Biological Report 82(11.81)
March 1988

TR EL-82-4

Species Profiles: Life Histories and Environmental Requirements of Coastal Fishes and Invertebrates (Pacific Northwest)

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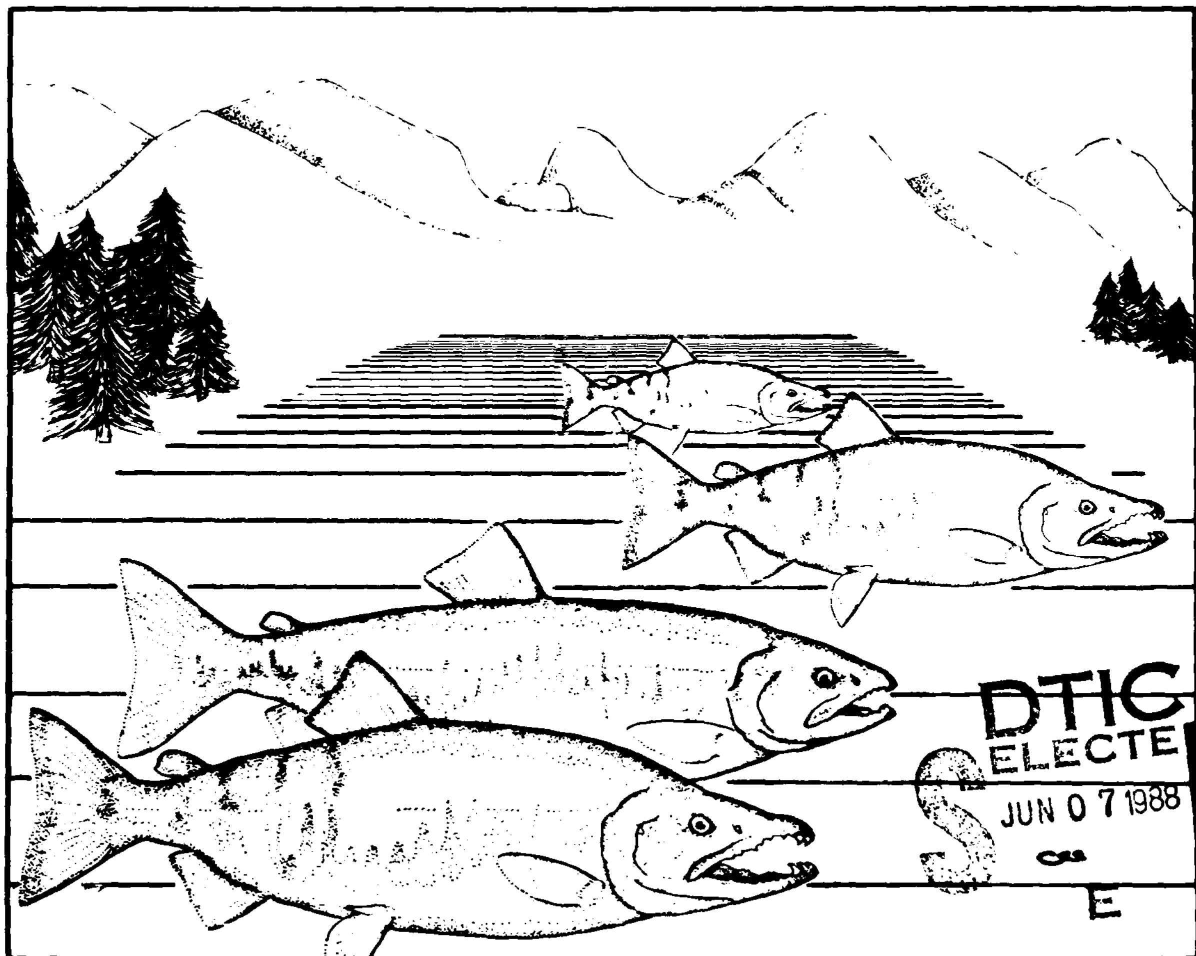

Fish and Wildlife Service
U.S. Department of the Interior

Coastal Ecology Group
Waterways Experiment Station
U.S. Army Corps of Engineers

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Species Profiles: Life Histories and Environmental Requirements of Coastal Fishes and Invertebrates (Pacific Northwest)

CHUM SALMON

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Performed for

Coastal Ecology Group
U.S. Army Corps of Engineers
Waterways Experiment Station
Vicksburg, MS 39180

and

National Wetlands Research Center
Research and Development
Fish and Wildlife Service
U.S. Department of the Interior
Washington, DC 20240

This series may be referenced as follows:

U.S. Fish and Wildlife Service. 1983-19__. Species profiles: life histories and environmental requirements of coastal fishes and invertebrates. U.S. Fish Wildl. Serv. Biol. Rep. 82(11). U.S. Army Corps of Engineers, TR EL-82-4.

This profile may be cited as follows:

Pauley, G.B., K.L. Bowers, and G.L. Thomas. 1988. Species profiles: life histories and environmental requirements of coastal fishes and invertebrates (Pacific Northwest) -- chum salmon. U.S. Fish Wildl. Serv. Biol. Rep. 82(11.81) U.S. Army Corps of Engineers, TR EL-82-4. 17 pp.

