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# Synopsis of Biological Data on the Chum Salmon, Oncorhynchus keta (Walbaum) 1792

By

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# Synopsis of Biological Data on the Chum Salmon, Oncorhynchus keta (Walbaum) 1792

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**ABSTRACT**

Information presented on the chum salmon includes nomenclature, taxonomy, morphology, distribution, ecology and life history, population dynamics, fishery, and protection and management.

## INTRODUCTION

The Fisheries Biology Branch of FAO has formed a "Synopsis Association," composed of fishery agencies willing to contribute to the preparation of synopses on fishes and other aquatic organisms of commercial value. Several organizations, including the U.S. Fish and Wildlife Service, Bureau of Commercial Fisheries, have agreed to collaborate with FAO in this undertaking. Synopses prepared by Bureau personnel will be published in the circular series and will follow the format prescribed by Rosa (1965).

The primary purpose of this series is to make existing information readily available to fishery scientists according to a standard format, and thereby to draw attention to gaps in knowledge. It is hoped that synopses in this series will be useful to scientists initiating investigations of the species concerned, or of related ones, as a means of exchange of knowledge among those already working on the species and as the basis for comparative study of fishery resources.

The chum salmon (Oncorhynchus keta) spawns in five countries (the United States, Canada, Japan, Korea, and the U.S.S.R.) and is most abundant on the Asian continent; therefore, a complete synopsis on its biology should be based on studies from all five countries. I tried to achieve this aim as nearly as possible. My review of the literature was restricted, however, to the studies published in English or to the Japanese and Russian studies that had been translated into English. Consequently some important information has undoubtedly been omitted, and I hope that it will be added to the synopsis when it is updated in the future.

## 1 IDENTITY

### 1.1 Nomenclature

#### 1.11 Valid name

Oncorhynchus keta (Walbaum) Jordan and Gilbert (1882: 305, fig. 1).

#### 1.12 Synonymy

Adapted from Jordan and Evermann (1896).

Salmo keta vel kayko Walbaum (1792' 72).

Salmo lagocephalus Pallas (1811: 372).

Salmo japonensis Pallas (1811: 382).

Salmo consuetus Richardson (1854: 167).

Salmo dermatinus Richardson (1854: 169).

Salmo canis Suckley (1862: 9).

Oncorhynchus lagocephalus Giinth e r (1866: 161).

Oncorhynchus keta Jordan and Gilbert (1882: 305).

### 1.2 Taxonomy

#### 1.21 Affinities (According to Berg, 1947)

Suprageneric

| | |
|---|---|
| Phylum | Vertebrata |
| Subphylum | Craniata |
| Superclass | Gnathostomata |
| Series | Pisces |
| Class | Teleostomi |
| Subclass | Actinopterygii |
| Order | Clupeiformes |
| Suborder | Salmonoidei |
| Family | Salmonidae |

F 1.--T , O (Walbaum). (P N F )

G

O Suckley, 1861 (1862: 313)

G :

S (R )

T G O ( ) ( ).

T J Evermann (1896):

"B , subfusiform, - . M ; , , ; , - - . Vomer , , , - ; ; ; vomer ; . Branchiostegals . S s . D ; , 14 20 . P . G . O . S - ; - mer ; - , , - ; . T ; - , ; , . S , , - N P N A A , ."

S

T S Walbaum (1792: 72) K R . T , O (1960) :

Salmo keta VEL KAYKO WALBAUM

D. 14. P. 15. V. 11. A. 18.

"C , obtusum. C immaculatum. C auda Lunat . C alba. Squamae argenteae. Dorsum viridescens. Capitur copiose fluminibus Kamtschatkae.

"S VEL KAYKO, Krascheinnikow, l.c. pag. 181. Salmonem Narkam magnitudine aliquatenus superat: C oblongum, planum. R resimum. Dentes, quam aliquamdin flumine moratus est, caninis fuint. L acuta. C uda parum bifurca. Dorsum atro-viride, latera & similiter colorata ac aliis selmonibus sed absque maculis."

S C Wilby (1946):

"B , ; . H ; ; , , - ; branchiostegals, 10 16; , 19 26, , , , . F : (1), 10 13; , , , ; , 13 17; , , ; , e r gina t e. L : decurved, . S : ; , 130 153;

[illegible], 126 [illegible] 151. P[illegible]: 140 [illegible] 185. C[illegible]: [illegible]; [illegible]; [illegible], [illegible], [illegible]; [illegible], [illegible]. F[illegible]. Y[illegible], [illegible].

"L[illegible] 3 [illegible] 2 [illegible].

"D[illegible], [illegible], [illegible], [illegible], [illegible] 20 [illegible] 26 [illegible], [illegible]. T[illegible], [illegible], [illegible]."

T[illegible] O[illegible] N[illegible] A[illegible] R[illegible] (1962).

"A. L[illegible]-[illegible] 160-198 ([illegible] 184); [illegible] 9-15; [illegible] 95-224 ([illegible] 136); [illegible] 16-20 ([illegible]); [illegible] 24-34 ([illegible] 29.7) [illegible]; [illegible]; [illegible]; [illegible]; [illegible]; [illegible] 2 [illegible]; [illegible]; [illegible]; [illegible] 2,000 [illegible] O[illegible], [illegible].

AA. L[illegible]-[illegible] 124-165; [illegible] 10-19; [illegible] 45-254; [illegible] 15-22 ([illegible]); [illegible] 19-39; [illegible], [illegible]; [illegible]; [illegible] 3-8, [illegible] 2,500 [illegible].

B. P[illegible] 85-254; [illegible]-[illegible] 130-165; [illegible] 10-19; [illegible] 16-22 ([illegible]); [illegible] 19-28.

C. L[illegible]-[illegible] 130-147 ([illegible] 139); [illegible] 10-16; [illegible] 140-254 ([illegible] 205); [illegible] 16-20 ([illegible]); [illegible] 19-26 ([illegible] 22), [illegible]; [illegible]; [illegible], [illegible], [illegible], [illegible]; [illegible]; [illegible]-[illegible], [illegible]; [illegible]; [illegible], [illegible], [illegible] O[illegible], [illegible].

CC. L[illegible]-[illegible] 130-165 ([illegible] 146); [illegible] 13-19; [illegible] 85-244 ([illegible] 158); [illegible] 16-22 ([illegible]); [illegible] 20-28 ([illegible] 24), [illegible]; [illegible]; [illegible], [illegible], [illegible], [illegible]; [illegible]; [illegible]; [illegible]; [illegible]--O[illegible], [illegible].

BB. P[illegible] 45-114; [illegible]-[illegible] 124-150; [illegible] 11-16; [illegible] 15-21 ([illegible]); [illegible] 19-39.

D. P[illegible] 45-114 ([illegible] 75); [illegible]-[illegible] 130-144 ([illegible] 135); [illegible] 11-15; [illegible] 15-19 ([illegible]); [illegible] 19-25 ([illegible] 21), [illegible], [illegible]; [illegible]; [illegible]; [illegible]; [illegible]-[illegible]-[illegible]; [illegible], [illegible]; [illegible], [illegible]; [illegible]; long [illegible]; [illegible]----O[illegible], [illegible].

DD. Pyloric caeca 45-114 (average about 86); lateral-line scales 124-150 (average about 135); branchiostegals 11-16; anal rays 15-21 (complete count); gill rakers 28-39 (average about 35), rakers close together with minute teeth and present on back of second and fourth gill arches; caudal peduncle slender; parr marks short, elliptical or oval, extending little, if any, below lateral line; black speckling, when present, is faint, fins without speckling, except faint speckling on margin of caudal in breeding fish; in breeding adults, body (except lower belly) and all fins except pectorals and caudal lobes a deep crimson to brick red, head a dull green on dorsal half, creamy white below; mouth lining dark; adaptively anadromous; long sea migrations; abundant far offshore---<u>Oncorhynchus nerka</u>, sockeye salmon.
<u>Oncorhynchus</u> n. <u>kennerlyi</u>, kokanee."

A sixth species, the masu salmon (O. <u>masou</u>) occurs on the Asian coast. Hikita (1962) separates it from other species of <u>Oncorhynchus</u> by the fine black spots, stout caudal peduncle, fewer ventral fin rays (mostly 10), the shorter and less numerous pyloric caeca (35-68, mean 47.05), and the small number of gill rakers (16-22, mostly 18-19).

Bilton, Jenkinson, and Shepard (1964) have prepared a key to the five species of Oncorhynchus in North America based on scale characters, and Foerster and Pritchard (1944) have developed a key for the identification of juvenile Pacific salmon in fresh water.

### 1.22 Taxonomic status

This is a morpho-species, and it is polytypic.

### 1.23 Subspecies

Berg (1934) separated the Asian chum salmon into seasonal races, summer and autumn. He assigned the autumn chums to a special race, the infraspecies <u>autumnalis.</u> The separation of chum salmon into seasonal races is supported by other investigators (Lovetskaya, 1948; Grigo, 1953; Birman, 1956; Hirano, 1958; Sano, 1966). Berg's infraspecies name <u>(autumnalis)</u> has not been widely used, however, in the literature.

Berg's justifications for separating autumn chum salmon from summer chum salmon and placing them in a separate race were: (1) later entrance into spawning streams, (2) less-developed sexual products at time of entry into the spawning streams, (3) later spawning period, (4) larger size, and (5) greater fecundity. Sano (1966), in a review of the life history of chum salmon in Asia, presented a recent summary of characters used to distinguish summer and autumn chum salmon (table 1). Scientists have not separated populations of chum salmon into seasonal races in North America, although differences in time

Table 1.--Distinguishing characteristics of seasonal races of chum salmon in Asia (Sano, 1966)

| Character | S[illegible] | A[illegible] |
|---|---|---|
| G[illegible] : A[illegible] | M[illegible] K[illegible], [illegible] O[illegible] S[illegible], [illegible] A[illegible] R[illegible]. | More [illegible] A[illegible] R[illegible], S[illegible], [illegible] N[illegible] J[illegible]. |
| A[illegible] R[illegible] | L[illegible]-- [illegible] 100 km. [illegible]. | U[illegible]--1,000-2,000 [illegible]. |
| T[illegible] | M[illegible] J[illegible] A[illegible] | S[illegible], O[illegible], [illegible] N[illegible]. |
| T[illegible] | A[illegible] S[illegible] | S[illegible] N[illegible]. |
| A[illegible] | 2.5 [illegible] | 3.5 [illegible]. |
| F[illegible] | | A[illegible] 500-1,000 [illegible] summer [illegible]. |
| A[illegible] | S[illegible] 3-[illegible]. | L[illegible] 3-[illegible]. |

[illegible] (S[illegible], H[illegible], [illegible] Y[illegible], 1967).

S[illegible] (1966) [illegible] N[illegible] (1966) [illegible] -[illegible] -[illegible]. F[illegible], [illegible], [illegible], [illegible] (W[illegible], 1955; B[illegible], 1956; R[illegible], 1957; [illegible] S[illegible], 1966).

1.24 S[illegible], [illegible] -[illegible]

C[illegible] 2.

## 1.3 M[illegible]

### 1.31 E[illegible]

K[illegible] (1935) [illegible] K[illegible] I[illegible] ([illegible] 3). T[illegible]

T[illegible] 2.--S[illegible] (B[illegible], 1948; A[illegible] F[illegible] S[illegible], 1960; H[illegible], 1962)

| C[illegible] | S[illegible] name | V[illegible] |
|---|---|---|
| U[illegible] S[illegible] | C[illegible] | D[illegible], [illegible]. |
| C[illegible] | [illegible]. | D[illegible]. |
| U.S.S.R. | K[illegible] | L[illegible] ([illegible]),<br>O[illegible] ([illegible]),<br>S[illegible]'[illegible] (A[illegible]),<br>H[illegible] (K[illegible]). |
| J[illegible] | S[illegible] | A[illegible], A[illegible]-[illegible], A[illegible]-[illegible], A[illegible]-[illegible]<br>T[illegible], Buna, B[illegible],<br>P[illegible], M[illegible], O[illegible], B[illegible]-[illegible], B[illegible]-[illegible]<br>H[illegible] (H[illegible]);<br>Shiro-sake, Shiro (N[illegible] P[illegible] O[illegible], K[illegible] I[illegible] K[illegible]);<br>Shyake (K[illegible] D[illegible]);<br>O[illegible], O[illegible], Inu-masu (Miyagi Prefecture);<br>Inu-masu (Ishikari P[illegible]);<br>H[illegible] (I[illegible] P[illegible]). |
| Korea[1] | Yon-o | Nyon-o, Y[illegible]-[illegible]-[illegible] ([illegible]). |

[1] P[illegible], J[illegible] R[illegible] C[illegible], S[illegible], U[illegible] W[illegible], S[illegible], W[illegible].

T[illegible] 3.--B[illegible] (Katayama, 1935)

| C[illegible] | F[illegible] (116 [illegible]) | | | M[illegible] (151 [illegible]) | | |
|---|---|---|---|---|---|---|
| | M[illegible] | S[illegible] | C[illegible] | M[illegible] | S[illegible] | C[illegible] |
| | Mm. | Mm. | | Mm. | Mm. | |
| B[illegible] | 624.6 | 29.4 | 4.7 | 641.0 | 30.5 | 4.8 |
| B[illegible] | 138.8 | 12.1 | 8.7 | 149.4 | 10.1 | 6.7 |
| H[illegible] L[illegible] | 117.5 | 7.7 | 6.6 | 130.7 | 9.3 | 7.1 |
| S[illegible] | 28.6 | 3.6 | 12.8 | 38.2 | 5.3 | 14.0 |
| C[illegible] | 40.4 | 2.4 | 6.0 | 42.0 | 2.8 | 6.6 |
| | | | C[illegible] | | | |
| B[illegible] | | | 0.7 | | | 0.8 |
| B[illegible] | | | 0.6 | | | 0.8 |
| H[illegible] | | | 0.7 | | | 0.8 |
| H[illegible] [illegible]. | | | 0.5 | | | 0.7 |

Table 4.--Morphometric characters which show differences in summer and autumn chum salmon (Grigo, 1953)

| Character | Summer | Autumn | Pooled variance |
|---|---|---|---|
| In percentage of median length of body: | | | |
| Maximum height of body | 25.3 0.2 | 23.4 0.14 | 9.5 |
| In percentage of distance from posterior border of operculum to the end of scale covering: | | | |
| Posterior edge of operculum to insertion of dorsal fin | 63.9 0.2 | 62.0 0.2 | 6.8 |
| Posterior edge of dorsal fin to end of scale covering | 52.6 - 0.2 | 53.9 0.2 | 5.6 |
| Posterior edge of operculum to anterior edge of anus | 93.2 ± 0.2 | 91.1 0.2 | 7.0 |
| Posterior edge of operculum to anterior edge of ventral fin | 72.0 ± 0.2 | 70.2 0.2 | 6.0 |
| Distance from pectoral to ventral fins | 45.1 ± 0.2 | 42.9 0.1 | 9.2 |
| In percentage of head length: | | | |
| Height of head in mid-eye region | 56.2 ± 0.3 | 51.0 ± 0.4 | 10.4 |
| Length of pectoral fin | 61.7 ± 0.4 | 66.7 ± 0.5 | 8.5 |
| Length of ventral fin | 47.4 ± 0.4 | 50.3 ± 0.3 | 5.7 |
| Height of anal fin | 43.6 ± 0.3 | 47.9 ± 0.3 | 9.5 |
| Distance from end of dorsal fin to anal fin | 50.5 ± 0.5 | 43.4 ± 0.5 | 9.6 |

male was larger in all characters measured. Several of the characters were correlated with each other, and correlation coefficients were highest for related characters in the males.

Grigo (1953) used several morphometric characters to support further the separation of chum salmon into summer and autumn races (table 4). Additional morphometric data presented by Birman (1956) indicated thatbody depth could not be used universally to separate summer chum salmon from autumn chum salmon (table 5).

Birman (1956) used morphometric characters in an attempt to demonstrate differences in populations from tributaries of the Amur River. Two characters (table 6) indicated that chum salmon from the Amgun River could be distinguished from chum salmon from the Ussuri and Bira Rivers. Svetovidova (1961) made a similar study of summer chum salmon from Amur River tributaries (table 7) and concluded that characters were not uniformly different between streams but that some characters were distinct for summer chum salmon from certain rivers. The Beshenaia River fish differed in length, in least depth of the body, and in length of the base of the dorsal fin; fish from the Ul and Dzhappi Rivers were much alike but had smaller eye diameters than fish in other tributaries. Summer chum salmon from the My River appeared to occupy an intermediate position; some morphological characters were close to those of the Beshenaia River fish, and others were close to those of the Ul and Dzhappi River fish. The My River fish were also characterized by a greater fecundity.

Table 5. --Relative depth of body of summer and autumn chum salmon (Birman, 1956)

| Place of capture | Fish | Greatest depth of body (as percentage of length of trunk) | |
|---|---|---|---|
| | | Range | Mean ± m |
| | Number | Percent | Percent |
| Autumn chum salmon | | | |
| Bira River | 30 | 27.1 - 33.8 | 30.2 ± 0.3 |
| Ussuri River | 24 | 27.9 - 33.9 | 30.2 ± 0.3 |
| Amgun River | 30 | 30.7 - 36.8 | 33.7 ± 0.3 |
| Amur estuary | 60 | 27.2 - 34.3 | 31.6 ± 0.2 |
| Summer chum salmon | | | |
| Amur estuary | 60 | 31.1 - 37.0 | 33.7 0.2 |

Meristic characters of chum salmon, both external and internal, are presented intable 8.

### 1.32 Cytomorphology

Chum salmon have a diploid chromosome number of 74 (Simon, 1963), made up of 28 metacentric (v-shaped) and 46 acrocentric (rod-shaped) chromosomes. Each metacentric chromosome has two arms and each acrocentric chromosome, one arm, for a total of 102 arms.

T[illegible] 6.--Morphometric [illegible] A[illegible] R[illegible] (B[illegible], 1956)

| C[illegible] | A[illegible] | | | P[illegible] | | |
|---|---|---|---|---|---|---|
| | A[illegible] | U[illegible] | B[illegible] | A[illegible]-U[illegible] | A[illegible]-B[illegible] | U[illegible]-B[illegible] |
| A[illegible] | | | P[illegible] | | | |
| D[illegible] | 22.6 ± 0.2 | 20.7 ± 0.2 | 20.7 ± 0.2 | 6.8 | 6.8 | 0 |
| G[illegible] | 33.7 ± 0.3 | 30.2 - 0.3 | 30.2 - 0.3 | 8.4 | 8.5 | 0 |

Table 7.--Comparison of meristic and morphological characters of sunner chum salmon from five tributaries of the Amur River (Svetovidova, 1961)

| Item | River and sex | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Beshenaia | | Amgun | | Dzhappi | | Ul | | My | |
| | Female | Male | Female | Male | Female | Male | Female | Male | Female | Male |
| Sample size | 26 | 31 | 16 | | 15 | 20 | 30 | 30 | 32 | 24 |
| Character: | | | | | | | | | | |
| Mean: | | | | | | | | | | |
| Fork length (cm.) | 55.5 | 57.5 | 57.6 | 61.5 | 60.6 | 62.7 | 60.8 | 62.3 | 57.3 | 61.7 |
| Weight (kg.) | 2.2 | 2.4 | 2.6 | 2.9 | 2.3 | 2.8 | 2.4 | 2.8 | 2.4 | 2.7 |
| Fecundity | 2,266 | | 2,190 | -- | 2,383 | -- | 2,381 | -- | 2,523 | -- |
| Vertebrae | 65.3 | 64.8 | 65.5 | | 66.6 | 66.4 | 66.6 | 66.4 | 66.1 | 66.2 |
| Gill Rakers | 22.8 | 23.1 | 22.1 | | 22.9 | 22.4 | 21.8 | 22.1 | 22.0 | 22.2 |
| In percentage of fork length: | | | | | | | | | | |
| Trunk length | 75.1 | 72.9 | 74.2 | | 73.4 | 70.8 | 73.0 | 71.8 | 73.3 | 70.5 |
| Head length | 21.6 | 23.5 | 21.4 | | 22.4 | 25.4 | 22.2 | 24.2 | 22.4 | 22.3 |
| Diameter of eye | 2.8 | 2.9 | 3.0 | | 2.6 | 2.6 | 2.5 | 2.5 | 3.0 | 2.8 |
| Greatest depth of body | 22.8 | 23.7 | 23.4 | | 22.0 | 22.5 | 22.8 | 22.8 | 22.9 | 23.5 |
| Least depth of body | 6.7 | 7.0 | 6.4 | | 6.3 | 6.6 | 6.2 | 6.3 | 6.4 | 6.5 |
| Length of anal fin | 11.5 | 11.5 | 10.9 | | 10.7 | 10.6 | 10.4 | 10.4 | 11.2 | 11.1 |
| Length of dorsal fin | 11.0 | 11.0 | 10.3 | | 9.9 | 10.0 | 9.6 | 10.0 | 9.7 | 10.2 |
| Length of digestive tract | 84.0 | 80.8 | 73.6 | | 83.6 | 84.3 | 87.2 | 85.3 | 95.0 | 97.2 |

### 1.33 P[illegible]

T[illegible] muscle [illegible] O[illegible] (T[illegible], R[illegible], [illegible] V[illegible], 1965; T[illegible], R[illegible], V[illegible], [illegible] M[illegible], 1965; Y[illegible], Y[illegible], H[illegible], [illegible] M[illegible], 1967). E[illegible]. S[illegible] O[illegible] (V[illegible], R[illegible], [illegible] T[illegible], 1964), [illegible]. M[illegible].

T[illegible] A[illegible] O. [illegible] S[illegible] (N[illegible], 1958). T[illegible] (T[illegible] [illegible] R[illegible], 1966). O[illegible] sequence [illegible] O[illegible] S[illegible] is [illegible]: O. [illegible], O. [illegible], O. [illegible], O. [illegible], [illegible] O. [illegible] (T[illegible] [illegible] R[illegible], 1966). T[illegible] O. [illegible] O. [illegible] H[illegible] (1962). I[illegible], S[illegible] (1963), [illegible].

Table 8.--Meristic characters of chum salmon as given by Hikita, by Rounsefell, and by Dark and Landrum

| Character | Mean | | | Range[4] | | | Sample size | | |
|---|---|---|---|---|---|---|---|---|---|
| | Hikita (1962) | Rounsefell[2] (1962) | Dark and Landrum[3] (MS.) | Hikita (1962) | Rounsefell (1962) | Dark and Landrum (MS.) | Hikita (1962) | Rounsefell (1962) | Dark and Landrum (MS.) |
| | | | | | Number | | | | |
| Fin rays: | | | | | | | | | |
| Dorsal | 14.0 | 14.6 | 14.7 | 11- 16 | 13- 16 | 14.0- 15.2 | 163 | 137 | 9,237 |
| Pectoral | 15.5 | -- | 15.6 | 14- 17 | | 15.0- 16.1 | 198 | | 9,222 |
| Anal | 17.1 | 17.3 | 18.1 | 14- 18 | 16- 20 | 17.1- 18.7 | 160 | 137 | 9,208 |
| Ventral | 11.1 | | -- | 10-13 | | -- | 108 | | -- |
| Branchiostegals | 13.4 | 13.8 | 14.5 | 11- 16 | 12- 16 | 13.6- 15.0 | 249 | 135 | 9,137 |
| Vertebrae | 67.6 | 68.9 | 67.0 | 64- 70 | 62- 71 | 65.8- 68.0 | 33 | 63 | 8,978 |
| Pyloric caeca | 160.6 | 205.0 | | 121-215 | 175-249 | | | 20 | |
| Gill rakers on first gill arch. | 22.9 | 22.7 | 22.9 | 19- 27 | 19- 26 | 22.1- 23.9 | 243 | 188 | 9,213 |
| Lateral line scales | 135.1 | 136.0 | 132.0 | 126-146 | 124-153 | 126.4-137.4 | 287 | 155 | 9,096 |

[1] Hikita's specimens were from Japan, the U.S.S.R., Canada, the Pacific Ocean, and the Bering Sea.
[2] Rounsefell's data were compiled by other investigators from specimens collected in British Columbia and Washington.
[3] Dark, Thomas A., and Betty J. Landrum (MS.). Meristic variation in three species of Pacific salmon (Oncorhynchus nerka, O. keta, and O. gorbuscha). Bur. Commer. Fish., Biol. Lab., Seattle, Wash. These samples were from Hokkaido and Kamchatka in Asia and the North American coast (from Kotzebue Sound on the Arctic coast of Alaska, south to Northern Oregon, including the Alaska Peninsula, Kodiak Island, and Puget Sound). All were inshore samples except some from off Hokkaido.
[4] Figures shown from Dark and Landrum (MS.) are ranges in sample means.

## 2 DISTRIBUTION

### 2.1 Total areas

**Chum salmon have the widest distribution of any of the Pacific salmon (fig. 2; table 9). Streams inhabited along the North American coast during reproductive and early life history stages extend from the Sacramento River in California (long. 122°30' W., lat. 37°50' N.) northward more or less continuously (including the Aleutian Islands) to the Arctic shore of Alaska (Walters, 1955; Atkinson, Rose, and Duncan, 1967; Aro and Shepard, 1967; Hallock and Fry, 1967). Some are found as far east as the Mackenzie River (long. 135° W., lat. 69 N.) on the Arctic coast of Canada. In Asia, the southern limits of spawning are in the Tone River (long. 141 E., lat. 36 N.) of Chiba Prefecture on the Pacific side of Honshu, in Nagasaki Prefecture (long. 130 E., lat. 33 N.) of Kyushu in the Sea of Japan, and in the Nakdong River system (long. 129 E., lat. 35 N.) of the Republic of Korea (Walters, 1955; Atkinson, Chun, Jeffries, Kim, Kim, Kim, Pressey, 1967[1]). Spawning streams extend northward to the Lena River (long. 125 E., lat. 73 N.) on the Arctic coast of the U.S.S.R.**

[1] Atkinson, Clinton E., Seung Kwan Chun, Ernest R. Jeffries, Jong Du Kim, Ki Young Kim, Kyun Hyun Kim, and Richard T. Pressey. 1967. A survey of the salmon and trout resources of the Republic of Korea. U.S. Dep. State, Ag. Int. Develop., and Repub. Korea, Off. Fish., Seoul, Korea, 103 pp. (Processed.).

Table 9.--Geographic distribution of chum salmon by FAO letter code

(Rosa, 1965, Appendix I)

| | Abundant | Rare |
|---|---|---|
| Marine areas | INE, INW | PNE, PNW, ANE |
| Land areas | 211,212,221<br>222,223,231<br>451,710 | 208,232,444 |

**Most chum salmon spawn within the lower reaches of streams and sometimes within the tidal zone. In most Asian streams, spawning areas are less than 200 km. from the sea (usually less than 100 km.) (Sano, 1966). Chum salmon, however, are known to spawn over 2,500 km. from the sea in the Amur River of the U.S.S.R. and in the Yukon River of Alaska and Canada,**

**After leaving fresh water, immature and maturing chum salmon live in the North Pacific Ocean and Bering Sea. By their second summer at sea, they are distributed throughout subarctic waters from the Asian to North American coasts. Present information places their southern limit at about lat. 40 N. in the western Pacific Ocean and at about lat. 44° N. in the eastern Pacific Ocean (fig. 2; Shepard et al, 1967). The southern limit shifts northward with**

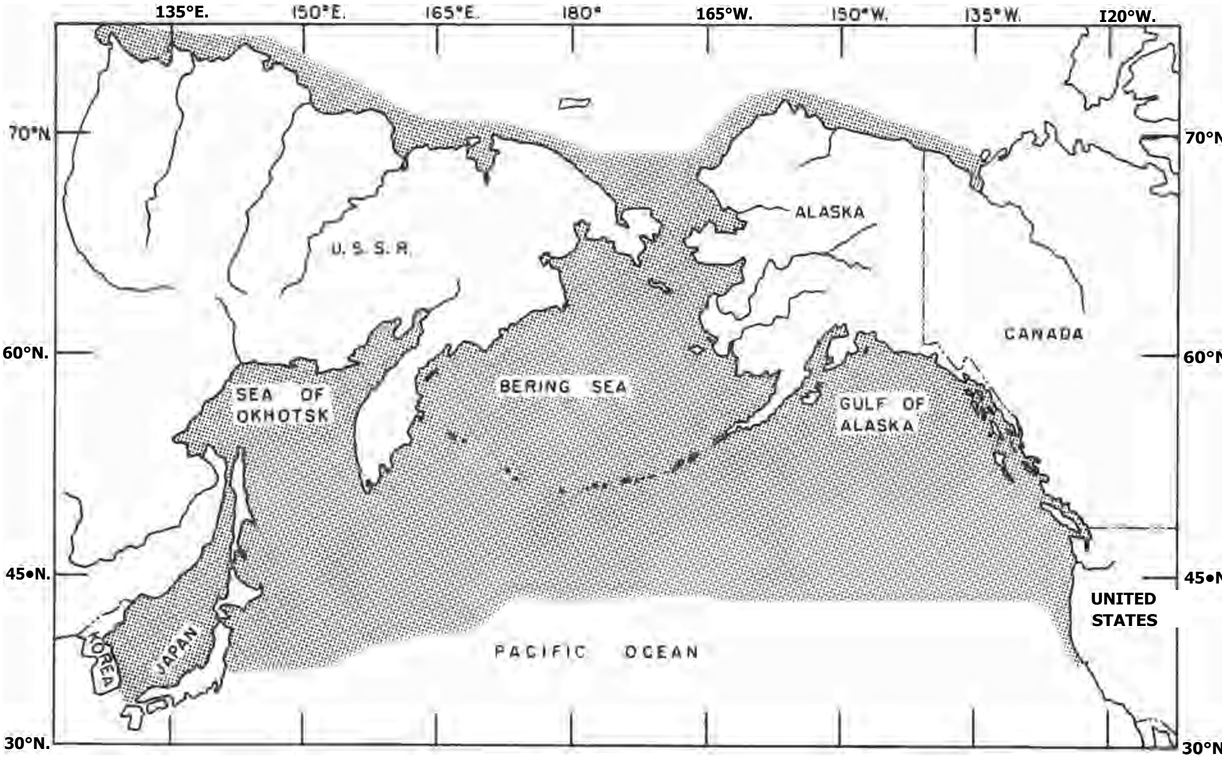


Figure 2.--K[illegible] coastal and ocean distribution of chum salmon.

warming surface waters during summer; the northern limit of their distribution is in the Arctic Ocean. Spawning streams extend beyond these latitudes; it is assumed that coastal routes are used by maturing fish to reach these streams and by young fish to reach ocean feeding areas.

Industrial development has brought some changes in the fresh-water range of chum salmon. Sano (1967) mentioned pollution and reduction of waterflow as a serious problem in Hokkaido. In both Asian and North American spawning streams obstructions such as dams, logjams, and weirs for trapping fish at hatcheries have reduced spawning areas to some degree. In recent years, stream improvement projects such as removal of logjams, laddering or removal of manmade and natural obstructions, and stream channelization have helped to reclaim and even extend some spawning areas.

2.2 <u>Differential distribution</u>

Chum salmon inhabit widely different environments during various stages of their life history. As sexually mature adults they reproduce in the intertidal zone or more commonly above the influence of salt water in freshwater streams. The eggs and larvae develop in streambed gravel, and upon reaching the fry stage, the young emerge from the gravel and spend a few days to several weeks in the stream before they descend to the sea. Most of their life is spent at sea where they grow and develop to adults.

2.21 Spawn, larvae, and adolescents

Adults deposit eggs in fresh water as early as June or July in some northern streams (Atkinson et al., 1967). In areas more to the south, adults reach the spawning grounds from September to January. Eggs are deposited in streambed gravel usually at depths of 15 to 30 cm.; the eggs and larvae (alevins) develop in this environment until the fry stage.

Emergence from the gravel is in March, April, and May (Sano, 1966; Neave, 1966). After leaving the gravel, chum salmon fry may immediately migrate downstream and enter the sea, or they may remain in fresh water for several weeks. They are found in streams from April to July, but most of the fry leave fresh water in April and May (Sano, 1966).

Juvenile chum salmon migrate extensively at sea and become widely distributed. The fry are found in coastal waters adjacent to their natal streams from April to midsummer. By the end of July or mid-August, nearly all the juveniles have left these waters (Sano, 1966;

Neave, 1966). In August and September young chum salmon have been found migrating predominantly northward within 32 km. of shore along the coasts of Washington, British Columbia, and southeastern Alaska (Hartt, Smith, Dell, and Kilambi, 1967). The migration routes of chum salmon from these as well as Asian coastal waters to offshore waters are unknown. In their first year at sea, chum salmon become widely distributed, and stocks from the Asian and North American continents are intermixed in the North Pacific Ocean and Bering Sea (Kondo, Hirano, Nakayama, and Miyake, 1965; Hartt, 1966; Shepard et al., 1967). Tagging and racial studies have shown that chum salmon from Asia and North America intermingle extensively on the high seas from at least long. 140° W. to long. 179° E. in the North Pacific Ocean and from about long. 169° W. to at least long. 177° E. in the Bering Sea (Shepard et al., 1967). Asian chum salmon dominate west of long. 175° W., whereas North American fish dominate east of long. 170° W.

2.22 Adults

In the last few months of life, chum salmon migrate from distant offshore waters to their natal stream, and thence upstream to spawning areas. In May and June maturing chum salmon are distributed throughout the North Pacific Ocean and Bering Sea from lat. 40° N. to the Bering Strait (Shepard et al., 1967). Theyleave high seas feeding grounds and enter coastal waters from June to November. Little time is spent in coastal waters before they migrate upstream to spawn (Chatwin, 1953; Semko, 1954). The earlier summer-run fish migrate into spawning streams from Julyto late August or early September. Spawning takes place in August and September. The autumn chum salmon enter and spawn in streams from October to January.

The summer runs spawn in the northern part of the chum salmon's range, and the autumn runs in the southern part. In Asia, the summer run spawns in streams bordering the northern coast of the Sea of Ohkotsk, Kamchatka, and the U.S.S.R. Bering Sea and Arctic coasts (Sano, 1966). The Amur River and the streams of Sakhalin have summer and autumn runs, whereas Japanese streams have only autumn spawners. The best available information indicates that only summer runs enter North American streams along the northern Bering Sea and Arctic coast. In southeastern Alaska and northern British Columbia, most chum salmon spawn in the summer and early fall, but a few later runs occur as well. North American streams from Vancouver Island southward have only autumn spawners (Shepard et al., 1967).

2.3 Determinants of distribution

It has been hypothesized and generally accepted that Oncorhynchus originated in fresh water from the Genus Salmo (Tchernavin, 1939; Berg, 1940; Semko, 1954; Hoar, 1958; Mamaev, Parukhin, Baeva, and Oshmarin, 1959; Margolis, 1965). Neave (1958) estimated that the initial separation from Salmo occurred not later than the early Pleistocene period, between half a million and 1 million years ago. Some of the species that evolved later (such as chum and pink salmon) would have a total evolutionary history of half this time or less. Berg (1940) suggested that the adaptation of Oncorhynchus to salt water evolved from the abundant food supply in the ocean, but Hoar (1958) attributed the adaptation to changes in behavior.

To reproduce successfully, chum salmon must find loos e streambed gravel in which they can excavate a depression and deposit and cover their eggs. Water must seep through the gravel during the incubation period to supply oxygen and remove waste products from the eggs. Chum salmon have been known to spawn over a wide range (4°-16° C.) of water temperatures (Neave, 1966). Bailey (1964)[2] found survival of chum salmon eggs in Olsen Creek, Alaska, to be limited to the 1.8 m. tide level and above; the 1.8-m. tide level was exposed to tidewater 55 percent of the time.

Lethal water temperatures for chum salmon fry in fresh water are 23.8° C. and -0.1° C. (Brett, 1952; Brett and Alderdice, 1958); the fry have shown the greatest preference for temperatures of 12° to 14° C.

Migration to salt water is obligatory for the fry within the first summer after hatching (Baggerman, 1960; Houston, 1961). The fry apparently become increasingly preadapted to the osmoregulatory necessities of marine life while still in fresh water, and many die when held in fresh water for 7 to 8 months after hatching. The deaths are apparently due to the loss of ability to regulate the levels of water and electrolyte.

In the ocean, chum salmon are limited to the Subarctic Region of the North Pacific Ocean and Bering Sea. This region is defined by a permanent halocline maintained by an excess of precipitation over evaporation with a brackish upper zone and a saline lower zone. Its southern boundary varies from lat. 40° N.

