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SYNOPSIS OF BIOLOGICAL DATA ON THE CHUM SALMON,

Oncorhynchus keta (Walbaum) 1792

UNITED STATES DEPARTMENT OF THE INTERIOR
U.S. FISH AND WILDLIFE SERVICE
BUREAU OF COMMERCIAL FISHERIES

Circular 315

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By

RICHARD G. BAKKALA

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By

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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 Günther (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

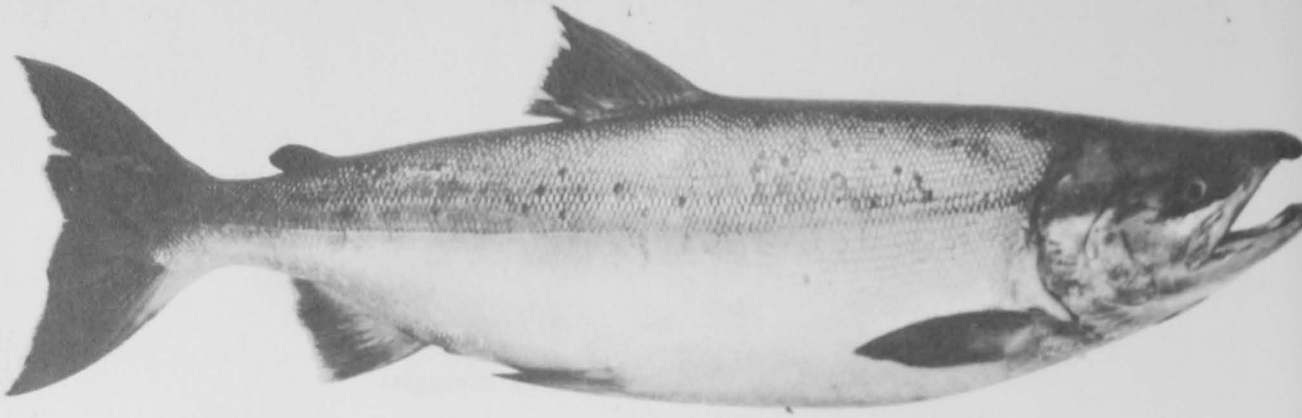

Figure 1.--The chum salmon, Oncorhynchus keta (Walbaum). (Photograph courtesy of National Fisherman)

Generic

Oncorhynchus Suckley, 1861 (1862: 313)

Genotype:

Salmo scouleri (Richardson)

The generic name is derived from Greek Onkos (hook) and rhynchos (snout).

The generic concept used here is that of Jordan and Evermann (1896):

"Body elongate, subfusiform, or compressed. Mouth wide; the maxillary long, lanceolate, usually extending beyond the eye; jaws with moderate teeth, which become in the adult male enormously enlarged in front. Vomer long and narrow, flat, with a series of teeth both on the head and the shaft, the latter series comparatively short and weak; palatines with a series of teeth; tongue with a marginal series on each side; teeth on vomer and tongue often lost with age; no teeth on the hyoid bone. Branchiostegals more or less increased in number. Scales moderate or small. Dorsal fin moderate; anal fin comparatively elongate, of 14 to 20 rays. Pyloric appendages in increased number. Gill rakers rather numerous. Ova large. Sexual peculiarities very strongly developed; the snout in the adult males in summer and fall greatly distorted; the premaxillaries prolonged, hooking over the lower jaw, which in turn is greatly elongate and somewhat hooked at tip; the teeth on these bones also greatly enlarged. The body becomes deep and compressed; a fleshy hump is developed before the dorsal fin, and the scales of the back become embedded in the flesh; the flesh, which is red and rich in spring, becomes dry and poor. Salmon, mostly of large size, ascending the rivers tributary to the North Pacific in North America and Asia, spawning in the fall."

Specific

The type specimen is Salmo keta of Walbaum (1792: 72) from the Kamchatka River. The original description, as cited by Okada (1960) is:

Salmo keta VEL KAYKO WALBAUM

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

"Caput breve, obtusum. Corpus immaculatum. Cauda Lunata. Caro alba. Squamae argenteae. Dorsum viridescens. Capitur copiose in flumininbus Kamtschatkae.

"Salmo keta VEL KAYKO, Krascheinnikow, l.c. pag. 181. Salmonem Narkam magnitudine aliquatenus superat: Caput oblongum, planum. Rostrum resimum. Dentes, post quam aliquamdin in flumine moratus est, caninis similes fuint. Lingua acuta. Cauda parum bifurca. Dorsum atro-viride, latera & abdomen similiter colorata ac aliis selmonibus sed absque maculis."

Species diagnosis according to Clemens and Wilby (1946):

"Body elongate, somewhat compressed; caudal peduncle slender. Head conical; mouth terminal; teeth conical, strongly developed, becoming fang-like in mature males; branchiostegals, 10 to 16; rakers on first gill arch, 19 to 26, short, stout, smooth, widely spaced. Fins: dorsal (1), 10 to 13; adipose, small, slender, fleshy; anal, 13 to 17; pelvic, abdominal, each with fleshy appendage at base; caudal, emarginate. Lateral line: slightly decurved, then straight. Scales: cycloid; in first row above lateral line, 130 to 153;

on lateral line, 126 to 151. Pyloric caeca: 140 to 185. Colour: metallic blue on dorsal surface with occasional black specklings; no black spots; black tinge on tips of pectoral, anal and caudal fins, especially in male; in maturing adults in fresh water irregular reddish to dusky streaks or bars across sides of body, white on tips of pelvic and anal fins. Flesh pale pink. Young with parr marks as slender bars, scarcely extending below lateral line and green iridescence on back.

"Length to 3 feet 2 inches.

"Distinguished by the absence of large black spots from the body and the fins, the slender caudal peduncle, the tips of all fins except dorsal tinged with black, the series of dusky streaks or bars across the sides of the body in mature adults in fresh water, the 20 to 26 smooth widely spaced rakers on the first gill arch, and the large number of pyloric caeca. The young are readily recognized by the slender parr marks, scarcely extending below the lateral line, and the green iridescence on the back."

The following key to the species of <u>Oncorhynchus</u> in North America is from Rounsefell (1962).

"A. Lateral-line scales 160-198 (average about 184); branchiostegals 9-15; pyloric caeca 95-224 (average about 136); anal rays 16-20 (complete count); gill rakers 24-34 (average about 29.7) with minute teeth; large black spots tending to oval on back and on entire caudal fin; young without parr marks; mouth lining dark; very pronounced hump on breeding males; mature at 2 years of age; obligatory anadromous; long sea migrations; abundant far offshore; usually less than 2,000 ova--------<u>Oncorhynchus gorbuscha</u>, pink salmon.

AA. Lateral-line scales 124-165; branchiostegals 10-19; pyloric caeca 45-254; anal rays 15-22 (complete count); gill rakers 19-39; no black spots on lower lobe of caudal fin, may be black speckling on dorsal edge of upper lobe; young with distinct parr marks; mature normally at ages 3-8, usually more than 2,500 ova.

B. Pyloric caeca 85-254; lateral-line scales 130-165; branchiostegals 10-19; anal rays 16-22 (complete count); gill rakers 19-28.

C. Lateral-line scales 130-147 (average about 139); branchiostegals 10-16; pyloric caeca 140-254 (average about 205); anal rays 16-20 (complete count); gill rakers 19-26 (average about 22), rakers wide apart and without teeth; caudal peduncle slender; parr marks short, elliptical or oval, extending little, if any, below lateral line; no black speckling on back or fins; breeding color anterior two-thirds of sides with bold jagged reddish line, posterior third of sides with jagged black line; mouth lining dark; obligatory anadromous, long sea migrations, abundant far offshore-----<u>Oncorhynchus keta</u>, chum salmon.

CC. Lateral-line scales 130-165 (average about 146); branchiostegals 13-19; pyloric caeca 85-244 (average about 158); anal rays 16-22 (complete count); gill rakers 20-28 (average about 24), rakers wide apart with large teeth; caudal peduncle stout; parr marks large vertical bars almost bisected by lateral line; small black speckling on back, dorsal fin, and upper lobe of caudal fin, sometimes extending onto adipose fin and lower lobe of caudal and faintly onto anal fin; breeding adults without red on sides; mouth lining black; obligatory anadromous; long sea migrations; not abundant far offshore--<u>Oncorhynchus tshawytscha</u>, king salmon.

BB. Pyloric caeca 45-114; lateral-line scales 124-150; branchiostegals 11-16; anal rays 15-21 (complete count); gill rakers 19-39.

D. Pyloric caeca 45-114 (average about 75); lateral-line scales 130-144 (average about 135); branchiostegals 11-15; anal rays 15-19 (complete count); gill rakers 19-25 (average about 21), rakers wide apart with large teeth, none on back of second and fourth gill arches; caudal peduncle stout; parr marks large vertical bars almost bisected by lateral line; anal fin of parr falcate with first ray whitish; other lower fins of parr orange-tinged and white-tipped; in adults black speckling on back, often extending along upper edge of caudal fin and base of dorsal fin; sides of breeding adults may be suffused with light pink, but no definite markings; mouth lining dark; adaptively anadromous; long sea migrations; not abundant far offshore----<u>Oncorhynchus kisutch</u>, silver salmon.

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----Oncorhynchus nerka, sockeye salmon.

Oncorhynchus n. kennerlyi, kokanee."

A sixth species, the masu salmon (O. masou) occurs on the Asian coast. Hikita (1962) separates it from other species of Oncorhynchus 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 autumnalis. 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 (autumnalis) 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	Summer chum salmon	Autumn chum salmon
Geographic distribution of spawning areas: Asian coast.	More northern populations including Kamchatka, the northern coast of the Okhotsk Sea, and the Amur River area.	More southern populations including the Amur River, Sakhalin, and Northern Japan.
Amur River	Lower river tributaries--within 100 km. from sea.	Upper river tributaries--1,000-2,000 km. from sea.
Time of spawning migration	Mainly July and August	September, October, and November.
Time of spawning	August and September	September to end of November.
Average weight	2.5 kg. or less	3.5 kg. or more.
Fecundity	--	Averages 500-1,000 eggs more than summer chum salmon.
Age at maturity	Small proportion of 3-year-olds.	Large proportion of 3-year-olds.

of spawning indicate that they exist (Shepard, Hartt, and Yonemori, 1967).

Sano (1966) and Neave (1966) commented on evidence of a well-developed homing instinct in chum salmon that would lead to reproductive isolation and development of independent populations. Fecundity, egg size, number of lateral line scales and vertebrae, and morphometric characters have indicated differences in some populations (Watanabe, 1955; Birman, 1956; Rounsefell, 1957; and Sano, 1966).

1.24 Standard common names, vernacular names

Common and vernacular names of chum salmon are given in table 2.

1.3 Morphology

1.31 External morphology

Katayama (1935) compared morphometric characters of male and female chum salmon from the northern Kurile Islands (table 3). The

Table 2.--Standard common and vernacular names of chum salmon (Berg, 1948; American Fisheries Society, 1960; Hikita, 1962)

Country	Standard common name	Vernacular names
United States	Chum salmon	Dog salmon, calico salmon.
Canada	do.	Do.
U.S.S.R.	Keta	Letnyaya keta (summer chum), Osennyaya keta (autumn chum), Sil'cha (Amur), Haiko (Kamchatka).
Japan	Sake	Akiaji, Aki-sake, Aki-zake, Aki-aji Tokishirazu, Buna, Bunake, Pinko, Mezika, Ohsuke, Buna-zake, Buchi-zake Hanamagari (Hokkaido); Shiro-sake, Shiro (North Pacific Ocean, Kurile Islands and Kamchatka); Shyake (Kanto Districts); Ohme, Ohmanako, Inu-masu (Miyagi Prefecture); Inu-masu (Ishikari Province); Hanamagari (Iwate Prefecture).
Korea[1]	Yon-o	Nyon-o, Yon-o-sari (young).

