

Changes in size and age at maturity of two North American stocks of chum salmon (*Oncorhynchus keta*) before and after a major regime shift in the North Pacific Ocean

John H. Helle and Margaret S. Hoffman

Auke Bay Laboratory, Alaska Fisheries Science Center
National Marine Fisheries Service, Juneau, Alaska 99801-8626, U.S.A.



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Changes in size and age at maturity of chum salmon (*Oncorhynchus keta*) were monitored for two locations in North America. Chum salmon spawners returning to Fish Creek, southeastern Alaska, were sampled yearly from 1972 through 1996. Spawners returning to the Quilcene National Fish Hatchery in Hood Canal, Washington, were sampled yearly from 1973 through 1996. Size at maturity of both populations declined significantly from about 1980 to the mid-1990s. Age at maturity increased during this time. These changes were associated with a major ocean climate regime shift in the North Pacific Ocean that occurred in 1976–77. Population abundance of chum salmon increased greatly after the regime shift, especially in Asia. Similar changes in size and age at maturity occurred in Asian chum salmon; because the range of North American and Asian chum salmon overlaps on the high seas, these changes are discussed in relation to possible density-dependent population factors. Since the mid-1990s, size at maturity and population abundance have increased, possibly indicating another climate change in the North Pacific Ocean.



INTRODUCTION

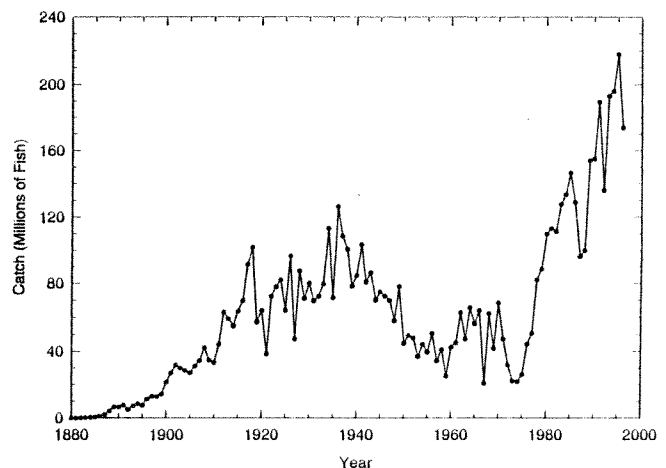
A major change in ocean climate (regime shift) occurred in the North Pacific Ocean during 1976–77 and has persisted into the mid-1990s (Graham 1994; McLain 1984; Miller et al. 1994; Trenberth 1990; Trenberth and Hurrell 1994). Salmon abundance in Alaska increased greatly after the regime shift (Fig. 1). However, mean size declined and the age at maturity increased in most populations of salmon in North America after the regime shift (Bigler et al. 1996; Helle and Hoffman 1995).

Helle and Hoffman (1995) monitored changes in size and age at maturity of chum salmon (*Oncorhynchus keta*) from two locations in North America between 1972 and 1992, before and after the regime shift. One population spawned in Fish Creek, a tributary of the Salmon River, which enters the ocean at the head of Portland Canal in southern southeast Alaska. The other population returned to the Quilcene National Fish Hatchery, in western Washington near Quilcene. Both populations declined significantly in size at maturity starting about 1980. Four-year-old males declined in weight by about 46% between the early 1970s and the early 1990s. As growth decreased during these years, mean age at

maturity increased. This information was reported for the years 1972–92 (Helle and Hoffman 1995).

We have collected four more years (1993–96) of data on age and size of maturity of these two populations. These data have been added to the 1972–92 data base and are discussed in this paper.

Fig. 1 Catch of all species of salmon in Alaska from 1880 through 1996. (Data from Alaska Department of Fish and Game).



STUDY AREA

Fish Creek

Fish Creek flows into the Salmon River near Hyder, Alaska, about 5 km upstream from the ocean (Portland Canal) in southern southeast Alaska (Fig. 2). The creek produces very large chum salmon (Helle 1984). A detailed description of the area is in Helle and Hoffman (1995).

Quilcene National Fish Hatchery

Quilcene National Fish Hatchery is next to the Quilcene River about 5 km from the ocean (Hood Canal) near Quilcene, Washington (Fig. 2). This salmon hatchery is operated by the U.S. Fish and Wildlife Service, Department of the Interior.