[2] Bailey, Jack E. 1964. Intertidal spawning of pink and chum salmon at Olsen Bay, Prince William Sound, Alaska. U.S. Bur. Commer. Fish., Biol. Lab. Auke Bay, Alaska, Ms. Rep. 64-6, 23 pp. (Processed.)

to 42° N. (Dodimead, Favorite, and Hirano, 1963). Within the Subarctic Region, churn salmon are mainly concentrated where surface water temperature exceeds [illegible] or 3 C. (Birman, 1958; Konda, 1959; Manzer, Ishida, Peterson, and Hanavan, 1965). Theyare rarely found where surface temperature falls below 1° C. Kasahara (1961) hypothesized that churn salmon leave the northern waters of the sea of Okhotsk and Bering Sea in the winter because of probable low surface temperature. As the North Pacific Ocean warms in the summer, the southern boundary of distribution shifts northward (Manzer, 1958; Birman, 1959; Konda, 1959; Shepard et al., 1967). Catch data suggest that the southern limit roughly parallels the 12 to 13 C. surface temperature isotherms. The probable preferred range is [illegible] or 3 to 11° C. (Manzer et al., 1965).

## 2.4 Hybridization

2.41 Hybrids: frequency of hybridization; species with which hybridization occurs; methods of hybridization.

Chum salmon have been experimentally cross bred with other species (table 10), Cytological observations on reciprocal cross breeding of chum and pink salmon have shown the insemination process to be monospermic and the early cleavage stages and chromosome behavior to be normal (Kobayashi, 1964). Smirnov (1954) described the external appearance of hybrids from a cross of female chum salmon and male pink salmon. Some of the hybrids acquire the coloration of the normal chum salmon fry, whereas about 37 percent developed

Table 10.--Results of experimental cross breeding of chum salmon with other species of salmonids in Canada, U.S.S.R., and Japan

| C[illegible] | Authority | | | |
|---|---|---|---|---|
| | Foerster (1935) British Columbia, Canada | Smirnov (1954) Sakhalin, U.S.S.R. | Hikita and Yokohira (1964) Hokkaido, Japan | Terao, Uchiyama, Kurahashi, and Matsumoto (1963) Hokkaido, Japan |
| Male chum salmon and female pink salmon. | Excellent hatch of healthy fry. | High percentage of fertilization and viable fry. | 81.8- to 91.5-percent survival over 3 years. | |
| Female chum salmon and male pink salmon. | 166 healthy fry from 1,196 eggs. | High percentage of fertilization and viable fry. | 93.3- to 94.5-percent survival over 3 years. | |
| Male chum salmon and female sockeye salmon. | Good hatch of healthy fry. | | | |
| Female chum salmon and male sockeye salmon. | Good hatch of healthy fry. | | | |
| Male chum salmon and female kokanee (O. nerka var. adonis). | | | | 17- and 90-percent survival over 2 years. |
| Female chum salmon and male kokanee. | | | | 80- and 90-percent survival over 2 years. |
| Male chum salmon and female chinook salmon. | [illegible]gs all died during early development. | | | |
| Female chum salmon and male chinook salmon. | Moderate hatch of healthy fry. | | | |
| Male chum salmon and female coho salmon. | No fertile eggs recovered. | | | |
| Female chum salmon and male coho salmon. | Very poor - only 5 fry from 965 eggs. | | | |
| Female chum salmon and male Siberian char (Salmo leucomaenis). | | No viable fry. | | |
| Male chum salmon and female Siberian char. | | Less than 30-percent fry. | | |

the coloration of the normal pink salmon fry. From the same cross, Hikita and Yokohira (1964) found that about half the hybrids were greenish blue to dark green, and thus different from normal pink and chum salmon fry; the other half were light to darkish brown, and thus similar to the normal fry. Hybrids from the reciprocal cross (male chum salmon and female pink salmon) had coloration similar to normal fry. In hybrids from female chum salmon and male pink salmon, parr marks were variable; some had no parr marks (as in pink salmon), whereas in others, they were distinct (as in chum salmon). In hybrids from the male chum salmon and female pink salmon, all of the fry had parr marks similar to chum salmon.

Foerster (1935) and Terao Uchiyama, Kurahashi, and Matsumoto (1965) reared hybrids to sexual maturity and backcrossed them with normal species and with other hybrids (table 11).

Kamyshnaya (1961) described artificially produced hybrids (from female chum salmon and male pink salmon) that had gone to sea and returned to their natal stream, the Takoi River in Sakhalin. Female hybrids were larger than males and resembled chum salmon in weight and fecundity. Males attained maturity at age 0.1[3] and females at age 0.2. In all female hybrids the size of eggs varied. The author presented meristic and morphometric data for fry and adult hybrids.

Mature hybrids (from female pink salmon and male chum salmon) have also returned to the Hood Canal hatchery in Washington (Washington State Department of Fisheries, 1964). Survival to the adult stage was 2.1 percent of the number of fingerlings liberated and exceeded the survival of the pink salmon stock returning to the same hatchery. The hybrids returned at age 0.1 (2,390 males and 565 females) and age 0.2 (37 males and 295 females). The age 0.1 adults had more of the normal pink salmon characteristics than did the age 0.2 hybrids. Size of eggs ranged from normal for chum salmon to the normal for pink salmon. When the hybrids were backcrossed, the spawn had poor viability (egg-to-fry survival of about 8 percent) and could not be used to perpetuate the run.

#### 2.42 Influence of natural hybridization in ecology and morphology

Hybrids of chum and pink salmon occur in nature (Kusnetzov, 1928; Hunter, 1949) but are extremely rare (Neave, 1958).

[3] See section 3.12 for method of reporting ages.

## 3 BIONOMICS AND LIFE HISTORY

### 3.1 Reproduction

#### 3.11 Sexuality

Chum salmon are heterosexual. The mature male is distinguished from the mature female by a hooked snout and more fanglike teeth. Hermaphrodites are found occasionally (Hikita, 1958a; Uzmann and Hesselholt, 1958; Nakatsukasa, 1965).

#### 3.12 Maturity

Three systems have been used to record the ages of Pacific salmon: Gilbert and Rich, 1927; Chugunova, 1959; and Koo, 1962. The Gilbert and Rich method records age from time of egg deposition; the other methods record age from time of hatching. An additional year or winter is therefore incorporated into ages under the Gilbert and Rich system, which has been widely used for Pacific salmon in North America and Japan. In this synopsis, I use the Koo system because of the advantages listed byKoo (1962). This method uses two digits separated by a period; for example, age 1.2 indicates that a fish spent one winter in fresh water, two winters in the ocean, and was in its fourth year of life. Chum salmon never spend a winter in fresh water, so the first digit is always 0. A chum salmon with three annuli (fig. 3) is in its fourth year of life, and its age is reported as 0.3. In reporting the ages of mature salmon, Russian scientists have added a + to indicate that fish have undergone a summer's growth after the last annulus was laid down. The+ has been deleted from Soviet age data reported here.

Mature chum salmon range from age 0.1 to age 0.6 (see section 4.12). Age 0.3 fish are usually dominant, but in certain years and areas 0.2 fish are more abundant. Adult fish of age 0.2 and age 0.4 make up a significant part of the runs; age 0.1 and age 0.5 chum salmon are reported in only small numbers, and age 0.6 fish are rare. In Asia and North America, the more southern populations of maturing fish have larger percentages of younger fish; populations in more northern areas have larger percentages of older fish (Gilbert, 1922; Marr, 1943; Pritchard, 1943; Kobayashi, 1961; Oakley, 1966; Sano, 1966).

Sex ratios of chum salmon at maturity vary with age. Sano (1966) concluded that almost all maturing chum salmon of age 0.1 were males and that males outnumbered females at age 0.2. The sex ratio was nearly equal at age 0.3, but females tended to outnumber males in ages 0.4 and 0.5.

Table 11.--Results of backcrossing hybrids with normal species and with other hybrids

| Female | Male | Progeny survival | Authority |
|---|---|---|---|
| Species: | Hybrid from: | | |
| Sockeye salmon | Male chum salmon and female sockeye salmon. | Excellent hatch of fry | Foerster (1935). |
| Do. | Male sockeye salmon and female chum salmon. | do. | Do. |
| Do. | Male chum salmon and female pink salmon. | do. | Do. |
| Hybrid from: | | | |
| Male chinook salmon and female chum salmon. | Male chinook salmon and female sockeye salmon. | No fertilization | Do. |
| Male chum salmon and female sockeye salmon. | Male chinook salmon and female chum salmon. | do. | Do. |
| Male chink salmon and female sockeye salmon. | Male chum salmon and female pink salmon. | Good hatch | Do. |
| Male chum salmon and female sockeye salmon. | Male chinook salmon and female chum salmon. | do. | Do. |
| Do. | Male sockeye salmon and female chum salmon. | do. | Do. |
| Do. | Male chum salmon and female pink salmon. | do. | Do. |
| Do. | Male chum salmon and female sockeye salmon. | do. | Do. |
| | Species: | | |
| Female chum salmon and male kokanee. | Chum salmon | 74-percent hatch of fry | Terao et al. (1965). |
| Do, | do. | 68-percent hatch of fry | Do. |
| Female kokanee and male chum salmon. | do. | 75-percent hatch of fry | Do. |
| Species: | Hybrid from: | | |
| Chum salmon | Female kokanee and male chum salmon. | 79-percent hatch of fry | Do. |
| Hybrid from: | | | |
| Female chum salmon and male kokanee. | Female chum salmon and male kokanee. | 25-percent hatch of fry | Do. |

Figure 3.--Scale of 0.3 chum salmon, captured July 30, 1963, in offshore waters of the North Pacific Ocean.

The length and weight of chum salmon at maturity (table 12) indicate that most Asian chum salmon are 45 to 96 cm. long and weigh 1.0 to 11.9 kg. and that most NorthAmerican fish are 53 to 92 cm. long and weigh 0.8 to 13.4 kg. Mature chum salmon under 50 cm. appear to be more common in Asia than in North America. The maximum length and weight for mature chum salmon is about 100 cm. and 20 kg. (L[illegible], 1948).

### 3.13 Mating

Promiscuous, male fish frequently attend more than one female (K[illegible], 1928; Hunter, 1959; S[illegible], 1963).

### 3.14 Fertilization

External; ova and sperm are ejected simultaneously into a depression excavated by the female in [illegible] gravel.

Yamamoto (1952) described the fertilization process in chum salmon. The area at which the spermatozoan enters the egg is marked by a funnel-shaped depression. P[illegible] the spermatozoan takes place when the female nucleus is in the metaphase stage of the second maturation division; the fact that one [illegible] has already been extruded from the female nucleus indicates that maturation of the egg is activated by water before insemination. About 1 hour after insemination, a sperm aster develops at the base of the head of the spermatozoan and the second polar division of the female nucleus proceeds to the [illegible] stage. After extrusion of the second [illegible], the chromosome mass begins its conversion into the vesicular female [illegible]. The head of the spermatozoan completes its metamorphosis into the male [illegible] at the same time and migrates from the margin toward the center of the egg accompanied by the sperm aster. The movement of the male nucleus starts about 2 1/2 hours after ins[illegible] and is completed in about 30 minutes. After completing its metamorphosis at about 3 hours after insemination, the female [illegible] begins its migration toward the male [illegible]. This movement also takes about 30 minutes. Conjugation of the [illegible] generally takes place within 3 1/2 to 4 hours after insemination. The first cleavage spindle appears about 8 hours or more after insemination.

### 3.15 Gonads

N[illegible] (1948) discussed the relation between the number of eggs produced by species of Oncorhynchus and the differences in their life histories which regulate the stability in relative abundance between the species. Only species with many eggs and relatively favorable

Table 12.--R[illegible] in length and weight of chum salmon at maturity in Asia and North America

| Area | Y[illegible] | Sample size | Fork length | Weight | Authority |
|---|---|---|---|---|---|
| | | Number | Cm. | Kg. | |
| *Asia:* | | | | | |
| Okhotsk coast | 1948, 1952-53 | 3,353+ | 45-78 | | B[illegible] (1956). |
| Amur River | 1925-27, 1933 | 10,848 | 48-96 | 1.2-11.9 | K[illegible] (1928). |
| | 1948-49, 1952-53 | 19,013+ | 45-90 | | B[illegible] (1956). |
| Sakhalin | 1946-49 | 2,397 | 45-82 | 1.1- 6.8 | D[illegible] (1952). |
| Primore (Tumnin River) | 1948-49 | 515 | 55-85 | | Birman (1956). |
| Hokkaido | 1956, 1958-59 | 852 | | 1.0-10.4 | (1) |
| Honshu (Miomote River) | 1936 | | 50-90 | 1.0- 8.0 | K[illegible] (1938). |
| North America: | | | | | |
| Northwest Alaska | 1920 | 448 | 53-80 | 1.8- 5.9 | Gilbert (1922). |
| | 1955-59 | 1,324 | | 1.4- 5.8 | (1) |
| Central Alaska | 1955-59 | 1,603 | | 0.8- 8.2 | (1) |
| Southeastern Alaska | 1955-59 | 1,913 | | 1.8-10.8 | (1) |
| British Columbia | 1916-17 | 1,024 | 53-84 | 1.8- 4.9 | Fraser (1921) |
| | 1955-59 | 1,784 | | 1.2-13.4 | (1) |
| Washington and Oregon | 1910, 1914, 1947-61 | 3,721 | 56-92 | | Gilbert (1913); M[illegible] (1943); Oakley (1966). |
| | 1955-59 | 410 | | 1.8- 8.6 | (1) |

[1] Data on *file,* Bureau *of* Commercial Fisheries, Biological Laboratory, Seattle, Wash. 98102.

conditions for incubation can withstand the mortality imposed by a prolonged fresh-water existence (sockeye and coho salmon spend a year or more in fresh water before migrating to sea). Species with fewer eggs and les s stable spawning grounds must migrate to sea soon after emerging from the gravel to maintain their abundance (chum and pink salmon).

The weight of the female sexual products in chum salmon exceeds that of the male (Lovetskaya, 1948). The weight of the female gonad in relation to the total weight of the fish in some Kamchatkan streams was 16.6 percent for age 0.2 fish, 14.0 percent for age 0.3 fish, and 14.6 percent for age 0.4 fish (Semko, 1954). The average for all ages was 14.3 percent. Eguchi, Hikita, and Nishida (1954) could not demonstrate a significant difference in egg count between the left and right ovaries of individual specimens. For a sample of 243 chum salmon, the averages were 1,134 in the left ovary and 1,146 in the right.

The fecundity of chum salmon ranges from about 900 to 8,000 eggs (table 13). Meanfecundities of samples from North America and Asia are about 2,000 to over 4,000 eggs; most are 2,000 to 3,000 eggs. In Asia, autumn chum salmon show a wide range in average fecundities (2,500 to 4,300), whereas summer chum salmon have a lower and much narrower range (about 2,000 to 2,550).

Fecundity varies among individuals, localities, and years; variation within the same population is considerable (table 13). Although reasons for these variations have not been fully investigated, Watanabe (1955) showed that /ecundity increases with length, and Lovetskaya (1948) found that the number of eggs increases with length and weight. Rounsefell (19 57 ) and Belyanina (1963) have shown the length-fecundity relation to be linear.

The number of eggs per unit of body weight generally is greater in relatively small and young fish and decreases proportionally in relatively large and old fish (Semko, 1954; Watanabe, 1955). Watanabe (1955) also found that the size of eggs generally increases with body length. Studies of the size of eggs from unspawned females sampled along the North American coast (table 14) showed that egg diameters increase from north to south within an age group and that they increase in older fish. The latitudinal differences as well as the differences by age group may actually be a function of fish size because it is known that older fish are larger and that, within an age group, size of fish increases from north to south.

Whether total fecundity varies with age is not clear. Sano and Nagasawa (1958) found an average of 2,171 eggs for age 0.2 chum salmon, 2,905 eggs for age 0.3, and 3,160 eggs for age 0.4 in the Memu River of Hokkaido, but their sample size was small (29 fish). Mattson and Rowland (1963)[4] and Mattson, Rowland, and Hobart (1964)[5] could not demonstrate a significant difference in fecundity of age 0.2, 0.3 and 0.4 chum salmon from a southeastern Alaska stream. Mean fecundities were:

| Year | Age | Number of fish | Mean fecundity |
|---|---|---|---|
| 1963 | 0.3 | 19 | 2,911 |
| 1963 | 0.4 | 32 | 2,804 |
| 1964 | 0.2 | 11 | 2,794 |
| 1964 | 0.3 | 54 | 3,052 |
| 1964 | 0.4 | 7 | 3,075 |

Smirnov (1963) studied production of spermatozoa from artificially spawned chum salmon. When the males were kept alive, they could be stripped of milt several times; fertile spermatozoa were produced for as long as 26 days. Males, from 55 to 67 cm. long, had a total volume of spermatozoa of 37.1 to 133.6 $cm.^3$ over the complete period of spermatozoa production. Spermatozoa per cubic millimeter of sperm averaged 24.1 million, and the total number of spermatozoa per stripping was 220 billion. Smirnov concluded that the long duration of sperm production allows males to spawn with more than one female.

### 3.16 Spawning

All species of Oncorhynchus die after spawning. They return to spawn in the stream from which they originated. Neave (1966) concluded that chum salmon share the strong homing tendencies of other species of Pacific salmon but that the frequency of departure from this habit has not been thoroughly examined in North America. In Asia, the return of chum salmon to their home stream is considered well established (Semko, 1954; Sano, 1966).

Conditions that influence the entry of maturing chum salmon into spawning streams are not entirely defined but some information is available. Mihara, Ito, Hachiya, and Ichikawa (1951) stated that chum salmon enter Japanese streams when temperatures drop to 15 C. and that most enter when the water temperatures are 10 to 12 C. Temperatures during the peaks of migration varied from 7° to 11 C.

[4] Mattson, Chester R., and Richard G. Rowland. 1963. Chum salmon studies at Traitors Cove Field Station--June 1960 to March 1963. Bur. Commer. Fish., Biol. Lab., Auke Bay, Alaska, Ms. Rep. 63-11, 32 pp. (Processed.)

[5] Mattson, Chester R., Richard G. Rowland, and Richard A. Hobart. 1964. Chum salmon studies in southeastern Alaska, 1963. Bur. Commer. Fish., Biol. Lab., Auke Bay, Alaska, Ms. Rep. 64-8, 22 pp. (Processed.)

Table 13.--Fecundity of chum salmon in Asia and North America

| Area | Year(s) | Sample size | Fecundity | | Authority |
|---|---|---|---|---|---|
| | | | Mean | Range in dividual fish | |
| | | Number of fish | Number of eggs | | |
| North America: | | | | | |
| Alaska: | | | | | |
| Prince William Sound | 1959 | 34 | 2,935 | 2,118-3,852 | Helle (1960). |
| Southeastern | 1959 | 296 | 2,763 | -- | Mattson and Hobart (1962).[1] |
| Do. | 1960 | 217 | 2,858 | -- | Do. |
| Do. | 1961 | 609 | 2,494 | 1,100-3,700 | Do. |
| British Columbia: | | | | | |
| Hook Nose Creek | 1947 | 85 | 2,107 | | Hunter (1959). |
| Do. | 1948 | 8 | 2,101 | | Do. |
| Do. | 1949 | 13 | 2,083 | | Do. |
| Do. | 1950 | 19 | 2,406 | | Do. |
| Do. | 1951 | 11 | 2,201 | | Do. |
| Do. | 1952 | 6 | 2,728 | | Do. |
| Do. | 1953 | 35 | 2,741 | | Do. |
| Do. | 1954 | 22 | 3,097 | | Do. |
| Do. | 1955 | 8 | 2,604 | | Do. |
| Do. | 1956 | 31 | 2,613 | | Do. |
| Port John Creek | 1947-48 | 94 | 2,107 | | Hunter (1948, 1949). |
| Namu | 1934 | 21 | 2,760 | | Foerster and Pritchard (1936). |
| Nile Creek | -- | 47 | 2,726 | | Neave (1953). |
| Fraser River | 1934 | 51 | 2,943 | | Foerster and Pritchard (1936). |
| Asia: | | | | | |
| U.S.S.R.: | | | | | |
| Bolshaya River | 1943 | | 2,400 | | Semko (1954). |
| Do. | 1944 | | 2,379 | | Do. |
| Do. | 1945 | | 2,160 | | Do. |
| Do. | 1946 | | 2,423 | | Do. |
| Do. | 1947 | | 2,424 | | Do. |
| Do. | 1948 | | 2,480 | | Do. |
| Do. | 1949 | | 2,038 | | Do. |
| Do. | 1950 | | 2,296 | | Do. |
| Amur River | | | | | |
| Summer runs | | | | | |
| Several tributaries | 1927 | 27 | 2,551 | 1,462-3,233 | Lovetskaya (1948). |
| Do. | 1929 | 9 | 2,097 | 1,900-2,692 | Do. |
| Do. | 1930 | 35 | 2,300 | 1,583-3,325 | Do. |
| My River | 1950 | -- | 2,205 | -- | Svetovidova (1961). |
| Do. | 1951 | | 2,282 | | Do. |
| Do. | 1952 | | 2,477 | | Do. |
| Do. | 1953 | | 2,214 | | Do. |
| Do. | 1954 | | 2,362 | | Do. |
| Do. | 1955 | | 2,373 | | Do. |
| Ul River | 1951 | | 2,151 | | Do. |
| Do. | 1952 | | 2,364 | | Do. |
| Do. | 1953 | | 2,060 | | Do. |
| Do. | 1954 | | 2,372 | | Do. |
| Do. | 1955 | | 2,247 | | Do. |
| Beshenaia River | 1949 | | 2,062 | | Do. |
| Do. | 1950 | | 2,306 | | Do. |
| Do. | 1951 | | 2,247 | | Do. |
| Do. | 1952 | | 2,434 | | Do. |
| Do. | 1953 | | 2,277 | | Do. |
| Do. | 1954 | | 2,295 | | Do. |
| Do. | 1955 | | 2,280 | | Do. |
| Autumn runs | | | | | |
| Several tributaries | 1925 | 72 | 4,316 | 2,000-5,906 | Kuznetsov (1928). |
| Do. | 1926 | -- | 4,278 | 2,636-6,439 | Do. |
| Do. | 1927 | 7 | 3,698 | 2,948-4,345 | Lovetskaya (1948). |
| Do. | 1928 | 43 | 4,046 | 2,786-5,477 | Do. |
| Do. | 1929 | 20 | 2,777 | 1,771-3,374 | Do. |
| Sakhalin: | | | | | |
| Summer runs | 1946-47 | | 2,366 | 1,254-3,528 | .Dvinin (1952). |
| Autumn runs | | | 2,505 | 1,712-3,928 | Do. |

See footnote at end of table.

Table 13.--Fecundity of chum salmon in Asia and North America-- Continued

| Area | Year(s) | Sample size | Fecundity | | Authority |
|---|---|---|---|---|---|
| | | | Mean | Range in individual fish | |
| | | Number of fish | Number of eggs | | |
| Asia--Continued | | | | | |
| Kurile Islands: | | | | | |
| Nikishiro River | 1939-40 | 40 | 1,800 | 997-2,633 | Eguchi et al., 1954. |
| Betsutobu River | | 20 | 1,959 | 1,540-2,485 | Do. |
| Betsusama River | " | 17 | 2,162 | 1,594-3,414 | Do. |
| Toro River | " | 19 | 2,044 | 1,365-2,779 | Do. |
| Shibetoro River | " | 36 | 2,110 | 1,546-3,320 | Do. |
| Hokkaido: | | | | | |
| Tonbetsu River | 1939-40 | 18 | 2,497 | 1,654-3,015 | Eguchi et al., (1954); Sano (1966). |
| Teshio River | 1939-40 | 19 | 2,825 | 1,967-3,103 | Do. |
| Do. | 1955-58 | 44 | 3,023 | 1,759-4,835 | Do. |
| Tokoro River | 1955-58 | 69 | 3,043 | 1,275-4,379 | Do. |
| Abashiri River | 1939-40 | 20 | 2,825 | 2,247-3,458 | Do. |
| Iwaobetsu River | 1955-58 | 51 | 2,544 | 909-4,959 | Do. |
| Shibetsu River | 1939-40 | 20 | 2,114 | 1,368-3,105 | Do. |
| Nishibetsu River | 1955-58 | 57 | 2,562 | 1,259-3,508 | Do. |
| Ishikari River | 1955-58 | 86 | 3,293 | 1,575-4,644 | Do. |
| Tokachi River | 1939-40 | 20 | 2,813 | 1,733-4,188 | Do. |
| Do. | 1955-58 | 79 | 2,951 | 1,274-4,768 | Do. |
| Yurappu River | 1955-58 | 24 | 3,361 | 2,625-4,627 | Do. |
| Shiriuchi River | 1955-58 | 18 | 3,740 | 1,945-7,779 | Do. |

Mattson, Chester R., and Richard A. Hobart. 1962. Chum salmon studies in southeastern Alaska, 1961. Bur. Commer. Fish., Biol. Lab., Auke Bay, Alaska, MS. Rep. 62-5, 32 pp. (Processed.)

Table 14.--Mean size and range in size of chum salmon eggs from unspawned females sampled along the North American coast in 1958-59

| Area | Mean diameter | | | Range in diameters | | | Fish sampled | | |
|---|---|---|---|---|---|---|---|---|---|
| | Age | | | Age | | | Age | | |
| | 0.2 | 0.3 | 0.4 | 0.2 | 0.3 | 0.4 | 0.2 | 0.3 | 0.4 |
| | Mm. | | | Mm. | | | Number | | |
| Alaska: | | | | | | | | | |
| Kotzebue Sound | 4.7 | 5.6 | 6.0 | 4-5 | 5-6 | 6 | 13 | 27 | 6 |
| Kuskokwim River | 5.2 | 5.8 | 6.5 | 4-7 | 5-7 | 6-7 | 51 | 56 | 6 |
| Bristol Bay | 5.6 | 5.9 | -- | 5-7 | 5-7 | -- | 88 | 37 | -- |
| Alaska Peninsula | 5.9 | 6.5 | 6.5 | 4-7 | 4-8 | 5-7 | 16 | 46 | 15 |
| Kodiak Island | 6.6 | 7.0 | -- | 5-8 | 5-9 | -- | 9 | 66 | -- |
| Cook Inlet | -- | 6.3 | 7.0 | -- | 5-7 | 6-8 | -- | 67 | 12 |
| Petersburg | | 7.2 | 7.4 | | 6-9 | 7-9 | | 67 | 20 |
| Ketchikan | | 7.0 | 7.8 | | 6-8 | 6-9 | | 51 | 37 |
| British Columbia: | | | | | | | | | |
| Skeena River | 6.7 | 7.4 | 7.7 | 5-8 | 5-9 | 7-8 | 20 | 77 | 7 |
| Rivers Inlet | 7.1 | 7.0 | 7.3 | 5-8 | 5-9 | 7-8 | 18 | 47 | 3 |
| Fraser River | 7.0 | 7.5 | -- | 6-8 | 6-9 | -- | 42 | 52 | |
| Washington: | | | | | | | | | |
| Skagit River | 7.3 | 7.8 | | 7-8 | 7-9 | | 34 | 22 | |

Data on file, Bureau of Commercial Fisheries Biological Laboratory, 2725 Montlake Boulevard East, Seattle, Wash. 98102. Egg diameters were obtained by measuring three or four eggs to the nearest millimeter from the midsection of the gonad of each female.

(Sano, 1966). At Hook Nose Creek, British Columbia, chum salmon migrating upstream responded most readily to high flows but were not dependent on them (Hunter, 1959). If flood levels were excessive the fish did not enter the stream and appeared to travel only against currents below a maximum level. Helle (1960) noted an absence of chum salmon i a glacially fed stream until flows had decreased and the water had been cleared of silt, even though the species was spawning in adjacent streams.

Most chum salmon spawn from June to January. Northern populations spawnbefore the end of August or the beginning of September; southern populations, after this period (Sano, 1966; Atkinson et al., 1967). Northern populations have peak periods of spawning in August or early September; southern populations, in October or November. The tendency for more northerly runs to spawn earlier is probably related to the relatively low temperatures during the egg stage which would lengthen the incubation period over that in more temperate streams (Committee on Biology and Research, 1961).

Chum salmon spawn in streams ranging from short coastal streams, where the adults may spawn within the tidal zone, to large river systems, such as the Amur River in the U.S.S.R. and the Yukon River in Alaska, where adults are known to migrate upstream over 2,500 km. Spawning takes place in 160 streams in Hokkaido, 1,270 streams in the United States, and at least 880 streams in Canada (Japan Fisheries Resource Conservation Association, 1966; Atkinson et al., 1967; Aro and Shepard, 1967). Of spawning streams in Hokkaido, 6 are more than 100 km. long, 12 are about 100 km. long, and most of the remaining streams less than 50 km. long. Most chum salmon spawn above the reaches of salt water and within 200 km. of the sea.

Characteristics of stream areas selected by chum salmon for spawning have been measured in some streams. In Hokkaido streams and the Amur River, they generally select areas with upwelling springs where winter temperatures exceed 4° C., thus protecting the eggs from freezing (Sano, 1966). Freezing of chum salmon eggs is an important cause of mortality at times in Alaska and the Okhotsk Sea area (McNeil, 1966; Sano, 1967). Water velocities selected by autumn chum salmon in Hokkaido were 10 to 20 cm./sec. (centimeters per second) (Sano and Nagasawa, 1958); summer chum salmon in the My River spawned in velocities of 10 to 100 cm./sec. (Soin, 1954; Strekalova, 1963). Water depths at spawning sites were about 20 to 110 cm. for chum salmon in Hokkaido (Sano, 1959) and from 30 to 100 cm. for chum salmon in the My River (Soin, 1954). The streambeds selected for spawning in Hokkaido had gravel sizes which averaged 25 percent less then 0.5 cm., 45 percent from 0.6 to 3.0 cm., and 30 percent greater then 3.1 cm. (Sano, 1959). In tributaries of the Columbia River, Burner (1951) found material in redds that consisted of gravel greater than 15 cm. (13 percent), 15 cm. or less (81 percent), and silt and sand (6 percent). In the My River, chum salmon spawned predominantly near the banks where the streambed consisted of gravel mixed with sand and small quantities of silt (Soin, 1954).

Sex ratios have been shown to change during the spawning migration, but for the entire period of migration they approached 1:1. Males predominated in the early part of the run and females in the later part (Gilbert, 1922; Marr, 1943; Henry, 1954; Semko, 1954). Sernko (1954) also found that sex ratios changed in this manner within age groups although the relation was not pronounced. On the spawning ground, the proportion of females was 47.0 percent for one year in a coastal stream of southeastern Alaska [Mattson, et al., 1964 (see footnote 5)]. In Hook Nose Creek, British Columbia, the proportion of females ranged from 43.7 to 55.4 percent (average 51 percent) in 10 years (Hunter, 1959) and in tributaries of Tillamook Bay, Oregon, from 49 to 77 percent (average 58 percent) in 7 years (Oakley, 1966). Oakley found a greater proportion of males in the commercial catch than in the escapement, which indicated that the selectivity of the fishing gear may have influenced the sex ratio in the streams he sampled.

The mating act is shown and described in figure 4. These excellent photographs (Sano and Nagasawa, 1958) were made by placing a pair of adults in a glass-walled tank, 150 cm. long, 80 cm. wide, and 60 cm. deep. Although the spawning took place in an artificial environment, it appears to approximate the behavior in natural streams.

Mattson and Rowland (1963, see footnote 4) observed two phases of spawning activity for males after they had chosen mates: spawning, which lasted 2 to 5 days; and expiration, which lasted 1 to 5 days. During the expirationphase courting and active attendance of the redd ceased, territorialism broke down, and, if the females were still active, other males moved in without opposition.

Females passed through three spawning phases: Phase 1, spawning lasted 2 to 4 days and consisted of preparation of the redd, deposition of eggs, guarding of the redd, and association with one or more males; phase 2, postspawning which lasted less than 1 to as much as 5 days--spawning ceased even though males were still in attendance and females guarded the redds against intruding females; phase 3, expiration which lasted 1 to 6 days--

Figure 4.--Construction of redd and spawning behavior of chum salmon (Sano and Naga sa wa , 1958).

(a) Male (foreground) and female before redd construction.

(b) Female digging redd by turning on side, rapidly flexing body, and fanning streambed with caudal fin. The female excavated the redd alone and repeated the digging motion every 1 to 5 minutes.

(c) From time to time during redd construction, the male came in contact with the female and exhibited body spasms which appeared to excite the female.

(d) As the redd building approached its completion, the male and female circled above the redd.

(e) To start the spawning act, the male and female lowered their bodies into the redd.

(f) In the spawning act, both the male and female exhibited body spasms as the sperm and eggs were released. Their mouths, fins, and opercula were extended.

(g) Front view of spawning act which lasted 5 to 10 seconds. The act was repeated until the female had ejected all of her eggs.

(h) Female covered the eggs after spawning.

females were no longer attended by males and passively guarded the redds. Strekalova (1963) reported that females guarded the redds 1 to 6 days (average 3 to 4 days) after depositing their eggs in the My River, U.S.S.R.

Egg retention (table 15) has not generally been considered an important cause of egg loss. Sernko (1954) presented data to show that egg retention can increase when spawning density is high:

| Year | Eggs retained per female | Total eggs deposited[6] |
|---|---|---|
| 1947 | 290 | 68,280 |
| 1948 | 45 | 16,050 |
| 1949 | 20 | 3,730 |
| 1950 | 28 | 2,940 |

Lister and Walker (1966) also reported an increased egg retention (24.5 percent) in a year of relatively high spawning density in the Big Qualicum River, British Columbia.

[6] The size of area in which these eggs were deposited was not given.

Eggs have been spawned at depths of 12 to 35 cm. below the surface of the gravel (Kuznetsov, 1928; Myren, Williamson, and Olson, 1959;[7] Vasilev, 1959). These eggs were deposited in two to four pockets which were parallel with the current. One egg pocket was 7.6 cm. deep and 15.2 cm. wide; the eggs were mixed with coarse sand and gravel rather than in a compact cluster [Myren, et al., 1959 (see footnote [7])].

As reported by Kuznetsov (1928), redds of autumn chum salmon were 125 to 320 cm. long and 106 to 213 cm. wide. The redd area averaged 1.3 m.$^2$ for summer chum salmon in one Asian stream (Vasilev, 1959), and 2.3 m.$^2$ for autumn chum salmon in four small North American streams (Burner, 1951).

[7] Myren, R. T., R. S. Williamson, and J. M. Olson. 1959. Salmon survival investigations. U.S. Fish. Wildl. Serv., Bur. Commer. Fish., Alaska Region (Juneau), Operations Rep. - July 1, 1958 to Feb. 3, 1959, with notes on 1957 studies. 44 pp. (Processed.)

T[illegible] 15.--E[illegible] A[illegible] N[illegible] A[illegible]

| A[illegible] | Y[illegible] | A[illegible] | | A[illegible] |
|---|---|---|---|---|
| | | N[illegible] | P[illegible] | |
| T[illegible] B[illegible], O[illegible]. | | <100 | | H[illegible] (1953). |
| H[illegible] N[illegible] C[illegible], B[illegible] C[illegible] | 1951 | 104.1 | 4.7 | H[illegible] (1959). |
| D[illegible]. | 1952 | 12.8 | 0.5 | D[illegible]. |
| D[illegible]. | 1953 | 18.2 | 0.7 | D[illegible]. |
| D[illegible]. | 1954 | 35.5 | 1.2 | D[illegible]. |
| D[illegible]. | 1955 | 5.4 | 0.2 | D[illegible]. |
| D[illegible]. | 1956 | 39.4 | 1.5 | D[illegible]. |
| B[illegible] Qualicum R[illegible], B[illegible] C[illegible] | 1959 | | 24.5 | L[illegible] W[illegible] (1966). |
| D[illegible]. | 1960 | | 5.0 | D[illegible]. |
| D[illegible]. | 1961 | | 4.4 | D[illegible]. |
| D[illegible]. | 1962 | | 5.5 | D[illegible]. |
| D[illegible]. | 1963 | | 2.7 | D[illegible]. |
| D[illegible] | 1964 | | 2.8 | D[illegible]. |
| Memu R[illegible], H[illegible] | 1957 | | 3.4 | N[illegible] S[illegible] (1961). |
| D[illegible]. | 1958 | | 4.7 | D[illegible]. |
| D[illegible]. | 1959 | | 6.1 | D[illegible]. |
| Memu [illegible] N[illegible] R[illegible], H[illegible] | 1954-56 | 45 | 1.5 | S[illegible] (1966). |
| A[illegible] R[illegible], U.S.S.R. | | | 0.5-1.5 | L[illegible] (1954). |

3.17 S[illegible]

D[illegible]: [illegible] 6.0 [illegible] 9.5 [illegible]., [illegible] 220 [illegible] 230 [illegible]. [S[illegible], 1954; W[illegible], 1955; M[illegible] H[illegible], 1956; M[illegible] R[illegible], 1963 ([illegible] 4)].

Y[illegible] (1952) [illegible]. T[illegible] --[illegible]. T[illegible] 20μ ([illegible]). T[illegible], [illegible], [illegible]. H[illegible] (1957) [illegible]: T[illegible] -[illegible]. B[illegible]. T[illegible]. T[illegible] (Y[illegible], 1952).