[1] Personal communication, Jong Rak Chung, Student, University of Washington, Seattle, Wash.

Table 3.--Body measurements of male and female chum salmon and correlation coefficient of body proportions (Katayama, 1935)

Character	Female (116 fish)			Male (151 fish)		
	Mean	Standard deviation	Coefficient of variation	Mean	Standard deviation	Coefficient of variation
	Mm.	Mm.		Mm.	Mm.	
Body length	624.6	29.4	4.7	641.0	30.5	4.8
Body depth	138.8	12.1	8.7	149.4	10.1	6.7
Head Length	117.5	7.7	6.6	130.7	9.3	7.1
Snout length	28.6	3.6	12.8	38.2	5.3	14.0
Caudal peduncle depth	40.4	2.4	6.0	42.0	2.8	6.6
			Correlation coefficient			
Body length to body depth			0.7			0.8
Body length to head length			0.6			0.8
Head length to snout length			0.7			0.8
Head length to depth of caudal peduncle.			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 that body 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

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

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.

Meristic characters of chum salmon, both external and internal, are presented in table 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.

Table 6.--Morphometric characters that indicate differences in populations of chum salmon from tributaries of the Amur River (Birman, 1956)

Character	Averages by tributary			Pooled variance		
	Amgun	Ussuri	Bira	Amgun-Ussuri	Amgun-Bira	Ussuri-Bira
As percentage of length of trunk.	Percent					
Depth of head through occiput.	22.6 ± 0.2	20.7 ± 0.2	20.7 ± 0.2	6.8	6.8	0
Greatest depth of body.	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 summer 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 Protein specificity

The molecular structures of blood and muscle proteins have been demonstrated to be species specific in Oncorhynchus (Tsuyuki, Roberts, and Vanstone, 1965; Tsuyuki, Roberts, Vanstone, and Markert, 1965; Yamanaka, Yamaguchi, Hashimoto, and Matsuura, 1967). Electrophoretic analysis of the muscle protein, myogen, results in patterns that are extremely stable within a species and permit a reliable identification of a single specimen. Some changes take place in blood protein during the life history of Oncorhynchus (Vanstone, Roberts, and Tsuyuki, 1964), whereas muscle myogens are practically unaffected by non-genetic factors. Muscle myogens are, therefore, more useful than blood proteins for establishing phylogenetic relationships.

The Asiatic O. masou is generally believed to be the first species to evolve from the genus Salmo (Neave, 1958). This hypothesis is supported by the relative positions of myogen patterns (Tsuyuki and Roberts, 1966). On the basis of similarities in these patterns, the sequence of derivation of the remaining species of Oncorhynchus from the genus Salmo is as follows: O. kisutch, O. tshawytscha, O. keta, O. nerka, and O. gorbuscha (Tsuyuki and Roberts, 1966). The positions of O. nerka and O. gorbuscha are still in doubt, based on myogen patterns, and their order may be reversed to conform with the order given by Hikita (1962). In contrast to these findings, Simon (1963), from evidence on the number of chromosomes, considered chum salmon to be the most primitive species.

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[1] (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	211,212,221 222,223,231 451,710	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

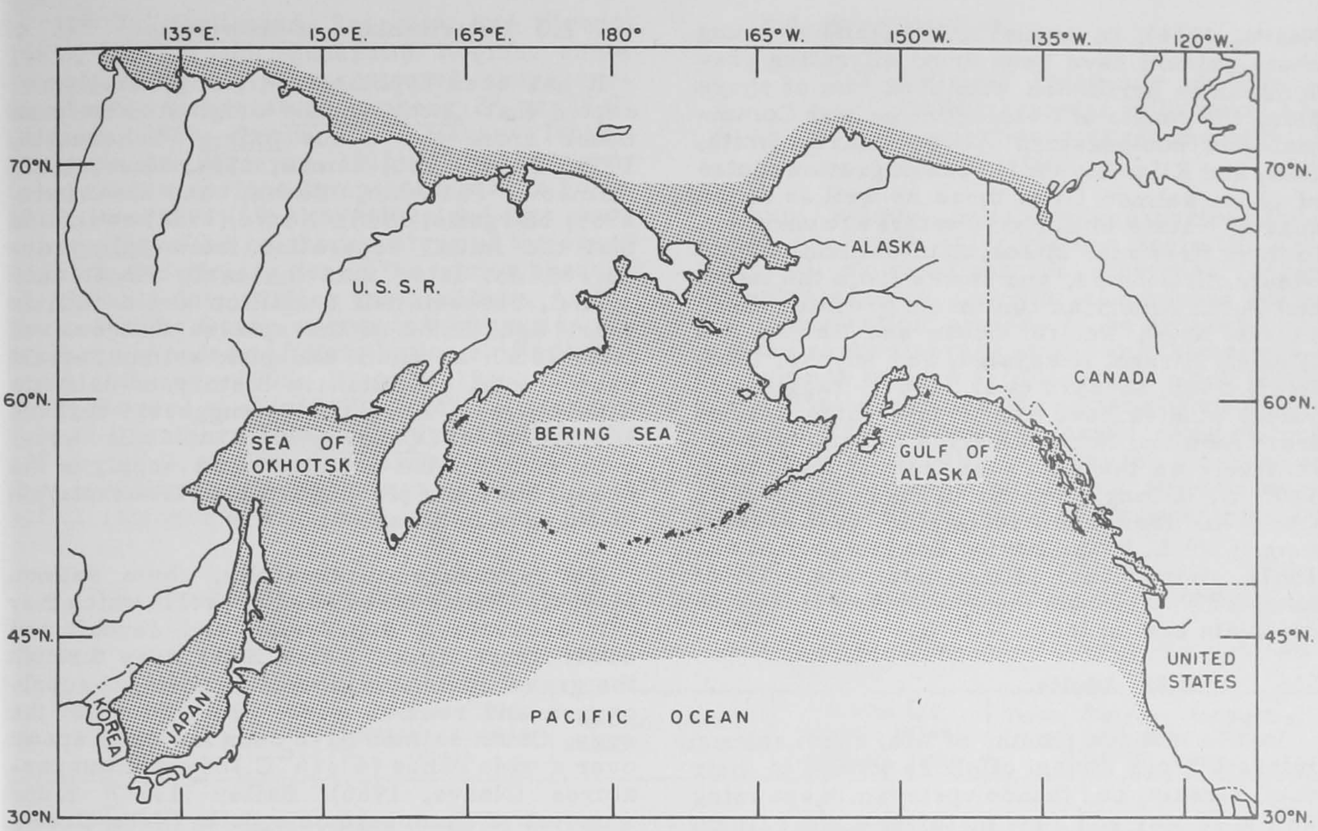

Figure 2.--Known coastal and ocean distribution of chum salmon.

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 Differential distribution

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 fresh-water 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). They leave 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 July to 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 loose 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.

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[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, chum salmon are mainly concentrated where surface water temperature exceeds 2° or 3° C. (Birman, 1958; Konda, 1959; Manzer, Ishida, Peterson, and Hanavan, 1965). They are rarely found where surface temperature falls below 1° C. Kasahara (1961) hypothesized that chum 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 2° 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

Cross	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.	Eggs 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 by Koo (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 chinook 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 North American 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. (Lovetskaya, 1948).

3.13 Mating

Promiscuous, male fish frequently attend more than one female (Kuznetsov, 1928; Hunter, 1959; Strekalova, 1963).

3.14 Fertilization

External; ova and sperm are ejected simultaneously into a depression excavated by the female in streambed 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. Penetration by the spermatozoan takes place when the female nucleus is in the metaphase stage of the second maturation division; the fact that one polocyte 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 telophase stage. After extrusion of the second polocyte, the chromosome mass begins its conversion into the vesicular female pronucleus. The head of the spermatozoan completes its metamorphosis into the male pronucleus 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 insemination and is completed in about 30 minutes. After completing its metamorphosis at about 3 hours after insemination, the female pronucleus begins its migration toward the male pronucleus. This movement also takes about 30 minutes. Conjugation of the pronuclei 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

Neave (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.--Range in length and weight of chum salmon at maturity in Asia and North America

Area	Year(s)	Sample size	Fork length	Weight	Authority
		Number	Cm.	Kg.	
Asia:					
Okhotsk coast	1948, 1952-53	3,353+	45-78	--	Birman (1956).
Amur River	1925-27, 1933	10,848	48-96	1.2-11.9	Kuznetsov (1928).
	1948-49, 1952-53	19,013+	45-90	--	Birman (1956).
Sakhalin	1946-49	2,397	45-82	1.1- 6.8	Dvinin (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	Kubo (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); Marr (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 less 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). Mean fecundities 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 fecundity increases with length, and Lovetskaya (1948) found that the number of eggs increases with length and weight. Rounsefell (1957) 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.

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[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 individual 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.

[1] 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[1] 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	--

[1] 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 in 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 spawn before 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).

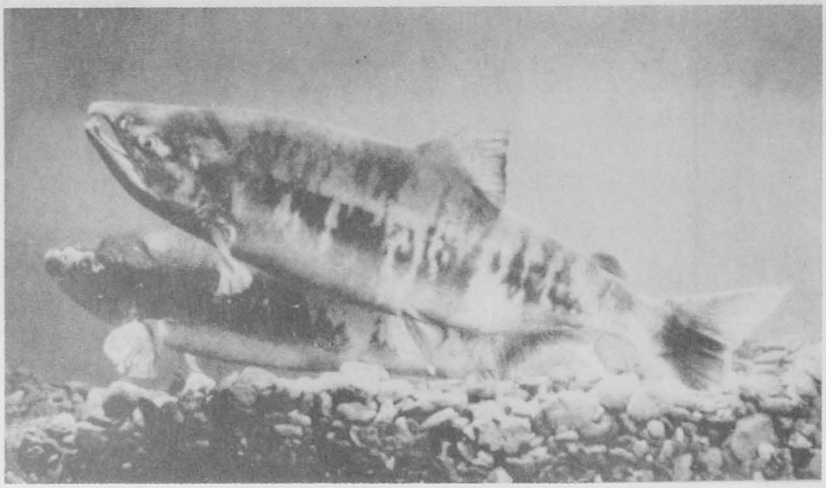
Sex ratios have been shown to change during the spawning migration, but for the entire period of migration they approached 1:1. Males predominated in the early part of the run and females in the later part (Gilbert, 1922; Marr, 1943; Henry, 1954; Semko, 1954). Semko (1954) also found that sex ratios 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.

