capacity of coastal waters in order to improve the efficiency of hatchery use. Research results achieved not only this goal, but also provided information on comparative feeding conditions for juvenile salmon over a period of twenty years.

In waters of south-east Sakhalin Island and in Terpeniya Bay, work was conducted during two periods, the 1970s, and late 1980s to 1990s. During the earlier period, juvenile salmon were studied during their migration from coastal areas to open waters (Shershnev et al. 1982). Later, emphasis was placed on the ecology of juvenile salmon in estuaries and coastal waters (Shubin 1994; Shubin et al. 1996; Ivankov et al. 1999). The major goal of the investigation was to assess carrying capacity of coastal waters and feeding conditions for juvenile salmon, again for the purpose of improving the efficiency of salmon hatcheries. The effect of predation on survival of both hatchery and naturally produced fish was also investigated.

In Nyiskiy Bay (north-east Sakhalin Island) the main purpose of investigations in the 1970s was to document predation on juvenile salmon and their resulting survival (Churikov 1975). Later, in the 1990s, trophic relations of juvenile chum salmon and their survival in coastal waters became the main focus of investigations (Ivankov et al. 1999).

Both naturally and hatchery produced juvenile salmon remain in Mordvinov Bay when conditions for feeding in coastal waters, particularly for pink salmon, are unfavorable. Pink salmon as small as 39 mm and 380 mg can be found 8 km offshore by the end of June. They are found in the stomachs of white spotted char, sculpins, saffron cod, and rock greenling (*Hexogrammus lagocephalus*); the first two species are major predators (Ivankov et al. 1999). A portion of both naturally and hatchery produced juvenile salmon from this region migrate through the brackish waters of Tunaycha Lake, but while pink salmon pass straight through, chum salmon remain there to feed. Juvenile chum remain after mid-May for a couple of months, and grow 39 mm in length (from 45.5 mm to 83.9 mm) and 3.7 g in weight (from 0.634 g to 4.389 g) during that time. Incidentally, on July 7, 1990, six juvenile (l+ years) sockeye salmon (*O. nerka*), that had been released from the Okhotsky hatchery, were caught in this lake.

In more northern areas of eastern Sakhalin Island, juvenile salmon are usually smaller, and feed and grow near the shore for only a short period. In this area, juvenile pink salmon predominate in catches (Ivankov et al. 1999). Chum salmon juveniles are usually bigger, and, though not as numerous, are caught in larger numbers in some net catches. Juvenile chum salmon feed in Nyisky Bay, increasing in fork length by 25 mm, and in weight by more than 1 g. Judging from the sizes of juveniles in this Bay, they remain 1.0–1.5 months, which is longer than they remain inshore at south-western Sakhalin Island (Andreyeva et al. 1994).

Sakhalin Bay chum and pink salmon

The chief objective of research in this area was to assess predation and survival on juvenile chum salmon from the Amur River during their migration to Sakhalin Bay. The work was conducted between 1986 and 1993, but most results were obtained in the early 1990s (Karpenko and Rosly 1989; Rosly and Novomodny 1996). These results indicated that, of all the possible predators in the Bay, the most important on post-migrant juvenile chum and pink salmon was Arctic lamprey (*Lampetra japonica*), which consumed, in some years, up to 93–96% of the juvenile population.

Arctic lamprey probably greatly reduce salmon stocks not only from the Amur River, but also from the Sea of Okhotsk and north Sakhalin Island because the migration paths of these stocks are similar. Lamprey begin preying on juvenile salmon in the Amur estuary, and continue through the Amur Strait and

Sakhalin Bay where different stocks of fish mix. Predation rates increase here. Because migrating salmon are in contact with lamprey for 1.5–3.0 months, reduction of these stocks may also be significant (Rosly and Novomodny 1996).

Predation on juvenile salmon by other species, Arctic smelt (*Osmerus mordax dentex*) and Ussuri whitefish (*Coregonus ussuriensis*) is less than that by lampreys. Exposure to these predators is usually relatively short, from mid-May to June, and in June and July these predators shift mainly to eating mysids, which act as a good buffer between predators and juvenile salmon. Rosly and Novomodny (1996) estimated that in 1989, under the most favorable conditions, predators removed 0.04% of juvenile chum and 0.15% of pink salmon while they were in the lower Amur River and its estuary.