PREFACE

This species profile is one of a series on coastal aquatic organisms, principally fish, of sport, commercial, or ecological importance. The profiles are designed to provide coastal managers, engineers, and biologists with a brief comprehensive sketch of the biological characteristics and environmental requirements of the species and to describe how populations of the species may be expected to react to environmental changes caused by coastal development. Each profile has sections on taxonomy, life history, ecological role, environmental requirements, and economic importance, if applicable. A three-ring binder is used for this series so that new profiles can be added as they are prepared. This project is jointly planned and financed by the U.S. Army Corps of Engineers and the U.S. Fish and Wildlife Service.

Suggestions or questions regarding this report should be directed to one of the following addresses.

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CONVERSION TABLE

Metric to U.S. Customary

Multiply	By	To Obtain
millimeters (mm)	0.03937	inches
centimeters (cm)	0.3937	inches
meters (m)	3.281	feet
meters (m)	0.5468	fathoms
kilometers (km)	0.6214	statute miles
kilometers (km)	0.5396	nautical miles
square meters (m^2)	10.76	square feet
square kilometers (km^2)	0.3861	square miles
hectares (ha)	2.471	acres
liters (l)	0.2642	gallons
cubic meters (m^3)	35.31	cubic feet
cubic meters (m^3)	0.0008110	acre-feet
milligrams (mg)	0.00003527	ounces
grams (g)	0.03527	ounces
kilograms (kg)	2.205	pounds
metric tons (t)	2205.0	pounds
metric tons (t)	1.102	short tons
kilocalories (kcal)	3.968	British thermal units
Celsius degrees (°C)	1.8(°C) + 32	Fahrenheit degrees

U.S. Customary to Metric

Multiply	By	To Obtain
inches	25.40	millimeters
inches	2.54	centimeters
feet (ft)	0.3048	meters
fathoms	1.829	meters
statute miles (mi)	1.609	kilometers
nautical miles (nmi)	1.852	kilometers
square feet (ft^2)	0.0929	square meters
square miles (mi^2)	2.590	square kilometers
acres	0.4047	hectares
gallons (gal)	3.785	liters
cubic feet (ft^3)	0.02831	cubic meters
acre-feet	1233.0	cubic meters
ounces (oz)	28350.0	milligrams
ounces (oz)	28.35	grams
pounds (lb)	0.4536	kilograms
pounds (lb)	0.00045	metric tons
short tons (ton)	0.9072	metric tons
British thermal units (Btu)	*0.2520*	kilocalories
Fahrenheit degrees (°F)	0.5556 (°F - 32)	Celsius degrees

CONTENTS

ACKNOWLEDGMENTS

We thank Jim Ames and Morris Barker of the Washington State Department of Fisheries, Olympia, Washington, for their constructive reviews of this species profile.

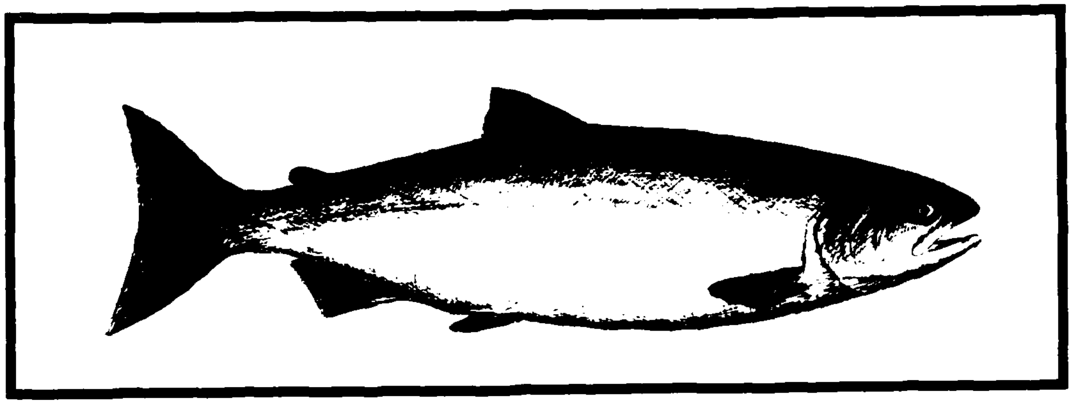

Figure 1. Chum salmon.

CHUM SALMON

NOMENCLATURE/TAXONOMY/RANGE

Scientific name.....*Oncorhynchus keta* (Walbaum 1792) (Figure 1)
Preferred common name......Chum salmon
Other common names....Dog salmon, fall salmon
Class....................Osteichthyes
Order....................Salmoniformes
Family.....................Salmonidae

Geographic range: Chum salmon have the widest distribution of the Pacific salmon, ranging from southern California (Hallock and Fry 1967) northward through Alaska, the arctic shore of Alaska, USSR, Japan, and Korea (Bakkala 1970; Hart 1973). The major rivers of the Pacific Northwest that support chum salmon runs are shown in Figure 2. Centers of abundance for chum salmon are southeastern Alaska and Prince William Sound in British Columbia (Atkinson et al. 1967).

MORPHOLOGY/IDENTIFICATION AIDS

Dorsal fin 10-13 rays; adipose fin small, slender, fleshy; caudal forked; anal fin 13-17 rays; pectorals 16 rays; pelvics 10 rays and abdominal location, each with a free-tipped fleshy appendage above its insertion. Gill rakers on first arch 18-30. Body elongate and moderately compressed (Hart 1973).

Recognizable by the absence of large black spots on the body and fins, and by the slender caudal peduncle; adult chum salmon are unique in having white tips on pelvic and anal fins, which distinguish them from sockeye salmon. Maturing fish have a series of dark bars and red coloring on sides, and some have gray blotches. Juvenile parr marks appear as slender bars, scarcely extending below lateral lines; have green irridescence on back (Hart 1973).

