SALMON OF THE NORTH PACIFIC OCEAN—PART III
A REVIEW OF THE LIFE HISTORY OF NORTH PACIFIC SALMON
2. PINK SALMON IN THE FAR EAST

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INTRODUCTION

The pink salmon, *Oncorhynchus gorbuscha* (Walbaum), is one of the most important commercial fish species in the northern areas of Asia. Since all pink salmon have a life span of two years, there is no inter-breeding between populations spawning in odd-numbered years and those spawning in even-numbered years. Hence, even in the same area, two populations spawning in alternate years may have followed different courses in the history of the species. Generally speaking, with salmon, there are more or less proportional relationships between the quantities of eggs spawned and the numbers of mature fish resulting therefrom. Therefore, once the level of abundance has become very high for one population and very low for another in the same area, such difference in abundance tends to be maintained for a considerable period of time, but in most cases the relationship is reversed sooner or later. There are certain examples, however, in which the same quantitative relationships between the two populations have been maintained from the earliest period of exploitation to the present time. It is possible that some hereditary factors may be involved in such cases.

As with all other species of Pacific salmon, pink salmon spawn in streams, go downstream as young, grow in the ocean, return to streams for spawning as sexual maturity approaches, and die after spawning, without exception. If we assume that the species of the genus *Oncorhynchus* originated in fresh water and adapted themselves to life in the ocean during the course of evolution, pink salmon may be considered the species of *Oncorhynchus* best adapted to oceanic life, as was pointed out by Rounsefell (1958) and Birman (1953).

The periods of pink salmon life history prior to their entrance into the sea and after their return to coastal waters have been studied intensively by many Russian scientists, such as P. A. Dvinin, I. I. Kuznetsov, I. F. Pravdin, R. S. Semko, A. G. Smirnov, V. K. Soldatov, etc. Particularly, Kaganovskii (1949) reviewed biological knowledge of pink salmon, including the questions of their offshore distribution and quantitative fluctuation. His review is excellent and covers most of the problems dealt with in this paper. Hence, many of the descriptions which follow are from his paper. Semko (1954), too, gives results of his laborious studies and observations on the pink salmon of West Kamchatka, and his paper is full of valuable observations and suggestions. Only a few biological studies of the freshwater period of pink salmon life history have been made in Japan. This is because salmon studies in Japan have been carried out mostly by scientists associated with hatcheries and their activities have been concentrated on the study of autumn chum salmon. However, studies by such hatchery staff members as Sano and Kobayashi (1953) and Sakano (1956) regarding the transplantation of pink salmon eggs and the marking of fry from the transplanted eggs are worth mentioning.

There was little study of pink salmon ecology in the ocean prior to 1955. N. V. Milovidova-Dubrovskaia, P. A. Dvinin, etc., reported on pink salmon appearing in coastal waters. Since the commencement of joint investigations for the International North Pacific Fisheries Commission in 1955 and offshore investigations by Russian scientists such as I. B. Birman, P. A. Dvinin, etc., in the same year, the ecology of pink salmon in the ocean has been revealed to a great extent.

SPAWNING HABITS

Spawning Seasons and Spawning Grounds

Pink salmon grow in offshore waters, approach the coast with fairly well-developed gonads, stay in estuarine waters for several days or more, and then enter streams. They do not spawn immediately after their entrance into streams, but after different lengths of time, depending on the condition of their gonads.

Many factors affect the timing of their coastal migration, upstream migration and spawning, and the actual places of spawning. Basically, these character-

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istics have been acquired by the species through adaptation in the course of evolution and are related to the peculiarities of their spawning streams. We must, however, obtain such factual data as the geographical differences in these characteristics, the extent to which physical and chemical environmental factors are affecting the spawning characteristics, and the changes in growth, maturity and distribution of fish over the spawning grounds associated with changes in stock size. The geographical distribution of spawning grounds and the periods of spawning will be discussed in detail in another part of this comprehensive report on salmon.

The timing of pink salmon coastal migration for spawning tends to be earlier in southern areas than in northern areas. Pink salmon migrate into coastal waters during the period from late June to July in Primore and the Amur, but they approach the coast during July and August in West Kamchatka. However, they approach the coast mostly in July in the northernmost areas, namely East Kamchatka. In Sakhalin, Hokkaido and the southern Kurils, they enter coastal waters during the period from June to September. Particularly on the Okhotsk Sea side of Hokkaido, most of the pink salmon approach the coast during August and September. Accordingly, it appears that there may be two groups of pink salmon in these southern areas, early runs and late runs, the former approaching the coast earlier than the pink salmon in northern areas and the latter approaching the coast later than those in northern areas. This seems to be analogous to the differentiation of autumn and summer chum salmon. Spawning, too, tends to occur earlier in southern than in northern areas. Thus, pink salmon spawn in mid-August in Primore, in late July through early September in the Amur, in mid-July through late September in Sakhalin and in early August through mid-October in West Kamchatka.