A[illegible]. S[illegible] (1954) [illegible] 3.5 [illegible]-[illegible]. U[illegible] 2 [illegible] (H[illegible], 1957). T[illegible]-[illegible]

[illegible], [illegible]. W[illegible], [illegible] (O[illegible], I[illegible], [illegible] K[illegible], 1956). A[illegible] 11 [illegible] 12° C., [illegible] 8 hours [illegible]; [illegible] 17 [illegible] 18 C., [illegible] 1 [illegible].

V[illegible]. F[illegible] (B[illegible], 1951). E[illegible] 72 [illegible] 2.5 [illegible] 5.8 C. [illegible] 90-[illegible] 22 [illegible] 24 [illegible]. A[illegible] 108 [illegible], [illegible] 80 [illegible] 32 [illegible] 36 [illegible]. T[illegible] 15 [illegible] 8 [illegible].

T[illegible] simple- [illegible], [illegible], [illegible]. T[illegible] 10 [illegible]; [illegible] 36μ. (Y[illegible], 1952; O[illegible] I[illegible], 1955). S[illegible] 30 [illegible] 60 [illegible] (O[illegible] I[illegible], 1955). S[illegible] 60 [illegible] 90 [illegible] 15° C.

Okado and Ito (1955) found that the viability of spermatozoa after stripping varied with temperature; the spermatozoa were viable for about 4 hours at 33° C. and about 7 days at 5° C. Barrett (1951) concluded that spermatozoa could be stored at 2.5° to 5.8° C. for at least 36 hours with low mortality.

## 3.2 Preadult phase

### 3.21 Embryonic phase

Mahon and Hoar (1956) described the development of the embryo from the first cleavage furrow through closure of the blastopore. Their paper contains photographs of transverse sections through the developing embryo and shows morphological changes in detail. They also have photographs that show gross stages of development (fig. 5).

When the embryo is 6 mm.long and the blastopore is closed, the main organ systems have been laid down (Mahon and Hoar, 1956). Later development is shown and described in figure 6. Eggs used in this study were older than those used in the previous description because of the lower average temperature (3.4° C.) at which they developed.

Toward the end of the embryonic period, the egg shell is softened (by secretions from hatching glands in the epidermis of the embryo) to facilitate hatching (Nishida, 1953; Disler, 1954). Movement of the embryo breaks the softened shell and the larva emerges.

The rate of embryonic development depends primarily on temperature; this relation has not been precisely described for chum salmon. Table 16 shows how temperature affects the rate of development and indicates that the time from fertilization to hatching can range from about 1.5 to 4.5 months.

Alderdice, Wickett, and Brett (1958) have shown that dissolved oxygen also can influence rate of development. The mean rate of hatching was delayed in eggs exposed to oxygen below air-saturation at 10° C. for 7 days at four developmental stages. The delay was greatest when eggs were exposed during early stages (between 100 and 200 C. thermal units) and dropped at about the time blood circulation within the egg was established. After the circulatory system became functional, the eggs could no longer survive extreme hypoxial conditions. Eggs in advanced developmental stages were stimulated to hatch prematurely by low concentrations of oxygen.

Soin (1954) reported that light may also slow the development of the embryo.

Poor environment is the principal cause of mortality of chum salmon eggs in natural streams (See section 4.42 for a discussion of specific factors). The one factor which directly or indirectly contributes most heavily to mortality has been fluctuation in streamflow, which may cause mortality directly by erosion, by shifting of gravel, or by leaving redds dry. Indirectly, flooding causes mortality by deposition of silt on spawning areas, which prevents water from seeping through the gravel at a satisfactory rate to supply the eggs with oxygen and remove waste products. Other factors that contribute to mortality are freezing, light, parasites, predation, high salinity, shock, and superimposition of redds.

Most of the mortality from egg fertilization to early fry stage occurs in the embryonic period; it varies from about 70 to over 90 percent (see section 4.31).

### 3.22 Larval phase (Alevin)

The larval phase (a salmon is commonly referred to as an alevin in this stage) covers the period from hatching to emergence from the gravel. Disler (1954) described the development of chum salmon in this phase (table 17) and separated the phase into two parts. In the first part food was derived solely from the yolk sac, whereas in the second part some external food was taken. Food organisms found in alevins were Diptera larvae, diatoms, and cyclops (Disler, 1953). The yolk sac was considered the main source of nutrition throughout the phase.

Alevins remain in the gravel until their yolk sacs are completely or almost completely absorbed. The alevin phase is completed in 30 to 50 days, depending on the water temperature; mortality in this stage averaged 9.7 percent in the Memu River, Hokkaido (Sano, 1966).

### 3.23 Adolescent phase

Life history stages of Pacific salmon do not fit some of the terminology proposed for FAO synopses by Rosa (1965). Biologists at the Bureau of Commercial Fisheries Biological Laboratory, Seattle, Wash., who prepared synopses on salmon, therefore decided to separate the adolescent phase into two stages: the fresh-water stage which begins as they emerge from the gravel and ends as they enter the sea; and the salt-water stage which lasts from entry into salt water to the year in which they reach maturity. We considered the adult phase to begin on January 1 of the year in which the fish spawns. The fresh-water stage of chum salmon lasts from a few days to several weeks; the salt-water stage is about 6 months for fish

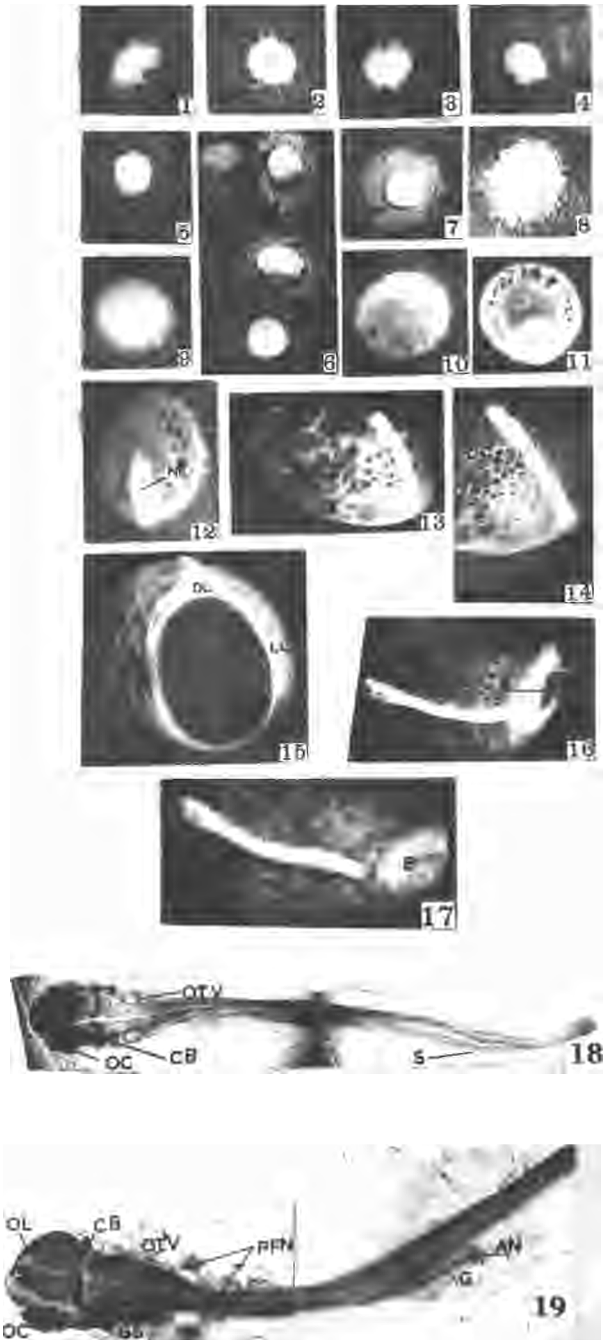


Figure 5.--Early development of the chum salmon embryo (photographs and description of photographs from figs. 1-17, 27, and 77 of Mahon and Hoar, 1956).

Photographs 1 to 19. Gross appearance of blastoderm and embryo in fixed fertilized egg after removal of chorion. Age from time of fertilization; magnification, X 10.

1. Unsegmented blastodisc. 5 hours, 7.6 C. (Note irregular shape of protoplasm.)
2. Unsegmented blastodisc showing protoplasm regular in outline and somewhat elevated. 12.5 hours, 7.4° C.
3. Two celled stage showing first cleavage furrow. 18.5 hours, 7.2° C.
4. Four celled stage. Note CM (coagulated material) due to Bouin's fixative on surface of yolk. 21 hours, 7.2 C.
5. Eight celled stage. 28 hours, 7.5 C.
6. A composite picture of the 8, 16, 32 and later segmentation stage (probably 64 cells). 12 to 16 celled stages are found from 31 to 39 hours after fertilization at 7.2° C., and 32- to 64-celled stages from 39 to 50 hours at same temperature.
7. Later segmentation stage. Note prominent MP (marginal periblast). 56 hours, 7.1° C.

8. and 9. Blastulae, 5 and 6 days, respectively, 7.0° C. Blastoderm has begun to spread over yolk, and marginal periblast diminishes in extent.

10. Formation of GR (germ ring). Note thickening on one side indicating future location of embryonic shield. Blastoderm 3 mm. in diameter, 9 days, 6.0° C.
11. Embryonic shield stage, 3.5 mm. in diameter; the caudal knob which is so prominent in photograph 12 is just appearing; 10 days, 20 hours, 5.9° C.
12. Early embryo formation. Blastoderm 4 to 5mm. in diameter; embryo 1.5 mm. in length; note prominent CK (caudal knob) and transitory NF (neural furrow). 11 days, 21 hours, 5.9° C.
13. 3-mm. embryo. Due to epiboly, the advancing GR (germ ring) covers almost one-half the yolk. 14 days, 20 hours, 6.4° C.
14. 5-mm. embryo. The OC (optic cups) and otic vesicles (not clearly defined in photomicrograph) were well developed at this stage; 20 days, 21 hours, 5.8 C.
15. Oval opening of blastopore showing DL, LL, VL (dorsal, lateral, and ventral lips, respectively) formed by germ ring. Dorsal lip is proximal to tail bud region of embryo. Embryo is same age as embryo in photograph 14, but epiboly had advanced to a greater degree.
16. 5.3-mm. embryo. B (blastopore) almost closed; head slightly raised from yolk. 21 days, 20 hours, 4.0 C.
17. 5.5-mm. embryo. B (blastopore) closed; head and tail freed from yolk. 23 days, 20 hours, 3.9° C.
18. 5.5-mm. embryo. OC (optic cup); OTV (otic vesicle); CB (cerebellum); S (somites). X 18.
19. 6.5-mm. embryo. Compare with photograph 18; additional features are cranial and cervical flexures, elaborate configuration of brain showing CB (cerebellum) and OL (optic lobe), PFN (pectoral fins), GS (gill slits), larger number of somites, G (gut), and AN (anal region). X 18.

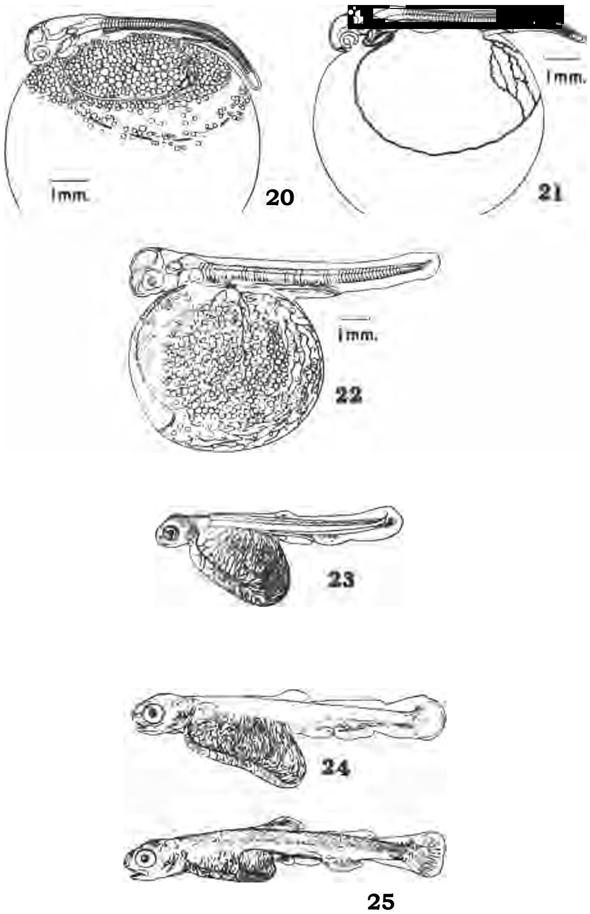


Figure 6.--Development of the chum salmon embryo from closure of the blastopore through the alevin stage (Photographs and description from Disler, 1954).

20. Embryo at 65-somite stage; 45 days of development; beginning of blood circulation.
21. Embryo at 72-segment stage; 50 days of development; beginning of differentiation of yolk-vascular system.
22. Embryo at 11-mm. stage (68 somites); 64 days of development.
23. Embryo at hatching; length 20.5 mm.; 122 days of development.
24. Embryo at 27-mm. stage; 18 to 22 days after hatching.
25. Embryo at 31.3-mm. stage; 44 days after hatching; stage of change from embryonic to larval phase of development.

maturing in their second year (uncommon) and 18 or 30 months for fish maturing in their third and fourth years.

Fresh-water stage.--Shortly after the young chum salmon leaves the redd, its swim bladder fills with air, the remains of the yolk disappear, and the fish makes a transition from mixed feeding to feeding on external food only (Disler, 1953). At the beginning of this stage the fish are about 30 to 32 mm. long and are called fry. Most fry leave the incubationareas soon after they emerge from the gravel; some remain near the spawning grounds to feed for a few weeks. Downstream migration occurs in April and May; entry into salt water is usually completed in June. Most fry entering the sea are 29 to 60 mm. long. Information on feeding, food, size, growth, and behavior of fry is contained in sections 3.41, 3.42, 3.43, and 3.5.

Scales on chum salmon first form near the lateral line between the dorsal and adipose fins and tend to proceed radiallyfrom this area (Kobayashi, 1961). Scales first appear onyoung chum salmon when they are 23 to 27.3 mm. long.

Robertson (1953) described the development of gonads in chum salmon and the stage at which sex differentiation is possible: "The organ forms as a fold from the splanchnic mesoderm and, at the time of first appearance, contains primordial germ cells. These enlarge to form the definitive germ cells which, after a series of divisions, form smaller oogonia and spermatogonia. Oogonia are followed by primary and secondary (growing) oocytes, the appearance of which is the criterion of sex distinction. Spermatogonia continue to multiply but do not undergo growth in the fry."

The sexes are clearly separated when the secondary oocytes appear at about 62 days after hatching (Robertson, 1953). The smaller, more primitive-looking gonad and nests of spermatogonia distinguish the testes.

Predation and lack of food are probably the main causes of mortality of naturally produced fry in fresh water. How food supply and competition for food may affect the survival of chum salmon fry has not been studied, but Levanidov (1954) listed them as factors that govern the abundance and quality of fry. Competitors of chum salmon fry in tributaries of the Amur River as listed by Levanidov (1959) were the lenok (Brachymystax lenok), Lagovsky's minnow (Phoxinus lagowskii), the common gudgeon (Gobio sp.), Amur grayling (Thymallus arcticus grubei), Amur ide (Leuciscus waleckii), common minnow (Phoxinus sp.), and the ninespine stickleback (Pungitius pungitius ).

Predation is probably a more serious source of mortality than lack of food (see section 4.42). Predation of fry (chum and other species of salmon) was estimated to range from 23 to 85 percent in Hook Nose Creek, British Columbia (Hunter, 1959), and from 20 to 85 percent in a tributary of the Bolshaya River, U.S.S.R. (Semko, 1954).

T[illegible] 16.--D[illegible]

| S[illegible] | R[illegible] | T[illegible] | | T[illegible] | T[illegible] | A[illegible] |
|---|---|---|---|---|---|---|
| | Mm. | D[illegible] | H[illegible] | C. | C. [illegible] | |
| B[illegible] | [1] 0.9- 1.2 | | 24 | [2] 3.4 | | D[illegible] (1954). |
| | | | 18.5 | 7.2 | | M[illegible] H[illegible] (1956). |
| (2-[illegible]). | | | 20 | 11-11.5 | | S[illegible] (1950). |
| B[illegible]. | [3] 1.4 | 8 | | 3.4 | | D[illegible] (1954). |
| F[illegible]. | [3] 2.6 | 18-19 | | 3.4 | | D[illegible] (1954). |
| | [3] 3.0 | 9 | | 6.0 | | M[illegible] H[illegible] (1956). |
| C[illegible]. | 6.5- 7.0 | 44-45 | | 3.4 | | D[illegible] (1954). |
| | 5.5- 6.0 | 24 | | | | M[illegible] H[illegible] (1956). |
| B[illegible]. | 7.8-11.0 | 50-64 | | 3.4 | | D[illegible] (1954). |
| | 13.3-13.9 | 61 | | | 338 | Ievleva (1951). |
| B[illegible]. | 14.0-17.0 | 95-100 | -- | 3.4 | | D[illegible] (1954). |
| H[illegible] | | 135 | | 0.0- 5.0 | - | K[illegible] (1950). |
| | 20.0-22.0 | 122-128 | | 3.4 | 408-420 | D[illegible] (1954). |
| | | 120 | | 1.0- 5.0 | - | K[illegible] (1950). |
| | | 74 | | 6.5- 7.5 | | D[illegible]. |
| | | 62-63 | | 11.0-11.5 | - | Saito (1950). |
| | | 52-61 | | 9.7- 9.9 | 510-589 | A[illegible], W[illegible], [illegible] B[illegible] (1958). |
| | | 56 | | 8.0- 9.6 | | S[illegible] (1955). |
| | | 54 | | 9.5-11.0 | | K[illegible] (1950). |
| | | 46 | | 7.0-15.0 | | D[illegible]. |

[1] R[illegible].
[2] D[illegible] 3.4 C. [illegible]. A[illegible] 1° C. [illegible].
[3] D[illegible].

L[illegible]. B[illegible] ([illegible] 4.43).

S[illegible] e.--After [illegible], [illegible] J[illegible] A[illegible]; [illegible] (M[illegible], 1956; S[illegible], 1966; N[illegible], 1966). B[illegible] 100 [illegible] 150 [illegible]. B[illegible], [illegible] N[illegible] P[illegible] O[illegible] B[illegible] S[illegible] ([illegible] 2.2).

M[illegible] 21,569 [illegible] vessels [illegible] J[illegible] J[illegible] (L[illegible], T[illegible], T[illegible], [illegible] D[illegible], 1966) [illegible]:

| Age | F[illegible] | W[illegible] |
|---|---|---|
| | Mm. | D[illegible] |
| 0.1 | 342 | 46 |
| 0.2 | 473 | 115 |
| 0.3 | 516 | 160 |
| 0.4 | 542 | 180 |
| 0.5 | 554 | 185 |

G[illegible]; [illegible] (R[illegible], 1964; L[illegible], [illegible]., 1966). M[illegible] (K[illegible], 1959; R[illegible], 1964).

T[illegible]; P[illegible] (1962) [illegible]-[illegible] basis. H[illegible]

T[illegible] 17.--Development [illegible] alevin [illegible] ([illegible] D[illegible], 1954)

| P[illegible] | D[illegible] |
| --- | --- |
| F[illegible] | S[illegible] formed--fin [illegible]. |
| | Y[illegible]. R[illegible] chial [illegible], [illegible] rhythmical [illegible]. R[illegible]. |
| | L[illegible]. |
| S[illegible] | I[illegible], [illegible]. T[illegible]. |
| | S[illegible]. R[illegible] appear--first [illegible] later [illegible] fins--and [illegible]. E[illegible]. F[illegible]. |
| | A[illegible] extremities [illegible] myotomes. R[illegible] branchial apparatus. F[illegible], [illegible]. |

salmon from Hook Nose Creek, British Columbia, during various stages of their ocean life as: coastal juvenile stage, 5.4 percent; pelagic stage, 56.6 percent; and coastal adult stage, 93.0 percent. These figures can be compared with the egg-to-fry survival in fresh water of 7.8 percent for the same population. Mean survival for the entire ocean life (including fishing mortality) was 0.8 percent for the Hook Nose Creek population (Hunter, 1959) (See also section 4.41).

Causes of mortality at sea are little understood, but it is known that predation and environmental factors are important. Low water temperatures and low salinity during early ocean residence have been shown to affect survival adversely (Wickett, 1958; Birman, 1959). Brown trout (Salmo trutta), Atlantic salmon smolts (S. salar), herring (Clupea harengus maris-albi), and young Gadidae including pollock (Pollachius virens), haddock (Melanogrammus aeglefinus), Atlantic cod (Gadus morhua morhua) and White Sea cod (Gadus morhua n-iaris-albi) were predators of young chum salmon that had been transplanted in tributaries of the Barents and White Seas (Bakshtanskii, 1964). In the Pacific Ocean predators include the hagfish (Polistotrema stoutii), lamprey (Entosphenus tridentatus), mackerel shark (Lamna ditropis), fur seal (Callorhinus ursinus), sea lion (Eumetopis jubata), harbor seal (Phoca vitulina), fin whale (Balaenoptera physalus), humpback whale (Megaptera nodosa), killer whale (Crcinus orca), and beluga (Delphinapterus leucas) (Ikeyama, 1935; Clemens and Wilby, 1946; Tomilin, 1957; Spalding, 1964).

When chum salmon enter the sea they feed on zooplankton in contrast to the bottom forms taken in fresh water (see section 3.4). In offshore waters, main types of food consist of polychaetes, pteropods, squid, crustacean larvae, copepods, amphipods, euphausiids, and fish (Andrievskaya, 1957; Allen and Aron, 1958; Birman, 1960; Ito, 1964; and LeBrasseur, 1966).

### 3.3 Adult phase

As discussed earlier, the adult phase was considered to begin on January 1 of the year in which the fish matures sexually and spawns. Because all chum salmon die after they spawn, this final phase of their life lasts about 6 or 7 months for populations that spawn first (June and July) and about 1 year for populations that spawn last (December).

#### 3.31 Longevity

Chum salmon mature from ages 0.1 to 0.6, but most fish mature at age 0.3. Age 0.2 and age 0.4 fish are also abundant; abundance of age 0.2 fish is greatest in southern streams, and that of age 0.4 fish in northern streams. Occasionally, age 0.2 or age 0.4 fish are more abundant than age 0.3 fish. The maximum age recorded for chum salmon in most studies is 0.6 (Pritchard, 1943; Lovetskaya, 1948; Manzer, et al., 1965), but Berg (1948), quoting Ivan Pravdin, reported age 0.7, 0.8, and 0.9.

Chum salmon spend most of the 6 to 12-month adult phase in the ocean and the remainder in fresh water (see section 2.2). The stream life varies with different populations. In one coastal stream of southeastern Alaska, the average stream life was 18.3 days for males and 17.6

days for females in 1962 and 11.6 days for males and 11.4 days for females in 1963 [Mattson, et al., 1964 (see footnote 5)]. These figures are probably typical for many populations that spawn in brackish water or within a short distance from the sea. For other populations that enter relatively large rivers and migrate upstream for hundreds of kilometers, the freshwater life may last 2 months or longer.

#### 3.32 Hardiness

Little is known about factors that cause premature death in adults. Hartt (1966) mentions that salmon have thin layers of mucus and skin and lose their scales readily during their ocean feeding period. The skin and scales become tougher as the fish mature, and injury from scaling becomes less likely. Low water levels during the upstream migration can cause death or excess stress on adult fish, which may not deposit their eggs properly (Wickett, 1958). Petrova (1964) reported that because of gill net injuries some fish die before spawning and fish that do spawn retain more eggs than the usual spawner. Levanidov (1954) stated that fall run chum salmon in the Amur River rarely died before spawning, but many summer run chum salmon died some years, because of high water temperatures.

#### 3.33 Competitors

Other species of Oncorhynchus are the principal competitors of chum salmon. They intermingle in ocean feeding grounds, in the inshore areas on the way to the spawning streams, and on spawning grounds. Pink salmon are the main competitors for spawning areas, but coho salmon also compete to some extent (Semko, 1954; Strekalova, 1963; McNeil, 1966; Neave, 1966; Sano, 1967).

#### 3.34 Predators

Adult chum salmon in offshore waters have the same predators as the larger immature fish (see section 3.23). In coastal waters of British Columbia, predation by sea lions and harbor seals on all species of adult salmon was estimated to be 2.5 percent of the commercial catch of salmon (Spalding, 1964). Predation in fresh water is probably insignificant. Bears (Ursidae) were reported to preyon adult fish in Kamchatka (Semko, 1954) and in Alaska (Helle, 1960; Thorsteinson, 1965[8]). Helle also mentioned seals (Phocidea) and wolverines (Cubo luscus) as predators in freshwater.

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[8] Thorsteinson, Fredrik V. 1965. Some aspects of pink and chum salmon research at Olsen Bay, Prince William Sound. Bur. Commer. Fish., Biol. Lab., Auke Bay, Alaska, Ms. Rep. 65-3, 30 pp. (Processed.)

#### 3.35 Parasites, diseases, injuries, and abnormalities

Parasites and diseases.--Parasites of chum salmon caught at sea or after their return to fresh water are listed in table 18 and the degree of infestation of Amur River fish is given in table 19. No information is available regarding the influence of parasites on the health of adult fish.

Injuries and abnormalities.--Wounds, apparently caused by predators, are found on salmon caught at sea, as are scars from gill nets or predators on fish in spawning streams. About 13 percent of the chum salmon returning to hatcheries in Washington had scars (Fiscus, 1963). Petrova (1964) stated that 8 to 15 percent of salmon entering the Bolshaya River had scars from gill nets, which he attributed to the Japanese high-seas fishery. In some Hokkaido rivers, an average of 1.4 percent of chum salmon had net marks in 1960; in rivers along the Kamchatka coast, 6.2 percent had net marks in 1960 and 15.6 percent in 1961 (Konda, 1966).

Rietze (1954) and Hikita (1955, 1958b) discussed chum salmon with missing fins, acutely sharp teeth, odd coloration, and abnormal head and body shapes.

French (1965) reported on adhesions that caused the visceral elements to be tightly compacted and joined to the body wall with mesenteric and peritoneal tissues; other than being tightly compacted, the internal organs appeared to be normal. These adhesions have been found only in immature chum salmon caught offshore, and then only rarely.

### 3.4 Nutrition and growth

#### 3.41 Feeding

While still in the redd, chum salmon larvae seek food by means of taste and touch. (Disler, 1953). The amount of food in their stomachs was largely insignificant.

After their emergence from the gravel, the fry depend basically on their eyes to locate and capture food (Disler, 1953; Hoar, 1958). As a rule, the fry eat small benthic organisms up to 10 mm. and only occasionally eat plankton.

Levanidov (1955) studied food selectivity of chum salmon fry by feeding natural foods in aquaria. He demonstrated that fry selected midge larvae (Chironomidae), but when midge larvae were not included in the food available, the fry preferred mayfly nymphs (Ephemeroptera) and Asellus (Isopoda). Midge and caddisfly (Trichoptera) pupae were consumed more readily than larvae because of their

Table 18.--Parasites of chum salmon (authorities: Uzmann and Hesselholt, 1957; Fisheries Agency of Japan, 1959; Bykhovskaya-Pavlovskaya et al., 1962; Akhmerov, 1963; Becker and Katz, 1965)

| Phylum | Class | Genus |
|---|---|---|
| Thallophyta | | *Saprolegnia* |
| Protozoa | Flagellata | *Crypt obia.* |
| | Cnidosporida | *Henneguya, Myxosoma, Wxidium.* |
| | Ciliata | *Tripartiella* and *Trichodina.* |
| Platyhelminthes | Cestoidea | *Eubothrium, Proteocephalus, Pelichnibothrium, Nybelinia, Hepatoxylon, Scolex, Diphyllobothrium, Phyllobothrium,* and *Triaenophorus.* |
| | Trematoda | *Tubulovesicula, Brachyphallus, Lecithaster, Isoparorchis, Hemiurus, Parahemiurus,* and *Bucephalops is.* |
| Nemathelminthes | Nematoda | *Contracaecum, Anisakis, Philonema, Cystidicola, Rhaphidascaris,* and *Porrocaecum.* |
| | Acanthocephala | *Echinorhynchus, Bolbosoma, Corynosoma, Rhadinorhynchus, Metechinorhynchus,* and *Acanthocephalos.* |
| Arthropoda | Crustacea | *Lepeophtheirus, Ergasilus, Salmincola, Argulus.* |
| Annelida | Piscicolidae | *Piscicola.* |

Table 19.--Degree of parasitic infection in summer and autumn chum salmon from tributaries of the Amur River (Akhmerov, 1963); ranges are for samples from different tributaries

| Parasite | Summer chum salmon (436 fish) | | | Autumn chum salmon (179 fish) | | |
|---|---|---|---|---|---|---|
| | Fish infected | Parasites per fish | | Fish infected | Parasites per fish | |
| | | Mean | Range | | Mean | Range |
| | Percent | No. | No. | Percent | No. | No. |
| *Brachyphallus crenatus* | 2-32 | 1-21 | 1-100 | 5-66 | 6-33 | 1-200 |
| *Lecithaster gibbosus* | 5-7 | 5-21 | 1-40 | 13 | | 2-16 |
| *Phyllobothrium caudatum* | 96-100 | 90-680 | 7-1000 | 100 | 40-860 | 9-5000 |
| *Scolex pleuronectis* | 36-93 | 1-6 | 1-27 | 39-98 | 3-8 | 1-28 |
| *Nybelinia surmonicola* | 1-11 | 1-2 | 1-3 | 4 | | 1 |
| *Eubothrium erassum:* | | | | | | |
| Imago | 2-9 | 1-2 | 1-3 | 4-26 | 4-10 | 1-38 |
| Plerocercoid | 2-36 | 3-9 | 1-100 | 14-45 | 26 | 1-400 |
| *Echinorhynchus gadi* | 2-4 | 1-8 | 1-22 | 6-7 | | 1 |
| *Bolbosoma coenoforme* | 2-23 | 3-14 | 1-58 | 7-18 | 1-7 | 1-18 |
| *Anisakis sp. (larvae)* | 31-72 | 2-3 | 1-8 | 35-81 | 2-3 | 1-7 |
| *Contracaecum aduncum* | 1-9 | | 1-2 | 4-7 | 1-3 | 1-3 |
| *Contracaecum sp. (larvae)* | | | | 2-13 | 2 | 1-3 |

accessibility in the water column. Other foods taken by the fry were larvae of mosquitoes (Culicidae) and oligochetes (Oligochaeta). Botton-living copepods (Copepoda) and ostracods (Ostracoda) were ingested only when other food was scarce and then in insignificant numbers.

Daily food intake is influenced by water temperature (Levanidov, 1955). At 4° to 10° C., the weight of food eaten daily was 5 to 10 percent of the body weight; between 12 and 20 C., it was 13 to 19 percent of the body weight.

Stomach contents of adolescent and adult fish in salt water are frequently difficult to identify because of the advanced stage of digestion. Chum salmon digest food faster than other species of salmon or feed more extensively on readily digestible organisms (LeBrasseur, 1966). LeBrasseur also noted that stomach contents differed more between chum salmon from different ocean water masses (Coastal, Transitional, Subarctic, and Alaskan Stream) than between chum salmon and other species of salmon. He suggested that feeding habits were based on availability of, rather than on preferences for, certain kinds of organisms. Chum salmon were less selective than either pink or sockeye salmon (Allen and Aron, 1958; Andrievskaya, 1966). LeBrasseur (1966) compared his findings with those of Ito (1964) and concluded that salmon from the eastern and western Pacific Ocean ate similar organisms but that salmon from the western Pacific Ocean ate greater amounts.

Feeding habits of immature and maturing chum salmon were not significantly different in offshore waters (LeBrasseur, 1966), but maturing fish ate less as they approached the coast than they did in offshore waters (Andrievskaya, 1957; Allen and Aron, 1958). Andrievskaya attributed this decrease to less abundant supplies of food and to the high concentration of salmon near shore during the spawning migration. Chum salmon stop feeding as they approach sexual maturity and enter fresh water.

### 3.42 Food

Benthic organisms, chiefly aquatic insects, constitute the basic food of young chum salmon in fresh water. The stomachs of preemergent larvae contained detritus, diatoms, cyclops, and chironomids (Disler, 1953).

Chironomid larvae were the most important food item of chum salmon fry (Konstantinov, 1951; Levanidov and Levanidova, 1951; Synkova, 1951; Levanidov, 1954; Hikita, 1960; and Kobayashi and Ishikawa, 1964). In one study (Levanidov and Levanidova, 1951), mayfly nymphs ranked highest, but chironomids were also important. Other important food items listed by most investigators were stonefly nymphs, mayfly nymphs, caddisfly larvae, blackfly larvae (Simuliidae), and terrestrial insects. Terrestrial forms taken in Amur River tributaries in order of their importance (Levanidov and Levanidova, 1957) were adult chironomids, blackflies, mosquitoes, other terrestrial Diptera, imagoes of mayflies and caddisflies, mites (Acarina), and thrips (Thysanoptera).

The major food of small chum salmon when they enter the sea is zooplankton. Off the British Columbia coast copepods, euphausiids, and tunicates (Larvacea) were main foods (Neave, 1966). Other food organisms were diatoms, ostracods, cirripedes, mysids, cumaceans, isopods, amphipods, decapods, chaetognaths, and fish larvae. Insects (Diptera) were found in stomach contents frequently. In Traitors Cove, Alaska, young chum and pink salmon ate cladocerans, copepods, barnacle nauplii, and barnacle cyprids (Commercial Fisheries Review, 1966). At times Diptera (mostly chironomids) and an intertidal species of the insect order Collembola were also important.

Andrievskaya (1957) found over 45 species of food organisms in the stomachs of chum salmon taken in offshore waters; however, only a few groups were consumed in appreciable numbers. The important groups of food organisms and their contribution to the diet of adolescent and adult chum salmon are listed in table 20. The rank in importance differed somewhat between studies, but four groups of organisms were consistently mentioned as the main types of food. Allen and Aron (1958) reported that amphipods were consistently important in inshore and offshore waters and that copepods and euphausiids were important only in the more offshore waters. Ito (1964) stated that euphausiids were the most important food of fish that he examined, but large amounts of pteropods and jellyfish were also consumed at times. LeBrasseur (1966) found amphipods and copepods most frequently in the stomachs he examined, whereas Andrievskaya (1957) and Birman (1960) mentioned that pteropods and euphausiids were the main types of food. In most studies the stomachs of chum salmon had considerable quantities of unidentifiable material (due to advanced stage of digestion).

Differences in stomach contents are probably related to the availability of food organisms at the time and location that the fish were sampled. Andrievskaya (1966), who studied seasonal differences in the food composition of chum salmon (table 21), reported that pteropods were the principal food (in the spring, summer, and fall of 1962) but that the species of pteropod changed from *Euclio* sp. in the spring to *Clione*

Table 20.--Food of chum salmon in offshore waters

| Item | Authority | | | |
|---|---|---|---|---|
| | Allen and Aron (1958) | Birman (1960) | Ito (1964) | LeBrasseur (1966) |
| Area | Western North Pacific Ocean and Okhotsk Sea. | Western North Pacific Ocean. | Western North Pacific Ocean and Bering Sea. | Eastern North Pacific Ocean. |
| Time period | May-August 1955. | May-August 1955-56. | May-August 1956-63. | May and June 1958. |
| Number of fish examined | 156 | | 3,889 | 361 |
| Method of presentation | Percentage composition by volume.[1] | Percentage composition by weight.[2] | Percentage composition by weight.[3] | Percentage composition by weight.[1] |
| Food organisms: | | | | |
| Polychaetes | | 0-25.9 | | |
| Pteropods | 9.4-19.1 | 6.0-40.0 | 0-33.3 | 0-33.1 |
| Squid | 1.1-23.3 | 1.8- 7.9 | 0- 3.5 | Trace - 2.8 |
| Crustacean larvae | 0.8-35.8 | | | |
| Copepods | 2.0-10.1 | 0.5- 6.0 | 0.2- 7.2 | 0- 5.3 |
| Amphipods | 7.8-30.1 | 5.0- 9.3 | 1.4-21.4 | Trace - 1.5 |
| Euphausiids | 3.0-50.1 | 0.4-60.0 | 4.1-21.0 | Trace - 2.7 |
| Fish (including Clupeidae and Myctophidae and juvenile Gadidae, Scorpaenidae, and Hexagrammidae). | 10.6-19.0 | 2.0-52.4 | 3.7-26.1 | Trace -50.2 |
| Others | | 0.7-10.0 | 0-38.8 | 0- 2.0 |
| Unidentifiable | | | 0-80.3 | 15.8-97.8 |

[1] Ranges represent differences in average composition of samples from different subareas of the ocean.