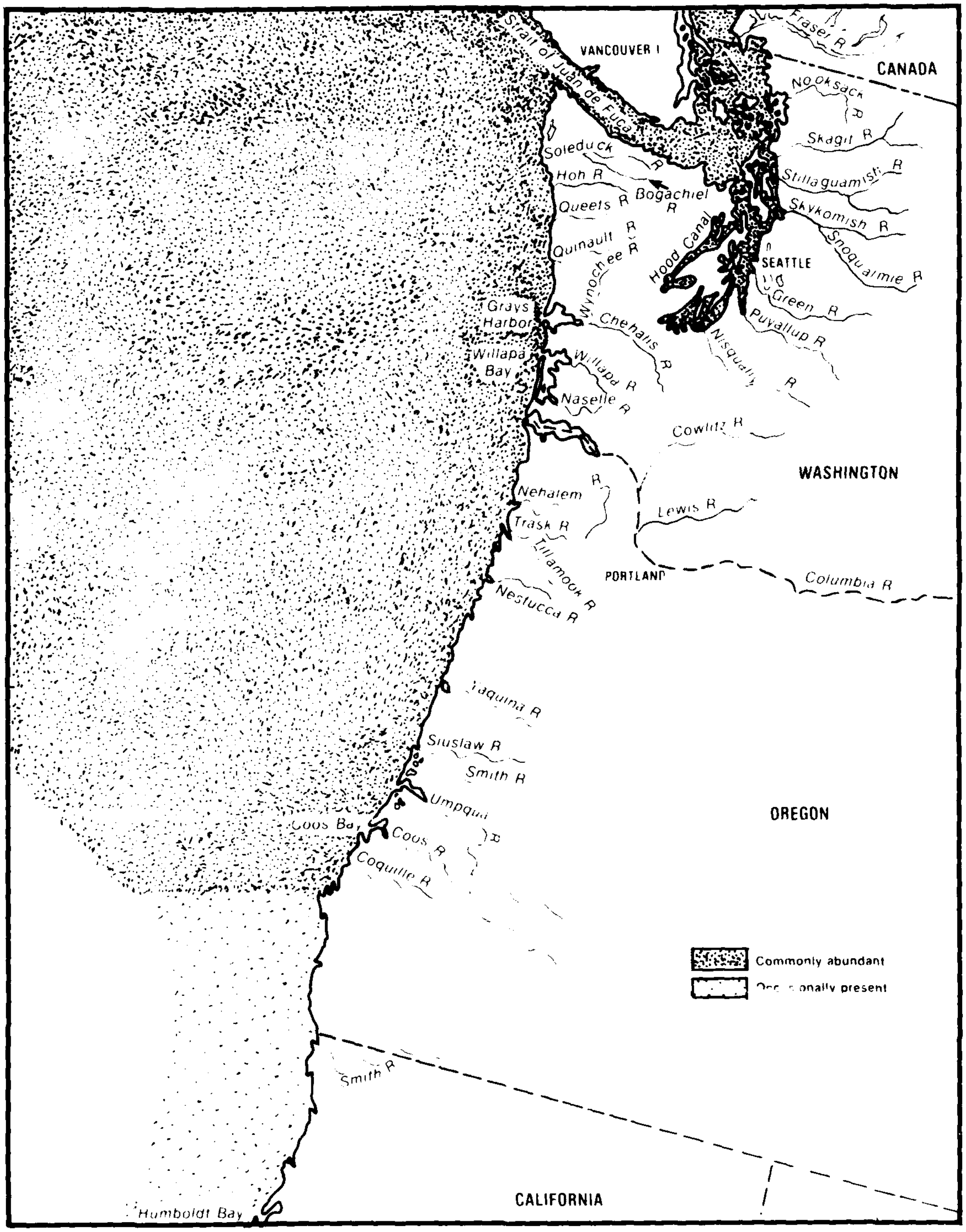

Figure 2. Major rivers and coastal areas supporting chum salmon in the Pacific Northwest.

REASON FOR INCLUSION IN SERIES

The chum salmon supports a valuable commercial fishery along the Pacific coast from Washington to Alaska. This fish is the main income producer for many villagers in southwestern Alaska. It occupies ecological niches in both marine and estuarine waters and is important as both a predator and prey species at various life stages.

LIFE HISTORY

Spawning

Chum salmon are anadromous like other North American species of salmon, but the time spent in freshwater is brief and primarily for reproduction (Bakkala 1970; Hale 1981). Chum salmon migrate to the estuaries during their first spring or summer of life and, like pink salmon, Oncorhynchus gorbuscha, spend minimal time rearing in freshwater. In this respect, they are considerably unlike sockeye, Oncorhynchus nerka, coho, Oncorhynchus kisutch, and chinook salmon, Oncorhynchus tshawytscha, which spend longer times in freshwater. Adult chum salmon live in the offshore marine or estuarine environments.

Like all species of Oncorhynchus, the chum salmon return to the stream in which they hatched, and then die after spawning. Chum salmon are the last of the Pacific salmon to return to their natal streams (Washington State Department of Fisheries 1959; Bakkala 1970), usually leaving the marine waters in summer and late fall to begin their upstream migration. However, in Puget Sound, adult chum salmon enter freshwater as late as March. Chum salmon may enter freshwater to spawn as 3-, 4-, or 5-year-old fish (Beacham 1984). Groups of fish that enter the rivers early in Southern British Columbia have higher proportions of older fish (4- and 5-year-olds) than those that enter the streams later (Beacham 1984). Most chum salmon spawn above the saltwater zone but within 200 km of the sea, although some chum salmon have been reported to migrate up to 322 km upstream to spawn (Hart 1973).

