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Vertical Movement of Chum Salmon, *Oncorhynchus keta*, in the western North Pacific Ocean as Determined by a Depth-recording Archival Tag

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ABSTRACT

The vertical movement of a chum salmon, *Oncorhynchus keta*, returning to Japan, was examined using a depth-recording archival tag in the western North Pacific Ocean. The chum salmon showed clear diel vertical movements, with an average swimming depth of 12.8 m during daytime and 4.8 m at nighttime. The chum salmon spent 48% of the daytime and 85% of the night time in the upper 10 m, 30% of the day and 10% at night in the 10-20 m layer, and 20% of the daytime and 5% of the night time in the 20-60 m depth layer. This strong surface preference may be one of the factors limiting the carrying capacity of salmon in the North Pacific Ocean.

INTRODUCTION

The swimming behavior of Pacific salmon has previously been studied by ultrasonic telemetry, which provides information on the horizontal and vertical movements of salmon in the ocean [1-8]. However, the maximum tracking times were very limited and ranged from 54 h for pink salmon to 133 h for coho salmon[7], chiefly due to the development of poor weather conditions during tracking in the ocean. On the other hand, archival (data storage) tags provide information on salmon movements over much longer periods.

The present study describes the vertical movements of a chum salmon in the western North Pacific Ocean using a depth-recording archival tag over a 23 day period and compares the results with previous findings obtained by ultrasonic telemetry.

METHODS

Chum salmon were caught by surface longline aboard the Japanese salmon research vessel *Hokuho maru* (46 m long, 386 GT weight) between

6-27 September 1994 in the western North Pacific Ocean, near the Kuril Islands (Fig. 1). In addition to ordinary disc tagging experiments, 8 chum salmon were tagged with an archival tag and then released on 6 September at 46 05'N, 152 10'E, and similarly tagged 5 chum salmon were released on 7 September at 45 30'N, 153 'E. These fish ranged from 550 to 696 mm in fork length and ocean age 4 or 5 years.

The depth sensing (pressure-sensitive) archival tag (120 mm long x 15 mm diameter, Alec Electronics Co. Ltd., Japan) weighed 30 g in water, and was attached externally. Four rubber bands (two in front and two in the back) were fastened around the archival tag, and two nylon cable ties (Dennison Cable Tie Product, Dennison Transoceanic Corp., Tokyo) were threaded through the rubber bands at each end of the tag. The archival tag was mounted to the fish by running the cable ties through the musculature immediately anterior to the dorsal fin. At the time of tag attachment, fork length was measured and a few scales were taken for age determination. The fish were out of the water for approximately 1 min during this procedure, and we did not use anesthesia. The fish were allowed 10-15 min to calm down before release, following the procedures of Ogura and Ishida [8].

One chum salmon fitted with archival tag was recovered from a set net at Shari, on the Okhotsk coast of Hokkaido (44 09'N, 145 07'E) on 12 October, 1994, 36 days after release on 6 September. This fish was 582 mm in fork length and age 4 at release.

The archival tag stored information on swimming depth every minute, so 1440 data points were accumulated per day. These data were used for analysis of the vertical distribution of the chum with time, and determination of the average depth. Daytime and nighttime were divided at the times of local sunrise and sunset, respectively.

RESULTS

For 3 days after release (6-8 September), the chum salmon swam deeper at nighttime (mean=13-16m) than during daytime (mean=8-12m). However, by the fourth day the chum salmon expressed clear diel differences in depth, with average depth during the day (mean=13 m) greater than at night (mean =5 m, $P<0.01$) (Table 1). Minimum swimming depth was near the surface (0.1 m) and maximum depth was 63.2 m (Fig.2).

Based on average vertical movements, the chum salmon stayed in the 5 m depth layer for most of the night, and began to descend at 3 A.M., before local sunrise (4:30 A.M.). The chum salmon reached the 15 m depth layer by 7 A.M. and remained there until it began a gradual ascent at 13:00, well before sunset. The fish reached the 5 m depth layer at sunset. On average, the overall diel cycle can be characterized as 9 hrs spent in the 5 m depth layer, 4 hrs descending, 6 hrs at the 15 m depth layer, and 5 hrs ascending (Fig. 3). Thus the average extent of the vertical migration was only 10m. The chum salmon spent 48% of the day and 85% at night in the upper 10 m, 30% of the day and 10% of the night in the 10-20 m depth layer, and 20% of the day and 5% of the night in the 20-60 m depth layer (Fig. 4).

