Abundance and Biology of Kamchatkan Salmon During the Initial Year of Ocean Residence

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Represented in this paper are results of a 15-year research study on juvenile biology of five Pacific salmon species, conducted during the fall period in Kamchatkan coastal waters of the Sea of Okhotsk and western Bering Sea. The variation in distribution, migration, feeding, and growth of juvenile salmonids was described in relation to hydrological conditions and juvenile abundance. Assessments of juvenile pink salmon abundance were used to forecast runs of pink salmon the following year.

INTRODUCTION

Regular studies of Pacific salmon species in their ocean life periods have been conducted in Kamchatka for 40 years. The biology of juvenile salmonids in Kamchatka coastal waters of the Sea of Okhotsk and Bering Sea have the been subject of intensive research during the most recent 25 years (Birman 1985; Karpenko 1992). Initially, juvenile sampling was done using passive fishing gear like drift nets; however, because of its selectivity, sampling was not thought to be representative of salmon abundance or their biological characteristics. During the mid 1970's, Kamchatkan scientists introduced active fishing gear such as beach seines, purse seines, and pelagic trawls for sampling purposes. These gears, because of their higher efficiency and effectiveness in capturing smaller individuals, provided a versatile and more quantitative sampling method for salmon populations at various life history stages in marine waters. Beach and purse seines were the main fishing gear deployed for juvenile salmon sampling in Kamchatkan coastal waters and trawls were the main fishing gears deployed in Kamchatkan offshore waters (Karpenko 1992).

The period when juvenile salmon reside in coastal waters, following seaward migration, is of great importance to salmon stock formation and reproduction. During this period, the mortality of pink and chum salmon, the most numerous salmon species in the Russian Far East, exceeds 2/3 of the total cohort entering the ocean. Mortality rates of other salmon species, was estimated to exceed one half of the total cohort entering the ocean. Knowledge of conditions during the first year of marine residence is very important for evaluation of salmon stocks returns. Kamchatka scientists monitor the ocean abundance of the largest salmon stocks in western and north-eastern Kamchatka for the purpose of forecasting runs enabling more rational management of salmon fisheries on these stocks.

The results of research on juvenile salmon ecology of five species - pink, chum, sockeye, coho, and chinook - in Kamchatka coastal waters of the Sea of Okhotsk and Bering Sea during the most recent 15-year period (1981-1995) and evaluation of pink salmon run forecast based on marine abundance juvenile salmon during fall season is presented.

MATERIALS AND METHODS

The data presented in this paper were collected on annual cruises of research vessels to the eastern Sea of Okhotsk and the south-western Bering Sea during summer and fall of 1981-1995. Sampling was conducted based on a standard station grid and was timed to occur after juvenile migration into the survey area was completed. Juvenile salmon sampling, since 1985, was done using adjustable depth wire trawl 54.4/192 meters, equipped with dally insert(cell size 12 mm), 3.3 m^2 boards, and hydrodynamic device. Duration of survey trawling was set at 1 hour after net deployment was completed, with an average trawling speed of 4.5 knots. Sampling was conducted in the 0-35 m depth interval which are the limits of juvenile salmon daily vertical migration.

The survey area was divided into sectors and estimates of salmon abundance were made, by sector, based on expansion of trawl catches by the ratio of the sector area and the estimated area swept of the trawl. The trawling area was calculated assuming a distance of 50 meters between the trawl wings.

Also, we used three biological characteristics for juveniles:

1 - Fulton's index - $F=W*100/L^3$;
2 - Clark's index - $C=W1*100/L^3$, where
W - total weight, g,
W1 - weight without internal organs, g,
L - fork length, cm; and
3 - Stomach fullness which changed from 0 to 4.

Data collection and data processing were conducted using standard methods, established in TINRO (Pacific Research Institute for Fisheries and Oceanography). It was not possible to determine age composition due to descaling of juvenile salmon due to trawling operations.

In addition to data collected during the fall juvenile salmon investigations, the data on spring-summer juvenile salmon investigations were used to forecast adult pink salmon runs (Karpenko 1992, 1994). Besides, annual studies of early marine period life of juvenile salmons have been carried out in the south-western Bering Sea since 1975, some results of which have been included in one of the reports of the present Symposium (Karpenko 1996). These data were used to describe the ecology of Kamchatka salmon and variation in stock reproduction.

RESULTS

Juvenile Salmon Biology

The Sea of Okhotsk

Pink Salmon. Seaward migration of pink salmon in western Kamchatka rivers occurred in late May through July. The peak of the migration occurred during the first part of June. Pink salmon moved rapidly through the narrow coastal desalinated zone, and then resided in coastal waters. Initially, due to their small sizes, juvenile salmon moved with strong oceanic currents in a northerly direction. In September, pink salmon juveniles occurred throughout the eastern Sea of Okhotsk. The highest density shoals were observed in the area 52°-56°N, 151°-154°E (See Fig.1). Later in the season, these Kamchatkan coastal shoals migrated in a southerly direction, and overwintered in the southern Sea of Okhotsk.

The western Kamchatka shelf and the central Sea of Okhotsk were important rearing and feeding areas for the juvenile salmon that originated from the Gulf of Shelekhova, Kamchatka West Coast. and Sakhalin East coast. The largest runs occur to the rivers of West Kamchatka and East Sakhalin. The abundance of these stocks fluctuates in asynchronous cycles with odd-year runs dominant in east Sakhalin and even-year runs dominant in west Kamchatka. Indeed, over the period 1985-1993 the odd-year total runs in the West Kamchatka rivers averaged 20 thousand t, and over the period 1986-1992 the even-year runs averaged 140 thousand t; in contrast for the same period the odd-year total runs in the East Sakhalin rivers averaged 550 thousand t, and even-year runs averaged 160 thousand t (Varnavskaya et al. 1995).

In common case, migratory patterns of most juvenile salmon out of rivers draining in the northern Sea of Okhotsk have directional tendencies such as follow: (a) in odd years they move **west** (exploitation of Western Kamchatka Shelf) - **south-west** (the central Sea of Okhotsk) - **south** (the southern Sea of Okhotsk)- **east** (entrance to the Pacific Ocean); (b) in even years they direct **north-east** - **east** - **south-west** - **south-east**. This migration cycle period covers five months at least, from August till December, according to V.P. Shuntov (1989a). The vanguard of migrating pink salmon is made of larger fish of earlier migrants.

The trawling survey in the Sea of Okhotsk provided aggregate stock abundance estimates in Kamchatkan coastal waters, although the lack of stock identification methods prevented quantitative determination of contribution made by each salmon stock to populations in the Sea of Okhotsk. Analysis of coastal runs suggested that three types of geographical distribution of pink salmon occur near the Kamchatka coast (Erokhin, press):

1- *Aboriginal* - when these waters are mostly inhabited by western Kamchatka pink salmon;
2- *Immigratory* - western Kamchatkan pink stock abundance is very low, under 10%;
3- *Intermediate* - most frequent type, where pink juveniles of Kamchatka origin rear jointly with visitor stocks in the eastern Sea of Okhotsk;

In September-early October, more than half of all pink salmon in Kamchatka coastal waters in the Sea of Okhotsk had average length 21-23 cm, and average weight 100-170 g (Table 1). The length of juvenile pink salmon north of 54°N was 1.5-2 cm less than the length of pink salmon in the southern areas. A decrease in Fulton's index (1.26 to 0.92) was also observed from the southern to northern areas of the Sea of Okhotsk. Juvenile pink salmon in southern areas tended to have a greater weight than juvenile pink salmon of the same size in the northern areas.

