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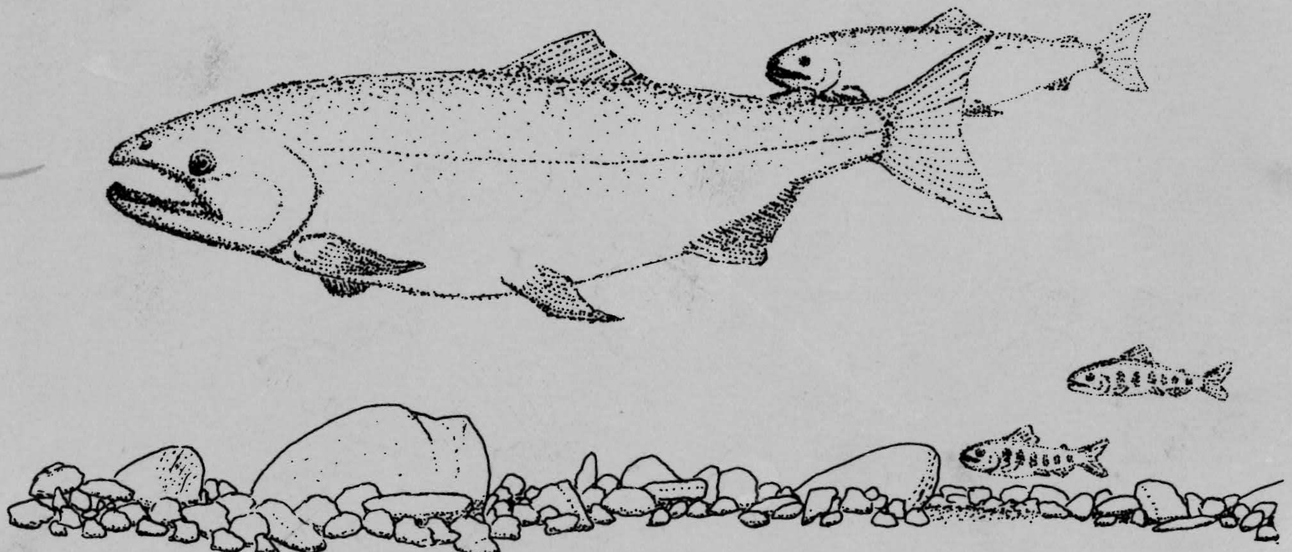

Fish and Wildlife Service

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STATUS AND PROPAGATION OF CHINOOK SALMON IN THE MID-COLUMBIA RIVER THROUGH 1985

by

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SUMMARY

Grand Coulee Dam barred anadromous salmonids from 1,835 km (1,140 miles) of the upper Columbia River drainage in 1939. To preserve the runs, returning salmon (*Oncorhynchus spp*.) and steelhead (*Salmo gairdneri*) were intercepted at downstream Rock Island Dam and transported to the upstream Wenatchee and Entiat rivers and released above temporary weirs, or to the new Leavenworth, Entiat, and Winthrop National Fish Hatcheries. This report examines the status and propagation of chinook salmon (*O. tshawytscha*) associated with the Grand Coulee Fish Maintenance (GCFM) Project through 1985.

Chinook salmon runs to the mid-Columbia River had been greatly depleted by overharvest, impassable dams, and unscreened irrigation diversions prior to construction of Grand Coulee Dam. Counts of returning adults increased markedly after the relocation of adult chinook salmon to tributary streams, the release of hatchery juveniles, and the correction of most environmental causes of original depletion. Aside from some initial fluctuation of counts, abundance of naturally produced (wild) chinook salmon passing Rock Island Dam has remained relatively stable at about 30,000 adults over almost three decades.

The GCFM Project succeeded in maintaining genetic diversity of wild chinook salmon in the mid-Columbia River to some unknown degree. Only nominal success was achieved in hatchery propagation because survival to adult return was 1% or less. To determine the reason, it was necessary to compare wild and hatchery stocks of spring, summer, and fall chinook salmon for clues, as well as examine fluctuations in abundance of coho (*O. kisutch*), sockeye (*O. nerka*), and steelhead runs.

Salient points were:

1. Population levels are related to ocean survival, with abundance of hatchery and wild fish fluctuating in the same manner.
2. There are no practical differences between summer-run and fall-run chinook salmon above Priest Rapids Dam.
3. The fall chinook population that spawns in the unimpounded Hanford Reach below Priest Rapids Dam has adapted to environmental changes in the Columbia River, with the young rearing in downstream reservoirs.
4. Chinook salmon are an adaptable species, as reflected in the

diversity of their life history stages and responses to environmental changes.

5. Varied and intermediate evidence suggested that adult life history patterns in chinook salmon may be influenced by environmental priming factors in fresh water.

6. The predominant coastal distribution of ocean-type chinook (migrating to ocean as young-of-year) and the offshore distribution of stream-type chinook (migrating to ocean as yearlings or older) could relate to how difference in one stage of the salmon's life history effects difference in another.

7. Spring chinook released as yearlings from the federal mitigation hatcheries evidently spent the greater part of their lives in the north Pacific Ocean well offshore where they were subject to low exploitation compared to summer and fall chinook that stay inshore.

8. Low ocean exploitation was irrelevant to high survival.

9. Low survival seems associated with latent bacterial kidney disease (BKD) in hatchery stocks, which is activated by the stresses of migration and saltwater adaptation.

Releasing chinook salmon from hatcheries early in their life cycle to mid-Columbia River reservoirs for short-term rearing and conditioning could result in better quality smolts. Exposure to BKD and other hatchery stressors would be reduced. Outplanting to tributary streams was rejected as a viable option because today the streams lack vacant habitat niches that could accommodate large numbers of hatchery juveniles.

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INTRODUCTION

Grand Coulee Dam barred anadromous salmonids from 1,835 km (1,140 miles) of the upper Columbia River[1] drainage in 1939. To preserve the runs, returning salmon (Oncorhynchus spp.) and steelhead (Salmo gairdneri) were intercepted at downstream Rock Island Dam and transported to the upstream Wenatchee and Entiat rivers and released above temporary weirs, or to the new Leavenworth, Entiat, and Winthrop National Fish Hatcheries (NFHs) (Figure 1). Goals of the Grand Coulee Fish Maintenance Project (GCFMP) were to restore and enhance runs in tributaries below Grand Coulee Dam to compensate for losses ascribed to the dam (Fish and Hanavan 1948).

Fish and Hanavan (1948) reported that the relocation of the salmon runs was a conclusive success, whereas only limited success was achieved in hatchery propagation. On the other hand, Ricker (1972) observed that the trapping of fish at Rock Island Dam for release in other streams "was a salvage operation which in the long run seems to have salvaged nothing."

The purposes of this report are to summarize and interpret observations regarding chinook salmon (O. tshawytscha) propagation at the mitigation hatcheries, and evaluate the success or failure of the GCFM Project.

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[1] I define the upper Columbia River as the area above Grand Coulee Dam, the middle river as the area between Grand Coulee Dam and the head of McNary Reservoir (confluence of the Snake River), and the lower Columbia River as the area below the head of McNary Reservoir.

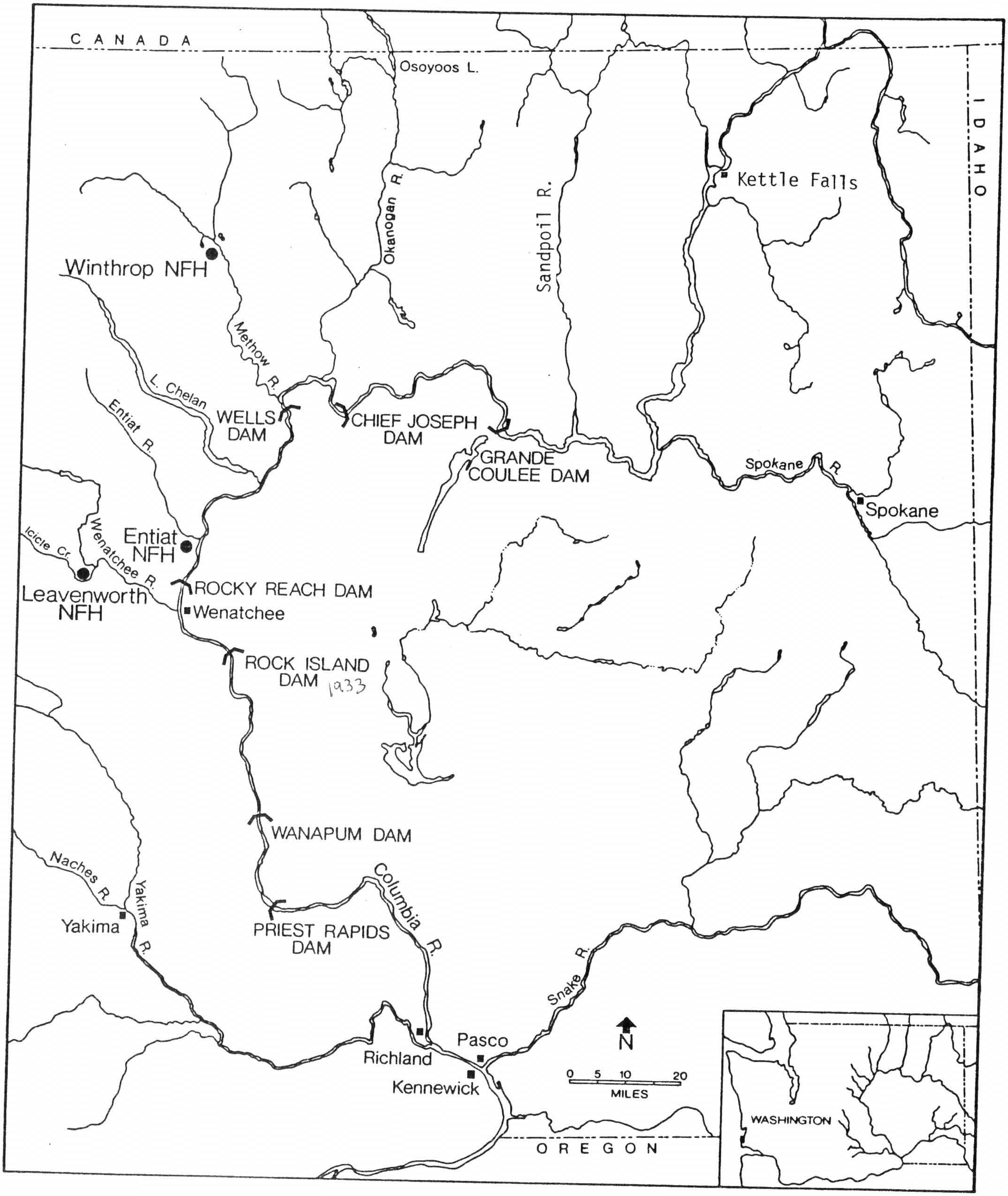
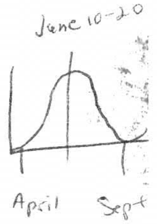


Figure 1. Upper and middle subregions of the Columbia River Basin.