The length of time between their coastal migration and entrance into the spawning stream varies from stream to stream. The Tokoro River and the Iwaobetsu River are closely located on the Okhotsk Sea coast of Hokkaido.* In the Tokoro River, the upstream migration of pink salmon through the Hashino Catching Station (in the lower reaches) is observed from late July through early October, with the peak in late August, while in the Iwaobetsu River, upstream migration takes place from mid-August through late October, with the peak in late September. One of the factors contributing to such differences seems to be the topography of the rivers. The Tokoro River is a relatively large stream opening near the tip of a cape and the influence of fresh water from this stream extends fairly far offshore. On the other hand, the Iwaobetsu River is a small, short stream. Pink salmon approach the coast in the vicinity of the Iwaobetsu River, but stay in estuarine waters until their gonads become fairly ripe. Amur River autumn chum salmon or Yukon River chum salmon are extremely well adapted, both morphologically and physiologically, to the peculiarities of their spawning streams, but such examples are not known for Asian pink salmon. Birman (1954) pointed out that the difference in water temperature encountered by pink salmon migrating from the ocean to the Amur Firth and the main river, where temperatures are warmer, and then to spawning tributaries, where temperatures are again cold, is not less than 10°C each time. He also stated that although 1948 was a year of great pink salmon abundance in the Amur, pink salmon did not utilize spawning grounds in the upper reaches, but spawned in the lower reaches or in small tributaries to Amur Firth (which were not occupied by pink salmon in ordinary years), because the water temperature in Amur Firth was high in that year and pink salmon entering the river had gonads in very advanced stages of maturity, mostly near full maturation. Spawning usually extends to the upper reaches when the spawning population is large.

According to Kaganovskii (1949), the distance from the sea to the spawning grounds of a river utilized by pink salmon is associated not only with the length of the river but also with the abundance of spawning fish. In general, only the spawning grounds in the lower reaches are utilized in years of low abundance, but all spawning grounds in lower and upper reaches are occupied in years of high abundance. Even grounds not suitable for spawning are occupied when other grounds are fully utilized. The distance from the sea to the spawning grounds may also be affected by the degree of gonad maturity.

Dvinin (1952) states that in Sakhalin, too, both upper and lower reaches of streams are occupied by spawning pink salmon in years of high abundance and that even tributaries which would not be used under normal conditions are utilized. He also mentions that when spawning populations are large many fish die sometimes from high water temperatures and lack of dissolved oxygen caused by low water levels.

According to Semko (1939), when spawning populations are small and most fish are therefore large, pink salmon occupy areas with relatively great depths and rapid currents in the middle and lower reaches and do not visit shallow channels or springs. When

* *Ed. note:* See Appendix Figure 1 of the chum salmon section of this bulletin (p. 57).

spawning populations are large and the average size is therefore small, pink salmon occupy all streams and small tributaries from the lower to the upper reaches, including shallow areas with slow currents ; some even spawn in springs.

The distance between the river mouth and the uppermost spawning grounds is about 700 km in the main Amur River (between the river mouth and a place where the Khungari River joins the main stream) and more than 700 km in the Amgun River of the Amur system. Although there are pink salmon which go upstream to the uppermost reaches of the Bolshaia River, the largest stream system in West Kamchatka, the distance from the river mouth does not exceed 350 km. The distance is smaller in other streams. Pink salmon do not occupy all spawning grounds of a river system evenly. In large river systems, their main spawning grounds may even be limited to one tributary. For example, in the Amur system, pink salmon spawn mainly in the Amgun River, one of the tributaries, and in the Tumnin River of Primore they mainly spawn in one tributary, the Ulikae River.

One of the characteristics of pink salmon spawning is that the spawning grounds of lower reaches are preferred to those of upper reaches, when they are available. Such a characteristic is observed even in pink salmon populations of such a large river system as the Amur. This implies that pink salmon possess a high degree of adaptability in their spawning habits and that pink salmon is the species of *Oncorhynchus* most closely associated with the sea. Since pink salmon fry begin downstream migration as soon as they emerge from the stream beds, with little feeding in fresh water, it is advantageous to have spawning grounds in the lower reaches.

The differentiation in spawning periods of pink salmon in southern areas is an interesting biological problem, when compared with similar features observed for other species of *Oncorhynchus* and herring, but is not touched upon in this paper.

Spawning Beds

The spawning beds of pink salmon are formed in a more or less similar fashion in the streams of Asia. According to Kuznetsov (1928), pink salmon spawning beds are rather loosely formed in West Kamchatka and in the Amur River. Pink salmon spawn in streams with relatively slow currents and round gravel and sand, with a maximum depth of 22–28 or 30 cm ; and in streams with relatively rapid currents and gravel bottoms, with depths of 13–17 cm. They do not spawn where current velocity is very low, nor do they spawn in still water. According to Semko (1939), pink salmon spawn, in most cases, on bottoms consisting of medium sized gravel mixed with small quantities of sand, and, in exceptional cases, on bottoms consisting of sand mixed with mud.

