ON THE DIURNAL CHANGE OF SALMON CATCH BY THE GILL-NET IN THE OKHOTSK SEA*

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Introduction

Detecting the diurnal movement of objective fish is important to capture fish school in the fishing grounds. There are some reports[1-4] on the diurnal movement of the fish based on the records of fish finder. Machidori[5)6)7)] and Manzer[8)] reported on the vertical distribution of salmon by using the salmon gill-net in the Aleutian Waters and the Gulf of Alaska respectively. But there is little knowledge on the behaviour of salmon. The present authors reported in a previous paper[9)] about the nocturnal movement of salmon that the surface distribution of pink and chum salmon in concentration is dominant for about 1.5 hours after sunset and before sunrise. Thereafter we made studies of the diurnal movement of salmon by a repeated fishing method in the Okhotsk Sea in July, 1967. Experiments were carried out by the No. 5 Kosho Maru, a Government research boat. The diurnal movement of salmon was grasped as an index of the the catch fluctuation of salmon by 20 *tans* of gill-net, 1000 m long and 6 m deep below the surface. In those experiments sockeye, chum, pink, coho and chinook salmon were caught, but the number of chinook salmon was too small to be dealt with, and therefore the data on this fish were not adopted for discussion in this paper. The authors express their gratitude to Dr. Tsujita for his invaluable advice and encouragement in the course of this work. We are also indebted to all the crew members of the No. 5 Kosho Maru for their kind assistance.

Materials and Methods

Experiments were carried out on 7–8 th, 24–25 th and 29–30 th of July in the Okhotsk Sea, 1967 (Fig. 1). The fishing method was the same as stated in a previous paper[9)]: operation was repeated 8–9 times a day continuously. The duration of a net setting into the sea was determined according to sunset and sunrise periods at Sta. A and Sta. B, but at Sta. C the time interval for each net setting was uniformely 2 hours during the day. Sea conditions were usually calm at

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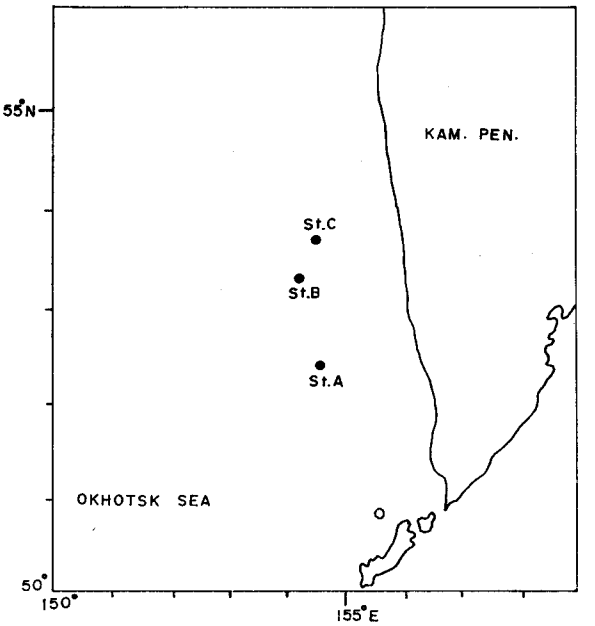

Fig. 1. Location of the repeated fishing experiments

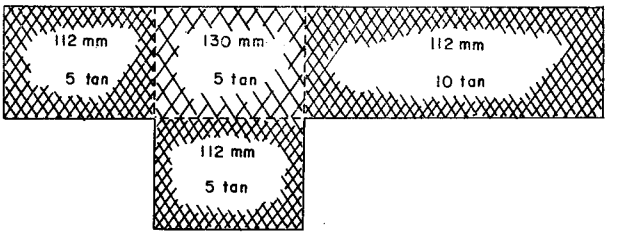

Fig. 2. Arrangement of the salmon gill-net set used

each station. The direction of the net ran from east to west. When a station was fixed, the ship's position was not corrected to the original point, so that it could be shifted by the current and tide. The set of the gill-net consisted of 20 *tans* of nylon multifilament net of which 15 *tans* of nets has a 112 mm mesh size. The other 5 *tans* of nets has a 130 mm mesh size in the upper parts and a 112 mm mesh size in the lower parts with vertical seams, so that the depth of the net was twice as great (Fig. 2). In every fishing series, biological measurements of salmon (fork length, body weight and sex distinction) were carried out for each species. During those experiments the Japanese Central Standard Time was adopted.