Most rivers have only a summer and fall run of spawning chum salmon. However, in Puget Sound streams, there are three distinct chum salmon runs: early - from mid-August through October; normal - from November through December; and late - from January through March (J. Ames, 1984, Washington State Department of Fisheries [WDF], Olympia; pers. comm.). Adult chum salmon do not feed during the upstream migration and generally travel about 20 km per day (Hart 1973). Mattson et al. (1964) reported the time spent by adults in freshwater (time of stream entry to death) to be 11 to 18 days. However, the freshwater life of adult chum salmon that spawn in large river systems is sometimes twice that long (J. Ames, 1984, WDF; pers. comm.). In Southern British Columbia, the average size of chum salmon that spawned in small streams was smaller than the average of those that spawned in large rivers (Beacham 1984).

The female chum salmon chooses a nest site on the basis of gravel substrate (Schroder and Duker 1979). The female chum salmon excavates the redd in gravel by turning to one side and rapidly flexing her body, creating water current and removing gravel with the caudal fin. After the depression is complete, the female and dominant male enter the redd and simultaneously extrude eggs and milt. Not all eggs are deposited at one time, as multiple egg pockets are made. Tautz and Grott (1975) described the female chum salmon as the dominant member of the spawning pair in the sense that the activity of the male occurs in response to the quivering and readying of the spawning area by the female.

The area of chum salmon redds ranges from 0.3 to 4.5 m^2 and averages about 2.3 m^2 (Burner 1951). It has been suggested that a spawning pair may require a total area of 9.2 m^2 (Burner 1951). However, since chum salmon tend to spawn in groups, this large additional amount of inter-redd spacing (approximately 7.0 m^2) is probably unnecessary and a realistic optimum is closer to 2.0 m^2 per female (J. Ames, pers. comm.). Superimposition of redds by later spawners may remove previously deposited eggs from the gravel. In areas of high spawning density, McNeil (1962) reported that up to 50% of the total egg losses were attributed to subsequent displacement. Thorenstein (1965) found that at densities of 45 females per m^2, as many eggs were dislodged as were deposited.

Fecundity, Eggs, and Alevins

Female chum salmon produce from 900 to 8,000 eggs, with the fecundity of samples from North America and Asia averaging 2,000 to 3,000 eggs (Bakkala 1970). Watanabe (1955) reported that fecundity and size of eggs increase with length of the spawning female. Several investigators (Hunter 1959; McNeil 1962) have proposed that most mortality that occurs between egg fertilization and the early fry stage occurs while eggs are incubating. Factors which influence egg survival include superimposition of redds by later spawners, sedimentation, low oxygen, predators, light, freezing, and erosion of streambeds caused by flooding and drought (Bakkala 1970). Drought can have two effects: (1) eggs or alevins may be killed through lack of streamflow, which can result in insufficient dissolved oxygen, siltation, or desiccation; and (2) spawners may be forced to use inappropriate spawning sites because of low flows.

Egg density did not affect fry survival but altered the time of emergence, which in turn influenced fry condition, which is measured by the length-to-weight relationship (Kapuscinski and Lannan 1983). The survival rate of eggs to fry is typically less than 10% (Hale 1981). Egg survival from fertilization to hatching was highest for eggs from small females and lowest for those from large females at various temperatures (Beacham and Murray 1985). Chum salmon eggs incubate in the gravel for 50 to 130 days (Hale 1981). After hatching, the larvae with yolk sacs attached (alevins) remain in the gravel. The yolk sacs are fully absorbed 30 to 50 days later. Alevins produced by larger females had more yolk reserves and more body tissue at hatching than those produced by smaller females (Beacham and Murray 1985). Alevins emerge from the gravel as fry in the spring.

Fry and Smolts

Most chum salmon fry begin their downstream migration to the ocean soon after emergence. In general, increased fry emergence results from increased deposition of eggs; the more spawning fish, the more progeny that are produced up to a limit of about 330 fry per m^2. Some fry remain in freshwater for several weeks--especially those that are hundreds of miles from the ocean. The outmigration occurs mainly at night in the spring (Hale 1981). A small percentage of juvenile chum salmon rear entirely in freshwater (J. Ames, pers. comm.). Chum salmon 80-mm long occur in the streams during the summer months, but they typically enter saltwater by the end of the summer. The work of Iwata and Komatsu (1984) indicated that it was important that some rearing take place in the estuary because chum fry reared exclusively in freshwater may be at a distinct disadvantage when they enter seawater. Several researchers have suggested that estuaries are important nursery areas for chum salmon (Mason 1974 ; Simenstad and Kenny 1978; Healey 1980;

Congleton et al. 1982; Levy and Northcote 1982; Bax 1983b; Iwata and Komatsu 1984).

In the State of Washington, Hood Canal provides an important passageway and nursery area for chum salmon, accounting for about 25% of Washington State's adult chum salmon returns (Fiscus 1969; Morrill 1974; Bax et al. 1979). The period of early marine residence, the estuarine-to-oceanic transition (at <55 mm total length), is considered the most critical phase in the life history of the chum salmon, and the one which ultimately determines the number of adult returns (Mathews and Senn 1975; Fraser et al. 1978; Bax 1983a,b). After the salmon reach a size greater than 55 mm, they move into the offshore marine neritic environment. It appears that the estuarine environment provides a refuge from predation (Parker 1971) and an abundance of preferred epibenthic prey (Feller and Kaczynski 1975) until juvenile chum salmon reach a length that is more advantageous for oceanic survival.