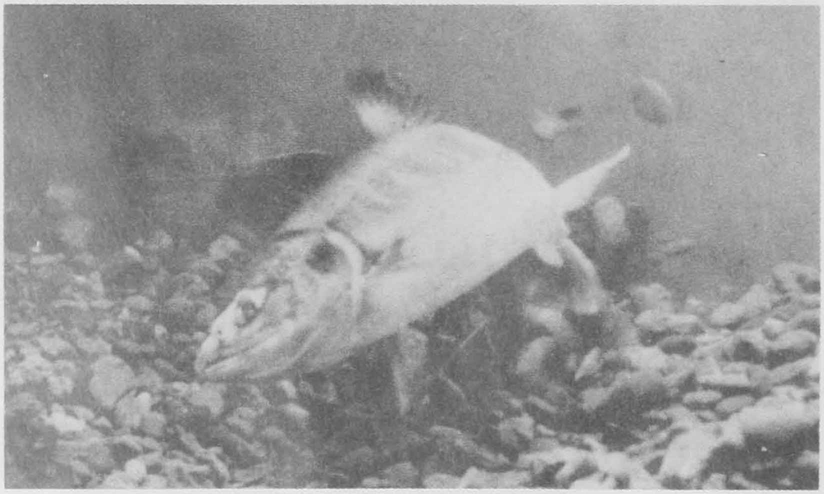
Mattson and Rowland (1963, see footnote 4) observed two phases of spawning activity for males after they had chosen mates: spawning, which lasted 2 to 5 days; and expiration, which lasted 1 to 5 days. During the expiration phase courting and active attendance of the redd ceased, territorialism broke 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--

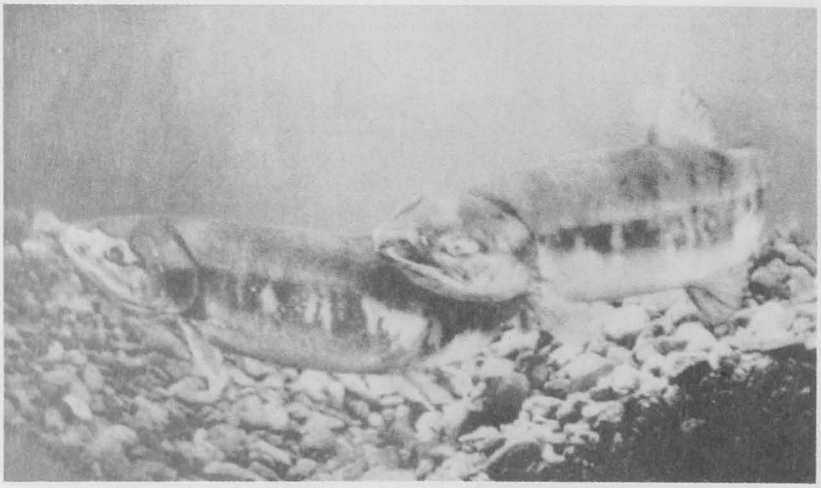
Figure 4.--Construction of redd and spawning behavior of chum salmon (Sano and Nagasawa, 1958).



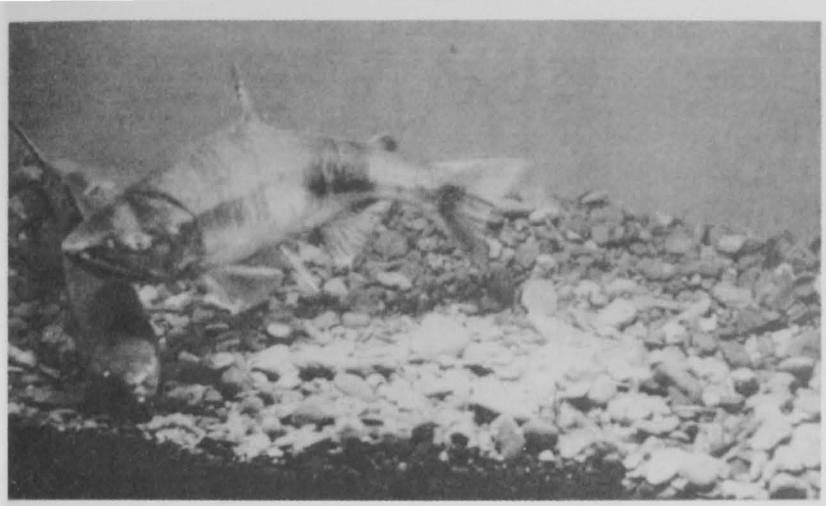
(a) Male (foreground) and female before redd construction.



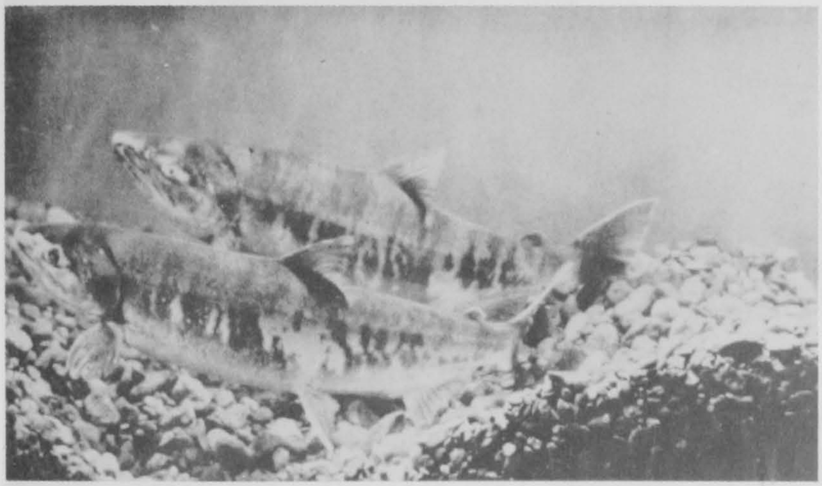
(b) Female digging redd by turning on side, rapidly flexing body, and fanning streambed with caudal fin. The female excavated the redd alone and repeated the digging motion every 1 to 5 minutes.



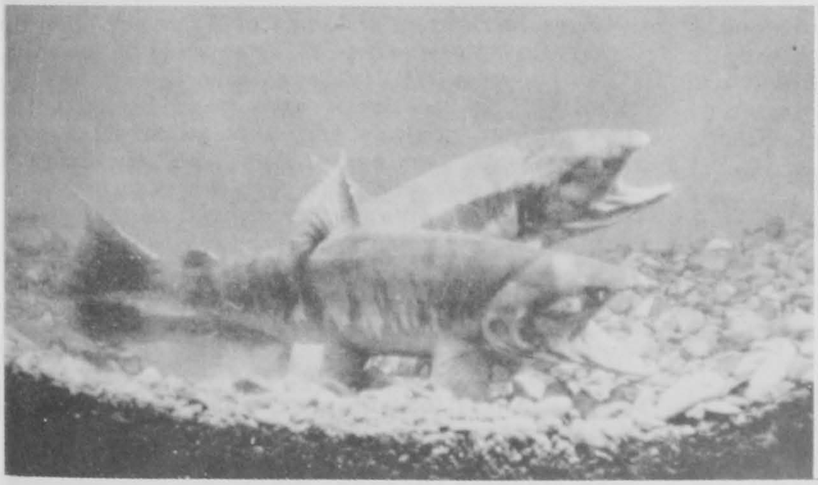
(c) From time to time during redd construction, the male came in contact with the female and exhibited body spasms which appeared to excite the female.



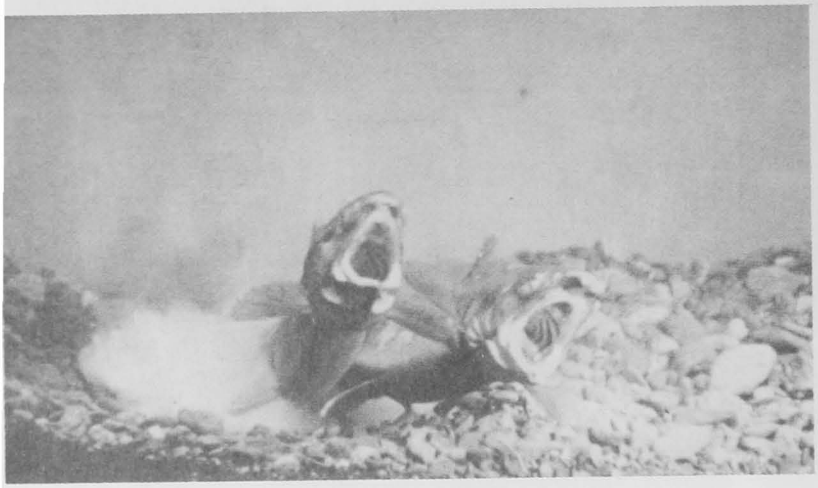
(d) As the redd building approached its completion, the male and female circled above the redd.



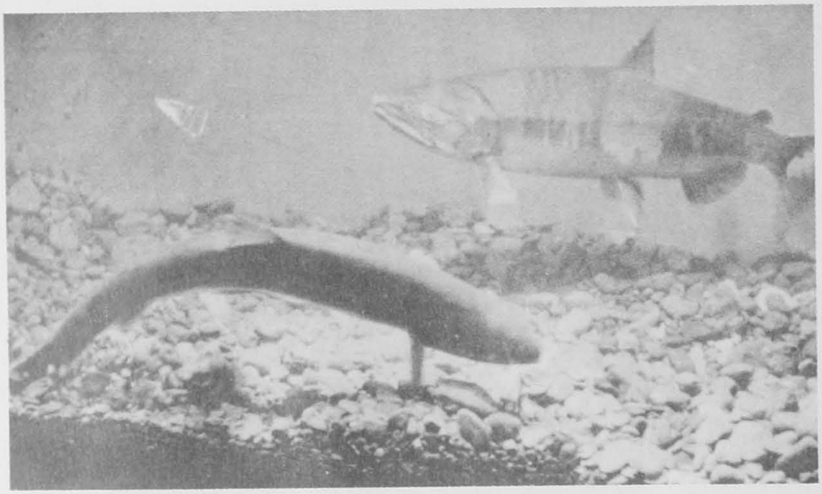
(e) To start the spawning act, the male and female lowered their bodies into the redd.



(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. Semko (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.)

Table 15.--Egg retention by chum salmon in Asian and North American spawning streams

Area	Year	Average egg retention		Authority
		Number	Percent	
Tillamook Bay, Oreg.	--	< 100	--	Henry (1953).
Hook Nose Creek, British Columbia	1951	104.1	4.7	Hunter (1959).
Do.	1952	12.8	0.5	Do.
Do.	1953	18.2	0.7	Do.
Do.	1954	35.5	1.2	Do.
Do.	1955	5.4	0.2	Do.
Do.	1956	39.4	1.5	Do.
Big Qualicum River, British Columbia	1959	--	24.5	Lister and Walker (1966).
Do.	1960	--	5.0	Do.
Do.	1961	--	4.4	Do.
Do.	1962	--	5.5	Do.
Do.	1963	--	2.7	Do.
Do	1964	--	2.8	Do.
Memu River, Hokkaido	1957	--	3.4	Nagasawa and Sano (1961).
Do.	1958	--	4.7	Do.
Do.	1959	--	6.1	Do.
Memu and Nishibetso Rivers, Hokkaido	1954-56	45	1.5	Sano (1966).
Amur River, U.S.S.R.	--	--	0.5-1.5	Levanidov (1954).

3.17 Spawn

Data on size of fertilized eggs are limited: their diameters are about 6.0 to 9.5 mm., and their mean weights about 220 to 230 mg. [Semko, 1954; Watanabe, 1955; Mahon and Hoar, 1956; Mattson and Rowland, 1963 (see footnote 4)].

Yamamoto (1952) described the eggs. They are nearly spherical and moderately red, and the chorion or outer shell consists of two layers--an outer hyaline layer and an inner membrane. The hyaline layer is transparent and measures about 20μ (microns). The inner membrane is thick, nontransparent, and can be subdivided into two layers. Hamano (1957) further described the three layers: The middle layer is composed of kerato-elastin and the inner and outer layers of glycoprotein. Beneath the chorion lies the egg proper. The ooplasm enclosing the yolk is fairly thick at the animal pole and becomes thinner towards the vegetable pole. The yolk contains fat globules of various sizes (Yamamoto, 1952).

A small percentage of eggs may be nonviable. Semko (1954) found that an average of 3.5 percent from chum and pink salmon could not be fertilized. Unfertilized eggs of chum salmon lose their viability after 2 minutes in water (Hamano, 1957). This is caused by hardening of the chorion from colloidal changes of the inner layer of the chorion, induced by the absorption of calcium ions. When left in the dead body of the female, the viable period for eggs varies with the temperature of the carcass (Okada, Ishikawa, and Kimura, 1956). At 11° to 12° C., the eggs can be fertilized with fresh spermatozoa for up to 8 hours or more with good results; at 17° to 18° C., the eggs remain viable for about 1 hour.