DISCUSSION

The most important finding in this study was that the chum salmon showed a very strong surface preference and a stable diel vertical movement. This movement was comparable with those found in previous studies in coastal waters off Hokkaido and Kuril Islands [1-8]. Diel vertical migration in fishes is thought to be a result of the combined effects of several selective forces, including predator avoidance, foraging efficiency, and bioenergetic efficiency [9].

In the North Pacific Ocean, predators of Pacific salmon include the hagfish (*Polistotrema stoutii*), lamprey (*Entosphenus tridentatus*), the salmon or mackerel shark (*Lamna ditropis*), fur seal (*Callorhinus ursinus*), sea lion (*Eumetopis jubata*), harbour seal (*Phoca vitulina*), fin whale (*Balaenoptera physalus*), humpback whale (*Megaptera nodosa*), killer whale (*Orcinus orca*), and beluga (*Delphinapterus leucas*) [10]. Dall's porpoise, *Phocoenoides dalli*, are not identified as a predator for salmon, but an avoidance movement of chum salmon from Dall's porpoise was observed in coastal waters off Hokkaido. When chum salmon encountered the Dall's porpoise over deep waters (deeper than 100 m), salmon usually remained at the surface, but those that came across the porpoise while in shallower waters tended to dive quickly, and steeply, to the bottom [11]. However, these types of predator avoidance movements are not directly related to the diel cycle, so they likely do not play a strong selective role in the development of a diel vertical movement in chum salmon.

The dominant food organisms consumed by chum salmon in the open ocean are amphipods, euphausiids, pteropods, fishes and, to a lesser extent, copepods. The stomachs of chum frequently contain unidentifiable material, which may be a mixture of gelatinous forms that are quickly digested relative to most crustacean, mollusk or fish prey [12]. It is also suggested that chum salmon feed opportunistically at the surface on aggregations of prey such as polychaetes, euphausiids, and gelatinous zooplankton [13]. Chum salmon in the western North Pacific also feed on several food items such as Japanese anchovy (*Engraulis japonicus*) and euphausiids[14]. A strong surface preference of chum salmon may increase foraging efficiency, because these food organisms usually are either distributed in or migrate to surface waters during the night.

In the Bering Sea, sockeye, chum, and pink salmon showed strong surface preferences in summer. Also chum salmon did not show a significant difference in swimming depth between daytime and night time [8]. However, near coastal waters off the Kuril Islands, Hokkaido, and Honshu in autumn, chum salmon showed a strong surface preference and a significant difference in swimming depth between daytime and night time [1-6]. One of the possible explanations is the difference of water temperature between two area and season. Sea surface temperature was about 7.0C in the Bering Sea in summer, although it was above 10-12C near coastal waters off the Kuril Islands in autumn (Fig. 5). Therefore, chum salmon can stay in the surface layers in the Bering Sea, but near coastal waters off the Kuril Islands chum salmon swim in 15 m during daytime, because the water temperatures at 15 m depth was 1-2 C lower than that in surface layer. Vertical movements of chum to the lower temperature of the deep layer during the day may reduce metabolic rates and increase bioenergetic efficiency. A strong night time surface preference combined with diel vertical movements could possibly be related to maximization of food intake rates by exploiting the high prey densities of the surface layer while minimizing metabolic rates during the daytime by moving to the lower temperatures of the deeper layer. This may be one of the reasons to limit the carrying capacity of salmon in the North Pacific Ocean.