The fry enter the estuaries in schools, usually by June, and remain until mid- or late summer. The young chum salmon feed mainly in the estuaries, though some go back into freshwater areas with the changing tides to feed (Mason 1974). By mid-August to September, all juveniles at lengths of 150-225 mm have left the river estuaries for the offshore ocean environment (Hale 1981). Migration of chum fry to saltwater is obligatory within the first summer after hatching and they will die if kept in freshwater for 7 to 8 months after hatching (Houston 1961). Prolonged rearing in freshwater and extended rearing close to their point of saltwater entry may cause higher mortality of the juvenile chum salmon than would otherwise be expected (Iwata et al. 1982; Bax 1983a).

After leaving the estuarine environment, immature chum salmon become widely distributed at sea throughout the North Pacific Ocean to a southern limit of about 40° to 44° N latitude. Large numbers of immature age 2 chum salmon occur in Puget Sound during the summer and fall months, but no immature age 3 chum have been observed, which would suggest that some chum salmon spend a year or more in Puget Sound and that all fish eventually enter the Pacific Ocean (J. Ames, pers. comm.). In the Gulf of Alaska, chum salmon were found in the upper 61 m of the water column from May to July, approaching the surface at night (Manzer 1956). Main food items in the offshore area consist of various invertebrates and fish (Bakkala 1970).

Mature salmon range from age 2 to age 7, although age 6 and age 7 fish are not commonly observed (Bakkala 1970; Hale 1981). Most chum salmon mature at age 4 to age 5 in Alaska and British Columbia and at age 3 to age 4 in Washington and Oregon (J. Ames, pers. comm.). Adults range from 45 to 96 cm in fork length and from 0.8 to 13.4 kg in weight, with the mean size for sexually mature fish being 60 to 75 cm and 4.0 to 7.0 kg (Bakkala 1970; Merrell 1970; Morrow 1980). Maturing adults begin their migration to natal streams in the last few months of their lives. Little time is spent in nearshore coastal waters by adults before they begin their upstream migration to the spawning grounds (Hale 1981). Most upstream migrants have spent 2 to 4 years at sea. Brannon (1982) described salmon spawning migrations toward their natal rivers as being initiated and dependent primarily upon odor. Temperature and river flow were proximal influences on locomotion and comfort, but did not play any role in home stream recognition (Brannon 1982).

GROWTH CHARACTERISTICS

The use of scale annulus formation to determine age in chum salmon was discussed by LaLanne and Safsten (1969). The length and weight of chum salmon at hatching are about 22 mm and about 0.16 g respectively, while after absorption of the yolk sac they are 27 to 32 mm long and weigh about 0.20 g (Bakkala 1970). In experimental situations, the growth rate of juvenile chum salmon was dependent on the concentration of food (LeBrasseur 1969). Ricker (1964) summarized the growth of chum salmon stocks from various areas along the Pacific Coast from scale analysis and noted that the percent weight increase declined each year as the fish grew older. Beacham (1984) noted that for each age group of returning adult chum salmon, fish from large rivers were larger in size than those from small streams.

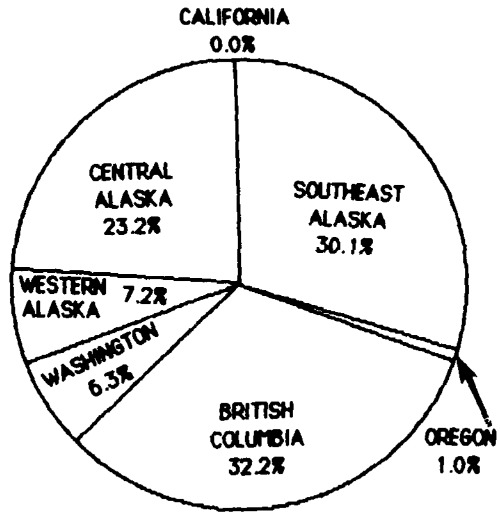

Figure 3. Average percentages of the Pacific Coast State and Province commercial harvest of chum salmon, 1920-79 (modification of data from Pacific Marine Fisheries Commission 1983).

THE FISHERY

The chum salmon is an important component of the commercial fishery from Washington northward along the Pacific Coast (Figure 2). The major chum salmon fishery is centered in Southeast Alaska and British Columbia (Figure 3). The total commercial salmon catch north of Bristol Bay, Alaska, consists primarily of chum salmon and provides income for many villagers in western Alaska (Hale 1981).

Chum salmon stocks in Washington State increased greatly in the mid-1980's because of a massive enhancement program; Hood Canal and the rivers that flow into it were managed principally for the production of chum salmon (Bax et al. 1979; Whitmus and Olsen 1979). Chum salmon production in Washington State has increased, in part due to hatchery production and in part due to increased management effort on this species. Chum salmon landings in relation to total landings for all salmon species in Washington State are shown in Table 1.

The 1978 and 1980 commercial harvests averaged 1,150,000 fish, which is equivalent to the high harvests in Washington State during the 1930's and 1940's (J. Ames, pers. comm.). Native runs also have benefited from the hatchery enhancement, and total chum salmon returns to Puget Sound now include a major portion of native stocks along with the hatchery returns (Table 2). Odd-numbered years are historically low-harvest years for chum salmon (Tables 1 and 2). Harvest rates determined for the terminal area fishery are based on preseason run size forecasts (minus escapement goals), and updates of the run size throughout the season (Washington State Department of Fisheries 1983).