Salmon of the north coast of the Sea of Okhotsk

The major goal of research in this area was to assess feeding conditions in some bays during construction and operation of the salmon hatcheries. Data collection began in the early 1980s, before construction of salmon hatcheries (Popov and Semyonova 1983). The most complete set of data was collected from 1988 to 1990 (Afanasyev and Mikhailov 1994; Afanasyev et al. 1994a, 1994b). The work was conducted both close inshore and in offshore waters in the open area of Tauyskaya Guba. Feeding, distribution, migration and growth of juvenile chum and pink salmon were studied during the first weeks of marine life. Results assessed feeding and survival, and permitted the development of recommendations to improve hatchery practices concerning optimum production capacity, feeding methods, and timing and sizes of releases from hatcheries.

Downstream migration of juvenile salmon begins here in the second week of May, and lasts until the end of June or July. Usually juveniles migrate both west and east along the coast. In rivers that have no estuaries, juvenile salmon move immediately to offshore waters, returning with incoming tides. Juvenile salmon from the Tauy and Motykleyka rivers fed in the tidal zone along the coast in June and July. They remained in the coastal waters of the Tauyskaya Guba a little more than 2.5 months on average; as they grew, they moved to outer, more open waters. Stocks disperse during this movement (Afanasyev et al. 1994a).

Downstream pink salmon migrants averaged 30 mm fork length and 152 mg; juvenile chum salmon were 35 mm and 321 mg. After a short adaptation period with low growth, both species began to grow rapidly in June and July, chum salmon in the Armansky estuary increasing from 36 to 50 mm and from 317 to 1017 mg. In coastal waters to the east and west of the Arman River estuary, juvenile pink salmon increased in length by a factor of 1.7 (from 32 to 54 mm) and in weight by a factor of 8.3 (from 147 mg to 1217 mg) between the time they migrated from the river and arriving in the deep waters of the Tauyskaya Guba. The biggest juvenile pink salmon was captured in the Tokarev Bay. Over the same path and time, juvenile chum increased in length by a factor of 1.5 (from 36 mm to 54 mm) and in weight by a factor of 4.1 (317 mg to 1310 mg) (Afanasyev et al. 1994b).

The food spectrum of juvenile salmon in the Tauyskaya Guba varied among areas, but remained relatively stable with time. Juveniles began to consume small harpacticoida, and shifted to larger organisms, gammarids, calanoida, mysids and other crustaceans, as they grew. The most commonly eaten organism was harpacticoida, followed in order by fish larvae and eggs, calanus, amphipoda, decapod larvae, and mysids.

Growth and food consumption generally varied together among areas. For example, in the Olskaya group of rivers, the daily growth of juvenile pink salmon was 5.1% at a daily ration of 10.1–13.1% body weight, and in the Armansky area daily growth was 5.6% at a ration of 11.2–13.2% body weight. Chum salmon in the Olskaya rivers grew at 2.8% daily at a ration of 7.7–9.9% body weight, and in the Armansky area they grew 3.8% on a daily ration that was 8.5–19.0% body weight (Afanasyev et al. 1994b).

West Kamchatka salmon

Technical difficulties permitted only intermittent investigations into juvenile salmon biology in this area. In 1987–1988 two complete surveys were conducted in the majority of estuaries in west Kamchatka rivers, from the Opala River in the south to Voyampolka River in the north (Karpenko 1998). In 1990–1992, detailed surveys were conducted in the estuaries of the Bolshaya River (Maximenkov and Tokranov 1994). Feeding, distribution, behaviour, and feeding-growth patterns were studied. Some predatory fish were identified as well. More recently, juvenile salmon were occasionally sampled in the estuaries of some rivers, mainly the Bolshaya River (Table 1).

Juvenile pink salmon, while small immediately upon leaving the estuaries, migrate great distances offshore (Karpenko and Safronov 1985). Juvenile chum salmon appear in coastal waters later, and at a larger size. Juvenile coho (*Oncorhynchus kisutch*), sockeye and chinook (*O. tschawytscha*) salmon migrate downstream at the same time as chum salmon, and co-habit coastal waters for a long time. Because individuals of these species live to different ages, fish of various ages are found in coastal waters at different times. The last to appear are chinook salmon, of which juveniles of age 0+ sometimes make up more than 50% of all juvenile chinook salmon present. In V.N. Leman's opinion (VNIRO, Verkhnaya Krasnoselskaya Str. 17, Moscow, personal communication), downstream migration by juvenile chinook salmon age 0+ is usual.