Results

1. Oceanographic conditions of the fishing stations

Horizontal distribution of temperature and salinity on the surface are shown in Fig. 3. Sta. A was located in the extension of the Pacific Waters and Sta. C was located in the waters influenced by the coastal waters of the west coast of Kamchatka. Sta. B was located in the convergence area between the Pacific Waters and the coastal waters. These stations are characteristically described and their characters are shown in the T.S. diagrams in Fig. 4. The vertical distribution of temperature and salinity are shown in Fig. 5. At Sta. A, the surface temperature showed about 7°.0C and the thermocline lay in a 10 m layer just below the surface of the sea and another layer from 30 m to 50 m deep. The salinity was rather high compared with other stations and had no sudden change from the surface to 50 m deep. At Sta. B, although the temperature fell gradually from the surface to the 50 m layer, the thermocline changed suddenly from 20 m to 50 m layer. Such feature is considered to be caused by a current of the Pacific Waters in the mid-layer. At Sta. C the temperature on the surface showed

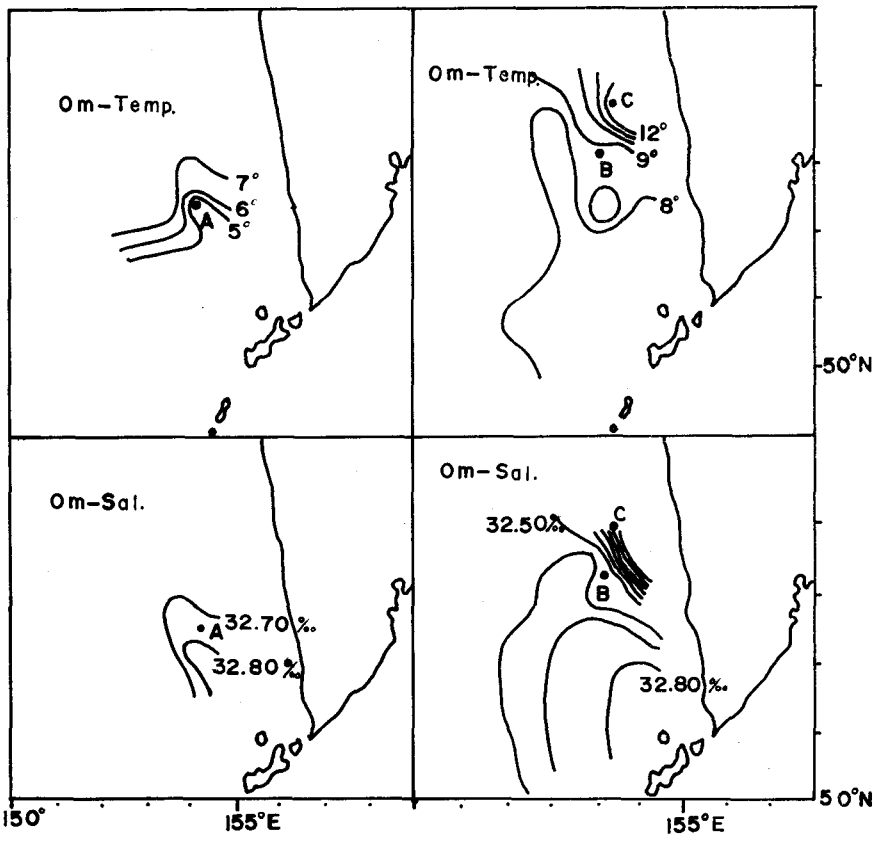

Fig. 3. Horizontal distribution of temperature and salinity on the surface at adjacent sea areas of experimental stations

about 12°C and a suddenly change was found from the surface to 10 m layer and from the 30 m to 50 m layer. The low salinity on the surface that was influenced by the coastal waters indicated below 32.20 ‰. The characteristic feature of this