The depth of spawning grounds is less than 90–100 cm, mostly 20–40 cm ; larger pink salmon tend to choose the deeper water for spawning. Typical hydrographic conditions on pink salmon spawning beds, as described by Krokhin and Krogius (1937) for the Bolshaia River, are: 0.3–0.6 m/sec current velocity, high oxygen content, low free carbonate content, and *p*H greater than 7.0.

According to Dvinin (1952), pink salmon in southern Sakhalin choose, under normal spawning conditions, stream beds consisting mainly of gravel of various sizes mixed with sand. The depth of water is usually 0.2–1 m, mostly around 0.5 m. Such conditions, however, are not necessarily chosen when spawning populations are excessive. When the distribution of spawning fish over spawning grounds was optimum, there was no spawning in waters shallower than 0.2 m, but when the spawning grounds were over-crowded, fish spawned in waters of a much wider depth range (0.1–1.2 m). The current velocity on spawning grounds is usually 0.4–0.8 m/sec, and water temperature ranges from 7° to 19°C. The dissolved oxygen content is 40–120% in terms of the degree of saturation at prevailing temperatures, and most frequently 70–80%. The free carbonate content averages 4–6 mg/l, and *p*H ranges from 6.8 to 8.0 and is usually higher than 7.0. The above values observed for pink salmon in southern Sakhalin generally resemble those observed for pink salmon in Kamchatka, except that Sakhalin pink salmon spawn in higher water temperatures than do Kamchatka pink salmon.

Spawning temperatures range from 5°C to 14°C and are most frequently 11.5–12°C in the Bolshaia River (Semko, 1939), and they range from 8.5°C to 15.6°C and are most frequently 9.2–13.7°C in the Amur River (Kuznetsov, 1928).

According to the observations in the Amur by Nikolskii and Soin (1954), pink salmon spawn in streams with higher current velocities than do other species of *Oncorhynchus*, and usually six to ten males accompany one female to secure the fertilization of eggs. The oxygen content in spawning beds is high, being close to that in water above the beds. According to their hypothesis, pink salmon eggs require higher concentrations of dissolved oxygen than eggs of other species of salmon, and this is associated with the smaller amounts of carotinoid pigments (which play an important role in egg respiration) found in pink salmon eggs than in eggs of other species of

TABLE 1. Variation in fecundity of pink salmon in even- and odd-numbered years in West Kamchatka (Kaganovskii, 1949).

Year	Fork length (cm)			Number of eggs			Ratio (no. of eggs/F.L.)	No. of specimens
	Min.	Max.	Mean	Min.	Max.	Mean		
1933	52.5	58.5	55.4	1450	2350	2020	36.4	20
1935	42.5	54.5	46.6	1000	2200	1546	33.1	67
1934	40.5	46.5	42.9	800	1800	1184	27.5*	25
1936	42.5	53.5	46.6	800	2000	1262	27.0	57

* This value is obtained by calculation using the data in the table and differs from that given in Table 10 of Kaganovskii (1949).

salmon.

According to Kaganovskii (1949), a female pink salmon deposits eggs usually in two or three nests placed at intervals of 25–30 cm, and these nests form one redd when covered by gravel. The shape and size of a redd varies, depending on the current velocity, quality and topography of the bottom, and other conditions. Many of the redds are oval or elliptic in shape, 2 to 5 m in length and 0.7–2 m in width. According to Taranets (1939), however, the length of a pink salmon redd is 1.18–1.32 m, and the width is 0.58–1.18 m.

Kuznetsov (1928) believes that normal spawning takes place when a spawning area of not less than 1.5–2 m^2 per pair of fish is available. When spawning grounds are poorly filled, a larger spawning area is allocated to a pair of fish, but when spawning grounds are over-crowded, an area of one square meter is occupied by 3–5 pairs or even 12–15 pairs of fish. Under such conditions, spawners arriving later dig up spawning redds made by earlier spawners. According to Dvinin (1952), pink salmon usually deposit eggs in two to three batches and occasionally in four batches. Accordingly, two or three nests are found in one redd. Eggs are embedded in gravel usually not deeper than 15–25 cm from the surface of the redd but occasionally they are found as deep as 30–45 cm from the surface.

Semko (1954) estimates that the amount of gravel moved by a pink salmon for spawning is approximately 100 kg and states that such removal of gravel is done by taking advantage of rapid currents. Usually, digging is done only by females.

The spawning grounds of pink salmon do not require the presence of ground water ; instead, spawning takes place in streams with rapid currents. This is considered to be a basis for their ability to occupy wide areas of streams for spawning.