DAM COUNT ESTIMATES OF RUN STRENGTH

Rock Island, Bonneville, and Grand Coulee dams began operation in 1933, 1938, and 1941, respectively; other dams followed. Dams have been detrimental to salmon runs of the Columbia River, but they have also served as counting fences recording the demise or enhancement of stocks (Salo and Stober 1977).

Separating chinook salmon into spring, summer, and fall races based on run timing at dams is arbitrary (Chapman et al. 1982). The historical chinook run entering the Columbia River was a continuous bell-shaped curve from April through September, with a peak generally between June 10-20, tapering off to tails in early April and late September. The fishery depleted the main summer segment, leaving the spring and fall segments as artifacts (Thompson 1951).



Different temperature regimes are the cause for the variation in run timing behavior that regulates incubation and emergence of fry (Miller and Brannon 1982). In the mid-Columbia River, spring chinook salmon spawn in the cooler headwater tributaries from July to mid-September. Summer chinook spawn in warmer downstream areas during October, and fall chinook spawn in the Columbia River during late October and early November (Meekin 1963; French and Wahle 1965; Chapman et al. 1982). In essence, a time-window exists for egg deposition in a specific site as water temperatures decrease from upstream to downstream reaches each fall. This time-space dimension was originally filled by successive waves of chinook salmon spawners.

French and Wahle (1965) separated the three modes (races) of chinook (1954-60) and showed that the different runs at Rock Island Dam varied from year to year, with spring chinook arriving by June 11 to about June 27, summer chinook from the end of the spring run to August 27, and fall chinook after August 27. Fish and Hanavan (1948) recognized only spring (before July 9) and summer (after July 9) races at Rock Island Dam for years 1933 to 1947. I examined the daily counts (when available) or weekly summaries and used modes in separating spring from summer chinook (Tables 1 and 2). Meekin (1963) determined that June 23 was an appropriate average date for separating spring from summer chinook at Rock Island Dam, and I agree. I also examined 13 of the 22 years of counts from Rocky Reach Dam to see whether a simultaneous cut-off date for separation of summer and spring chinook at Rocky Reach and Rock Island dams was warranted (Table 1). In most years, spring chinook salmon destined for upstream of Rocky Reach Dam consisted mostly of the early run fish passing Rock Island Dam, so I concluded that June 23 was an appropriate time for separation of spring and summer chinook salmon at either dam.

at Rock Island:

June 11 - June 27	springs	until July 9
June 27 - August 27	Summers	after July 9
after August 27	falls	

June 23 = average RI
spring / summer

Table 1. Mid-Columbia River dam counts of adult spring chinook salmon, 1935-85 (Rock Island 1935-47; Fish and Hanavan 1948, 1948-49; Bryant and Parkhurst 1950, 1950-58; raw data USFWS, 1959; Zimmer et al. 1960, 1961; Zimmer and Davidson 1962, 1961-65; Zimmer and Broughton 1962, 1964, 1965a, 1965b, 1966; all other data: Chelan, Grant, and Douglas Counties PUD's).

Year	Priest Rapids Dam			Rock Island Dam			Rocky Reach Dam			Wells Dam		
	Total	Jacks (%)	End date	Total	Jacks (%)	End date	Total	Jacks (%)	End date	Total	Jacks (%)	End date
1935				2,380		6/25*						
1936				2,000		6/25*						
1937				180		6/25*						
1938				1,339		6/18*						
1939				4,256		7/9*						
1940				3,303	(7)	6/18*						
1941				1,392	(7)	6/25*						
1942				1,106	(19)	7/2*						
1943				7,374	(11)	7/9*						
1944				1,265	(32)	7/2*						
1945				1,938		6/25*						
1946				3,040	(8)	6/18*						
1947				7,877	(2)	6/25*						
1948				1,839		7/9						
1949				4,234		7/9						
1950				2,194	(16)	6/25*						
1951				7,781	(4)	6/11*						
1952				5,006	(21)	6/25*						
1953				12,078	(15)	6/18*						
1954				12,981	(25)	6/25*						
1955				3,944	(36)	6/25*						
1956				1,433	(11)	6/11*						
1957				16,646	(18)	6/25*						
1958				7,334	(18)	6/25*						
1959				7,349	(11)	6/22*						
1960	8,534	(14)	6/17	7,774	(10)	6/18*						
1961	8,385	(8)	6/24	7,409	(9)	6/22*	3,747	(3)	6/8*			

*Estimated by the division between modes of fish passing with time.

(Continued)

Table 1 (Concluded)

Year	Priest Rapids Dam			Rock Island Dam			Rocky Reach Dam			Wells Dam		
	Total	Jacks (%)	End date	Total	Jacks (%)	End date	Total	Jacks (%)	End date	Total	Jacks (%)	End date
1962	7,993	(13)	6/24	6,670	(7)	6/17*	4,708	(23)	6/18*			
1963	7,597	(41)	6/15	6,874	(31)	6/17*	5,624	(44)	6/18*			
1964	9,814	(12)	6/23	9,326	(10)	6/23*	7,056	(4)	6/9*			
1965	5,718	(29)	6/21	4,885	(24)	6/22*	3,315	(42)	6/21*			
1966	13,358	(12)	6/5	9,292	(15)	6/16*	6,782	(18)	6/18*			
1967	10,307	(17)	6/15	6,882	(22)	6/17*	4,987	(15)	6/7*	960	52	6/28
1968	10,739	(13)	6/8				5,919	(14)	6/5*	4,932	(17)	6/28
1969	7,142	(5)	6/8				4,244	(11)	6/19*	3,713	(15)	6/28
1970	5,789	(14)	6/4				4,288	(18)	6/19*	2,627	(21)	6/28
1971	5,086	(15)	6/3				4,132	(20)	6/23*	3,172	(20)	6/28
1972	8,775	(4)	6/13				4,693	(6)	6/19*	3,617	(7)	6/28
1973	9,967	(11)	6/12	7,891	(21)	6/12*	4,121	(20)	6/23	3,006	(17)	6/28
1974	11,127	(2)	6/14	9,425	(4)	6/27*	4,261	(8)	6/23	3,413	(6)	6/28
1975	8,170	(6)	6/14	6,297	(5)	6/20*	3,388	(6)	6/23	2,221	(6)	6/28
1976	13,306	(14)	6/12	9,065	(29)	6/23*	3,429	(45)	6/23	2,778	(45)	6/28
1977	21,217	(31)	6/13	19,382	(8)	6/23	6.344	(6)	6/23	4,212	(6)	6/28
1978	21,427	(1)	6/13	20,406	(1)	6/23	7,460	(1)	6/23	3,616	(2)	6/28
1979	7,750	(5)	6/13	7,520	(5)	6/23	2,388	(8)	6/23	1,088	(12)	6/28
1980	11,136	(23)	6/13	7,664	(8)	6/23*	2,119	(12)	6/23	1,177	(20)	6/28
1981	14,787	(2)	6/13	8,120	(2)	6/23*	3,668	(4)	6/23*	1,834	(5)	6/28
1982	9,084	(5)	6/13	8,336	(4)	6/23	2,908	(3)	6/23	2,391	(5)	6/28
1983	10,780	(3)	6/13	10,273	(4)	6/22	3,499	(3)	6/22	2,870	(5)	6/28
1984	12,633	(4)	6/13	12,774	(6)	6/23	4,171	(6)	6/23	3,272	(7)	6/28
1985	24,706	(3)	6/13	26,758	(3)	6/23	8,910	(2)	6/23	5,239	(2)	6/28

Table 2. Mid-Columbia River dam counts of adult summer chinook salmon, 1933-85 (sources same as Table 1; cut-off dates Aug. 27 to Sept. 3, except for Priest Rapids, Aug. 14 to Sept. 1.

Year	Priest Rapids Dam		Rock Island Dam		Rocky Reach Dam		Wells Dam	
	Total	Jacks (%)	Total	Jacks (%)	Total	Jacks (%)	Total	Jacks (%)
1933			4,732*					
1934			6,482*					
1935			10,643					
1936			4,535					
1937			4,088					
1938			2,747					
1939			6,294					
1940			4,926					
1941			1,014					
1942			5,082	(6)				
1943			3,369	(14)				
1944			1,909	(32)				
1945			3,328					
1946			6,695					
1947			3,424					
1948			5,256**					
1949			8,609**					
1950			7,271	(21)				
1951			9,606	(10)				
1952			13,754	(15)				
1953			17,699	(35)				
1954			17,747	(25)				
1955			20,768	(31)				
1956			22,311	(22)				
1957			29,899	(23)				
1958			20,769	(16)				
1959			14,158	(28)				
1960	20,852	(18)	13,087	(17)				
1961	18,245	(24)	16,833	(28)	14,421	(49)		
1962	20,824	(22)	18,548	(27)	12,247	(32)		

*Incomplete count.
**Includes fall chinook.

(Continued)

Table 2 (Concluded)

Year	Priest Rapids Dam		Rock Island Dam		Rocky Reach Dam		Wells Dam	
	Total	Jacks (%)	Total	Jacks (%)	Total	Jacks (%)	Total	Jacks (%)
1963	18,511	(30)	15,841	(40)	7,492	(31)		
1964	26,489	(35)	21,597	(33)	15,069	(34)		
1965	24,936	(39)	21,766	(36)	16,034	(42)		
1966	29,736	(27)	29,657	(27)	19,625	(33)		
1967	26,256	(26)	20,413	(25)	16,131	(39)	12,266	(31)
1968	26,544	(23)			15,224	(36)	8,918	(46)
1969	21,277	(28)			13,152	(38)	6,854	(56)
1970	21,641	(31)			11,909	(43)	8,041	(44)
1971	20,481	(14)			10,031	(30)	6,007	(36)
1972	18,083	(13)			7,189	(28)	4,058	(38)
1973	14,351	(14)	15,548	(21)	9,646	(36)	5,089	(46)
1974	13,703	(6)	11,518	(10)	8,298	(23)	4,572	(35)
1975	22,205	(15)	23,175	(30)	14,676	(40)	8,532	(55)
1976	19,344	(11)	18,580	(34)	11,892	(35)	7,889	(32)
1977	19,605	(17)	22,693	(33)	15,374	(31)	7,526	(33)
1978	22,580	(9)	22,673	(17)	10,232	(21)	6,422	(20)
1979	22,689	(10)	24,141	(19)	10,933	(22)	9,506	(30)
1980	18,708	(14)	16,936	(14)	6,646	(19)	5,520	(24)
1981	12,381	(6)	11,011	(13)	5,472	(15)	4,241	(27)
1982	9,883	(11)	10,560	(35)	4,102	(34)	3,258	(33)
1983	9,573	(11)	9,921	(30)	3,712	(25)	2,763	(29)
1984	17,027	(7)	18,791	(23)	6,999	(16)	5,885	(19)
1985	17,324	(8)	18,435	(14)	6,781	(12)	4,379	(8)

I did not alter cutoff dates as reported (Table 1) for separating spring from summer chinook salmon at Priest Rapids or Wells dams. Cutoff dates between summer and fall chinook have been relatively consistent over time (i.e., August 27 to September 3 at Wells, Rocky Reach, and Rock Island dams; August 14 to September 1 at Priest Rapids Dam (Table 3)). I used September 1 in separating summer and fall chinook for years 1933-47 at Rock Island Dam.

late June — late August for summers

Table 3. Mid-Columbia River dam counts of adult fall chinook salmon, 1933-85 (details in Tables 1 & 2).