Most juvenile pink salmon migrate to coastal waters in June, and in the beginning of July they move offshore, remaining only a short time in shallow water. In rough seas, juveniles are found deeper. In July, juvenile chum and coho salmon predominate in western Kamchatka river estuaries; in some of these, juvenile masu salmon (*O. masou*) also occur. Age structures of juvenile sockeye and chinook salmon usually include 0+ and 1+ ages, and coho and masu three ages (0+, l+ and 2+). In some areas, 0+ juveniles of these species are by far the most numerous.

The appearance of the different species in coastal waters is determined by conditions at the time they pass through the estuaries, particularly in the Bolshaya River. This timing influences subsequent feeding, growth and migration of each species in coastal waters. Species that migrate downstream at a young age when small (pink, sockeye and chum salmon) are planktivores and remain for a relatively long time in coastal waters; those species that migrate downstream at an older age (coho and chinook) are larger, eat bigger prey, and migrate offshore sooner.

East Kamchatka salmon

Avacha Bay and the Kamchatka River estuary are the main locations for juvenile salmon in east Kamchatka, and their biology was investigated here and in coastal waters of north-west Kamchatka. Results were published in a monograph (Karpenko 1998), and therefore only some of the most recent data are reviewed here.

The ecology of juvenile salmon in Avacha Bay has been investigated from time to time since the 1930s (Baranenkova 1934; Gribanov 1948; Karpenko 1979; Safronov 1998; Vasilets et al. 1998). Initially feeding and survival of juvenile wild salmon was investigated. In the mid-1990s, two salmon hatcheries began operating in the watersheds of the Avacha and Paratunka rivers. These two hatcheries have been releasing about 30 million juveniles annually. Since the mid-1990s, therefore, the Avacha Bay ecosystem has been investigated because of its importance as a feeding area for various species of juvenile salmon.

Juvenile salmon were also occasionally sampled in the estuaries of the Kamchatka River. The purpose was to familiarize researchers with the area, and to study its features particularly as they affected sockeye salmon (Bugaev and Karpenko 1983; Bugaev 1995).

The most regular and long standing investigations on the ecology of the five species of Pacific salmon (pink, chum, sockeye, coho and chinook salmon) have been conducted in the south-west Bering Sea (Karpenko 1991, 1998). Data were first obtained from this area in the 1960s (Andrievskaya 1968; Nikolayeva 1972). For more than 20 years, starting in 1975, annual ichthyological surveys have been conducted here. Special methods were developed and later applied in some other far eastern areas (Karpenko et al. 1997). Investigations conducted in this area evaluated the role of early marine life on later abundance of adult salmon of that brood class. The role of major limiting factors was also investigated. A method of correcting fishing estimates nearly a year prior to when fishing occurs was also developed for pink salmon (Karpenko 1982a, 1982b, 1982c, 1983, 1985, 1989, 1994). In addition, a preliminary database for computation of production of crustacean forage species and evaluation of the role of juvenile salmon in coastal ecosystems was compiled.

To estimate the effect of feeding by juvenile salmon on the food base, the diet and time each species inhabited specified areas of coastal waters was considered. Over a 20 year period, the total stock of zooplankton in the upper 10 m of Karaginskii Bay in June–August was estimated to have increased from 7,760 to 34,640 tons. Food requirements of juvenile pink, chum and sockeye salmon, the main planktivores, were 18.2 to 12,032.5 tons to be consumed from 335.6 to 20,756.3 tons of zooplankton. The juvenile salmon therefore ate between 0.23% and 46.2% of the total stock of zooplankton, pink salmon being the main consumers (up to 45.1% of the total stock) (Karpenko et al. 1999) (Table 2).

The main fish species in the north-eastern Kamchatka estuaries and coastal waters were flounders, Pleuronectidae (frequency, 50%), three-spine stickleback, *Gasterosteus aculeatus* (47.1%) and juvenile chum salmon (36.9%) (Vasilets et al. 1999). Species of juvenile salmon other than pink, chum and sockeye occur less frequently and remain for only a short time. They therefore have less effect on these coastal communities.

Feeding periods and growth patterns, distribution, and migration have therefore been documented for the majority of areas, providing information on factors affecting survival of juvenile salmonids and the abundance of their resulting brood classes (Table 3).