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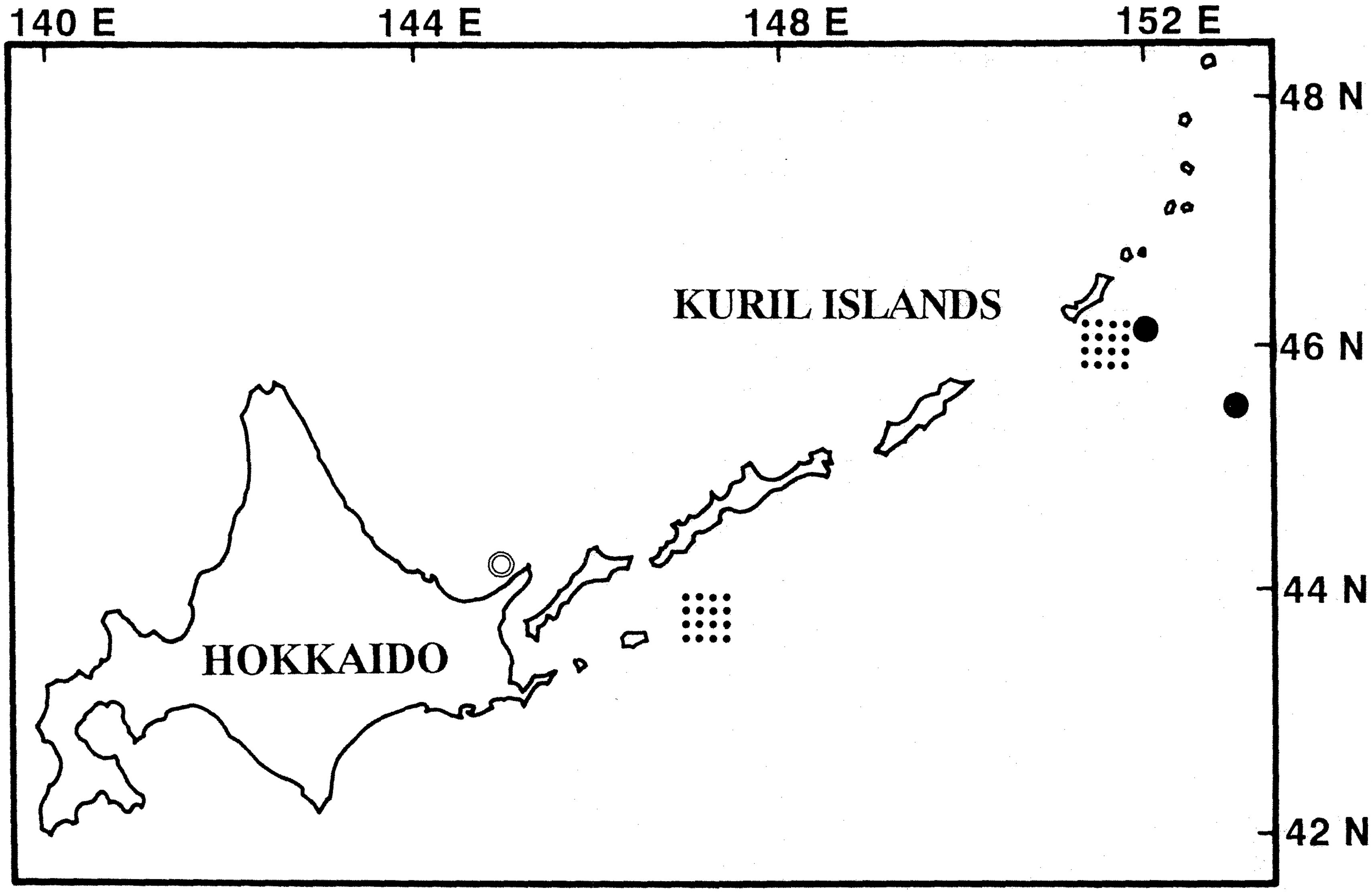

Fig. 1. Closed circles indicate release locations open circle indicates recovery locations for chum salmon with archival tag. Dotted areas indicate locations for XBT observation.