[2] Ranges represent differences in average composition of samples taken in June-July 1955 and May-June and August 1956.

[3] Ranges represent differences in average composition of samples by years.

[4] Stomach contents reported by Birman contained octopi rather than squid.

Table 21.--Seasonal and yearly differences in the stomach contents of chum salmon from the western Pacific Ocean (Andrievskaya, 1966)

| Food | Composition by weight | | | | |
|---|---|---|---|---|---|
| | Seasonal differences, 1962 | | | Yearly differences | |
| | Spring | Summer | Fall | 1956 | 1957 |
| | | | Percent | | |
| Polychaetes | 9.4 | 0 | 1.0 | 0 | 3.4 |
| Pteropods | 51.6 | 51.3 | 47.5 | 4.3 | 2.6 |
| Squid | 0 | 0.3 | 7.4 | 0 | 0 |
| Copepods | 0 | 0.4 | 0.1 | 0 | 0 |
| Amphipods | 12.1 | 11.8 | 1.2 | 10.8 | 0.1 |
| Euphausiids | 22.4 | 15.0 | 2.7 | 73.2 | 0.1 |
| Decapods and Jellyfish | 4.5 | 12.6 | 0.9 | 0 | 72.6 |
| Fish | 0 | 8.3 | 39.2 | 2.4 | 3.9 |
| Others | 0 | 0.3 | 0 | 9.3 | 17.3 |

limacina in the summer and fall. This change in diet occurred when the fish migrated north in the spring to a region of the North Pacific Ocean not inhabited by Euclio. Euphausiids ranked next to pteropods in importance in the spring but declined during the summer and fall, whereas immature fish ranked high in the diet in the fall.

Yearly differences in the stomach contents of chum salmon (table 21) followed changes in the abundance of pink salmon in even and odd years according to Andrievskaya (1966). In a year of low abundance of pink salmon (1956), she found that chum salmon ate euphausiids, which were the principal food of pink and sockeye salmon. In a year when the abundance of pink salmon was high (1957), the weight of stomach contents of chum salmon was about the same as in 1956 but the types of food changed. Ito (1964), however, found that weight of stomach contents of chum salmon decreased in odd years.

### 3.43 Growth rate

Growth begins in the alevin stage. At hatching, chum salmon are about 22 mm. long and weigh about 0.16 g., and after absorptionof the yolk-sac they are 27 to 32 mm. and 0.20 to 0.23 g. (Kuznetsov, 1928; Sano and Kobayashi, 1953; Levanidov, 1955).

Chum salmon may migrate seaward soon after losing their yolk-sac or they may remain in fresh-water feeding areas up to several weeks. For those fish which remain in streams, two periods of growth have been described. Levanidov (1955) considered the initial period to last from mid-April to mid-May, and fry grew from about 0.20 to 0.28 g. in this period. In the second period (mid-May to July) they grew more rapidly- -from about 0.27 to 0.55 g. in an average of 27 days. The slower growth period was from March to April in one Hokkaido stream, during which most of the fry migrated to sea (Kobayashi and Ishikawa, 1964). More rapid growth of the remaining fry in April was attributed to higher water temperature and increased feeding. By increasing water temperature from 8° C. to 14° - 20 C. in laboratory experiments, Levanidov (1955) found that the growth rate increased from 3 percent of body weight per day to 5 to 6 percent. He also found that 50 percent of the food energy was used to increase body weight during the fresh-water rearing period.

Table 22 presents some measurements of fry for the period of seaward migration. The small size indicates little growth in most fry before they leave fresh water. The length-weight relation for chum salmon fry during fresh-water migration in the Chitose and Ishikari Rivers of Hokkaido was $W = 2.364 \times 10\ L^{2\,817}$ (Sano and Kobayashi, 1953).

Hatchery fry were smaller than naturally produced fry when they were compared during their migration downstream (Hikita, 1960). Hatchery fry were 37.5 to 44.5 mm. long; naturally produced fry were from 46.5 to 56.5

Table 22.--Size of young chum salmon in fresh water in North America and Asia

| Area | Sample size | Period covered | Range in sample means | | Authority |
|---|---|---|---|---|---|
| | | | Length | Weight | |
| | Number | | Mm. | G. | |
| United States: | | | | | |
| Tillamook Bay, Oreg. | 55 | Mar. 22-May 29, 1948-51 | 38.5-42.0 | | Henry (1953). |
| U.S.S.R.: | | | | | |
| Khor River | 230 | Apr. 26-June 30, 1950 | 33.4-38.0 | 0.24-0.48 | Levanidov and Levanidova (1951). |
| Iski River | 205 | Mar. 23-July 31, 1940 | 28.8-35.1 | 0.20-0.41 | Do. |
| Amur River tributaries | 494 | Migration period 1951 | 35.3 | 0.31-0.32 | Levanidov and Levanidova (1957). |
| | 800 | Do. 1952 | 33.4-34.5 | 0.31-0.34 | Do. |
| | 2,997 | Do. 1953 | 33.4-37.6 | 0.31-0.48 | Do. |
| | 1,700 | Do. 1954 | 35.1-37.7 | 0.27-0.35 | Do. |
| Japan: | | | | | |
| Ishikari and Chitose Rivers. | 758 | Apr. 2-June 11,1952 | 29.7-42.8 | | Sano and Kobayashi (1952). |
| | 1,601 | Feb. 21-June 24, 1961 | 27.8-56.5 | | Kobayashi and Ishikawa (1964). |
| Ishikari River | 1,047 | April | 34.5-40.8 | | Sano (1966). |
| | | May | 35.7-42.0 | | Do. |
| | | June | 45.1-49.8 | | Do. |
| Memu River | 274 | Late Feb. - late Apr. 1958 | 43.8-57.1 | 0.56-1.29 | Nagasawa and Sano (1961). |
| | 455 | Late Jan. - mid-May, 1959 | 43.3-69.4 | 0.49-2.56 | Do. |
| | 462 | Late Mar. - mid-June, 1960 | 45.8-78.8 | 0.65-3.82 | Do. |

The size of young chum salmon marked by removal of ventral fins and a [illegible] the gill cover was compared with unmarked fish at different points of recapture downstream and in coastal waters (Sano and Kobayashi, 1953). Length of marked and unmarked fish were as follows:

| Date | Stage | Length of juveniles Marked | Length of juveniles Unmarked |
|---|---|---|---|
| | | Mm. | Mm. |
| Apr. 28 | Early fry | 30.6 | 30.9 |
| May 22-23 | Entrance into sea | 41.5 | 41.2 |
| June 11 | Coastal [illegible] | 45.6 | 45.8 |
| June 11-17 | do. | 62.0 | 63.8 |

The authors concluded that marking had no recognizable effect on the growth of chum salmon in their studies.

Chum salmon range in length from about 30 to 55 mm. when they enter estuaries and from 100 to 150 mm. when they leave coastal waters (Sano and Kobayashi, 1952; Sano, 1966). In southeastern Alaska, chum salmon that entered the estuary from March to May were, on the average, 35 mm. long (L[illegible] and Wright, 1962). By June 10, size of fish in the estuary ranged from 50 to 72 mm. and at the end of June, from 52 to 115 mm. The lengths of chum salmon in Ishikari Bay, Hokkaido are given in table 23.

Table 23.--Lengths of juvenile chum salmon in Ishikari Bay, Hokkaido (Sano, 1966)

| Location of collection | Period of collection | Fish sampled | Total length Range | Total length Mean |
|---|---|---|---|---|
| | | Number | Mm. | Mm. |
| Ishikari | May | 202 | 44-93 | 61.2 |
| Do. | do. | 45 | 62-103 | 77.5 |
| F[illegible] | do. | 8 | 95-108 | 95.1 |
| Hamamasu | June | 934 | 37-88 | 54.3 |
| Ishikari | do. | 153 | 45-82 | 58.0 |
| Hamamasu | do. | 93 | 62-98 | 76.2 |
| Y[illegible] | do. | 11 | 62-88 | 77.6 |

Ricker (1964) summarized data on the ocean growth of chum salmon from scale studies (table 24). According to these studies, older fish show a declining rate of annual growth and fish that mature earlier grow faster and are larger than immature fish at any given age. It was also found that the size attained at the first annulus among the eastern Pacific stocks (282 g.) averages considerably more than for stocks in the western Pacific Ocean (237 g.). Monthly instantaneous rates of weight increase in the penultimate year averaged 0.067 for eastern Pacific fish and 0.068 for western Pacific fish and showed little variability. Ricker also computed and plotted the increase in weight for three age groups of Amur River chum salmon (fig. 7); the absolute increase in weight from the last annulus to capture was similar for all three groups (1,350-1,640 g.), but the percentage of the final weight added during the last growth year was 47 percent for age 0.2, 37 percent for age 0.3, and 32 percent for age 0.4.

The growth of immature and maturing chum salmon at various ages based on actual measurements taken at sea is shown in figure 8. Conclusions from these data were similar to those of Ricker (1964); immature fish weigh less than maturing fish at a given age and the rate of increase in the weight of immature fish decreases after 1 winter at sea.

Most of the annual growth is attained during the summer (K[illegible], 1959 and 1961; Ricker, 1964). A comparison of seasonal and annual rates of growth from tagging studies (table 25) has shown that fish added their last yearly increment in less than 4 months, as indicated by the growth rate in June and July (K[illegible], 1959). From June to October, growth was fastest in June, slowed down in July, and dropped further thereafter. Similar conclusions were reached from examination of scales (K[illegible], 1961). Widely spaced [illegible] were added from May to August;

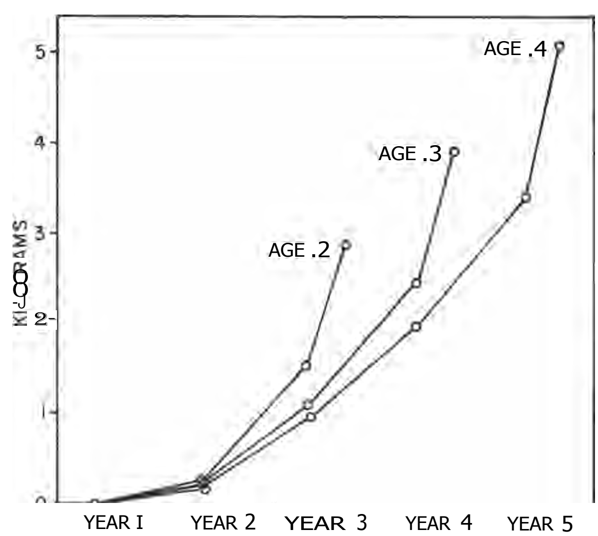



Figure 7.--Growth in weight of autumn chum salmon from the Amur River (Ricker, 1964). Points computed using the expression: $\log W = -3.780 + 3.2 \log l$ from lengths obtained by backcalculation from scale readings. Lines merely connect the annual points and do not represent the seasonal course of increase in weight.

Table 24.--Growth of chum salmon stocks from various studies as summarized by Ricker (1964)

| Location | Year | Age | Fish sampled: Male number | Fish sampled: Female number | $L_1$ | $G_2$[2] | $L_2$ | $G_3$ | $L_3$ | $G_4$ | $L_4$ | $G_5$ | $L_5$ | Weight increase in last year |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Mm. | | Mm. | | Mm. | | Mm. | | Mm. | Percent |
| United States: | | | | | | | | | | | | | | |
| Tillamook Bay | 1949 | 0.2 | 12 | 3 | 305 | 1.61 | 505 | 0.94 | 678 | -- | | | | 156 |
| | | 0.3 | 128 | 129 | 300 | 1.59 | 493 | 0.65 | 604 | 0.65 | 739 | | | 92 |
| Columbia River | 1914 | 0.2 | 184 | 178 | 319 | 1.83 | 565 | 0.80 | 725 | | | | | 123 |
| | | 0.3 | 81 | 67 | 297 | 1.74 | 512 | 0.79 | 655 | .55 | 777 | | | 73 |
| | | 0.4 | 4 | 0 | 282 | 1.75 | 488 | 0.53 | 585 | .48 | 668 | .42 | 762 | 52 |
| Canada: | | | | | | | | | | | | | | |
| Lower Strait of Georgia. | 1916 | 0.2 | 395 | 379 | 307 | 1.76 | 533 | 0.87 | 700 | | | | | 139 |
| | | 0.3 | 767 | 436 | 285 | 1.72 | 487 | 0.88 | 642 | .54 | 759 | | | 72 |
| | | 0.4 | 19 | 3 | 282 | 1.67 | 475 | 0.84 | 617 | .55 | 732 | .38 | 825 | 46 |
| Central British Columbia. | 1960 | 0.2 | 100 | | 274 | 2.10 | 528 | 0.93 | 706 | -- | -- | | | 153 |
| | | 0.3 | 96 | | 261 | 2.04 | 493 | 0.91 | 650 | .58 | 784 | | -- | 79 |
| | | 0.4 | 4 | | 213 | 2.31 | 439 | 1.07 | 614 | .69 | 761 | .38 | 856 | 46 |
| High Seas: West of long. 180°. | 1952-54 | 0.2 | 37 | 11 | 262 | 1.50 | 419 | 0.50 | 490 | | | | | 65 |
| | | 0.3 | 50 | 58 | 257 | 1.88 | 462 | 0.34 | 514 | .35 | 574 | | | 42 |
| | | 0.4 | 1 | 10 | 224 | 1.50 | 358 | 0.95 | 482 | .58 | 578 | .22 | 619 | 25 |
| U.S.S.R.: | | | | | | | | | | | | | | |
| Amur River (autumn fish). | 1946-48 | 0.2 | 91 | | 280 | 1.78 | 489 | 0.63 | 595 | -- | -- | | | 88 |
| | | 0.3 | 296 | | 263 | 1.64 | 439 | 0.81 | 566 | .47 | 655 | -- | | 60 |
| | | 0.4 | 150 | | 260 | 1.54 | 421 | 0.73 | 529 | .56 | 630 | .39 | 711 | 48 |
| | Avg. of 6 years | 0.3 | 1,285 | | 269 | 1.64 | 449 | 0.81 | 578 | .48 | 672 | | | 62 |
| Sakhalin Tarondomari River (autumn fish). | 1948 | 0.3 | | | 291 | 1.33 | 440 | 0.83 | 571 | .61 | 690 | | | 84 |
| Khor River (summer fish). | 1948 | 0.3 | | | 255 | 1.60 | 420 | 0.82 | 543 | .49 | 633 | | | 63 |

[1] $L_1$, $L_2$, etc., are lengths at successive annuli as computed from scales; the last length in the series is the observed average fork length at capture.
[2] Instantaneous rates of increase in weights ($g_2$, $g_3$, etc.) are computed by the expression: $g = b (\log_e l_2 - \log_e l_1)$; b = 3.2.

most of the growth was in June and July. From September to April, growth was represented by a narrow annulus band, which usually consisted of 4 to 6 closely placed circuli for the first annulus and 2 to 4 circuli for later ones.

Birman (1951) noted a relation between the size of chum salmon and the density of stocks in the ocean. More intensified competition for food during periods of high abundance (Ito, 1964; Andrievskaya, 1966) leads to a decrease in the growth rate. This slower growth rate in turn results in later maturity.

Some conclusions concerning growth were made from size of chum salmon at maturity. Within sex and age groups the increase in size and weight of fish from north to south (tables 26 and 27) shows that chum salmonfrom northern areas grow less and do not become as large as fish from more southern areas (Gilbert, 1922; Marr, 1943; Henry, 1954; Sano, 1966). It is also evident from these data that males grow faster than females. Although a comparison of sizes between Asia and North America may be invalid because inmost cases samples were taken in different years, it appears that growth was similar between chum salmon from Alaska and those from the U.S.S.R. and among fish from British Columbia, Washington, Oregon, and Japan.

Semko (1954), in his analysis of data from the Bolshaya River (table 27), concluded that fish grew larger in years of abundant runs (1937, 1941, and 1943) than they did in years of smaller runs (1938, 1939, 1940, and 1944). On the other hand, Birman (1951) in his study of chum salmon from the Amur River and Petrova (1964) in her study of more recent data from the Bolshaya River (1951-60, table 27) considered the size of fish to increase as their numbers declined.

The following length-weight relations have been calculated for chum salmon where W is

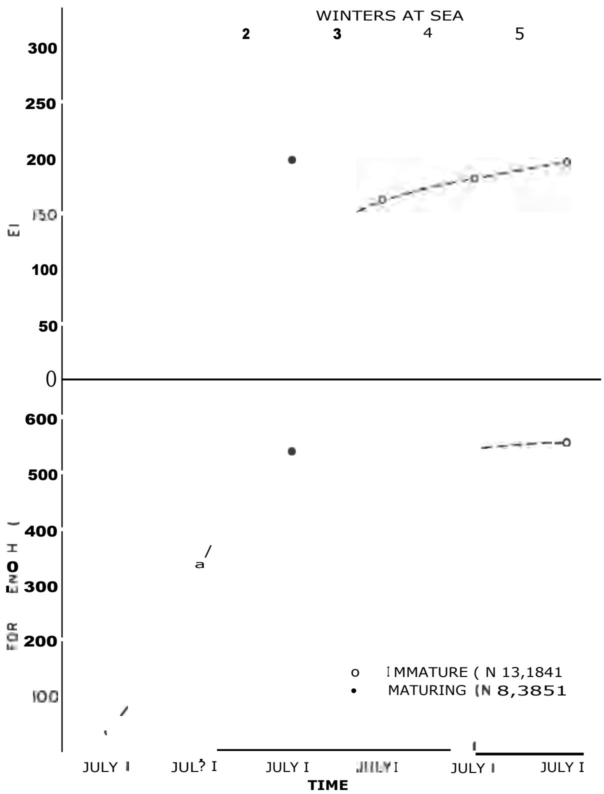



Figure 8.--Estimated mean body lengths and weights of chum salmon on July 1 (Lander et al. 1966). Connecting lines indicate related stages, not actual growth.

the whole weight in g. and L is the fork length in cm.:

| | |
|---|---|
| Ocean-caught chum salmon ranging in size from fingerling to subadult (Ricker, 1964) | Log W =-3.780 + 3.2 log L |
| Mature chum salmon from the Columbia River (Marr, 1943)[9] | Log W =-1.204 ± 2.6 log L |
| Mature chum salmon from Tillamook Bay, Oreg. (Henry, 1954)[9] | Males Log W = -2.270 + 3.2 log L<br>Females Log W =-1.925 + 3.0 log L |

### 3.44 Metabolism

Metabolic rates.--Oxygen consumption by chum salmon at various stages of their life history are given in table 28. Alderdice et al. (1958) concluded that oxygen consumption per egg rises from time of fertilization to hatching and that the consumption per gram of larval tissue declines from a high level in early stages of development to a low at about the time of blastopore closure. Oxygen uptake by eggs was independent of carbon dioxide below about 125 p.p.m. of $CO_2$ (Carbon dioxide) (Alderdice and Wickett, 19 5 8).

The metabolic rate, as measured by oxygen consumption, in fry and spawning adults was influenced by temperature (table 28). The relation between oxygen consumption (Y) and water temperature (x) was: $Y = 0.03983e^{0.1232x}$ (Awakura, 1 9 6 3). Awakura found no difference between oxygen consumption by males and females, but maturing chum salmon had a higher rate than mature fish. Winberg (1956) concluded that the metabolism of adult fish migrating upstream at an average speed of 115 km. per day was seven to eight times greater than the metabolic rate of resting fish.

Chum salmon stop feeding as they enter fresh water and obtain energy from body fat and protein for the upstream migration and spawning. The fish becomes emaciated as reserves of fat and protein are gradually depleted. The average daily use of energy was equivalent to 25,810 calories per 1 kg. of weight for males and 28,390 calories for females of the Arnur River (Nikolskii, 1954). The fat content, which was 9 to 11 percent of body weight before the fish entered the river, decreased to 0.5 percent or less at death.

The red blood cell count, blood glucose, and blood protein decreased and the erythrocyte sedimentation rate increased during sexual maturation in fresh water (Lysaya, 1951; Nishino, 1967; Hashimoto, 1967). Lysaya (1951) considered the decline in red blood cells to be related to the metabolism of the gonads. The increase in rate of erythrocyte sedimentation was attributed to the normal fatigue experienced by salmon during their spawning migration (Hashimoto, 1967). Lysaya (1951) also found increased urea in the blood which he suggested as a possible cause of death of salmon after spawning.

Endocrine systems and hormones.-- Thyroid activity of chum salmon fry during their downstream migration was considered to be highby Baggerman (1960) but relatively low by Eales (1963). Thyroid activity increased in fry held in fresh water past their normal time of entry into the sea (Eales, 1963; Hoar and Bell, 1950).

[9] The equations of Marr (1943) and Henry (1954) were converted to change units of weight and length to grams and centimeters.

Table 25.--Monthly and annual growth rates of chum salmon in the ocean as calculated from lengths at tagging and recovery (Koo, 1959)

| Sample size | Monthly growth rate | | | | |
|---|---|---|---|---|---|
| | Average date tagged | Average date recovered | Average days out | Average length at recovery | Average growth per month |
| Number | | | Number | Mm. | Mm. |
| 12 | June 2 | June 22 | 20 | 576 | 35.6 |
| 19 | June 22 | July 26 | 34 | 594 | 29.4 |
| 10 | August 14 | October 17 | 64 | 633 | 24.2 |

| Sample size | Annual growth rate | | | |
|---|---|---|---|---|
| | Years of tagging and recovery | Average days out | Average length at recovery | Average growth per year |
| Number | | Number | Mm. | Mm. |
| 5 | 1956-58 | 776 | 613 | 91.3 |
| 28 | 1956-57 | 388 | 598 | 104.2 |
| 56 | 1957-58 | 351 | 552 | 90.6 |

Table 26.--Mean size of age 0.3 chum salmon at maturity from Asia and North America

| Asia | | | | | | North America[1] | | |
|---|---|---|---|---|---|---|---|---|
| Area and year | | Fork-length | | Weight | | Fork-length | | Area and year |
| | | Female | Male | Female | Male | Female | Male | |
| | | Cm. | Cm. | Kg. | Kg. | Cm. | Cm. | |
| Kamchatka: | | | | | | | | Alaska: |
| East coast | (1959) | 59.8 | 63.5 | 2.8 | 3.5 | 62.0 | 67.1 | Yukon River (1920). |
| Southeast coast | (1959) | 61.7 | 65.2 | 2.8 | 3.3 | 65.4 | 68.2 | Traitors Cove (1961). |
| Northwest coast | (1959) | 63.0 | 68.3 | 2.9 | 3.7 | | | |
| Okhotsk District | (1959) | 59.1 | 62.6 | 2.7 | 3.3 | | | |
| Amur River: | (1959) | | | | | | | |
| (Summer fish) | | 55.5 | 57.7 | 2.2 | 2.6 | | | |
| (Autumn fish) | | 66.1 | 69.4 | 3.4 | 4.2 | | | |
| Sakhalin | (1959) | 64.7 | 64.9 | 3.3 | 3.7 | | | |
| Hokkaido: | | | | | | | | British Columbia: |
| Nemuro district | (1959) | 70.3 | 73.1 | 3.8 | 4.0 | 71.0 | 73.9 | Vancouver Island (1916-17). |
| Okhotsk sea coast | (1959) | 69.1 | 70.7 | 4.0 | 4.4 | | | Washington: |
| Pacific coast | (1959) | 73.3 | 76.7 | 4.5 | 5.6 | 70.4 | 76.0 | Bellingham (1910). |
| Southwest coast | (1958) | 77.6 | 77.2 | 5.4 | 5.5 | 74.8 | 80.6 | Columbia River (1914). |
| Honshu: | | | | | | | | Oregon: |
| Japan sea coast | (1959) | 73.9 | 75.9 | 4.8 | 5.2 | 72.1 | 80.0 | Tillamook Bay (1959). |
| Pacific coast | (1959) | 75.7 | 76.4 | 4.6 | 5.2 | | | |

[1] Data from Sano (1966) for Asia and from Gilbert (1913; 1922), Fraser (1921), Marr (1943), Mattson and Hobart (1962; see Footnote 1, table 13), and Oakley (1966) for North America.

Table 27.--Average lengths and weights of mature chum salmon, by age, for some North American and Asian stocks

| Area and year | Fish sampled | Fork length | | | | | | | | Weight | | | | | | | | Authority |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Age 0.2 | | Age 0.3 | | Age 0.4 | | Age 0.5 | | Age 0.2 | | Age 0.3 | | Age 0.4 | | Age 0.5 | | |
| | | Female | Male | Female | Male | Female | Male | Female | Male | Female | Male | Female | Male | Female | Male | Female | Male | |
| | Number | Cm. | | | | | | | | Kg. | | | | | | | | |
| North America: | | | | | | | | | | | | | | | | | | |
| Alaska | | | | | | | | | | | | | | | | | | |
| Yukon River | | | | | | | | | | | | | | | | | | |
| 1920 | 448 | 58.4 | 61.0 | 62.0 | 67.1 | 65.3 | 71.6 | | | 2.54 | 2.95 | 2.95 | 3.76 | 3.49 | 4.76 | | -- | Gilbert (1922). |
| Oregon | | | | | | | | | | | | | | | | | | |
| Tillamook Bay | | | | | | | | | | | | | | | | | | |
| 1947 | 65 | 69.7 | 75.2 | 73.2 | 79.7 | 76.2 | | | | 3.86 | 4.81 | 4.76 | 5.63 | -- | | | -- | Henry (1954). |
| 1949 | 287 | 64.8 | 70.8 | 70.9 | 76.9 | 71.1 | | | | 3.54 | 4.72 | 4.67 | 5.86 | 4.54 | | | | Do. |
| Asia: | | | | | | | | | | | | | | | | | | |
| U.S.S.R. | | | | | | | | | | | | | | | | | | |
| Bolshaya River | | Sexes combined | | | | | | | | Sexes combined | | | | | | | | |
| 1932 | | -- | | 63.0 | | 65.6 | | -- | | -- | | 3.10 | | -- | | -- | | Semko (1954). |
| 1935 | | 54.4 | | 59.1 | | 63.6 | | 70.3 | | 1.94 | | 2.62 | | 3.29 | | 4.64 | | Do. |
| 1936 | | 47.1 | | 60.4 | | 63.6 | | -- | | 1.30 | | 2.65 | | 3.30 | | -- | | Do. |
| 1940 | | 51.0 | | 61.7 | | 64.0 | | 64.5 | | 1.75 | | 2.83 | | 3.20 | | 3.45 | | Do. |
| 1941 | | 55.9 | | 61.1 | | 63.2 | | 63.9 | | 2.28 | | 3.17 | | 3.59 | | 3.60 | | Do. |
| 1942 | | 57.2 | | 60.0 | | 65.1 | | -- | | 2.46 | | 2.50 | | 3.36 | | -- | | Do. |
| 1943 | | 56.4 | | 60.4 | | 62.8 | | 64.2 | | 2.63 | | 2.84 | | 3.24 | | 3.77 | | Do. |
| 1944 | | 56.8 | | 58.4 | | 61.1 | | -- | | 2.48 | | 2.69 | | 3.02 | | -- | | Do. |
| 1945 | | 57.0 | | 61.2 | | 63.0 | | 66.2 | | 2.55 | | 3.07 | | 3.29 | | 3.80 | | Do. |
| 1946 | | 57.1 | | 62.6 | | 65.1 | | 72.4 | | 2.57 | | 3.10 | | 3.43 | | 4.61 | | Do. |
| 1947 | | 62.0 | | 62.7 | | 68.8 | | -- | | 2.90 | | 2.79 | | 3.27 | | -- | | Do. |
| 1948 | | 58.3 | | 64.1 | | 65.5 | | 72.0 | | 2.54 | | 3.35 | | 3.61 | | 4.95 | | Do. |
| 1949 | | 52.5 | | 62.5 | | 64.4 | | 66.8 | | 1.91 | | 2.78 | | 3.01 | | 3.77 | | Do. |
| Averages 1932-49 | | 55.5 | | 61.3 | | 64.1 | | 67.5 | | 2.27 | | 2.88 | | 3.30 | | 4.07 | | Do. |
| 1951 | | -- | | 58.9 | | 62.0 | | -- | | -- | | 2.76 | | 3.06 | | -- | | Petrova (1964). |
| 1952 | | 55.1 | | 59.3 | | 60.2 | | 64.1 | | 2.29 | | 2.77 | | 3.07 | | 3.52 | | Do. |
| 1953 | | -- | | 61.0 | | 59.4 | | 61.7 | | -- | | 3.03 | | 3.02 | | 2.96 | | Do. |
| 1954 | | 55.4 | | 62.0 | | 65.6 | | 67.4 | | 2.15 | | 2.75 | | 3.21 | | 3.39 | | Do. |
| 1955 | | -- | | 59.6 | | 61.0 | | -- | | -- | | 2.77 | | 2.99 | | -- | | Do. |
| 1956 | | 54.6 | | 62.8 | | 63.2 | | 66.0 | | 2.99 | | 3.16 | | 3.23 | | 3.71 | | Do. |
| 1957 | | -- | | 64.1 | | 69.0 | | 69.6 | | -- | | 3.06 | | 3.48 | | -- | | Do. |
| 1958 | | 60.5 | | 64.5 | | 66.3 | | 66.0 | | 2.64 | | 3.21 | | 3.53 | | 3.17 | | Do. |
| 1959 | | -- | | 64.8 | | 68.7 | | 63.5 | | -- | | 3.12 | | 3.71 | | 2.73 | | Do. |
| 1960 | | | | 63.7 | | 64.7 | | 64.8 | | | | 2.36 | | 3.37 | | 3.15 | | Do. |

T[illegible] 28.--Oxygen [illegible]

| S[illegible] | T[illegible] | O[illegible] | | A[illegible] |
|---|---|---|---|---|
| E[illegible] (°C. [illegible]) | C. | Mm.³ $O_2$/[illegible]/hr | Mm.³ $O_2$/g. [illegible] | |
| 121.2 | 11.0 | 0.68 | 295 | Alderdice [illegible]., (1958). |
| 268.2 | | 1.60 | 103 | D[illegible]. |
| 353.0 | | 2.78 | 120 | D[illegible]. |
| 452.4 | | 3.80 | 131 | D[illegible]. |
| | | | Mm.³ $O_2$/g. [illegible] wt./hr. | |
| F[illegible] | 10.0 | | 228 | Levanidov (1955). |
| | 20.0 | | 445 | D[illegible]. |
| | 8.6-9.0 | | 188 | Awakura (1963). |
| F[illegible] | 9.0-9.4 | | 144 | D[illegible]. |
| M[illegible]: | | | | |
| H[illegible] | 9.0-9.3 | | 71 | D[illegible]. |
| Migrating [illegible] | | | | |
| M[illegible] | 12.0 | | 215 | Winberg (1956). |
| F[illegible] | 12.0 | | 236 | D[illegible]. |

3.5 Behavior

3.51 Migrations and local movements

Chum salmon migrate throughout most of their lives. Soon after emerging from the gravel, they start moving downstream to the ocean and in their first year at sea, migrate to offshore waters of the North Pacific Ocean and Bering Sea. Recent studies indicated that migrations continue during ocean residence. In the year of sexual maturity, the adults leave feeding areas on the high seas, migrate to coastal waters, and finally enter the spawning streams.

Chum salmon fry migrate downstream almost entirely during darkness (Abramov, 1949; Semko, 1954; Neave, 1955). Very little migration takes place during daylight except during flooding or high turbidity. In the Chitose River of Japan, fry actively moved downstream within 2 to 3 hours after sunset; migrationdecreased before dawn and was limited until darkness approached the next day (Saito, 1950). In Hook Nose Creek, British Columbia, fry traveled near the surface and in the center of the stream where water currents were strongest (Hunter, 1959). Migration rates in one Japanese stream were about 76 km. in 25 days for one group of fry and 113 km. in 24 days for another (Sano and Kobayashi, 1953).

Behavior of chum salmon fry migrating in a large river (Fraser River, British Columbia) differed from behavior in smaller streams (Todd, 1966). At the beginning of the season, the daily migration peaked in the early afternoon but became progressively earlier in the day as the season advanced. Less than 20 percent of the fry migrated at night. The fry were distributed laterally over the entire width of the river throughout the migration period (February to early June); from 65 to 75 percent were near the river surface, but some were found to depths exceeding 4 m.

After becoming distributed throughout the North Pacific Ocean and Bering Sea, immature chum salmon continue their migratory behavior during their life at sea. A westward migration south of the Alaska Peninsula and the Aleutian Islands was detected from mid-June to August or later (Hartt, 1962 and 1966; Johnsen, 1964; Larkins, 1964a). These investigations have also shown a similar westward migration for maturing fish in late May through July with a peak in June. Researchers have hypothesized that chum salmon migrate from the colder northern waters of the Okhotsk and Bering Seas during the winter and make a return northward migration in the spring and summer (Shepard et al., 1967).

The vertical distribution of chum salmon in offshore waters was studied by Manzer (1964) during the spring and summer in the Gulf of Alaska. From mid-May to early June, fish were caught between the surface and a depth of 60 m. and were most abundant below 12 m.; later in the summer, they were most abundant at surface to 12 or 12 to 25 m. Diurnal descent was indicated, but no relation was found between age or temperature and vertical distribution.

In the western Pacific Ocean, from mid-July to early August, most of the mature and immature chum salmon were taken between the surface and 10 m.; mature fish were also taken as deep as 40 m. and immature fish to 50 m. (Machidori, 1966). More immature than mature fish were caught at depths exceeding 10 m.; chum salmon had the widest vertical range of any species of salmon. In Machidori's study, chum salmon were distributed similarly by depth during the day and night.

Birman (1964), who discussed vertical migrations by season, stated that salmon are at greater depths in winter than in summer. He suggested that changes in depth were linked with the vertical migrations of zooplankton.

The distribution and migratory routes of important Asian stocks on their spawning migrations (fig. 9) have been suggested by Kondo et al. (1965). The authors point out that these routes may only apply to the years of tagging (1958-61) and may be altered by changes in the abundance of various stocks and by changes in oceanographic conditions. The rate of travel for maturing fish in their last 30 days at sea was about 40 km. per day over distances that varied from 1,100 km. to 1,900 km. (Hartt, 1966).

The spawning migration of maturing fish takes them into coastal waters from June to November and into spawning streams from June to January. The migration in streams may end in the tidal zone or continue for more than 2,500 km. (Yukon and Amur Rivers). Rates of upstream migration in the Yukon River were 80 km. per day for the first 1,300

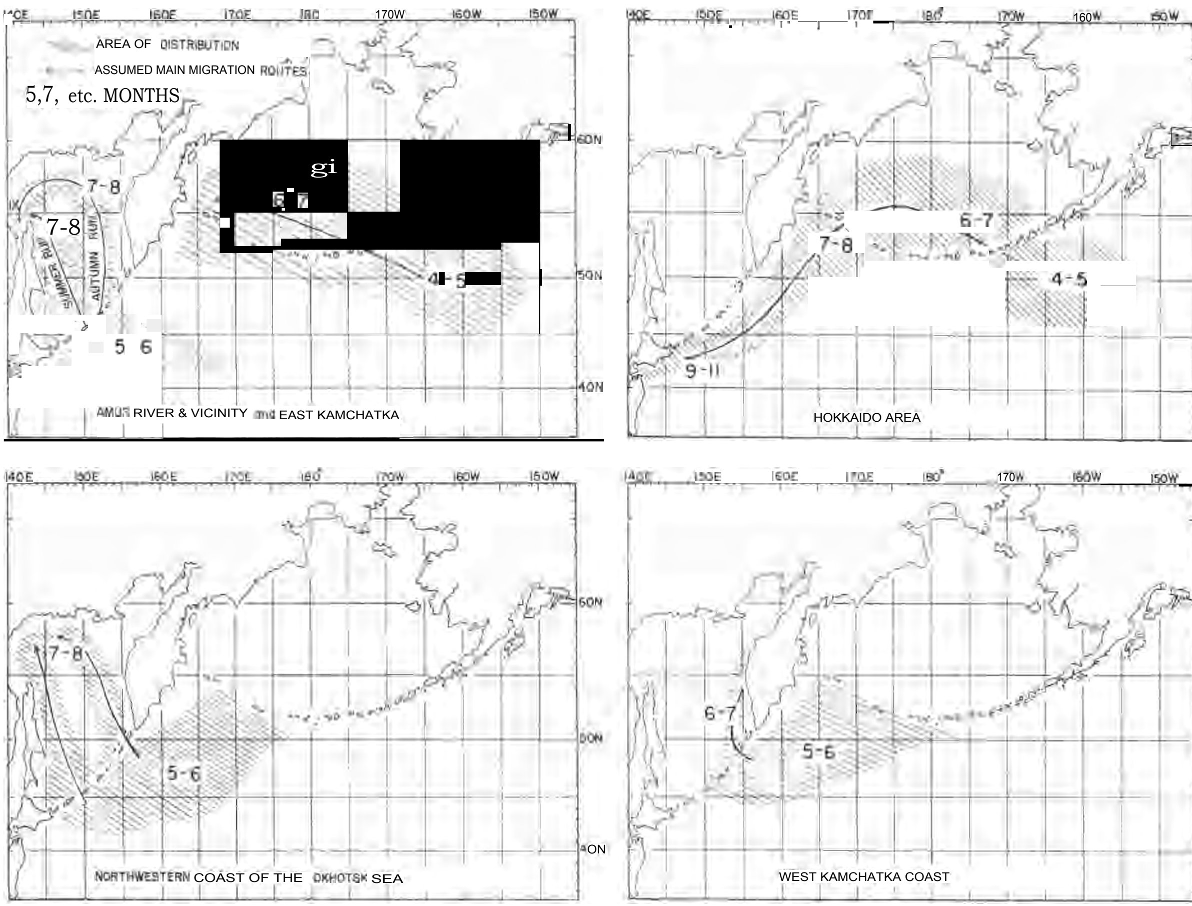



Figure 9.--Estimated areas of distribution and migration routes for important stocks of Asian chum salmon (Kondo et al. 1965).

km. and 56 km. per day for the next 1,100 km. (Gilbert, 1922). In the Amur River, the average rate of migration was 115 km. per day (Pentegov, Mentov, and Kurnaev, 1928). In some rivers of Japan where spawning grounds are much closer to the sea, the average rate of travel was 1.9 to 4.2 km. per day (Sano, 1966).

