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The use of special-purpose rope trawl 54.4/192 m for studying biology and abundance of juvenile pacific salmon foraging in fall season

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Abstract

This paper presents 19 years (1985-2003) of data using a special rope trawl (54.4/192 m) on the abundance of Juvenile Pacific salmon in the Eastern Sea of Okhotsk and Western Bering Sea during fall season. In addition, two rope trawl calibration experiments (1989, 2003) were conducted. The paper includes information on the configuration of the rope trawl, trawl equipment, fishing methods, location of stations, cruise data, etc.
The abundance estimation period varied among species according to the time of seaward migration in principal areas of Kamchatkan waters: first – coho and pink salmon, next – chum salmon, and last – sockeye and chinook salmon. The entire estimation period extended from early September to mid October (in the Sea of Okhotsk ten days later). During this period the fork lengths of juvenile salmon were 8-40 cm. The total catch of all species exceeded 20-30 thousand specimens in each survey area. The most abundant species were pink, chum, and sockeye salmon in the Sea of Okhotsk; pink and chum salmon in the Bering Sea.

Introduction

KamchatNIRO began to conduct trawl surveys to study biology of salmon juveniles in coastal waters of the Bering Sea and the Sea of Okhotsk in 1981. Different modifications of trawls have been used for that purpose. However, the specificity of salmon stock surveys imply stability of trawling in a surface layer of water inhabited by juveniles, and at that time such trawling operations were quite problematic (Voinikanis-Mirskiy 1969).

By the mid-eighties of the last century scientists of Kamchatka had gained significant experience in manufacturing pelagic trawls. Taking such a fact into account, in 1985, Experimental Commercial Fisheries Base of Kamchatka (Commercial Fisheries Laboratory of KamchatNIRO since 1994), being commissioned by KamchatNIRO, designed pelagic rope trawl (54.4/192 m) for specialized juvenile salmon surveys to be conducted on the middle-class vessels (STR 503) (Karpenko et al. 1997).

26 standard and experimental trawl surveys had been performed in the Bering Sea and in the Sea of Okhotsk for almost 20 years. Experimental trawlings were carried out twice (1989 and 2003) in the Sea of Okhotsk to improve juvenile salmon fishing techniques. However, it should be noted that trawl operation and trawling methods were adjusted in all expeditions prior to standard surveys conducted within monitoring network developed for surveyed areas in both seas (Fig. 1). The purpose of trawl surveys was to estimate the abundance of salmon juveniles (mainly pink salmon) in fall season, before their migration to wintering areas, for adjustment of abundance of fish in spawning runs.

Summarized results of above studies are presented in this article.

Trawl 54.4/192 m specifications

The trawl consists of four planes (Fig. 2). The front part of the trawl consists of rope and net components. The rope component has a hexagonal shape formed by rope elements. The net component has a rhombus shape with a mesh size varying from 1600 to 60 mm. The trawl itself is used in combination with a trawl sack. A fine-meshed (24 mm) net insertion is installed along the entire length of the sack.

In 1985 the trawl was successfully used to perform surveys of salmon juveniles and was approved by KamchatNIRO scientists. Since that period, 54.4/192 m trawl became a number one tool for juvenile salmon surveys performed by KamchatNIRO.

Trawl complex is a dynamic system including a vessel, warps, trawl boards, cables and trawl itself with head and bottom lines (Ivanov et al. 1976; Korotkov and Kuzmina 1972; Korotkov 1998). Spatial position of the trawl during operation and its trajectory are determined by correlation of forces bringing the entire trawl system into equilibrium and maintaining stable movement of the trawl to the desired direction. Correlation of static and hydrodynamic forces influencing on the trawl system during surface trawling brings it into the position at which trawl boards are dipped into the water and the head line stays on the surface (Fig. 3).

Designed parameters of trawl opening and its injection into a surface level are attained with duly tuned up assembly of head line and boards' angle of incidence optimal for trawling on the surface. If the system is unadjusted the trawl either cannot move steadily along the surface or the length of warps is not sufficient to reach design opening.

Vertical opening of the trawl is performed with hydrodynamic hoisting device, sinkers and loads attached to the bottom line.

Preparation and adjustment of hoisting device should be done with a great accuracy. The size of its elements and its symmetry against longitudinal axis of the trawl must be carefully observed. The angle of incidence of the hydrodynamic device is adjusted by difference between the length of head line elements and trawl guy-ropes. The difference for 54.4/192 m trawl is 0.32 m. This parameter needs to be constantly checked during trawling.

Weight of sinkers and loads attached to the bottom line can be calculated.

Surface trawling is the most difficult among the other trawling operations. The crew must consist of highly skilled specialists with extensive practical experience in accurate adjustment of trawl system. 54.4/192 trawl design team had to calibrate the trawl on a regular basis as the skill level of crew members was not always adequate for such work.

In 1989 such calibration was performed on board of the research vessel "Professor Kaganovsky" in the Sea of Okhotsk for 20 days. The trawl was calibrated in good weather conditions (waves 0-2 points, wind 2-4 m/sec). Trawling was performed downwind. Emergence of the trawl head line was visually determined by formation of foaming. The results of test trawlings are presented in Table 1.

In 1989, sixty nine trawlings were conducted. Horizontal opening of the trawl was conducted by means of spherical 4.2 sq. m trawl boards. The total catch of salmon juveniles reached 32112 individuals, 57% of the catch - pink salmon, 32% - chum, 9% - sockeye, 1.6% - coho salmon, both chinook and masu - less than 1%.