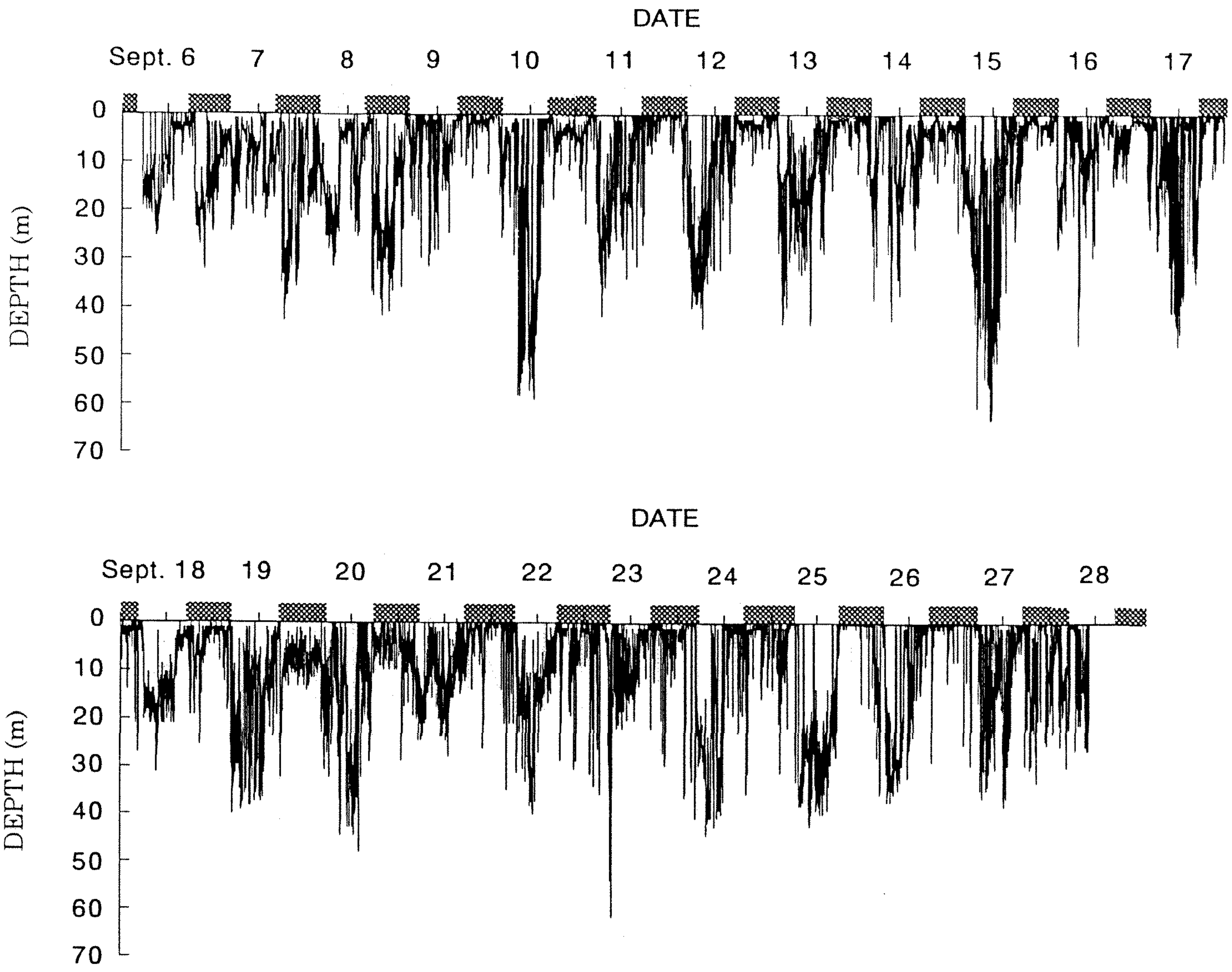

Fig. 2. Vertical movement of chum salmon from September 6 to 28, 1994. Shaded time zones indicate nighttime.