Some local intrastream movement occurs after the fish have started to spawn [Mattson et al., 1964; (see footnote 5)]. Upstream and downstream movements of 180 to 365 m. were common in a southeastern Alaska stream after redd building had begun; migrations were as great as about 1,800 m. About 35 percent of the males and 22 percent of the females spawned in more than one section of the stream.

### 3.52 Schooling

Schooling was listed by Hoar (1958) as a behavior of chum salmon fry in fresh water, which becomes more pronounced when they reach the sea (Shelbourn, 1966). Schooling of adult salmon during their inshore migration, in coastal areas, and at the mouths of spawning streams is well recognized. This behavior makes them susceptible to capture by commercial fishing gear such as purse seines.

### 3.53 Responses to stimuli

Environmental stimuli.--Hoar (1953, 1954, 1956, 1958) studied the behavior of chum salmon fry in relation to environmental stimuli and listed distinct patterns of behavior: (1) hiding under stones, (2) occupying territories, (3) schooling, (4) feeding, and (5) escaping predators. These patterns varied with respect to environmental gradients of light, temperature, current, salinity, and to objects in the environment.

Following initial emergence from the gravel, chum salmon fry prefer bright light. More than 50 percent may be expected in exposed areas, although they will retreat to deeper, less illuminated areas when the intensity rises to 500 to 1,000 foot-candles. When schools of chum salmon fry were placed in a natural side channel, large numbers of them could be observed at all light intensities during the day.

In comparison with the other species of salmon, young chum salmon responded most consistently and strongly to currents at all times of the day. They showed strong preference for the compartment of a trough to which they were previously drawn by current or salinity. These activities showed that chum salmon have a keen recognition of objects in the environment, awareness of spatial relations, and an ability to adjust accordingly.

Downstream migration is thought to be a combination of displacement (drifting at night with the current because of diminished visual orientation) and active swimming. The importance of either factor depends on the relative strength of orienting mechanisms such as current, temperature, and visual reference points. Experiments have indicated that a rising temperature changes a predominantly positive rheotaxis to a negative rheotaxis in which chum salmon swim with, but usually more rapidly than, the current. This behavior was considered a mechanism which hastens or induces downstream movement in chum salmon which have remained past the peak period of downstream migration. Fry migrated downstream quickly when temperatures in Hokkaido streams reached 15 C. (Mihara, 1958) and disappeared from coastal waters when water temperatures reached 17 C.

Laboratory experiments have shown that growth of chum salmon fry is accompanied by an increased preference for sea water (Shepard, 1948; Houston, 1961). Larger fry also adapt better when transferred directly from fresh to salt water as measuredbythe changes in whole-body levels of chloride. McInerney (1964) has shown that these preferences for salinity increase in an orderly sequence. Beginning with a modal preference for fresh water (0 $^{o}$/oo Cl) in May, the sequence progressed to 3 $^{o}$/oo in June, 6 $^{o}$/oo in July, about 8 $^{o}$/00 in August, and finally to 10 $^{o}$/00 Cl in October. The intensity of response to higher salinity also increased in an orderly sequence from a 14.3 percent response to 3 $^{o}$/oo Cl to a 25 to 30 percent response for subsequent preferred concentrations. These observations suggest that the juvenile fish, while still in fresh water, becomes increasingly preadapted to the osmoregularity of marine life. The length of daylight was found to have some controlling influence on the time when changes in preference for salt water takes place (Baggerman, 1960).

The increased adaptability to sea water appears to be unchangeable in chum salmon (Hoar and Bell, 1950; Baggerman, 1960). The fry are difficult to maintain in fresh water for more than 2 or 3 months after their normal time of downstream migration. Almost all the hatchery fry at Cowichan Lake in British Columbia died toward the end of their first summer. When the fish were held in fresh water for prolonged periods, their thyroid glands became hyperactive--a change attributed to increased demands for thyroid hormone in the metabolism of fish that were no longer completely adjusted to fresh water (Hoar and Bell, 1950). Mortalities were accompanied by increases in water content and decreases in density, which suggested that death was caused, at least in part, by loss of ability to regulate water and electrolyte levels (Houston, 1961).

Artificial stimuli.- -Chum salmon fry avoided an air bubble screen (Kobayashi and Sasaki, 1965). Migrant fry also responded to artificial light by swarming under it.

Suetake (1959) described an electrical weir that effectively prevented the upstream migration of adult chum salmon even during floods. Two electrodes in the stream with 95 to 135 volts (50-cycle, alternating current), provided the electrical stimulus.

# 4 POPULATION

## 4.1 Structure

### 4.11 Sex ratio

Sex ratios of maturing fish, as determined by sampling of commercial catches from the high seas and from the Asian and Alaskan coasts, show in general that males outnumber females at younger ages and that the proportion of females increases with age (table 29). Sano (1966) concluded that on the Asian coast almost all maturing fish of age 0.1 were males; males also outnumbered females at age 0.2. At age 0.3, however, the sex ratio was nearly 1:1, and at ages 0.4 and 0.5 females tended to outnumber males. When all age groups were combined, the ratio was about 1:1. See section 3.16 for sex ratios on the spawning ground.

### 4.12 Age composition

Immature and maturing chum salmon range from less than age 0.1 to age 0.6. Data obtained by the International North Pacific Fisheries Commission from catches on the high seas (table 30) reflect the availability of various ages to the sampling gear (surface gill nets) rather than the age composition of the population. Only age 0.1 or older fish have been taken by this gear, and immature fish have not been taken consistently until summer. The selectivity of catches is evident from the seasonal change in age composition; the dominant age in winter and spring was 0.3, in early summer, 0.2, and in the latter half of July, 0.1. These changes result from an increase in availability of age 0.2 and 0.1 fish and a decrease in the number of older fish, many of

T[illegible] 29.--P[illegible] A[illegible] N[illegible] A[illegible]

| A[illegible] | Y[illegible] | F[illegible] | P[illegible] Age 0.1 | 0.2 | 0.3 | 0.4 | 0.5 | A[illegible] | A[illegible] |
|---|---|---|---|---|---|---|---|---|---|
| | | Number | | | P[illegible] | | | | |
| N[illegible] A[illegible]: | | | | | | | | | |
| A[illegible]: | | | | | | | | | |
| A[illegible] P[illegible] | 1951-57 | 6,140 | | 28.7 | 51.0 | 52.4 | | 49.1 | T[illegible], |
| K[illegible] I[illegible] | 1948-51, 1955-57 | 1,753 | | 30.5 | 48.7 | 50.6 | | 48.4 | N[illegible], |
| P[illegible] W[illegible] S[illegible] | 1952-58 | 2,137 | | 29.0 | 52.0 | 45.3 | | 48.3 | [illegible] S[illegible] (1963). |
| B[illegible] C[illegible]: | | | | | | | | | |
| C[illegible], N[illegible], [illegible] Q[illegible] | 1916-17 | 2,996 | | 50.5 | 35.4 | -- | | 42.2 | F[illegible] (1921). |
| W[illegible] O[illegible]: | | | | | | | | | |
| P[illegible] S[illegible] | 1963 | 5,000 | | 51.0 | 57.0 | -- | | 53.0 | F[illegible] (1963). |
| C[illegible] R[illegible] | 1914 | 514 | | 49.0 | 45.6 | -- | | 48.1 | M[illegible] (1943). |
| A[illegible]: | | | | | | | | | |
| E[illegible] K[illegible] | 1959 | | | 20.0 | 55.6 | 39.0 | 27.0 | 52.5 | S[illegible] (1966). |
| S[illegible] K[illegible] | 1959 | | | 25.0 | 45.0 | 40.0 | | 51.5 | D[illegible]. |
| N[illegible] K[illegible] | 1959 | | | | 57.2 | 68.8 | | 57.5 | D[illegible]. |
| O[illegible] D[illegible] | 1959 | | | 36.3 | 46.6 | 50.0 | 60.0 | 47.1 | D[illegible]. |
| A[illegible] R[illegible]: | | | | | | | | | |
| S[illegible] | 1959 | | | 47.6 | 48.7 | 41.3 | | 47.9 | D[illegible]. |
| A[illegible] | 1959 | | | 52.3 | 51.3 | 44.7 | 40.0 | 50.0 | D[illegible]. |
| S[illegible] | 1959 | | | 11.0 | 38.0 | 42.8 | | 36.0 | D[illegible]. |
| H[illegible]: | | | | | | | | | |
| N[illegible] D[illegible] | 1959 | | | 12.5 | 67.0 | 71.8 | | 67.5 | D[illegible]. |
| O[illegible] S[illegible] | 1959 | | 0 | 24.3 | 50.7 | 43.6 | | 36.2 | D[illegible]. |
| P[illegible] | 1959 | | | 44.5 | 59.9 | 60.4 | 75.0 | 58.9 | D[illegible]. |
| S[illegible] | 1958 | | 0 | 40.4 | 71.2 | 100.0 | | 48.7 | D[illegible] |
| J[illegible] S[illegible] | 1959 | | 0 | 26.0 | 34.8 | 37.5 | | 32.0 | D[illegible]. |
| H[illegible]: | | | | | | | | | |
| J[illegible] S[illegible] | 1959 | | 0 | 40.4 | 67.5 | 50.0 | | 55.6 | D[illegible]. |
| P[illegible] | 1959 | | 0 | 48.7 | 56.2 | 66.6 | | 52.5 | D[illegible]. |
| H[illegible] S[illegible]: | | | | | | | | | |
| W[illegible] N[illegible] P[illegible] O[illegible] | | | | | | | | | |
| B[illegible] S[illegible]. | | | | | | | | | |
| J[illegible] | 1953-57 | | | 35.0 | 57.0 | 63.0 | 70.0 | 55.0 | I[illegible] (1963). |
| | 1956-62 | | | 35.0 | 55.0 | 62.0 | 67.0 | | D[illegible]. |

Table 30.--Age composition of chum salmon caught at sea by research vessels

| Area | Year and time period | Fish sampled | Age 0.1 | 0.2 | 0.3 | 0.4 | 0.5 | Unknown | Authority |
|---|---|---|---|---|---|---|---|---|---|
| | | Number | Percent | | | | | | |
| Mid-Pacific Ocean | 1962 Feb. 10 - Mar. 6 | 143 | 0.7 | 7.0 | 49.0 | 41.3 | 1.4 | 0.7 | French and Mason |
| | 1963 Jan. 28 - Feb. 22 | 64 | 0 | 1.6 | 60.9 | 34.4 | 1.6 | 1.6 | (1964). |
| Northeast Pacific Ocean. | 1962 Apr. 9 - May 6 | 847 | 1.4 | 22.7 | 52.9 | 22.8 | 0.2 | | Fisheries Research |
| | 1962 May 10 - 24 | 323 | 3.4 | 23.5 | 49.3 | 23.8 | 0 | | Board of Canada |
| | 1962 May 28 - June 13 | 635 | 4.9 | 46.0 | 40.8 | 8.3 | 0 | | (1960 and 1964). |
| | 1959 May 18 - June 29 | 763 | 0.3 | 39.4 | 27.5 | 1.4 | 0 | 22.8 | |
| | 1962 June 18 - 30 | 445 | 6.5 | 68.5 | 20.5 | 4.3 | 0.2 | | |
| | 1962 July 3 - 14 | 492 | 41.9 | 49.6 | 7.9 | 0.4 | 0.2 | | |
| | 1962 July 15 - 26 | 117 | 82.0 | 15.4 | 2.6 | 0 | 0 | | |

which are maturing and leaving the high-seas areas (Fisheries Research Board of Canada, 1964).

Manzer et al. (1965) summarized present knowledge on the high-seas distribution of age groups for the period from Mayto August from catches of research vessels and Japanese commercial vessels. Fish in their first year were taken in coastal areas during the summer, but their distribution after they left coastal areas was unknown.

Age 0.1 fish were taken only in the southeastern Gulf of Alaska in May, after which this age group became more numerous in southern waters of the Gulf of Alaska and near the central Aleutian Islands. By July they were present throughout the North Pacific Ocean and Bering Sea. Centers of concentration during July and August were in the southwestern areas of the Gulf of Alaska, eastern Aleutian Islands, and in the western areas of the Bering Sea and North Pacific Ocean.

Age 0.2 fish were widespread in May across the western and central areas of the North Pacific Ocean and generally throughout the eastern part of the Gulf of Alaska. After May, age 0.2 fish were caught throughout the North Pacific Ocean and Bering Sea. During July and August they were relatively more numerous in the western Gulf of Alaska, south of the eastern Aleutian Islands, and in the western Bering Sea.

Age 0.3 and 0.4 fish were in all waters fished during May, after which their relative numbers increased coastward from the high-seas areas.

Age 0.5 fish were caught only west of the eastern Aleutian Islands in the North Pacific Ocean, and west of about long. 175° W. in the Bering Sea. After May their numbers increased coastward.

The older the age group, the closer to major land masses were the centers of concentration, regardless of the month. Because most age 0.3 and 0.4 and almost all age 0.5 fish were maturing, the coastward shift in the centers of abundance was expected.

The age composition of mature chum salmon in Asia and North America (tables 31 and 32) shows that age 0.3 fish dominate in most areas. Populations from southern localities have a larger percentage of younger fish, whereas northern populations have a larger percentage of older fish (Gilbert, 1922; Marr, 1943; Pritchard, 1943; Kobayashi, 1961; Oakley, 1966; Sano, 1966). This trend applies to both Asian and North American stbcks (tables 31 and 32).

Considerable year-to-year variation in age composition is common for populations of mature chum salmon. This phenomenon has been recognized by Pritchard (1943), Henry (1954), Semko (1954), and others and is evident from data in table 32.

Age composition changes as the spawning season progresses. Generally, the older fish appeared in the earlier part of runs and the younger fish appeared later [Marr, 1943; Semko, 1954; Helle, 1960; Thorsteinson et al., 1963; Mattson et al., 1964 (see footnote 5)]. Mattson and Rowland (1963; see footnote 4), however, found that age 0.3 fish dominated early migrants and age 0.4 fish dominated late migrants at Traitors Cove, Alaska, in one year.

### 4.13 Size composition

Published data on actual size composition of chum salmon populations are limited; often only mean sizes have been reported. To cover the available information on size, some data are included which do not deal strictly with size composition.

Lengths of chum salmon during ocean residence range from about 3.5 cm. for the smallest fish when they first enter the sea to about 100 cm. for the largest fish. Meanlengths of age 0.1 and older chum salmon (table 33) show that within ages, males are larger thanfemales and that maturing fish are larger than immature fish. The mean lengths for the total monthly samples changed during the summer as the maturing fish left the areas sampled and immature fish became available to the sampling gear. In May and June, when maturing fish dominated catches, the sample means were about 53 cm., but averages dropped to about 46 cm. in July as immature fish became dominant. Mean sizes increased in August and September as the immature fish grew.

The length composition for ages of chum salmon taken by the Japanese high-seas fishery (mesh sizes of 12.1- and 13.0-cm. stretched measure) in the western North Pacific Ocean and Bering Sea is presented in table 34. The length ranges overlap considerably among the three ages; the greatest overlap is between ages 0.3 and 0.4. The greatest proportion of fish (about 80 percent) fell within 43 to 50 cm. for age 0.2, 50 to 57 cm. for age 0.3, and 53 to 60 cm. for age 0.4.

Mature fish range from about 45 to 90 cm. long and from about 1 to 10 kg. or more (see section 3.12). The record size was 108.8 cm. and 20.8 kg. (Lovetskaya, 1948, citing Rich[10]).

Data on size composition for chum salmon on the North American coast are limited in the areas covered, and sampling was restricted to only 1 year (table 35). The influence of variability between years on a comparison of size composition between areas is therefore unknown. Other sources of variation in these data are sampling by different types of gear (gill net, purse seine, and trap) and differences in segments of the run sampled. Generally,

[1] Rich's paper could not be located from the reference citation given by Lovetskaya.

Table 31.--Age composition of spawning populations of chum salmon in North America and Asia

| Area | Year | Fish sampled | Age | | | | | | Authority |
|---|---|---|---|---|---|---|---|---|---|
| | | | 0.1 | 0.2 | 0.3 | 0.4 | 0.5 | 0.6 | |
| | | Number | Percent | | | | | | |
| North America: | | | | | | | | | |
| Alaska: | | | | | | | | | |
| Yukon River | 1920 | 448 | 0 | 3.3 | 68.1 | 28.6 | 0 | | Gilbert (1922). |
| Alaska Peninsula, Prince William Sound, Kodiak Island. | 1948-58 | 10,030 | 0 | 9.2 | 73.1 | 17.0 | 0 | | Thorsteinson et al. (1963). |
| Southeastern Alaska | 1961-63 | 1,354 | 0 | 5.1 | 81.4 | 13.5 | 0 | | Mattson and Hobart (1962, see footnote 1, table 13); Mattson and Rowland (1963, see footnote 4); Mattson et al. (1964, see footnote 5). |
| British Columbia | 1916-17, 1928-35, 1940-42 | 6,295 | 0.01 | 21.4 | 43.3 | 31.7 | 3.5 | 0.04 | Pritchard (1943). |
| Washington: | | | | | | | | | |
| Bellingham | 1910 | 58 | 0 | 53.5 | 44.8 | 1.7 | 0 | 0 | Gilbert (1922). |
| Admiralty Inlet | 1935 | 872 | 0 | 38.2 | 52.9 | 8.9 | 0 | 0 | Rounsefell and Kelez (1938). |
| Columbia River | 1914 | 518 | 0 | 70.5 | 28.7 | 0.8 | 0 | 0 | Marr (1943). |
| Oregon: | | | | | | | | | |
| Tillamook Bay | 1947, 1949 | 352 | 0 | 10.2 | 89.2 | 0.6 | 0 | 0 | Henry (1954). |
| Asia: | | | | | | | | | |
| East Kamchatka | 1959 | | 0 | 0.8 | 88.6 | 9.4 | 1.4 | 0 | Sano (1966). |
| Southwest Kamchatka | 1959 | | 0 | 1.7 | 94.9 | 3.4 | 0 | 0 | |
| Northwest Kamchatka | 1959 | | 0 | 0 | 88.6 | 11.4 | 0 | 0 | |
| Okhotsk District | 1959 | | 0 | 2.2 | 86.8 | 7.9 | 3.1 | 0 | |
| Amur River: | | | | | | | | | |
| Summer fish | 1959 | | 0 | 3.5 | 86.0 | 10.5 | 0 | 0 | |
| Autumn fish | 1959 | | 0 | 10.7 | 81.8 | 7.2 | 0.3 | 0 | |
| Sakhalin | 1959 | | 0 | 9.0 | 84.0 | 7.0 | 0 | 0 | |
| Hokkaido: | | | | | | | | | |
| Tokoro River | 1950-57 | | 0.3 | 33.4 | 59.8 | 6.3 | 0.2 | 0 | Japan Fisheries Resource Conservation Association (1966). |
| Nishibetsu River | 1950-57 | | 0.1 | 27.1 | 61.9 | 11.0 | 0 | 0 | |
| Ishikari River | 1950-57 | | 3.2 | 30.8 | 52.4 | 13.3 | 0.3 | 0 | |
| Tokachi River | 1950-57 | | 0.4 | 18.3 | 57.6 | 23.0 | 0.6 | 0 | |
| Yurappu River | 1950-57 | | 0.1 | 15.0 | 68.0 | 17.0 | 0 | 0 | |
| Honshu: | | | | | | | | | |
| Japan Sea coast | 1959 | | 6.9 | 61.5 | 31.6 | 0 | 0 | 0 | Sano (1966). |
| Pacific coast | 1959 | | 1.3 | 11.2 | 79.8 | 7.7 | 0 | 0 | |

Table 32.--Yearly variation in age composition of chum salmon populations

| Area and year | Fish sampled | Age 0.2 | Age 0.3 | Age 0.4 | Age 0.5 | Authority |
|---|---|---|---|---|---|---|
| | Number | Percent | | | | |
| North America: | | | | | | |
| Alaska | | | | | | |
| Kotzebue Sound | | | | | | |
| 1962 | 68 | 7.3 | 63.3 | 28.0 | 1.4 | Regnart, Fridgen, and Geiger (1967). |
| 1963 | 255 | 32.6 | 47.4 | 18.8 | 1.2 | |
| 1964 | 463 | 55.7 | 42.5 | 1.8 | 0 | Do. |
| 1965 | 480 | 2.7 | 92.3 | 5.0 | 0 | Do. |
| Yukon River | | | | | | |
| 1961 | 97 | 4.1 | 75.3 | 20.6 | 0 | Do. |
| 1962 | 915 | 1.9 | 69.3 | 28.8 | 0 | Do. |
| 1963 | 650 | 6.0 | 83.3 | 10.2 | 0.5 | Do. |
| 1964 | 268 | 33.2 | 63.0 | 3.7 | 0 | Do. |
| 1965 | 486 | 0.2 | 97.3 | 2.5 | 0 | Do. |
| Prince William Sound | | | | | | |
| 1952 | 187 | 23.5 | 47.1 | 29.4 | 0 | Thorsteinson et al. (1963). |
| 1953 | 819 | 8.4 | 76.4 | 15.1 | 0 | Do. |
| 1954 | 100 | 45.0 | 45.0 | 10.0 | 0 | Do. |
| 1955 | 55 | 10.9 | 81.8 | 7.3 | 0 | Do. |
| 1956 | 617 | 11.0 | 86.2 | 2.8 | 0 | Do. |
| 1957 | 218 | 6.9 | 72.0 | 21.1 | 0 | Do. |
| 1958 | 141 | 15.6 | 76.6 | 7.8 | 0 | Do. |
| British Columbia | | | | | | |
| Nootka | | | | | | |
| 1933 | 160 | 14.4 | 24.4 | 59.4 | 1.8 | Pritchard (1943). |
| 1934 | 124 | 16.9 | 73.3 | 9.0 | 0.8 | Do. |
| 1935 | 186 | 17.2 | 44.6 | 36.6 | 1.6 | Do. |
| 1941 | 518 | 9.1 | 50.6 | 39.6 | 0.7 | Do. |
| Oregon | | | | | | |
| Tillamook Bay | | | | | | |
| 1947 | 65 | 32.3 | 66.2 | 1.5 | 0 | Oakley (1966). |
| 1949 | 287 | 4.9 | 94.7 | 0.4 | 0 | Do. |
| 1950 | 481 | 76.2 | 22.5 | 1.3 | 0 | Do. |
| 1959 | 310 | 51.2 | 48.0 | 0.8 | 0 | Do. |
| 1960 | 92 | 68.2 | 30.8 | 1.0 | 0 | Do. |
| 1961 | 123 | 83.4 | 16.0 | 0.6 | 0 | Do. |
| Asia: | | | | | | |
| Okhotsk Sea coast | | | | | | |
| 1957 | | 1.4 | 63.1 | 9.8 | 25.7 | Kondo et al. (1965). |
| 1958 | | 6.8 | 25.2 | 68.0 | 0 | Do. |
| 1959 | | 1.9 | 86.0 | 9.5 | 2.6 | Do. |
| 1960 | | 0.3 | 42.1 | 57.0 | 0.6 | Do. |
| 1961 | | 1.2 | 32.9 | 63.0 | 2.8 | Do. |
| West Kamchatka coast | | | | | | |
| 1957 | | 0 | 68.2 | 23.0 | 8.8 | Do. |
| 1958 | | 19.0 | 58.6 | 22.4 | 0 | Do. |
| 1959 | | 0.6 | 91.7 | 7.7 | 0 | Do. |
| 1960 | | 0.2 | 59.8 | 39.7 | 0.3 | Do. |
| 1961 | | 0 | 37.6 | 59.2 | 3.1 | Do. |
| East Kamchatka | | | | | | |
| 1957 | | 5.0 | 72.5 | 21.5 | 1.0 | Do. |
| 1958 | | 9.0 | 75.6 | 15.4 | 0 | Do. |
| 1959 | | 0.8 | 83.7 | 13.7 | 1.8 | Do. |
| 1960 | | 1.0 | 41.4 | 54.8 | 2.8 | Do. |
| 1961 | | 0.8 | 51.1 | 44.7 | 3.4 | Do. |

Table 32.--Yearly variation in age composition of chum salmon populations--Continued

| Area and year | Fish sampled | Age 0.2 | Age 0.3 | Age 0.4 | Age 0.5 | Authority |
|---|---|---|---|---|---|---|
| Amur River: | Number | Percent | | | | |
| Summer chum salmon | | | | | | |
| 1927 | 501 | 3.6 | 79.2 | 15.8 | 1.4 | Lovetskaya (1948). |
| 1928 | 134 | 0 | 88.1 | 11.5 | 0.7 | Do. |
| 1929 | 425 | 60.2 | 26.6 | 13.2 | 0 | Do. |
| 1930 | 826 | 0.6 | 98.1 | 1.3 | 0 | Do. |
| Autumn chum salmon | | | | | | |
| 1927 | 308 | 3.2 | 79.2 | 15.3 | 2.3 | Do. |
| 1928 | 522 | 1.5 | 67.1 | 29.5 | 1.9 | Do. |
| 1929 | 641 | 12.2 | 73.7 | 14.1 | 0 | Do. |
| 1932 | 468 | 1.7 | 38.7 | 56.2 | 3.4 | Do. |
| 1933 | 298 | 1.7 | 84.6 | 12.4 | 1.0 | Do. |
| Hokkaido coast: | | | | | | |
| 1957 | | 32.0 | 59.7 | 7.4 | 0.9 | Kondo et al. (1965). |
| 1958 | | 24.1 | 70.0 | 5.9 | 0 | Do. |
| 1959 | | 18.4 | 68.8 | 12.5 | 0.3 | Do. |
| 1960 | | 25.4 | 65.6 | 8.9 | 0.1 | Do. |
| 1961 | | 18.5 | 66.0 | 14.3 | 0.2 | Do. |

the mean lengths within age groups and the total mean length increased from north to south. The total increases in length from north to south are offset to some degree by the greater strength of younger fish in more southern streams and by the actual dominance of younger age groups in some areas.

The length composition within and between areas of Alaska, based on mean length (mid-eye to fork of tail), is compared in table 36. Yearly changes in size composition within areas were partially due to differences in mean length within age groups but were primarily due to changes in strength of age groups. Age 0.3 fish were dominant in all areas and in most years, but age 0.2 fish varied from 0 to 56 percent of the samples and age 0.4 fish from 2 to 51 percent. The size differences between areas also changed because of increasing mean lengths within ages from north to south. A shift to younger ages from north to south was not evident for areas in Alaska as it was for samples with a wider latitudinal distribution. Mean lengths for age 0.3 fish are further summarized from table 36 as follows:

| Area | Female | Male | Percentage age 0.3 |
|---|---|---|---|
| | Range in cm. | | |
| Kotzebue Sound | 58-60 | 60-62 | 42-92 |
| Yukon River | 55-58 | 57-59 | 63-97 |
| Alaska Peninsula | 58-60 | 59-61 | 60-92 |
| Kodiak Island | 59-63 | 60-67 | 43-88 |
| Prince William Sound | 60-63 | 60-65 | 45-86 |
| Southeastern Alaska | 67-68 | 69-71 | 64-77 |

Chum salmon of this age were smallest in the Yukon River. Fish from Kotzebue Sound and the Alaska Peninsula appeared to be of similar size. Fish from areas in the Gulf of Alaska were largest, particularly those from southeastern Alaska.

The considerable overlap in length distributions for different ages prevents the use of length to determine age of fish (Henry, 1954; Kobayashi, 1961; Thorsteinson et al., 1963). Samples of age 0.2 and age 0.4 chum salmon from central Alaska overlapped over almost half their length distribution, age 0.3 fish overlapped the entire ranges of the other two age groups.

### 4.2 Abundance and density (of population)

#### 4.21 Average abundance

Neave (1961) calculated gross estimates of abundance for the entire ocean population of Pacific salmon, on the basis of commercial catches in 1936-39. Disregarding the relatively small mass of fish which were in their first summer at sea, his estimates were:

| Species of salmon | Mature stock | Immature stock | Total |
|---|---|---|---|
| | Thousands of metric tons | | |
| Chum | 510 | 845 | 1,355 |
| Sockeye | 236 | 300 | 536 |
| Pink | 790 | | 790 |
| Chinook | 42 | 55 | 97 |
| Coho | 58 | | 58 |
| Masu | 24 | | 24 |
| Total | 1,660 | 1,200 | 2,860 |

Table 33.--Mean fork length of immature and maturing chum salmon, by sex and age, in offshore waters of the North Pacific Ocean and Bering Sea--samples from U.S. research vessel catches for 1955-61

| Month | Age | Fish sampled | | Mean fork length | | | | | Percentage of catch | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Immature | Maturing | Immature | | Maturing | | Total | Immature | Maturing |
| | | | | Female | Male | Female | Male | | | |
| | | Number | Number | Cm. | | | | | Percent | Percent |
| May | 0.1 | 0 | 0 | -- | -- | -- | -- | -- | -- | -- |
| | 0.2 | 62 | 63 | 47.1 | 48.2 | 52.4 | 51.6 | 49.8 | 2.2 | 2.2 |
| | 0.3 | 473 | 1,627 | 48.4 | 49.8 | 53.0 | 54.9 | 52.8 | 16.5 | 56.8 |
| | 0.4 | 53 | 555 | 50.3 | 54.1 | 56.1 | 57.8 | 56.3 | 1.8 | 19.4 |
| | 0.5 | 3 | 26 | -- | 54.5 | 55.4 | 56.4 | 55.5 | 0.1 | 0.9 |
| | Total | | | | | | | 53.4 | 20.6 | 79.3 |
| June | 0.1 | 109 | 0 | 32.8 | 33.5 | -- | -- | 33.1 | 1.2 | -- |
| | 0.2 | 705 | 525 | 44.9 | 46.2 | 53.3 | 53.1 | 48.9 | 8.1 | 6.0 |
| | 0.3 | 2,264 | 3,764 | 48.8 | 50.6 | 55.0 | 56.2 | 53.3 | 26.0 | 43.2 |
| | 0.4 | 173 | 1,129 | 50.4 | 53.4 | 56.7 | 57.8 | 56.4 | 2.0 | 12.9 |
| | 0.5 | 3 | 49 | -- | 53.9 | 57.7 | 61.6 | 58.3 | <0.1 | 0.6 |
| | Total | | | | | | | 52.9 | 37.3 | 62.7 |
| July | 0.1 | 2,849 | 0 | 31.8 | 37.5 | -- | -- | 32.2 | 24.4 | 3.8 |
| | 0.2 | 4,590 | 443 | 46.1 | 47.4 | 52.8 | 52.1 | 47.3 | 39.3 | 15.1 |
| | 0.3 | 1,611 | 1,762 | 50.2 | 52.4 | 55.3 | 56.6 | 53.7 | 13.8 | 2.6 |
| | 0.4 | 71 | 304 | 52.8 | 54.9 | 57.2 | 57.9 | 56.7 | 0.6 | 0.3 |
| | 0.5 | 3 | 32 | -- | 55.9 | 56.9 | 59.1 | 57.3 | <0.1 | -- |
| | Total | | | | | | | 45.8 | 78.1 | 21.8 |
| Aug. | 0.1 | 956 | 0 | 40.4 | 41.3 | -- | -- | 40.9 | 16.2 | -- |
| | 0.2 | 3,343 | 267 | 49.0 | 50.1 | 54.8 | 56.7 | 50.0 | 56.7 | 4.5 |
| | 0.3 | 696 | 529 | 51.3 | 54.2 | 57.1 | 58.5 | 55.0 | 11.8 | 9.0 |
| | 0.4 | 45 | 54 | 52.8 | 55.9 | 57.8 | 59.9 | 56.8 | 0.8 | 0.9 |
| | 0.5 | 3 | 2 | -- | 53.6 | 56.9 | -- | 55.6 | 0.1 | <0.1 |
| | Total | | | | | | | 49.7 | 85.6 | 14.4 |
| Sept. | 0.1 | 125 | 0 | 41.8 | 42.6 | -- | -- | 42.2 | 18.6 | -- |
| | 0.2 | 227 | 40 | 49.9 | 52.0 | 58.7 | 58.5 | 52.0 | 33.8 | 4.3 |
| | 0.3 | 235 | 5 | 53.1 | 54.8 | 61.4 | 59.9 | 55.1 | 35.0 | 6.0 |
| | 0.4 | 10 | 0 | 56.3 | 57.9 | 57.2 | -- | 57.3 | 1.5 | 0.7 |
| | 0.5 | 0 | 0 | -- | -- | -- | | -- | -- | -- |
| | Total | | | | | | | 51.6 | 88.9 | 11.0 |

[1] Data on file, Bureau of Commercial Fisheries, Biological Laboratory, Seattle, Wash. 98102.

Table 34.--Length composition, by age, of chum salmon in the western North Pacific Ocean and Bering Sea as estimated from catches of the Japanese [illegible] fishery (K[illegible], 1966)

| Fork length | Age | | |
|---|---|---|---|
| | [1]0.2 | 0.3 | 0.4 |
| Cm. | Percent | Percent | Percent |
| 38 | 0.1 | | |
| 39 | 0.3 | | |
| 40 | 0.9 | | |
| 41 | 2.1 | | |
| 42 | 3.9 | | |
| 43 | 8.6 | | |
| 44 | 9.7 | | |
| 45 | 11.7 | 0.1 | |
| 46 | 12.3 | 0.3 | |
| 47 | 11.7 | 0.9 | |
| 48 | 11.1 | 2.1 | 0.3 |
| 49 | 8.4 | 3.9 | 0.5 |
| 50 | 6.4 | 8.6 | 2.2 |
| 51 | 4.9 | 9.7 | 2.9 |
| 52 | 3.0 | 11.7 | 4.9 |
| 53 | 2.3 | 12.3 | 7.5 |
| 54 | 1.2 | 11.7 | 9.5 |
| 55 | 0.7 | 11.1 | 13.0 |
| 56 | 0.4 | 8.4 | 12.1 |
| 57 | 0.2 | 6.4 | 11.3 |
| 58 | 0.1 | 4.9 | 10.2 |
| 59 | -- | 3.0 | 8.0 |
| 60 | | 2.3 | 7.4 |
| 61 | | 1.2 | 3.7 |
| 62 | | 0.7 | 2.6 |
| 63 | | 0.4 | 1.6 |
| 64 | | 0.2 | 1.0 |
| 65 | | 0.1 | 0.7 |
| 66 | | | 0.3 |
| 67 | | | 0.1 |
| 68 | | | 0.1 |
| 69 | | | 0.1 |
| Mean length | 46.8 | 53.8 | 56.4 |

[1] The length composition for age 0.2 fish was estimated from the length composition of the age 0.3 fish by assuming an annual increase in length of 7 cm.

Neave noted that seasonal abundance reaches its maximum shortly before maturing fish leave the ocean and its minimum immediately thereafter. These figures are based on a period of high general abundance; estimates for recent years would be lower.