Similar work was performed in 2003 in the Sea of Okhotsk by vessel STR 503 "Esso". Unlike other expeditions two types of trawl boards were used to provide horizontal opening of the trawl: standard 3.3 sq. m spherical boards and V-shaped 4.0 sq. m vertical boards.

Correct adjustment of trawl boards is a guarantee of successful surface trawling. High inclination toward trawl arches causes moving of trawl boards to the surface, which can partially or completely lose their ability to spread.

Standard spherical trawl boards can be inclined toward the internal side of the trawl axis by a shifting point at which the warp was fixed to the uppermost position. In this case, angles of incidence for spherical trawl boards should be at maximum. This can be done by tilting nose arch toward the front edge of the board. The results of test trawlings with spherical boards are presented in Table 2.

V-type trawl boards, used for the first time, were adjusted by subsequent changes made to gear arrangements. Positions of points at which warps and door legs were fixed had been checked during calibration trawlings. The results of such trawlings are presented in Table 3.

Trawl coverage area depends on its vertical and horizontal opening.

It was quite easy to determine vertical opening of the trawl. It was measured by cable test device IGEK-U while trawling. However, we had some difficulties while measuring horizontal opening of the trawl since special test instruments were not available. That problem was resolved as follows:

Horizontal opening of the trawl was determined by divergence angle of warps (Fig. 4) which was used for calculating the distance between trawl boards according to the formula:

$$D = \sin(a_{right.} + a_{left.}) \times L_w + в$$

, where
D – distance between trawl boards, m;
a_{right} + a_{left} – horizontal angles of right and left warp divergence from trawl axis, degrees;
L_w – length of paid out warp, m;
в – distance between suspended aft warp blocks.

The following formula has been used to calculate horizontal opening of the trawl (distance between the ends of trawl wings):

$$d = D \times L_t / L_{c.+n}$$

, where
d – horizontal opening of the trawl, m;
D – distance between trawl boards, m;
L_t – length of trawl along the pennant with trawl sack, m;
L_{c+n} – cable length and naked end of wing, m.

Warps divergence angles were measured by protractor at each trawling after the trawl system had been stabilized. The accuracy of estimated distance between trawl boards was checked by IGEK-U device. Emitting antenna of IGEK-U was attached to one of the trawl boards to do the sounding of the opposite board while trawling. The results were compared with estimated values.

Results of calibration trawlings with vertical V-type boards are presented in Table 4.

77 test (valid) trawlings had been conducted during the expedition. Trawling was considered to be valid when head line steadily stayed on the surface and trawl boards were dipped into the water. Juvenile salmon occurred in 69 trawlings. Total landings reached 25590 individuals. Pink salmon catch averaged 42%, chum salmon – 41%, sockeye salmon – 13%, chinook salmon – 1.4%, coho salmon – 1.8%, masu salmon – 0.8%. The results of some test trawlings are presented in Table 5.

It should be noted that 54.4/192 m trawl shows presentable results provided that adjustment is performed on a professional level. Sea trawling is quite a difficult task as trawling process depends on ambient factors – waves, surface currents, etc. Trawl system should be constantly checked while performing stock survey of salmon juveniles, as frequent check-ups contribute to a successful assessment of juvenile salmon stocks and their distribution in certain areas.

Results of stock assessments and biological characteristics of juveniles

In the eastern Sea of Okhotsk we have conducted 14 trawl surveys for 13 years (in 1986 - 2 surveys were performed by two vessels – "Vasilievsk" and "Surovsk"). 993 trawlings have been made and catch of 6 species of juvenile salmon totaled over 186 thousand individuals (Table 6). Total annual catch of juvenile salmon changed from 3.5 (1985) to 32.1 thousand individuals (1989). Pink salmon and chum salmon were predominant in catches (54.3% and 34.6% respectively). Percentages of other salmon species were much lower: sockeye salmon – 6.3%, coho salmon – 2.9%, chinook salmon 1.7% and masu salmon – 0.2%. In recent years (2001-2003), catches of pink and chum salmon juveniles were almost identical. Same identical catches were registered in 1986 and 1991.

In the Southwestern Bering Sea we have performed 12 trawl surveys consisting of 614 trawlings. Total catch of 5 species of juvenile salmon reached over 50 thousand individuals and contained 75% of northeastern pink salmon, 19% of chum, 1.9% of sockeye, 1.8% of coho and 2.3% of chinook (Table 7). Almost every year (except 1987) pink salmon were predominant in catches. Percentages of other species varied significantly each year. For instance, percentage of chum salmon was very low in 1992, 1994 and 1998 (no chum occurred in 1993). High catches of chinook were registered in 1987, 1989-1991. Catches of sockeye were high only in 2000 and 2002.

Taking into account the peculiarities of downstream migration of salmon juveniles in Western and Eastern Kamchatka and time of their subsequent seaward migration, stock survey of salmon juveniles is usually performed 10-15 days earlier in the Bering Sea than that one in the Sea of Okhotsk. Late August is an optimal time for commencement of surveys in the Bering Sea. Surveys in the Sea of Okhotsk are commenced in mid September. Catadromous migration at both coasts of Kamchatka begins almost at the same time. However, sizes of juveniles of some species are not identical, due to the fact that conditions for foraging in coastal waters of both seas and time of surveys are different. Usually, pink, chum and coho salmon juveniles of the Okhotsk Sea are bigger (especially in weight) than those of the Bering Sea (Table 8). However, chinook salmon of the Bering Sea and sockeye salmon of the Olutorskaya population are bigger, but sockeye salmon of the Karaginskaya population are 1.5- 2 times smaller than that ones of the Sea of Okhotsk. In general, variability of salmon juveniles is higher in the Sea of Okhotsk.