Year	Priest Rapids Dam		Rock Island Dam		Rocky Reach Dam		Wells Dam	
	Total	Jacks (%)	Total	Jacks (%)	Total	Jacks (%)	Total	Jacks (%)
1933			936*					
1934			816					
1935			3,287					
1936			861*					
1937			865					
1938			1,717					
1939			1,074					
1940			1,263					
1941			165					
1942			626					
1943			402	(23)				
1944			543					
1945			430					
1946			257					
1947			465					
1948			**					
1949			**					
1950			900	(25)				
1951			1,375	(18)				
1952			1,354	(14)				
1953			1,303	(24)				
1954			2,555	(35)				
1955			1,013	(34)				
1956			1,471	(48)				
1957			3,943	(34)				
1958			4,585	(24)				
1959			2,734	(42)				
1960	10,687	(24)	5,689	(35)				
1961	11,108	(41)	8,825	(43)	3,110	(66)		
1962	10,082	(22)	6,833	(23)	1,649	(52)		
1963	17,563	(80)	11,973	(88)	4,039	(86)		

*Incomplete
**Included with summers, Table 2.

(Continued)

Table 3 (Concluded)

Year	Priest Rapids Dam		Rock Island Dam		Rocky Reach Dam		Wells Dam	
	Total	Jacks (%)	Total	Jacks (%)	Total	Jacks (%)	Total	Jacks (%)
1964	14,760	(53)	9,028	(73)	3,378	(93)		
1965	21,149	(61)	9,756	(83)	5,995	(91)		
1966	18,821	(50)	9,605	(67)	4,108	(82)		
1967	12,375	(58)	3,752	(62)	2,328	(88)	2,735	(76)
1968	11,031	(52)			2,268	(72)	2,623	(71)
1969	12,367	(61)			3,638	(84)	2,972	(78)
1970	16,372	(68)			5,756	(87)	4,354	(75)
1971	10,591	(33)			3,294	(80)	2,027	(63)
1972	5,782	(60)			3,451	(83)	2,414	(78)
1973	10,083	(52)	2,925	(41)	4,760	(85)	2,649	(71)
1974	7,618	(34)	1,032	(19)	1,677	(71)	1,116	(60)
1975	13,365	(68)	8,032	(17)	4,373	(84)	3,774	(83)
1976	10,774	(49)	7,472	(77)	4,275	(77)	3,834	(68)
1977	6,856	(41)	5,384	(74)	4,187	(77)	3,250	(65)
1978	6,523	(27)	3,049	(55)	1,853	(56)	1,338	(36)
1979	7,727	(37)	3,534	(68)	1,570	(66)	1,659	(36)
1980	8,441	(29)	2,396	(44)	1,395	(43)	724	(34)
1981	5,438	(29)	1,684	(52)	1,119	(45)	690	(37)
1982	13,100	(33)	5,043	(64)	2,186	(63)	1,809	(57)
1983	8,288	(13)	3,201	(48)	1,795	(39)	1,089	(46)
1984	11,668	(38)	5,476	(62)	3,322	(52)	1,896	(52)
1985	20,131	(45)	10,226	(60)	5,124	(58)	2,056	(47)

POPULATION FLUCTUATIONS IN SALMONID RUNS

The trends in abundance of salmon and steelhead runs in the Columbia River are examined to show that the GCFM Project involved species other than chinook, to see if other species have trends similar to that of chinook, and to discuss and assess factors that have been implicated as contributing to fluctuations in abundance.

CHINOOK SALMON

Harvest records of chinook salmon from the Columbia River show a peak of 43 million pounds (2.3 million fish) in 1883. Yield was about 24 million pounds a year through the period 1890-1920, followed by a steady decline. Present yield is three to four million pounds or less (almost all fall chinook) (Chapman et al. 1982).

Kettle Falls, 129 km (80 miles) upstream of Grand Coulee Dam, was the second most important Indian fishing area on the Columbia River in the pre-settlement era (Chance 1973). As much as 800,000 pounds or 40,000 salmon[2] may have been taken at Kettle Falls during good years in the early 1800's (Chance 1973). Salmon remained abundant at Kettle Falls as late as 1878, but virtually disappeared by 1890 (Gilbert and Evermann 1895).

Chinook salmon also spawned below Kettle Falls and in tributaries such as the Colville, Spokane, and Sanpoil rivers. These runs also sustained Indian fisheries that collapsed about the same time as the disappearance of the salmon runs at Kettle Falls (Gilbert and Evermann 1895; Ray 1977). The combined catch of salmon and steelhead by Indians, upstream from the Okanogan River prior to the late 1800's, may have amounted to 2,373,000 pounds (Koch 1976) or 119,000 fish.

The average annual harvest in the lower Columbia River in the 1800's was about 30 million pounds or 1.5 million chinook salmon. Geographic distribution of habitat suggests that 250,000 chinook may have been produced in the mid-Columbia River, and another 250,000 above Grand Coulee Dam (Haas 1975).

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[2] Numbers could have been higher or lower depending on the mix of species caught and their average weight. In these harvest estimates, I have retained Craig and Hacker's (1940) average weight of 20 pounds as applied only to chinook salmon, which has been used by all estimators of historical Indian catches.

The huge annual catches (30 to 43 million pounds) in the lower river during the 1880's not only affected the number of fish returning to the upper Columbia, but also their reproductive success. As the summer chinook dwindled, fall chinook, steelhead, sockeye (O. nerka), and coho (O. kisutch) were heavily exploited to make up the loss (Chapman et al. 1982). Not surprisingly, catches at Kettle Falls by the decade before Grand Coulee Dam were but a fraction of the historical highs (Table 4).

Spring Chinook

The low levels to which upriver spring chinook salmon had declined is illustrated by Rock Island Dam counts which ranged from 180 to 4,256 in 1935-42. Most of these spring chinook apparently did not go above Grand Coulee Dam. Bell (1937) reported that only 4% of the spring chinook salmon that entered the Columbia River originated in areas above Rock Island Dam. The steep-sided morphology of the upper Columbia Basin results in headwater streams not typically associated with spring chinook, because of high gradient, lack of gravel, or inaccessibility due to cascades (Bryant and Parkhurst 1950; Hutchinson 1957; Fulton 1968). The historical dominance of summer chinook in the upper river will be detailed shortly. In addition, while runs of spring chinook to tributaries between Rock Island and Grand Coulee dams, were extinct (Entiat River) or diminished (Wenatchee River 200 fish, Methow River 200 to 400 fish) by 1935 (Craig and Suomela 1936, 1941; Bell 1937), remnants could have been appreciable in some years. For example, in 1928 and 1929, 1,112 and 1,268 spring chinook were hand-dipped below a dam on the Methow River and released upstream.

Lowest counts of spring chinook salmon at Rock Island Dam occurred when the commercial catch in the lower Columbia River accounted for up to 86% of the estimated runs (Figure 2). Following the relocation of adult spring chinook from Rock Island Dam (Table 5) and releases of hatchery juveniles to the Wenatchee, Entiat, and Methow Rivers 1939-43 (Tables 6, 7, 8), Rock Island Dam counts of returning spring chinook increased. Aside from some initial fluctuation of counts, abundance of wild spring chinook has remained relatively stable over almost three decades (Figure 2).

Summer Chinook

The awe of pioneers chronicling "millions" of salmon ascending Kettle Falls, with a minor peak in June and a major peak in August, depicts summer chinook as the dominant upstream run of salmon (Gilbert and Evermann 1895; Kennedy 1975; Ray 1977). Chief James Bernard of the Lake and Colville Tribes stated in 1930, based on recollections to 1872, that there would be two or three weeks of the heaviest fishing always about August 1 (Koch 1976). In 1929, when the Columbia River was unobstructed at the Rock Island Dam site, the Indian catch at Kettle Falls peaked on August 1. No data are available on run timing for the catch of 1,000 chinook in 1930. But in 1931, the catch was greater than in 1929 and 1930 (1,500 fish) and the peak also occurred August 1 (Table 4).

Table 4. Counts of chinook salmon at Rock Island Dam, 1933-38, in relation to Indian catches of salmon and steelhead at Kettle Falls, 1929-38.

		Catches(a) of salmon and steelhead at Kettle Falls			
Year	Rock Island Dam	Chinook	Coho b	Sockeye b	Steelhead
1929		1,353			
1930		1,000			
1931		1,500			
1932		400			
1933	5,668	263			
1934	7,298	139			
1935	15,310	505			126
1936	7,396	540			
1937	5,133	205			
1938	17,803	122			

a Peter Lemery, a Colville Tribal member, employed by the Washington Dept. of Fisheries (WDF), conducted the census (Ray 1977). His estimates of catches are reported in Craig and Suomela 1936, Bell 1937, Koch 1976, and Ray 1977.

b Ray (1972) reported that the chinook salmon was the primary species harvested at Kettle Falls, and that sockeye salmon did not ascend the Columbia River beyond the Okanogan River. Kennedy (1975), however, showed that there were runs of sockeye at Kettle Falls, which, along with coho salmon, were caught to supplement the catch of chinook. By 1929-1938, however, it is likely that sockeye were vying in importance with chinook in Indian catches, at least below Kettle Falls (Chapman 1943), although coho salmon runs to the upper Columbia River were by then essentially extirpated (Mullan 1984). Why Ray (1972), as well as Bell (1937), were misled to believe that sockeye salmon did not ascend Kettle Falls is found in WDF (1938), pages 13 and 14. High-back baskets were strung along the edge of the falls. When the fish jumped over the falls, those that hit the back of the baskets fell into the bottom of the baskets and were captured. Sockeye salmon ascending the falls swam up through the eddies bordering the main current instead of following the swift water and did not jump like the chinook and steelhead making them hard to observe and to catch. Due to this behavior, sockeye salmon experienced no problems in finding and ascending left and right bank fishways at Rock Island Dam in initial years whereas chinook salmon did (Bell 1937).