Autumn Assessment of Juvenile Salmon

The studies of Pacific salmon that have continued the longest are those on their biology in autumn following the period of highest mortality. These studies began in the 1960s, though some preliminary

Table 2. Consumption of forage resources by Pacific salmon juveniles during sojourn in Karaginskii Bay (June–early August).

Year	Parameters		Forage resources & consumption in tons	% of resource consumed
1985	Forage resources		7,763.83	-
	Consumption	pink	10.22	0.13
		chum	7.96	0.10
		Total	18.18	0.23
1987	Forage resources		19,120.24	-
	Consumption	pink	107.91	0.56
		chum	115.61	0.60
		sockeye	11.17	0.06
		Total	234.69	1.22
1988	Forage resources		26,007.60	-
	Consumption	pink	11,735.05	45.10
		chum	297.43	1.14
		Total	12,032.48	46.26
1992	Forage resources		34,229.07	-
	Consumption	pink	11,058.27	32.30
		chum	85.51	0.26
		sockeye	5.44	0.02
		Total	11,149.22	32.58
1993	Forage resources		34,642.55	-
	Consumption	pink	156.38	0.45
		chum	58.02	0.17
		Total	214.40	0.62

Table. 3. Food and predators of pink and chum juveniles in the coastal waters of Russia's Far East seas.

Area and salmon spp	Feeding Period	Food Item	Predators	% reduction of salmon
Primorye, chum	April–May (June)	Copepoda	-	-
Iturup Island, pink	May–June	Copepoda	-	-
Iturup Island, chum	May–June	Copepoda	-	-
S-E Sakhalin, pink	June–July	Copepoda, fish eggs, Hyperiidae	White spotted & Arctic char, Arctic smelt	-
S-E Sakhalin, chum	June–July	Copepoda, fish eggs, Hyperiidae	White spotted & Arctic char, Arctic smelt	-
S-W Sakhalin, pink	May–June	-	White spotted char, saffron cod, sculpins	-
S-W Sakhalin, chum	May–July	Harpacticoidae, Amphipoda, Insecta	White spotted char, saffron cod, sculpins	41.7
N-E Sakhalin, pink	May–June	-	Arctic smelt	7.7–51.6
N-E Sakhalin, chum	May–July	Mysidae, Insecta, Hyperiidae	Arctic smelt	11.1
Sakhalin Bay, pink	May–July	-	Arctic lamprey, Arctic smelt, Ussuri whitefish	67–96
Sakhalin Bay, chum	May–July	-	Arctic lamprey, Arctic smelt, Ussuri whitefish	28–93
North coast Sea of Okhotsk, pink	May–July	Harpacticoidae, Amphipoda, Copepoda	Arctic smelt, Arctic char	-
North coast Sea of Okhotsk, chum	May–July	Amphipoda, Insecta, Harpacticoidae	Arctic smelt, Arctic char	-
West Kamchatka, pink	May–July	Copepoda, Harpacticoidae	White spotted char, Arctic smelt, Kamchatka trout*	40–50
West Kamchatka, chum	May–July	Harpacticoidae, Insecta	White spotted char, Arctic smelt, Kamchatka trout*	-
Avacha Bay, pink	May–July	Copepoda, Insecta	-	-
Avacha Bay, chum	May–July	Insecta, Copepoda	-	-
Karaginskii Bay, pink	June–July	Copepoda, Harpacticoidae, fish larvae	Arctic smelt & char, white spotted char	11.2–28.8
Karaginskii Bay, chum	June–July	Insecta, Cumacea, Gammaridae	Arctic smelt & char, white spotted char	1.8–16.8