Apart from the time of downstream migration, distribution of stocks during survey operations also plays an important role for assessment of juvenile salmon stocks. 54.4/192 m trawl was designed for such species as juvenile pink and chum salmon that migrate from coast to the ocean in stocks rather than in separate groups. Downstream migration of pink salmon begins earlier hence their seaward migration begins earlier as well. As a rule, species with long freshwater life period, such as sockeye, coho and chinook salmon migrate to the ocean in echelons; fish of different age may migrate at different times. Older fishes abandon the coast earlier than the younger ones; fingerings migrate later than the others (Karpenko 1998).

In September, juvenile pink salmon of the Sea of Okhotsk are usually found beyond the West Kamchatka shelf, forming separate, highly concentrated stocks (usually 2-3) stretching from north to south (Fig. 5). The highest density of stocks is observed in the central and southern parts of the area. In September pink salmon begin migration from the other reproductive areas. Characteristics of those concentrations are similar in different year. The concentration's contant depends from abundance of two basic stocks, pink juveniles from Western Kamchatka predominating in odd years, and ones from Sakhalin and Kurils Islands - in even years. Pink salmon from other reproductive zones begin migration to this area in October (Yerokhin and Shershneva 2000; Erokhin 2002). Chum salmon prefer to stay on the periphery of main concentrations of pink salmon, closer to the shore, however sometimes, their concentrations have the same density as those of pink salmon (Fig. 5). Sockeye salmon in September concentrate closer to the shore as compared to pink and chum salmon. Their density depends on the number of downstream-migrants from the main reproductive areas: Kurilskoye Lake in southern, and Palanskoye Lake in northern Kamchatka (Fig. 6). Distribution of coho salmon concentrations is almost identical to that of sockeye. Coho abandon the Sea of Okhotsk earlier than the other species (Fig. 7).

Downstream migration of salmon into the Bering Sea in different areas occurs in different time periods: two weeks earlier in the north than in the south (Karpenko 1998). This fact determines differences in seaward migration of fish which manifests itself as dense concentrations of juveniles (especially juveniles of pink salmon) located at different distances from the shore. As a rule, juveniles organize three significant concentrations (Fig. 8). This fact is proved by differences in sizes of juveniles which form such concentrations. Chum salmon of the Bering Sea usually keep close to the shore and may remain there for quite a long period of time, as well as chinook salmon (Fig. 8). Sockeye salmon (same as in the Sea of Okhotsk) form coastal concentrations and can be found quite close to the coastline until late October (Fig. 9). Coho salmon migrate to the open waters quite early. On the contrary, chinook, as well as sockeye salmon are foraging near the coast until late fall.

Different times of downstream-migration and foraging in coastal waters for various species of salmon and fishes of different ages require duplicate surveys to be conducted in order to assess abundance of generations. In recent years, such duplicate surveys were performed in both seas (In 2000 and 2002 in the Bering Sea, and in 2001 and 2003 in the Sea of Okhotsk). They allow to assess the abundance of salmon juveniles of all species more accurately, to trace the direction of their migration, and obtain the data for assessment of natural mortality of generations (Karpenko, Erokhin, Smorodin 1998; Karpenko, Smorodin 2001).

Conclusions

Described trawling method allows to fulfill many theoretical and practical tasks associated with stock management. Some of them are:

- collection of presentable data on abundance and biological characteristics;
- annual assessment of distribution, migration and foraging conditions of juvenile salmon in surveyed areas;
- application of survey results for forecast of commercial runs of certain stocks and populations for their rational exploitation;
- assessment of role of juvenile salmon in coastal ecosystems of seas of the Far East; etc.

This method was also used to design a series of trawls for catching salmon at different phases of life cycle, and it allows to obtain reliable data for stock assessment of this important commercial fish.

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Table 1

Parameters of calibration trawlings

Warps length, m	Speed, knots	Upper horizon of trawl line, m	Vertical opening, m
150	5.3	0	30
200	5.0	10	30
200	5.5	0	30
250	5.1	13	28
250	5.5	0	28
300	5.0	14	29
300	5.5	0-5	29
300	5.6	0	28
350	5.2	27	27
350	5.5	19	27
350	5.7	0	26
240	5.3	0	28
250	5.2	0	28
260	5.4	0	27
270	5.5	0	28
280	5.5	0	28
290	5.4	0	28

Table 2

Adjustment of 3.3 m^2 spherical trawl boards

№ trawl	Speed, knots	Warps length, m	Warps distance angles, degree		Distance between trawl boards, m	Distance between wing ends, m
			Right	Left		
1	5.2	210	9	10	76	35

2	4.7	125	9	5	38	18
	5.1	150	9	7	49	23
	5.1	175	9	10	65	30
	5.1	200	10	9	73	34

Table 3

Adjustment of vertical V-type trawl boards

№ trawl	Speed, knots	Vertical opening, m	Distance between trawl boards, m	Distance between wing ends, m	Warps distance angles, degree		Warps length, m
					Right	Left	
1	4.5	28	50	23	12	0	200
2	5.6	28	50	23	12	0	200
3	5.0	28	32	15	4	3	200
4	5.3	29	71	33	9	8	210
5	4.7	29	48	22	0	10	200
6	5.0	29	33	15	2	4	250
7	5.5	29	53	25	0	8	280
8	4.4	27	42	20	0	10	200
9	5.7	28	38	18	-2	8	300