Although not a prime target for sport fishermen in the Pacific Northwest (Haw and Buckley 1973), chum salmon are caught incidently by anglers fishing for coho and chinook salmon. Chum salmon sport fisheries in Washington State are localized primarily in southern Puget Sound. Interest in this species as a recreational

Table 1. Annual commercial landings of chum salmon in pounds in the State of Washington, 1978-81 (J. Ames, WDF, 1984, pers. comm.).

Year	Total salmon landings	Chum salmon landings	Percent chum
1978	40,759,008	14,250,639	35.0
1979	52,537,997	1,358,458	2.6
1980	34,442,823	10,540,046	30.6
1981	47,035,973	6,036,699	12.8
Total	174,775,801	32,185,842	18.4

fish has been growing each year (J. Ames, pers. comm.).

ECOLOGICAL ROLE

Because most chum salmon begin to migrate to marine waters as juveniles, they feed very little in freshwater (LeBrasseur and Parker 1964). Bakkala (1970) described benthic organisms, chiefly aquatic insects, as their primary food in freshwater. During their estuarine existence, chum salmon are size-selective predators that preferentially feed on epibenthic organisms: harpacticoid copepods, gammaridean amphipods, cumaceans, and mysids (Gerke and Kaczynski 1972; Feller and Kaczynski 1975; Simenstad and Kenny 1978). Harpacticoid copepods were found to be numerically dominant as food items of chum salmon fry, while a single prey item, the copepod Harpacticus unirevais, often composed more than 80% of the diet, even though it was comparatively rare in the epibenthic fauna (Gerke and Kaczynski 1972; Healey 1979).

After reaching a length greater than 55 mm, juvenile chum salmon migrate to the offshore neritic zone and feed on larger planktonic organisms such as calanoid copepods, hyperiid amphipods, larvaceans, and fish larvae (Simenstad and Kenny 1978). Peterson et al. (1982) found that an euphausiid, Thysanoessa spinifera, and a hyperiid amphipod, Hyperoche medusarum, were the primary food items of juvenile chum salmon off the coast of Oregon. Juvenile chum salmon off the southern British Columbia coast shifted from crustaceans and other invertebrates to fish as they grew larger than 95 mm (Shepard 1981). LeBrasseur (1966) suggested that feeding habits and differences in stomach contents of adult chum salmon in offshore areas were based on availability rather than on preferences for certain kinds of organisms. Chum salmon digest food faster than any

Table 2. Puget Sound chum salmon total run size, of both hatchery and wild fish, 1980-83 (J. Ames, WDF, 1984, pers. comm.).

Return year	Total chum run size	Hatchery chum	Wild chum	Percent wild
1980	1,015,737	284,815	730,922	72.0
1981	708,622	177,576	531,046	74.9
1982	1,347,109	333,991	1,013,118	75.2
1983	608,371	227,123	381,248	62.7
Total	3,679,839	1,023,505	2,656,334	72.2

other species of salmon and feed extensively on readily digested organisms, thereby making stomach analysis difficult (Bakkala 1970).

Predation on chum salmon fry in the freshwater during their downstream migration is a major source of mortality (Hale 1981), where common predators are cutthroat trout (Salmo clarki), rainbow trout (Salmo gairdneri), Dolly Varden (Salvelinus malma), coho salmon smolts (Oncorhynchus kisutch), sculpins (Cottus spp.), belted kingfishers (Ceryle alcyon), and mergansers (Mergus sp.). Predation on juvenile chum salmon in the estuaries by coho salmon smolts, Dolly Varden, and fish-eating birds is possibly correlated with juvenile chum salmon hatchery release time (Shepard 1981). Allen (1974) reported pigeon guillemots (Cepphus columba), marbled murrelets (Brachyramphus marmoratus), and pelagic cormorants (Phalacrocorax pelagicus) were in close association with juvenile chum salmon in a British Columbia estuary. Cardwell and Fresh (1979) concluded that bird predation on salmon fry was low in Puget Sound. However, available evidence indicates that the mortality of juvenile chum salmon during early life at sea is high and is probably size dependent (Parker 1971; Healey 1982). The most important predators of chum salmon in the offshore marine environment include marine birds, killer whales (Orcinus orca), sea lions (Eumetopias jubatus and Zalophus californianus), harbor seals (Phoca vitulina), and various pelagic fishes and sharks (Bakkala 1970).

Other Pacific salmon are the principal competitors of chum salmon. The various species intermingle in the marine environment, estuaries, and on the spawning grounds. Parker (1971) noted that juvenile coho salmon preyed heavily on juvenile chum salmon. However, Hargreaves and LeBrasseur (1985) found that yearling coho salmon prey selectively on pink salmon, even when chum salmon are both significantly smaller and more abundant than pink salmon. However, pink salmon fry, although abundant in the tidal channels in even-numbered years, normally do not stay in estuaries at the same times that chum salmon fry are abundant there, because the pink salmon migrate quickly through the marsh and into the sea (Levy and Northcote 1982). The two species of salmon whose fry overlap most in estuarine marsh areas are chum and chinook (Congleton et al. 1982; Levy and Northcote 1982). However, detrimental interaction between these two species is limited by differences in migration timing, with chum preceding chinook in the marsh, and by different marsh residency periods, with chum fry spending a relatively short time in the estuaries compared to chinook fry (Levy and Northcote 1982). Beacham and Starr (1982) indicated that the return to escapement ratio for odd-numbered brood years of chum salmon was positively statistically correlated with (1) early downstream migration of chum salmon fry relative to that of pink salmon fry and (2) with increased spawning escapement of chum salmon relative to that of pink salmon.