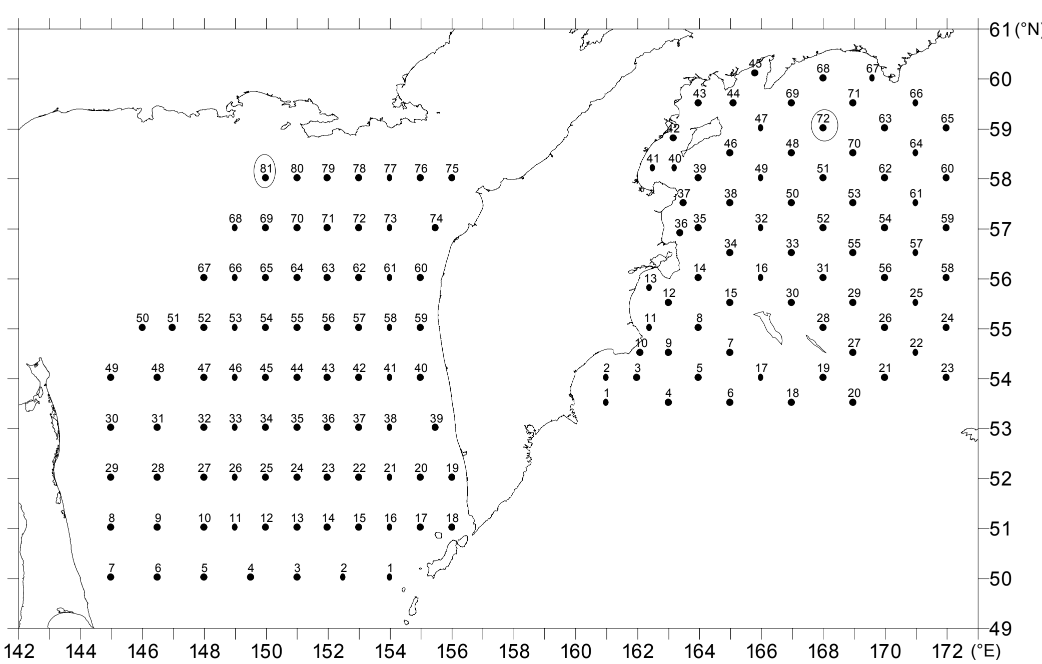
**Oncorhynchus mykiss* or *Parasalmo mykiss*.

data were collected earlier. Small mesh drift nets were used initially to catch juvenile salmon until 1981, when pelagic trawls were used (including large trawls, 108/528 and 118/620 m). The work has been conducted by two institutions, KamchatNIRO and TINRO-centre, and surveys have been carried out in the waters of the east Sea of Okhotsk, west Bering Sea, east Sea of Japan (through 1976), the Kuril area, and the north-west Pacific. Trawl surveys have been conducted in a standard pattern of stations (Figs. 1, 2).

Since the 1960s KamchatNIRO has investigated juvenile salmon biology during fall in Kamchatka waters of the Sea of Okhotsk and the Bering Sea, and in winter in the eastern Sea of Japan. Originally these surveys were combined with investigations of anadromous salmon species when small mesh (20–40 mm) drift nets for catching juveniles were added to gear used to catch adult salmon. Beginning in the 1970s, the work was conducted from vessels equipped only with small mesh drift nets which were fished in late August to November (January to March in the Sea of Japan), when juvenile salmon had already migrated away from coastal waters. Due to a shortage of needed equipment, catching juvenile salmon with drift nets was labour-intensive. It required good weather, and it often was unproductive. The data were not always sufficient for correctly estimating brood abundance. However, the main features of the ecology of all salmon species were identified during that time; habitation times, distribution, migration, feeding, major biological parameters, growth rates, interspecific interactions, and some other features (Andrievskaya 1966, 1968, 1970, 1988; Birman 1969, 1985). However, the problem of brood abundance assessment was not solved. Only with the inauguration of trawl fishing for juvenile salmon did the collection of data on abundance of individual broods of juvenile salmon of the various species become possible.

Trawling for juvenile salmon was conducted for the first time in the Bering Sea in 1981. KamchatNIRO organized an expedition of three vessels. One of them was to catch juvenile salmon with a midwater trawl of 32.5 m, the second was to use drift nets, and the third was to conduct hydrological and hydrobiological surveys. Prior to 1985 KamchatNIRO used variously modified trawls to try to catch juvenile salmon near the surface. In 1985 the Kamchatrybprom Laboratory of Fishing Gear for Commercial Fishing invented a special pelagic trawl 54.4/192 m. Since then, this trawl has been used in all areas to assess juvenile salmon (Fig. 2). Data collected using these trawls are remarkably representative, allowing investigators to estimate the number and production of salmon in different feeding areas. This new gear allowed Kamchatka scientists to obtain better information on juvenile salmon biology in autumn. Most important, it permitted the development of a method of assessing abundance that has been used to correct fishing forecasts 8–9 months prior to fishing (Karpenko et al. 1997, 1998).