Table 4

4 m^2 V-type trawl boards

Speed, knots	Warps length, m	Warps distance angles, degree		Distance between trawl boards, m		Distance between wing ends, m
		Right	Left	Measured	Calculated	
4.5	240	7	10	79	78.26	36
4.0	120	8	15	58	54.98	26
4.3	150	7	14	62	61.85	29
4.5	175	7	11	65	62.18	30
4.7	200	6	11	69	66.57	31
4.8	225	7	11	76	77.63	35
4.9	250	6	10	78	77.01	36

Table 5

Trawling parameters and catches in 2003

№	Data	Speed	Vertical opening	Distance		Warps distance angles		Warps length	Улов					
				Between trawl boards	Between wing ends	Right	Left		Pink	Chum	Sockeye	Chinook	Coho	Masu

		knots	m	m	m	degree	degree	m	Ind.	Ind.	Ind.	Ind.	Ind.	Ind.
1	26.9	4.5	28	50	23	12	0	200	-	1	-	-	71	-
10	29.9	4.8	27	85	39	9	10	245	229	127	-	-	-	1
20	3.10	5.2	28	67	31	0	13	260	176	116	-	-	-	1
30	8.10	5.4	30	80	37	9	12	200	1208	139	-	-	1	-
40	11.10	4.4	32	87	41	9	13	210	309	41	-	-	-	-
50	15.10	4.9	35	80	37	9	10	220	486	42	-	-	-	1
60	18.10	4.3	33	78	36	10	7	240	450	185	1	-	1	-
70	27.10	5.3	30	62	29	8	7	210	3	12	2	-	-	-

Table 6

Catches of salmon juveniles in the Sea of Okhotsk (1985-2003)

	1985	1986	1987	1989	1990	1991	1993	1995	1997	1999	2001	2002	2003
Pink	1685	8611	4966	18204	5273	6054	4844	3241	15803	5672	3803	11839	11168
Chum	623	7999	2791	10321	4072	5750	1141	1068	4713	3237	2957	9732	10153
Sockeye	266	882	158	2809	388	381	40	21	957	1092	311	1108	3411
Coho	516	1449	357	523	147	287	54	135	452	262	281	518	462
Chinook	418	375	272	239	27	194	116	37	232	241	245	182	376
Masu	41	107	2	16	2	47	5	0	19	0	29	156	20
Total	3549	19423	8546	32112	9909	12713	6200	4502	22176	10504	7626	23535	25590
Trawls	92	133	86	69	57	75	28	45	52	77	65	137	77

Table 7

Catches of salmon juveniles in Bering Sea (1986-2002)

	1986	1987	1988	1989	1990	1991	1992	1993	1994	1998	2000	2002
Pink	2017	86	232	1813	7296	1319	358	267	81	1103	12834	10240
Chum	370	161	64	202	516	111	14	0	19	77	4302	3731
Sockeye	50	9	14	33	68	69	9	1	2	33	261	398
Coho	84	60	19	111	169	96	8	14	0	1	208	139
Chinook	68	123	42	176	195	117	12	12	0	23	207	159
Total	2589	439	371	2335	8244	1712	401	294	102	1237	17812	14667
Trawls	51	57	55	52	61	44	19	26	17	35	85	112

Table 8

Sizes salmon juveniles in Bering Sea and the Sea of Okhotsk

Species	Fork length, cm		Weight, g	
	Min	Max	Min	Max
		Sea of Okhotsk		
Pink	9	36	15	460

Chum	13	33	20	450
Sockeye	13	30	31	295
Coho	20	38	40	770
Chinook	17	31	70	440
Masu	20	40	118	960
		Bering Sea		
Pink	10	26	8	190
Chum	9	25	10	190
Sockeye	8	32	7	370
Coho	16	37	48	550
Chinook	15	38	43	740