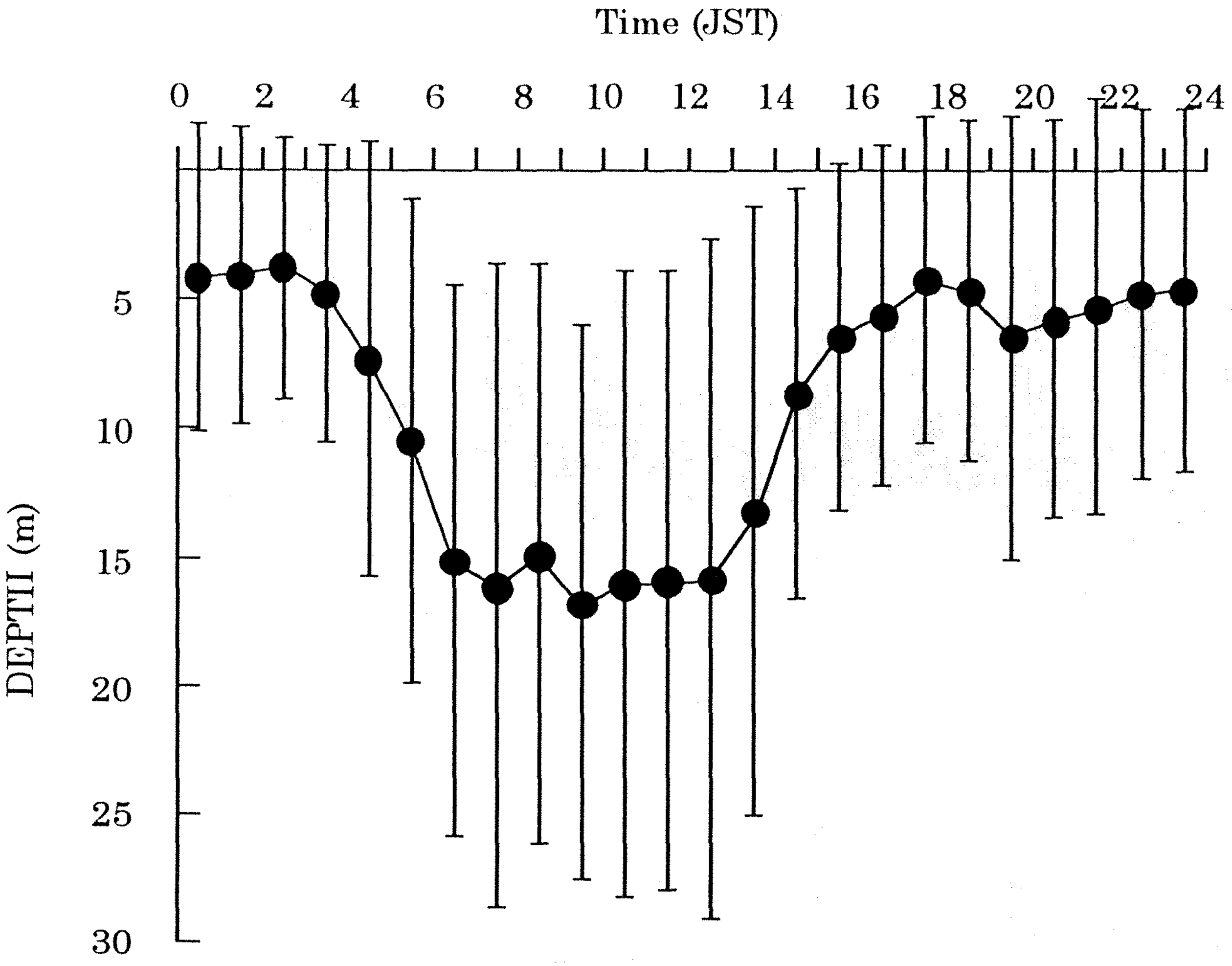

Fig. 3. Average vertical movement of chum salmon.

The average depth during 1 hr. Values are means and standard deviations.

JST Japan Standard time.