Viability of eggs can be prolonged by storage at low temperatures. Fertility of stored eggs varies with the length of storage although the trend is not precise (Barrett, 1951). Eggs stored for 72 hours at 2.5° to 5.8° C. were more than 90-percent fertile in 22 of 24 samples. After being stored for 108 hours, more than 80 percent of the eggs were fertile in 32 of 36 samples. The percentage of fertile eggs dropped rapidly to 15 percent after 8 days.

The form of the spermatozoan is simple--a spheroidal head, a short, round middle section, and a long tail. The tail is more than 10 times the length of the head; the total length of the sperm is about 36μ. (Yamamoto, 1952; Okada and Ito, 1955). Spermatozoa placed in water become active within 30 seconds and gradually lose mobility and become inactive after about 60 seconds (Okada and Ito, 1955). Spermatozoa left in the body of dead males lose mobility in 60 to 90 minutes at a body temperature of 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

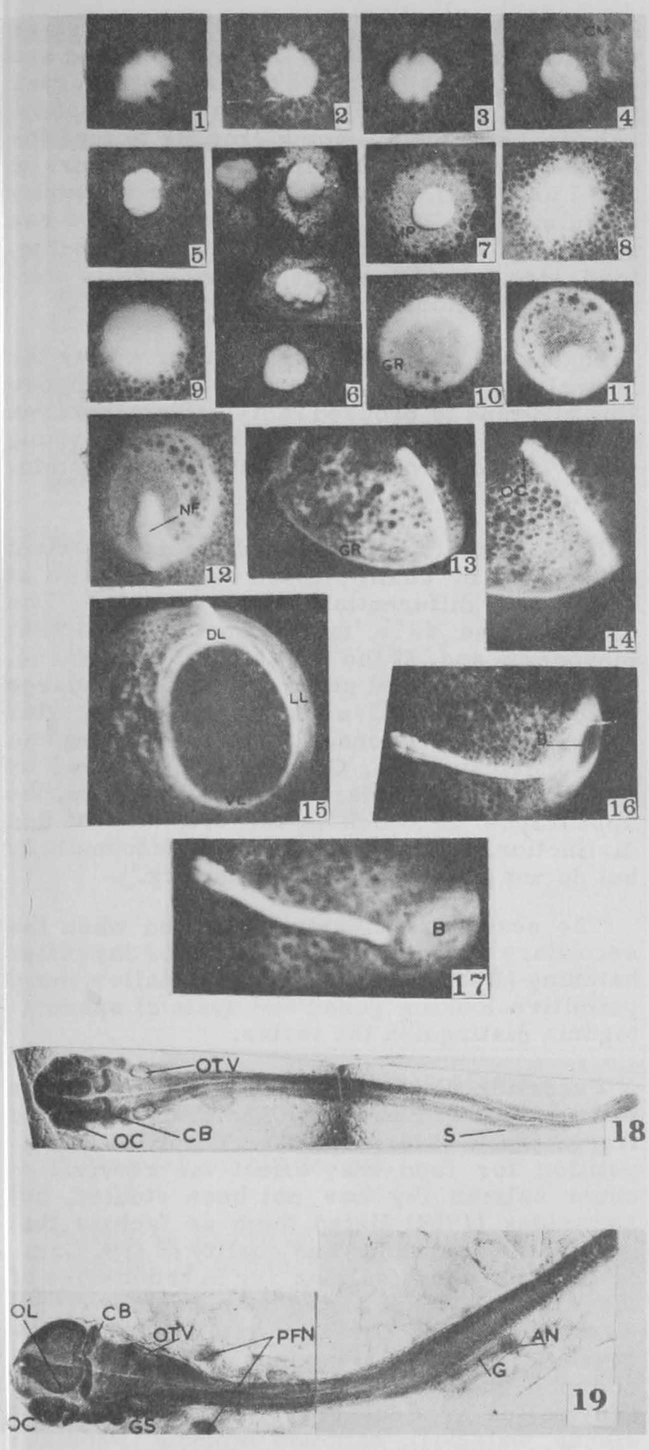


Figure 5.--Early development of the chum salmon embryo (photographs and description of photographs from figs. 1-17, 27, and 77 of Mahon and Hoar, 1956).

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 5 mm. 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.

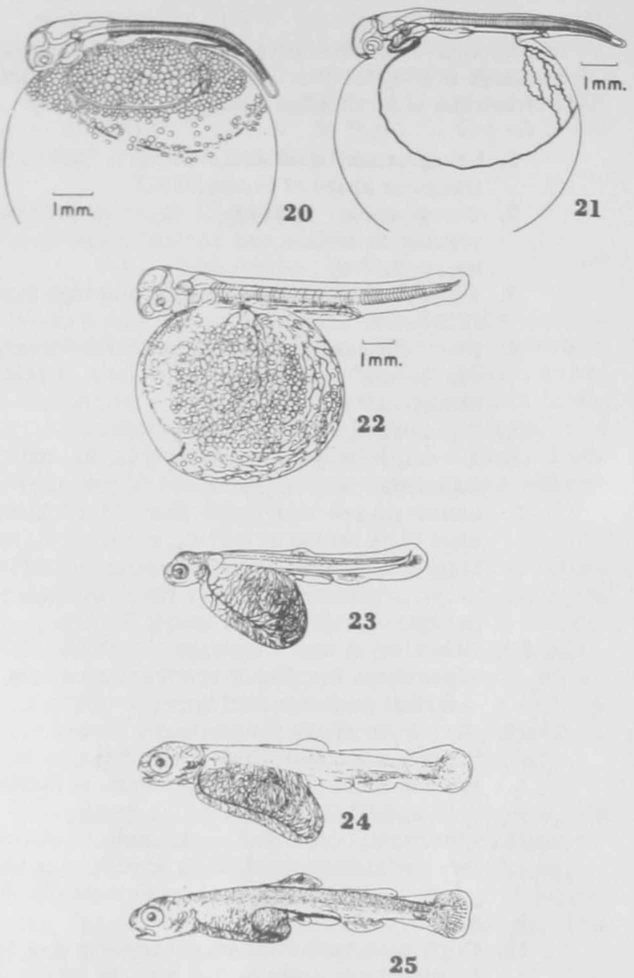


Figure 6.--Development of the chum salmon embryo from closure of the blastopore through the alevin stage (Photographs and description from Disler, 1954).

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 incubation areas 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 radially from this area (Kobayashi, 1961). Scales first appear on young 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).

Table 16.--Development of the chum salmon embryo

Stage of development	Range in length of embryo	Time after fertilization		Temperature	Thermal units	Authority
	Mm.	Days	Hours	°C.	°C. days	
Beginning of cleavage (2-cell stage).	[1] 0.9- 1.2	--	24	[2] 3.4	--	Disler (1954).
	--	--	18.5	7.2	--	Mahon and Hoar (1956).
	--	--	20	11-11.5	--	Saito (1950).
Beginning of the blastula stage.	[3] 1.4	8	--	3.4	--	Disler (1954).
Formation of germ ring.	[3] 2.6	18-19	--	3.4	--	Disler (1954).
	[3] 3.0	9	--	6.0	--	Mahon and Hoar (1956).
Closing of blastopore.	6.5- 7.0	44-45	--	3.4	--	Disler (1954).
	5.5- 6.0	24	--	--	--	Mahon and Hoar (1956).
Beginning of eye pigmentation.	7.8-11.0	50-64	--	3.4	--	Disler (1954).
	13.3-13.9	61	--	--	338	Ievleva (1951).
Beginning of embryo movement.	14.0-17.0	95-100	--	3.4	--	Disler (1954).
Hatching	--	135	--	0.0- 5.0	--	Kubo (1950).
	20.0-22.0	122-128	--	3.4	408-420	Disler (1954).
	--	120	--	1.0- 5.0	--	Kubo (1950).
	--	74		6.5- 7.5	--	Do.
	--	62-63	--	11.0-11.5	--	Saito (1950).
	--	52-61	--	9.7- 9.9	510-589	Alderdice, Wickett, and Brett (1958).
	--	56	--	8.0- 9.6	--	Smirnov (1955).
	--	54	--	9.5-11.0	--	Kubo (1950).
	--	46	--	7.0-15.0	--	Do.

[1] Range in diameter of blastodisc.
[2] Disler gave a mean temperature of 3.4° C. for the entire incubation period. Apparently temperatures varied less than 1° C. from this mean.
[3] Diameter of blastoderm.

Little is known of the diseases encountered by naturally produced fry. Bacterial diseases have caused severe mortalities in hatchery reared fry (see section 4.43).

Salt-water stage.--After leaving fresh water, young chum salmon remain near shore until late July or August; some remain near shore until autumn (Manzer, 1956; Sano, 1966; Neave, 1966). By midsummer they are 100 to 150 mm. long. Between midsummer of their first year and their second summer, they disperse throughout the offshore waters of the North Pacific Ocean and Bering Sea (see also section 2.2).

Mean sizes of immature chum salmon from a sample of 21,569 fish taken by research vessels in June and July over several years (Lander, Tanonaka, Thorson, and Dark, 1966) were:

Age	Fork length	Weight
	Mm.	Dekagram
0.1	342	46
0.2	473	115
0.3	516	160
0.4	542	180
0.5	554	185

Growth rate declines as the fish grow older; fish that mature at an early age grow faster than fish that mature later (Ricker, 1964; Lander, et al., 1966). Most of the growth is in summer (Koo, 1959; Ricker, 1964).

The early ocean life of salmon is a period of high mortality; Parker (1962) stated that mortality is probably at its highest on a per-month basis. He estimated the survival of chum

Table 17.--Development of chum salmon in the alevin stage (adapted from Disler, 1954)

Part of stage	Development
First	Skeleton and muscle of fins become formed--fin fold is resorbed.
	Yolk sac becomes elongated and decreases in area. Role of branchial apparatus as respiratory organ becomes more marked, and mouth performs rhythmical respiratory movements. Rudiments of teeth appear.
	Larvae have positive reaction to tactile stimuli and negative reaction to light.
Second	Intestine begins to permit passage of food, and peristaltic movements of its walls begin. The yolk sac continues to be the main source of food but some external food is also ingested.
	Spotted coloration appears and becomes deeper as development continues. Rudiments of branched soft rays appear--first in dorsal and later in other fins--and formation of upper and lower lobes of caudal fin begins. Eyes become mobile and teeth cut through on jaw. Formation of lateral line canals begins.
	At the end of stage the yolk sac disappears and is enveloped by lower extremities of myotomes. Respiratory function is taken over completely by branchial apparatus. Fry emerge from gravel, and the air bladder fills with air.

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 maris-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 (Orcinus 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 prey on adult fish in Kamchatka (Semko, 1954) and in Alaska (Helle, 1960; Thorsteinson, 1965[8]). Helle also mentioned seals (Phocidea) and wolverines (Gulo luscus) as predators in fresh water.

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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	Cryptobia.
	Cnidosporida	Henneguya, Myxosoma, Myxidium.
	Ciliata	Tripartiella and Trichodina.
Platyhelminthes	Cestoidea	Eubothrium, Proteocephalus, Pelichnibothrium, Nybelinia, Hepatoxylon, Scolex, Diphyllobothrium, Phyllobothrium, and Triaenophorus.
	Trematoda	Tubulovesicula, Brachyphallus, Lecithaster, Isoparorchis, Hemiurus, Parahemiurus, and Bucephalopsis.
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	[4] 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 absorption of 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 $W = 2.364 \times 10^{-5} L^{2.817}$ (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 mm.