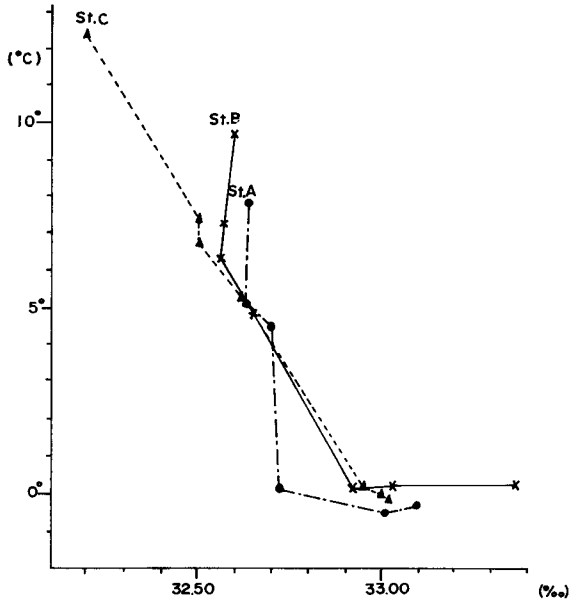

Fig. 4. T.S. diagrams at each station

Table 1. Catch data of salmon by the repeated fishing method

Station (Date)	Series	1	2	3	4	5	6	7	8	9	Sunset and sunrise
A	Duration of net set	1241 1541	1615 1915	1952 2159	2228 2330	0007 0207	0242 0542	0619 0919	0912 1212		
(52°-26′N 154°-36′E	Sockeye	11	4	1	0	1	8	1	2		1905
July-7 (8)	Chum	36	6	5	5	22	24	4	51		0228
	Pink	23	6	20	6	34	11	4	6		
B	Duration of net set	1307 1535	1607 1848	1917 2046	2119 2245	2322 0044	0121 0243	0214 0556	0623 0909	0934 1212	
(53°-18′N 154°-15′E	Sockeye	4	4	2	1	1	1	1	0	0	1853
July-24 (25)	Chum	15	8	6	20	11	7	16	7	13	0247
	Pink	34	35	141	218	216	125	31	9	6	
	Coho	3	2	10	4	10	5	3	1	1	
C	Duration of net set	1300 1500	1600 1800	1900 2100	2200 2400	0100 0300	0400 0600	0700 0900	1000 1200		
(53°-40′N 154°-32′E	Sockeye	3	1	2	0	3	3	6	1		1846
July-29 (30)	Chum	6	5	11	4	15	12	10	6		0251
	Pink	1	5	175	56	66	5	18	4		
	Coho	1	3	26	5	26	1	0	0		

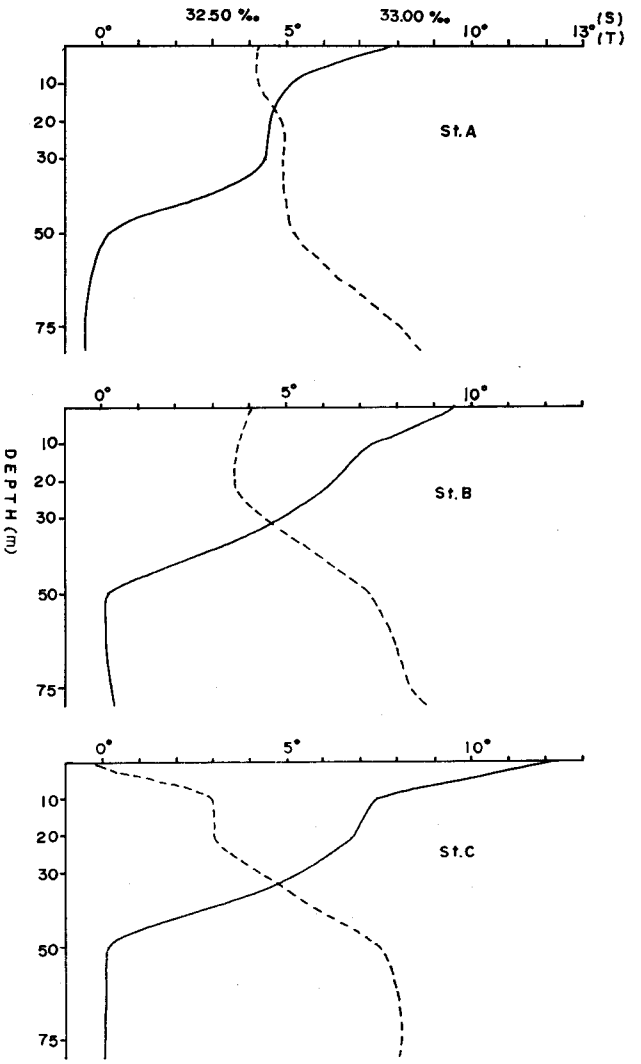

Fig. 5. Horizontal distribution of temperature and salinity at each station

station is the conspicuous change of temperature and salinity. Surface temperature fluctuated between 7.0°–7.8°C at Sta. A, 8.7°–9.6°C at Sta. B and 12.3°–12.8°C at Sta. C. during 24 hours. At Sta. B, where two waters converge, the change of temperature was excessive.

2. Diurnal change of the catch

Table 1 shows the catch data of repeated fishing during one day in the three stations. At Sta. A the catch of chum salmon accounted for 53% and pink salmon accounted for 38% of the total, but Sta. B and Sta. C catch percent of pink salmon were predominated. In late July the catch of coho salmon increased. Not only

the mesh size of the net was incongruous for the fish body but also the catch of sockeye salmon were rather scarce in abundance. Further, the catch percent of the total at each station also showed below 10%. The relative catch between each series catch of the total during one day was calculated by the following formula and given as hitograms in Fig. 6–9.