Fig. 1 Distribution of pink salmon sample juveniles in the Sea of Okhotsk (fish/trawl): A - September-October 1990; B - September-October 1991.

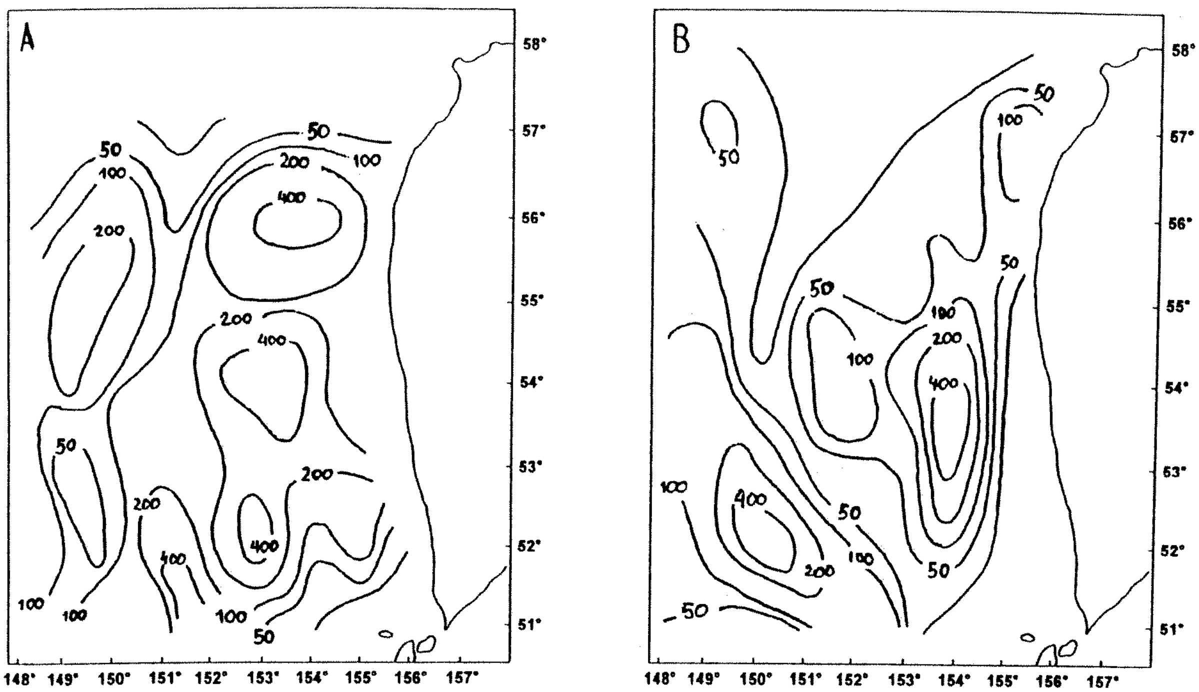


Table 1. Average length (cm) and weight (g) of juvenile salmon in Kamchatka coastal waters of the Sea of Okhotsk and Bering Sea during fall seasons of 1981-95.

Year	Pink		Chum		Sockeye		Coho		Chinook	
	l, cm	m, g	l, cm	m, g	l, cm	m, g	l, cm	m, g	l, cm	m, g
					Sea of Okhotsk					
1981	19.3	77.2	20.2	88.6	21.7	117.7	28.5	310.0	22.8	157.5
1982	18.7	66.1	18.3	68.1	22.5	134.0	26.6	243.0	21.2	142.4
1986	20.7	97.3	21.9	112.6	23.0	140.7	29.7	378.4	23.1	174.0
1987	20.4	87.3	23.0	141.1	-	-	28.7	326.9	24.1	190.0
1989	22.0	122.7	22.7	143.4	23.0	162.7	30.3	396.6	24.5	210.8
1990	21.0	107.1	22.7	138.6	22.0	122.6	28.7	308.1	22.4	172.6
1991	22.1	114.3	22.1	121.0	22.9	138.2	28.1	306.4	22.5	168.1
1995	19.5	87.1	21.3	111.9	20.8	103.6	27.9	318.2	24.8	195.2
					Bering Sea					
1981	18.0	62.1	21.5	73.3	18.2	66.5	30.4	145.2	22.7	173.2
1982	15.7	36.6	15.4	36.6	20.8	103.7	27.1	267.7	21.9	135.9
1984●	12.8	19.3	13.4	25.5	18.8	74.8	21.9	132.6	16.9	60.0
1986	19.0	72.1	18.1	65.6	21.4	118.0	28.3	310.4	23.0	163.1
1987	19.4	85.7	18.6	74.0	21.5	114.8	27.0	235.7	21.6	130.2
1988	19.5	71.5	19.5	83.3	23.9	153.1	26.7	232.6	20.8	111.0
1989	20.4	82.4	18.5	69.4	23.5	145.0	27.7	280.0	20.4	120.0
1990	18.9	69.1	18.7	73.6	22.7	144.2	26.5	236.4	21.6	126.9
1991	20.0	80.0	20.0	91.4	17.6	73.1	25.5	255.4	19.4	110.0
1992	18.5	55.5	17.4	51.6	20.8	113.7	24.7	165.0	22.5	104.7
1994	17.8	55.5	21.4	120.2	-	-	-	-	-	-

● - August

Growth rates of pink salmon in the eastern Sea of Okhotsk were higher than those in the other parts. The juveniles reached 20 cm in length after 3-3.5 months of rearing. Daily growth rate during September were 1.5-2.8 mm/day and 3-4.2 g/day south of 55°N, and 2 mm/day and 2.9 g/day north of 55°N (Table 2). Growth rate of pink salmon during winters were low, 0.7 mm/day and 1.31 g/day from October through March, 1985-1986 (Erokhin 1990).

Biological indicators of pink juveniles varied, depending on distribution type. During the years with *immigratory* and *intermediary* distributions (1986, 1989-91) pink salmon were larger with 60-90% of length 21-23 cm and of weight 80-120 g. In years with *aboriginal* distribution (1982, 1995) pink salmon were smaller with 70% of fish of length 17-22 cm and weight less than 70 g. During years with *aboriginal* distribution, 50% of fish were of length less than 18.5 cm, while years with *immigratory* and *intermediary* distributions, only 14% of fish were of length less than 18.5 cm.

Pink salmon feeding intensity was high in fall, especially in the evening. In 1995, stomach fullness averaged 2.1-2.53 at various locations, with no empty stomachs occurring. The major prey for pink salmon were *hyperiids* and *euphausiids*.