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

Area	Sample size	Period covered	Range in sample means: Length	Range in sample means: Weight	Authority
	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 portion of 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	Unmarked
		Mm.	Mm.
Apr. 28	Early fry	30.6	30.9
May 22-23	Entrance into sea	41.5	41.2
June 11	Coastal rearing period	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 (Lagler 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	Mean
		Number	Mm.	Mm.
Ishikari	May	202	44-93	61.2
Do.	do.	45	62-103	77.5
Furubira	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
Yoichi	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 (Koo, 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 (Koo, 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 (Koo, 1961). Widely spaced circuli were added from May to August;

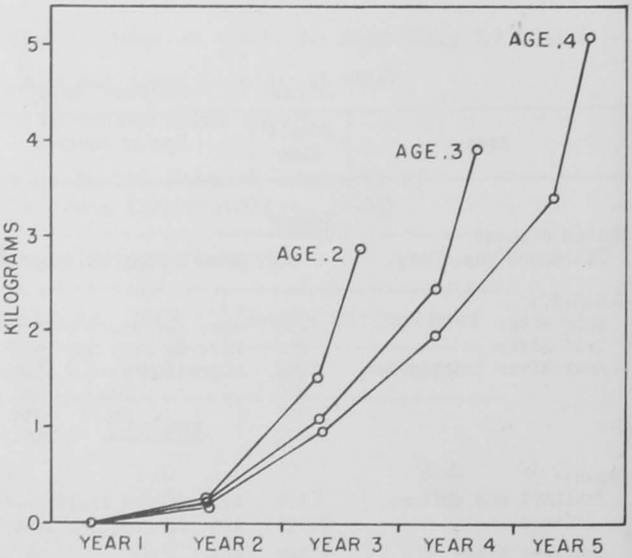

Figure 7.--Growth in weight of autumn chum salmon from the Amur River (Ricker, 1964). Points computed using the expression: $\log w = -3.780 + 3.2 \log l$ from lengths obtained by backcalculation from scale readings. Lines merely connect the annual points and do not represent the seasonal course of increase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

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

Location	Year	Age	Fish sampled		L_1[1]	G_2[2]	L_2	G_3	L_3	G_4	L_4	G_5	L_5	Weight increase in last year
			Male number	Female number	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 salmon from 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 in most 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

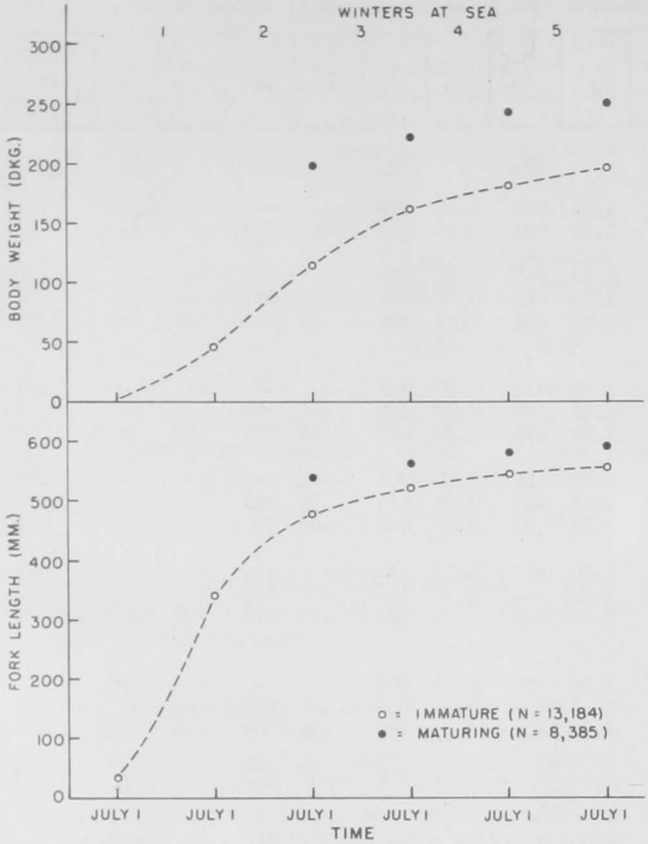

Figure 8.--Estimated mean body lengths and weights of chum salmon on July 1 (Lander et al. 1966). Connecting lines indicate related stages, not actual growth.

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)	$\text{Log } W = -3.780 + 3.2 \log L$
Mature chum salmon from the Columbia River (Marr, 1943) [9]	$\text{Log } W = -1.204 + 2.6 \log L$
Mature chum salmon from Tillamook Bay, Oreg. (Henry, 1954) [9]	Males $\text{Log } W = -2.270 + 3.2 \log L$ Females $\text{Log } W = -1.925 + 3.0 \log L$

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, 1958).

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: $Y = 0.03983e^{0.1222x}$ (Awakura, 1963). 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 Amur 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 high by 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[1]						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	
North America:																		
Alaska	Number	Cm.								Kg.								
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.

Table 28.--Oxygen consumption of chum salmon eggs, fry, and mature adults

Stage of development	Temperature	Oxygen consumption		Authority
Egg (°C. days)	°C.	$Mm.^3$ O_2/egg/hr.	$Mm.^3$ O_2/g. larval tissue/hr.	
121.2	11.0	0.68	295	Alderdice et al., (1958).
268.2	-	1.60	103	Do.
353.0	-	2.78	120	Do.
452.4	-	3.80	131	Do.
			$Mm.^3$ O_2/g. body wt./hr.	
Fry	10.0		228	Levanidov (1955).
	20.0		445	Do.
	8.6-9.0		188	Awakura (1963).
Fingerling	9.0-9.4		144	Do.
Mature adults:				
Holding position	9.0-9.3		71	Do.
Migrating upstream				
Males	12.0		215	Winberg (1956).
Females	12.0		236	Do.

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; migration decreased 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 m. 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

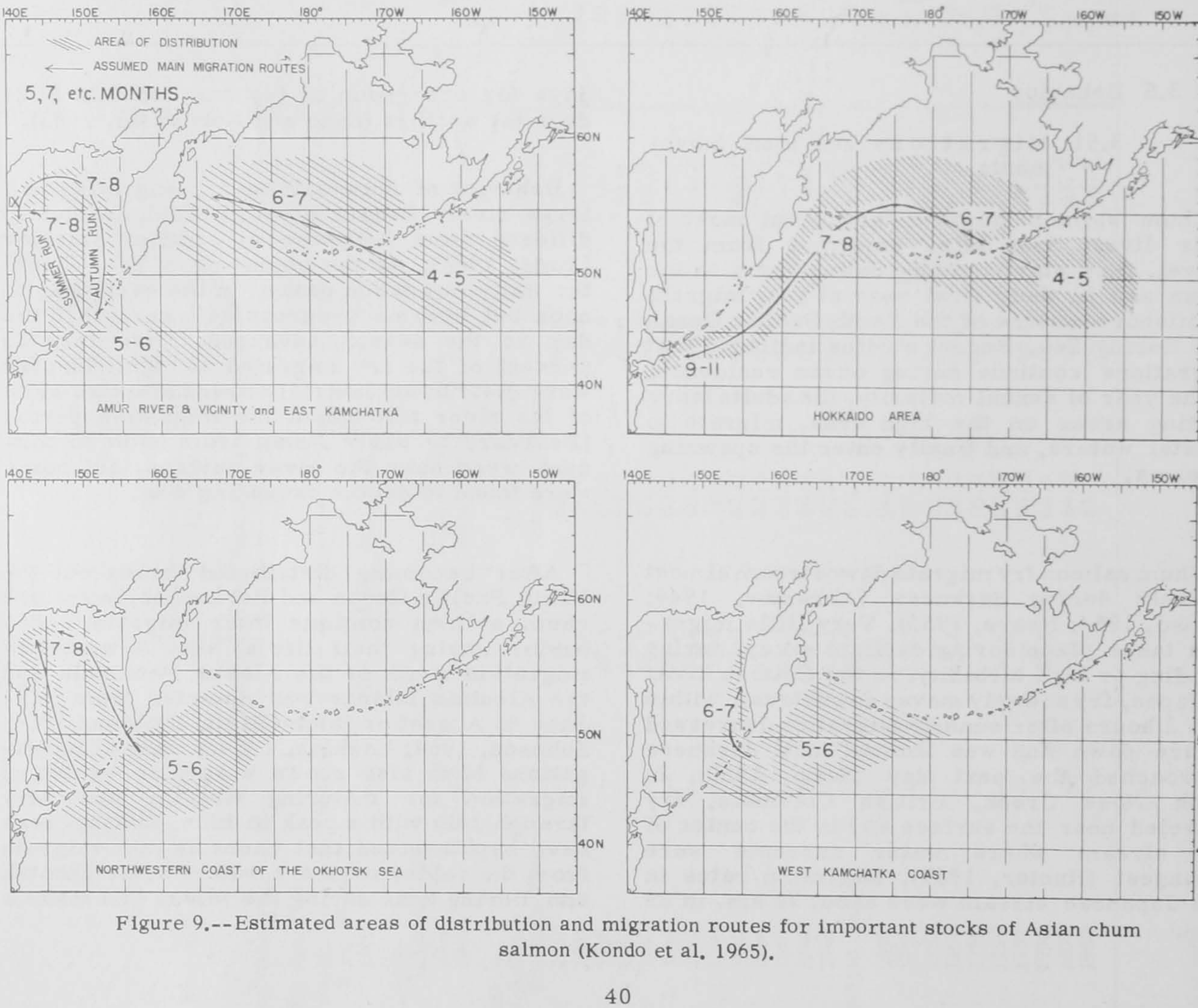

Figure 9.--Estimated areas of distribution and migration routes for important stocks of Asian chum salmon (Kondo et al. 1965).

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 measured by the 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 °/oo Cl) in May, the sequence progressed to 3 °/oo in June, 6° /oo in July, about 8 °/oo in August, and finally to 10 °/oo Cl in October. The intensity of response to higher salinity also increased in an orderly sequence from a 14.3 percent response to 3 °/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

Table 29.--Percentage of female chum salmon in commercial catches on the Asian and North American coasts and on the high seas

Area	Years	Fish sampled	Percentage females						Authority
			Age					All ages	
			0.1	0.2	0.3	0.4	0.5		
		Number	Percent						
North America:									
Alaska:									
Alaska Peninsula	1951-57	6,140	--	28.7	51.0	52.4	--	49.1	Thorsteinson,
Kodiak Island	1948-51, 1955-57	1,753	--	30.5	48.7	50.6	--	48.4	Noerenberg,
Prince William Sound	1952-58	2,137	--	29.0	52.0	45.3	--	48.3	and Smith (1963).
British Columbia:									
Chemainus, Nanaimo, and Qualicum	1916-17	2,996	--	50.5	35.4	--	--	42.2	Fraser (1921).
Washington and Oregon:									
Puget Sound	1963	5,000	--	51.0	57.0	--	--	53.0	Fiscus (1963).
Columbia River	1914	514	--	49.0	45.6	--	--	48.1	Marr (1943).
Asia:									
East Kamchatka	1959	--	--	20.0	55.6	39.0	27.0	52.5	Sano (1966).
Southwest Kamchatka	1959	--	--	25.0	45.0	40.0	--	51.5	Do.
Northwest Kamchatka	1959	--	--	--	57.2	68.8	--	57.5	Do.
Okhotsk District	1959	--	--	36.3	46.6	50.0	60.0	47.1	Do.
Amur River:									
Summer fish	1959	--	--	47.6	48.7	41.3	--	47.9	Do.
Autumn fish	1959	--	--	52.3	51.3	44.7	40.0	50.0	Do.
Sakhalin	1959	--	--	11.0	38.0	42.8	--	36.0	Do.
Hokkaido:									
Nemuro District	1959	--	--	12.5	67.0	71.8	--	67.5	Do.
Okhotsk Sea coast	1959	--	0	24.3	50.7	43.6	--	36.2	Do.
Pacific coast	1959	--	--	44.5	59.9	60.4	75.0	58.9	Do.
Southwest coast	1958	--	0	40.4	71.2	100.0	--	48.7	Do.
Japan Sea coast	1959	--	0	26.0	34.8	37.5	--	32.0	Do.
Honshu:									
Japan Sea coast	1959	--	0	40.4	67.5	50.0	--	55.6	Do.
Pacific coast	1959	--	0	48.7	56.2	66.6	--	52.5	Do.
High Seas:									
Western North Pacific Ocean and Bering Sea.									
Japanese mothership fishery	1953-57	--	--	35.0	57.0	63.0	70.0	55.0	Ishida (1963).
	1956-62	--	--	35.0	55.0	62.0	67.0	--	Do.