EGGS AND FRY

According to Semko (1939), the fecundity of West Kamchatka pink salmon is from 1,300 to 2,300 eggs for a female of 42.5–58.5 cm in length (averaged over four years). According to Semko (1954), the seasonal average fecundity was between 1,286 eggs (1944) and 1,600 eggs (1946). According to Dvinin (1952), the average fecundity of pink salmon on the west coast of southern Sakhalin was 1,525 eggs with an average body length of 44.9 cm in 1946, and 1,576 eggs with an average length of 53.6 cm in 1947, the difference between these two years being very small. The fecundity was very low in 1948 on the west coast of Sakhalin. The average fecundity on the east coast of Sakhalin was 1,230 eggs in 1947 and 1,306 eggs in 1949. Vedenskii (1949) mentions that the average number of eggs carried by a female was 1,728–1,800 on Iturup (Etorofu) Island of the southern Kurils. Kaganovskii (1949) presented a table showing the year-to-year changes in the length and fecundity of West Kamchatka pink salmon and the ratio between the two, by using data collected by

TABLE 2. Variation in fecundity of Bolshaia River pink salmon in 1937–1943 (Kaganovskii, 1949).

Year	Fork length (cm)	No. of eggs	No. of eggs/F.L.
1937	46.8	1512	32.3
1938	46.2	1310	28.3*
1939	44.1	1267	28.7
1940	48.3	1449	30.0
1941	46.4	1503	32.3*
1942	—	—	—
1943	44.3	1445	32.6

* These values are obtained by calculation using the data in the table and differ from those given in Table 11 of Kaganovskii (1949).

Semko (Tables 1 and 2). During the period 1933–1936, West Kamchatka pink salmon were much more abundant in even-numbered years than in odd-numbered years ; accordingly, both length and fecundity were smaller in even-numbered years than in odd-numbered years. Also, the ratio of fecundity to length was lower in years of high abundance

(Table 1). The pink salmon cycle in West Kamchatka changed after 1936 and odd-numbered years became years of high abundance. Length and fecundity as well as the ratio between the two for the years after 1936 are shown in Table 2. It is seen from this table that the value of fecundity/length did not change right away for even-numbered years after 1936 (after the change in cycle and an increase in the length), but appeared to be changing gradually. Kaganovskii mentions that this phenomenon is an indication of inertia in this character.

According to observations in the Amur River by Kuznetsov (1928), fertilized eggs hatched during the period from late September to December, but some eggs did not hatch until mid-January. The number of days required for hatching was usually 63–73, with an average of 67, but some eggs hatched after 110 days. Larval fish still carry large amounts of yolk and spend 80–120 days before they emerge from the gravel bottom. Some yolk still remains when they emerge from the gravel, but they immediately commence downstream migration. Large mortalities take place from various natural conditions between the time of spawning and the time fry emerge, and sometimes most of the eggs and larvae perish. First, when spawning grounds are over-populated, eggs deposited by early spawners may be dug out by late-comers. Eggs spawned at the time of high water levels may dry out as the water level drops, and spawning grounds may freeze depending on temperature, water level and snowfall in the winter.

LARVAL STAGE

Downstream Migration

The downstream migration of pink salmon fry occurs immediately after their emergence from the gravel beds, as in the case of chum salmon. For the downstream migration of pink salmon fry there are observations by Dvinin (1959) in Sakhalin. The timing of the emergence of pink fry from spawning beds is dependent on the spawning period and the water temperature. In general, the mass emergence and mass seaward migration of pink fry occurs at the time of spring flood. In Sakhalin streams, downstream migration takes place at temperatures from 2°C to 17°C. It usually begins during the first five days of May and the greatest numbers migrate during the period between the middle of May and the middle of June. Migration ends in July. During the period of mass migration, water temperature varies from 8°C to 12°C and the time of peak migration varies within a period of 7–10 days. According to Milovidova-Dubrovskaia (1937), the seaward migration of fry in the Tumnin and Ulikae Rivers of Primore usually takes place during late May through mid-July. Vedenskii (1954) mentions that downstream migration ended in August in the southern Kurils. According to references made in Vedenskii's paper, Baranenkova mentions that downstream migration in East Kamchatka is observed from the end of May and Taranets (1939) pointed out that pink salmon migrate downstream in the Iski River (Amur area) during the period from May 20 to the end of June. Semko (1954) found out that in some cases fry remained in river beds until the beginning of July.

Pink salmon fry migrate downstream mainly at night, and they hide between gravel and stones during the daytime. Under moonlight, they migrate downstream along the bottom. Migration takes place even during the daytime in delta areas at ebb tide. (Dvinin, 1959.)

The observation by Dvinin (1959) in Sakhalin revealed that fry went downstream with considerable amounts of yolk still remaining in their bodies. On the average, the amount of yolk remaining was approximately 10% of the body weight for fry on their way downstream, and 5% for fry found in river mouths. Examination of the stomachs and intestines of fry during this period revealed very small amounts of food. Of 100 fry examined, 71 contained no food and the amount of food was very small in the rest. The food item most frequently encountered was *Microchironomus laccophilus* larvae, followed by Plecoptera larvae and Ostracoda. Fry in the latest stage of downstream migration were examined at the Poronai River mouth. Fry whose average yolk content was 1% of the body weight contained mainly chironomid larvae, Plecoptera, Ephemeroptera, Harpacticidae and larval fish.