$$Cr = \frac{CE}{CM}$$

$$CM = \frac{\text{Total catch at a station}}{\text{Total time of net set at a station}}$$

$$CE = \frac{\text{Catch at a series}}{\text{Time of net set at a series}}$$

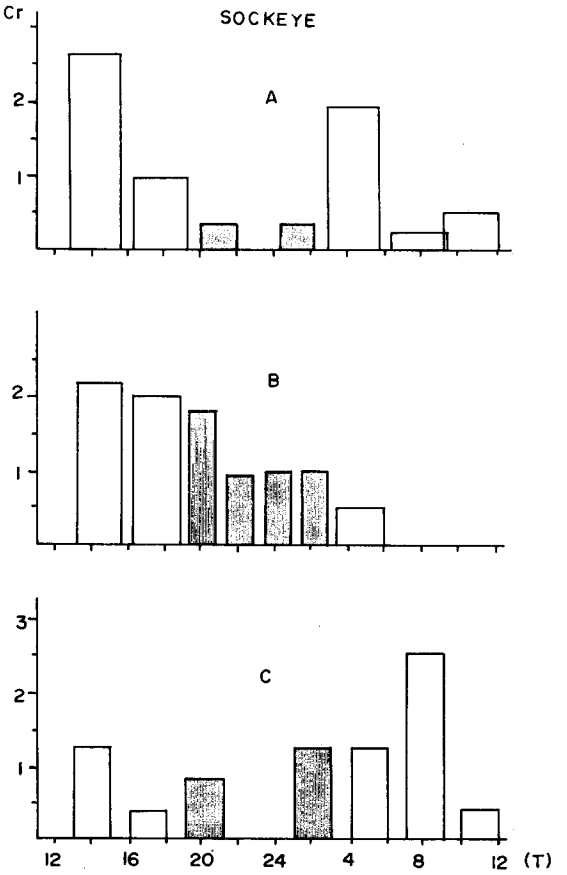

Fig. 6. Fluctuation of sockeye salmon catch at each station during a day

$$Cr = \frac{\text{C.P.U.E. of each fishing series}}{\text{C.P.U.E.E. of the station}}$$

T = Time

sockeye salmon:

At Sta. A the catch was highest in the afternoon, and then decreased until midnight, while in the next morning the catch increased again after sunrise. Sta. B also had its highest catch done in the afternoon, thereafter it decreased gradually and the next morning after 6 o'clock the catch became nil at two times of fishing. At Sta. C although the highest catch was done the mext morning after sunrise, it had been nil at midnight. Regular fluctuation of relative catch at three hours' interval during a day are characteristic phenomena at this station (Fig. 6).

Consequently, it is almost impossible to find the common feature in the flucutation of the catch among three stations. However it seems that the highest catch tends to occur in daytime clearly noticed at each station.

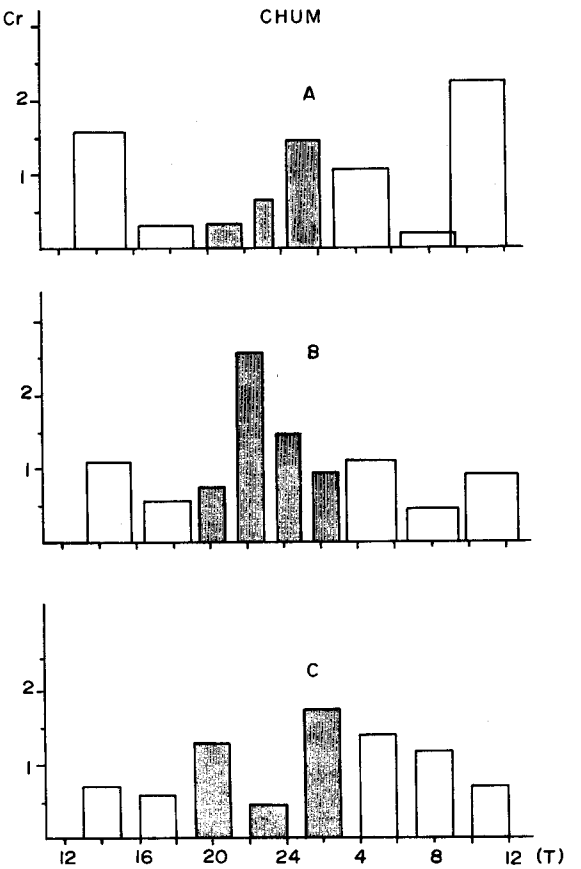

Fig. 7. Fluctuation of chum slamon catch at each station during a day
Foot note: same as in Fig. 6

Chum salmon:

Relative catch predominated during daytime, but a peak was shown at night at Sta. A. Similarily, At Sta. B a high catch was observed at night before midnight and the relative day catch was not remarkable. At Sta. C two predominant catches were found at night and the lowest catch was shown at midnight (Fig. 7). Although chum salmon were caught by the gill-net every fishing time during the day, the common feature in the flucutation of the catch could not be found at three stations.