Fig. 2. Location of trawl stations in the Sea of Okhotsk and Bering Sea in September–October 1985–2000 (cruises by KamchatNIRO). At stations 72 and 81 (ringed), eight trawl samples were collected over a 24-hr period (day and night); at all other stations only one trawl sample was taken.



The results of research on juvenile salmon in autumn using close-mesh drift net catches are summarized by Birman (1969, 1985). Birman described the length of time juvenile salmon remained in different zones of the coastal waters of the Sea of Okhotsk and Bering Sea, their migrations, growth, feeding and other factors that influence the numbers and productivity of each brood class. A comparative analysis of juvenile growth rates in different feeding areas showed regional differences arising from the particular food resources and predator abundance. Later research determined that growth rates were typically higher in the Okhotsk Sea compared with those in other areas of the north Pacific Ocean (Karpenko 1987b). Most planktivorous fish in this area, i.e., pink, sockeye and chum salmon, consumed those organisms that had the highest caloric content: crustaceans–hyperiids, *Parathemisto japonica*.

Estimated abundance of juveniles in the fall were used to correct commercial forecasts of pink salmon approaching their spawning areas in north-eastern and western Kamchatka (Karpenko et al. 1998). Note that if in one area the forecast correction was relatively small because of a local isolated stock, in the Sea of Okhotsk juveniles congregated from different origins for fattening: West Kamchatka, East Sakhalin, Magadan area, Japan etc. Usually the captured juveniles are from mixed stocks, and cannot be identified as to origin. This requires a special systemic analysis to separate and estimate the numbers in each stock, and the use of such techniques is not always successful (V.G. Erokhin, KamchatNIRO, 18, Naberezhnaya Str., Petropavlovsk-Kamchatsky, personal communication). In addition, methods used to estimate mortality of pink salmon at different stages in their life at sea suggested that mortality in some broods changed from 55.4% to 95.8% after migration offshore (Karpenko 1995, 1998). Data on numbers of other juvenile salmon species are also used to estimate the numbers in brood classes and the conditions promoting survival at sea, as well as to investigate the role of juvenile salmon in ocean ecosystems.

TINRO-center began investigations of juvenile Pacific salmon biology with its first voyage to the north-west Pacific Ocean in the winter of 1985–86 (Erokhin 1990; Erokhin et al. 1990). A large pelagic trawl (112/528 m) was used for fishing. Work in the area continued until 1992; since 1988 the area covered was expanded to the north-east Pacific Ocean (Table 1).

In the autumn of 1986, with its voyage to the western Bering Sea, TINRO-centre began assessing juvenile salmon (Shuntov 1989b). However, only two expeditions have been sent to this area. Since 1990, the Sea of Okhotsk and Pacific waters around the Kuril Islands have become major areas of investigation (Shuntov 1989a) (Table 1). These investigations not only enabled the gathering of good information on ecology of Pacific salmon during autumn and winter, but also regularly collected data on feeding of juveniles, which was important for prediction of adult salmon abundance (Shuntov et al. 2000). It was also found that in some years pink salmon in particular remained for the winter in the southern part of the Sea of Okhotsk (Radchenko et al. 1991, 1997; Zhigalov 1992).

Data collection during TINRO-centre voyages in the fall was thorough in order to obtain a variety of data on ecosystems of the far eastern seas and northwestern Pacific Ocean. To this end, the major areas of the Sea of Okhotsk and Bering Sea where juvenile salmon feed and fatten were subdivided into smaller biostatistical areas (Shuntov 1989a, 1989b). The estimated numbers of juvenile salmon so obtained were used to correct estimates of returning mature salmon, which were later further refined using the results from spring surveys of anadromous maturing salmon (Shuntov and Chigirinskii 1995). To conduct this detailed work, scientists from different fisheries institutes, and also from the Russian State Academy, were invited to participate.

Data collected over many years from these expeditions to the Sea of Okhotsk shed light on the role of age 0+ pink and chum salmon in the trophic structure of the epipelagic zone. In the fall and winter of 1994–95 these juvenile salmon consumed mainly hyperiid amphipods — 3–4.3 thousand tons or 35.5–42.3% of their daily production (Dulepova 1998). Daily consumption of other organisms, with the exception of euphausids, did not exceed 3% of daily production. Interspecific competition with other species that consume the same crustacea could be intense.