According to a compilation by Vedenskii (1954), the size of pink salmon fry during their downstream

Table 3. Sizes of pink salmon fry descending U.S.S.R. rivers (Vedenskii, 1954).

Area	Date	Fork length (mm)	Data of:
Amur	May 3, 1908	32–35	Soldatov (1912)
	May 27, 1908	32–35	
	May 28, 1908	34–37	
East Kamchatka	End of May 1933	30–40	Baranenkova
	June 6–13, 1933	34.5	(1934)
Northern Primore	May–June	34–36	Milovidova-Dubrovskaia (1934)
Kamchatka	June 29, 1936	31–33	Semko (1939)
	(on spawning ground)		
	June 1, 1935	31–40	
	May 29, 1935	32–40	

migration in various streams of the U.S.S.R. was 30–40 mm (Table 3). There is practically no growth during the period of downstream migration.

Residence in Coastal Waters

After entering the sea, pink salmon fry stay in waters close to the coast until about August. According to Yamamoto (1949), the coast of Antonovo, Sakhalin, was visited by small schools of young pink salmon of 120–130 mm in total length during June-July. Vedenskii (1954) mentions that pink salmon fry stayed in coastal waters of Iturup Island of the southern Kurils until early August and left the coast thereafter. During the period of inshore residence, fry stayed in waters not too far from the river mouths of their home streams and within 1 km from the coast, where they were protected from rough waves to some extent. They formed schools of several hundreds to several thousands each. Fry stay in the surface layer day and night, without making any directional movements. In early August, the numbers of young pink salmon in inshore waters decreased sharply, and they had left for offshore waters by mid or late August.

Practically no other descriptions of the ecology of young pink salmon in coastal waters are available. It is assumed that in most areas they stay in the surface layer of inshore waters until about August, and leave for offshore waters thereafter.

OCEANIC LIFE

Growth in Offshore Waters

After leaving inshore waters, young pink salmon move with waters of preferred temperatures as the water temperature drops in autumn. Birman (1960) points out, from his observations on scale circulus counts and body lengths, that the growth of pink salmon is fast and occurs even in winter. Table 4 shows the average lengths of pink salmon during various periods of their offshore residence. Birman (1960) mentions that the growth of pink salmon is most rapid during the summer of the first year, slackens in the autumn, and becomes rapid again after they have arrived in wintering grounds. He also states that most of the growth in the second year takes place during the wintering period, that the rate of growth somewhat decreases after they have commenced their spawning migration, and that the increment in length is not greatly different between the first and second years. Examination of the formation of the resting zone on the pink salmon scale, which reflects changes in growth rate, seems to support the view that pink salmon continue to grow in the winter, although it may not be true in all cases.

Table 4. Average fork length of Asiatic pink salmon in each month of their life history.

July and August	31–80 mm (coast of Iturup I., July 7–August 4, Vedenskii, 1954).
September	22 cm (East Kamchatka, end of September, Birman, 1960).
October	23.3 cm (west coast of southern Sakhalin, end of October to early November, Dvinin, 1952).
November	21.2 cm (west coast of southern Sakhalin, Dvinin, 1949).
	22.8 cm (Nelma Bay of Primore, Dubrovskaia, 1934).
December	20–30 cm in total length (east coast of northern Korea, end of November to December, Yoshida, 1942).
	28 cm (East Kamchatka, end of December, Birman, 1960).
April	41 cm (East Kamchatka, late April, Birman, 1960).
July	48 cm (East Kamchatka, Birman, 1960).