METHODS

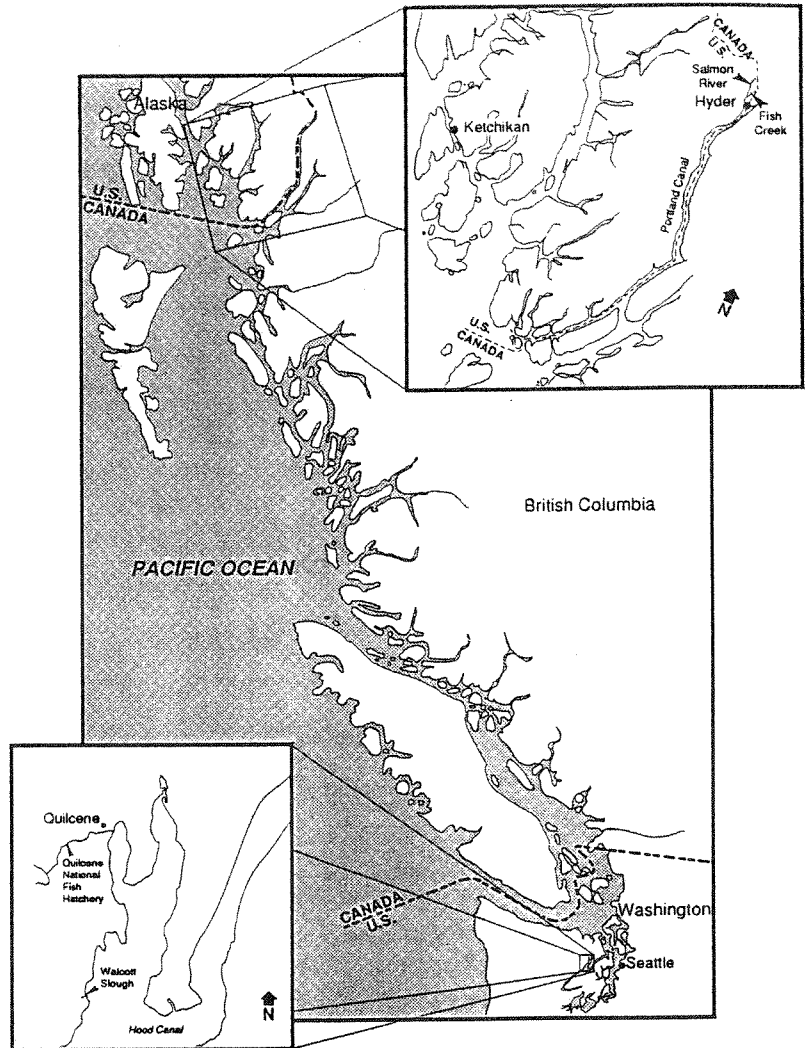
Fish Creek

Spawning chum salmon were counted several times during each spawning season by observers walking along the stream bank. Most of the counts were made by the senior author. Spawners were also estimated periodically during the season by Alaska Department of Fish and Game (ADF&G) biologists from low-flying fixed-wing aircraft. A counting fence (weir) was also operated at the mouth of Fish Creek between 1991 and 1995 by ADF&G personnel.

Scales and length measurements were taken from spawned dead chum salmon. Scales from chum salmon do not usually show excessive resorption on the edge and can be used for ageing (Helle 1979; Oakley 1966). The age composition of chum salmon changes during the season (Helle 1979). Therefore, to make consistent age-specific comparisons between years, samples were taken during the approximate peak of the spawning run—mid to late August (Table 1). The target sample size was a minimum of 100 males and 100 females, which was attained in most years.

One scale was removed from the left side of each fish with a forceps and placed onto a gummed card. The scale was taken from the area about four rows above the lateral line immediately below the posterior insertion of the dorsal fin. Later, a plastic impression of the gummed card was made in the laboratory

Fig. 2 Location of Fish Creek at the head of Portland Canal, near Hyder, Alaska, and of Quilcene National Fish Hatchery and Walcott Slough, near Quilcene, Washington.



(Arnold 1951). Age was determined from a projected image of the scale impression magnified 80 diameters. All fish were aged by the senior author. Age designation is by the method of Gilbert and Rich (1927) minus the subscript, which is always 1 in chum salmon.

Length of each fish was measured with a caliper to the nearest 1 mm with the fish flat on the ground. Length was measured from the middle of the eye to the end of the hypural plate. All lengths were measured by the senior author for continuity from year to year.