Chum Salmon. The seaward migration of Sea of Okhotsk chum salmon was coincident with that of pink salmon, although the downstream migration was more protracted (Maksimenkov and Tokranov 1994), and the residence period in coastal brackish waters was longer than that of pink salmon. In the fall season, chum salmon occurred throughout the area off west Kamchatka, and mostly in the area bounded by 51°-56°N and 151°-155°E. The area of chum salmon concentration was between areas of pink salmon concentration on the west, and sockeye, chinook, and coho salmon concentration on the east (Fig. 2). In September and October, the number of chum salmon juveniles south of 53°N were 2-3 times the number of those north of 53°N in Kamchatka coastal waters. The rearing of chum salmon to the south of 53°N continued into November.

Kamchatka chum salmon shoals were a mixture of chum salmon from west Kamchatka and from the northern parts of the Sea of Okhotsk. The abundance of chum salmon in the area between 56°-57°N increased rapidly from late September through mid-October due to influx of the juveniles from the northern parts of the Sea of Okhotsk.

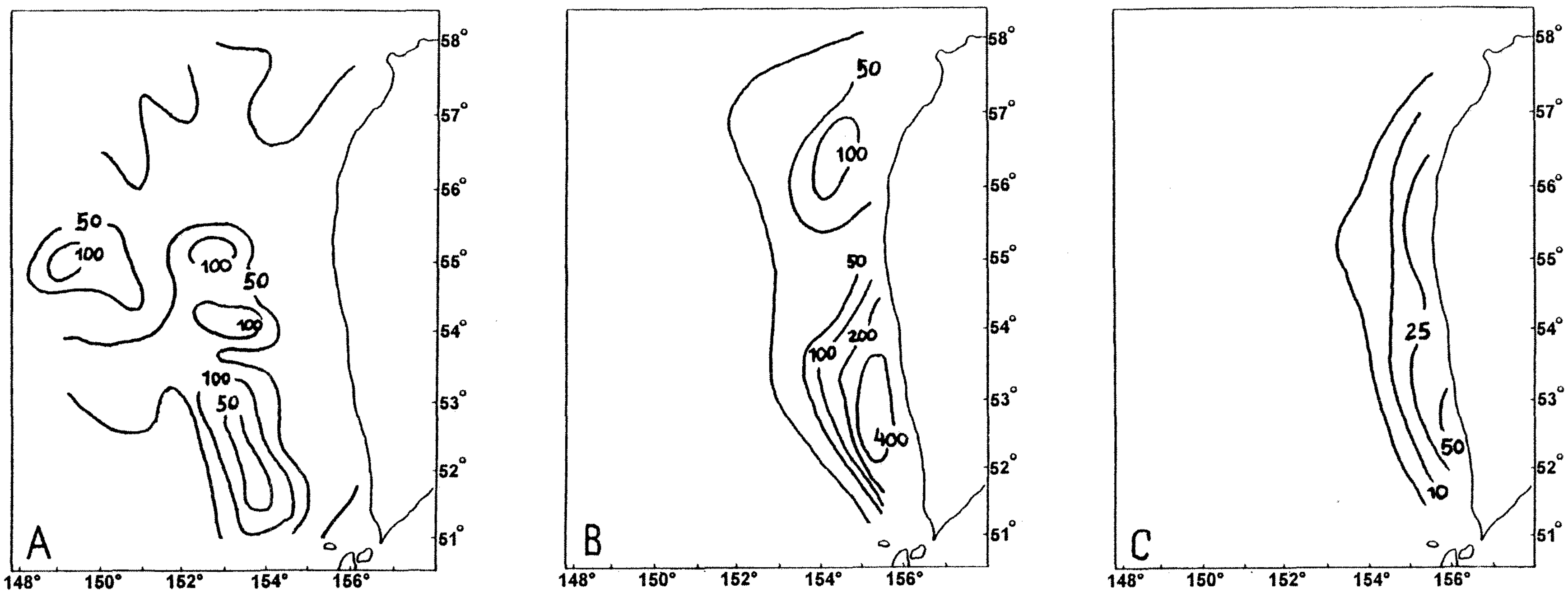
In September, over 60% of chum salmon were of length 21-24 cm and weight 100-120 g, with larger fish occurring in the south (Table 1). Smaller fish, 12-19 cm, occurred within the 20-50 mile coastal zone in the north-east of the area. Chum salmon growth rates in September were relatively stable, although lower than those of pink salmon. Growth rates, 1989-91 were estimated to be 1.4-1.7 mm/day and 2.2-3.8 g/day. Feeding intensity of chum salmon was similar to pink salmon; however, the diet was different. Fulton's index for juvenile chum salmon ranged from 1.06 to 1.20, and was higher in coastal locations.

Sockeye Salmon. The seaward migration of Sea of Okhotsk sockeye salmon juveniles occurred over a protracted period from May to August (Bugaev 1995). During September - October, sockeye salmon formed two aggregations between 51°-58°N and 152°E-off the Kamchatka Coast (Fig. 2). Abundance in the southern aggregation was usually higher and accounted for 92%, 78%, 63%, and 46% of total juvenile sockeye abundance in 1986, 1989, 1990, and 1991, respectively.

Table 2. Growth rate of juvenile salmon in Kamchatka coastal waters of the Sea of Okhotsk and Bering Sea.

Species	Daily linear growth rate, mm	Daily weight growth rate, g
	Sea of Okhotsk	
Pink	0.51-2.85	1.43-4.28
Chum	1.40-1.73	2.21-3.76
Sockeye	1.53-3.16	1.57-2.74
Coho	1.30-5.50	4.57-18.7
Chinook	0.70-1.50	1.14-3.48
	Bering Sea	
Pink	1.1-1.8	1.7-2.8
Chum	1.8-2.3	1.3-1.6
Sockeye	1.8-2.2	1.3-1.8
Coho	2.0-2.7	3.0-4.0
Chinook	1.5	3.5

Fig. 2 Typical distributions of chum (A), sockeye (B), and chinook (C) juveniles in September-October in the Sea of Okhotsk, fish/trawl.



As is the case with other salmon species, juvenile sockeye migratory patterns during the marine rearing period were highly dependent on directions of oceanic currents in the eastern part of the Sea of Okhotsk, particularly that of the Western Kamchatka Stream. Since 90% of sockeye in this region originated from Kuril Lake, it was easy to determine the direction of migration of sockeye juveniles in Kamchatka coastal waters. On entering the ocean, most juveniles were carried westward along Kamchatka's west coast by the western Kamchatka stream (Fig. 3).

A large shoal of sockeye, originating from Kuril Lake and Bolshaya River, forms in September. It was believed that a portion of Kuril Lake and Bolshaya River sockeye migrated northward and intermingle with sockeye that originated from rivers of northwestern Kamchatka. The second shoal was formed in northern area and persisted until October. The northern aggregation migrated southward, and during the third week in September joined the southern aggregation. By mid-October, sockeye salmon did not occur north of 55°N.

The length and weight of sockeye during the fall season ranged from 15 to 30 cm, and from 50 to 295 g, respectively. Most fish were of length 21-24 cm and weight, 100-200 g. There occurred a longitudinal gradient in fish size with larger fish occurring offshore. The longitudinal size gradient was greater than the latitudinal gradient in length. The growth rates of sockeye were high and similar to pink salmon. In 1986-91, daily growth rate was estimated to be 1.5-3.2 mm/day and 1.57-2.74 g/day. Fulton's index ranged between 1.00 and 1.19. The major prey for sockeye were larger crustaceans and fish fry.