Most of the pink salmon grow in offshore waters during the autumn and spring. In the absence of fisheries during these periods they do not come under our observation. It is not true, however, that they do not appear in coastal waters at all. According to Dvinin (1949), large concentrations of young pink salmon were found during the period from late October to early November along the southwestern coast of Sakhalin. The quantities of such pink salmon varied from year to year, the catch of one fish kombinat varying from 20 to 250 metric tons. These young pink salmon were feeding intensively on *Parathemisto oblivia* (Kroeyer). Large schools of young pink salmon have also been observed in Aniva Bay during October and November, the catch reaching more than 100 tons in some years. Along the southwestern coast of Sakhalin, young pink salmon have also been found in large quantities during July, August and September. Observations on young pink salmon along Primore have been reported by Dubrovskaia (1934). Young pink salmon were caught by a trap in Nelma Bay, Primore, in early November and two were caught in an area 60 miles south of Furuhelm Island. Yoshida (1942) states that pink salmon of 20–30 cm in total length were caught in North Korea by traps from late November to December, and that pink salmon were caught again by gillnets from early April onwards. As to the feeding grounds of pink salmon, particularly the areas of their winter distribution, Kaganovskii (1949) speculated that the wintering grounds were in a zone of water with temperatures suitable for pink salmon, which extended, in both the Japan Sea and the North Pacific, along the Polar Front, and that they were continuous from waters off Hokkaido to waters south of the Aleutians in the Pacific. His hypothesis has been confirmed by data from the offshore fisheries which began to develop in 1952, and data from the offshore investigations conducted by Japan, Canada, the United States and the U.S.S.R. beginning in 1955. The offshore distribution of pink salmon is the subject matter of another part of the comprehensive report on salmon. Most of the Asian pink salmon are forced to conduct long migrations, because their spawing grounds and wintering grounds with suitable temperatures are greatly distant from each other. The distribution of Asian pink salmon during the winter extends, in the Japan Sea, from waters off Korea to waters off the Noto Peninsula of Honshu Island along the boundary between the Tsushima current region and the Liman current region. In the Pacific Ocean, they occur from waters off Kinkazan (northeast Honshu) to the western part of the Gulf of Alaska in a zone of water with suitable temperatures which runs along the Polar Front. Their distribution is continuous both in the Japan Sea and in the Pacific Ocean, although their concentration is different from area to area.

Pink salmon grow rapidly during their ocean residence by feeding vigorously. According to Ito (1964), their food composition is very similar to that of sockeye salmon. They feed on nekton and plankton. They take different amounts of squid in different years; much smaller quantities of squid were found in their stomachs in 1958 than in 1959. On the other hand, the quantities of Euphausiacea and Copepoda tended to be greater in 1959 than in 1958. The feeding index (weight of stomach contents divided by the difference between body weight and gonad weight) of pink salmon was higher than in the other four species of *Oncorhynchus* and the variability in the index was greater, too. There were no great differences in food composition between pink salmon caught in central Kuril waters and those from Aleutian waters. Among the five species of salmon, chinook and coho salmon took larger quantities of nekton than the other species. Pink and sockeye salmon had larger quantities of *Euphausia*, *Themisto*, Copepoda, etc., than the former species, and chum salmon took small quantities of nekton and large quantities of *Euphausia*, *Themisto* and Copepoda, and also Pteropoda and jellyfishes. Pink salmon tended to have smaller quantities of food when their abundance in offshore waters was higher, and vice versa.

According to observations by Hashimoto and Maniwa (1956) using a sonic detector, salmon tend to rise to the upper layers at dusk and night, part of them reaching the surface, and descend to the lower layers in the morning. Part of them, however, stay in a 30–50 m layer throughout the day. The vertical distribution of fish is closely related to the D.S.L. and their vertical movements follow the diurnal changes in the depth of the D.S.L. It is assumed that the diurnal vertical movements of salmon are affected both by light intensity and by the availability of food organisms.

According to the results obtained by Andrievskaia (1957) from investigations in waters off the southern tip of the Kamchatka Peninsula and the northern Kuril Islands, the food composition of pink salmon did not vary greatly by sex or maturity during the month of July. A total of 28 species of food animals was identified by stomach examination. Practically all were animals found in surface or sub-surface layers, including only very few benthonic species. Of the stomachs examined, 16% were empty, and most did not contain large quantities of food. Few stomachs were full. This was interpreted as an indication that these fish would spawn within a short period of time. The larvae of such fish species as *Hexagrammos*, *Theragra* and *Gobiidae* comprised 60% of the stomach contents. Approximately 39% was crustaceans, such as *Parathemisto*, *Thysanoessa* and *Brachyura* larvae. The food composition of pink salmon was more similar to that of sockeye than to any other salmon species.

In relation to the question of feeding, it might be pointed out that inverse relationships have been observed between the density and growth of fish in offshore waters. Semko (1939) demonstrated that there were inverse relationships between the average size and the abundance of West Kamchatka pink salmon (Figure 1). Without exception, the average size was small in years of especially high abundance and large in years of particularly low abundance. Semko (1954) also summarized the changes in body length for Bolshaia River pink salmon over a period of 20 years (Table 5). He discussed the question of intra-specific competition for food in relation to population size, and considered that the above inverse

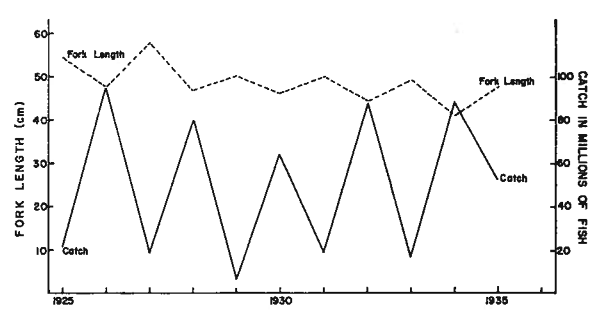

FIGURE 1. Comparison of catch and fork length of West Kamchatka pink salmon (Semko, 1939).