Table 5. Releases of adult chinook salmon intercepted at Rock Island Dam 1939-43 (Fish and Hanavan 1948).

Year	Race[a]	Area	Number	Number of carcasses recovered	Percent spawned
1939	S & Su	Nason Cr.	3,957	423	77%
1940	"	"	3,165	574	67%
1941	"	"	1,215	417	37%
1942	"	"	1,014	255	51%
1943	"	"	1,191	243	86%
1939	Su & F	Wenatchee R.	3,498	1,052	83%
1940	"	"	752	169	93%
1941	"	"	446	94	60%
1942	"	"	3,050	776	39%
1943	"	"	386		
1939	"	Entiat R.	2,913	959	42%
1940	"	"	102	71	83%

[a] Race: S = spring chinook; Su = summer chinook; F = fall chinook

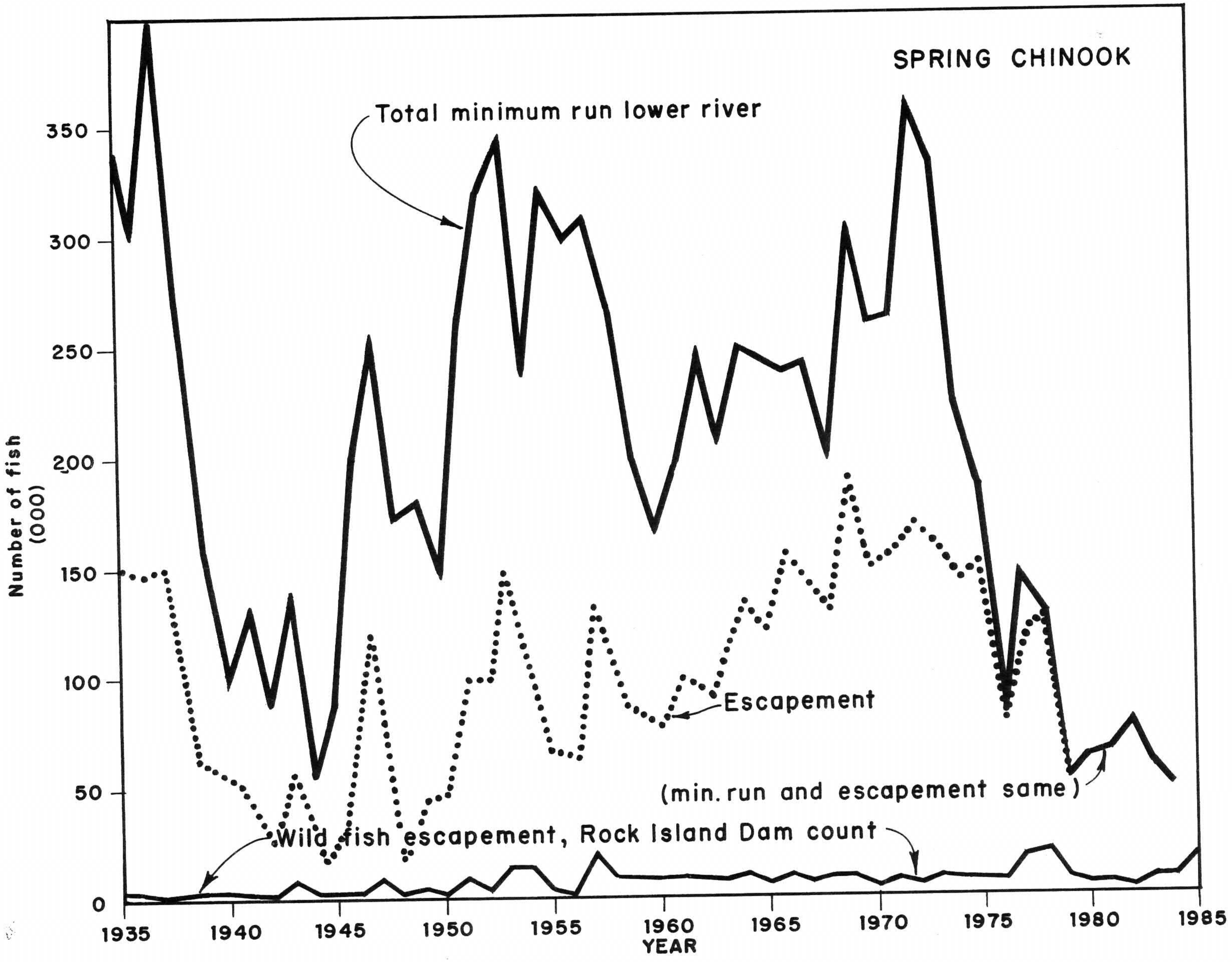

Figure 2. Trends of Columbia River spring chinook salmon abundance as related to wild fish escapement at Rock Island Dam (Wild escapement is estimated by subtracting hatchery escapement; lower river minimum run and escapement are from Gangmark 1957, Fish Commission of Oregon and Washington Department of Fisheries 1971, Beiningen 1976, North Pacific Fishery Management Council 1982, and Columbia River Inter-Tribal Fish Commission 1984).

Table 6. Release of chinook salmon from the Leavenworth Hatchery, 1941-85.

Brood year	Egg source	Race[a]	Releases			
			Area	Number (000)	Date	Fish/ pound
1940	Rock Isl. Dam	S&SU	Entiat R.	483.0	8/41	215
"	" " "	"	"	157.8	10/41	115
"	" " "	"	Methow R.	182.0	10/41	115
"	" " "	"	Icicle Cr.	135.5	10/41	115
"	" " "	"	"	200.8	5/42	37
1941	" " "	"	Entiat R.	85.5	9/42	215
"	McKenzie R.	S	Icicle Cr.	239.4	10/42	84
1942	Rock Isl. Dam	S	Methow R.	30.1	8/43	425
"	" " "	S	Icicle Cr.	117.6	10/43	90
"	L. Col. R.	F	"	70.9	10/43	90
1943	Rock Isl. Dam	S	"	356.1	5/44	359
"	" " "	"	Nason Cr.	365.1	5/44	359
"	" " "	"	Wenatchee R.	188.3	"	359
"	" " "	"	Chewawa R.	144.1	"	359
"	" " "	SU	Icicle Cr.	59.0	10/44	90
1944	-- -- --	--	--	0	--	--
1945	B. White NFH					
"	& Icicle Cr.	F	Icicle Cr.	616.0	10/46	86
1946	Icicle Cr.	SU	"	73.6	10/47	30
1947	" "	S	"	804.3	2/48	359
1948	" "	SU	"	50.6	10/49	43
1949	-- -- --	--	--	0	--	--
1950	Icicle Cr.	SU	Icicle Cr.	10.3	?/51	257
1951	" "	SU	"	197.7	8/52	257
"	" "	SU	"	41.6	?/52	45
1952	" "	SU	"	50.5	?/53	249
1953	" "	SU	"	30.2	?/53	45
1954	" "	SU	"	21.2	?/55	272
1955	" "	SU	"	1.2	9/56	83
1956	" "	SU	"	6.7	9/57	85
1957	" "	SU	"	79.8	9/58	82
1958	" "	SU	"	3.7	9/59	87
1959	" "	SU	"	19.0	9/60	90
1960	" "	SU	"	10.2	5/61	291
1960	" "	SU	Yakima R.	18.5	5/61	330
1961	" "	SU	Icicle Cr.	6.5	8/62	375
1961	" "	SU	Yakima R.	5.1	2/62	1,020
1962	" "	S	"	5.3	12/62	1,060
1963	" "	?	Snake R.	8.1	3/64	1,011
1964	Spr. Cr. NFH	F	Icicle Cr.	2,854.0	1/65	1,080
"	" " "	F	"	68.0	5/65	300
1965	" " "	S	"	251.0	3/67	19

(Continued)

Table 6 (Concluded)

Brood year	Egg source	Race[a]	Releases			
			Area	Number (000)	Date	Fish/ pound
1966	Eagle Cr. NFH	F	Columbia R.	659.0	5/67	659
"	" " "	S	Icicle Cr.	86.0	3/68	20
1967	----	-	----	0	--	--
1968	----	-	----	0	--	--
1969	Carson NFH	S	Icicle Cr.	64.0	3/71	25
1970	" "	S	"	290.0	3/72	19
1971	" "	S	"	523.0	4/73	19
1972	" "	S	"	480.0	4/74	19
1973	" "	S	"	717.0	4/75	15
1974	Cowlitz R.	S	"	771.6	3/76	15
"	Icicle Cr.	S	"	598.9	4/76	15
"	" "	S	Columbia R.	149.9	5/76	15
1975	Carson NFH	S	Icicle Cr.	1,832.0	4/77	19
"	" "	S	Columbia R.	104.0	5/77	17
1976	Cowlitz R.	S	L. Roosevelt	2.7 M	5/77	fry
"	" "	S	Icicle Cr.	217.0	4/78	17
"	Carson NFH	S	"	1,320.0	4/78	17
"	Icicle Cr.	S	"	342.0	4/78	17
"	" "	S	Columbia R.	101.2	5/78	15
1977	L. White NFH	S	Icicle Cr.	721.0	4/79	19
"	Carson NFH	S	"	433.0	4/79	20
"	" "	S	Columbia R.	519.0	5/79	15
1978	Carson NFH	S	Icicle Cr.	1,319.0	4/80	20
"	L. White NFH	S	"	406.0	4/80	18
"	Icicle Cr.	S	"	199.0	4/80	19
"	Carson NFH	S	Columbia R.	589.0	5/80	20
"	" "	S	Yakima R.	30.0	4/80	19
1979	Icicle Cr.	S	Icicle Cr.	2,177.0	4/81	19
"	" "	S	Yakima R.	400.2	4/81	20
1980	Icicle Cr.	S	Icicle Cr.	1,723.3	4/82	19
"	Carson NFH	S	"	155.0	4/82	19
"	" "	S	Columbia R.	400.0	5/82	18
"	Icicle Cr.	S	Yakima R.	401.7	4/82	19
1981	Icicle Cr.	S	Icicle Cr.	1,906.5	4/83	19
"	Carson NFH	S	Columbia R.	361.5	4/83	21
"	Icicle Cr.	S	Yakima R.	97.0	5/83	19
1982	Icicle Cr.	S	Icicle Cr.	2,316.5	4/84	15
1983	Icicle Cr.	S	Icicle Cr.	2,190.0	4/85	17

[a] Race: S = spring chinook; SU = summer chinook; F = fall chinook

Table 7. Release of chinook salmon from the Entiat Hatchery, 1941-85.