Mean lengths of 4-year-old chum salmon are plotted with 95% confidence intervals. Small, non-overlapping confidence intervals of the means between years usually indicate significant differences (Simpson et al. 1960).

A more detailed description of the sampling

Table 1. Number of chum salmon by date and sex, sampled at Fish Creek and Quilcene National Fish Hatchery 1972-96. Dash indicates no data.

Year	Fish Creek			Quilcene		
	Date	Males (no.)	Females (no.)	Date	Males (no.)	Females (no.)
1972	Aug. 17	90	100	—	—	—
1973	Aug. 16	108	89	Dec. 10	78	69
1974	Aug. 22	127	105	Dec. 9	110	124
1975	Aug. 20	100	99	Dec. 10	129	79
1976	Aug. 24	163	181	Dec. 8	150	109
1977	Aug. 24	99	103	Dec. 9	108	90
1978	Aug. 29	117	109	Dec. 11	118	103
1979	Aug. 29	131	133	Dec. 10	80	46
1980	Sep. 7	112	117	Dec. 15, 17	53	152
1981	Aug. 26	103	127	Dec. 8, 10	71	134
1982	Aug. 24	150	150	Dec. 6	106	98
1983	Aug. 9, 10	94	103	Dec. 19	132	154
1984	Aug. 23	146	178	Dec. 10	139	139
1985	Aug. 27	167	130	Dec. 10	124	82
1986	Aug. 14, 15	134	145	Dec. 10	168	196
1987	Aug. 27	160	152	Dec. 10	75	150
1988	Aug. 29	206	190	Dec. 5	152	154
1989	Aug. 26	152	160	Dec. 4	88	51
1990	Aug. 19	115	128	Dec. 5	184	89
1991	Aug. 23-29	47	45	Dec. 16	30	25
1992	Aug. 25	158	125	Dec. 7	99	36
1993	Aug. 17	144	135	Dec. 7	155	128
1994	Aug. 9	162	148	Dec. 15	160	121
1995	Aug. 1, 17	237	235	Dec. 12	138	156
1996	Aug. 15	67	126	Dec. 10	144	144

methods is in Helle and Hoffman (1995).

Quilcene National Fish Hatchery

Chum salmon were captured in a weir-trap as they returned to the hatchery facilities. Before 1985, fry were released at Walcott Slough, a small, spring-fed intertidal stream near Brinnon, about 16 km south of the hatchery. Adults returned to Walcott Slough. In the early 1980s, fry were also released at the hatchery on the Quilcene River and in 1985 no more fry were released at Walcott Slough, due to a change in fishery management plans (see Helle and Hoffman 1995).

Scale samples and length measurements were taken from chum salmon used for gametes for the hatchery. Sample sizes, scale samples, and length measurements were collected as described for Fish Creek. Except for 1973, all fish were measured by the senior author for year-to-year continuity. All fish were aged by the senior author. Detailed descriptions of the sampling methods are in Helle and Hoffman (1995).

RESULTS

Abundance of Spawners

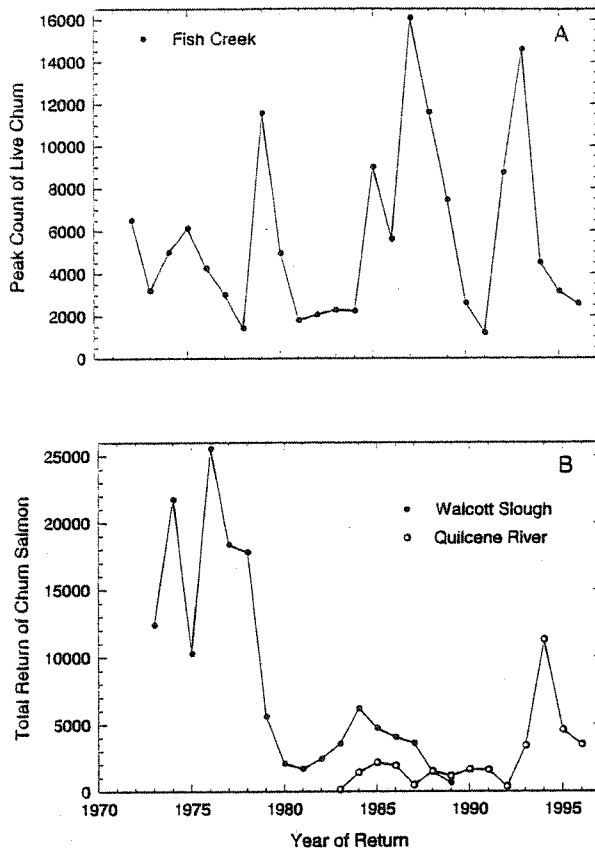
Chum salmon return from the ocean to spawn in Fish Creek from late June to November. Peak numbers of fish are usually in the stream during mid- to late August. Yearly peak counts of chum salmon spawners in Fish Creek vary greatly (Fig. 3a).