Coho Salmon. The seaward migration of coho salmon occurred at the time as sockeye salmon. Coho salmon formed 2 aggregations. During September-October a northwestern group was located north of 54°N and west of 153°E, and a southeastern group was located south of 54°N and east of 153°E (see Fig.4). The northwestern aggregation formed earlier, during August-early September however, a migration occurred from the northwestern group to the southeastern group and by the second half of September only 30% of the total coho population remained in the northern area.

Coho salmon migration from the Sea of Okhotsk to Pacific Ocean began in mid September. By early November coho shoals left the Sea of Okhotsk. It appeared that migration was initiated when temperature decreases to 8°C (Erokhin 1987).

Coho salmon in western Kamchatka rivers migrated to the sea at age 1+ or 2+. Scale samples of rearing coho salmon (143 fish) collected in 1986 from the area to the south of 55°N were 40.6% age 1+ and 59.4% age 2+, with younger fish occurring closer to shore. Based on samples averaged over all years, the length of juvenile coho salmon during September-October ranged from 21-35 cm, with 60% of fish 28-30 cm and 17% less than 28 cm. Average length and weight during September ranged from 28.1 cm and 306.4 g in 1989 to 30.3 cm and 396.6 g in 1991. September growth rate of coho salmon ranged from 1.3 to 5.5 mm/day and 5 and 18.7 g/day. Coho salmon growth rates were the highest observed among the Pacific salmon genus. Growth rates for age 1+ coho salmon during the August - September period were believed to be higher than those for age 2+ coho, based on greater number of circuli observed for the initial year of marine growth.

Coho salmon juveniles fed actively, consuming mostly pollock fry (up to 95% of total prey). Fulton's index ranged from 1.34 to 1.49, and Clark's index from 1.19 to 1.34.

Chinook salmon. Chinook salmon reared in the eastern Sea of Okhotsk for an average of two weeks longer than coho salmon and were generally located east of 153°E. Chinook started moving from the areas located to the north of 55°N in the second part of September after water temperature decreased to 7-7.5°C. Chinook salmon did not occur north of 55°N in the Sea of Okhotsk after mid or late October (see Fig. 2). The exact timing of departure of chinook salmon from the Sea of Okhotsk to the Pacific Ocean is uncertain, but based on low catches in early November, chinook salmon probably left by late November.

In September, the majority of chinook juveniles were of length 22-25 cm and weight 150-220 g (Table 1). Growth rate during the fall was increasing but low relative to other species and ranged from 0.7-1.5 mm/day and 1.14-3.48 g/day. Feeding intensity of chinook salmon was lower than that of coho salmon, with the diet in 1986 consisting mainly of sandfish (62%). Fulton's index ranged from 1.34 and 1.47, and Clark's index ranged from 1.17 and 1.29.

The Bering Sea

Pink Salmon. The seaward migration of pink salmon in north-eastern Kamchatkan rivers occurred during June through the first half of July, with the peak of the migration occurring in the second half of June. During the early period of marine residence pink salmon occurred in nearshore areas as well as Lithke Strait. By late August pink salmon moved to offshore areas in the Bering Sea. The major concentrations of pink salmon juveniles at the time of offshore migration from the Lithke Strait occurred in

Fig. 3 Juvenile sockeye migrations in the eastern Sea of Okhotsk: A - (July) August, B - September, C - October. Arrows - migratory patterns; bold arrows - stable shoals without migratory manifestations; shaded areas- areas occupied by juvenile sockeye.

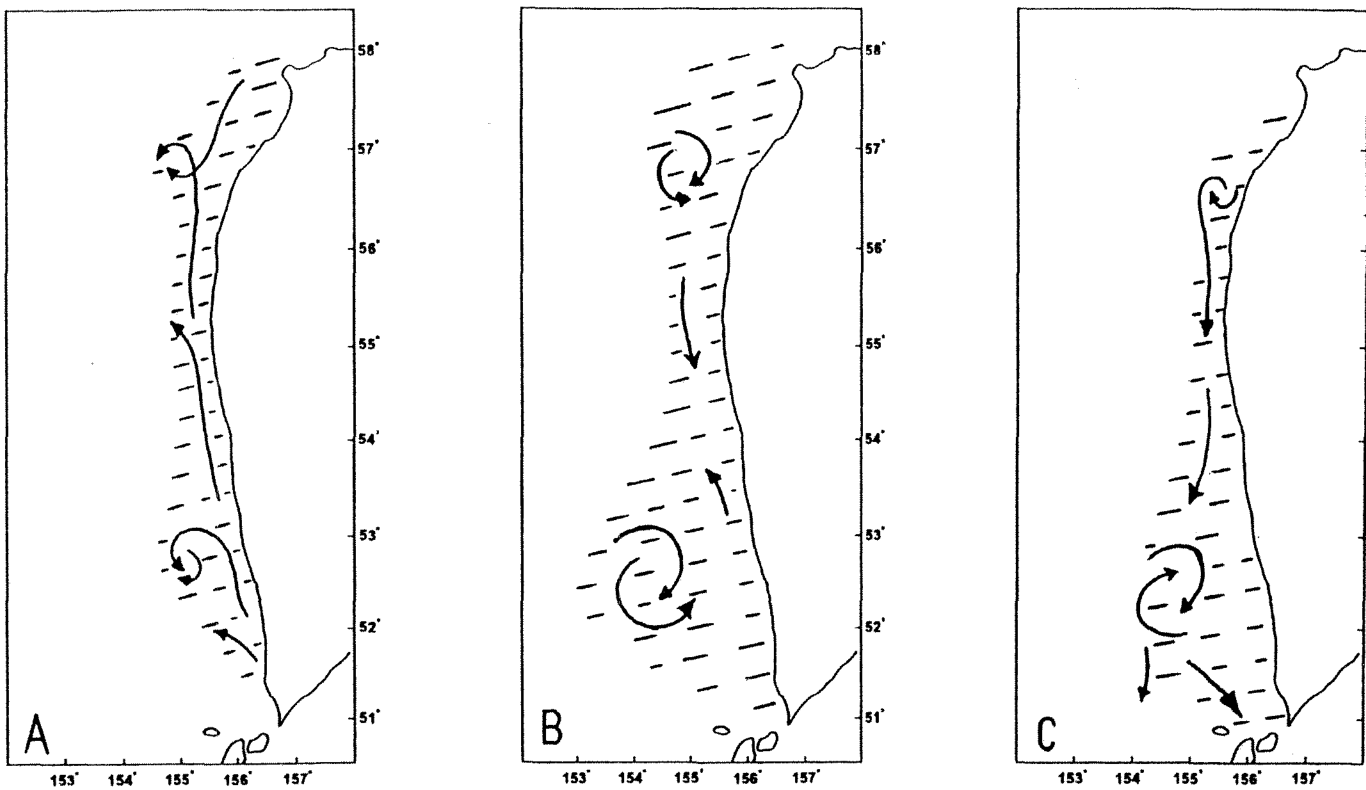
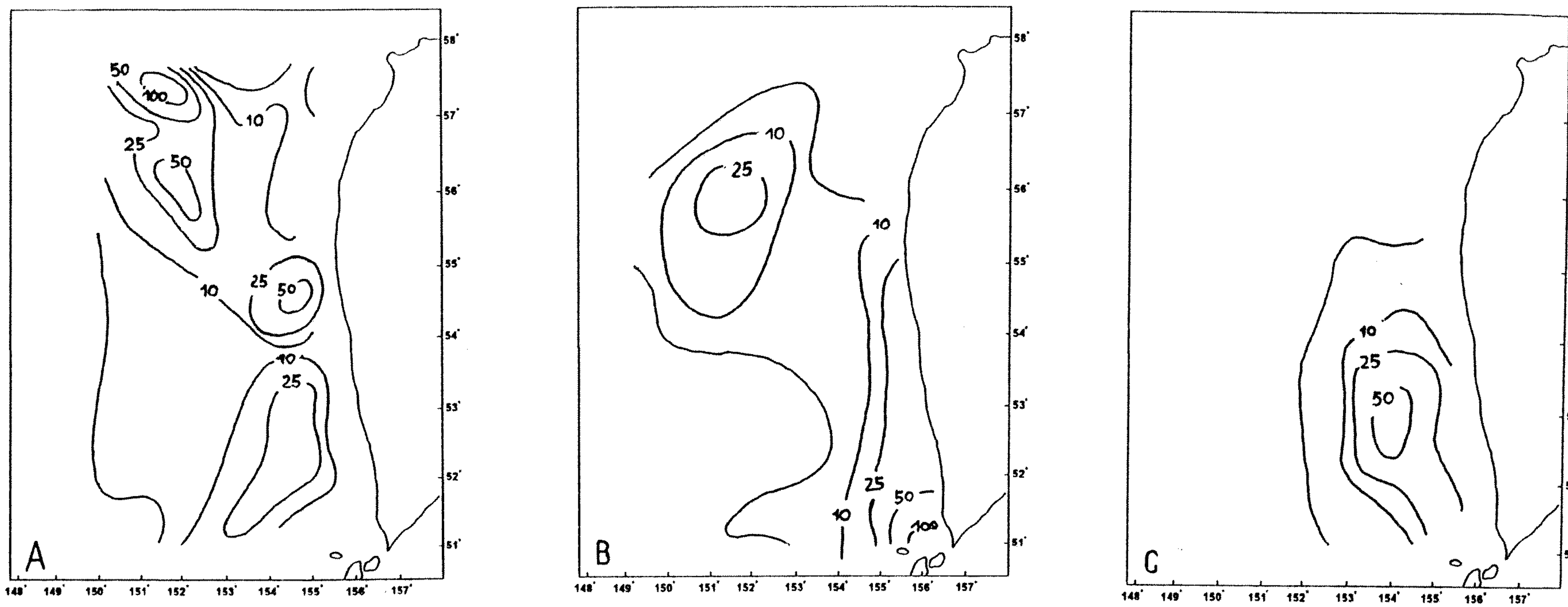