By September, juvenile salmon in both coastal and open waters of the Sea of Okhotsk are a mix of stocks from different origins. The identification of their origins helped to confirm the distribution and migration routes of the different stocks of juvenile pink salmon that had been suggested from classical fisheries research (Varnavskaya et al. 1998; Varnavskaya 2001). At first juveniles migrate along the coasts of origin, then later move offshore (Shuntov 1994a). As the water cools, the fish migrate to the southern Sea of Okhotsk where some remain over winter (Radchenko et al. 1991, 1997; Zhigalov 1992). Estimates of abundance of juveniles in the Sea of Okhotsk over many years have permitted forecasts of return rates of spawners (Radchenko 2001), and elucidated their return migration routes to different coastal areas (Shuntov et al. 2000).

Voyages to the Bering Sea were made periodically in 1986–1992, but did not always cover the fall period optimally. As a result the data were not as satisfactory as those from the Sea of Okhotsk, but some worthwhile conclusions were drawn nevertheless (Radchenko 1994a; Shuntov 1994b; Sobolevsky et al. 1994). For instance, juvenile pink salmon were found to migrate off north-eastern Kamchatka coasts in wide fronts, and to spread along the Komandorskaya gully in a generally south-eastern direction. Shuntov (1994a) stated that "there are no noticeable pink migrations to the Kuril waters". The last surveys by KamchatNIRO confirmed this. Juvenile pink salmon usually migrate in two or three directions; there are one or two routes heading southeastward, and a third, with the smallest fish, heading along the Kamchatka coast (Smorodin et al. 2001). Migrations in similar directions are followed by other salmonids, in particular by juvenile chum and sockeye salmon. Sockeye salmon have somewhat different feeding, growth, and distribution patterns from other species (Radchenko 1994b; Sobolevski et al. 1994; Karpenko 1998).

Juvenile Pacific salmon, when surveyed by trawl under optimal conditions (in September), provide data not only for estimating a brood year's abundance, but in some cases also for estimating mortality over the entire marine life, including before fall migration to wintering grounds. For instance, Karpenko and Smorodin (2001) determined from two surveys in September–October, 2000, that monthly mortality rates of juvenile pink and chum salmon were about 3%.

Investigation of Coastal and Marine Ecosystems

Data obtained on the biology of Pacific salmon during their early marine and first autumn of life permitted an evaluation of their role in coastal marine ecosystems in some regions. For instance, detailed surveys in the estuary of the Bolshaya River (west Kamchatka) revealed the interrelations among species in this watershed, including major trophic interrelations (Tokranov 1994; Maximenkov and Tokranov 1999, 2000). Three ecologically distinct groups of fish make up the community in the estuary; permanent inhabitants, 19.3%; migrants, 35.5%; and temporary residents, 45.2%. Six species are the main representatives of the fish community of the Bolshaya River estuary: starry flounder (*Platichthys stellatus*), belligerent sculpin (*Megalocottus platycephalus platycephalus*), pink and coho salmon, threespine stickleback (*Gasterosteus aculeatus*), and ninespine stickleback (*Pungitius pungitius*). Juvenile salmon play an important role in interspecies relations despite their short time in the estuary, but starry flounder and threespine stickleback (permanent residents) are the main consumers there.

Similar investigations have been conducted in Avacha Bay since the 1990s. To date they have provided preliminary data on trophic relationships among fish in this watershed (Vasilets et al. 1998). As in the Bolshaya River estuary, threespine stickleback and belligerent sculpin are the main consumers. In addition, some data have been obtained for the first time on feeding interactions between juvenile wild and hatchery produced salmon (Karpenko 1987a, 1998; Karpenko and Safronov 1999). This research has proven timely because of the increased releases from two hatcheries, Paratunsky and Ketkino, which have recently reached full production capacity. So, estimated carrying capacity of Avacha Bay is very important now.

Year-to-year investigations on the biology of juvenile salmon in coastal waters of southwest Bering Sea revealed the role of some fish in ichthyocenosis (Karpenko and Maximenkov 1988, 1990). These investigations also showed the scale of predation by juvenile salmon on various species of crustaceans and other animals inhabiting coastal waters, and allowed analysis of the predator-prey relationship (Karpenko 1982a, 1994, 1998; Karpenko et al. 1999). Juvenile salmon were found to consume about one third of the total stock (biomass plus production) of planktonic crustaceans in the area; at the same time about one third of each year's migrating yearling pink and chum salmon were consumed by predators. These findings emphasize the need for assessment of the production capacity of areas where salmon hatcheries are to be installed and operated (Karpenko and Safronov 1999).