From 1991 through 1995, ADF&G operated a weir near the mouth of Fish Creek to obtain a total count of the chum salmon entering the stream. A comparison of the weir counts with foot-survey counts during the 5 years shows a significant positive relationship (Fig. 4).

Chum salmon return from the ocean to the Quilcene National Fish Hatchery facilities from late November through December. A remnant summer run also returns to spawn in the Quilcene River in August. Only the late chum salmon were sampled for abundance, age, and size in this study.

A planned reduction in the number of releases and eventual cessation of chum salmon fry released at Walcott Slough is evident from the declining adult returns from 1979 through 1989 (Fig. 3b). Returns to the hatchery on the Quilcene River have been increasing slowly in recent years since consolidating fry releases at the hatchery on the Quilcene River.

Fig. 3 Changes in the peak count of live chum salmon spawners in Fish Creek, 1972-96, and the total return of chum salmon spawners to Quilcene National Fish Hatchery facilities at Walcott Slough and Quilcene River, 1973-96.



Age of Spawners

Age-4 chum salmon are the most abundant age group in most years at Fish Creek; however, age-5 fish have generally been increasing in abundance since the mid-1980s (Fig. 5). Age-6 fish were absent in the early years of this study, but they have been increasing in frequency in recent years.

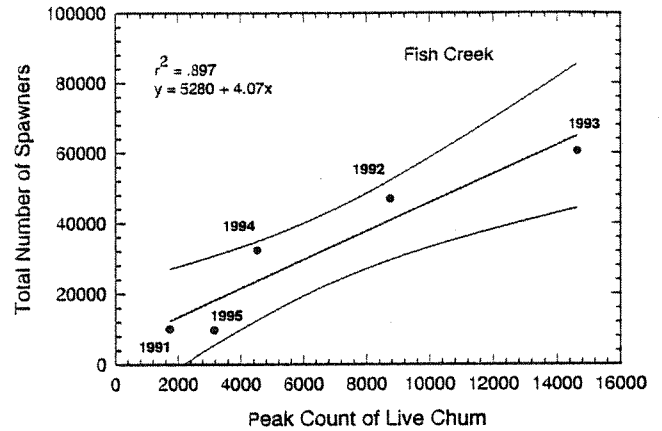
At Quilcene National Fish Hatchery, age-4 and -3 fish are the predominant age groups (Fig. 5). However, in general the fish have become older since the mid-1980s.

Size of Spawners

Generally, at both Fish Creek and Quilcene older fish are longer in any given year (Fig. 6). Age-4 and -5 fish are the dominant age groups at Fish Creek and generally decreased in length from 1980 through 1994. In the same year, Quilcene age-4 fish are longer than age-3 fish. Age-5 fish were abundant at Quilcene only in later years.

Age-4 chum salmon were usually the most

Fig. 4 Comparison of the relation between the peak count of live spawners and the total number (weir count) of chum salmon spawners in Fish Creek, 1991-95. Weir count data from J. Koerner and B. van Alen, Alaska Department of Fish and Game, Juneau.



abundant age group during the study. At Fish Creek the mean length of age-4 fish declined from about 1983 through 1987 (Fig. 7). Mean length increased significantly (in males) in 1988, then declined again through 1994. In 1995 and 1996, mean length increased significantly at Fish Creek for both sexes. Mean length of age-4 Quilcene chum salmon generally declined from the mid-1980s through 1993, then increased in 1994, 1995, and 1996.