Pink salmon:

Although the low peak of the catch showed in the afternoon, two peaks of catch in the night were conspicuous at Sta. A. The catch of pink salmon at Sta. B was the most abundant in three stations. A high catch showed at night from

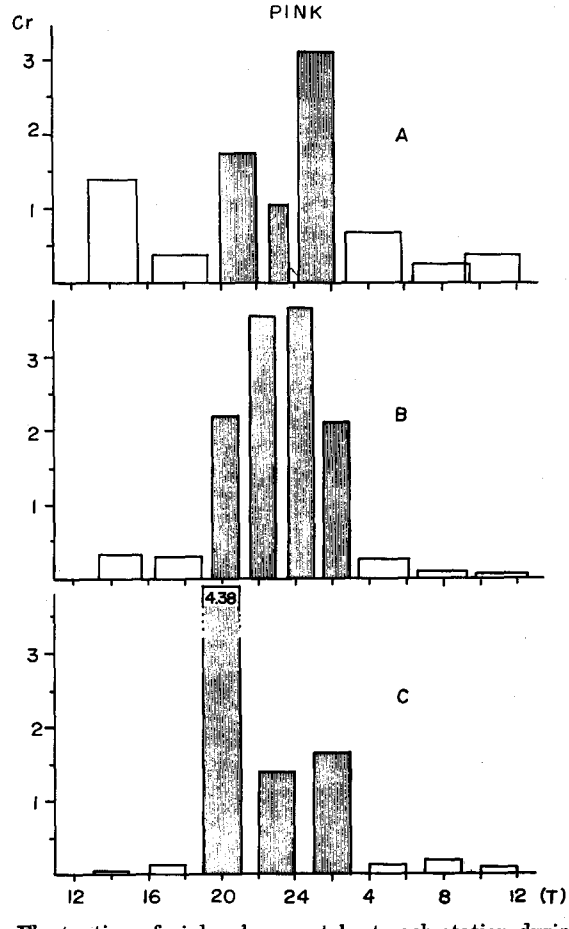

Fig. 8. Fluctuation of pink salmon catch at each station during a day
Foot note: same as in Fig. 6

sunset to sunrise and the catch during theday was very small. At Sta. C the relative night catch was abundant like at Sta. B, but at night two peaks of the catch predominated. The relative catch decreased temporarily at night like at Sta. A (Fig. 8). Pink salmon caught every fishing time looked like the catch of chum salmon but the abundance of catch was conspicuous at night contrarily to the catch of sockeye salmon.

Coho salmon:

In early July (Sta. A) coho salmon were not caught in the Okhotsk Sea. From the middle to late July the catch increased. Diurnal changes of the catch of coho salmon at Sta. B and Sta. C resembled in their fluctuation (Fig. 9). Those tendencies were almost the same in regard to the catch of pink salmon, that is, the catch concentrated at night and decreased relatively about midnight.

Diurnal changes of the catch of four species of salmon were interpreted above. But the timely periodicity of the movement was not found for each species. Nevertheless the catch of the pink and coho salmon at night and sockeye salmon in day time were found to be prevailing, whiles the catch of chum salmon did not show any characteristic feature in flucutation.

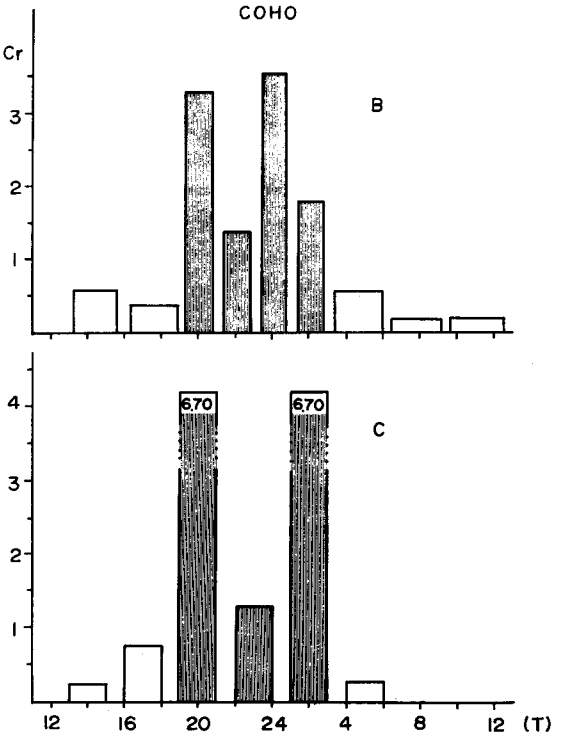

Fig. 9. Flucutuation of coho salmon catch at each station during a day
Foot note: same as in Fig. 6

3. Catch in daytime and nighttime

1) There are differences in the intensity of illumination on the surface between daytime and nighttime. Therefore the conditions of the encounter would differ between the movement of the fish and the laid net. Catch data were divided into two groups according to day and night and relative catch was calculated respectively by the above mentioned formula. Each value was plotted in the midst of time of the duration of the net set (Fig. 10). According to the figure, the fluctuations of catch between fish species in each station were discussed.