Gerke and Kaczynski (1972) reported that juvenile pink and chum salmon school together in Puget Sound in odd-numbered years, and found no significant difference in the size of prey chosen by the two species. LeBrasseur et al. (1969) found that pink and chum salmon in the Fraser River Estuary consumed varying amounts of the same food items. In neither of these studies was there any evidence that competition for any food items limited growth or survival of either salmonid species.

Puget Sound offers a unique opportunity to examine interactions between chum and pink salmon because the pink salmon are not present during even-numbered years. If Puget Sound is considered as a whole, approximately half as many wild chum salmon return in the odd-numbered years when pink salmon are present (Ames 1981); the wild chum salmon runs average 808,000 fish in even-numbered years compared to 374,000 fish in odd-numbered years (J. Ames, pers. comm.). The early estuarine life of these two salmon species seems to be the critical period of their interaction, since it is well known that no interaction occurs in freshwater and open-ocean interaction is minimal (Ames 1981). In Puget Sound, it has been shown that as the number of wild pink salmon recruits (down stream migrants) per spawning adult increases, there is a significantly correlated decline in escapement of wild chum salmon (Figure 4). A similar impact on chum salmon by pink salmon has been observed by Beacham and Starr (1982), in which a decline in downstream migration of chum fry and spawning of chum salmon was correlated to an increased number of pink salmon.

ENVIRONMENTAL REQUIREMENTS

Temperature

According to Manzer et al. (1965) chum salmon at sea are found through a wide range of temperatures from 3 to 22 °C. An optimum temperature of 10.1 °C with a range of 8.3 to 15.6 °C has been noted for successful upstream migration of adult chum salmon (Bell 1973; Reiser and Bjornn 1979). Spawning temperatures for chum salmon range between 7.2 and 12.8 °C (Reiser and Bjornn 1979). Stream water temperatures of 0 to 15 °C have been noted for chum salmon incubation, although eggs are thought to survive best at 4.4 to 14 °C (Schroder 1973; Koski 1975; Reiser and Bjornn 1979). Egg survival was highest at 8 °C and among eggs produced by the smallest females (Beacham and Murray 1985). Brett (1952) observed chum salmon fry to prefer temperatures of 12 to 14 °C and to avoid temperatures above 15 °C. The upper lethal temperature for young chum salmon has been documented at 23.8 °C and the lower lethal temperature at 0 °C (Brett 1952).

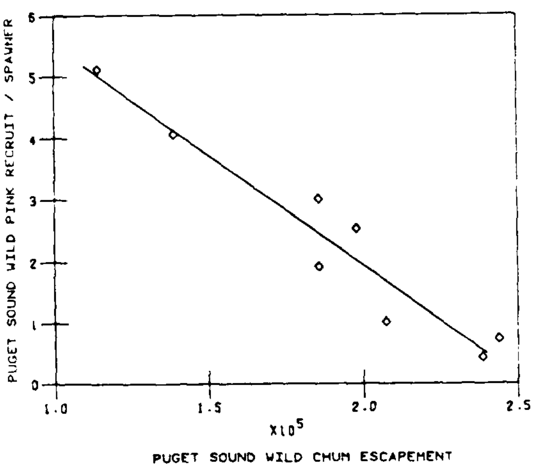

Figure 4. Relationship of Puget Sound wild chum salmon escapement to Puget Sound wild pink salmon recruits (young downstream migrants) per spawner (after Ames 1981).

Salinity

Saline water can interfere with fertilization of the eggs of chum salmon spawning in or near the intertidal marine zone (Rockwell 1956). After absorption of the yolk sac, chum salmon can tolerate full-strength seawater (Weishart 1978). Hoar (1976) reported that chum salmon appear to have a physiological requirement for seawater 3 to 4 months after emergence if normal development is to proceed. Shepard (1948) experimentally showed that chum salmon fry would preferentially choose a seawater run over a freshwater run, regardless of flow strength.

Dissolved Oxygen

Reiser and Bjornn (1979) reported that low concentrations of dissolved oxygen can reduce swimming performance by adult salmonids and sometimes causes migration to cease. Daykin (1965) reported that the rate of supply of dissolved oxygen is more important to the eggs or alevins than the actual concentration. Water saturated with oxygen may be regarded as an optimal condition for eggs and alevins although concentration of oxygen in freshwater depends largely on temperature (Alderdice et al. 1958). Critical oxygen levels (above which respiratory rates are unmodified by oxygen availability) range from 1 ppm in early embryonic stages to 7 ppm shortly before hatching (Alderice et al. 1958). Wickett (1954) linked high mortality of eggs with low dissolved oxygen and low water velocity. Reiser and Bjornn (1979) summarized the effect of oxygen concentration on egg development as follows: (1) fry reared at low oxygen levels were smaller and weaker than those reared at higher concentrations; and (2) reduced oxygen concentrations lengthened incubation periods and caused premature hatching.