DISCUSSION

Chum salmon returning to Fish Creek are intercepted in commercial fisheries in southern southeast Alaska and northern British Columbia. Some of these fisheries target chum salmon, but most of the fisheries in both areas target pink (*O. gorbuscha*) or sockeye (*O. nerka*) salmon, and chum salmon are captured incidentally. Catches of chum salmon (and pink and sockeye salmon) have generally increased in southern southeast Alaska since the early 1980s (Fig. 8). Catches of chum and sockeye salmon in northern British Columbia have also been large in recent years. Catches of chum salmon in Puget Sound, Washington, have generally increased since the early 1980s (Fig. 9).

Exploitation rates of chum salmon returning to Fish Creek and Quilcene National Fish Hatchery are not known precisely and certainly vary from year to year (see Helle and Hoffman 1995). Therefore, the escapements in each year may not reflect the same proportion of the actual total production of chum salmon in each year. Escapement of chum salmon in Fish Creek varied greatly during this study. However, some large escapements have occurred between 1979 and 1993 (Fig. 3); the largest had a

Fig. 5 Percent age composition in year of return of age-3, -4, -5, and -6 male and female chum salmon at Fish Creek and age-3, -4, and -5 at Quilcene National Fish Hatchery. Data for ages 3, 4, and 5 smoothed by a 3-year moving average with equal weights.

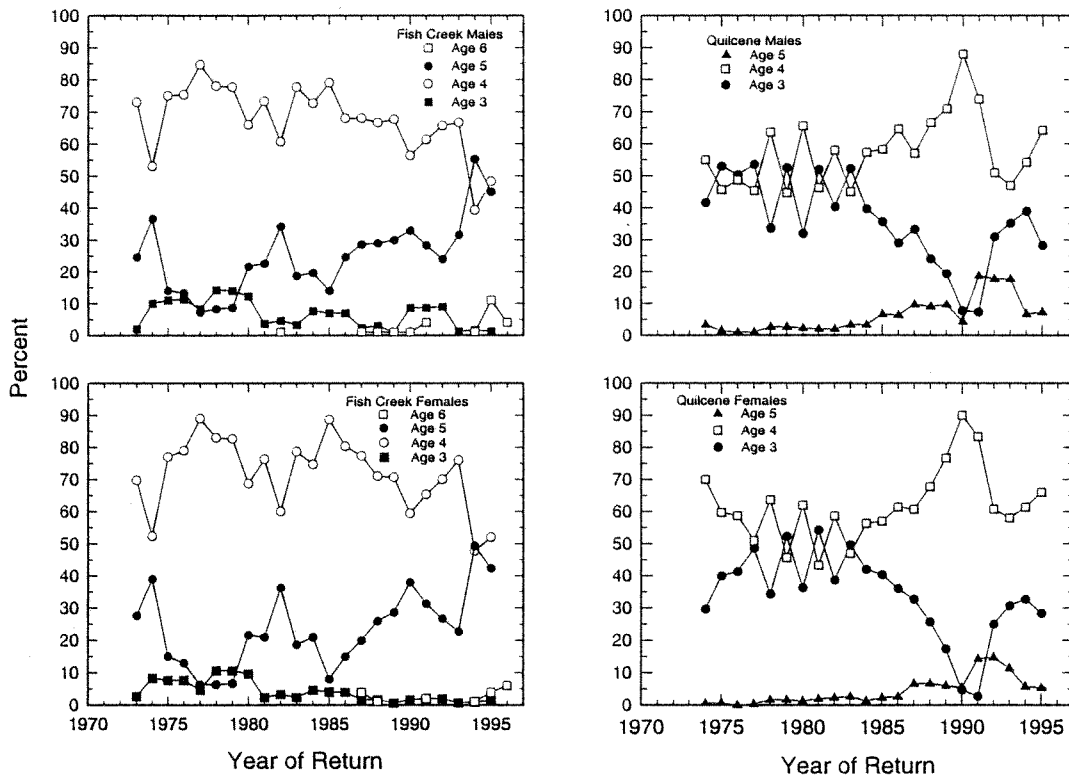


Fig. 6 Mean length of age-3, -4, and -5 chum salmon spawners at Fish Creek, and age-3 and -4 spawners at Quilcene National Fish Hatchery. Means were not calculated for sample sizes fewer than four fish. Dotted lines connect means when data for intervening years are based on $N < 4$.