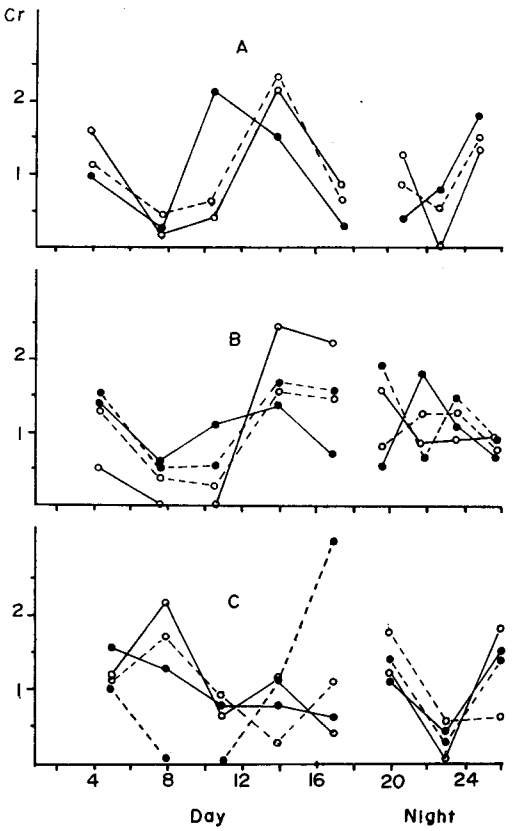

Fig. 10. Flucutation of the relative catch of each species in daytime and nighttime
Sockeye ○——○ chum •——• pink ○····○ Coho •····•

Catch in daytime:

The fluctuation of sockeye and pink salmon had high congruity with one another. However, the catch peak of chum salmon at Sta. A. was found to be about four hours earier than that of pink and sockeye salmon. At Sta. B the fluctuation of the catch had congruity among four species although the density of the catch was different; especially the catch peak at 14 o'clock were similar.

The fluctuation of the catch at Sta. C was different from the other stations the congruity of the fluctuation among four species were not found in daytime, although the tendencies of sockeye and pink salmon were alike.

Catch at nighttime

At Sta. A there was found a similar tendency of the catch fluctuation of sockeye and pink salmon, but chum salmon differed from those two species. The congruity of the catch was found also among the four species of salmon at Sta. C. At Sta. B, the congruity in the flucutation of the catch between species could not be found.

According to the results, the fluctuation of the catch at the same station had considerable congruity between salmon species and also between the different localities. These phenomena would suggest a common feature of the behaviour of all salmon species.

2) C.P.U.E. in daytime and nighttime

The C.P.U.E. were classified into two groups in daytime and nighttime as shown in table 2. Although the C.P.U.E. of sockeye salmon at Sta. B were more predominant at night than in the day, the other two stations exceeded those of the day catch. Chum salmon catch predominated during the day at Sta. A, but the other stations it was higher at night. There was a slight difference in the mean of the C. P. U. E. of chum salmon. Pink and coho salmon predominated evidently at night at every station especially at Sta. B and Sta. C. Thus the C.P.U.E. of sockeye salmon during the day, pink and coho salmon at night were

Table 2. C.P.U.E. during the day and at night at each station

Fishing time	Day catch							Night catch				
Station	Series	1	2	6	7	8	Mean	3	4	5		Mean
A	Sockeye	3.67	1.33	2.67	0.33	0.67	1.73	0.47	0	0.50		0.39
	Chum	12.00	2.33	8.00	1.33	17.00	8.13	2.37	4.85	11.00		6.21
	Pink	2.30	0.60	1.10	0.40	0.60	3.33	0.82	0.50	1.46		11.65
	Series	1	2	7	8	9	Mean	3	4	5	6	Mean
B	Sockeye	1.62	1.49	0.37	0	0	0.68	1.35	0.70	0.73	0.73	0.88
	Chum	6.07	2.99	5.93	2.53	4.94	4.45	4.05	13.99	8.03	5.11	7.79
	Pink	13.77	13.06	11.48	3.25	2.28	8.68	95.27	152.45	157.66	91.24	123.89
	Coho	1.21	0.75	1.11	0.36	0.38	0.75	6.76	2.80	7.30	3.65	5.13
	Series	1	2	6	7	8	Mean	3	4	5		Mean
C	Sockeye	1.50	0.50	1.50	3.00	0.50	1.40	1.00	0	1.50		0.83
	Chum	3.00	2.50	6.00	5.00	3.00	3.90	5.50	2.00	7.50		5.00
	Pink	0.50	2.50	2.50	4.00	2.00	2.30	8.75	28.00	33.00		49.50
	Coho	0.50	1.50	0.50	0	0	0.50	13.00	2.50	13.00		9.50

obvious, but the conspicuous feature of the catch of chum salmon in daytime or nighttime was not found.