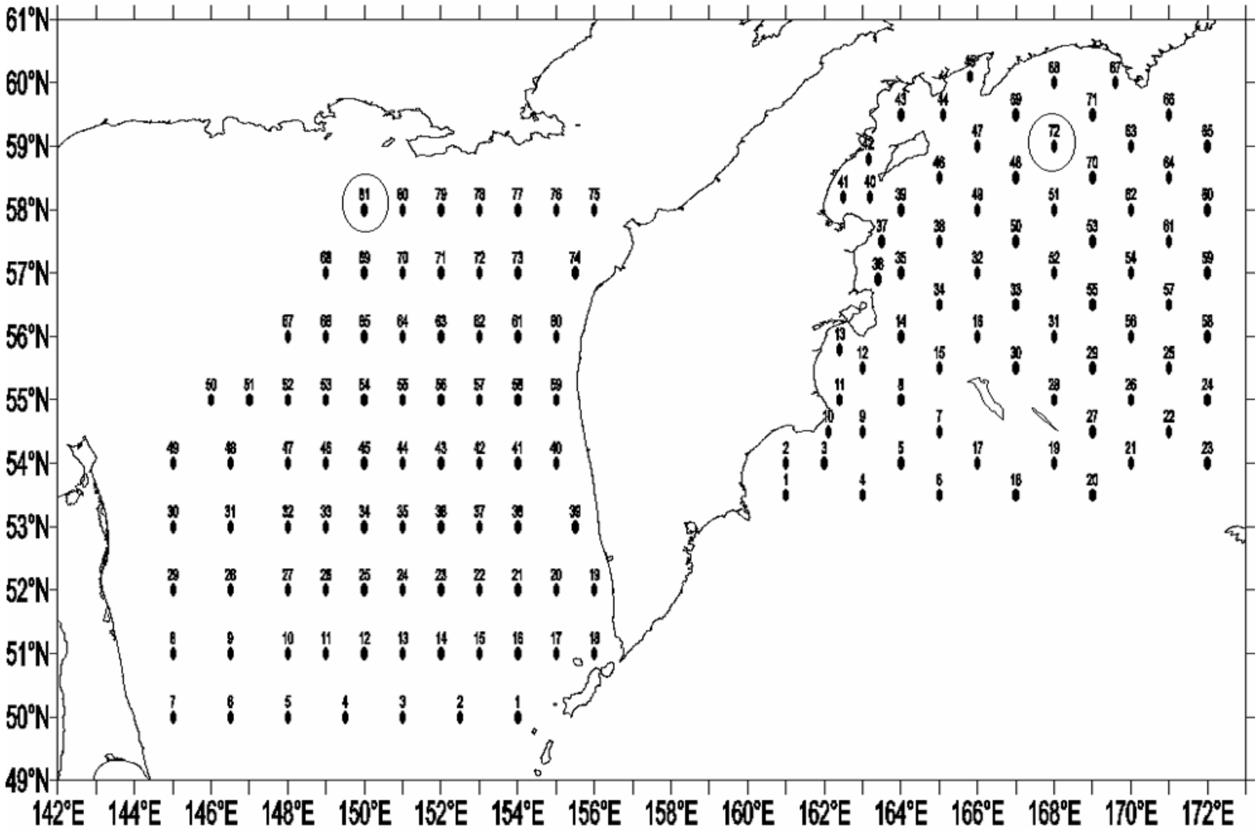

Fig. 1. Monitoring network for trawl surveys in Bering Sea and the Sea of Okhotsk