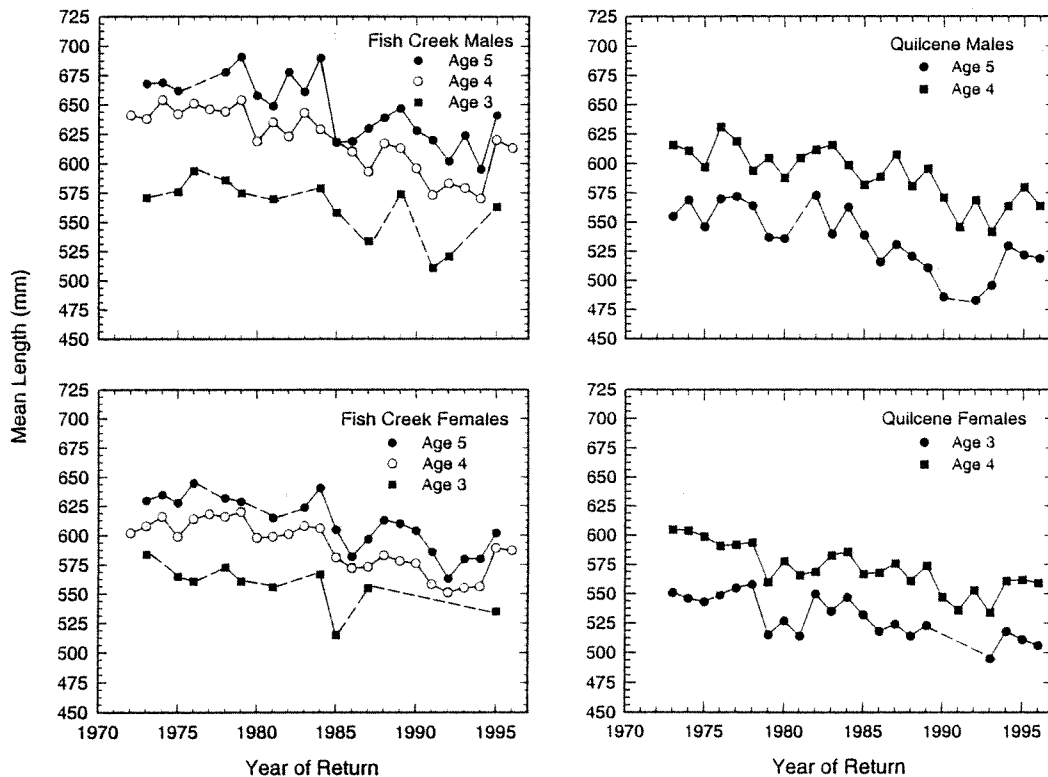


Fig. 7 Mean length and 95% confidence interval for age-4 male and female chum salmon spawners at Fish Creek, 1972-96, and at Quilcene National Fish Hatchery, 1973-96.