### 4.22 Changes in abundance

Extreme fluctuations in abundance have characterized chum salmon populations (Hoar, 1951; Birman, 1957; Neave, 1966). Before 1930, chum salmon had low abundance in 1918-22 in British Columbia (Hoar, 1951) and in 1914-21 in the Amur River (Birman, 1957). After 1930, total commercial catches (fig. 10) indicated

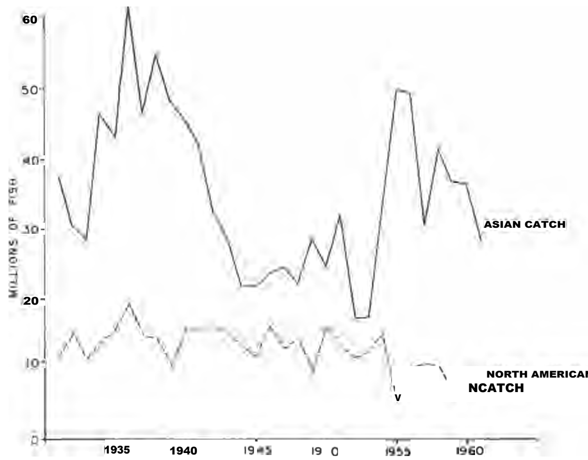



Figure 10.--Commercial catches of chum salmon in Asia and North America (data from section 5.43).

that abundance of Asian stocks was high (43-64 million fish) from 1934 to 1941, low (17-32 million fish) from 1942 to 1953, and high again (30-50 million fish) from 1954 to 1960. North American catches fluctuated between 9 and 19 million fish from 1931 to 1954 and between 6 and 11 million fish from 1955 to 1961.

These fluctuations may originate in fresh or salt water. Neave (1966) showed that survival from the egg to migrant fry has varied from 0.08 to 13.6 percent (170-fold) in one stream and from 0.96 to 22 percent (23-fold) in another. These fluctuations are large enough to produce substantial changes in abundance between consecutive generations; in British Columbia the abundance of a year class of adult fish and their progeny has varied as much as 4 to 1. Fluctuations in abundance have also been caused by changes in temperature and salinity of coastal waters during the inshore residence of young chum salmon (Wickett, 1958; Birman, 1959).

### 4.23 Average density

Neave (1961) calculated gross estimates of the total biomass of Pacific salmon for 1936-39 (see section 4.21). On the basis of these figures and his estimates of the ocean area occupied by considerable numbers of salmon

Table 35.--Length composition, by locality, age, and sex, of some chum salmon poplations on the North American coast[1]

| Area | Year | Fish sampled | Statistic | Age 0.2 | | Age 0.3 | | Age 0.4 | | Total | Source of data |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Female | Male | Female | Male | Female | Male | | |
| | | Number | | | | | | | | | |
| Alaska: | | | | | | | | | | | |
| Yukon River | 1920 | 448 | Percentage age composition | 1.6 | 1.8 | 31.5 | 36.6 | 9.4 | 19.2 | 100 | Gilbert (1922). |
| | | | Length (cm.) | | | | | | | | |
| | | | Range | 53-62 | 58-62 | 56-70 | 60-76 | 61-72 | 61-80 | 53-80 | |
| | | | Mean | 58.4 | 61.0 | 62.1 | 67.1 | 65.2 | 71.7 | 66.0 | |
| | | | S.D. | | | 2.59 | 3.02 | 2.74 | 3.45 | -- | |
| British Columbia: | | | | | | | | | | | |
| Qualicum[2] | 1917 | 506 | Percentage age composition | 18.4 | 18.6 | 16.4 | 45.9 | 0.0 | 0.6 | 100 | Fraser (1921). |
| | | | Length (cm.) | | | | | | | | |
| | | | Range | 58-70 | 61-72 | 67-79 | 66-84 | | 76-83 | 58-84 | |
| | | | Mean | 65.8 | 67.6 | 71.0 | 74.0 | | 78.3 | | |
| | | | S.D. | | | 2.03 | 2.62 | | | | |
| Nanaimo[2] | 1917 | 379 | Percentage age composition | 39.6 | 30.6 | 14.0 | 15.6 | 0.0 | 0.3 | 100 | |
| | | | Length (cm.) | | | | | | | | |
| | | | Range | 56-71 | 58-72 | 66-75 | 70-80 | | -- | 56-80 | |
| | | | Man | 65.8 | 67.5 | 70.9 | 73.9 | | 78.7 | 68.3 | |
| | | | S.D. | 2.62 | 2.79 | 1.80 | 2.31 | | -- | -- | |
| Chemainus[2] | 1917 | 139 | Percentage age composition | 43.9 | 46.8 | 6.5 | 2.9 | 0.0 | 0.0 | 100 | |
| | | | Length (cm.) | | | | | | | | |
| | | | Range | 55-69 | 57-72 | 66-74 | 70-75 | | | 55-75 | |
| | | | Mean | 61.7 | 63.5 | 70.8 | 72.4 | | | 63.4 | |
| | | | S.D. | 2.21 | 3.12 | | | | | | |
| Washington: | | | | | | | | | | | |
| Bellingham Bay | 1910 | 57 | Percentage age composition | 17.5 | 36.8 | 15.8 | 29.8 | 0.0 | 0.0 | 100 | Gilbert (1913). |
| | | | Length (cm.) | | | | | | | | |
| | | | Range | 58-74 | 58-76 | 69-74 | 66-84 | | | 58-84 | |
| | | | Mean | 63.5 | 68.8 | 70.3 | 76.0 | | 88.9 | 70.6 | |
| | | | S.D. | | 5.51 | | 7.26 | | | | |
| Columbia River | 1914 | 518 | Percentage age composition | 34.6 | 35.9 | 13.1 | 15.6 | 0.0 | 0.8 | 100 | Marr (1943). |
| | | | Length (cm.) | | | | | | | | |
| | | | Range | 60-79 | 66-88 | 66-81 | 69-92 | | 80-82 | 60-92 | |
| | | | Mean | 70.0 | 75.8 | 74.9 | 80.6 | | 76.3 | 74.4 | |
| | | | S.D. | 3.07 | 4.06 | 3.89 | 5.51 | | | | |
| Oregon: | | | | | | | | | | | |
| Tillamook Bay[3] | 1949 | 287 | Percentage age composition | 1.0 | 4.2 | 47.8 | 46.7 | 0.3 | 0.0 | | Henry (1954). |
| | | | Length (cm.) | | | | | | | | |
| | | | Range | 62-69 | 64-79 | 64-77 | 62-89 | | | 56-91 | |
| | | | Mean | 64.8 | 70.8 | 70.9 | 76.9 | 71.1 | | 72.7 | |
| | | | S.D. | 2.08 | 4.09 | 2.44 | 4.42 | | | | |

[1] Mean lengths and standard deviations of mean for age and sex categories were calculated by Marr (1943) and Henry (1954).

[2] Fraser excluded the caudal rays in his measurements.

[3] Length data by age and sex for 1949 from Henry (1954); total length data are for 1947-50 and 1959-61 from Oakley (1966).

Table 36.--Mean lengths (mideye to fork of tail) by year, age, and sex, and percentage age composition of some chum salmon populations in Alaska

| Area and year | Fish sampled | Mean lengths (cm.) | | | | | | | | Percentage age composition | | | | | | | | Authority |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Age 0.2 | | Age 0.3 | | Age 0.4 | | Age 0.5 | | Age 0.2 | | Age 0.3 | | Age 0.4 | | Age 0.5 | | |
| | | Female | Male | Female | Male | Female | Male | Female | Male | Female | Male | Female | Male | Female | Male | Female | Male | |
| | Number | Cm. | | | | | | | | Percent | | | | | | | | |
| Kotzebue Sound | | | | | | | | | | | | | | | | | | |
| 1962 | 58 | 54.7 | 53.1 | 58.4 | 61.0 | 62.0 | 62.8 | | 64.5 | 5.9 | 1.4 | 50.0 | 13.3 | 17.7 | 10.3 | 0 | 1.4 | Regnart et al. |
| 1963 | 255 | 52.3 | 55.9 | 59.5 | 61.2 | 61.8 | 66.2 | 60.2 | 62.0 | 18.0 | 14.6 | 32.5 | 14.9 | 13.7 | 5.1 | 0.8 | 0.4 | (1967). |
| 1964 | 463 | 56.8 | 58.1 | 60.2 | 61.9 | 61.7 | 64.0 | | | 29.4 | 26.3 | 26.1 | 16.4 | 0.9 | 0.9 | 0 | 0 | |
| 1965 | 480 | 55.6 | 57.6 | 59.0 | 60.4 | 59.6 | 61.0 | | | 1.0 | 1.7 | 54.6 | 37.7 | 2.3 | 2.7 | 0 | 0 | |
| Yukon River | | | | | | | | | | | | | | | | | | |
| 1962[1] | 915 | 50.5 | 54.0 | 54.7 | 56.7 | 56.6 | 59.2 | | | 1.2 | 0.7 | 40.0 | 28.9 | 14.2 | 14.4 | 0 | 0 | |
| 1963 | 650 | 50.3 | 51.3 | 54.7 | 56.6 | 57.5 | 59.2 | 58.0 | 61.0 | 3.7 | 2.3 | 51.5 | 31.8 | 4.8 | 5.4 | 0.3 | 0.2 | |
| 1964 | 268 | 53.8 | 57.4 | 57.8 | 58.8 | 57.8 | 62.0 | -- | -- | 20.9 | 12.3 | 38.4 | 24.6 | 2.2 | 1.5 | 0 | | |
| 1965 | 486 | 51.5 | - | 55.2 | 58.4 | 60.0 | 62.6 | | -- | 0.2 | 0 | 41.7 | 55.6 | 0.4 | 2.1 | 0 | 0 | |
| Alaska Peninsula | | | | | | | | | | | | | | | | | | |
| 1951 | 144 | - | 55.0 | 58.2 | 58.9 | 59.2 | 62.3 | -- | | 4.9 | 9.7 | 29.9 | 30.6 | 13.9 | 11.1 | 0 | 0 | Thorsteinson |
| 1952 | 230 | 55.7 | 56.4 | 59.9 | 61.2 | 62.5 | - | -- | | 8.6 | 25.0 | 36.6 | 21.6 | 4.7 | 3.4 | 0 | 0 | et al. (1963). |
| 1953 | 551 | 58.1 | 58.1 | 58.1 | 60.7 | 60.5 | 63.1 | -- | | 9.0 | 9.9 | 34.8 | 33.2 | 6.9 | 6.1 | 0 | 0 | |
| 1954 | 2,403 | 55.0 | 56.7 | 59.7 | 61.1 | 62.7 | 64.0 | -- | | 1.9 | 7.6 | 35.2 | 35.0 | 11.0 | 9.4 | 0 | 0 | |
| 1955 | 561 | 53.0 | 53.6 | 58.2 | 60.4 | 60.9 | 63.0 | -- | | 1.8 | 5.3 | 42.4 | 39.9 | 5.5 | 5.0 | 0 | 0 | |
| 1956 | 1,579 | 54.0 | 54.6 | 57.8 | 59.2 | 60.3 | 62.4 | -- | | 1.2 | 2.6 | 46.7 | 45.3 | 2.0 | 2.2 | 0 | 0 | |
| 1957 | 667 | 53.3 | 55.8 | 58.4 | 60.5 | 60.7 | 62.4 | -- | | 2.1 | 4.2 | 31.9 | 30.7 | 15.1 | 15.9 | 0 | 0 | |
| Kodiak Island | | | | | | | | | | | | | | | | | | |
| 1948 | 232 | | 57.1 | 59.4 | 59.6 | 62.2 | 64.7 | | | 3.4 | 6.4 | 29.6 | 27.0 | 18.0 | 15.5 | 0 | 0 | |
| 1949 | 316 | - | | 58.8 | 60.3 | 60.9 | 63.1 | | | 1.3 | 1.3 | 34.5 | 31.0 | 12.5 | 19.4 | 0 | 0 | |
| 1950 | 113 | | | 59.8 | 61.7 | 62.8 | 65.2 | | | 1.8 | 0.9 | 32.7 | 33.6 | 15.0 | 15.9 | 0 | 0 | |
| 1951 | 35 | - | - | - | 65.1 | 61.5 | - | | | 2.9 | 2.9 | 11.4 | 31.4 | 31.4 | 20.0 | 0 | 0 | |
| 1955 | 314 | | | 63.4 | 66.6 | 64.8 | 68.1 | | | 0 | 1.3 | 27.4 | 25.8 | 26.1 | 19.4 | 0 | 0 | |
| 1956 | 75 | | | 61.0 | 61.2 | - | - | | | 1.3 | 1.3 | 44.0 | 44.0 | 4.0 | 5.3 | 0 | 0 | |
| 1957 | 283 | | | 61.4 | 63.0 | 62.3 | 66.3 | | | 1.4 | 4.7 | 35.4 | 42.2 | 8.1 | 8.3 | 0 | 0 | |
| Prince William Sound | | | | | | | | | | | | | | | | | | |
| 1952 | 186 | 59.3 | 60.6 | 63.4 | 64.4 | 66.9 | 68.1 | 0 | 0 | 9.1 | 14.4 | 21.9 | 25.1 | 17.1 | 12.3 | 0 | 0 | Thorsteinson |
| 1953 | 818 | 58.1 | 56.5 | 61.8 | 63.4 | 65.1 | 65.3 | | | 2.3 | 6.1 | 39.6 | 36.9 | 6.1 | 9.0 | 0 | 0 | et al. (1963). |
| 1954 | 99 | 57.5 | 56.9 | 62.5 | 64.7 | - | - | | | 15.0 | 30.0 | 25.0 | 20.0 | 3.0 | 7.0 | 0 | 0 | |
| 1955 | 55 | - | - | 62.9 | 63.8 | - | - | | | 3.6 | 7.3 | 41.8 | 40.0 | 3.6 | 3.6 | 0 | 0 | |
| 1956 | 616 | 57.3 | 56.4 | 59.8 | 60.1 | - | 63.3 | | | 2.3 | 8.8 | 46.5 | 39.7 | 1.0 | 1.8 | 0 | 0 | |
| 1957 | 216 | - | 62.3 | 62.3 | 62.5 | 64.7 | 62.8 | | | 1.4 | 5.5 | 36.7 | 35.3 | 11.0 | 10.1 | 0 | 0 | |
| 1958 | 140 | | 59.7 | 61.2 | 62.9 | - | - | | | 5.7 | 9.9 | 37.6 | 39.0 | 2.8 | 5.0 | 0 | 0 | |
| Southeastern Alaska | | | | | | | | | | | | | | | | | | |
| 1962 | 378 | | | 68.1 | 70.8 | 68.7 | 71.3 | | | 0 | 0 | 27.5 | 36.8 | 16.7 | 19.0 | 0 | 0 | Mattson and |
| 1963 | 286 | 63.7 | 64.1 | 66.6 | 68.6 | 68.5 | 70.8 | | | 2.4 | 6.3 | 29.7 | 46.9 | 5.9 | 8.7 | 0 | 0 | Rowland (1963; see footnote 4); Mattson et al. (1964; see footnote 5). |

[1] Percentage age composition does not add up to 100 percent because a small percentage of the data was listed as unknown in the original source.

(7,500,000 km.$^2$), the average density of salmon in the ocean for this period was estimated as follows:

| Nature of estimates | Chum salmon | All salmon |
|---|---|---|
| | Kg./km.$^2$ | Kg./km.$^2$ |
| Seasonal minimum (immature stock) | 110 | 160 |
| Seasonal maximum (total stock) | 180 | 380 |
| Mature stock | 70 | 220 |

Because chum and other species of salmon were at a high level of abundance in 1936-39, average density in more recent years wouldbe lower.

### 4.24 Changes in density

World catches of chum salmon (see section 5.43) indicate that density in the ocean and in fresh water have changed considerably during the history of the fishery. The density of females in spawning areas of British Columbia has ranged from 1 female in 0.25 m.$^2$ to 1 female in 1,400 m.$^2$ (Wickett, 1958); it has ranged from 1 female in 0.3 m.$^2$ to 1 female in 10.1 m.$^2$ in the Karymaisky Spring of the Bolshaya River, U.S.S.R. (Semko, 1954).

## 4.3 Natality and recruitment

### 4.31 Reproduction rates

No annual rates of egg production exist for the population as a whole, but some estimates are available for specific streams (Semko, 1954; Soin, 1954; Parker, 1962; Levanidov, 1964; Lister and Walker, 1966) (See section 3.15 for fecundity). The most comprehensive data available are for the Japanese islands of Hokkaido and Honshu, where an intensive program of artificial propagation is carried out; about 57 percent of the adults that enter Hokkaido streams are diverted to hatcheries (Japan Fisheries Resource Conservation Association, 1966). Egg production from artificially spawned fish has ranged from 168 million to 772 million in Hokkaido for 1945-65 and from 42 million to 158 million in Honshu for 1954-64 (see section 6.51).

Survival rates from the egg to fry stage for various types of environment are presented in table 37. Survival has usually averaged less than 10 percent in natural streams; although it averaged as much as 28 percent in the Memu River, Japan, over 3 years (Nagasawa and Sano, 1961). Survival has been increased in natural streams by control of stream flow (table 37). In Nile Creek, British Columbia, survival was increased from 1.5 to 7.5 percent after regulation of the flow. In the Big Qualicum River, British Columbia, survival was increased from 11 to 25 percent.

In Asian hatcheries, egg-to-fry survival has been about 70 to 90 percent. The rate of return of adults from hatchery-released fry does not increase in proportion to the increase in egg-to-fry survival, however. The Japan Fisheries Resource Conservation Association (1966) estimated that mortality of hatchery fry, from the time of their release as fry until their return as adults, was about twice that of naturally produced fry.

Estimates of return per spawner are given in table 38. For central and southeastern Alaska, the estimates indicate that reproduction rates have declined from about 3 to 4 returns per spawner for 1920-29 to about 1.5 to 2 returns per spawner for 1950-59. The return per spawner in the Johnstone Strait area of British Columbia was similar to that in central and southeastern Alaska. Estimates for Hokkaido chum salmon (Japan Fisheries Resource Conservation Association, 1966), including returns from artificial and natural spawning, averaged about four returns per spawner for 1931-49 and increased to six returns per spawner in the 1950's. The increase was attributed to improved hatchery techniques.

#### 4.32 Factors that affect reproduction

Neave (1953) separated factors that influence population levels into three categories: (1) compensatory mortality which becomes relatively heavier as the density of the population increas es, (2) depensatory mortality which becomes relatively greater as the population decreases, and (3) extra-pensatory mortality which is independent of population density. Compensatory mortality occurs primarily during the period of reproduction. When adults are crowded in spawning areas, interference between fish may result in egg retention, removal of eggs from the gravel by later spawners, displacement of adults into unfavorable spawning areas, and mortality of eggs during incubation because of the inability of the streambed environment to meet biological needs.

Depensatory mortality, which is inversely related to population density, occurs primarily during fry migration. Predators take a relatively fixed number rather than a percentage of downstream migrants. Thus, the percentage mortality decreases with increasing numbers of fry migrants.

Extra-pensatory mortality may be caused by fishing and by environmental conditions such as extremes of stream flow and temperature. The specific effects of various factors on reproduction are discussed in section 4.42.

#### 4.33 Recruitment

Historically the salmon fishery has operated near the coast and in rivers where the fish are concentrated during their spawning migration. In addition to being more easily caught, the fish have reached their maximum size.

Since 1952, the Japanese have developed a high-seas fishery which takes maturing fish several weeks before they normally reach coastal waters; it also takes some immature fish. See section 5.3 for fishing seasons.

Estimates by Neave (1961) for 1936-39 indicated that the annual recruitment of chum salmon to the fishable stock was 510,000 metric tons. The annual catch for this period was estimated to be 275,000 metric tons. Recent catch figures indicate that present recruitment levels are much lower. From 1961 to 1964, world catches of chum salmon have varied from about 134,000 to 149,000 metric tons (Food and Agricultural Organization [FAO], 1965a).

### 4.4 Mortality and morbidity

#### 4.41 Mortality

Parker (1962) estimated total and instantaneous mortality for one population of chum salmon throughout its life history (table 39). Parker states that his estimates were based on assumptions for which little information was available. Mortality was highest (at least on a per-month basis) during the juvenile coastal period, and next highest during the egg to fry stages in fresh water. Mortality was much lower in the other life stages.

Mortality for the total marine period of life, including fishing mortality, was estimated to range from 97.4 to 99.2 percent for chum salmon from Hook Nose Creek (Hunter, 1959). Levanidov (1964) estimated total marine and fresh-water mortality for summer run chum

Table 37.--Survival of chum salmon in early stages of development in natural and artificial environments

[Percentage survival calculated from potential egg deposition]

| Location | Years | Method of measuring survival | Survival | | Authority |
|---|---|---|---|---|---|
| | | | Range | Mean | |
| | Number | | Percent | Percent | |
| Natural stream environment | | | | | |
| Big Qualicum River, Canada | 4 | Downstream migrant fry counts. | 5.0-17.0 | 11.2 | Lister and Walker (1966). |
| Nile Creek, Canada | 4 | do. | 0.1- 7.0 | 1.5 | Wickett (1952). |
| Hook Nose Creek, Canada | 14 | do. | 1.0-22.0 | 8.5 | Parker (1962). |
| Karymaisky Spring, Bolshaya River, U.S.S.R. | 7 | do. | 0.7- 4.2 | 2.4 | Semko (1954). |
| Khor River, U.S.S.R. | | Examination of redds at hatching. | 25.0-30.0 | | Levanidov (1954). |
| Five tributaries of the Amur River, U.S.S.R. | 7 | | 2.0-12.0 | | Levanidov (1964). |
| Menu River, Japan | 3 | Downstream migrant fry counts. | 16.2-34.4 | 27.6 | Nagasawa and Sano (1961). |
| Controlled stream environment | | | | | |
| Abernathy Creek spawning channel, United States. | 1 | Downstream migrant fry counts. | | 82.1 | Bur. Commer. Fish.' |
| Jones Creek spawning channel, Canada. | 1 | do. | | 30.0 | Trade News (1956). |
| Nile Creek (natural stream protected from floods), Canada. | 4 | do. | 3.4-11.8 | 7.5 | Wickett (1952). |
| Big Qualicum River (natural stream with controlled flow), Canada. | 2 | do. | 24.5-25.2 | 24.9 | Lister and Walker (1966). |
| Hatcheries | | | | | |
| Teplovsky Hatchery, Amur River, U.S.S.R. | 18 | Count of fry | | 73.1 | Semko (1954). |
| Adatymovsky Hatchery, Sakhalin Island, U.S.S.R. | 17 | do. | | 74.1 | Do. |
| Ushkovsky Hatchery, Kamchatka, U.S.S.R. | 11 | do. | | 68.2 | Do. |
| Karymaisky Incubator, Bolshaya River, U.S.S.R. | 1 | do. | | 42.0 | Do. |
| Hokkaido (49 hatcheries) | 20 | do. | 82.3-91.1 | | Japan Fisheries Resource Conservation Association (1966). |
| Honshu (19 hatcheries) | 7 | do. | 85.3-92.8 | | Do. |

- Data on file, Bureau of Commercial Fisheries, Biological Laboratory, Seattle, Wash. 98102.

T[illegible] 38.--Estimates [illegible] N[illegible] A[illegible] A[illegible]

| I[illegible] | A[illegible] | | | | | |
|---|---|---|---|---|---|---|
| | C[illegible] A[illegible] T[illegible] 1965a | S[illegible] A[illegible] T[illegible] (1965a) | | B[illegible] C[illegible] (J[illegible] S[illegible]) Ricker [illegible] Manzer 1967 | H[illegible] H[illegible] J[illegible] F[illegible] R[illegible] C[illegible] A[illegible] 1966 | |
| M[illegible] | U[illegible] 0.5 | U[illegible] 0.5 [illegible] 0.65 | | E[illegible] | C[illegible] C[illegible]; [illegible] | |
| T[illegible] | N[illegible] | N[illegible] | | N[illegible] | Artificial A[illegible] | |
| Y[illegible] | | | | | | |
| 1920-29 | | | | | | |
| R[illegible] | .8-11.0 | 0.6-9.6 | 0.9-13.2 | | | |
| M[illegible] | 4.0 | 2.7 | 3.8 | | | |
| 1930-39 | | | | | | |
| R[illegible] | 1.6-4.4 | 1.1-4.0 | 1.5-5.8 | | 2.4-6.4 | |
| M[illegible] | 2.5 | 2.4 | 2.4 | | 4.2 | |
| 1940-49 | | | | | | |
| R[illegible] | 1.3-2.5 | 1.0-3.0 | 1.4-4.2 | - | 2.3-6.9 | |
| M[illegible] | 1.9 | 2.0 | 2.8 | | 3.8 | |
| 1950-59 | | | | | | |
| R[illegible] | 1.0-2.8 | 0.7-1.9 | 1.0-2.7 | 0.2-3.8 | 4.4-8.8 | 2.1-7.3 |
| M[illegible] | 2.0 | 1.4 | 1.9 | 1.8 | 6.0 | 14.9 |
| 1960-62 | | | | | | |
| R[illegible] | | | | 0.7-1.7 | | |
| M[illegible] | | | | 1.2 | | |
| M[illegible] | 2.6 | 2.1 | 3.0 | 1.7 | 4.7 | 4.9 |

[illegible] A[illegible] R[illegible]:

| Y[illegible] | F[illegible] P[illegible] | E[illegible] P[illegible] |
|---|---|---|
| 1955 | 98.50 | 99.98 |
| 1956 | 96.80 | 99.82 |
| 1957 | 97.10 | 99.62 |
| 1958 | 98.20 | 99.82 |
| 1960 | 96.90 | 99.89 |
| M[illegible] ([illegible] 4 [illegible]) | 97.50 | 99.79 |

F[illegible]:

| A[illegible] | Year s | F[illegible] M[illegible] P[illegible] | A[illegible] |
|---|---|---|---|
| A[illegible] R[illegible] ([illegible]) | 1950-53 | 50-55 | Levanidov 1964 |
| J[illegible] | 1955-58 | 75 | C[illegible] B[illegible] R[illegible] 1961 |
| B[illegible] C[illegible] | | | |
| C[illegible] | 1934-49 | 40-50 | Neave 1966 |
| J[illegible] S[illegible] | 1949, 1950, 1953 | 50-52 | DO. |
| O[illegible] | | | |
| T[illegible] B[illegible] | 1953 | 39 | O[illegible] 1966 |

T[illegible] 39.--E[illegible] H[illegible] N[illegible] C[illegible], B[illegible] C[illegible], [illegible] (P[illegible], 1962)

| L[illegible] | M[illegible] | S[illegible] | I[illegible] (i)[1] |
|---|---|---|---|
| | | P[illegible] | |
| E[illegible]-[illegible] | 7 | 7.8 | 2.55 |
| C[illegible] ([illegible]) | 5 | 5.4 | 2.91 |
| P[illegible] | 34 | 56.6 | 0.57 |
| C[illegible] ([illegible]) | 2 | 93.0 | 0.07 |
| F[illegible] | -- | 35.0 | 1.05 |
| T[illegible] | 48 | 0.08 | 7.15 |

[1] I[illegible] (i) = $\log_e (N_2/N_1)$ [illegible] $N_1$ [illegible] N2 [illegible] 1 [illegible] 2.

## 4.42 Factors causing or affecting mortality

**Egg mortality.**--Most of the mortality from egg fertilization to early fry stage occurs while eggs are incubating in the gravel. Hunter (1959), who examined redds in Hook Nose Creek, British Columbia, found that loss of eggs and alevins was 93.6 and 97.9 percent in two year s. Of there losses 95.9 percent occurred in the pre-eyed stage. In some southeastern Alaska streams, mortality before hatching exceeded 93 percent (McNeil, 1962). Levanidov (1954) found mortality to the alevin stage to be 70 to 75 percent in the Khor River, U.S.S.R.

Environmental factors which may influence egg survival of chum salmon are discussed in alphabetical order.

Ammonia is a metabolic product of egg respiration which has been suggested (McNeil, 1966) as possibly reaching toxic concentrations when the density of eggs and larvae is high and the circulation of intragravel water is poor. Ammonia is the most toxic metabolite of eggs.

Carbon dioxide is another metabolic product of eggs. High levels of $CO_2$ (>125 mg./l. milligrams per liter)) in laboratory experiments produced mortality of developing eggs by inhibiting the uptake of oxygen (Alderdice and Wickett, 1958). Oxygen uptake was independent of $CO_2$ below about 125 mg./1.

The range of free $CO_2$ in spawning gravel of some southeastern Alaska streams was 2 to 24 mg./l. (McNeil, 1962). Intragravel $CO_2$ in some Russian streams reached 25 to 30 mg./1. (Levanidov, 1954). $CO_2$ measured in natural streams has not been shown to influence egg survival.

Drought may cause egg mortality directly by leaving redds dry (Smirnov, 1947; Levanidov, 1954; Neave, 1953) or indirectly by allowing other mortality-causing factors to operate. McNeil (1966) and Wickett (1958) found low oxygen and exceptionally high egg mortality when stream discharge was low during and after spawning. Low stream flow led to poor egg survival of the same brood year (1958) in British Columbia, southeastern Alaska, and the Amur River (Ricker and Manzer, 1967; McNeil, 1966; Levanidov, 1964). In British Columbia, the poor survival was attributed to low discharge and high water temperatures in the fall and in southeastern Alaska and the Amur River, to freezing at low water levels in the winter.

Erosion of eggs and young fish from the streambed by floods has long been recognized as a cause of mortality during incubation (Neave, 1947; Wickett, 1958; Smirnov, 1947). In some southeastern Alaska streams (McNeil, 1966), erosion and shifting gravel destroyed 50 to 90 percent of eggs and larvae in some years. Flooding during the last month of the incubation season in Minter Creek, Wash., reduced fry survival to less than 50 percent of the expected survival (Smoker, 1956).

Freezing during periods of low flow can destroy large numbers of incubating eggs. McNeil (1966) concluded that freezing destroyed up to 65 percent of the eggs in one southeastern Alaskan stream in 1 year. In tributary streams of the Amur River in the U.S.S.R., freezing in some years resulted in 95-percent mortality (Levanidov, 1954). Smirnov (1947) reported that freezing of water to a depth of 1 m. caused complete egg mortality in other U.S.S.R. streams.

Light is detrimental to chum salmon embryos which normally develop in total darkness within the streambed. Direct sunlight is fatal, according to Disler (1953), and indirect sunlight slows the rate of embryo development (Soin, 1954). The harmful effects of light decrease as the embryo grows. Soin (1954) found greater mortality of eggs and lower vitality of fry when eggs were incubated in light than when they were incubated in darkness.

[11]Smoker, William A. 1956. Preliminary report on Minter Creek biological studies. Part II. Effects of Minter Creek stream flows on the juvenile production of silver salmon, chum salmon, and steelhead trout. Wash. Dep. Fish., 12 pp. text, [8 pp.] figs. (Processed.)

L[illegible] ... (1958), [illegible] 7 [illegible] 100 [illegible] 200 [illegible] 1[illegible] 7[illegible] "[illegible]" [illegible]

U[illegible], W[illegible] (1954) [illegible] M[illegible] N[illegible] (1966) [illegible] S[illegible] (1947) [illegible] 94.5 [illegible] (9.8[illegible]) [illegible] 7.0 [illegible] (0.4[illegible]) [illegible]

T[illegible] (N[illegible], 1948; Disler, 1953; S[illegible], 1954). [illegible] (S[illegible], 1954); [illegible]

P[illegible] W[illegible] (1958), [illegible] 2.

P[illegible] L[illegible] (1959) [illegible]

| S[illegible] | P[illegible] [12] | Survival by species of salmon | Years of observation |
|---|---|---|---|
| | C[illegible] | Percent | Number |
| Nile Creek | 1,914 | 1.2, chum | 8 |
| Morrison Creek | 3,849 | 5.7, pink | 2 |
| Hook Nose Creek | 4,035 | 7.6, chum; 7.2, pink | 10 |
| McClinton Creek | 9,617 | 13.2, pink | 6 |

[illegible] A[illegible] R[illegible]. Levanidov [illegible] 20 [illegible] 30 [illegible] D[illegible] V[illegible] (S[illegible]), [illegible] (C[illegible]). I[illegible] A[illegible] (Salmo [illegible]), [illegible] (C[illegible]) [illegible] (R[illegible], 1967). T[illegible] R[illegible] E[illegible]

S[illegible] 18 [illegible] (R[illegible], 1956), I[illegible] 6 °/oo; [illegible] 12 °/oo [illegible] 30 °/oo [illegible] 4 [illegible] 5.8° C. L[illegible] (6 °/oo) [illegible] T[illegible] H[illegible] I[illegible], B[illegible] (1964; [illegible] 2) [illegible] 2-m. [illegible] 55 [illegible]

---

[12] Permeability (K) of [illegible] gravel is defined by K= [illegible] where [illegible] is the apparent velocity of the water in cm./hour and [illegible] is the hydraulic gradient or slope of the water surface. Since the hydraulic gradient has no units, permeability has the same units as velocity, i.e. cm./hour.

time. Sea water was not definitely identified as the cause of the mortality.

Sedimentation was reported to be an important cause of egg mortality by many investigators (Smirnov, 1947; Neave, 1953; Levanidov, 1954; Semko, 1954; Soin, 1954; Wickett, 1954; McNeil, 1966). Sediment accumulates in spawning areas and fills the interspaces between gravel so that water does not move easily through the gravel. Salmon eggs may die when the intragravel water moves so slowly that insufficient oxygen is carried to the eggs and lethal amounts of waste products from the eggs are not carried away.

Shock was studied by Smirnov (1955)by subjecting eggs to mechanical agitation at various stages of development. The eggs developed in water temperatures from 8.0° to 9.6° C. Results were as follows:

| Time after fertilization | Stage of development | Sensitivity and range in percentage mortality in two tests |
|---|---|---|
| 0-15 min. | Before water hardening | Highly resistant to shock (0.5 - 0.9) |
| 15 min.-2 hr. | Water hardening | Highly sensitive to shock (8.6 - 89.0) |
| 2-8 hr. | Completion of water hardening to cell division | Resistant to shock (1.0 - 18.2) |
| 8 hr. to 5 days | Beginning of cell division to formation of caudal knob | Moderate sensitivity to shock (3.5 - 17.4) |
| 6 days | Early embryo formation (caudal knob visible) | Marked increase in sensitivity to shock (18.5 - 32.5) |
| 8-12 days | Embryonic streak visible | Resistant to shock (1.6 - 17.8) |
| 15 days | Closure of blastopore | Sensitive to shock (20.5 - 24.7) |
| 18 days to hatching | Closure of blastopore to hatching | Resistant to shock (0.0 - 1.2) |

Smirnov noted that eggs were highly resistant to shock after closure of the blastopore (18 days and 174 C.-degree-days); this stage was reached before eye pigmentation (22 days and 211.5 C.-degree-days), when fish culturists normally consider eggs to be resistant to handling. He did not find any increased mortality from shock just before hatching.

Superimposition of redds by later spawners removes previously deposited eggs from the gravel and is an important cause of egg mortality in some areas. McNeil (1962) estimated that as much as 50 percent of the egg losses could be attributed to this cause in years of high spawning density. In another study, when densities of spawners (chum and pink salmon) exceeded 5 females per 1 m.$^2$, the additional females dislodged about as many eggs as they deposited [Thorsteinson, 1965 (see footnote 8)]. A decrease in density of chum salmon eggs in the gravel as the season progressed was also noted and was attributed to superimpositionby later spawning pink salmon. The carrying capacity of the gravel (defined as the number of eggs deposited in the streambed which is not substantially increased by additional spawning) was estimated at 5,000 eggs per 1 m.$^2$. This egg density could be reached by four female spawners per 1 Thorsteinson (1965; see footnote 8) also found evidence that two to four females (chum and pink salmon) commonly spawned at the same site in Olsen Creek, Alaska, and occasionally as many as seven females spawned at the same site.

Fry mortality.--Possible causes of mortality of fry in fresh water are lack of an adequate food supply, adverse physical conditions of the environment, and predation. Little is known of the influence of food supply and physical conditions on mortality. The number of fry consumed by predators within a stream is more or less constant, but the percentage mortality varies with the size of the migration (Neave, 1953; Hunter, 1959). Neave also concluded that the percentage mortality from predation increases with the distance over which the fry travel and increases during the migration.

Predators of chum salmon fry, as listed by Abramov (1949), Hunter (1959), Levanidov (1959), and Sano (1966) were:

| | |
|---|---|
| Coho salmon | |
| Sockeye salmon | |
| Dolly varden | Amur grayling |
| Cutthroat trout (Salmo clarkii clarkii) | Amur ide |
| Steelhead trout (Salmo gairdneri) | Lagovsky's minnow |
| Aleutian sculpin (Cottus aleuticus) | Pike (Esox reicherti) |
| Prickly sculpin | Merganser (Mergus sp.) |
| Taimen (Hucho taimen) | Common tern (Sterna hirundo) |
| Lenok | Kingfisher (Alcedo athis) |

Most of the above predators had one or two fry in their intestines during the period of fry migration (Levanidov, 1959; Hunter, 1959). Young coho salmon in some British Columbia streams averaged two to four fry per stomach (Hunter, 1959; Pritchard, 1936). Hunter (1959) found the average number of fry per stomach to increase with the size of the predator.

Predators ate an estimated 23 to 85 percent of the salmon fry (chum and other species of salmon) in Hook Nose Creek, British Columbia (Hunter, 1959), and from 20 to 84 percent in a tributary of the Bolshaya River, U.S.S.R. (Semko, 1954).