From 1% to 63% of juvenile pink salmon migrating downstream in the Khailyulya River are consumed by Arctic char (*Salvelinus alpinus*) (Tyller 1999). This predator, together with Arctic smelt (*Osmerus mordax dentex*) and white spotted char (*Salvelinus leucomaenis*) consume sufficient juvenile salmon in estuaries and marine coastal waters over 1.5–2.0 months to reduce their numbers (Karpenko 1998). Both food supply and predators, therefore, regulate salmon stock abundance in the marine environment.

The most successful assessments were those conducted on juvenile salmon in the autumn by TINRO-centre scientists. Detailed data were collected on abundance and biological state (characteristics) of salmon, as well as on co-habitants in and physical characters of water masses (Shuntov et al. 1993). The numerical abundance and biomass of major fish species, including their larvae and eggs, as well as the plankton and nekton, were assessed in the majority of areas. This detailed information permitted the tracking of changes in the ecosystems of the far eastern seas and the north-west Pacific Ocean, and the assessment of the effects of these changes (Radchenko 1994a; Shuntov 1994a; Lapko 1996; Dulepova 1997; Shuntov and Dulepova 1997; Shuntov et al. 1997).

In some areas of the Bering Sea during summer and fall Pacific salmon stocks make up 60% of the fish biomass (Radchenko 1994a), of which pink and chum salmon are the main species in the western part of the Bering Sea, and sockeye, chinook, and, in summer, pink salmon are the main species in the eastern part. Salmon stocks are expanding into the North Pacific Ocean to feed. In the 1990s, their consumption of food organisms increased almost a third in comparison with the 1980s, and it is still increasing owing to immigration of many southern salmon populations to feed.

In the Sea of Okhotsk in the 1980s, salmon stocks comprised about 1% of the total biomass of fish during the summer–fall, and in the early 1990s this increased to 4.6% (Lapko 1996). There followed a period of rapid increase in the stocks of these species, which continues to the present. However, the number of returning adults has fluctuated considerably, especially those of pink salmon even in adjacent years (Shuntov and Dulepova 1997). This is confirmed by the results of the most recent annual trawl surveys by the TINRO-centre (Shuntov et al. 2000; Lapko and Glebov 2001).

FUTURE INVESTIGATIONS

Russian investigations of the marine life of Pacific salmon have identified the major causes of mortality in juvenile salmon, and developed methods of assessment necessary for predicting abundance of returning spawners of the two main species, pink and chum salmon.

Further investigations will address the following four topics.

1) Use of defined standard areas for monitoring and identifying causes of mortality, and abundance of each year's brood class. As mentioned above, the methods of investigation can be specific and different for each standard area.
2) Assessment of interrelations between wild and hatchery produced salmon in areas where these stocks mix to feed. This work has been done both where hatcheries were already operating, and where their construction was expected. Depending on the specific goals, investigations take the form of monitoring or surveying. The overall goal is to determine what is a rational combination of the two types of salmon production, sustainable natural production and efficient hatchery production.
3) Efforts must continue to improve methods of stock assessment of Pacific salmon, through assessment of juvenile abundance in the fall, and to use stocks more efficiently. Mesosurveys are assessments performed in standard near-shore areas that are considered to be the main feeding grounds of specific salmon stocks and populations (e.g., the shelf waters of east and west Kamchatka, Sakhalin, the north shelf of the Sea of Okhotsk (Fig. 2), etc.). Macrosurveys are assessments in large offshore and oceanic areas (Fig. 1). Mesosurveys occur in August–September, prior to offshore migration, and mixing of juvenile salmon stocks that originate from different reproductive areas. This permits assessment of the abundance of each stock. Macrosurveys are conducted later, in October–November, to obtain data on total abundance throughout a large area such as the Sea of Okhotsk, the Bering Sea, or the north Pacific Ocean. The two types of survey provide important data both for predicting escapement to the commercial fishery, and for evaluating pelagic community interactions.
4) Ecosystem studies are the fourth topic of investigation in the marine life of Pacific salmon. Such studies utilize data gathered both during standard monitoring and during investigation of specific components of the ecosystem in the area under investigation.

Integration and organization of the studies on the above topics will continue to contribute to the conservation and efficient use of Pacific salmon stocks in the far east basin.

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