Brood year	Egg source	Race[a]	Releases			
			Area	Number (000)	Date	Fish/ pound
1940	Rock Isl. Dam	SU	Entiat R.	100.0	7/41	--
"	" " "	SU	"	50.0	10/41	--
"	" " "	S&SU	"	25.0	3/42	--
"	" " "	S&SU	"	25.4	5/42	--
1941	McKenzie R.	S	Icicle Cr.	443.8	10/42	88
1942	Rock Isl. Dam	SU	Entiat R.	55.9	10/43	77
1943	" " "	S	"	591.0	3/44	271
"	" " "	SU	"	24.9	10/44	--
"	" " "	SU	"	25.7	3/45	23
1944	Entiat R.	SU	"	8.2	3/46	10
"	Methow R.	SU	"	27.0	12/45	14
"	Carson NFH	SU	"	8.2	10/45	23
1945	Entiat R.	SU	"	184.2	10/46	19
"	"	SU	"	22.3	3/46	--
1946	"	SU	"	177.7	5/47	215
"	"	SU	"	73.7	9/47	37
1947	"	SU	"	241.6	5/48	116
"	"	SU	"	155.1	9/48	38
1948	"	SU	"	235.2	9/49	39
1949	"	SU	"	89.1	7/50	75
"	"	SU	"	343.5	9/50	32
1950	"	SU	"	488.5	7/51	70
"	"	SU	"	110.3	10/51	--
1951	"	SU	"	281.0	10/52	36
1952	"	SU	"	404.5	7/53	115
"	"	SU	"	254.6	10/53	24
1953	"	SU	"	212.0	10/54	22
1954	"	SU	"	228.8	7/55	116
"	"	SU	"	212.0	10/55	19
1955	"	SU	"	250.5	10/56	24
1956	"	SU	"	32.9	7/57	52
"	"	SU	"	273.9	10/57	24
1957	"	SU	"	270.2	6/58	53
"	"	SU	"	113.8	7/58	49
"	"	SU	"	137.5	10/58	18
1958	"	SU	"	522.5	10/59	38
1959	"	SU	"	143.8	9/60	24
1960	"	SU	"	152.3	10/61	24
1961	"	SU	"	316.5	9/62	24
1962	"	SU	"	229.8	10/63	26
1963	"	SU	"	230.1	9/64	39
1964	Spr. Cr. NFH	SU	"	990.8	12/64	921

(Continued)

Table 7 (Concluded)

			Releases			
Brood year	Egg source	Race[a]	Area	Number (000)	Date	Fish/ pound
1974	Cowlitz R.	S	"	436.0	3/76	13
"	Wells Dam	SU	"	294.0	3/76	16
1975	Carson NFH	S	"	631.2	4/77	15
"	L. White NFH	S	"	400.0	7/76	70
"	Carson NFH	S	Snake R.	25.3	9/76	17
"	"	S	Entiat R.	268.4	10/76	17
1976	L. White NFH	S	Columbia R.	39.2	4/78	16
"	Carson NFH	S	Entiat R.	257.0	4/78	20
"	L. White NFH	S	"	165.0	4/78	20
"	" "	S	Columbia R.	115.9	5/78	23
1977	Carson NFH	S	Entiat R.	459.0	4/79	15
1978	Carson NFH	S	"	61.9	4/80	18
"	L. White NFH	S	"	596.2	4/80	18
1979	Carson NFH	S	"	247.9	4/81	17
"	L. White NFH	S	"	326.8	4/81	17
"	Icicle Cr.	S	"	48.6	4/81	17
1980	Entiat R.	S	"	481.3	4/82	18
"	Carson NFH	S	"	380.6	4/82	18
"	Icicle Cr.	S	"	136.0	4/82	18
1981	Carson NFH	S	"	136.2	4/83	20
"	L. White NFH	S	"	621.8	4/83	18
"	Entiat R.	S	"	197.9	4/83	15
1982	Entiat R.	S	"	386.4	4/84	17
"	Carson NFH	S	"	259.0	4/84	21
"	Carson NFH	S	Yakima R.	42.6	4/84	24
1983	Entiat R.	S	Entiat R.	894.6	4/85	19

Race: S = spring chinook, SU = summer chinook

Table 8. Release of chinook salmon from the Winthrop Hatchery, 1943-85.

Brood year	Egg source	Race[a]	Releases Area	Number (000)	Date	Fish/ pound
1942	Leav. NFH	SU	Methow R.	66.6	10/43	84
"	" "	SU	"	10.6	4/44	22
1943	" "	S	"	653.8	4/44	589
1944	Methow R.	S	"	3.6	2/45	534
1945	"	S	"	46.3	3/46	589
1946	"	S	"	480.6	2/47	589
"	Entiat R.	SU	"	112.1	10/47	84
1947	Methow R.	S	"	912.9	2/48	420
1948	"	S	"	23.3	3/49	434
1949	Entiat R.	S	"	143.0	10/50	31
"	Methow R.	S	"	61.0	4/50	420
"	"	S	"	117.4	7/50	205
1950	"	S	"	150.3	3/51	425
1951	"	S	"	151.4	4/52	212
1952	"	S	"	180.0	?/53	115
1953	"	S	"	356.3	?/54	39
1954	"	S	"	347.4	?/55	34
1955	"	S	"	69.5	?/56	26
1956	"	S	"	66.9	?/57	423
1957	"	S	"	77.8	?/58	24
1958	"	S	"	9.0	?/59	84
1959	"	S	"	91.1	?/60	320
1960	"	S	"	57.3	?/61	23
1961	"	S	"	34.8	?/62	32
1974	Cowlitz R.	S	"	271.1	3/76	10
1975	L. White NFH	S	"	412.0	4/77	14
"	Wells Dam	SU	"	213.3	4/77	11
"	"	SU	Columbia R.	97.9	5/77	11
1976	L. White NFH	S	Methow R.	700.0	1/77	1,250
"	Carson NFH	S	"	365.0	4/78	15
"	Wells Dam	SU	"	501.7	4/78	15
"	"	SU	Columbia R.	94.4	5/78	14
1977	Carson NFH	S	Methow R.	427.2	4/79	15
"	Wells Dam	SU	"	169.6	4/79	13
"	"	SU	Columbia R.	67.2	4/79	14
1978	Methow R.	S	Methow R.	60.0	4/80	17
"	L. White NFH	S	"	1,147.0	4/80	17
1979	Methow R.	S	"	78.0	4/81	18
"	Leav. NFH	S	"	268.0	4/81	18
"	Carson NFH	S	"	620.3	4/81	17
1980	Wells Dam	SU	"	268.1	4/82	21

(Continued)

Table 8 (Concluded)

Brood year	Egg source	Race	Releases Area	Number (000)	Date	Fish/ pound
"	Methow R.	S	"	100.2	4/82	15
"	Leav. NFH	S	"	612.5	4/82	16
1981	Carson NFH	S	"	785.1	4/83	18
	Methow R.	SU	"	170.5	4/83	13
1982	"	S	"	601.5	4/84	16
1983	"	S	"	1,167.6	4/85	17

[a] Race: S = Spring chinook; SU = Summer chinook

The year after the completion of Rock Island Dam in 1932, however, only 400 chinook salmon were harvested at Kettle Falls and only after August 20. In 1933 and 1934, catches were also small, 263 and 139 chinook, and they again were late, after August 25 and 20. As a result of the delay imposed on chinook salmon by Rock Island Dam, a third fishway, midway in the dam, was installed and no further passage problems for adult chinook were observed (Bell 1937).

Columbia River summer chinook salmon were further reduced by overfishing in the 1930's and early 1940's (Figure 3), coincident with the lowest counts at Rock Island Dam and meager catches at Kettle Falls (Table 4). Reduction of harvest rates from 84% to 47% in the mid-1940's increased the escapement. Subsequently, the abundance of summer chinook improved until it peaked in 1957, then declined steadily despite little or no in-river harvest after the mid 1960's. Counts of wild summer chinook at Rock Island Dam reflected the improved escapement of the mid 1940's and the peak in lower river abundance in 1957, but have remained relatively stable from 1953-84 (Figure 3).

The importance of summer chinook to the mid-Columbia River is illustrated by the large share of the total escapement to the Columbia River at Rock Island Dam in years of diminished runs (e.g., 42-69% in 1975-79) (Figure 3). Most of these summer chinook have originated in the Wenatchee River in recent years.

Historically, the run of summer chinook to the Wenatchee River was much larger than the run of spring chinook but was virtually extirpated by the 1920's (Craig and Suomela 1941; Tumwater Dam counts 1935-1937, Table 9). Interception of adult chinook at Rock Island and their relocation to the Wenatchee River occurred from 1939 to 1943 (Table 5) (Fish and Hanavan 1948). Reestablishment of the run was reflected in recovery of progeny tagged at Rock Island in 1942-44 (Fish and Hanavan 1948) and spawning escapements beginning in 1944 (Table 9).

Fall Chinook

The trend of fall chinook salmon at Rock Island Dam bears little relationship to other chinook salmon runs (Figure 4).

While differences in run timing clearly separate summer from fall chinook salmon in the lower Columbia River, this distinction between the two races at Rock Island Dam was blurred. Reasons include: appreciable overlap in run timing between summer and fall runs, tendency toward bimodality of the summer run, and frequent lack of a definitive mode in the fall run (Fish and Hanavan 1948; Meekin 1963; French and Wahle 1965; Galbreath 1966).