3) Changes of the fork length at each fishing time

The change of fork length at fishing time was discussed in regard to chum and pink salmon which were caught abundantly throughout these experiments. The mean fork length in each series catch was plotted at midtime of the net set duration as shown in Fig. 11, and also the frequency distribution of the fork length as shown in Tables 3, 4, and 5. A large sized chum salmon was found in the morning after sunrise. It became smaller in the afternoon and the smallest at night. The fork length of pink salmon did not show so obvious a tendency as for chum salmon. As the data of sockeye and coho salmon were very few, our discussion does not dealt with these two species.

4. Phenomena of decrease of the catch at night

We pointed out in a previous paper[9] that a temporal decrease of the catch was often found during nocturnal fishing. It is assumed that such phenomena would be caused by the movement of salmon on account of either temporal submergence to midwater or the slow moving of the fish at night. In order to confirm the movement of the fish at night, the authors made their fishing experiments by 5 *tans* of double-depth net, as shown in Fig. 2, at the same time the surface net fishing was carried. Data were collected from repeated fishing operations independently from the catch of surface net. The number of the catch caught by

Table 3. Frequency distribution of fork length of chum salmon at St. A

F. L. (cm)	Series							
	1	2	3	4	5	6	7	8
49				1	1			
50	3				1			
51	1		1		1			
52	1	1			1			
53	2				1			
54			1					1
55				1	1	2		
56	2	1		1	2			1
57	3	1	1		2			2
58	5	1	1	1	3	3		5
59	2	2	1		2	5		4
60	2	1			1	2	1	5
61	3				2	3		1
62	2							2
63	1				1	2	1	
64					1		1	3
65	3				1	3		1
66				1	1	2		1
67						1	1	2
67								1
71						1		
75								1

Table 4. Frequency distribution of fork length of chum salmon at St. B

F. L. (cm)	Series								
	1	2	3	4	5	6	7	8	9
46			1						
47									
48									
49					1				
50	1	1		1	1				
51	1	1	1		1				
52			1	2		1		2	
53		1		2					1
54	2			1	3				
55		1		2			1		1
56	1			1					
57	1	1				1	1		2
58							1		1
59	2				1	2			2
60	1	1		4			2		1
61	1	1	1	3			1		2
62			1	2			3	1	1
63	2			1	1		1	1	1
64				1	1	1	1	3	
65					2		3		
66		1	1				2		
67									
68	2								
69						1			1

Table 5. Frequency distribution of fork length of chum salmon at St. C

F. L. (cm)	Series							
	1	2	3	4	5	6	7	8
49					1		1	
50								
51					1		1	
52						1	1	
53	1	1	1					
54					2	1	1	
55			1		1	1	1	1
56			1		1			1
57	1	1		2	1	1	1	2
58			2	1		1	1	1
59		1	2	1	1	1		
60	1	1				1		
61					1		3	
62					1	2		
63					2	2		
64	1				2	1		
65	1							
66	1	1				1		
67								
68								
69								
70			1					

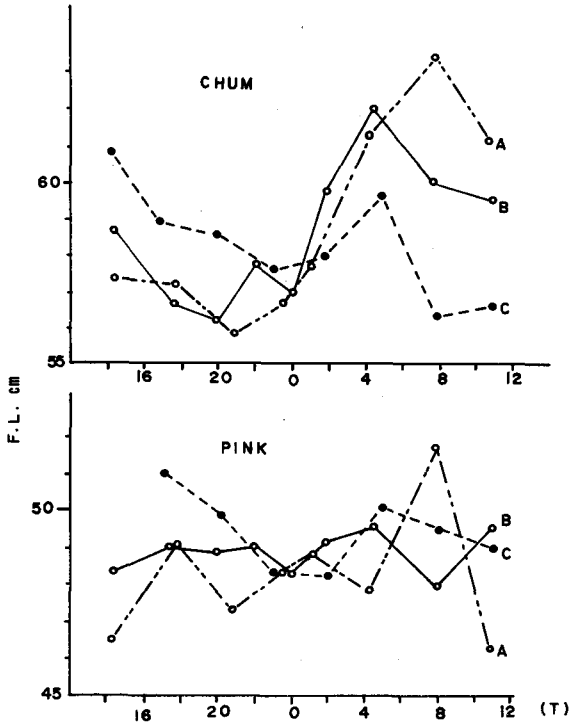

Fig. 11. Diurnal change of fork length of chum and pink salmon schools

Table 6. Relation between the catch within the same time of surface net and double depth net converted into 15 tans of nets