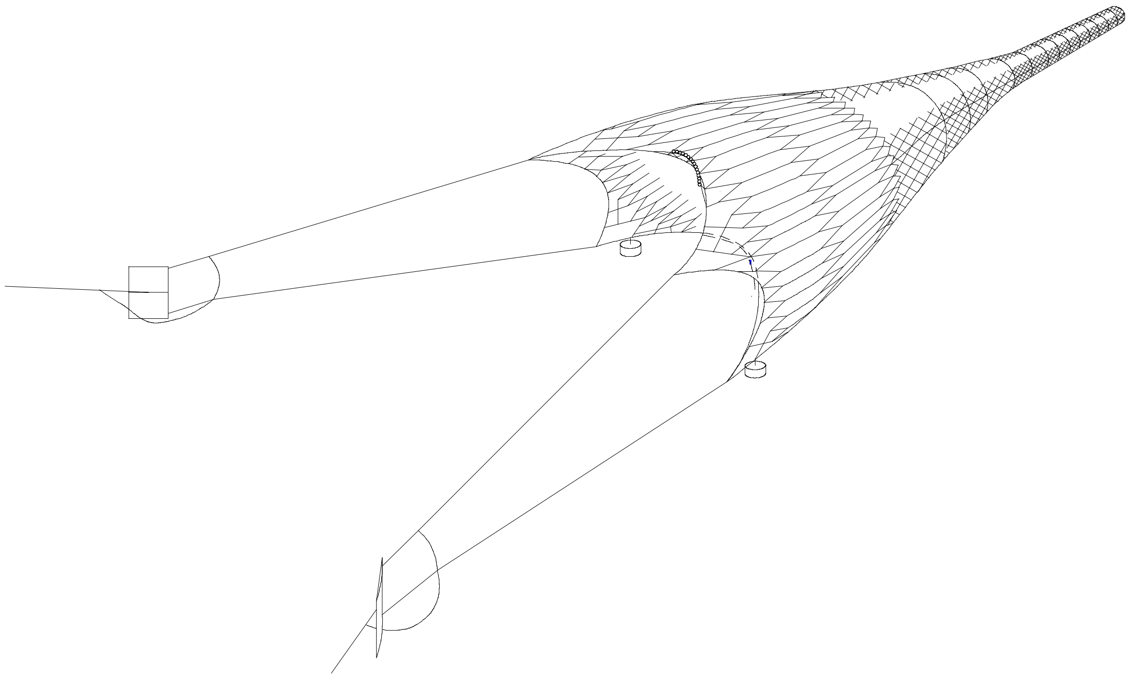

Fig 2. 54.4/192 m trawl for stock survey of salmon juveniles

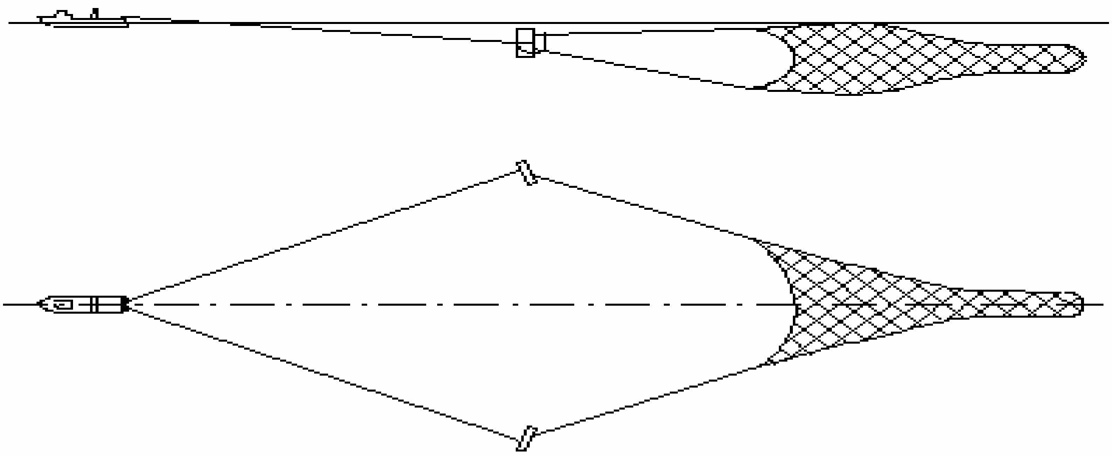

Fig. 3. Operation of trawl system on the surface

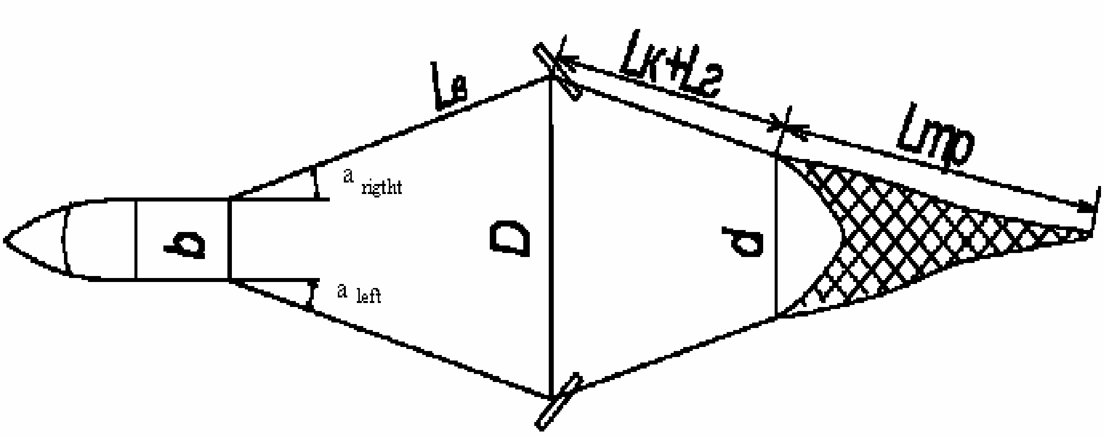

Fig. 4. Method for measuring divergence angle of warps

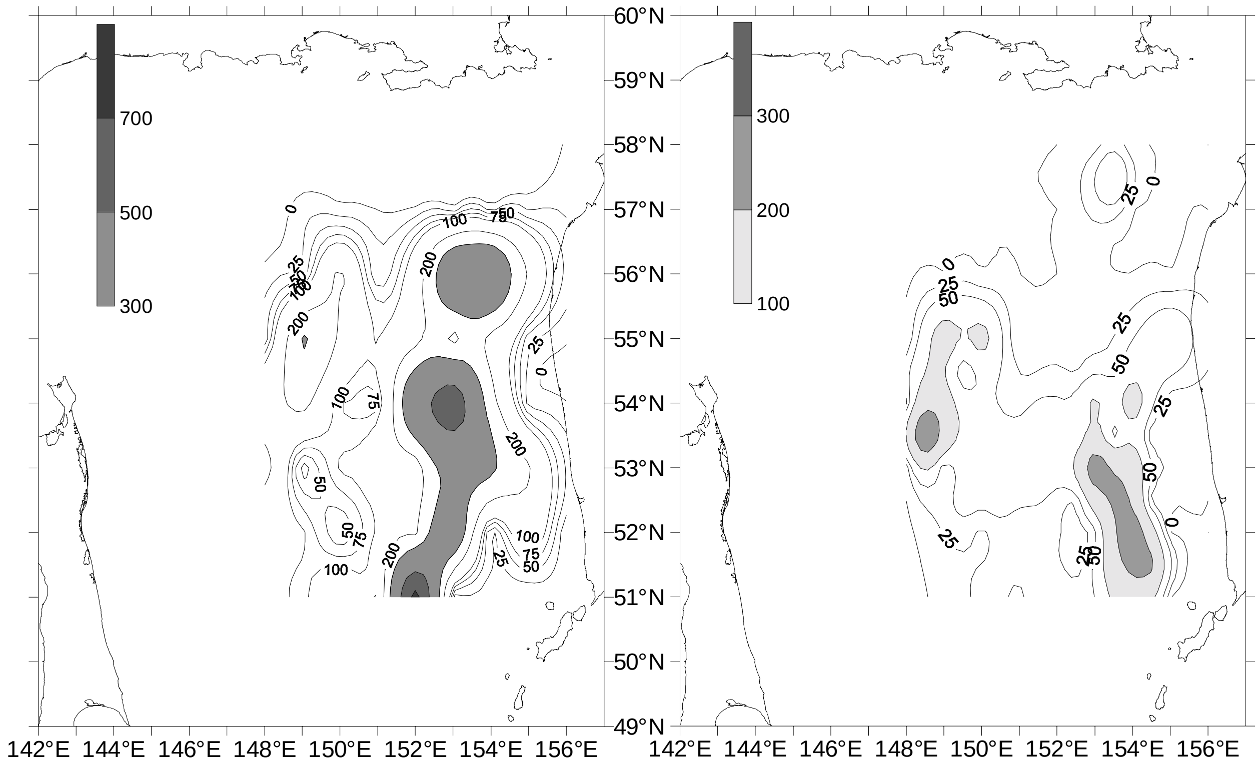

Fig. 5. Typical distribution of juvenile pink (left) and chum (right) salmon in the Sea of Okhotsk in September