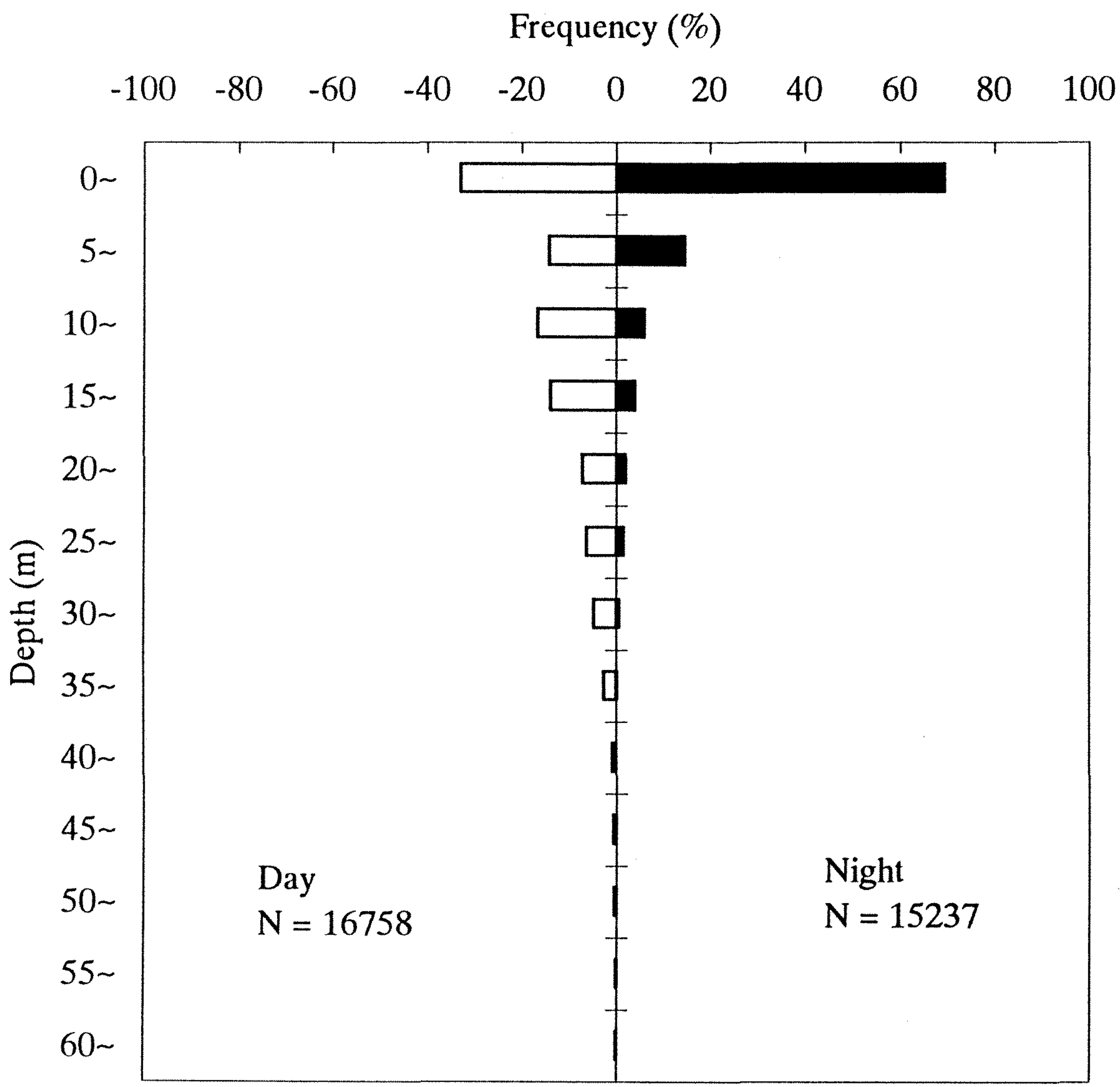

Fig. 4. Depth distributions expressed as a percentage of records averaged during 1 min of chum salmon.