Juvenile and adult mortality.--Predators of salmon during their ocean residence were listed in section 3.23. Spalding (1964) estimated that sea lions and harbor seals near British Columbia eat 1.8 million kg. of salmon annually or about 2.5 percent of the average commercial catch in British Columbia. Spalding concluded that predation of this magnitude was of negligible importance in the reduction of existing salmon stocks. Tomilin (1957) indicated that the amount of chum salmon in the diet of beluga whales in the western Pacific Ocean increased with age of the whale; in younger belugas, chum salmon made up 4.4 percent of the food intake and in adult belugas, 60 percent.

Little has been published on other causes of natural mortality during ocean residence. Wickett (1958) observed that low temperature and reduced salinity near the coast in June were unfavorable to survival. Birman (1959) noted that survival was higher than average when ocean water near the coast was relatively warm and lower when ocean temperatures were relatively cool. He believed these temperature changes had the greatest influence on survival of chum salmon during their first winter at sea.

Fishing mortality is discussed in section 4.41. An indirect cause of mortality from fishing may result from fish that escape from gill nets but become injured (net-marked) while in the net (Konda, 1966). These fish are susceptible to infection from fungus (Saprolegnia) when they enter fresh water and may die before spawning. Petrova (1964) reported that net-marked chum salmon often spawn less than 80 percent of their eggs.

Factors that affect mortality of adult fish in fresh water are discussed in section 3.3.

#### 4.43 Factors affecting morbidity

Parasites of chum salmon are listed in section 3.35.

Rucker, Earp, and Ordal (1954) summarized information on diseases of Pacific salmon. They concluded that trematodes are of little consequence as a cause of fatal disease in salmon of the Pacific Northwest. External protozoan parasites cause low-grade infections and may cause epizootics in young salmon in hatcheries. These diseases are easily controlled with formalin. Saprolegnia commonly infects eggs, young, and adult salmon in fresh water. This infection is a secondary agent that follows injury, poor environment, malnutrition, and external parasites.

Bacteria are the most important agents of disease in several species of Pacific salmon. Kidney disease, from a small unnamed Gram-positive diplobacillus, has caused high mortality in young hatchery-reared salmon and has also been found in wild fish. Aquatic myxobacteria are also important agents of disease in hatcheries and the natural habitat. Rucker (1959) described an infection by the marine bacteria Vibrio spp. of chum salmon being reared in sea water. These bacteria have caused catastrophic losses but have been treated satisfactorily with sulfonomides. Kobayashi, Awakura, Honma, and Tamura (1963) described a second bacterial disease caused by Bacterium salmonicida in salt-water rearing areas. It was highly contagious and caused high mortality but was also treated satisfactorily with sulfonomides.

#### 4.44 Relation of morbidity to mortality

No information.

### 4.5 Dynamics of population

The size of any fish population, even when not fished, is limited by natural controls. The mechanism of control involves factors of mortality which become more effective as the density of the stock increases (Ricker, 1954).

These factors may operate in one or more life history stages. In Pacific salmon, the fresh-water environment is perhaps more limiting to size of population than the salt-water environment, although this has not been definitely established. Factors that may limit the maximum population size in fresh water are redd superimposition during spawning and mortality factors associated with density of eggs in the streambed (McNeil, 1965).[13] If the hypothesis is accepted that the fresh-water environment is the most limiting, then the fishery should be managed to allow an escapement that will produce maximum numbers of downstream migrants.

Wickett (1958) and McNeil (1965; see footnote 13) suggested optimum densities of spawners for maximum production of fry for mixed populations of chum and pink salmon, on the basis of studies of the relation between potential egg deposition and production of fry. The observed relation appears to be best described by a dome-shaped curve (fig. 11). Maximum production of fry is achieved by a spawning population that is intermediate between maximum and minimum. When the optimum density is surpassed, fry production is reduced. Fluctuations in production of fry for any given level of spawning density are commonly observed and are attributed to "non-density" causes of mortality such as flooding, freezing, and drought [McNeil, 1965 (see footnote 13)]. McNeil concluded from his data that a potential egg deposition of less than 1,000 eggs per 1 m.$^2$ usually produced a relatively low number of fry. Relatively large numbers of fry came from potential egg depositions that varied between 2,000 and 3,000 eggs per 1 m.$^2$, an escapement equivalent to about one pair of pink or chum salmon per 1 m.$^2$ of spawning area. Wickett (1958) considered the optimum density of spawners to vary with permeability of the streambed gravel. In one British Columbia stream (Nile Creek), he estimated that about 4.8 m.$^2$ of spawning area was needed for a pair of spawners to produce the maximum number of fry, but in another stream with higher permeability (McClinton Creek), optimum density was achieved with 1.2 m.$^2$ of spawning area per pair of spawners.

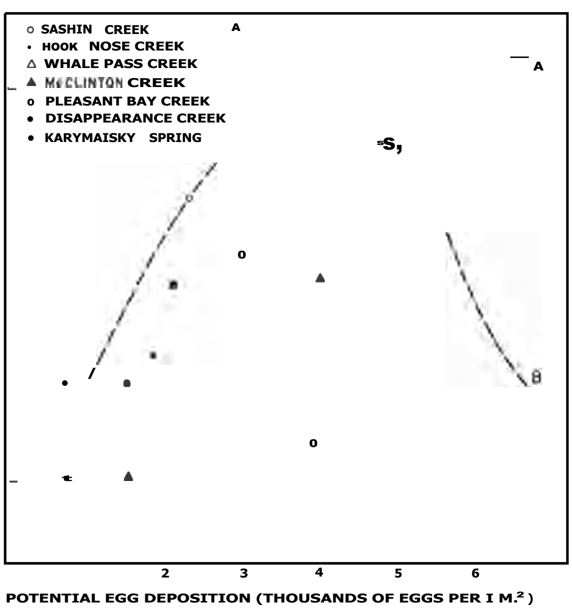



Figure 11.--Observed relation between potential egg deposition and production of fry per 1 m.$^2$ in pink and chum salmon spawning streams [McNeil, 1965 (see footnote 13)]. A and B are two possible types of fresh-water reproduction curves, and for these data, the dome-shaped curve provides the best fit.

Reproduction curves based on the relation between escapement and return of adults have also been developed for chum salmon (Ricker, 1958; Taguchi, 1965a, b; and Japan Fisheries Resource Conservation Association, 1966). The reproduction curves calculated for hatchery-produced fish in Japan (see fig. 12 for one curve) have led to estimates of the optimum number of spawners needed for maximum sustained yield in that country (Japan Fisheries Resource Conservation Association, 1966):

| | Hokkaido[14] | HonshU |
|---|---|---|
| Optimum escapement of spawners | 350,000 - 500,000 | 100,000 |
| Maximum yield of progeny | 2,640,000 - 2,740,000 | 440,000 |
| Yield per spawner | 7.6 - 5.5 | 4.4 |

Taguchi (1965a, b) estimated that yield per spawner ranged from 2.4 to 3.6 at near-maximum sustained levels of production in Kamchatka and Alaska. Comparing these findings with those for artificial propagation in Japan, the Japan Fisheries Resource Conservation Association (1966) concluded that the efficiency of artificial propagation in Hokkaido was about 1.8 times better than the efficiency of natural propagation.

The offshore salmon fishing by the Japanese mothership fleet led to studies to determine the time and area of harvest for achievement of maximum yield. The net gain or loss of the stock for different periods of fishing are measured by comparing losses from natural

[13]McNeil, William J. 1965. Pink salmon studies at Little Port Walter, winter and spring 1964. Bur. Commer. Fish., Biol. Lab., Auke Bay, Alaska, Ms. Rep. 65-1, 20 pp. (Processed.)

[14]Ranges in values were derived to cover the possible maximum and minimum percentages of the total run used for artificial propagation.

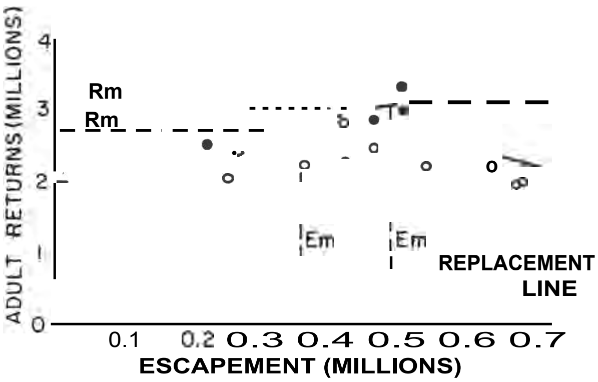



Figure 12.--Reproduction curve for artifically spawned chum salmon of Hokkaido (Japan Fisheries Resource Conservation Association, 1966). Em is optimum escapement and Rm, maximum return. Solid line and open dots are for 1932-59; broken line and solid dots are for 1950-59. Replacement line represents the level of production where the stock is producing only enough progeny to replace its current numbers.

mortality and gains from growth between the fishery offshore and the fishery along the coast. Taguchi (1961) calculated that the instantaneous rates of natural mortality for chum salmon in their last 50 days at sea were 0.36 to 0.40 per month; and the instantaneous rate of growth was 0.14 per month. Using these estimates, he contended that natural mortality in this period exceeded growth and therefore that offshore fishing approximated maximum yield more closely than inshore fishing. Parker (1963) and Ricker (1964) considered Taguchi's estimates of natural mortality to be much too high. Ricker (1964) also used two rates of instantaneous mortality--0.02 per month, which he considered a resonable estimate, and 0.04 per month, which he considered to be extreme and much too large for chum salmon. The instantaneous rates of growth used by Ricker were 0.12 per month for the final year at sea and 0.14 per month in the next-to-last year. From these statistics, Ricker concluded that growth exceeded any reasonable estimate of natural mortality throughout the final and next-to-last growth years for chum salmon. A fishery that took salmon at any time before their arrival inshore, therefore, would yield less than a fishery that took survivors of the same fish inshore. The total increase in bulk of fish was estimated to be 52 percent in the final growth year and 169 percent in their next-to-last and final years together. Losses in yield from pelagic fishing for age 0.3 chum salmon (in which the lower instantaneous rate of natural mortality, or 0.02, was used) ranged from 63 to 33 percent for fish caught between April 25 and September 1 of their next-to-last year at sea and from 34 to 7 percent for fish caught in the same period of their final year at sea. Losses would be somewhat greater for age 0.2 chum salmon and somewhat smaller for age 0.4 fish at comparable times before maturity.

4.6 Population in community and ecosystem

Physical features of the fresh-water environment of chum salmon have not been summarized. Some information for specific areas and times were presented in earlier sections that cover the spawning migration and early life history stages in fresh water.

Some aspects of the interrelations of chum salmon with other organisms in the freshwater environment also were covered in earlier sections. Additional information presented by Hikita (1960) gave the animal composition of one chum salmon stream in Japan (table 40). Figure 13 shows the interrelations of chum salmon with organisms in this stream. Levanidov (1959) measured the abundance andfeeding competition of fish that were associated with chum salmon fry in a section of the Khor River, U.S.S.R. (table 41). Levanidov concluded that the role of the lenok as a competitor was probably exaggerated because they were mainly migratory fish which were only passing through the sampling area. He considered Lagovsky's minnow and the gudgeon as the main competitors of chum salmon fry, and considered other resident species to be relatively unimportant as competitors.

General oceanographic features of the area occupied by Pacific salmon have been described by Dodimead et al. (1963). Physical and biological features that influence the distribution of chum salmon within this general area have not been defined. Manzer et al. (1965) concluded that chum salmon at sea probably tolerate temperatures of 1° to 15° C.; however, they probably prefer temperatures of 2° or 3° to 11° C.

Chum salmon intermingle extensively with other species of Oncorhynchus over much of their ocean range. The similar distribution and food habits indicate a high degree of competition between species of salmon. Manzer et al. (1965) showed that the relative abundance of species varied annually, seasonally, and regionally. For most areas of the North Pacific Ocean and Bering Sea, either chum or sockeye salmon were the dominant species during summer. Maturing pink salmon, especially in odd years, were dominant in the central and western Bering Sea and western North Pacific Ocean in some time periods. Chum salmon usually ranked second in abundance when other species of salmon were more abundant than chums.

T[illegible] 40.--A[illegible], Memu R[illegible], H[illegible] (H[illegible], 1960)

| C[illegible] | C[illegible] | C[illegible] |
|---|---|---|
| P[illegible] | F[illegible] | F[illegible] |
| F[illegible] | B[illegible] | S[illegible] |
| D[illegible] gonocephala | L[illegible] (Dybowskii) | Pungitius pungitius [illegible] L[illegible] |
| L[illegible] | C[illegible] | P[illegible] pungitius [illegible] (Niklosky) |
| L[illegible] | O[illegible] (W[illegible]) | G[illegible] (L[illegible]) |
| H[illegible] lineata | P[illegible] | G[illegible] |
| G[illegible] complanat[illegible] | O[illegible] (Walbaum) | R[illegible] (J[illegible] Sr[illegible]der) |
| M[illegible] | M[illegible] | F[illegible] |
| S[illegible] | O[illegible] (B[illegible]) | C[illegible] |
| L[illegible] | R[illegible] | B[illegible] |
| S[illegible] | S[illegible] (G[illegible]) | Merganser |
| F[illegible]-[illegible] | D[illegible] | M[illegible] L[illegible] |
| S[illegible] | T[illegible] hakonensis (G[illegible]) | M[illegible] |
| M[illegible] | Y[illegible]-[illegible] | A[illegible] platyrhynchus L[illegible] |
| W[illegible] | M[illegible] | A[illegible] S[illegible] |
| S[illegible] [illegible]. | Prussian [illegible] ([illegible]) | E[illegible] |
| C[illegible] | C[illegible] (L[illegible]) | G[illegible] |
| I[illegible] | Carp | T[illegible] |
| Asellus [illegible] | C[illegible] (L[illegible]) | N[illegible] L[illegible] |
| A[illegible] | M[illegible] | W[illegible] D[illegible] |
| G[illegible] [illegible]. | B[illegible] toni [illegible]. (Jordan and Fowler) | A[illegible] L[illegible] |
| D[illegible] | M[illegible] (C[illegible]) | K[illegible] |
| L[illegible] | | C[illegible] M[illegible] |
| I[illegible] | | A[illegible] G[illegible] |
| M[illegible] | | W[illegible] |
| E[illegible] | | C[illegible] |
| E[illegible] [illegible]. | | T[illegible] |
| E[illegible] l[illegible] fulium | | |
| B[illegible] [illegible]. | | |
| N[illegible] [illegible]. | | |
| Paraleptophlebia [illegible] | | |
| C[illegible] | | |
| A[illegible] [illegible]. | | |
| G[illegible] | | |
| P[illegible] [illegible]. | | |
| H[illegible] [illegible]. | | |
| Stenopsyche [illegible] | | |
| L[illegible] [illegible]. | | |
| T[illegible]-[illegible] | | |
| C[illegible] [illegible]. | | |
| S[illegible] | | |
| A[illegible] [illegible]. | | |

L[illegible] (1964[illegible]) [illegible] ([illegible] 42). H[illegible] ([illegible], [illegible], [illegible], P[illegible]) [illegible] "[illegible]" [illegible]-[illegible].

## 5 FISHERY

### 5.1 F[illegible]

#### 5.11 G[illegible]

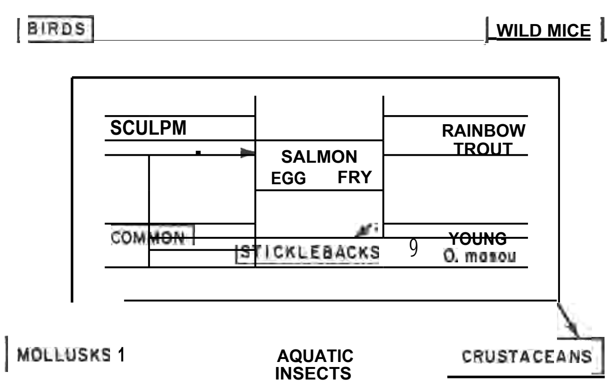
C[illegible] U[illegible] S[illegible].--D[illegible] N[illegible] A[illegible] 20[illegible]

T[illegible] 41.--Relation [illegible] T[illegible] R[illegible], *U.S.S.R.* (Levanidov, 1959)

| S[illegible] | Relative [illegible] | Equivalent [illegible] competition | C[illegible] value[2] |
|---|---|---|---|
| | P[illegible] | | P[illegible] |
| Lenok | 5.0 | 26.1 | 55.7 |
| G[illegible] | 2.0 | 4.8 | h.1 |
| Amur ide | 7.0 | 1.1 | 3.3 |
| C[illegible] | 28.0 | 1.2 | 1/4.0 |
| Lagovsky's [illegible] | 36.0 | 1.11 | 20.9 |
| C[illegible] | 12.0 | 0.2 | 1.2 |
| S[illegible] loach | 0.3 | 0.8 | 0.2 |
| Ninespine [illegible] | 8.0 | 0.1 | 0.4 |
| Bullhead | 1.5 | 0.1 | 0.1 |
| Burbot | *0.2* | 1.0 | 0.1 |

[1] E[illegible]. F[illegible] lenok [illegible] lenok [illegible] 26.1 [illegible].

[2] T[illegible]-[illegible].




F[illegible] 13.--Relation [illegible] Memu R[illegible], J[illegible] (Hikita [illegible] Nagasawa, 1960).

century (Shepard et al., 1967). Their efficiency has been improved by the development of power drums and blocks for handling the nets and by the use of nylon for the webbing (International North Pacific Fisheries Commission, 1962a). Before 1959 (when almost all traps were abolished by regulation), an extensive trap-net fishery existed in Alaska. Traps were also widely used in Washington and Oregon before 1934 and to a much lesser extent in British Columbia before 1958 (Shepard et al., 1967).

At present, gill nets, purse seines, and beach seines are the principal types of gear (table 43). Some chum salmon are also taken by reef nets, trolling, traps, and fish wheels (International North Pacific Fisheries Commission, 1962a; 1962b). The percentage of catches taken by types of gear in 1966 (data from INPFC Statistical Yearbook, 1966) was as follows:

| | C[illegible] T[illegible] | S[illegible] | G[illegible] | O[illegible] |
|---|---|---|---|---|
| | [illegible] | P[illegible] | P[illegible] | P[illegible] |
| A[illegible] | 6,456 | 73.5 | 26.3 | 0.2 |
| B[illegible] C[illegible] | 1,311 | 44,2 | 55.5 | 0.3 |
| W[illegible] | 4 5 | 48.2 | 41.1 | 10.7 |
| O[illegible] | 1 | 0 | 100.0 | 0 |

Along the North American coast, regulations establish the length and sometimes the mesh size and depth [illegible]. G[illegible] and other species of salmon are generally made with multifilament nylon and have mesh

T[illegible] 42.--E[illegible], 1955-61 (L[illegible], 1964b); [illegible] B[illegible] S[illegible], N[illegible] P[illegible] O[illegible], [illegible] G[illegible] A[illegible]

| C[illegible] | F[illegible] | S[illegible] | N[illegible] |
|---|---|---|---|
| A[illegible] | S[illegible] | T[illegible] | 299 |
| A[illegible] flounder | P[illegible] | A[illegible] | 1 |
| A[illegible] | H[illegible] | Pleurogrammus [illegible] | 7,322 |
| B[illegible] | L[illegible] | C[illegible] | 1 |
| B[illegible] | Bramidae | T[illegible] sp. | 1 |
| B[illegible] | C[illegible] | P[illegible] | 877 |
| B[illegible] | H[illegible] | P[illegible] | 9 |
| C[illegible] | Z[illegible] | A[illegible] | 1 |
| D[illegible] | A[illegible] | A[illegible] | 31 |
| D[illegible] V[illegible] | S[illegible] | S[illegible] | 60 |
| E[illegible] ([illegible]) sole | P[illegible] | P[illegible] | 2 |
| E[illegible] | O[illegible] | T[illegible] | 1 |
| J[illegible] | C[illegible] | T[illegible] | 1,295 |
| O[illegible] | L[illegible] | L[illegible] | 1 |
| P[illegible] | G[illegible] | M[illegible] | 23 |
| P[illegible] | C[illegible] | C[illegible] | 4,649 |
| P[illegible] | P[illegible] | L[illegible] | 5 |
| P[illegible] | A[illegible] | A[illegible] | 14 |
| P[illegible] | T[illegible] | T[illegible] | 3 |
| P[illegible] | S[illegible] | C[illegible] | 2 |
| P[illegible] | B[illegible] | B[illegible] | 4,425 |
| R[illegible] | I[illegible] | I[illegible] | 9 |
| R[illegible] | S[illegible] | S[illegible] sp. | 2 |
| S[illegible] | A[illegible] | A[illegible] | 93 |
| S[illegible] | L[illegible] | Lamna [illegible] | 172 |
| Sculpin | C[illegible] | U[illegible] | 1 |
| S[illegible] poacher | A[illegible] | U[illegible] | 6 |
| S[illegible] | H[illegible] | H[illegible] | 1 |
| S[illegible] | A[illegible] | E[illegible] | 145 |
| S[illegible] | T[illegible] | T[illegible] | 247 |
| S[illegible] | S[illegible] | S[illegible] | 105 |
| S[illegible] ([illegible]) [illegible] | S[illegible] | S[illegible] | 602 |
| T[illegible] | G[illegible] | G[illegible] | 38 |
| W[illegible] | G[illegible] | T[illegible] | 145 |
| W[illegible]-[illegible] | A[illegible] | A[illegible] | 2 |
| Y[illegible] sole | P[illegible] | L[illegible] | 12 |
| Y[illegible] | S[illegible] | T[illegible] | 1 |
| C[illegible] ([illegible]) [illegible] | Salmonidae | O[illegible] | 390 |
| C[illegible] | S[illegible] | O. [illegible] | 32,637 |
| C[illegible] ([illegible]) [illegible] | S[illegible] | O. [illegible] | 2,031 |
| P[illegible] | Salmonidae | O. [illegible] | 15,026 |
| S[illegible] ([illegible]) [illegible] | Salmonidae | O. [illegible] | 20,371 |

[1] B[illegible].

[illegible] 12 [illegible] 24 [illegible]. R[illegible] A[illegible] 1962 [illegible] (91 [illegible] 366 [illegible].) [illegible] (A[illegible] D[illegible]- [illegible] F[illegible] G[illegible], 1962). W[illegible], [illegible] 25 [illegible] 30 [illegible] 5.5 m. (W[illegible], 1951).

T[illegible]. T[illegible], [illegible] 300 [illegible] 350 [illegible]. F[illegible] A[illegible] 1962, [illegible] 183 [illegible] 274 m. [illegible] 274 [illegible] 548 m. (Alaska D[illegible] F[illegible] Game, 1962). M[illegible] - [illegible] 9 [illegible] 10 [illegible]. [illegible] 8.3 [illegible] 8.9 [illegible]. [illegible] bunt

T[illegible] 43.--T[illegible] P[illegible] (S[illegible], 1957; N[illegible], 1960; N[illegible], 1964; N[illegible], 1967)

| V[illegible] | J[illegible] | | | U[illegible] S[illegible] C[illegible] | |
|---|---|---|---|---|---|
| | L[illegible] | H[illegible] | | G[illegible] | P[illegible] |
| | | Motherships | C[illegible] | | |
| L[illegible] (m.) | | | 24-27 | 7-13 | 12-28 |
| I[illegible] | 5-75 | [1] 8,400 | [1] 90 | 0.5-7 | 7-40 |
| C[illegible] | W[illegible] | S[illegible] | S[illegible] | W[illegible], [illegible] aluminum. | S[illegible] |
| Engine | | | | | |
| Type | | D[illegible] | D[illegible] | G[illegible] | G[illegible] |
| I[illegible] | | | 280-400 | 50-140 | 35-300 |
| C[illegible] (km./hour) | -- | 22-26 | 19 | 13-41 | 15-26 |
| C[illegible] | 6-20 | | 20-22 | 1-2 | 4-9 |

1 A[illegible] 1964.

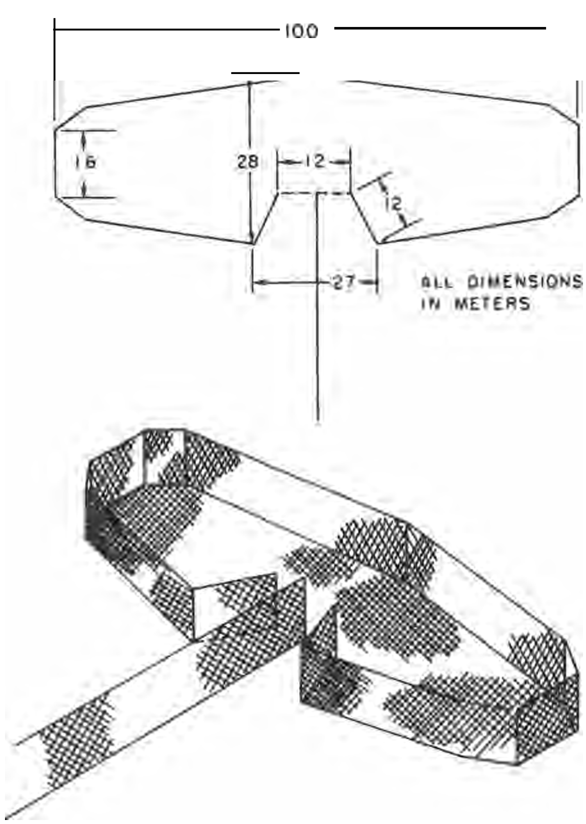
(J[illegible], 1967; F[illegible] A[illegible] O[illegible], 1965). 

S[illegible]. P[illegible] 17.7 [illegible]. A[illegible], [illegible] B[illegible] B[illegible] A[illegible] 9.8 [illegible].

J[illegible].--T[illegible] J[illegible], [illegible]. G[illegible], [illegible] 1955. M[illegible] 1963, [illegible] (N[illegible], 1967). T[illegible] N[illegible] P[illegible] O[illegible] B[illegible] S[illegible]. T[illegible] H[illegible] K[illegible] I[illegible] 48° N. [illegible]; [illegible] H[illegible] H[illegible] (N[illegible], 1967).

M[illegible] N[illegible] P[illegible] F[illegible] T[illegible] J[illegible] U.S.S.R. M[illegible] 11.4 [illegible] 11.5 [illegible] 12.1 [illegible] 13.0 [illegible] (K[illegible], 1966). N[illegible] 15 [illegible] (N[illegible], 1964).

U.S.S.R.--The [illegible] R[illegible] (F[illegible]. 14), [illegible] 1900's, [illegible] (A[illegible], 1964). B[illegible], [illegible].




F[illegible] 14.--Plan [illegible] R[illegible] (A[illegible], 1964).

The Japanese have also fished on Soviet stocks of salmon (see section 5.22). The types of gear used by the combined Soviet and Japanese fishery have undergone changes as the Russians have restricted the Japanese from fishing near their coast. Semko (1964) summarized these changes as follows:

Percentage of catch by gear

| Period | Coastal set net | River set net | Ocean drift net | Longline | Catch |
|---|---|---|---|---|---|
| | Percent | | | | Thousand metric tons |
| 1926-33 | 60 | 40 | | | 210 |
| 1934-43 | 70 | 24 | 6 | | 380 |
| 1944-51 | 70 | 30 | | - | 190 |
| 1952-60 | 26 | 10 | 60 | 4 | 250 |

5.12 Boats

Types of vessels used in the fishery are given in table 43.

## 5.2 Fishing areas

### 5.21 General geographic distribution

Historically, the fishery has operated in coastal waters, but has been extended to offshore waters by the Japanese. Along the North American coast, fishing areas extend from Oregon north to the Yukon River. In Asia they range along the coasts of Japan and the U.S.S.R. to as far north as the Gulf of Anadyr. Since 1952 the Japanese have had a high-seas mothership fishery in the western North Pacific Ocean and Bering Sea (Kasahara, 1963).

### 5.22 Geographic ranges

The important fishing areas for chum salmon are shown in figure 15. The range of coastal fishing in Asia and North America has not changed substantially since the early days of the fishery. Areas fished by a part of the Japanese salmon fishery have changed, however. By treaty the Japanese were allowed to fish for salmon in Russian territory beginning in the 19th century (Atkinson, 1964). Increasing difficulty in negotiation for these fishing rights in 1928-45 led to a Japanese mother ship operation off the Kamchatkan coast. The fishery caught salmon with drift gill nets and processed the catch aboard factoryships or motherships. Fishing was concentrated near the spawning rivers and took mature salmon. This type of fishery continued until 1944. In 1952 the mothership fishery was resumed, but now fishing extends far offshore into the western Aleutian Islands, where the salmon are a mixture of stocks in different stages of maturity. This type of fishery also began in the Okhotsk Sea in 1955 and continued until the Soviets closed this area to the Japanese in 1958.

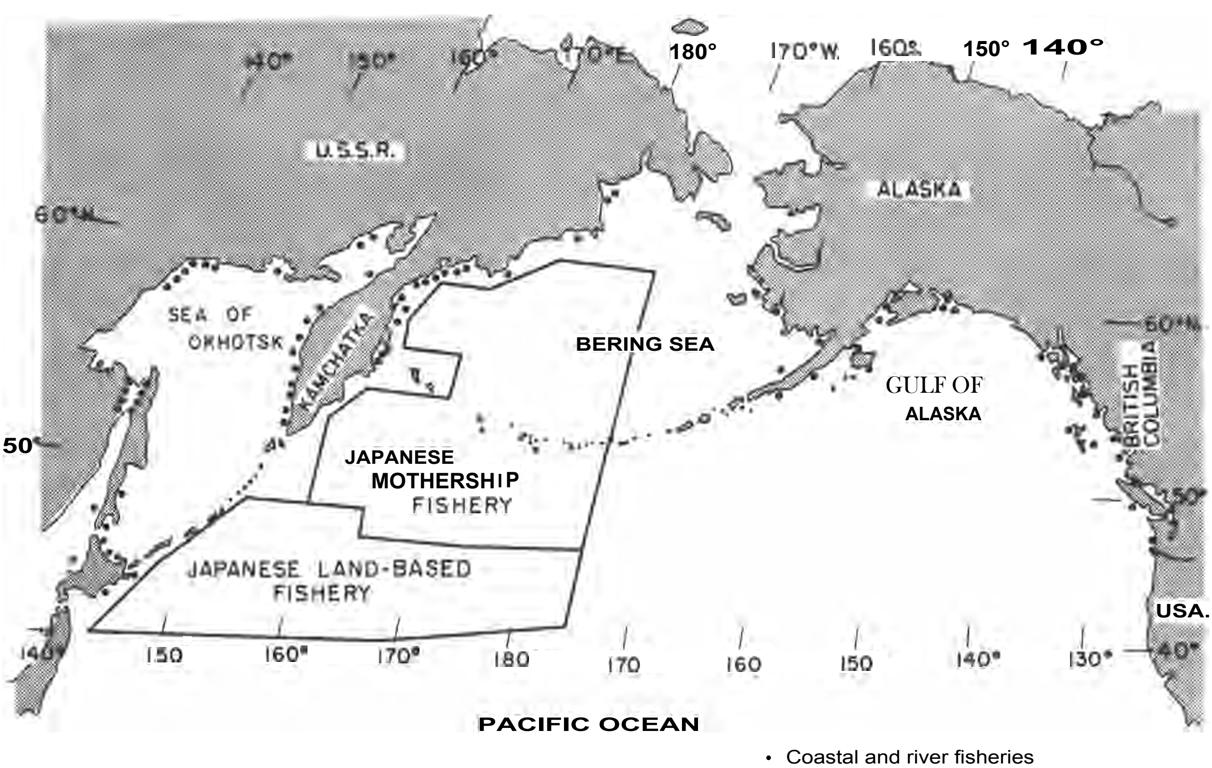



Figure 15.--Important fishing areas for chum salmon in Asia and North America (Kasahara, 1961; International North Pacific Fisheries Commission, 1964; Manzer et al., 1965).

5.23 Depth ranges

Fukuhara (1953) reported that gill net catches were greatest near the surface and decreased with depth in offshore waters fished by the Japanese mothership fleet. From 85 to 90 percent of the catch was made from the float line down to 10 m.

5.24 Condition of the grounds

No information.

5.3 Fishing seasons

5.31 General seasons

Coastal fisheries are timed to intercept maturing salmon as they approach spawning streams. Peak catches along the Asian and North American coasts are made earlier in the more northern areas (late June to August) than in the southern areas (September to November or later). The Japanese mothership fishery and land-based offshore fishery intercept the maturing and immature fish earlier, and peak catches are usually in June (table 44).

5.32 Dates of beginning, peak and end of season(s)

Duration of the fishing seasons and periods of peak catches are shown in table 44.

5.33 Variation in date or duration of season

The lengths of seasons have varied because of regulation changes intended to ensure adequate escapement of adults to spawning grounds, inclement weather that interferred with fishing, and price disputes that prevented fishing.

5.4 Fishing operations and results

5.41 Effort and intensity

Fishing effort is controlled primarily through national and international regulations (see section 6.1). Effort for some chum salmon stocks is also influenced by the effort of fishing for other species such as pink and sockeye salmon. This would apply to the fishery in parts of Alaska and the Japanese mothership fishery.

No data were found that completely adhere to the definitions of effort and intensity (see footnote 15). Available information is given by major political area.

Washington.--From 1944 to 1959, the number of purse seine licenses issued annually increased by 300 percent and gill net licenses by 94 percent (INPFC, 1962b). Because of shorter fishing seasons, effort had probably not increased at a rate proportional to the number of licenses issued but some increase had taken place. Yields fluctuated widely around an annual average of 742,000 fish. From a peak production in 1946 of 1.4 million fish, the catch trend was downward to a low of 168,000 fish in 1956 and 1957. This level of production continued to 1966.

British Columbia.--International North Pacific Fisheries Commission (1962a) summarized the effort of the British Columbia fishery as follows: (1) Since a low in 1932, the number of purse seiners had about doubled; (2) increases in efficiency of gill netters had offset the moderate decrease in this type of gear; (3) the result has been a greater effort of fishing for chum salmon but not an increase in the sustained yield.

Alaska.--Fishing effort and catch per unit of effort for the commercial fisheries of Alaska have been summarized by the International North Pacific Fisheries Commission (1962b) for all species of salmon collectively. Because much of the effort was for species other than chum salmon these data are not reported here.

Japanese mothership and land-based fisheries.--Units of gear, catches, and catch per unit of effort for the mothership fishery are shown in table 45. Catches increased as the fishery expanded from 1952 to 1955. Catches were at their highest (10.5-18.5 million fish) in 1955-60 but declined in later years as the U.S.S.R. reduced the quota on this fishery. Catch per unit of effort also increased in early years of the fishery, remained near 1.8 fish per tan (51 m. of gill net) for several years, and then declined to about 1.0 fish per tan from 1961 to 1965.

The number of boats in the land-based fishery has decreased (table 45) as larger, more efficient vessels have replaced many smaller boats. Catches increased substantially from 1952 to 1958 as the effort of the fishery increased, were highest (19,100-19,600 metric tons) from 1958 to 1960, and declined to 13,000 to 15,000 metric tons in more recent years.

U.S.S.R.--Semko (1964) described, in general terms, the intensity of the fishery operations on the stocks of salmon from the Soviet Coast. Dividing the fishery into four historical periods, he concluded: (1) From 1926 to 1933 the salmon resources were fully utilized and escapement was sufficient; (2) from 1934 to 1943 the Japanese offshore fishery developed rapidly and the coastal catches declined despite a curtailment of inshore gear; (3) from 1944 to 1951 only coastal trap nets and beach

[15] Fishing effort is the total fishing gear in use per unit of time, and fishing intensity is the fishing effort per unit area (Ricker, 1958).