TABLE 5. Fluctuations in the length ranges of West Kamchatka pink salmon of " big " and " poor " years (Semko, 1954).

	Overall range in body length (cm)		Range of main* group (cm)	
Sex	" Big " year	" Poor " year	" Big " year	" Poor " year
Males	34–59	37–63	41–56	45–59
Females	36–52	40–55	41–51	43–52
Both sexes	34–59	37–63	41–56	43–59

* Fish of all size classes which comprise separately not less than 1% of the population.

relationships between population size and body length were caused by the differences in the suitability of the offshore feeding grounds which pink salmon were able to occupy in different years. In other words, in years of large population sizes, it is not possible for all schools to occupy feeding grounds of favourable conditions and some schools must utilize grounds of unfavourable conditions. Kaganovskii (1949), too, pointed out the differences in length between years of high and low abundance and ascribed the smaller fish size in years of high abundance to an overall shortage of food for the population and not to competition for food.

Also in this connection, it has been observed by fishermen that the ratio of the longline catch to the gillnet catch is greater in years of high abundance than in those of low abundance in the offshore fishery for pink salmon carried out in the Japan Sea during May and June. One of the factors affecting such differences may be that pink salmon bite better when the density of fish is higher, although other factors such as gillnet selectivity, etc., may also be involved.

According to Birman (1956) and Dvinin (1952), the relationships between length and abundance for West Sakhalin and Primore pink salmon during 1946–1949 were opposite to those mentioned above. In other words, fish were smaller when the abundance of spawners was lower and vice versa. Birman explained this phenomenon by the fact that there were populations of Amur pink salmon growing in the Japan Sea which were much larger than West Sakhalin and Primore populations and whose cycle is opposite to that of the latter populations.

SPAWNING MIGRATION

As do other species of *Oncorhynchus*, pink salmon expand their distribution towards the north as water temperatures rise in the spring. In general, such seasonal movements are continuous to their spawning migrations. Pink salmon feed vigorously during this period, and feeding still takes place when they approach the coast, although the amounts of food taken decrease. Gonads develop rapidly during the spring. The seasonal changes in gonad weight of pink salmon in high seas areas of Aleutian waters during May through July, as analyzed by Ishida and Miyaguchi (1958), were analogous to those of sockeye salmon maturing in the same year. Most of the fish had ovaries weighing less than 40 g or testes weighing less than 20 g during early and mid-May. Both the mode and the range of gonad weight became greater as the season progressed and in mid and late July ovaries weighed 20–150 g with a mode at 75 g and testes weighed 10–130 g with a mode at 40 g.

Pink salmon form large concentrations and tend to move directionally during the period of spawning migration. However, the smallest unit of pink salmon schools consists of several to several tens of fish—much smaller than those of such fishes as sardines or mackerel. When we say that they form large concentrations, it means that the number of such unit schools per unit of area becomes great. The average speed toward one direction during the period of spawning migration is approximately 24.5 miles per day, according to Hartt (1962). Tagging results reveal that the straight lines connecting tagging locations and recovery locations are approximately parallel and seem to indicate that the relative positions of different schools are maintained in their spawning migrations. As in the case of other species of salmon, the structure and the mechanism of formation of pink salmon schools in offshore waters are little known and require future study.

Pink salmon return for spawning to the streams in which they were born. The degree of homing instinct of pink salmon was studied by Sano and Kobayashi (1953) and Sakano (1956) for fish released in the Yurappu River, which flows into Volcano Bay on the Pacific coast of Hokkaido. There used to be considerable numbers of pink salmon spawning in this stream, but very little pink salmon spawning occurred at the time these studies were made. One million pink salmon eggs were transplanted from other streams to the Yurappu River during the autumn of 1951, and 963,900 pink salmon fry were released in the spring of 1952. Of this number, 41,300 (4.3%) were marked by removing the adipose fin and the left operculum. In 1953, approximately 4,500 fish were caught in the coastal areas adjacent to the Yurappu River, where there had been no pink salmon catches for a number of years. In addition, 461 pinks were caught by the hatchery in this stream, of which 22 (4.77%) had markings. Five additional pink salmon, with presumably the same markings, were reported from the coast and streams of the

Okhotsk Sea side of Hokkaido. In the spring of 1954, 524,500 pink salmon from transplanted eggs were released in the same river, of which 99,100 (19%) were marked in the same manner as mentioned above. In 1955, six marked pink salmon were recovered in the Yurappu River and one was recovered from the Shiretoko Peninsula, the eastern end of the Okhotsk coast of Hokkaido. Due to a flood, the total catch of pink salmon by the Yurappu River hatchery was only 33 in 1955, and the above six fish constituted 18% of the catch, which was in good agreement with the proportion of marked fry mentioned above.

From these studies, it might be assumed that the return of pink salmon to their home streams is fairly accurate.