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

Area	Year and time period		Fish sampled	Age					Unknown	Authority
				0.1	0.2	0.3	0.4	0.5		
			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	1962	Apr. 9 - May 6	847	1.4	22.7	52.9	22.8	0.2	--	Fisheries Research
Ocean.	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 May to 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 stocks (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.

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		Number	Percent						
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Chemainus, Nanaimo, and Qualicum	1916-17	2,996	--	50.5	35.4	--	--	42.2	Fraser (1921).
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Columbia River	1914	514	--	49.0	45.6	--	--	48.1	Marr (1943).
Asia:									
East Kamchatka	1959	--	--	20.0	55.6	39.0	27.0	52.5	Sano (1966).
Southwest Kamchatka	1959	--	--	25.0	45.0	40.0	--	51.5	Do.
Northwest Kamchatka	1959	--	--	--	57.2	68.8	--	57.5	Do.
Okhotsk District	1959	--	--	36.3	46.6	50.0	60.0	47.1	Do.
Amur River:									
Summer fish	1959	--	--	47.6	48.7	41.3	--	47.9	Do.
Autumn fish	1959	--	--	52.3	51.3	44.7	40.0	50.0	Do.
Sakhalin	1959	--	--	11.0	38.0	42.8	--	36.0	Do.
Hokkaido:									
Nemuro District	1959	--	--	12.5	67.0	71.8	--	67.5	Do.
Okhotsk Sea coast	1959	--	0	24.3	50.7	43.6	--	36.2	Do.
Pacific coast	1959	--	--	44.5	59.9	60.4	75.0	58.9	Do.
Southwest coast	1958	--	0	40.4	71.2	100.0	--	48.7	Do.
Japan Sea coast	1959	--	0	26.0	34.8	37.5	--	32.0	Do.
Honshu:									
Japan Sea coast	1959	--	0	40.4	67.5	50.0	--	55.6	Do.
Pacific coast	1959	--	0	48.7	56.2	66.6	--	52.5	Do.
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	1962 May 10 - 24	323	3.4	23.5	49.3	23.8	0	--	
	1962 May 28 - June 13	635	4.9	46.0	40.8	8.3	0	--	
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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. Mean lengths of age 0.1 and older chum salmon (table 33) show that within ages, males are larger than females 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,

[10] 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	0	Gilbert (1922).
Alaska Peninsula, Prince William Sound, Kodiak Island.	1948-58	10,030	0	9.2	73.1	17.0	0	0	Thorsteinson et al. (1963).
Southeastern Alaska	1961-63	1,354	0	5.1	81.4	13.5	0	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	875	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
North America:	Number	Percent				
Alaska						
Kotzebue Sound						
1962	68	7.3	63.3	28.0	1.4	Regnart, Fridgen, and
1963	255	32.6	47.4	18.8	1.2	Geiger (1967).
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				Authority
		0.2	0.3	0.4	0.5	
	Number	Percent				
Amur River:						
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[1]

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 mothership fishery (Konda, 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

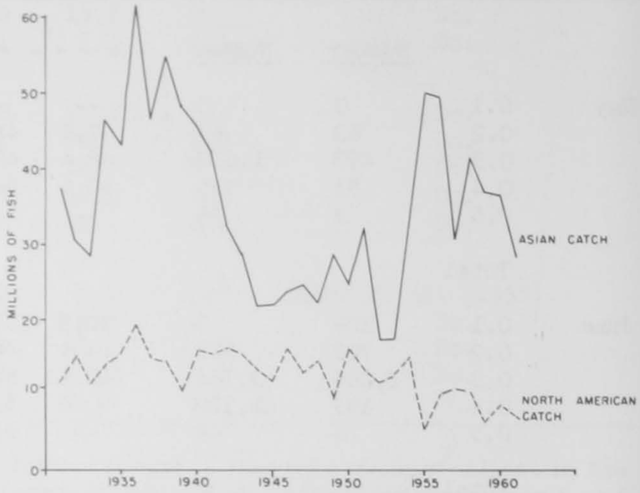

Figure 10.--Commercial catches of chum salmon in Asia and North America (data from section 5.43).

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	
			Mean	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	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 would be 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 increases, (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 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	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 would be 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 increases, (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).
Memu 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.[1]
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.

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

Table 38.--Estimates of returns per spawner from areas in North America and Asia

Item	Area and authority					
	Central Alaska	Southeastern Alaska		British Columbia (Johnstone Strait)	Hokkaido	Honshu
	Taguchi (1965a)	Taguchi (1965a)		Ricker and Manzer (1967)	Japan Fisheries Resource Conservation Association (1966)	
Method of estimating escapement	Used estimated fishing mortality of 0.5	Used estimated fishing mortality of 0.5 and 0.65		Estimated count of spawners	Counted hatchery spawners; estimated number of natural spawners	Counted hatchery spawners
Type of reproduction	Natural	Natural		Natural	Artificial and natural	Artificial
Years						
1920-29						
Range	0.8-11.0	0.6-9.6	0.9-13.2	-	-	-
Mean	4.0	2.7	3.8	-	-	-
1930-39						
Range	1.6-4.4	1.1-4.0	1.5-5.8	-	2.4-6.4	-
Mean	2.5	2.4	2.4	-	4.2	-
1940-49						
Range	1.3-2.5	1.0-3.0	1.4-4.2	-	2.3-6.9	-
Mean	1.9	2.0	2.8	-	3.8	-
1950-59						
Range	1.0-2.8	0.7-1.9	1.0-2.7	0.2-3.8	4.4-8.8	2.1-7.3
Mean	2.0	1.4	1.9	1.8	6.0	4.9
1960-62						
Range	-	-	-	0.7-1.7	-	-
Mean	-	-	-	1.2	-	-
Mean for all years	2.6	2.1	3.0	1.7	4.7	4.9

salmon in five Amur River tributaries as follows:

Year	Fry to adult Percent	Egg to adult Percent
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
Mean (over 4 years)	97.50	99.79

Fishing mortality has been estimated for a few coastal areas and time periods:

Area	Year(s)	Fishing Mortality Percent	Authority
Amur River			
(summer fish)	1950-53	50-55	Levanidov (1964)
Japan	1955-58	75	Committee on Biology and Research (1961)
British Columbia			
Central coast	1934-49	40-50	Neave (1966)
Johnstone Strait	1949, 1950, 1953	50-52	DO.
Oregon			
Tillamook Bay	1953	39	Oakley (1966)

Table 39.--Estimated mortality for chum salmon from Hook Nose Creek, British Columbia, during various life stages (Parker, 1962)

Life history stage	Months	Survival	Instantaneous mortality (i)[1]
		Percent	
Egg - fry	7	7.8	2.55
Coastal (juvenile)	5	5.4	2.91
Pelagic	34	56.6	0.57
Coastal (adults)	2	93.0	0.07
Fishing	--	35.0	1.05
Total	48	0.08	7.15

[1] Instantaneous mortality $(i) = \log_e (N_2/N_1)$ where N_1 and N_2 are the numbers of fish present at times 1 and 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 years. 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./l.

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./l. (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).[11]

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.)

Low oxygen concentrations are frequently mentioned as a cause of egg mortality. In laboratory experiments, Alderdice et al. (1958), exposed chum salmon eggs to various concentrations of dissolved oxygen for 7 days at different stages of development. They concluded that eggs were most sensitive to hypoxia at 100 to 200 centigrade degree-days and compensated for reduced availability of oxygen by reducing the demand for oxygen and rate of development. Low oxygen at early incubation stages produced monstrosities. Eggs subjected to low dissolved oxygen just before hatching hatched prematurely at a rate dependent on the degree of hypoxia. Critical levels of dissolved oxygen that were calculated appeared to define the value above which respiratory rate is unmodified by availability of oxygen. Critical levels ranged from about 1 p.p.m. in early stages to over 7 p.p.m. shortly before hatching. The authors suggested that these "critical levels" could be regarded as a measure of oxygen requirement for successful incubation until information to the contrary is available.

Under natural conditions, Wickett (1954) linked high mortality of chum salmon eggs with low oxygen and slow water flow through the gravel. McNeil (1966) observed that lower dissolved oxygen in one stream accompanied higher egg mortality. Smirnov (1947) also reported high egg and fry losses in a Soviet stream where oxygen decreased from 94.5 percent saturation (9.8 p.p.m.) in October to 7.0 percent saturation (0.4 p.p.m.) in February.

The parasitic fungus Saprolegnia infects eggs in natural and artificial environments (Neave, 1948; Disler, 1953; Semko, 1954). Saprolegnia establishes itself initially on dead eggs (Semko, 1954); once it begins to develop, it surrounds live eggs, which soon die. Saprolegnia is controlled in hatcheries by treating the eggs with malachite green; its contribution to mortality of eggs in natural stream gravel is unknown.

Permeability of the streambed is a measure of the ease with which water can flow through the gravel. When fine materials such as sand and silt are deposited on the streambed, permeability is reduced. Low permeability influences survival of embryos by reducing the rate at which oxygen-bearing water is carried to the eggs. The influence of permeability of stream gravel on survival of pink and chum salmon is illustrated by the data from Wickett (1958), column 2.

Predators consume eggs that are not deposited in redds or are dug up by later spawners. Levanidov (1959) stated that un-

Stream	Permeability[12]	Survival by species of salmon	Years of observation
	Cm./hour	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

deposited eggs of chum salmon are an important source of food for some species of fish in tributaries of the Amur River. Levanidov estimated that 20 to 30 percent of the spawned eggs are lost to fish such as the Dolly Varden (Salvelinus malma), grayling, lenok, amur ide, and sculpin (Cottus poecilopus). In one southeastern Alaska stream, young coho salmon, rainbow trout (Salmo gairdneri), and prickly sculpin (Cottus asper) ate eggs of spawning chum salmon (Reed, 1967). The eaten eggs were mainly drift eggs that would probably have died anyway if not taken by predators. Reed considered prickly sculpins to be true predators because the eggs they took directly from the redd were eggs that potentially could survive. Eggs covered by several centimeters of gravel are thought to be protected from predators.

Sea water of 18 ‰ salinity and below did not inhibit fertilization (Rockwell, 1956). In the laboratory, he found that eggs hatch in a constant salinity of 6 ‰; all died before hatching at 12 ‰ and above; however, no mortality differences were observed in up to 30 ‰ during the first 4 days at 5.8° C. Larvae held in a mildly saline sea water (6 ‰) had better survival, growth, and vigor than his controls in fresh water. The ultimate tolerance increased as temperature decreased. He concluded from his experiments and field observations that sea water in the upper and middle intertidal zone does not kill eggs that are immersed for short periods at low temperatures. In field investigations, Bailey (1964; see footnote 2) found egg-to-fry survival to be highest in the upper levels of the intertidal zone and, in general, progressively lower until it reached zero at about the 2-m. level, which was exposed to tidewater 55 percent of the

[12] Permeability (K) of streambed gravel is defined by $K = \frac{v}{s}$ where v is the apparent velocity of the water in cm./hour and s 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 superimposition by 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 $m.^2$. 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.