Fall chinook salmon in the Columbia River drainage have been reported to spawn principally in the lower portions of major tributaries and in sections of the middle and lower mainstem (Fulton 1968). However, Edson (1958) and Fulton (1968) believed that both summer and fall-run migrants were intermingled on some mainstem and tributary spawning areas above Rock Island Dam. Chapman (1943) estimated that 800 to 1,000 chinook salmon spawned in a two-mile area below Kettle Falls in 1938, or between 47% and 58% of the 1,717

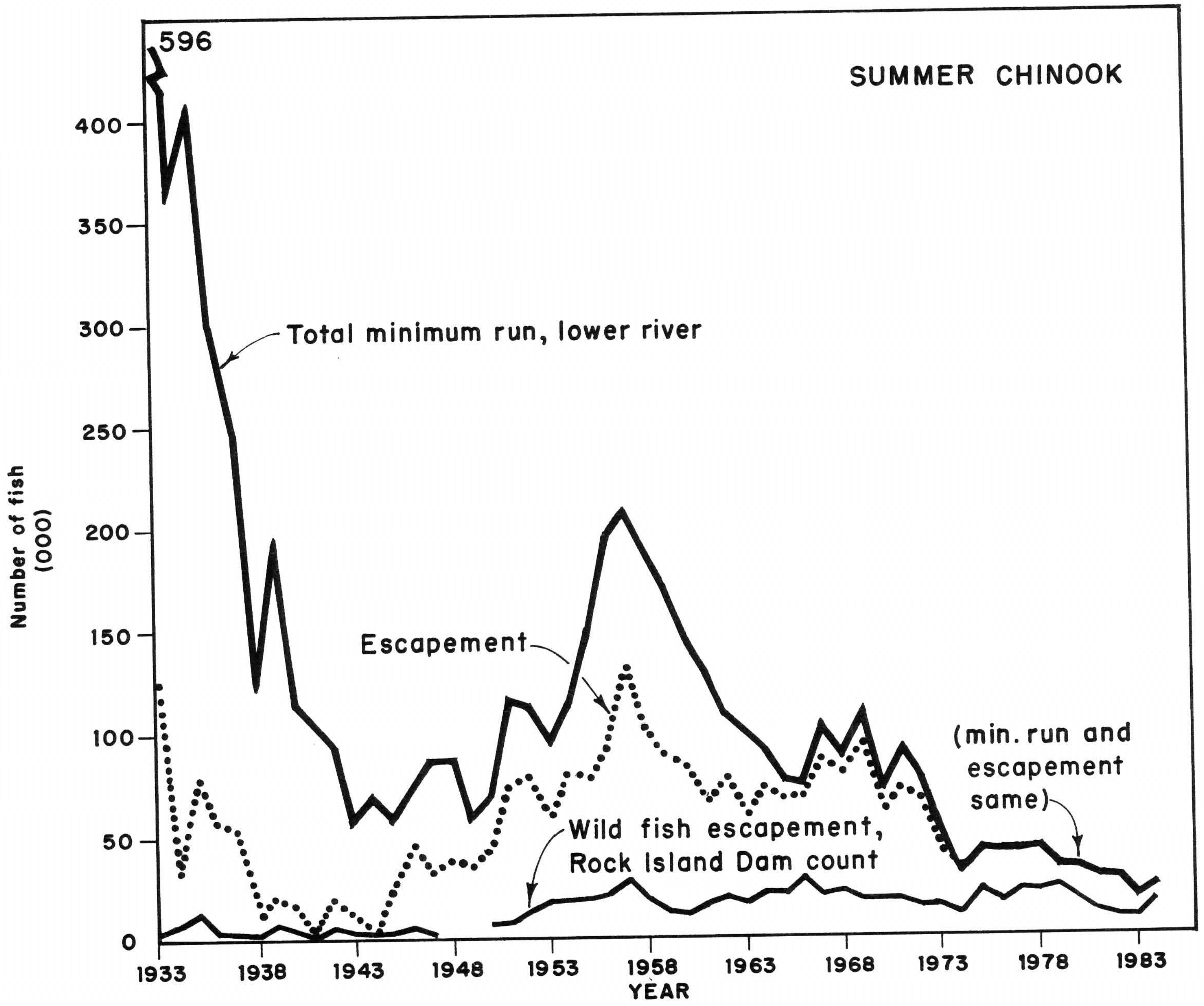

Figure 3. Trends of Columbia River summer chinook salmon abundance as related to wild fish escapement at Rock Island Dam (Data source: same as Figure 2).

Table 9. Escapements of summer chinook slamon to the Wenatchee River, 1935-1985 (unpublished USFWS, WDF, Chelan County PUD; and French and Wahle 1960, 1965).

Year	Inter-dam[a] count	Hatchery escapement (Icicle Cr spawners)	Tumwater Dam count (RM 32.7)	Spawning Ground Count		
				Above Tumwater Dam	Below Tumwater Dam	Total[b]
1935			10			
1936			5			
1937			2			
1944	1,524[c]	8				1,471
1945	2,826[c]	47				
1946	5,396[c]	267		411	1,181	1,592
1947	2,781[c]			120	194	314
1948		31		148	126	274
1949				60	279	339
1950	7,271[c]	20		52	70	122
1951	7,803[c]	219		71	253	324
1952	13,754[c]	42		8	1,452	1,460
1953	16,600[c]	51	796		571	1,367
1954	17,747[c]	66	3,540	400	651	4,191
1955	19,509[c]	3	1,428		2,095	3,523
1956		20	3,235		2,147	5,382
1957	23,999[c]	71	2,861	221	7,276	10,137
1958	11,069[c]	2		91	1,900	1,991
1959	10,058[c]	12	1,121	25	1,950	3,071
1960	8,987[c]	16		60	1,717	1,777
1961	2,412	8				2,722
1962	6,301	8		184	3,167	3,351
1963	8,349	5				4,232
1964	6,528		2,073	174	3,925	5,998
1965	5,732		1,192	375	6,870	8,062
1966	10,032		1,505			3,906
1967	4,282		2,158	385	4,879	7,037

(Continued)

Table 9 (Concluded)

				Spawning Ground Count		
Year	Inter-Dam[a] count	Hatchery Escapement (Icicle Cr spawners)	Tumwater Dam count (RM 32.7)	Above Tumwater Dam	Below Tumwater Dam	Total[b]
1968	11,320			208	5,351	5,559
1969	8,125			207	4,086	4,292
1970	9,732			298	3,901	4,199
1971	10,450					4,399
1972	10,894		1,718			4,228
1973	5,901					3,546
1974	3,220					3,580
1975	8,499					2,868
1976	6,688			163	3,326	3,489
1977	7,319			400	4,455	4,855
1978	12,441			883	5,301	6,184
1979	13,208			608	4,740	5,348
1980	10,290			461	5,995	6,456
1981	5,539			555	4,216	4,771
1982	6,458			155	4,225	4,380
1983	6,209			239	2,012	2,251
1984	11,792			651	3,447	4,098
1985	9,979			605	2,840	3,445

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[a] Usually esitmates based on difference between counts at Rock Island Dam downstream and Rocky Reach Dam upstream.

[b] Peak counts of spawners, with Tumwater Dam counts substituted for spawner counts upstream, if appropriate, and with aerial redd counts x 3.1 adult spawners (Meekin 1967) beginning in 1961.

[c] Ratio of spawners observed above (Entiat, Methow, and Okanogan drainages) and below (Wenatchee drainage) Rocky Reach Dam site as applied to Rock Island Dam counts (after French and Wahle 1960).

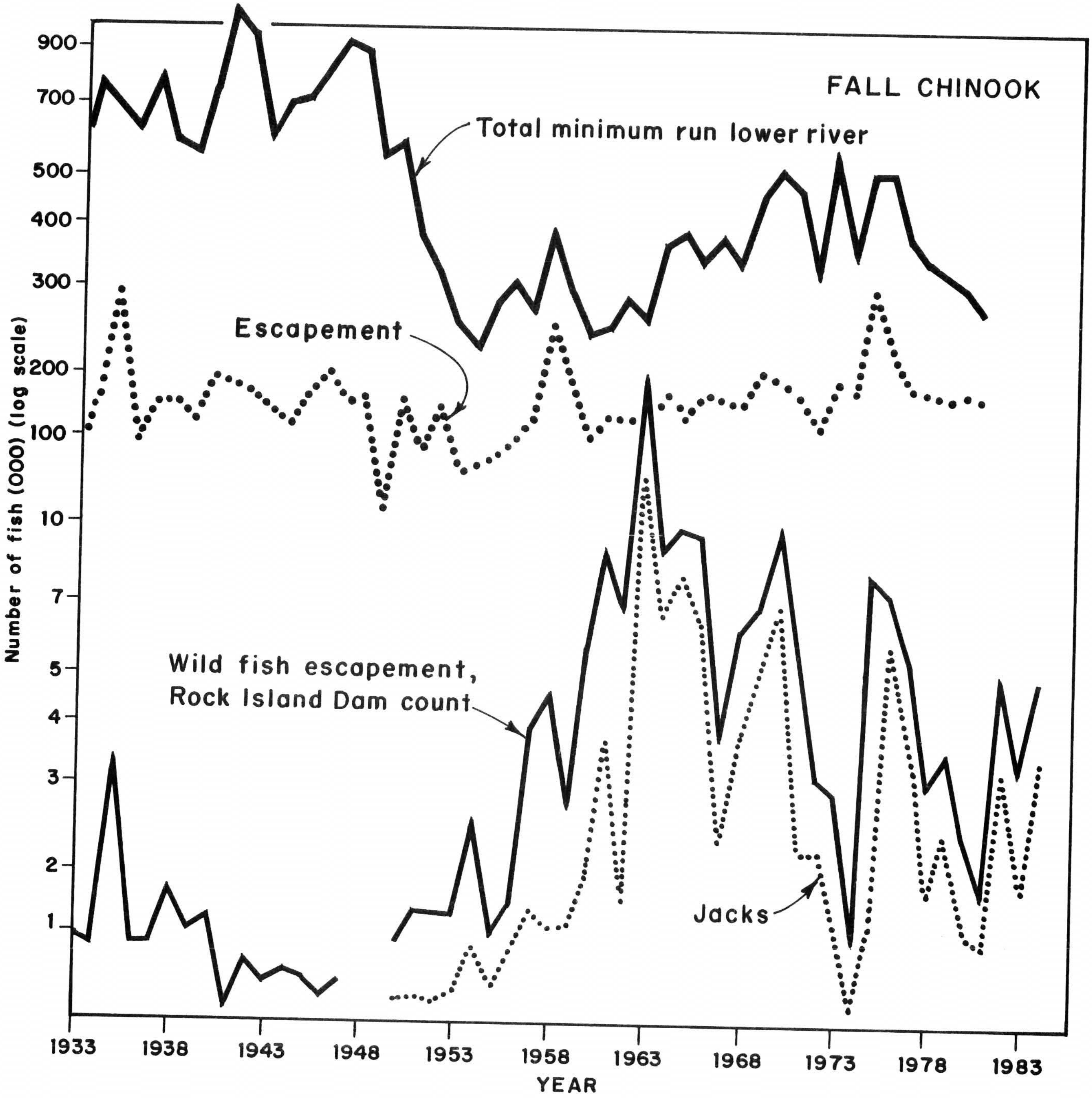

Figure 4. Trends of Columbia River fall chinook salmon abundance as related to wild fish escapement at Rock Island Dam (Data source: same as Figure 2, except negligible hatchery fish ignored).

fall chinook passing Rock Island Dam. He also reported mainstem spawning areas 19 miles and 38 miles below Kettle Falls. Additional spawning areas from Grand Coulee Dam to the head of Rock Island Reservoir were identified prior to inundation (Fish and Hanavan 1948; Edson 1958). These observations suggest that it is unlikely that half of the fall chinook passing Rock Island Dam in 1938 were accounted for in the spawning area below Kettle Falls, and that Chapman's (1943) estimates of chinook spawning there included summer and fall chinook.

The number of fall chinook salmon that spawn in the unimpounded Hanford Reach increased markedly after construction of the upstream Priest Rapids Dam in 1960. The increase is generally attributed to the upstream translocation of fish whose spawning grounds were inundated by dams below Hanford. Fall chinook pass through the Hanford Reach to areas above Priest Rapids Dam from mid-August to November. However, the largest part of the upriver run spawns in the Hanford area from October through November (Watson 1976; Chapman et al. 1983).