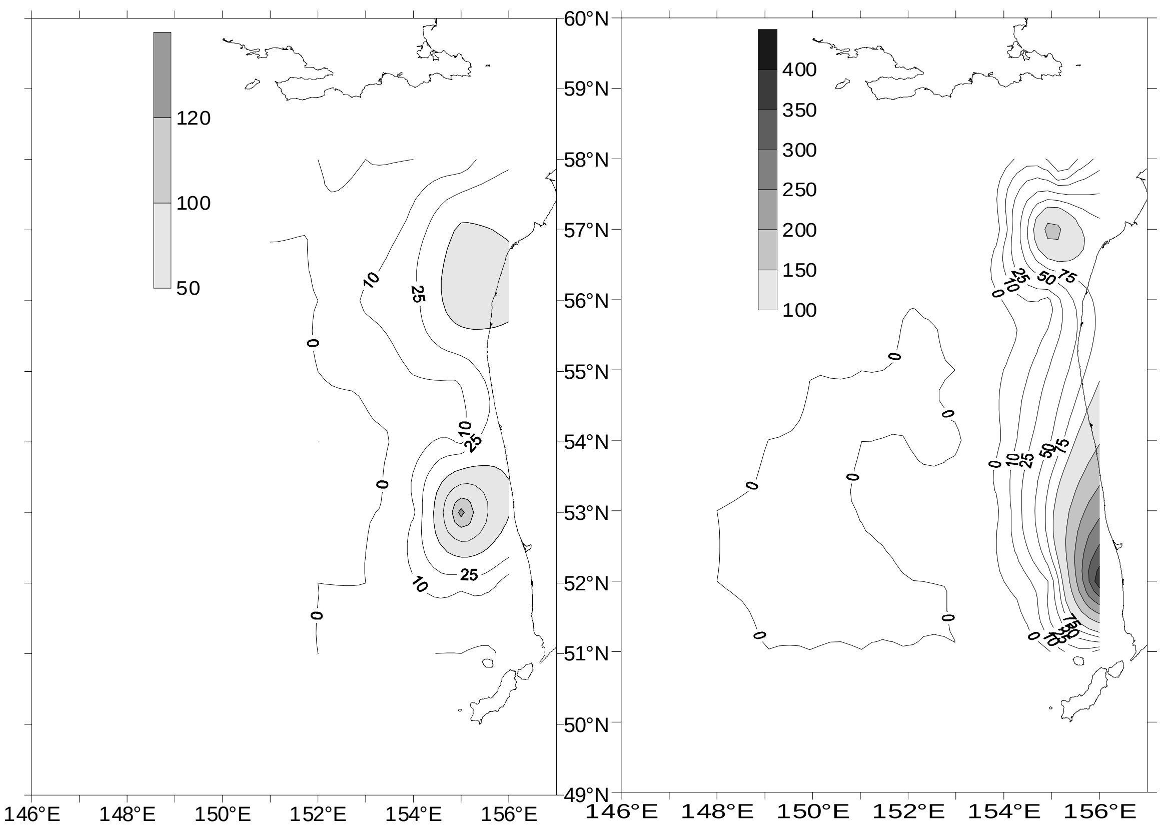

Fig. 6. Typical distribution of juvenile sockeye salmon in the Sea of Okhotsk in September

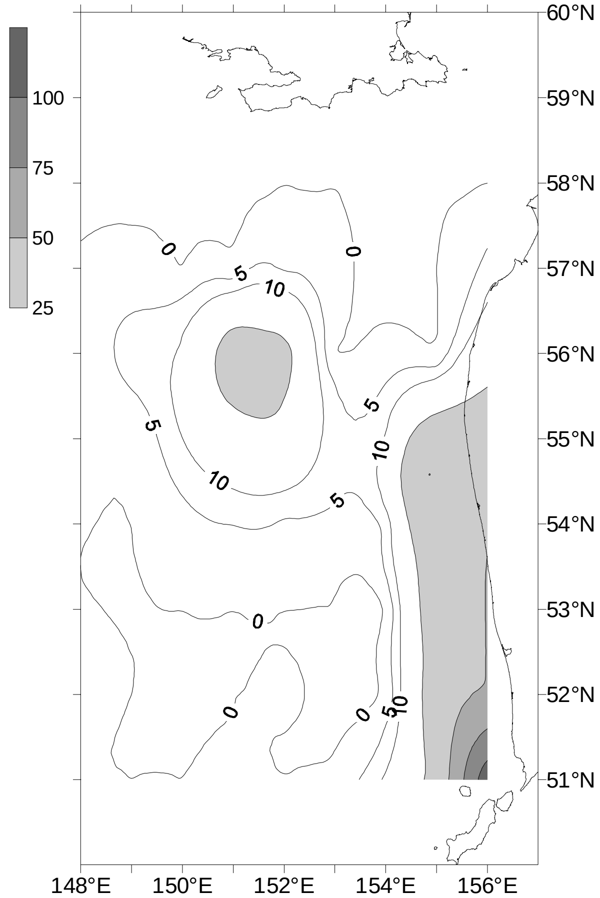

Fig. 7. Typical distribution of juvenile coho salmon in the Sea of Okhotsk in September