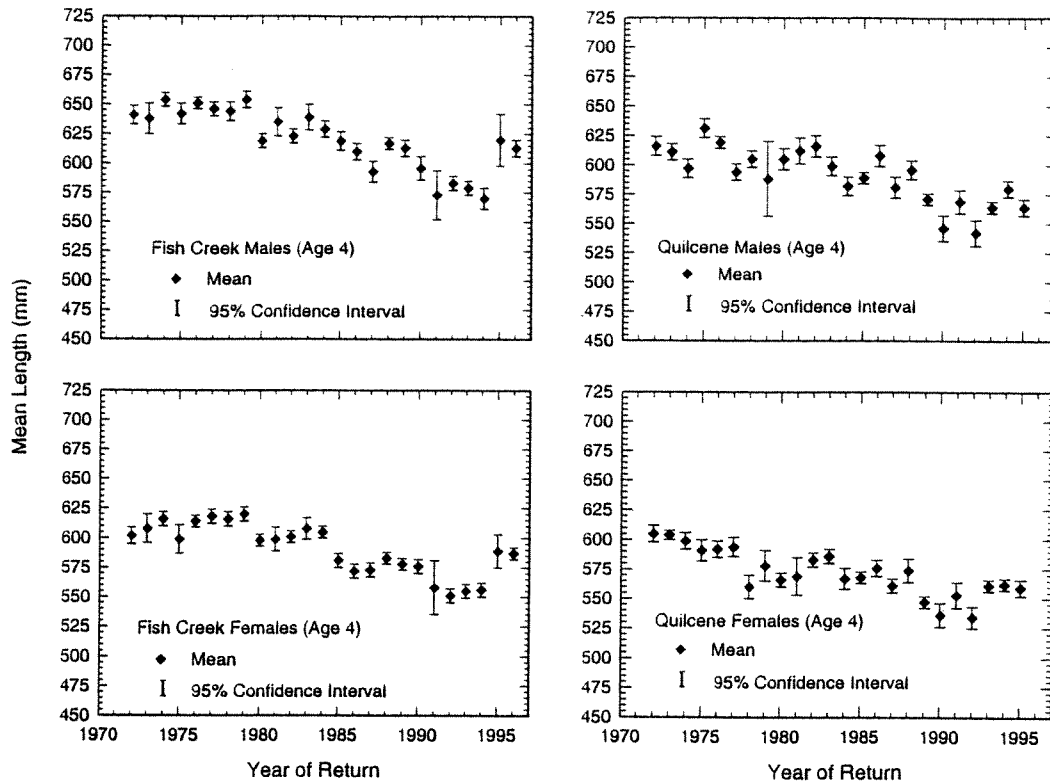


Fig. 8 Commercial catch of pink, sockeye, and chum salmon in southern southeast Alaska and northern British Columbia, 1972-96. Data from Northern Boundary Technical Committee (1997).

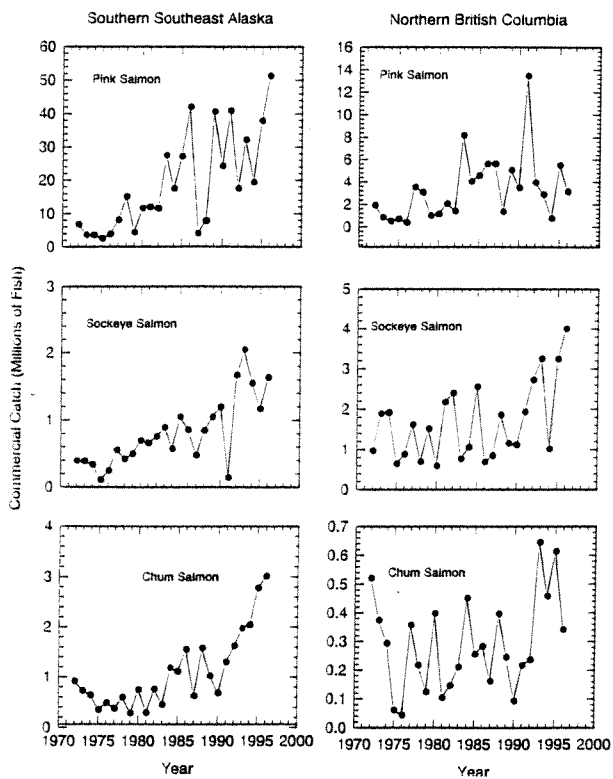
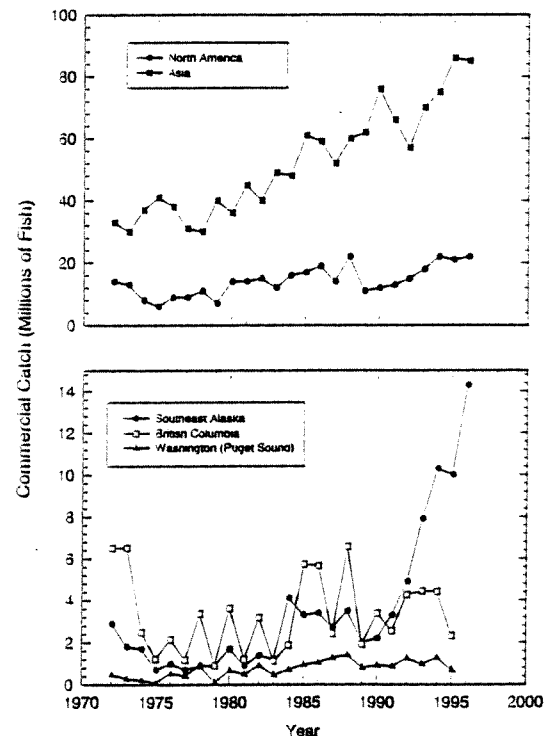


Fig. 9 Commercial catch of chum salmon in North America and Asia, southeastern Alaska, British Columbia, and Washington (Puget Sound). Data from D. Rogers, Fisheries Research Institute, University of Washington, Seattle; B. Snyder, Canada Department of Fisheries and Oceans, Vancouver; and J. Ames, Washington Department of Fisheries, Olympia.