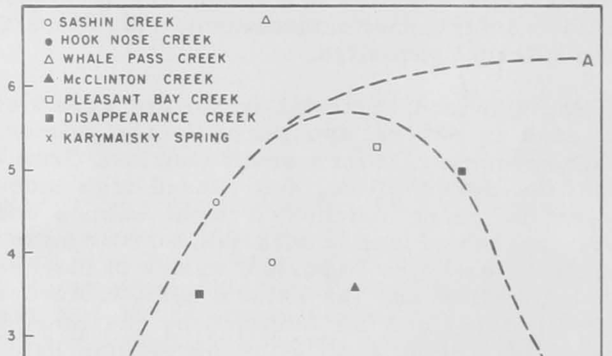

Figure 11.--Observed relation between potential egg deposition and production of fry per 1 m.^{2} in pink and chum salmon spawning streams [McNeil, 1965 (see footnote 13)]. A and B are two possible types of fresh-water reproduction curves, and for these data, the dome-shaped curve provides the best fit.

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.

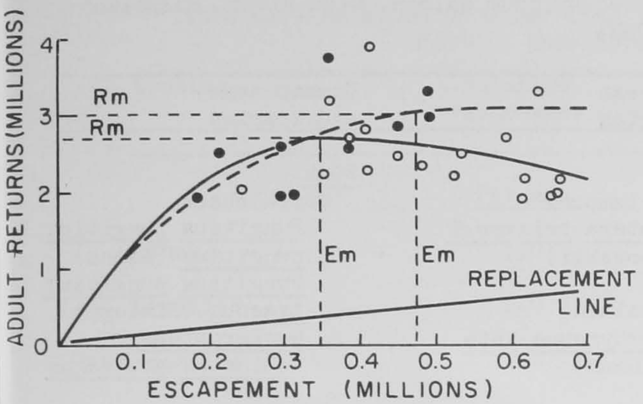

Figure 12.--Reproduction curve for artifically spawned chum salmon of Hokkaido (Japan Fisheries Resource Conservation Association, 1966). Em is optimum escapement and Rm, maximum return. Solid line and open dots are for 1932-59; broken line and solid dots are for 1950-59. Replacement line represents 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 fresh-water 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 and feeding 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.

Table 40.--Animal composition of stream inhabited by chum salmon, Memu River, Hokkaido (Hikita, 1960)

Common name and species	Common name and species	Common name and species
Platyhelminthes Flat worm *Dugesia gonocephala* Leeches Leach *Herpobdella lineata* *Glossiphonia complanata* Mollusks Snail *Lymnea japonica* *Segmontina nitidella* Fresh-water bivalve Species unknown Mites Water mite *Sperchon* sp. Crustaceans Isopod *Asellus nipponensis* Amphipod *Gammarus* sp. Decapod *Leander paucidens* Insects Mayfly *Ephemerella nigra* *Ephemerella* sp. *Epearus latifulium* *Bactis* sp. *Nemora* sp. *Paraleptophlebia spinosa* Caddisfly *Apatania* sp. *Goera japonica* *Pharyganea* sp. *Hydroptila* sp. *Stenopsyche griseipennis* *Leptocerus* sp. Two-winged flies *Chironomus* sp. *Simulium aokii* *Atherix* sp.	Fish Brook lamprey *Lamptera reissneri* (Dybowskii) Chum salmon *Oncorhynchus keta* (Walbaum) Pink salmon *Oncorhynchus gorbuscha* (Walbaum) Masu salmon *Oncorhynchus masou* (Brevoort) Rainbow trout *Salmo gairdneri ipdeus* (Gibbons) Dace *Tribolodon hakonensis hakonensis* (Gunther) Yachi-dace *Moroco percnurus* (Pallas) Prussian carp (goldfish) *Carassius auratus* (Linne) Carp *Cyprinus carpio* (Linne) Mud fish *Barbatula toni oreas* (Jordan and Fowler) *Misgurnus anguillicaudatus* (Cantor)	Fish Stickleback *Pungitius pungitius pungitius* (Linne) *Pungitius pungitius tymenus* (Niklosky) *Gasterosteus aculeatus aculeatus* (Linne) Goby *Rhinogobius similis* (Jordan and Snyder) Freshwater sculpin *Cottus nozawae* (Snyder) Birds Merganser *Mergus merganser* Linne Mallard *Anas platyrhynchus platyrhynchus* Linne *Anas poecilorhyncha zonorhyncha* Swinhoe *Eunetta falcata* Georgi Teal *Nettion crecca crecca* Linne Wood Duck *Aix galericulata* Linne Kingfisher *Ceryla lugubris pallida* Momiyama *Alcedo atthis bengalensis* Gmelin Water ouzel *Cinclus pallasii* Temmick

Larkins (1964b) listed species of fish taken incidentally by gill nets used to sample salmon on the high seas (table 42). He concluded that only six species (albacore, atka mackerel, blue shark, jack mackerel, Pacific herring and pomfret) could be classified as "abundant" in ocean areas where salmon live and that these fish were common in only two or three subareas.

5 FISHERY

5.1 Fishing equipment

5.11 Gear

Canada and United States.--Drift gill nets and purse seines have been used in the North American fishery since early in the 20th

Table 41.--Relation of other fish to chum salmon fry as competitors for food in Khor River, U.S.S.R. (Levanidov, 1959)

Species	Relative abundance	Equivalent of feeding competition[1]	Competitive value[2]
	Percent		Percent
Lenok	5.0	26.1	55.7
Grayling	2.0	4.8	4.1
Amur ide	7.0	1.1	3.3
Common gudgeon	28.0	1.2	14.0
Lagovsky's minnow	36.0	1.4	20.9
Common minnow	12.0	0.2	1.2
Stone loach	0.3	0.8	0.2
Ninespine stickleback	8.0	0.1	0.4
Bullhead	1.5	0.1	0.1
Burbot	0.2	1.0	0.1

[1] Equivalent of feeding competition is best defined by an example. For the lenok it means that one lenok ate the same quantity of food organisms as 26.1 chum salmon fry.

[2] The figures in this column are the product of the first two columns expressed in percentage.

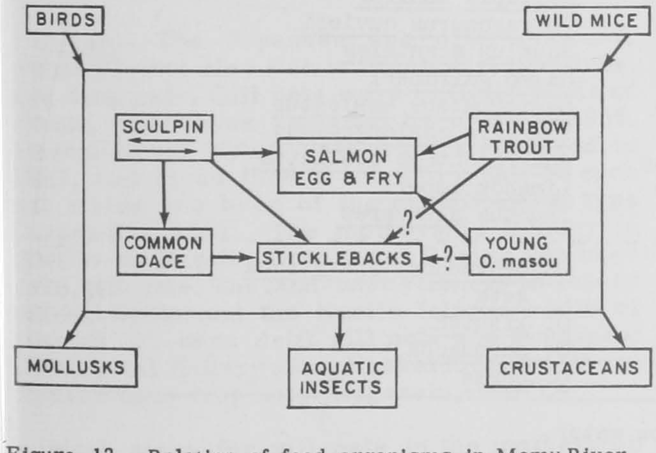

Figure 13.--Relation of food organisms in Memu River, Japan (Hikita and Nagasawa, 1960).

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:

	Catches Thousands of fish	Seines Percent	Gill nets Percent	Other gear Percent
Alaska	6,456	73.5	26.3	0.2
British Columbia	1,311	44.2	55.5	0.3
Washington	425	48.2	41.1	10.7
Oregon	1	0	100.0	0

Along the North American coast, regulations establish the length and sometimes the mesh size and depth of gill nets. Gill nets used for chum and other species of salmon are generally made with multifilament nylon and have mesh

Table 42.--Epipelagic fishes taken on the high seas incidental to catches of salmon by gill nets, 1955-61 (Larkins, 1964b); catches were made in the Bering Sea, North Pacific Ocean, and Gulf of Alaska

Common name	Family name	Scientific name	Number taken
Albacore	Scombridae	*Thunnus alalunga*	299
Arrowtooth flounder[1]	Pleuronectidae	*Atheresthes stomias*	1
Atka mackerel	Hexagrammidae	*Pleurogrammus monopterygius*	7,322
Basking shark	Lamnidae	*Cetorhinus maximus*	1
Bigscale pomfret	Bramidae	*Taractes* sp.	1
Blue shark	Carcharhinidae	*Prionace glauca*	877
Boarfish	Histiphoridae	*Pseudopentaceros richardsoni*	9
Coster dory	Zeidae	*Allocyttus verrucosus*	1
Daggertooth	Anotopteridae	*Anotopterus pharao*	31
Dolly Varden	Salmonidae	*Salvelinus malma*	60
English (lemon) sole[1]	Pleuronectidae	*Parophrys vetulus*	2
Eulachon	Osmeridae	*Thaleichthys pacificus*	1
Jack mackerel	Carangidae	*Trachurus symmetricus*	1,295
Opah	Lamprididae	*Lampris regius*	1
Pacific hake	Gadidae	*Merluccius productus*	23
Pacific herring	Clupeidae	*Clupea harengus pallasi*	4,649
Pacific lamprey	Petromyzontidae	*Lampetra tridentata*	5
Pacific lancetfish	Alepisauridae	*Alepisaurus richardsoni*	14
Pacific sandfish	Trichodontidae	*Trichodon trichodon*	3
Pacific saury	Scomberesocidae	*Cololabis saira*	2
Pomfret	Bramidae	*Brama rayi*	4,425
Ragfish	Icosteidae	*Icosteus aenigmaticus*	9
Rockfish	Scorpaenidae	*Sebastodes* sp.	2
Sablefish	Anoplopomatidae	*Anoplopoma fimbria*	93
Salmon shark	Lamnidae	*Lamna ditropis*	172
Sculpin[1]	Cottidae	Unknown	1
Sea poacher[1]	Agonidae	Unknown	6
Sixgill shark	Hexanchidae	*Hexanchus griseum*	1
Skilfish	Anoplopomatidae	*Erilepis zonifer*	145
Smalleye squaretail	Tetragonuridae	*Tetragonurus cuvieri*	247
Spiny dogfish	Squalidae	*Squalus acanthias*	105
Steelhead (rainbow) trout	Salmonidae	*Salmo gairdneri*	602
Threespine stickleback	Gasterosteidae	*Gasterosteus aculeatus*	38
Walleye pollock	Gadidae	*Theragra chalcogrammus*	145
Wolf-eel	Anarchichadidae	*Anarrhichthys ocellatus*	2
Yellowfin sole[1]	Pleuronectidae	*Limanda aspera*	12
Yellowfin tuna	Scombridae	*Thunnus albacares*	1
Chinook (king) salmon	Salmonidae	*Oncorhynchus tshawytscha*	390
Chum salmon	Salmonidae	*O. keta*	32,637
Coho (silver) salmon	Salmonidae	*O. kisutch*	2,031
Pink salmon	Salmonidae	*O. gorbuscha*	15,026
Sockeye (red) salmon	Salmonidae	*O. nerka*	20,371

[1] Benthic forms captured in sets made in shallow water.

sizes of 12 to 24 cm. stretched measure. Regulations for Alaska in 1962 limited the maximum length of gill nets (91 to 366 m.) in various regulatory districts (Alaska Department of Fish and Game, 1962). When the depth of gill nets has not been regulated, they are usually limited by practical fishing considerations to 25 to 30 meshes or about 5.5 m. (Wigutoff, 1951).