Fig. 4 Distribution of juvenile coho in the eastern Sea of Okhotsk, fish/trawl: A - late August-early September 1986; B - September-early October 1989; C - late September-first half of October 1991.



areas of active mixing at the boundary of sea currents in the vicinity of capes in the southern part of Karaginskii Bay. Later, the offshore distribution of pink salmon juveniles was determined by water temperature conditions and thickness of the surface mixed layer in the south-western Bering Sea (Fig. 5). Pink salmon migrated along isotherms and was southbound in years when isotherms had a north-south orientation and eastbound when isotherms had an east-west orientation (Karpenko at al. 1993). In September, pink juveniles were fully recruited to the rearing areas surveyed.

The length and weight of pink salmon juveniles were in the range 17-22 cm and 60-100 g, respectively (Table 1). The size of pink salmon juveniles varied among brood years, with fish of smaller and more variable size occurring in years of high pink salmon abundance. The highest growth rates (2.3-2.6 mm/day and 1.4-1.8 g/day) of pink salmon juveniles were observed in August in the Karaginskii Bay. During the period of offshore residence, pink salmon growth rates decreased to 1.1 to 1.8 mm/day and 1.7 to 2.8 g/day. Fulton's index ranged from 1.0 to 1.2. Growth rates and Fulton's indices were lower than those observed for pink salmon in the Sea of Okhotsk. These differences were due to diet and the length of the offshore rearing period. Thus, juvenile pink of the Bering Sea reared less in offshore waters and longer in coastal waters. Bering Sea pink salmon fed mostly on euphausiids while Sea of Okhotsk pink salmon fed on hyperiids and fish larvae of various species.

Chum Salmon. The seaward migration of western Bering Sea chum salmon was later than pink salmon, with the peak of the migration occurring in July. Chum salmon juvenile aggregations occurred closer to shore relative to pink salmon (Fig. 5), and presumably due to their later seaward migration and delayed offshore migration. Although chum salmon had a later migration, the distribution and migration routes were similar to those of pink salmon (Birman 1985). In September, chum salmon shoals seemed to be located on the peripheries of the most dense shoals of pink salmon. However, because of greater pink salmon abundance in this region, catches of chum salmon were lower and more dispersed.

In September, the length of chum salmon juveniles ranged from 17 to 21 cm and weight ranged from 50 to 100 g (Table 1). The average size of juvenile chum salmon was generally smaller than that of pink salmon, due to later entry to marine rearing areas and to lower growth rate. In September, average daily growth rates ranged from 1.8 to 2.3 mm/day and 1.3 to 1.6 g/day. The maximum growth rates observed for chum salmon occurred 10 to 15 days later than those of pink salmon. Fulton's index ranged between 1.15 and 1.22.