peak live count of about 16,000 spawners in 1987. Using the inverse regression method (Fig. 4), the total escapement of chum salmon in 1987 was estimated to be about 70,700 fish (see Aitchison and Dunsmore, 1975). Considering the variation within the data, this method lets us estimate the relation between peak live counts and the total escapement for each year at Fish Creek. The returns of chum salmon to the Quilcene National Fish Hatchery do not reflect the abundance of chum salmon returning to Puget Sound (Figs. 3, 9). Hatchery output was modified due to fishery management concerns (Helle and Hoffman 1995). Escapements to Fish Creek and Quilcene National Fish Hatchery vary greatly; nevertheless, the overall abundance of chum salmon in North America, as reflected in the catches, has generally increased during the past 15 years (Fig. 9).

Anomalously cold winters in the North Pacific Ocean (1971-75) preceded the regime shift in 1976-77 (McLain and Favorite 1976). Salmon catches in Alaska declined immediately after these cold winters, followed by a generally increasing trend in catches from the late 1970s into the late 1990s (Fig. 1). The regime shift resulted in climate and oceanographic conditions that were highly favorable for salmon survival (Freeland 1990; McLain 1984; Miller et al. 1994; Percy 1992; Tabata 1984, 1989). Increasing catches of chum salmon in both North America and Asia (Fig. 9) and general increases in most other species of salmon in northern British Columbia and Alaska occurred after the regime shift in the North Pacific Ocean in 1976-77 (Beamish 1993; Beamish and Bouillon 1993; Hare and Francis 1995).

Along with the general increases in abundance, age at maturity has generally increased (Fig. 5) and the length at age has decreased (Fig. 6) at both Fish Creek and Quilcene National Fish Hatchery through the early 1990s (Helle and Hoffman 1995). These same trends in abundance, age at maturity, and size of chum salmon in North America have also been described in Asia. Kaeriyama (1989, 1996) and Ishida et al. (1993) report these age and size changes in Asian chum salmon stocks and suggest these changes may be due to density-dependent population factors in the ocean. Asian catches of chum salmon have increased since the late 1970s (Fig. 9). These increasing catches in Asia are predominately from artificial production facilities in Japan (see Percy 1992).

The distribution of both North American and Asian chum salmon overlaps extensively on the high seas (Manzer et al. 1965; Myers et al. 1996; Neave et al. 1976; Ogura and Ito 1994; Salo 1991). This overlap in forage range and the increased abundance, decline in size, and older age at maturity of chum salmon from both sides of the Pacific Ocean suggest that density-dependent population factors may be

affecting both North American and Asian stocks of chum salmon.

Size-dependent and density-dependent effects on growth and survival of salmon are not understood clearly (Peterman 1978, 1987; Peterman and Wong 1984; Ricker 1962, 1976). Evidence for density-dependent population effects on growth of salmon in the ocean has been accumulating in recent years (e.g., Bigler et al. 1996; Helle and Hoffman 1995; Ishida et al. 1993; Kaeriyama 1996; Peterman 1984; Rogers 1980). Also, size of parents may influence the survival of their offspring (Forbes and Peterman 1994; Helle 1989; Vladimirov 1973). Clearly, the ocean regime change of 1976-77 influenced the abundance and size of salmon populations in the North Pacific Ocean (Figs. 1, 7-9). Most species of salmon in the North Pacific Ocean declined in length soon after the abundance started increasing, about 1980, through the early 1990s (Bigler et al. 1996; Helle and Hoffman 1995; Ishida et al. 1993; Kaeriyama 1989, 1996; Ricker 1995).

Mean size at maturity at Fish Creek remained small in 1993 and 1994; however, in 1995 and 1996 mean length increased significantly. At Quilcene River the mean length of chum salmon dropped in 1993, but increased significantly in 1994, 1995, and 1996. If density-dependent population factors were influencing size at maturity in 1995 and 1996, the mean length should have continued to decrease because catches in southeastern Alaska and Asia increased (Fig. 9). Instead, mean length increased significantly.

Chum salmon may be indicators of ocean carrying capacity because they respond to competition by changing their size and age at maturity (Salo 1988). We suggest that size at maturity of chum salmon may be a surrogate for ocean conditions. Increases in size at maturity seen in 1995 and 1996 may signal another ocean regime shift and a change in the steep declines in length that started about 1980.

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