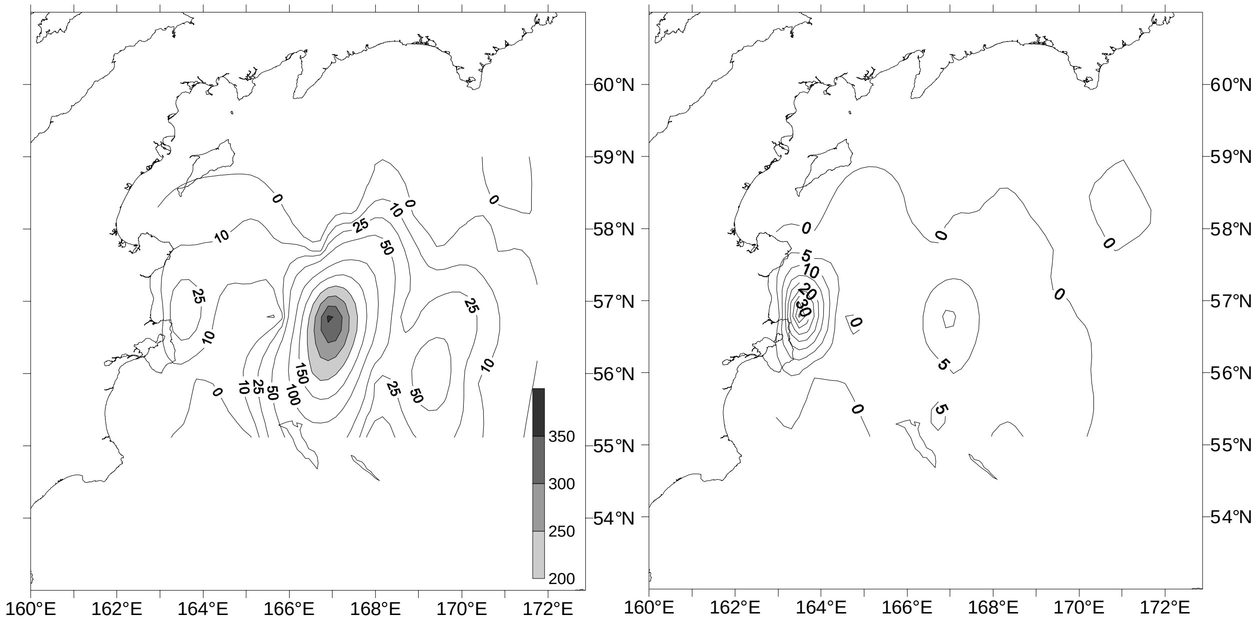

Fig. 8. Typical distribution of juvenile pink (left) and chum (right) salmon in Bering Sea in September

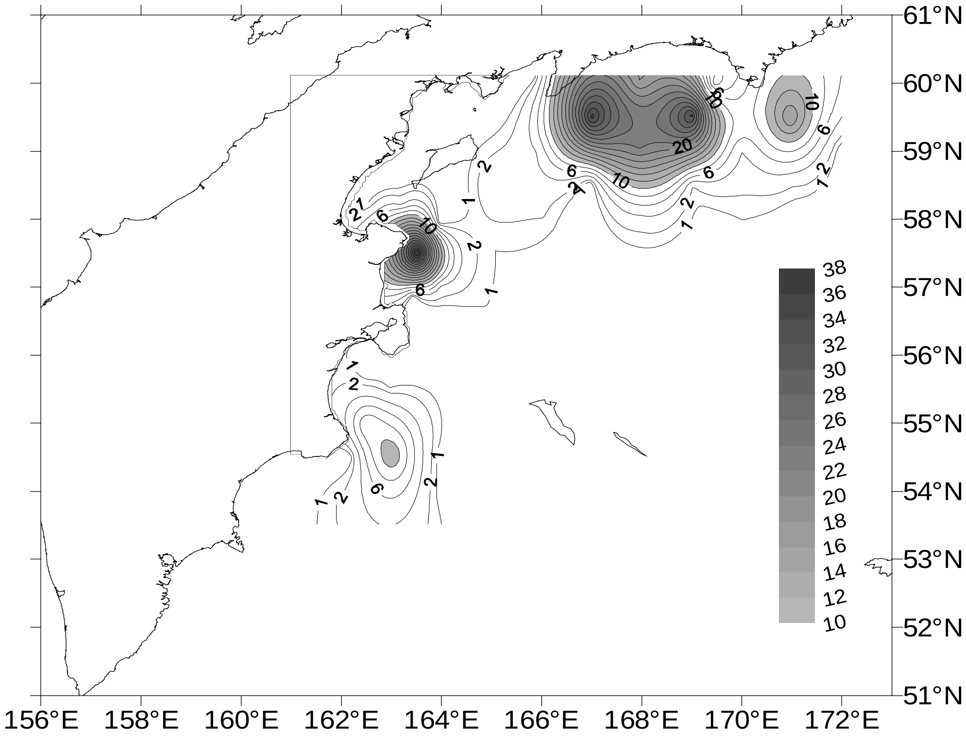

Fig. 9. Typical distribution of juvenile sockeye salmon in Bering Sea in September