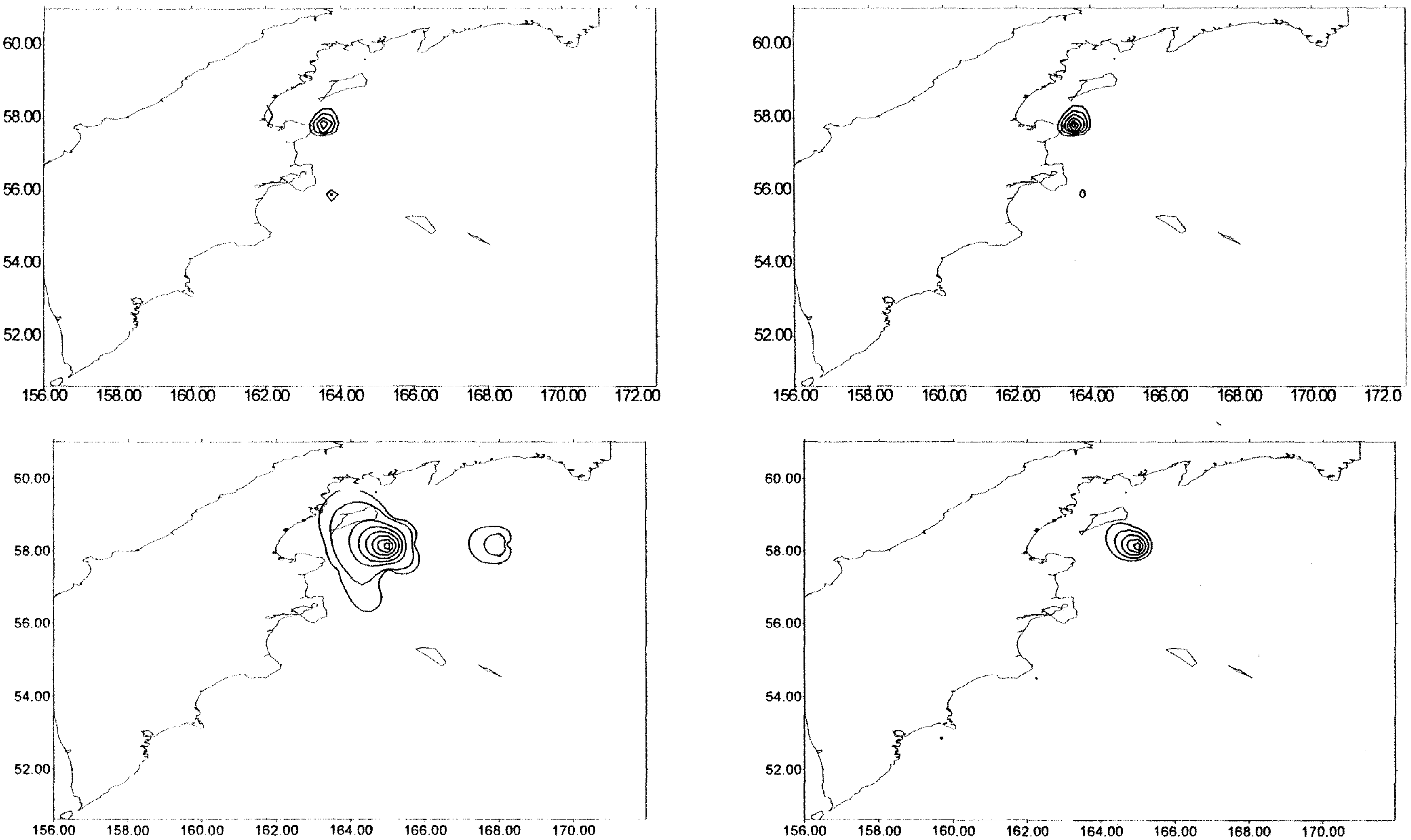
Because of the limited rearing areas and high density of competitors in the south-western Bering Sea, there was a potential for strong competition among pink and chum salmon. In years of high abundance for pink salmon, a decreasing similarity in diet occurred between these species. During periods of high pink salmon abundance, the chum salmon diet included lower energy prey such as tunicates, polychaete larvae, and fish larvae.

Sockeye Salmon. The peak of sockeye salmon seaward migration in north-eastern Kamchatkan rivers was similar to that in Kuril Lake, but was less protracted. The relative magnitude of the three freshwater age classes of sockeye juveniles in coastal waters was 67.4% age 0+, 30.2% age 1+, and 2.4% age 2+. During September, in high seas areas of the Bering Sea ages 1+ and 2+ predominated, and age 0+ sockeye salmon juveniles were rare due to their later timing of seaward migration. By mid September, the major juvenile sockeye shoals were located offshore, 80 - 120 miles south-east of Karaginskii Island. Juvenile sockeye (0 ocean age) were caught together with 1 and 2 ocean age fish which were often more abundant than juvenile sockeye. Sockeye juveniles occurred in this region until mid-October and then migrated offshore after water temperature decreased to 6-7°C.

The length of sockeye salmon juveniles ranged from 12 to 22 cm and weight ranged from 70 to 120 g (Table 1). In general, older, larger fish tended to be farther offshore. There was little difference in mean size of juvenile sockeye between years, with observed differences due to variability in timing of survey and migration timing. The highest juvenile sockeye salmon growth rates were observed in September, and ranged from 1.8 to 2.2 mm/day and 1.3 to 1.8 g/day. Growth rates in coastal waters were generally lower and averaged 1.5 mm/day and 0.5 g/day. Fulton's index ranged 1.20 to 1.32. In the Bering Sea high seas' area the juvenile sockeye salmon diet consisted of euphausiids, crab and hyperiid larvae. In Bering Sea coastal waters the sockeye salmon diet consisted of small copepodes and fish larvae.

Coho Salmon. The seaward migration of coho salmon in eastern Kamchatkan rivers was similar to that of chum salmon, with the peak of the migration occurring in July. The relative magnitude of the four freshwater age classes of coho salmon juveniles in coastal waters was 3.0% age 0+, 50.8% age 1+, 44.9% age 2+, and 1.3% age 3+. In offshore Bering Sea areas freshwater age 1+ and 2+ were

Fig. 5 Distribution of pink (left) and chum (right) juveniles in the south-western Bering Sea. Above - 1989, and Below - 1991.



predominant. Distribution of coho salmon is relatively even, although it may be higher in the south of the region, which may be associated with the common migratory pattern of all salmon species. Coho salmon are primarily concentrated around junctions of oceanic currents (commonly in the peripheral zones of shoals of other salmon juveniles), the venue for the major prey of coho salmon, fry of sandfish, pollock and other fish species. The coho salmon diet consisted of pollock and sandfish larvae, crab larvae and zooplankton (euphausiids, hyperiids and copepods).

In September, the length of most coho salmon juveniles was in the range 23 to 27 cm and weight in the range 150 to 200 g. Older and larger fish generally occurred offshore in the southern areas of the survey area, and younger coho occurred closer to shore. Like coho salmon of the Sea of Okhotsk, coho juveniles of the Bering Sea had higher growth rates than juveniles of other salmon species, and in September, ranged from 2-2.7 mm/day and 3-4 g/day. Growth rates were similar among freshwater age groups. Fulton's index of juvenile coho salmon in coastal areas ranged from 1.30 to 1.40, and in offshore areas ranged from 1.45 to 1.58.

Chinook Salmon. The seaward migration of chinook salmon occurred later than other salmon species, with the peak of the migration occurring in July-August. The relative magnitude of the three freshwater age classes of chinook salmon juveniles in coastal waters was 3.5% age 0+, 71.9% age 1+, and 24.6% age 2+. In the western Bering Sea, chinook salmon spent longer periods in coastal waters than other species, and were found within 20-50 miles of river estuaries in mid October. It is believed that juvenile chinook migrated from coastal waters to the offshore areas of the south-western Bering Sea in late October when water temperature decreased to 6.2-6.5°C.

In September, the length of chinook juveniles ranged from 18 to 23 cm and weight ranged from 70 to 160 (Table 1). The growth rate was low relative to other species and was estimated to be 1.5 mm/day and 3.5 g/day (or 3-4% per day). The maximum growth rate occurred in the mid August and averaged 1.84 mm/day and 2.32 g/day (or 6-7 % per day), and is conditioned by the shift to rapacious feeding among chinook juveniles, which prevails thereafter. The diet of juvenile chinook salmon included juveniles of smelt, herring, pollock, and sandfish, with minor occurrence of larger crustaceans. Fulton's index of chinook salmon in coastal waters ranged from 1.15 to 1.25, and in offshore areas ranged from 1.23 to 1.35.