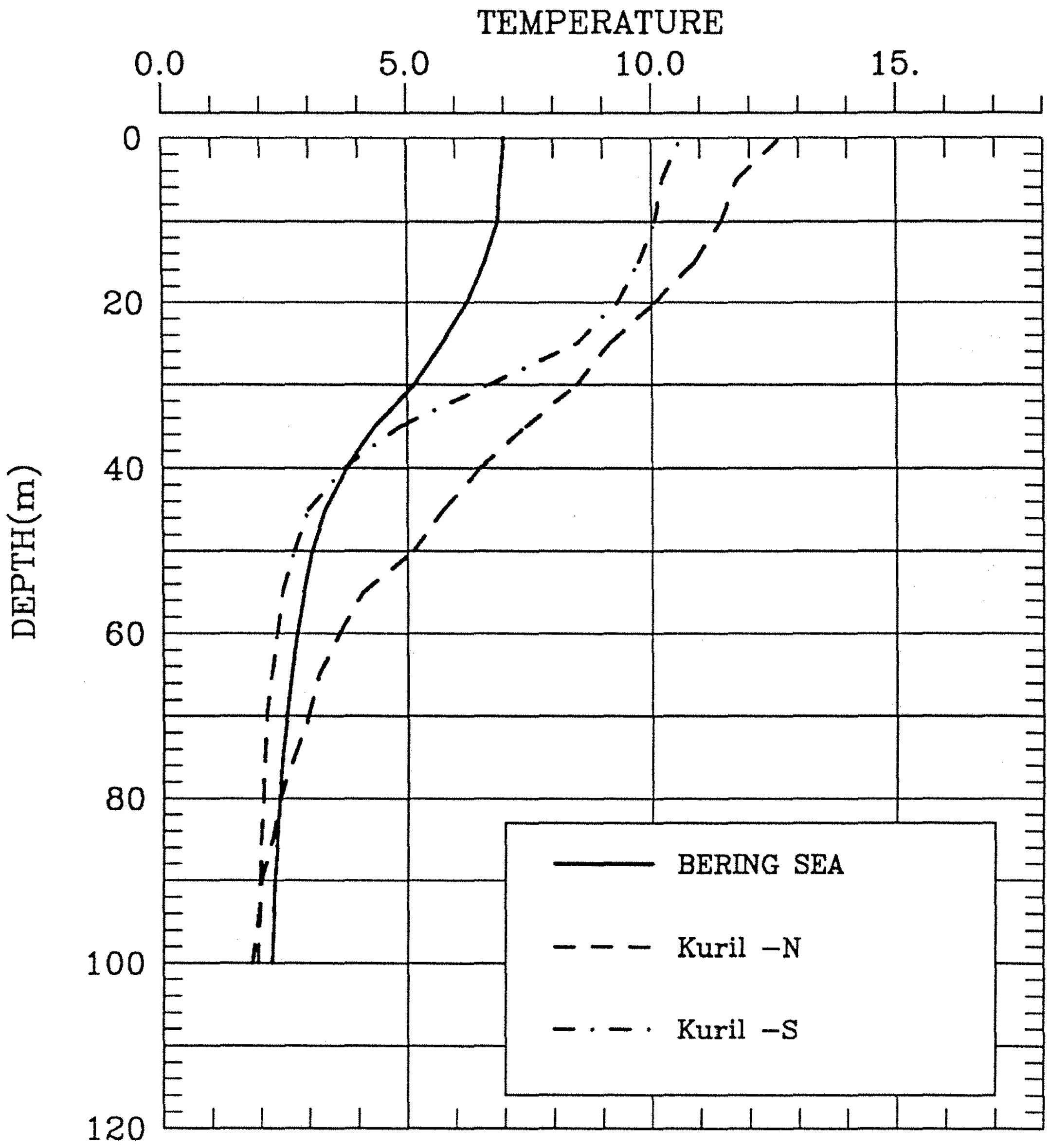

Fig. 5. Vertical profiles of water temperature in the Bering Sea in summer and waters off the Kuril Islands in autumn.

Table 1. Average swimming depth of chum salmon during day and night for each date.

Date	Average swimming depth			
	Day		Night	
	Mean	(S. D.)	Mean	(S. D.)
Sept. 6	9.63	(7.04)	13.10	(8.84)
Sept. 7	7.88	(5.06)	14.80	(10.66)
Sept. 8	11.64	(8.61)	15.79	(10.22)
Sept. 9	5.02	(5.57)	5.21	(7.64)
Sept. 10	17.37	(18.18)	3.00	(2.73)
Sept. 11	12.34	(10.30)	2.14	(3.05)
Sept. 12	15.05	(11.85)	2.30	(3.06)
Sept. 13	15.07	(8.41)	1.89	(3.13)
Sept. 14	8.86	(8.36)	3.00	(2.98)
Sept. 15	21.62	(14.84)	3.69	(4.91)
Sept. 16	7.37	(7.00)	3.90	(3.85)
Sept. 17	12.29	(12.50)	2.10	(4.38)
Sept. 18	11.98	(6.77)	3.98	(4.59)
Sept. 19	16.84	(10.26)	6.38	(5.45)
Sept. 20	15.69	(11.66)	5.85	(3.91)
Sept. 21	10.73	(5.76)	4.75	(4.57)
Sept. 22	12.71	(8.49)	3.43	(5.31)
Sept. 23	8.48	(9.22)	2.54	(5.41)
Sept. 24	15.90	(14.41)	3.63	(7.37)
Sept. 25	22.11	(11.80)	2.25	(4.23)
Sept. 26	12.77	(13.14)	2.36	(5.95)
Sept. 27	11.90	(10.00)	4.02	(6.86)
Sept. 28	8.79	(7.91)	6.66	(6.65)
Overall average	12.77	(11.26)	4.83	(6.91)