Table 44.--Fishing [illegible] salmon in Asia and North America

| Fishery | Years of record | Beginning of season | Peak of season | End of season | Authority |
|---|---|---|---|---|---|
| Asia: | | | | | |
| Northeastern coast of Kamchatka. | 1932-41 | June 15-25 | July 2-23 | Aug. 5-16 | K[illegible] (1963). |
| Kamchatka River | 1932-41 | June 7 | July 14-Aug. 18 | Sept. 6 | Do. |
| West coast of Kamchatka | 1932-41 | June 2-9 | July 19-Aug. 24 | Aug. 21-30 | Do. |
| Northern Okhotsk coast | 1932-41 | June 12 | Aug. 4-21 | Sept. 1 | Do. |
| Sakhalin | 1959-64 | August-September | September | October-November | Research Institute of Marine Fisheries and Oceanography, U.S.S.R. (1960, 1961, 1964, 1965). |
| Kurile Islands | 1959-64 | Do. | October | November | Do. |
| Amur River | 1959-64 | July-August | September | September-October | Do. |
| Japanese mothership | 1952-64 | May-July | July | July 31-Aug. 22 | International North Pacific Fisheries Commission (1953-64). |
| Japanese land-based | 1952-64 | April | June (marine fisheries) October ([illegible]). | December-January | Do. |
| North America: | | | | | |
| Western Alaska | 1955-64 | June 1-11 | Late June to early July. | Aug. 27-Sept. 29 | International North Pacific Fisheries Commission (1952-64). |
| Central Alaska | 1955-64 | May 1-June 1 | Late June to early August. | Sept. 16-Oct. 3 | Do. |
| Southeastern Alaska | 1955-64 | Do. | June, August, and September. | Oct. 26-Dec. 31 | Do. |
| British Columbia | 1952-64 | Do. | September and October | Do. | Do. |
| Washington | 1956-64 | June 1-Sept. 1 | Late October to early November. | Jan. 18-Mar. 3 | Do. |

Table 45.--Catches of chum salmon by Japanese mothership and land-based fisheries in the North Pacific Ocean and Bering Sea (Manzer et al., 1965; Fisheries Agency of Japan, 1967; Nagasaki, 1967)

| Year | Mothership fishery | | | | | Land-based fishery | |
|---|---|---|---|---|---|---|---|
| | Motherships | Catcher boats | Gear | Catch | | Boats | Catch |
| | | | | Fish | Per tan | | |
| | Number | Number | Million tans[1] | Millions | Number | Number | Thousand metric tons |
| 1952 | 3 | 57 | - | 0.6 | 1.1 | 1,497 | 1.8 |
| 1953 | 3 | 105 | | 2.7 | 2.1 | 1, 32 | 4.0 |
| 1954 | 7 | 205 | - | 9.4 | 2.8 | 1,897 | 7.1 |
| 1955 | 14 | 407 | - | 18.5 | 2.3 | 1,242 | 9.6 |
| 1956 | 16 | 557 | 9.3 | 16.1 | 1.7 | 510 | 5.6 |
| 1957 | 16 | 461 | 6.6 | 11.9 | 1.8 | 490 | 7.9 |
| 1958 | 16 | 460 | 8.6 | 17.2 | 2.0 | 452 | 19.6 |
| 1959 | 16 | 460 | 7.1 | 12.9 | 1.8 | 430 | 19.4 |
| 1960 | 12 | 410 | 6.5 | 10.5 | 1.6 | 415 | 19.1 |
| 1961 | 12 | 410 | 5.0 | 6.1 | 1.2 | 414 | 13.1 |
| 1962 | 11 | 369 | 5.9 | 6.4 | 1.1 | 333 | 13.7 |
| 1963 | 11 | 369 | 6.0 | 5.9 | 1.0 | 333 | 14.0 |
| 1964 | 11 | 369 | 7.5 | 8.6 | 1.1 | 333 | 14.8 |
| 1965 | 11 | 369 | 6.1 | 6.0 | 1.0 | | |

[1] 1 tan = 51 m. of gill net.

seines were used and the runs increased; and (4) the period from 1957 to 1960 was characterized by an intensified Japanese fishery on the high seas and a decrease in Soviet catches as well as a decline in escapement of fish.

### 5.42 Selectivity

Peterson (1964) described the selectivity of nylon gill nets used experimentally by U.S. vessels in connection with research for INPFC. These nets were used to sample immature and maturing salmon of age 0.1 or older and therefore had smaller meshes (6.4, 8.3, 11.4, and 13.3 cm., stretched measure) than commercial nets. Lengths of fish caught most efficiently by each mesh size were 30 cm. for the 6.4-cm. mesh, 38 cm. for the 8.3-cm. mesh, 53 cm. for the 11.4-cm. mesh, and 62 cm. for the 13.3-cm. mesh. The composite mesh selection curve for these mesh sizes shows that the catch efficiency is not equal at all lengths. Fish from 44 cm. to 47 cm. are caught less efficiently because of the larger (3.1-cm.) gap between the 8.3-cm. and 11.4-cm. mesh sizes.

Konda (1966) determined size ranges of chum salmon taken in experimental and commercial nets of various mesh sizes. He assummed that fish gilled just behind the preopercle were the largest fish gilled by a certain mesh, and the fish gilled immediately in front of the base of the dorsal fin (where the girth was greatest) were the smallest fish caught with a certain mesh size. These ranges (table 46) include the bulk of fish actually caught by a certain mesh, but some fish are also taken which become entangled in the mesh even though their size would normally allow them to escape. For example, the size range of fish taken by the 6.4-cm. mesh was given by Konda (1966) as 26.5 to 37.0 cm., but in actual fishing, the range of fish taken by this mesh was 23 to 65 cm. according

Table 46.--Range in length of chum salmon taken by various mesh sizes of multifilament nylon gill nets (Konda, 1966)

| Mesh size | Fork length | |
|---|---|---|
| | Maximum | Minimum |
| Cm. | Cm. | Cm. |
| 6.4 | 26.5 | 37.0 |
| 7.6 | 31.0 | 43.0 |
| 8.3 | 33.0 | 45.5 |
| 9.1 | 36.0 | 50.5 |
| 9.7 | 37.5 | 53.5 |
| 10.6 | 41.0 | 57.5 |
| 11.0 | 42.5 | 59.0 |
| 11.4 | 43.0 | 60.5 |
| 11.5 | 4)4.0 | 61.0 |
| 12.1 | 46.0 | 63.5 |
| 12.6 | 47.5 | 65.0 |
| 13.0 | 48.5 | 67.0 |
| 13.3 | 49.5 | 67.5 |
| 13.6 | 50.5 | 69.5 |

to Manzer et al. (1965). Most of the fish (98 percent), however, were 28 to 35 cm. inthe latter study.

Konda (1966) also determined the optimum mesh sizes for chum salmon encountered by the Japanese mothership fisheries on the high seas as follows:

| Age of fish | Mean length of fish | Optimum mesh size |
|---|---|---|
| | Cm. | Cm. |
| 0.2 | 46.8 | 10.4 |
| 0,3 | 53.8 | 12.4 |
| 0.4 | 56.4 | 13.0 |

### 5.43 Catches

Chum salmon have provided the second highest catches among the species of Pacific salmon. Total world catch in 1953-62 averaged 44.2 million fish per year (132,000 metric tons), which was 20.7 percent of the total average catch of Pacific salmon in numbers of fish and 29.2 percent in weight (Shepard et al., 1967). Annual yields of chum salmon by area in Asia and North America are presented in tables 47 and 48. Kasahara (1963) considered these figures as only "very rough estimates" because statistics from some sources were inaccurate and factors used to convert weight of fish to numbers were chosen rather arbitrarily.

Commercial catches of chum salmon on the Asian side have been considerably larger than those from the North American coast. The Asian catch averaged about 43 million fish in 1932-41, whereas the North American catch was about 14.5 million (34 percent of the Asian catch). In 1955-60 the Asian catch averaged about 41.5 million chum salmon compared to the average North American catch of 8.7 million (21 percent of the Asian catch). The difference in abundance of stocks from the two continents, based on commercial catch statistics, may be exaggerated because of the probable lower level of fishing on North American stocks (Committee on Biology and Research, 1961).

The proportion of chum salmon taken by each country (table 49) shows that catches were rather evenly divided among Japan, Russia, and North America during World War II. In the 10 years following the war, the largest catches were made by the U.S.S.R. and in later years by the Japanese as their

Table 47.--Total annual catches of chum salmon in Asia (Kasahara, 1963; Research Institute of Marine Fisheries and Oceanography, U.S.S.R., 1964-65; International North Pacific Fisheries Commission, 1962-66)

| Year | U.S.S.R. | | | Japan | | | Total |
|---|---|---|---|---|---|---|---|
| | By Japan | By Japan and U.S.S.R. | By U.S.S.R. | Mothership and North Kurile | South Sakhalin | South Kuriles, Hokkaido and Honshu | |
| | Millions of fish | | | | | | |
| 1908 | 2.8 | | | | 0.3 | 1.0 | (4.1) |
| 1909 | 4.6 | | | | 0.5 | 0.9 | (6.0) |
| 1910 | 11.6 | | | | 0.6 | 3.1 | (15.3) |
| 1911 | 7.9 | | | | 0.7 | 4.7 | (13.3) |
| 1912 | 6.6 | | | | 0.7 | 3.7 | (11.0 |
| 1913 | 11.3 | 0 | | | 0.6 | 2.7 | (14.6) |
| 1914 | 9.9 | | | | 1.1 | 3.1 | (14.1) |
| 1915 | 5.0 | | | | 0.8 | 5.0 | (10.8) |
| 1916 | 3.9 | | | | 0.3 | 2.3 | (6.5) |
| 1917 | 6.7 | | | | 0.4 | 3.0 | (10.1) |
| 1918 | 9.3 | | | | 0.9 | 3.6 | (13.8) |
| 1919 | 11.9 | | | | 1.1 | 4.7 | (17.7) |
| 1920 | 10.8 | | | | 0.7 | 3.5 | (15.0) |
| 1921 | 10.3 | | | | 0.5 | 3.4 | (14.2) |
| 1922 | 10.1 | | | | 0.4 | 3.3 | (13.8) |
| 1923 | 8.8 | | | | 0.7 | 5.7 | (15.2) |
| 1924 | 5.1 | | | | 0.4 | 2.7 | (8.2) |
| 1925 | 0 | 12.0 | 0 | | 0.3 | 4.3 | 16.6 |
| 1926 | 0 | 14.7 | 0 | | 0.6 | 4.7 | 20.0 |
| 1927 | 0 | 15.4 | 0 | | 0.5 | 3.9 | 19.8 |
| 1928 | 0 | 25.8 | 0 | | 0.5 | 2.4 | 28.7 |
| 1929 | 0 | 28.7 | 0 | ([3]) | 0.3 | 3.8 | 32.8 |
| 1930 | 0 | 37.1 | 0 | 0.2 | 0.7 | 5.2 | 43.2 |
| 1931 | 0 | 32.8 | 0 | (0.4) | 0.5 | (3.6) | (37.3) |
| 1932 | 0 | 27.2 | 0 | (0.7) | 0.2 | (2.2) | (30.3) |
| 1933 | 0 | 22.3 | 0 | 3.5 | 0.3 | 2.3 | 28.4 |
| 1934 | 0 | 34.8 | 0 | 6.5 | 0.4 | 4.7 | 46.4 |
| 1935 | 0 | 28.6 | 0 | 8.3 | 0.5 | 5.6 | 43.0 |
| 1936 | 0 | 42.0 | 0 | 18.5 | 0.4 | 3.6 | 64.5 |
| 1937 | 0 | 26.2 | 0 | 16.8 | 0.7 | 3.0 | 46.7 |
| 1938 | 0 | 30.2 | 0 | 19.7 | 0.3 | 4.5 | 54.7 |
| 1939 | 0 | 27.1 | 0 | 15.8 | 0.6 | 4.6 | 48.1 |
| 1940 | 9.3 | 0 | 17.3 | 15.0 | 0.7 | 3.4 | 45.7 |
| 1941 | 9.4 | 0 | 16.8 | 11.8 | 0.9 | 2.9 | 41.8 |
| 1942 | 3.6 | 0 | 12.4 | 13.8 | 0.3 | 2.4 | 32.5 |
| 1943 | 2.6 | 0 | 19.6 | 4.1 | 0.3 | 2.1 | 28.7 |
| 1944 | 0.5 | 0 | 17.3 | 2.0 | - | 1.6 | (21.4) |
| 1945 | - | 0 | 19.2 | 0.2 | | 2.4 | 21.8 |
| 1946 | 0 | 0 | 21.5 | | | 2.2 | 23.7 |
| 1947 | 0 | 0 | 21.7 | | | 2.7 | 24.4 |
| 1948 | 0 | 0 | 19.5 | | | (2.7) | (22.2) |
| 1949 | 0 | 0 | 24.8 | | | (3.7) | (28.5) |
| 1950 | 0 | 0 | 19.2 | | | (5.4) | (24.6) |
| 1951 | 0 | 0 | 26.1 | | | (5.9) | (32.0) |
| 1952 | 0 | 0 | 13.8 | 0.6 | | 3.2 | 17.6 |

See footnotes at end of table.

Table 47.--Total annual catches of chum salmon in Asia (Kasahara, 1963; Research Institute of Marine Fisheries and Oceanography, U.S.S.R., 1964-65; International North Pacific Fisheries Commission 1962-66)--Con.

| Year | U.S.S.R. | | | Japan | | | Total |
|---|---|---|---|---|---|---|---|
| | By Japan' | By Japan and U.S.S.R. | By U.S.S.R. | Mothership and North Kurile | South Sakhalin | South Kuriles, Hokkaido and Honshu[2] | |
| | Millions of fish | | | | | | |
| 1953 | | | 10.6 | 2.7 | | 4.1 | 17.4 |
| 1954 | | | 16.4 | 9.4 | | 6.6 | 32.4 |
| 1955 | | | 20.5 | 22.0 | | 7.1 | 49.6 |
| 1956 | 0 | 0 | 24.2 | 20.4 | | 4.4 | 49.0 |
| 1957 | 0 | 0 | 10.0 | 11.9 | | 8.5 | 30.4 |
| 1958 | 0 | 0 | 8.7 | 18.8 | | 13.6 | 41.1 |
| 1959 | 0 | 0 | 11.9 | 12.9 | | 12.0 | 36.8 |
| 1960 | 0 | 0 | 13.5 | 10.5 | | 12.2 | 36.2 |
| 1961 | 0 | 0 | 11.4 | 6.1 | | 10.6 | 28.1 |
| 1962 | 0 | 0 | 9.2 | 6.4 | | 10.9 | 26.5 |
| 1963 | 0 | 0 | 9.4 | 5.9 | | 12.4 | 27.7 |
| 1964 | 0 | 0 | 6.5 | (8.6) | | 23.4 | (38.5) |
| 1965 | 0 | 0 | - | (6.0) | | 16.4 | |
| 1966 | 0 | 0 | - | (8.6) | | 16.0 | |

- Figures for 1908-24 include coho salmon catches.
2 May include small numbers of sockeye, coho, and chinook salmon from 1908-57.
- Less than 50,000 fish.
Estimate.
- No data.
O Figures incomplete.

Table 48.--Total annual catches of chum salm. in North America and totals for Asia and North America (Kasahara, 1963; International North Pacific Fisheries Commission, 1962-66)

| Year | United States | | | | | Canada | Total North American | Total Asian[1] and North American |
|---|---|---|---|---|---|---|---|---|
| | Western Alaska | Central Alaska | Southeastern Alaska | Washington | Oregon | British Columbia | | |
| | Millions of fish - - - - | | | | | | | |
| 1908 | | | | | | | | |
| 1909 | | | | | | | | |
| 1910 | | | | | | | | |
| 1911 | | - | - | | | | | |
| 1912 | | - | - | - | - | | | |
| 1913 | | | - | | | | | |
| 1914 | | | | | | | | |
| 1915 | | | | | | | | |
| 1916 | - | | | | | | | |
| 1917 | | | | - | - | - | - | - |
| 1918 | | | | | | | | |
| 1919 | | | | - | | | - | - |
| 1920 | 0.6 | 1.5 | 8.0 | - | - | 1.0 | 11.1 | (26.1) |

See footnotes at end of table.

Table 48.--Total annual catches of chum salmon in North America and totals for Asia and North America (Kasahara, 1963; International North Pacific Fisheries Commission, 1962-66)--Con.

| Year | United States | | | | | Canada | Total North American | Total Asian[1] and North American |
|---|---|---|---|---|---|---|---|---|
| | Western Alaska | Central Alaska | Southeastern Alaska | Wash- ington | Oregon | British Columbia | | |
| | | | | Millions of fish | | | | |
| 1921 | 0.5 | 0.4 | 1.8 | | | 1.3 | 4.0 | (18.2) |
| 1922 | 0.7 | 0.9 | 3.7 | 0.6 | (2) | 3.2 | 9.1 | (22.9) |
| 1923 | 0.9 | 0.9 | 4.0 | 0.9 | 0.1 | 4.9 | 11.7 | (26.9) |
| 1924 | 1.6 | 2.0 | 5.1 | 1.2 | .3 | 6.4 | 16.6 | (24.8) |
| 1925 | 0.7 | 2.2 | 8.6 | 1.1 | .2 | 6.7 | 19.5 | 36.1 |
| 1926 | 1.7 | 3.2 | 6.0 | 1.3 | .1 | 7.3 | 19.6 | 39.6 |
| 1927 | 1.0 | 2.5 | 2.2 | 1.1 | .3 | 5.3 | 12.4 | 32.2 |
| 1928 | 1.4 | 3.8 | 4.9 | 1.7 | .5 | 7.7 | 20.0 | 48.7 |
| 1929 | 1.7 | 5.1 | 2.6 | 2.0 | .2 | 3.9 | 15.5 | 48.3 |
| 1930 | 1.1 | 2.8 | 2.7 | 1.2 | .1 | 5.1 | 13.0 | 56.2 |
| 1931 | 1.5 | 2.2 | 2.9 | 1.0 | .1 | 4.0 | 11.7 | (49.0) |
| 1932 | 2.5 | 1.5 | 5.6 | 1.5 | .1 | 3.9 | 15.1 | (45.4) |
| 1933 | 1.1 | 2.2 | 4.5 | 0.7 | .1 | 3.1 | 11.7 | 40.1 |
| 1934 | 1.2 | 3.1 | 3.8 | 1.0 | .1 | 4.8 | 14.0 | 60.4 |
| 1935 | 1.0 | 3.4 | 5.1 | 0.8 | .1 | 5.0 | 15.4 | 58.4 |
| 1936 | 1.2 | 3.3 | 7.6 | 1.0 | .2 | 6.1 | 19.4 | 83.9 |
| 1937 | 1.1 | 2.3 | 5.6 | 1.0 | .1 | 4.9 | 15.0 | 61.7 |
| 1938 | 1.3 | 2.7 | 4.6 | 1.0 | .2 | 4.7 | 14.5 | 69.2 |
| 1939 | 1.4 | 2.7 | 3.4 | 0.4 | .1 | 2.6 | 10.6 | 58.7 |
| 1940 | 1.7 | 3.7 | 4.6 | 0.7 | .1 | 5.0 | 15.8 | 61.5 |
| 1941 | 1.1 | 3.5 | 3.0 | 1.2 | .4 | 6.3 | 15.5 | 57.3 |
| 1942 | 0.4 | 4.2 | 5.4 | 1.2 | .5 | 4.4 | 16.1 | 48.6 |
| 1943 | 0.7 | 2.2 | 6.8 | 0.6 | .1 | 4.9 | 15.3 | 44.0 |
| 1944 | 0.5 | 3.1 | 6.9 | 0.4 | (2) | 2.3 | 13.2 | (34.6) |
| 1945 | 1.0 | 3.9 | 3.3 | 0.5 | .1 | 3.0 | 11.8 | 33.6 |
| 1946 | 0.5 | 3.1 | 4.0 | 1.5 | .1 | 6.8 | 16.0 | 39.7 |
| 1947 | 0.4 | 2.6 | 3.4 | 0.7 | .1 | 5.7 | 12.9 | 37.3 |
| 1948 | 0.9 | 3.4 | 4.0 | 1.1 | .1 | 5.1 | 14.6 | (36.8) |
| 1949 | 0.4 | 2.5 | 2.9 | 0.5 | .1 | 3.0 | 9.4 | (37.9) |
| 1950 | 0.4 | 2.5 | 4.8 | 1.1 | .1 | 7.3 | 16.2 | (40.8) |
| 1951 | 0.5 | 2.0 | 4.1 | 1.0 | .1 | 5.8 | 13.5 | (45.5) |
| 1952 | 0.5 | 3.5 | 4.2 | 0.9 | (2) | 2.5 | 11.6 | 29.2 |
| 1953 | 0.6 | 3.1 | 3.5 | 0.5 | (2) | 4.7 | 12.4 | 29.8 |
| 1954 | 0.8 | 3.3 | 4.2 | 0.7 | (2) | 5.9 | 14.9 | 47.3 |
| 1955 | 0.3 | 1.6 | 1.5 | 0.4 | (2) | 1.6 | 5.4 | 55.0 |
| 1956 | 0.8 | 3.7 | 2.7 | 0.2 | (2) | 2.5 | 9.9 | 58.9 |
| 1957 | 0.5 | 4.4 | 3.4 | 0.2 | (2) | 2.4 | 10.9 | 41.3 |
| 1958 | 0.6 | 3.2 | 2.8 | 0.5 | (2) | 3.2 | 10.3 | 51.4 |
| 1959 | 0.9 | 1.9 | 1.2 | 0.5 | (2) | 2.0 | 6.5 | 43.3 |
| 1960 | 1.9 | 3.7 | 1.0 | 0.2 | (2) | 1.8 | 8.6 | 44.8 |
| 1961 | 1.0 | 2.1 | 2.6 | 0.2 | (2) | 1.2 | 7.1 | 35.2 |
| 1962 | 1.1 | 4.0 | 2.0 | 0.2 | (2) | 1.5 | 8.8 | 35.3 |
| 1963 | 0.6 | 2.4 | 1.5 | 0.3 | (2) | 1.5 | 6.3 | 34.0 |
| 1964 | 1.2 | 4.2 | 1.9 | 0.3 | (2) | 2.3 | 9.9 | (48.4) |
| 1965 | (0.3) | (1.6) | (1.5) | (0.2) | (2) | 0.6 | (4.2) | |
| 1966 | (0.6) | (2.6) | (3.3) | (0.4) | (2) | 1.3 | (8.2) | |

[1] See table 47 for total Asian catches.
[2] Less than 50,000 fish.

\- No data.
( ) Figures incomplete.

Table 49.--Percentage of world catch of chum salmon taken by each country

[Percentage calculations were made from data in tables 47 and 48]

| Period | Catch of chum salmon | | | | |
|---|---|---|---|---|---|
| | Japan | U.S.S.R. | United States | Canada | Total |
| | ---------- | ---------- | Percent | ---------- | Millions of fish |
| 1940-45 | 31.9 | 36.7 | 22.1 | 9.3 | 279.6 |
| 1946-50 | 8.7 | 55.4 | 21.4 | 14.5 | 192.5 |
| 1951-55 | 29.8 | 42.3 | 18.0 | 9.9 | 206.8 |
| 1956-60 | 52.2 | 28.5 | 14.3 | 5.0 | 239.7 |
| 1961-64 | 55.1 | 23.9 | 16.7 | 4.3 | 152.9 |

Table 50.--Percentage contribution by *area* to the total coastal catch of chum salmon in *Asia* (Sano, 1967)

| Year | Kamchatka Peninsula | Northern coast of the Sea of Okhotsk | Amur River | Sakhalin coast | Primore coast | Japanese coast |
|---|---|---|---|---|---|---|
| | ---------- | ---------- | Percent | ---------- | ---------- | ---------- |
| 1955 | 37.6 | 28,14 | 11.9 | 7.3 | 0.2 | 9.6 |
| 1956 | 28.3 | 43.7 | 17.6 | 4.0 | .1 | 6.3 |
| 1957 | 15.3 | 35.6 | 13.9 | 13.3 | | 21.9 |
| 1958 | 13.3 | 31.6 | 25.4 | 6.4 | | 23.3 |
| 1959 | 34.0 | 26.7 | 24.3 | 1.8 | | 13.2 |
| 1960 | 14.3 | 43.0 | 29.7 | 1.9 | | 11.1 |
| Average | 23.8 | 34.8 | 21.3 | 5.8 | | 14.2 |

salmon fishery expanded. A summary of the contribution of various areas to the Asian catch in prewar years (Committee on Biology and Research, 1961) showed that the Kamchatka Peninsula provided the largest catches (about 25 million fish annually). The northern coast of the Sea of Okhotsk also produced great numbers of chum salmon in this period (about 11 million annually). The Amur River, and rivers in Sakhalin, Hokkaido, and Honshu provided a similar annual yield of about 10.5 million fish (7.5 million from the Amur and 3.0 million from the other rivers). In more recent years (table 50), catches along the coast of Kamchatka have been less important; the largest annual yields for most years have been from the northern coast of the Sea of Okhotsk.

In North America, the commercial catches are rather evenly divided between central Alaska, southeastern Alaska, and the area from British Columbia southward (Shepard et al., 1967). Northern Alaska streams (north of Bristol Bay) have substantial runs that are used by the Alaska natives.

# 6 PROTECTION AND MANAGEMENT

## 6.1 Regulatory (legislative) measures

### 6.11 Limitation or reduction of total catch

In Asia, catches have been reduced by quotas and closures on fishing. The Soviets have restricted their own coastal fisheries (Atkinson, 1964) and, through the Northwest Pacific Fisheries Treaty, have imposed a quota on the Japanese mothership and land-based fisheries (Nagasaki, 1967). The Japanese have regulated their own land-based fishery by restricting the number of boats and the length of the fishing season (Nagasaki, 1967).

In North America, catches have been reduced by periodic closures on fishing during the season and by reducing gear efficiency, which has been accomplished by limiting the length of nets and size of boats and by prohibiting the use of monofilament nylon gill nets, electronic fish finders, or airplanes to locate salmon (Bevan, 1965). Efficient types of gear such as fish wheels and fish traps have been banned for many years.

### 6.12 Protection of portions of the population

International treaties have restricted the Japanese mothership fishery to certain areas. A treaty with the United States and Canada restricted the Japanese from fishing east of a provisional line (long. 175° W.) in the North Pacific Ocean and Bering Sea (Oda, 1967). Through a Japanese-Soviet treaty, the fishery has been excluded from the Okhotsk Sea, the Kurile Islands, and the east coast of Kamchatka (Oda, 1967). Moreover, the Russians have established minimum mesh sizes, which reduces the catch of small immature salmon on the high seas.

Regulations for North America were summarized by the International North Pacific Fisheries Commission (1962b) as follows:

1. "Time restriction - limiting the time at which fishing may be carried on both seasonally and within seasons. In general, fishing time is set to coincide with the peak of abundance of local runs, with intermittent closures to allow for escapement throughout the runs."
2. Area restrictions - widely employed to curtail or prohibit commercial fishing within rivers or estuaries where mature or spawning fish could easily be caught. "In Alaska, area restrictions include all offshore waters. Recent regulations have shown a trend toward reducing netting in all rivers, except by Indians who have special treaty rights."
3. "Gear restrictions - prohibiting certain gear according to area, limiting size and specifications of gear and fishing vessels, and restricting number of units of gear that may be fished."

## 6.2 Control or alteration of physical features of the environment

### 6.21 Regulation of flow

No information is available on the influence of hydroelectric and storage dams on populations of chum salmon. See section 6.26.

### 6.22 Control of water levels

Vasilev (1957) reported on experiments that involved raising the water level to prevent chum salmon redds from drying and freezing. A dam that increased the water level 40 to 50 cm. but allowed intragravel water to move under the dam was constructed on a tributary of the My River, U.S.S.R. The cessation of spawning a week after the dam was installed was attributed to the accumulation of silt on the gravel surface or to the change in flow characteristics created by the dam. Water velocity and oxygen within the gravel were improved and eggs previously deposited in this section developed normally. The effect of raising the water level on freezing of redds was not determined because of heavy snowfall in the winter of the test.

### 6.23 Control of erosion and silting

See section 6.26.

### 6.24 Fishways at artifical and natural obstructions

Although the North American coast has many fishways over artificial and natural obstructions, most of them are upstream from the spawning grounds of chum salmon (Atkinson, Rose, and Duncan, 1967). Weber (1965) listed 22 fishways in Washington and 4 in Alaska that are used by the species. Chum salmon pass over fishways at three major dams on the Columbia River (Bonneville, The Dalles, and McNary Dams). In Hokkaido, over 100 man-made dams or other facilities either totally or partially obstruct the migration of adult and young fish (Japan Fisheries Resource Conservation Association, 1966).

6.25 Fish screens

Because of the short distances to their spawning grounds, chum salmon seldom encounter fish screens, but Weber (1965) listed six such installations that confront chum salmon in Washington.

6.26 Improvement of spawning grounds

Some experiments on improvement of spawning areas have been carried out in the United States and Canada, based on research which has shown that flooding, gravel erosion, silting, and predation cause serious losses. These detrimental characteristics of natural streams have been partially eliminated by regulating flow, improving spawning gravel, and excluding predators. Improved spawning areas for chum salmon are of two types: One consists of a completely artificial streambed, excavated and supplied with clean gravel, an example of which is the Jones Creek channel in British Columbia (Woodland, 1961); a second is a natural stream in which a storage dam regulates flow and where the natural streambed has been improved by loosening and cleaning of the gravel. This type of improvement was recently undertaken on the Big Qualicum River in British Columbia (Lister and Walker, 1966). Egg-to-fry survival has been increased in these controlled-flow spawning areas over that in uncontrolled streams (see section 4.31).

Other stream improvements on spawning areas of chum salmon include the removal of rock slides, logjams, beaver dams, debris, and gravel deposits and the channelization of streambeds

6.27 Habitat improvement

Measures to improve natural habitat have not been reported except for those listed in section 6.26.

6.3 Control or alteration of chemical features of the environment

6.31 Water pollution control

Waste products from mining and the production of wood pulp, dairy products, alcohol, gas, sugar, and starch were detrimental to chum salmon in Hokkaido (Japan Fisheries Resource Conservation Association, 1966). Similar kinds of pollution occur in other countries and undoubtedly affect chum salmon.

6.32 Salinity control

No information.

6.33 Artificial fertilization of waters

No information.

6.4 Control or alteration of the biological features of the environment

6.41 Control of aquatic vegetation

No information.

6.42 Introduction of fish foods

No information.

6.43 Control of parasites and disease

See section 4.43.

6.44 Control of predation and competition

Populations of predators and competitors have been reduced in artificial spawning channels and in some rearing areas of chum salmon in North America.

6.45 Population manipulation

No information.

6.5 Artificial stocking

6.51 Stocking to maintain runs

Hatchery operations for chum salmon are much more extensive in Asia, particularly in Japan, than in North America (table 51). From 10 to 12 hatcheries produce less than 10 million fry annually in North America, whereas in Hokkaido alone, 49 hatcheries have produced from 200 million to over 400 million fry. Japanese scientists consider artificial propagation as the only practical method to maintain runs of salmon in Japan, which are faced with deterioration of spawning streams from industrial growth (Japan Fisheries Resource Conservation Association, 1966). In Hokkaido, where chum salmon enter 160 streams, from 300,000 to 500,000 adults (57 percent of the escapement) are taken annually from 52 to 64 of the streams for artificial propagation; from 150,000 to 200,000 fish in Honshu are also taken each year for artificial propagation.

The Japanese have estimated maximum sustainable yields and economic returns for their

Table 51.--Hatchery production of chum salmon, 1950-65

[No production hatcheries for chum salmon exist in Canada or Alaska]

| Country | Hatcheries | Brood year | Eggs collected | Fry released[1] | Authority |
|---|---|---|---|---|---|
| | Number | | Thousands | Thousands | |
| United States: | | | | | |
| Washington | 9 | 1950 | 329 | 3,421 | Washington State Department of Fisheries (1964). |
| | 9 | 1951 | 6,996 | 7,808 | |
| | 9 | 1952 | 10,480 | 9,157 | |
| | 9 | 1953 | 2,974 | 2,460 | |
| | 9 | 1954 | 2,907 | 1,639 | |
| | 9 | 1955 | 340 | 248 | |
| | 9 | 1956 | 564 | 559 | |
| | 9 | 1957 | 5,815 | 4,578 | |
| | 9 | 1958 | 7,466 | 7,266 | |
| | 9 | 1959 | 7,010 | 7.106 | |
| | 9 | 1960 | 7,980 | 6,618 | |
| | 9 | 1961 | 2,347 | 1,864 | |
| | 9 | 1962 | 6,230 | 4,787 | |
| | 9 | 1963 | 4,226 | 4,101 | |
| | 9 | 1964 | 3,551 | 2,870 | |
| Oregon | 1-3 | 1955 | 450 | 452 | Fish Commission of Oregon (1957-65). |
| | 1-3 | 1956 | 524 | 478 | |
| | 1-3 | 1957 | 314 | 306 | |
| | 1-3 | 1958 | 254 | 230 | |
| | 1-3 | 1959 | 2,703 | 2,693 | |
| | 1-3 | 1960 | 1,554 | 1,456 | |
| | 1-3 | 1961 | 267 | 254 | |
| | 1-3 | 1962 | 447 | 315 | |
| | 1-3 | 1963 | 404 | 281 | |
| | 1-3 | 1964 | 345 | 319 | |
| U.S.S.R. | [2] 25 | 1959 | 150,000-170,000 | | Chernyavskaya (1964). |
| | 28 | 1960 | | 201,000 | Sano (1967). |
| Japan: | | | | | |
| Hokkaido | 49 | 1950 | 283,000 | 222,000 | Japan Fisheries Resource Conservation Association (1966). |
| | 49 | 1951 | 238,000 | 189,000 | |
| | 49 | 1952 | 221,000 | 160,000 | |
| | 49 | 1953 | 211,000 | 170,000 | |
| | 49 | 1954 | 334,000 | 269,000 | |
| | 49 | 1955 | 298,000 | 248,000 | |
| | 49 | 1956 | 168,000 | 140,000 | |
| | 49 | 1957 | 461,000 | 362,000 | |
| | 49 | 1958 | 566,000 | 417,000 | |
| | 49 | 1959 | 410,000 | 314,000 | |
| | 49 | 1960 | 269,000 | 203,000 | |
| | 49 | 1961 | 455,000 | 359,000 | |
| | 49 | 1962 | 355,000 | 281,000 | |
| | 49 | 1963 | 362,000 | 272,000 | |
| | 49 | 1964 | 413,000 | 334,000 | |
| | 49 | 1965 | 772,000 | -- | |
| Honshu | 82 | 1954 | 45,000 | 39,000 | |
| | 82 | 1955 | 43,000 | 39,000 | |
| | 82 | 1956 | 42,000 | 35,000 | |
| | 82 | 1957 | 42,000 | 54,000 | |
| | 82 | 1958 | 67,000 | 81,000 | |
| | 82 | 1959 | 71,000 | 64,000 | |
| | 82 | 1960 | 72,000 | 65,000 | |
| | 82 | 1961 | 92,000 | 85,000 | |
| | 82 | 1962 | 153,000 | 138,000 | |
| | 82 | 1963 | 133,000 | 116,000 | |
| | 82 | 1964 | 158,000 | 140,000 | |

Fry are released in year following brood years. Eggs were apparently transferred in years when the number of fry released exceeded the number of eggs taken.

[2] Does not include hatcheries on Amur River system.

hatchery operations. They concluded that maximum sustainable yields were achieved from artificial propagation in Hokkaido with 350,000 to 500,000 spawners, which would produce from 2.6 to 2.8 million returns annually. In Honshu, they estimated that the hatchery program achieved maximum sustainable yields with 100,000 spawners, for an adult return of 440,000 fish. On the basis of studies of Taguchi (1965a), the Japan Fisheries Resource Conservation Association (1966) considered that Hokkaido hatcheries produced about twice as many returns per spawner as did natural spawners in Alaska. It also estimated that hatchery-produced fry suffered from 2 to 2.5 times as much mortality before they returned as adults as did naturally produced fry from Hook Nose Creek, British Columbia. The cost of producing a returning adult was given as 45 to 65 yen (about 12-18 cents); since each adult fish sells for an average price of 892 yen (about $2.50), the economic return from hatchery operations in Hokkaido was considered to range from 14 to 20 times the expenditure.

Noble (1963) cited experiments by the Washington State Department of Fisheries which indicated that releases of unfed chum salmon fry from hatcheries have not been as effective as allowing the fish to spawn naturally. Success has been greater when the fry were reared for a short time, but an adequate diet has not been found for young chum salmon.

6.52 Transplantation; introduction

Through hatchery operations in the United States, chum salmon eggs have been transferred between streams within their natural range, but the results of these experiments have not been studied and reported in detail. From 1933 to 1939, the Russians attempted to introduce chum salmon to the Atlantic coast by transplanting about 9 million eggs to tributaries of the White and Barents Seas (Isaev, 1961) but were unsuccessful. More recent experiments to introduce chum salmon to this area were started in 1957 by transferring eyed eggs from hatcheries in Sakhalin to hatcheries on the Kola Peninsula. The numbers of fry released into tributaries of the White and Barents Seas were:

| Year | Fry Thousands | Authority |
|---|---|---|
| 1958 | 1,847 | Isaev (1961). |
| 1959 | 1,900 | |
| 1960 | 14,425 | Karpevich and Bokova (1963). |
| 1961 | 17,362 | |
| 1962 | 7,409 | Karpevich and Lokshina (1965a). |
| 1963 | 21,295 | Karpevich and Lokshina (1965b). |

Information regarding the success of adult returns from these releases was not available, but Azbelev and Surkov (1963) reported that some adult migrants were caught in 1961 and 1962. In their opinion runs of chum salmon to this area can be maintained only by artificial propagation.

7 POND FISH CULTURE

Not applicable.

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