FORECASTS OF PINK SALMON RUNS BASED ON JUVENILE ABUNDANCE DURING THE FALL PERIOD OF OCEAN RESIDENCE

The highest mortality of salmon juveniles occurs during the first months of ocean residence. By fall, Kamchatkan scientists believe that abundance in ocean rearing areas has stabilized and further mortality occurs at a constant rate that varies little among years. Because of this, a method of forecasting future runs of salmon was developed based on estimation of juvenile salmon abundance in the fall following migration to ocean rearing areas. Estimates of juvenile abundance were based on trawling with standardized methods on a standard station grid covering Kamchatkan coastal waters of the Sea of Okhotsk and Bering Sea. In fall, abundance of salmon juveniles of all species varied considerably in both the Sea of Okhotsk and Bering Sea survey areas. In the eastern Sea of Okhotsk, salmon abundance fluctuated between 150 and 300 million individuals, and in the western Bering Sea between 70 and 150 million individuals. Pink salmon constitute the majority of the catches in both areas, and abundance estimation is believed to be of great importance in preseason forecasting of adult salmon runs.

The trawl survey was carried out over a considerable area in a relatively short time and therefore is believed to provide a quantitative evaluation of juvenile salmon distribution and abundance (Shuntov at al. 1986; Shuntov 1989a,b; Kislyakov 1990; Erokhin at al. 1990). In two weeks, two research vessel covered with a grid of 100-120 survey stations, an area of over 600,000 km^2 in the Kamchatkan coastal waters of the Sea of Okhotsk and in the Bering Sea. The optimum period for conducting the survey was September through the first 10 days of October, after juvenile fish of Kamchatkan salmon stocks had completed their migration from coastal waters to the offshore waters.

In the western Bering Sea, the accuracy of preseason forecasts based on the juvenile salmon survey depended on strict observance of standard surveying methods and whether the survey covered the marine distribution of juvenile salmon. The origin of juvenile salmon in the western Bering Sea, in contrast to the eastern Sea of Okhotsk, is from northeastern Kamchatkan rivers. Results of pink salmon run forecasts for north-eastern Kamchatka are presented in Table 3. Note that preseason run forecasts were made for 1986 to 1992 and used survey data collected with the 54.4/192 m special trawl that was first deployed in the 1985 survey. Forecasts with satisfactory accuracy (% deviation of adjusted forecast and actual run less than 25%)

Table 3. Juvenile pink salmon abundance and runs to the Kamchatka northeastern rivers, million fish.

Survey Periods	Juvenile Abundance	Runs Forecast		Actual Runs
		preliminary, 2 yr advance	adjusted, based on trawling survey results	
1981 26.08-09.09	2.6	6.6	n/a	15.1
1982 optimum	45.2	46.0	n/a	40.5
1983 -	n/a	13.0	-	24.5
1984 09-27.08	7.05	30.2	n/a	22.0
1985 -	n/a	14.0	-	4.3
1986 optimum	40.0	26.1	46.0	54.8
1987 optimum	1.2	8.3	2.0	9.1
1988 optimum	7.5	42.1	65.0	67.0
1989 optimum	26.7	12.6	21.2	27.1
1990 optimum	87.0	54.4	70.0	99.2
1991 optimum	26.9	10.0	10.5	9.8
1992 03-14.10	-	41.3	41.3	65.0

occurred for 67% of years where juvenile surveys were conducted (1986-91), 75% for brood years of high abundance (see Fig.6).

The accuracy of the preseason forecasts were poor for some years, due to the following conditions:

1- In years when juvenile abundance was low (less 10 million), the relative error in surveys of juvenile abundance is high, e.g. in 1981 and 1987.

2- For certain years (i.e., 1981 and 1984), the survey occurred prior to the time that migration from coastal rearing areas was complete.

3- Standard sampling methods were not observed during the 1988 survey. In 1988 the ship was equipped with larger trawl doors instead of standard doors (4.2 m^2 instead of 3.3 m^2). This slowed the trawling speed and decreased the distance between the vessel and the trawl so that the net could not be deployed near surface.

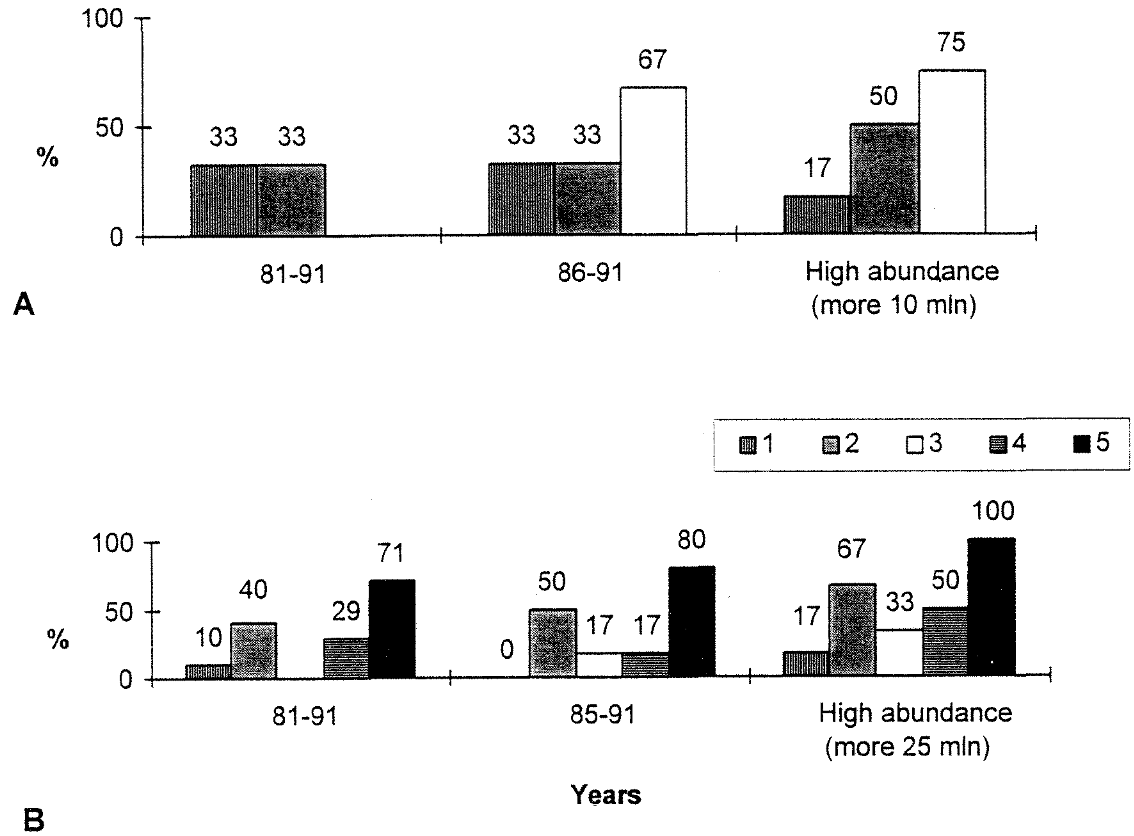
Similar problems may have occurred in the trawl surveys in the Sea of Okhotsk; however, the accuracy of forecasts of western Kamchatkan salmon runs based on juvenile abundance was mainly affected by the presence of juvenile salmon from Sakhalin, the Amur River, and northern coast of the Sea of Okhotsk. Because stock identification methods were not available, it was not possible to sort out the presence of juveniles originating from rivers outside western Kamchatka. Therefore the survey results give only the data on overall juvenile pink abundance rearing in Kamchatkan coastal waters of the Sea of Okhotsk. Evaluation of juvenile pink originating in Kamchatka rivers and lakes is made depending on the type of pink salmon distributed, as specified above.