FLUCTUATIONS IN ABUNDANCE

The question of fluctuations in abundance of Asian pink salmon has been discussed by many scientists (Birman, 1954; Kaganovskii, 1949; Semko, 1939 and 1954). Semko (1939) described the tendencies in catch fluctuations over the period from the early 1900's to 1930 for the pink salmon of East and West Kamchatka and the Amur River. He pointed out, as a characteristic of pink salmon fluctuations, that the catch level was relatively low when year-to-year fluctuations in abundance were small, while it rose as year-to-year fluctuations became more pronounced. He also pointed out that the cycles in abundance became reversed on many occasions. He mentioned the fact that the over-crowding of spawning grounds (which results in poor production of young salmon) and the small sizes of spawners (which prevent them from spawning normally) in years of high abundance are factors causing such reversal of cyclic fluctuations. Kaganovskii (1949) pointed out that high abundance of pink salmon was associated with colder temperatures in the sea and vice versa. He also considered that the major cause of mortality in offshore waters was perhaps predation rather than a shortage of food. He also mentioned several factors which may be causing fluctuations in pink salmon abundance during their freshwater residence.

Birman (1954) discussed the quantitative fluctuations of Amur River chum and pink salmon populations, pointed out the apparent inverse relationships between the levels of abundance of consecutive year classes, and considered the possible competition for food between consecutive year classes. He also pointed out that there were correlations between the fluctuations in catches of pink salmon and those in solar activity, and speculated that high solar activities caused high water levels in the summer (which might cause the exposure and freezing of spawning beds in the following winter) and high air temperatures (which might upset the timing of sexual maturation), resulting in low levels of pink salmon abundance. Semko (1954) made very detailed observations on the factors affecting the quantitative fluctuations of West Kamchatka salmon, especially pinks, during their freshwater residence. He determined the numbers of eggs deposited, the numbers of eggs unspawned, the rate of survival in spawning beds, the numbers of downstream migrants, etc., and forecast the sizes of returns based on these observations.

Pink salmon receive predation from other fishes and mammals throughout their life cycle. Predation begins at the time of spawning. According to Kuznetsov (1928), the most numerous and dangerous predator on salmon eggs in the Amur and Kamchatka is *Salvelinus malma;* in some of the tributaries, *Brachymystax lenok*, *Thymallus arcticus* and various species of minnow are important predators. *Salvelinus malma* is also the most important predator on salmon fry (Popov, 1958). Russian scientists named seals, fur seal, beluga, etc., as predators on salmon in the sea. Sano (1960) presented an interesting report on the predation by *Lamna*. It is not known whether the mortalities caused by these predators vary from year to year. It is possible that predation may be a cause of the cyclic fluctuations in salmon populations, but there has been no case in which this was actually demonstrated.

We may assume that there are two categories of quantitative fluctuations in pink salmon. One is long-term changes and the other is sharp changes occurring in short periods of time. As shown in Kasahara (1963), the total catch of pink salmon in Asia has shown long-term fluctuations during the past 50 years. The level of catch was higher in the years around 1940 than during the period before, although this was partially caused by an increase in fishing intensity. Also, the level of catch has been considerably lower in recent years than in the above period. This is apparent from the fact that the total catches around 1955, when the Russian fisheries had fully developed and the efforts by Japanese fisheries had increased sharply, were still much lower than the total catches in the years around 1940. Such long-term changes may be assumed to be caused by changes in oceanographic conditions, as pointed out by Kaganovskii (1949) and other scientists. Aside from such long-term fluctuations, there have been many examples in which the year class strength sharply decreased or increased. Such variations are perhaps caused by changes in meteorological conditions, which result in the freezing of spawning beds, abnormal spawning, etc. The size of a population might decrease due to abnormal spawning caused by overcrowding.

The number of spawners is an important factor affecting the abundance of the next generation. It must be the most important factor contributing to two-year cycles in pink salmon populations, which may last over long periods of time. The sharp decrease in the catch of pink salmon in West Kamchatka in 1960 was perhaps a result of the very small populations of parent spawners.

In some areas, hatchery operations play an important role in the life history of pink salmon. Among these are Hokkaido, southern Sakhalin and the southern Kuril Islands. In Hokkaido, practically all important pink salmon spawning streams have hatcheries. Pink salmon are caught, in most cases, at catching stations not far from the river mouths, and kept for certain periods of time before the eggs can be collected. Considerable numbers of pink salmon may escape and spawn in the upper reaches, but the quantities of such fish are not known. Approximately 30 million eggs are collected annually (average for 1951–1955) from the entire island of Hokkaido. The total number of pink salmon fry released by hatcheries in Sakhalin and the southern Kuril Islands ranged, according to Cherniavskaia (1959), from 40 to 110 million per year during the period 1955–1958, with an average of 80 million. The rate of return in individual areas reached as high as 9.6%, with an overall return of 2.5%. It is widely known that considerable numbers of adult fish returned from pink salmon eggs transplanted from Sakhalin hatcheries to the Barents and White Sea basins (Kossov *et al.*, 1960).

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