Substrate

The suitability of substrate particles of a particular size depends mostly on fish size and may vary from 1.3 to 10.2 cm for spawning chum salmon (Reiser and Bjornn 1979). There is a positive correlation between highly permeable gravel substrate and survival of chum salmon eggs (Wickett 1958). Dill and Northcote (1970) reported that chum salmon survival to emergence approaches 100% in large gravel (5.1 to 10.2 cm), but is only 31% in small gravel (< 5.0 cm), and they concluded that the lower survival was due to entrapment of the fry by silt. Rukhlov (1969) reported a positive relationship between increasing sand content and egg mortality, and considered sedimentation during the incubation period as a major source of egg mortality. The size and shape of substrate particles are directly correlated with the incubation time of eggs and the normal development of alevins (Hale 1981).

Water Depth

Water depth must be adequate to enable adult salmon to migrate upstream to spawn. Extremely low water levels, especially when coupled with barriers, can make streams impassable to spawning adults. The average water depth over chum salmon redds in Oregon streams was 30 cm, while in Washington streams it ranged from 23 to 46 cm (Smith 1973).

Water Velocity

Low stream velocity and high stream velocity can both adversely affect chum salmon (Wickett 1958; Reiser and Bjornn 1979). Spawning adult chum salmon use water with velocities varying between 46 and 101 cm/sec (Smith 1973; Reiser and Bjornn 1979). Tautz and Grott (1975) reported that chum salmon chose to spawn in an area of accelerating water flow, such as that encountered at pool-riffle interchanges. Stream flow regulates the amount of spawning area available (Reiser and Bjornn 1979): increased flow covers more gravel, thus making more suitable spawning substrate available; but when the flow reaches a velocity that causes erosion of the substrate, suitable spawning is decreased.

Wickett (1958) showed a significant relationship between spawners and the amount of rainfall in July and August. This association can be fairly well depicted by an inverted parabola, suggesting that increased rainfall is beneficial up to a point (approximately 20 inches), but too much rainfall is detrimental to spawning.

Pacific salmon eggs require velocities of running water that keep the water well-oxygenated, protect the substrate from freezing temperatures, and remove waste metabolites such as carbon dioxide (Hale 1981). Adequate water velocity is necessary to prevent siltation buildup in the gravel substrate, which is a major cause of egg and alevin mortality (Reiser and Bjornn 1979; Duker and Colley 1981; Hale 1981).

Turbidity

Turbidity that leads to sedimentation has been reported to be an important cause of egg mortality (McNeil 1962; Bakkala 1970). High turbidity of the water can be inhibiting to adults attempting upstream migration (Reiser and Bjornn 1979; Hale 1981). Suspended sediment concentrations of 15.8 to 54.9 g/l were found to be the 96-h LD_{50} value for Puget Sound juvenile chum salmon (Bakkala 1970), indicating that chum salmon tolerate very high concentrations of suspended sediments. Suspended sediment is much more detrimental to eggs, juvenile stages, and invertebrates in the diet of the young fish than it is to adult fish.

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50272-101

REPORT DOCUMENTATION PAGE

1. REPORT NO.	2.	3. Recipient's Accession No.
Biological Report 82(11.81)*		

4. Title and Subtitle
Species Profiles: Life Histories and Environmental Requirements of Coastal Fishes and Invertebrates (Pacific Northwest)--Chum Salmon

5. Report Date
March 1988

6.

7. Author(s)
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8. Performing Organization Rept. No.

9. Performing Organization Name and Address
Washington Cooperative Fishery Research Unit
University of Washington
Seattle, WA 98195

10. Project/Task/Work Unit No.

11. Contract(C) or Grant(G) No.
(C)
(G)

12. Sponsoring Organization Name and Address
National Wetlands Research Center
Fish and Wildlife Service
U.S. Department of the Interior
Washington, DC 20240

U.S. Army Corps of Engineers
Waterways Experiment Station
P.O. Box 631
Vicksburg, MS 39180

13. Type of Report & Period Covered

14.

15. Supplementary Notes
*U.S. Army Corps of Engineers Report No. TR EL-82-4

16. Abstract (Limit: 200 words)

Species profiles are literature summaries of the taxonomy, morphology, range, life history, and environmental requirements of coastal aquatic species. They are designed to assist in environmental impact assessment. Chum salmon are anadromous fish found throughout a large part of the North Pacific Ocean and are the most widely distributed of all the Pacific salmon. Adults return to spawn in late summer and fall. Young fish migrate downstream quickly and rear in estuaries. Chum salmon mature later in life in more northerly water: in Alaska and British Columbia at age 4 to age 5, in Washington and Oregon at age 3 to age 4. Fish from larger river systems grow to the largest size. The major commercial fishery is centered in Southeast Alaska and British Columbia. Harvest has increased in Washington to 1,150,000 fish annually due to increased hatchery production, with Hood Canal rivers accounting for 25% of all Washington fish. In odd-numbered years, the adult return-to-escapement ratio in any given river system is positively statistically correlated with increased spawning escapement of chum salmon relative to that of pink salmon.

17. Document Analysis a. Descriptors

Competition	Streams	Temperature	Animal migrations
Growth	Fisheries	Feeding habits	Predators
Oxygen	Salinity	Life cycles	Spawning

b. Identifiers/Open-Ended Terms

Chum salmon	Oncorhynchus keta
Life history	Environmental requirements

c. COSATI Field/Group

18. Availability Statement	19. Security Class (This Report)	21. No. of Pages
Unlimited distribution	Unclassified	17
	20. Security Class (This Page)	**22. Price**
	Unclassified	

(See ANSI-Z39.18)

OPTIONAL FORM 272 (4-77)
(Formerly NTIS-35)
Department of Commerce