Spawning of summer chinook salmon in the Wenatchee River peaks about October 24. Spawning of fall chinook peaked about November 10 in the Columbia River off the mouth of the Wenatchee River in the late 1960's and early 1970's. Spatial-temporal differences in time of spawning do not indicate innate differences between summers and falls, because all chinook races spawn at declining water temperatures of about 12.8°C (55°F) (Miller and Brannon 1982).

With the advent of Grand Coulee Dam and storage reservoir in 1941, the downstream Columbia River became warmer in fall and winter and cooler in spring and summer (Jaske and Goebel 1967). The seasonal shift in water temperature caused a temperature differential between the Columbia River and the Wenatchee River, with peak spawning of chinook in the mainstem possibly delayed by 1 week to 10 days. Spawning of summer chinook in the Wenatchee River begins and peaks in a continuum from upstream to downstream in unison with declining water temperatures, subject to annual variations in climate and flow. Consequently, the average time of spawning between summer chinook in the Wenatchee, and fall chinook off the mouth of the Columbia River were probably similar before the dam era. Chapman's (1943) preimpoundment observations below Kettle Falls suggest spawning between mid-October and early November. Bryant and Parkhurst (1950) indicated chinook usually began spawning during the last week in August or the first week in September in terminal reaches of the Columbia River 1,831 km (1,200 miles) from the ocean, a phenology that is consistent with mid-October to early November spawning 805 km (500 miles) downstream at Kettle Falls.

Aside from the lack of difference between summer and fall chinook salmon above Rock Island, the trend of fall chinook at the dam is confounded by hatchery propagation. Because only a bimodal time distribution of chinook salmon at Rock Island Dam, separating springs from summers, was recognized at the time of the GCFM Project (Fish and Hanavan 1948), there are no records that fall chinook were propagated. We know, however, that the 3,584 adult chinook introduced into the Wenatchee River in 1939 included both summers and falls (Table 5) because they were intercepted at Rock Island Dam between July 18 and October 20 (Craig and Suomela 1941).

Propagation of fall chinook in the Washington Department of Fisheries-Public Utility District (WDF-PUD) Rocky Reach spawning channel (1961-67) resulted in negligible returns (Meekin et al. 1971). Propagation of fall chinook in the downstream WDF-PUD Priest Rapids spawning channel was also ineffective (Allen and Meekin 1973), but effectiveness was increased by conversion to a hatchery (Kaczynski and Moos 1979). Adult fall chinook destined for upriver areas are trapped for broodstock in the fishways at Priest Rapids Dam. Possible effects of trapping are the unusually high incident of jacks in fall chinook counts at the upstream Rock Island Dam (Figure 4) and the disappearance of fall chinook that spawned off the mouth of the Wenatchee River (Table 10). According to Meekin et al. (1971), these fall chinook originally spawned in the mainstem Columbia River that was inundated by Rocky Reach Reservoir but, after completion of the dam, they spawned downstream at the head of Rock Island Reservoir.

COHO SALMON

Current and historical abundance of coho salmon center in lower Columbia River tributaries. Peripheral coho runs to the mid and upper Columbia had been largely destroyed prior to Grand Coulee Dam. The low level to which upriver stocks declined is illustrated by annual counts at Rock Island Dam from 1933 to 1943: 183, 69, 10, 0, 58, 78, 13, 12, 29, 1, and 22 (Mullan 1984).

Columbia River coho salmon declined steadily from the 1930's to 1960, but then showed a strong recovery. Recovery to historical levels of abundance in the early 1970's (Gunsolus 1978) was initially attributed to improvements in fish culture (i.e., pelletized diets). Abundance peaked in 1976 and then declined to near pre-1960 levels despite increases in smolt releases (62 million in 1981). It is now recognized that ocean upwelling, or favorable marine conditions associated with ocean upwelling, are the major factors influencing coho abundance (Nickelson 1986). Strong upwelling occurred less than 30% of the time since 1946, but occurred 9 out of 12 years between 1964 and 1975.

Despite releases of 46 million juveniles in the period 1942-75 and correction of most environmental causes of original depletion, there is no evidence of coho salmon reestablishment above the threshold levels recorded in the 1930's and early 1940's. Failure to reestablish viable populations of coho salmon in tributary streams of the mid-Columbia River appears to have been primarily related to agency reliance (because of severe depletion of upper river stocks) on short-run, late-spawning lower river stocks lacking genetic suitability (Mullan 1984).

Table 10. Fall chinook salmon redd counts (aerial) in the mid-Columbia River by impounded sections.[a]

Year	Priest Rapids to Rock Island Dam	Rock Island Reservoir [b]		Rocky Reach Reservoir		Wells Reservoir	
		WDF	PUD	WDF	PUD	WDF	PUD
1933		c					
1947	266						
1948	887						
1949	251						
1950	490						
1951	724						
1952	493						
1953	182						
1954	175						
1955	111						
1956	168	0		17		228	
1957	756	33		187		526	
1958	593	222		217	302	722	
1959	14	180	160	1	0	126	126
1960	117	167	167	70	75	590	591
1961	415	625	684	0[c]	0[c]	447	517
1962	897	283	255	0	0	437	490
1963	0[c]	468	454	0	0	445	404
1964	222	320	320	0	0	335	324
1965	50	165	160	0	0	653	508
1966	98	259	249	0	0	903	903
1967	117	157	176	6	0	0[c]	0[c]
1968	135	258	292	57	46	0	0
1969	40	142	160	19		0	
1970	80	191	316	10	13	0	
1971	22	86	229	35	3	0	
1972	13	3	0	53	0	0	
1973	0	107		50	0	0	
1974	0	13	0	2	0	0	
1975	0	10	10	6	0	0	
1976	5	5	4	0	0	0	
1977	0	1	1	2	0	0	
1978			0	3	0	0	
1979			0				
1980			7				
1981			0				
1982			0				
1983			0				
1984			0				
1985	0		0		0		0

(Continued)

Table 10 (Concluded)

[a] Counts through the late 1950's were by U.S. Fish and Wildlife Service (USFWS) and thereafter by Washington Department of Fisheries (WDF) and Chelan County Public Utility District (PUD) (Edson 1958; Meekin 1963; Leman 1968).

[b] Mouth of Wenatchee River.

[c] Year impounded.

SOCKEYE SALMON

After blockage of the upper Columbia River by Grand Coulee Dam, sockeye salmon became almost entirely dependent for rearing in Wenatchee and Osoyoos lakes, located on the Wenatchee and Okanogan rivers (Figure 1). Both the relocation of adults trapped at Rock Island Dam from 1939-43 to the two lakes and hatchery releases involved mingling of discrete stocks. Seemingly, there was no impairment of genetic viability based on a high resilience of survival in the face of major perturbations (Mullan 1986).

Columbia River sockeye salmon are rarely caught in the ocean, and the fishery has been largely confined to the lower river. Annual catches ranged from 0.25 to 1.3 million fish before 1900, and were 50,000 to 730,000 fish through the early 1920's. Catches after the 1930's were only a fraction of the earlier highs (Mullan 1986).

In the 1930's and early 1940's, sockeye salmon abundance remained depressed in relation to annual escapements of about 2% to 24% (2,000-20,000 fish) at Rock Island Dam. When catch and escapement were brought more nearly into balance beginning in 1945, the runs revived and comparative abundance was maintained until the 1960's. Since then, the runs have only occasionally been of the magnitude of 1945-1960's.

The early post-1900 decline in sockeye salmon can be largely ascribed to losses of nursery lakes when access was blocked by dams. Original surface area of nursery lakes in the Columbia River Basin was at least 90,186 ha, of which about 4% remained after 1939. Average unit area smolt production today apparently is similar or improved compared to the past, but most smolts are now lost in mainstem dam turbines or reservoirs (Mullan 1986).

Unexpectedly large runs of sockeye salmon returned in 1984 to the Columbia River (160,500), Lake Washington (478,000), and the undammed Fraser River (5,900,000; a record dating to 1904, IPSPS 1984), indicating that high ocean survival may mask the importance of freshwater mortality in some years. In coho salmon, the level of ocean upwelling or associated phenomena determined the marine survival rate (which was similar for hatchery and wild fish), and the number of smolts determined the ultimate population size (Nickelson 1986). Because there were so many more hatchery than wild smolts to take advantage of infrequent marine conditions, huge variability in runs occurred just as in sockeye.

STEELHEAD

Steelhead enter the Columbia River in winter and summer, but spawn in the spring. The young reside for two or more years in streams before migrating to the sea. The extended stream-residency apparently prevents steelhead from achieving abundance comparable to salmon. Steelhead composed only about 5% of the historical anadromous salmonid complex in the Columbia River (Chapman, in press).

Steelhead catches averaged about 400,000 from 1892 to 1896, but then declined sharply, an apparent result of overfishing, inasmuch as environmental degradation should not have been responsible (Chapman, in press). In contrast to spring and summer chinook and sockeye salmon catches, steelhead landings were fairly consistent from 1912 to 1940 at near 300,000 fish, suggesting that the run maintained itself under the escapement and environment that prevailed at that time. For 1938-42, the lower river commercial fishery took an average of 215,000 fish and the escapement averaged 93,000 fish or 31% (Chapman et al. 1982). Only a fraction (4%) of these fish reached Rock Island Dam (Figure 5) for relocation and hatchery propagation as part of the GCFM Project.

Steelhead runs to above Rock Island Dam increased slowly beginning in the late 1940's, then oscillated widely, followed by dramatic increases (300%-400%) recently (Figure 5). The erratic trend in abundance would seem rooted in instability due to overharvest of wild steelhead in natal streams in the 1960's and 1970's (Howell et al. 1985b), and improvements in fish culture allowing for the release of quality subyearling (5-7/lb) smolts. Recently, a minimum 1% to 2% escapement and harvest of steelhead, subject to only minor ocean exploitation, from mid-Columbia River hatcheries has been normal (Howell et al. 1985b). Different rivers in different geographic areas throughout the State of Washington produced record runs in 1984 and 1985, indicating the in-common importance of ocean survival for all runs.

FINAL NOTES FROM THE HISTORICAL RECORD

Abundance of salmon and steelhead runs above Rock Island Dam has been influenced by a combination of man-made stresses and natural factors. Man-made stresses are presumably reflected in long-term trends, while natural factors are reflected in temporal variations in abundance. Nevertheless, barring extremes of impact (i.e., 90% harvest rates, total blockage of runs), it is difficult to distinguish between man-made and natural influences on abundance of anadromous salmonids.