St.	Series	Depth of net	Sockeye	Chum	Pink	Coho
A	2	0～ 6	4	6	6	
		6～12	0	3	0	
	3	0～ 6	1	5	20	
		6～12	0	0	6	
	5	0～ 6	1	22	34	
		6～12	0	12	3	
B	7	0～ 6	1	16	31	3
		6～12	0	0	6	0
C	3	0～ 6	2	11	175	26
		6～12	0	0	21	15
	5	0～ 6	3	15	66	25
		6～12	0	0	3	3
	6	0～ 6	3	12	5	0
		6～12	0	0	15	3

double-depth net were converted into 15 *tans* of surface net (Table 6). At Sta. A chum and pink salmon were caught in the fishings of No. 2, 3 and 5 series. At Sta. B pink salmon were caught only in the fishing of No. 7 series. At Sta. C pink and coho salmon were caught in the fishing of No. 3, 5 and 6 series. Sockeye salmon were not caught throughout any experiment. If the school of salmon submerged to midwater at night, the decreasing catch of the surface net would correspond to the increasing of the double-depth net. Nevertheless such relationship between the catch of those two sorts of nets were not found. Consequently it might be asserted that the phenomena of decreasing catch at night would not be caused by the movement of fish sumberging to midwater. Probably such phenomena would be caused by the slow or perturbed direction of the fish.

Discussion

We stated above that surface catch of mature sockeye salmon were predominating in daytime in the Okhotsk Sea, but Suzuki[10] reported the same feature on immature sockeye salmon in the Aleutian Sea Area. According to the results of the investigation conducted by J.I. Manzer[8] these feature were not always apparent. It would be due to the differences of oceanographic conditions. The main feature of the predominance of pink and coho salmon at night is that these two species spend their maturing life in the sea one year after leaving the native rivers. Surface distribution of chum salmon, either daytime or nighttime, did not show any notable feature. The latter case, it is presumed, could be due to the age distribution of this school of fish, the development of their maturity, sex distinction and their feeding time, etc. Although the six hour's interval of abundant catch of sockeye salmon at St. C was considerable, another fish species had not the timely periodicity of abundance found on the surface.

Ogaki et al.[11] observed the phenomena of internal wave at the west coast off Kamchatka Peninshula after the data provided by continuous oceanographic observation. They stated that there were two types of internal currents to be found, that is, a long period current of 1–0.5 days, a short one of 4–7 hours, and the 4 hours' period was especially excellent. They also reported that the phenomena would be closely related with salmon gill-net fishing. Due to the phenomena of internal wave, temperature and salinity changed vertically, so that the swiming layer of salmon could probably be affected.

It is presumed that the catch changes during daytime in regard to sockeye and pink salmon at Sta. A, four species at Sta. B show considerable congruity caused by these physical phenomena. Hence, fising experiments and environmental surveys must be carried out simultaneously. As shown in Fig. 6–9 the characteristic feature of the catch decreasing in the middle of the night were often similarly noticed in each fish species of salmon. It is assumed that after sunset, salmon

move briskly during the ascending process to the surface, thereafter slow down and swim confusedly, but from midnight until sunrise, salmon move briskly again in the descending process to midwater. All of a sudden, the fish started swimming randomly on the surface while falling off the gill-net during the hauling or when the ship shifted her position in the midst of the night. These phenomena indicated that salmon do not descent temporarily to midwater but move slowly at night. It requires the diurnal wave of environmental feature and ecological chracters to study the diurnal movemant of salmon.

Summery

1. To study the diurnal movement of salmon, repeated fishing operations were carried out in the Okhotsk Sea in July, 1967. Resulting from the changes of the catch, the movement of salmon was discussed.
2. Sockeye salmon catch, predominating on the surface during the day, while at night becomes minimum.
3 Chum salmon were caught every fishing time during the day. But no characteristic movement neither in daytime nor at night could be noticed. Large size fish appear in the morning after sunrise and smaller fish at night.
4. Pink salmon catch predominated both after sunset and before sunrise but midnight the catch fell considerably. Pink salmon as well as chum salmon were caught every fishing time during the day
5. The movement of coho salmon resembles to that of pink salmon considerably.
6. At a same station the movement of salmon between different species present considerable congruity: and it was the same also in different localities.
7. It is presumed that catch phemomena decreasing temporarily at night, would be due to the disturbance in the swimming direction and the slowmoving of the fish.
8. The phenomena of internal wave suggest a close relation to the diurnal movement of salmon in the Okhotsk Sea.

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