Accordingly, the *aboriginal* type of pink juveniles distributed in the East part of the Sea of Okhotsk were identified by the following criteria: 1 - high return of spawners to the rivers of the West Kamchatka; 2 - small average size of juveniles (length 17-22 cm, weight less then 70 g); 3 - high variability of body size: from 11 to 30 cm; 4 - significant number of individuals smaller then 18-19 cm (>50%); 5 - the size of juveniles increased from the shore of Kamchatka to the offshore.

The *immigratory* and *intermediate* types were identified by the followng criteria: 1 - low return of spawners to the rivers of the West Kamchatka; 2 - large average size of juveniles (length 21-23 cm, weight 80-120 g); 3 - low variability of body size: from 15 to 28 cm; 4 - number of individuals smaller than 18-19 cm, less than 50 % of total abundance; 5 - the size of juveniles decreased from the shore of Kamchatka to the offshore. Criteria 2-5 were thought to be caused by differential migration of early emerging and larger sized individuals from the east Sakhalin rivers to the west Kamchatkan shelf.

For years of *aboriginal* distribution (i.e., 1982 and, partially, 1983), the eastern Sea of Okhotsk was primarily occupied by western Kamchatka origin pink salmon. Thus, in fall 1982, 128.5 million juvenile pink salmon were estimated ($K_{catch}=1$), while total return of adult pink salmon to western Kamchatka 1983 was 141.3 million. For years of *immigratory* distribution (i.e., 1984, 1986, 1990), the Sea of Okhotsk was primarily occupied by juvenile pink salmon that originated outside of western Kamchatka. In fall 1990, 92.7 million juvenile pink salmon were estimated, while the total run of adult pink salmon to western Kamchatka in 1991, was 2.0 million fish. In 1991, the run of pink salmon to the rivers draining into the northern Sea of Okhotsk and Sakhalin Island and excluding the Amur River, was 150 million fish. So assumming perfect assessment of abundance, negligible overwinter mortality, and no contribution

Fig. 6 Frequency of satisfactory forecasts for pink salmon in northeastern (A) and western (B) Kamchatka: 1 - traditional forecast; 2 - forecast based on the trawling survey; 3 - adjusted forecast; 4 - forecast based on the linear growth rate analysis; 5 - forecast based on body length analysis.



of Amur River pink salmon, 60% of juveniles from non western-Kamchatkan rivers reared in Kamchatkan coastal waters the previous year, while juveniles from western Kamchatkan rivers accounted for 5%. For years of mixed or intermediate distribution (i.e., 1981, 1985, 1987, 1989, 1991, 1995) it is necessary to sort out pink salmon of western Kamchatka origin.

Table 4 presents the evaluation of the preseason forecasts of western Kamchatka pink salmon runs based on the previous fall juvenile abundance. There were significant errors in the forecast using the aggregate juvenile abundance during years with *immigratory* and *intermediate* distribution of pink salmon stocks. We attempted to sort out western Kamchatka pink salmon assuming that smaller pink salmon within 60 miles of the coast were of western Kamchatka origin and those outside of 60 miles were mixtures of stock. The proportion of Western Kamchatka pink salmon was estimated as the proportion of smaller sized fish in the aggregate stock size distribution.

Satisfactory accuracy (percent deviation less than 25%) of the adjusted forecast based on the trawl surveys occurred in 17% of years where trawl survey was used (Table 4) and represented a slight improvement over that observed for traditional forecasting. Satisfactory accuracy for brood years of high abundance was 33% using the adjusted trawl survey forecast and 67% using traditional forecast method (see Fig.6).

Fish growth rates and size have been observed to be an indicator of run strength and used to forecast pink salmon runs in the Karaginskii area of north-eastern Kamchatka (Karpenko 1985) and for pink and chum salmon runs in Iturup Island (Kaev and Chupakhin 1986). An attempt was made to apply this method to western Kamchatka pink salmon. It was believed that pink salmon in the area adjacent to the Kamchatka Peninsula, 52-55°N and 152-155°E, were likely to be of western Kamchatka origin. Pink salmon growth rates during September in this area varied between 1.28 and 2.51 mm/day, and average length varied between 20 and 25 cm. Regressions of daily growth rate and length and western Alaska pink

Table 4. Juvenile pink salmon abundance and runs to the Kamchatka western rivers, million fish.

Survey Periods	Juvenile Abundance		Runs Forecast		Actual Runs
	east of 150°E	Western Kamchatka	preliminary, 2 yr advance	adjusted, based on trawling survey results	
1981 optimum	15.5	15.5	28.0	n/a	37.3
1982 26.09-15.10	128.5	128.5	55.0	n/a	141.3
1983 optimum	11.0	11.0	41.6	n/a	87.0
1984 optimum	17.7	17.7	17.0	90.0	7.6
1985 optimum	9.2	9.2	89.0	35.0	36.6
1986 optimum	50.3	15.0	15.9	15.0	1.7
1987 optimum	24.7	24.7	37.7	37.7	26.0
1989 optimum	165.1	24.8	48.1	80.0	26.3
1990 optimum	92.7	19.4	6.0	6.0	2.0
1991 optimum	36.3	28.9	30.0	30.0	15.9

salmon abundance were developed:

$$N=66.27-26.92l$$

and

$$N=245.66-9.75L,$$ where

N - salmon return, millions;
l - daily linear growth rate, mm;
L - average length in September, cm.

The above equations were used to forecast abundance and improved the accuracy of western Kamchatka pink salmon forecasts considerably (Fig. 6).

CONCLUSIONS

Forecasts of pink salmon runs based on trawl surveys of juvenile abundance the previous fall are more accurate than traditional forecasts based on brood year returns. This method provide an adjustment to traditional forecasts 8 to 9 months in advance of the run and has potential for application to other species' forecasts. Trawling survey have been successfully applied in identifying salmon natal migration routes (Shuntov et al. 1993a,b). The criteria for optimum trawling conditions for surveys of juvenile salmon abundance during the fall season included:

1. Survey conducted from September 1 through October 10.
2. Trawl towed between 4 to 5 knots;
3. The distance between vessel and trawl mouth be maintained at 200 m;
4. The upper rope of the trawl must emerge from the water surface.

The juvenile salmon abundance should be considered with auxiliary biological data on juvenile salmon, presence of stocks in the survey area from other areas in Sea of Okhotsk, and in the Bering Sea very weak brood year runs.

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