The size of purse seines is also limited by regulation. These nets, which are now almost all nylon are usually 300 to 350 meshes deep. For Alaska in 1962, they were regulated in length from a minimum of 183 to 274 m. to a maximum of 274 to 548 m. (Alaska Department of Fish and Game, 1962). Mesh sizes commonly are about 9 to 10 cm. in the main part of the net and 8.3 to 8.9 cm. in the bunt

Table 43.--Types of vessels used in the Pacific salmon fishery (Sundstrom, 1957; Nakatsu, 1960; Neo, 1964; Nagasaki, 1967)

Vessel characteristic	Japan			United States and Canada	
	Land based	High seas		Gill netters	Purse seiners
		Motherships	Catcher boats		
Length (m.)	--	--	24-27	7-13	12-28
Individual vessel gross tonnage.	5-75	[1] 8,400	[1] 90	0.5-7	7-40
Construction	Wood	Steel	Steel and wood.	Wood, fiberglass, and aluminum.	Steel and wood.
Engine					
Type	--	Diesel	Diesel	Gas or diesel	Gas or diesel
Individual vessel horsepower	--	--	280-400	50-140	35-300
Cruising speed (km./hour)	--	22-26	19	13-41	15-26
Crew	6-20	--	20-22	1-2	4-9

[1] Average tonnage in 1964.

(Jurkovich, 1967; Food and Agriculture Organization, 1965b).

Size restrictions on fishing vessels are imposed in some areas. Purse seine vessels cannot exceed an over all length of 17.7 m. in Alaska, and gill net vessels in the Bristol Bay area of Alaska are limited to 9.8 m.

Japan.--The Japanese use drift gill nets primarily but also fish with set nets, longlines, and trap nets. Gill nets were initially made of ramie, which was replaced by nylon in 1955. Monofilament nylon nets were introduced in 1963, and since then a third to a half of each net string has been of the monofilament type (Nagasaki, 1967). The mothership fishery in the North Pacific Ocean and Bering Sea uses drift gill nets. The land-based fishery in waters off Hokkaido and the Kurile Islands south of lat. 48° N. uses drift gill nets and longlines; the coastal fishery along Hokkaido and northern Honshu uses trap nets (Nagasaki, 1967).

Mesh sizes for gill nets in the mothership and land-based fisheries are regulated by the Northwest Pacific Fisheries Treaty between Japan and the U.S.S.R. Mesh sizes commonly used are 11.4 cm. and 11.5 cm. stretched measure in the land-based fishery and 12.1 cm. and 13.0 cm. stretched measure in the mothership fishery (Konda, 1966). Net strings are up to 15 km. long (Neo, 1964).

U.S.S.R.--The principal gear used by the Russians is the trap net (fig. 14), a type of gear which has been used since the early 1900's, although improved in design and operation (Atkinson, 1964). Beach seines, fishing basically for domestic consumption and for limited commercial markets, are also fished in the rivers.

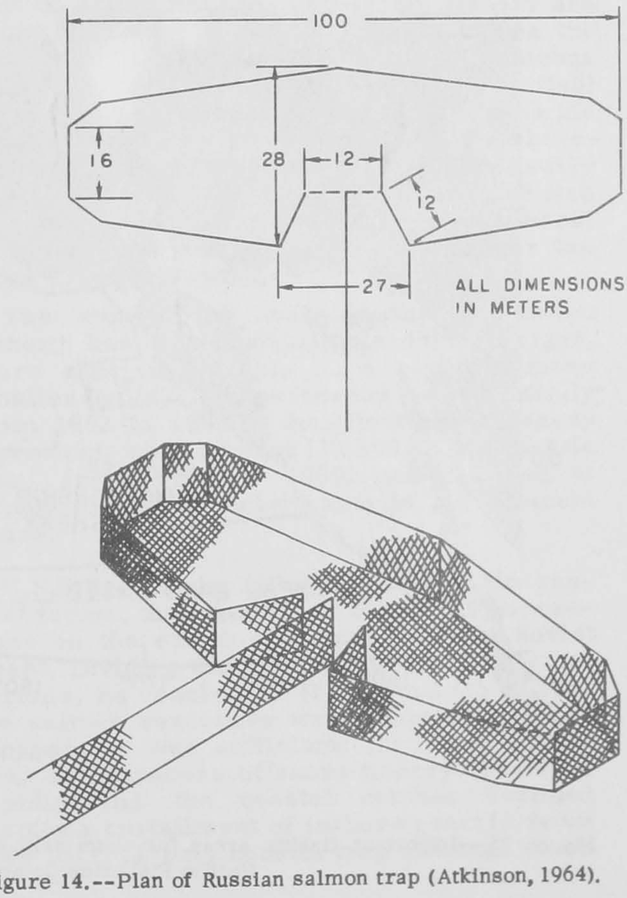

Figure 14.--Plan of Russian salmon trap (Atkinson, 1964).

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:

Period	Coastal set net	River set net	Ocean drift net	Longline	Catch
	Percentage of catch by gear				
	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 mothership 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 mothershipfishery 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.

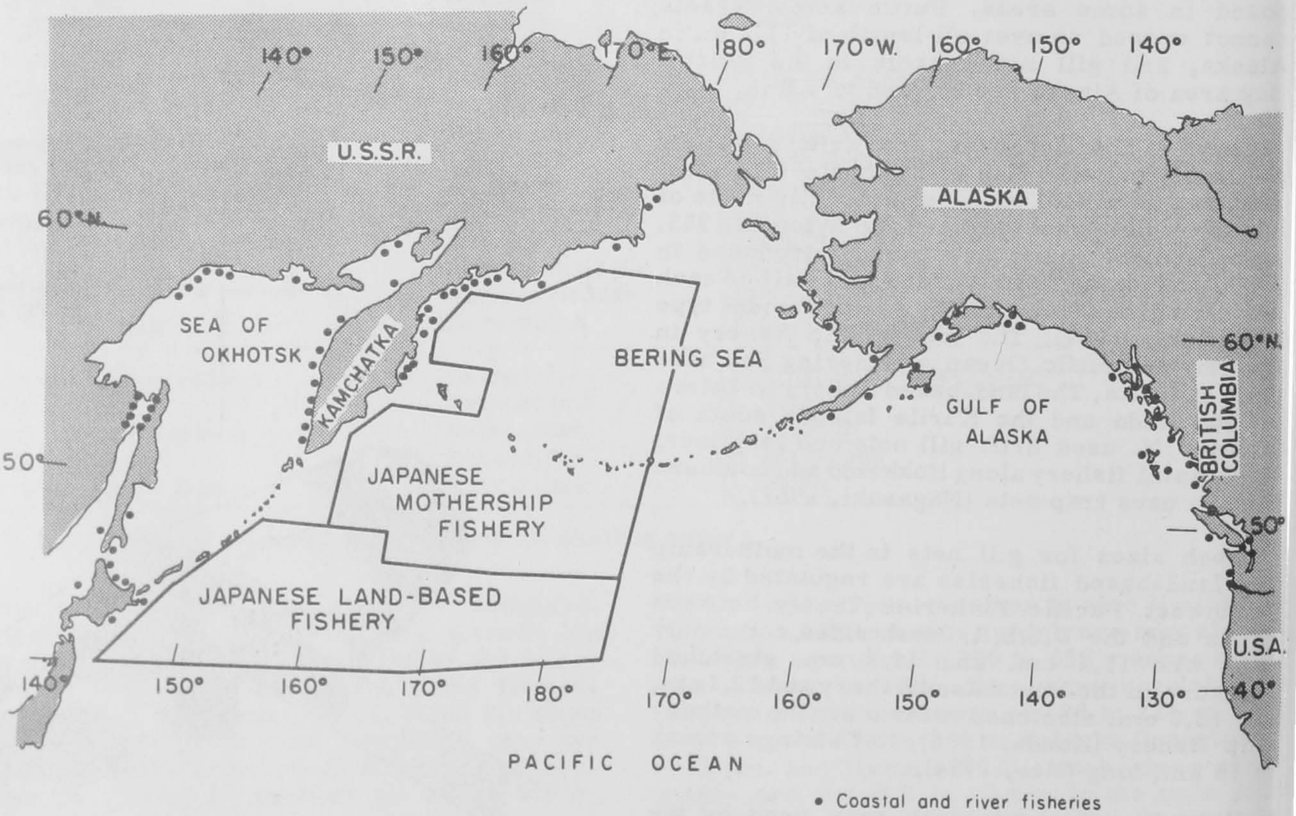

Figure 15.--Important fishing areas for chum salmon in Asia and North America (Kasahara, 1961; International North Pacific Fisheries Commission, 1964; Manzer et al., 1965).

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[15]

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 seasons and peak periods of catches for chum salmon in Asia and North America

Fishery	Years examined	Beginning of season	Peak of catch	End of season	Authority
Asia:					
Northeast coast of Kamchatka.	1932-41	June 15-25	July 2-23	Aug. 5-16	Kasahara (1963).
Kamchatka River	1932-41	June 7	July 14-Aug. 18	Sept. 6	Do.
West coast of Kamchatka	1932-41	July 2-9	July 19-Aug. 24	Aug. 21-30	Do.
Northern Okhotsk coast	1932-41	July 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	June-August	September	September-October	Do.
Japanese mothership	1952-64	May-June	June	July 31-Aug. 22	International North Pacific Fisheries Commission (1953-64).
Japanese land-based	1952-64	April	June (marine fishery) October (coastal fishery).	December-January	Do.
North America:					
Western Alaska	1955-64	June 1-11	Late June or early July.	Aug. 27-Sept. 29	International North Pacific Fisheries Commission (1952-64).
Central Alaska	1955-64	May 1-June 1	Late July or early August.	Sept. 16-Oct. 3	Do.
Southeastern Alaska	1955-64	do.	July, August, or September.	Oct. 26-Dec. 31	Do.
British Columbia	1952-64	do.	September or October	do.	Do.
Washington	1956-64	July 1-Sept. 1	Late October or 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[1]		
	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	1,932	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	44.0	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. in the 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[1]	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						
1908	2.8	0	-	-	0.3	1.0	(4.1)
1909	4.6	0	-	-	0.5	0.9	(6.0)
1910	11.6	0	-	-	0.6	3.1	(15.3)
1911	7.9	0	-	-	0.7	4.7	(13.3)
1912	6.6	0	-	-	0.7	3.7	(11.0)
1913	11.3	0	-	-	0.6	2.7	(14.6)
1914	9.9	0	-	-	1.1	3.1	(14.1)
1915	5.0	0	-	-	0.8	5.0	(10.8)
1916	3.9	0	-	-	0.3	2.3	(6.5)
1917	6.7	0	-	-	0.4	3.0	(10.1)
1918	9.3	0	-	-	0.9	3.6	(13.8)
1919	11.9	0	-	-	1.1	4.7	(17.7)
1920	10.8	0	-	-	0.7	3.5	(15.0)
1921	10.3	0	-	-	0.5	3.4	(14.2)
1922	10.1	0	-	-	0.4	3.3	(13.8)
1923	8.8	0	-	-	0.7	5.7	(15.2)
1924	5.1	0	-	-	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	([3])	0.5	2.4	28.7
1929	0	28.7	0		0.3	3.8	32.8
1930	0	[4] 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[1]	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	0	0	10.6	2.7	-	4.1	17.4
1954	0	0	16.4	9.4	-	6.6	32.4
1955	0	0	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	-

[1] Figures for 1908-24 include coho salmon catches.
[2] May include small numbers of sockeye, coho, and chinook salmon from 1908-57.
[3] Less than 50,000 fish.
[4] Estimate.
- No data.
() Figures incomplete.

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)

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	28.4	16.9	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	

[1] 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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