Evidence from the past shows that the middle and upper Columbia River yielded far from regular salmon harvest in the presettlement era (Chance 1973):

> "At the end of August 1811, David Thompson and his men had to subsist on horse flesh at Kettle Falls (Glover 1962:380). That would have been toward the end of the heavy fishing. John Work (1830) makes it very clear that the Kettle Falls fishery during the seasons from 1826 through 1829 only generally yielded enough fish to maintain the people of Fort Colville <u>during the fishing season</u>. In 1828, the men at the fort were relying upon horse meat as early as October (Work 1828). During those years, some Sxoielpi (Indians) starved to death and others ate horses (Heron and Kittson 1831). The total strength of the extra people at the fort during these summer seasons amounted to no more than twenty adults and as many children. Salmon, roots, and berries were far from adequate to feed these few people at the fort during the rest of the year.

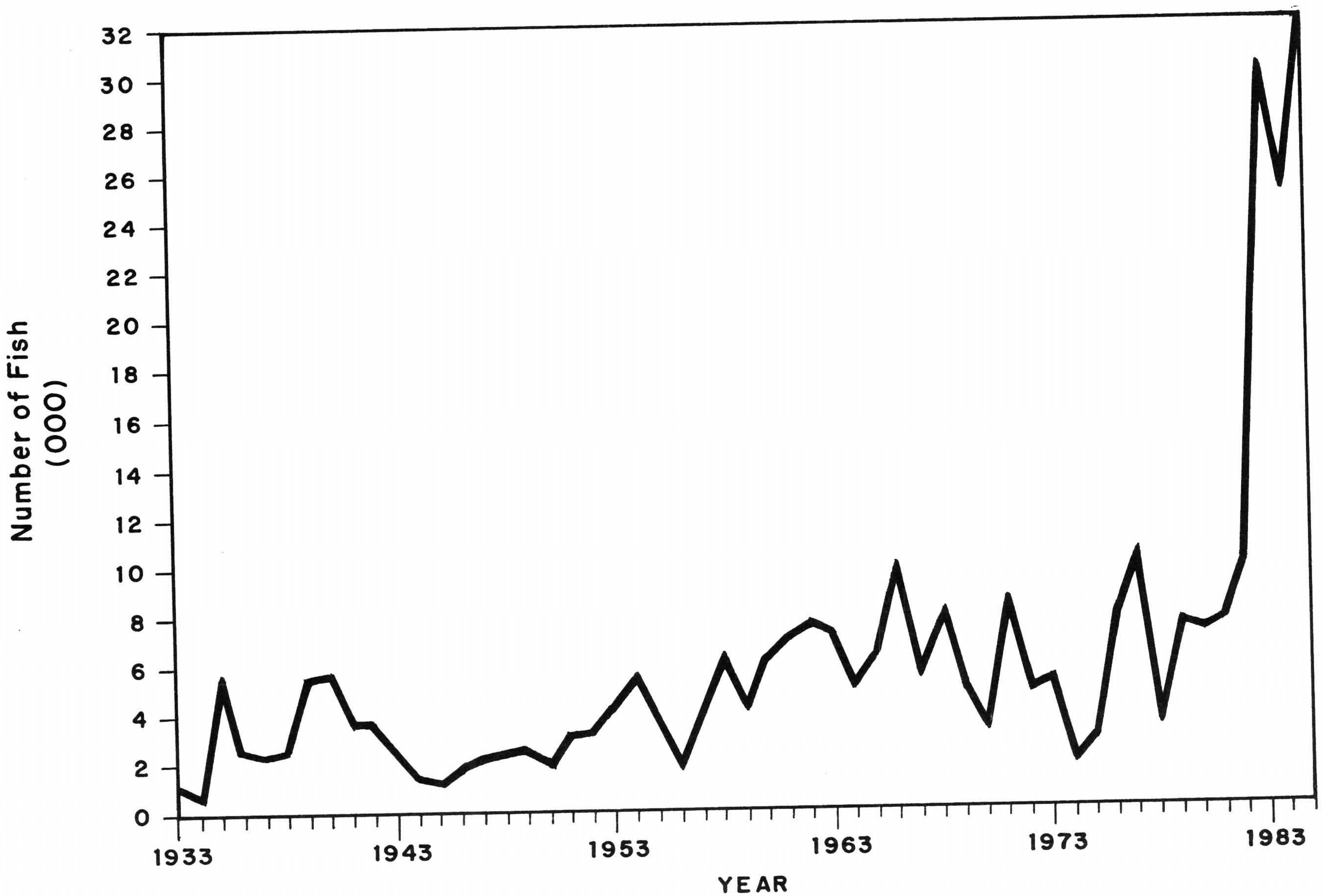

Figure 5. Annual steelhead counts at Rock Island Dam (Data Source: Same as Table 1).

> The traders ate horses frequently, and they also had the benefit of crops which had been harvested since 1825. Even with horse meat and crops, the food scarcity at Kettle Falls was still a problem."

and

> "In 1826, there was no salmon harvest at all on the Middle Columbia by late July (Black 1826b). In July of 1831, the traders at Fort Walla Walla were eating salmon brought not from kettle Falls after its abundant catch in 1830, but from Thompson's River (Fraser River system, British Columbia) (McGillivray and Kittson 1831). In July of 1832, John McLoughlin (1832b) decided that Fort Colville should maintain an extra years' reserve of agricultural produce in case there should be further shortages of salmon."

Smith (1983) commented specifically on the middle Columbia:

> "The spring of 1811 could not have been an easy season for these groups (Indians). For even in early July when Thompson stopped briefly at the large village at Rock Island, he found the villagers "poor in provisions". Their fisheries were then yielding some salmon, but the catch must have been singularly meager in spite of the fact that the salmon season should have been nicely underway."

and

> "In early August 1828, Work reports that along the White Bluffs (Hanford Reach) there were few Indians to be seen and these were starving, for they were catching no salmon. And at Priest Rapids, the salmon seemed very scarce. When, on August 6, he reached Rock Island Rapids, the salmon were found to be very scarce in this area also."

Much of the natural fluctuation common in salmon abundance has been ascribed to variations in survival of the young in freshwater, during either the egg or fry-fingerling stages. The historical accounts of feast and famine lie outside of freshwater control. Nickelson (1986) described freshwater control as creating the variability within a generally high or low level of abundance in coho salmon, with the mechanisms playing a secondary role in population regulation. Primary control centers on ocean survival, which I have also suggested as controlling the huge variability in sockeye salmon abundance.

Ocean control seems to operate by producing conditions either favorable or unfavorable, without much gradation (Nickelson 1986). Resident stream trout do not exhibit the wide variation in population size common in Pacific salmon (Hall and Knight 1981). The extremes of temporal variation occur in short-lived (two years) pink salmon (_O_. _gorbuscha_). The enormous fluctuations in abundance characterizing this species are widely ascribed to the variable environment in estuarine and marine rearing areas, and not the relatively stable freshwater spawning grounds.

Spring chinook salmon are also significantly influenced by ocean conditions during the first year at sea (Barton 1979), and it is possible that ocean survival could periodically override turbine mortality of smolts in importance. However, it is clear that the quantity of salmon and steelhead available to local groups at any place in a river system is determined by the extent to which migrating fish are intercepted by other groups situated downstream.

Schalk and Mierendorf (1983) suggested that 30,000 Indians fished along the Columbia River below Rock Island (dam site) in late prehistoric times, and that the potential for shortages of salmon, due to downstream interception, was very real in areas above Rock Island. This possibility seems even more likely in a year of low flow if, as demonstrated in 1941, migration of runs was impeded at Celilo Falls (Fish and Hanavan 1948), the major downstream fishing area for Indians. Indian fisheries were typically situated at falls and rapids where the migrating fish were vulnerable to capture, especially at low flows. However, in 1811 when salmon were scarce at Kettle Falls, we know that the Columbia River was "exceedingly high" in early July according to the journal of David Thompson (Smith 1983). On the other hand, the highest catch rate of salmon at Celilo Falls 1938 to 1950 occurred in the low flow year of 1941 (Table 11); when this obstruction to upstream fish passage was flooded out by The Dalles Dam in 1957, chinook salmon runs increased dramatically upstream at Rock Island Dam (Figures 2 and 3).

Aside from illustrating that the Columbia River yielded far from regular salmon harvests in the presettlement era, ethnographic data are valuable for the light they throw on what the maximum potential of habitat might have been.

Anadromous salmonids were the staff of life of Northwest Indians. Through thousands of years, the native population might be expected to have come into balance with its principal food supply. Estimates for Indian populations who relied on salmon for food in the nineteenth century are beset by numerous perplexities (e.g., reduction by European diseases, changes in culture from Euro-American contact). Considering such problems, Smith (1983) estimated maximum (summer) populations of 1,748 Indians for the Wenatchee River and 140 Indians for the Entiat River during the middle of the last century. Using one pound of salmon per day per capita for 12 months, as in all estimates of early Indian harvest, one arrives at annual catches of 638,000 and 51,100 pounds for the Wenatchee and Entiat rivers, respectively. These yields amount to 31,900 and 2,555 chinook salmon using 20 pounds per fish. Of course, such normative characterization does not take into account when the salmon appeared in only limited numbers, essentially failed, or that other fish species were taken as part of the harvest total, depending on relative abundance. For example, sockeye salmon was the primary species harvested by Indians on the Okanogan River, which had a large run of sockeye and a small run of chinook (Craig and Suomela 1941).

Admitting that these estimates of primordial salmon abundance are very rough and that species composition of the harvest is especially so, they do reinforce two speculations. First, the difference in harvest between the

Table 11. Minimum harvest rates[a] of salmon and steelhead trout by Indian dip net fishery at Celilo Falls, Columbia River, 1938-50 (from Schoning et al. 1951).

Year	Spring and summer chinook		Fall chinook		Sockeye		Steelhead	
	Run Size[b]	Harvest (%)	Run Size[b]	Harvest (%)	Run Size[b]	Harvest (%)	Run Size[b]	Harvest (%)
1938	37,148	17	234,651	28	75,041	31	107,003	27
1939	100,138	15	186,051	25	73,382	26	122,032	17
1940	88,343	16	303,244	25	148,807	28	185,174	20
1941	88,703	32	372,740	47	65,741	44	118,089	30
1942	65,108	26	336,834	36	55,464	23	151,800	20
1943	78,984	12	234,139	33	39,845	19	92,133	26
1944	43,470	29	197,294	30	15,072	29	100,518	34
1945	71,125	11	226,353	20	9,501	11	120,133	28
1946	118,757	8	327,295	30	74,376	8	142,807	27
1947	172,422	7	307,955	43	171,139	19	135,444	25
1948	108,965	34	310,590	43	131,541	11	139,062	21
1949	96,806	13	180,891	39	51,444	11	119,285	26
1950	106,893	13	250,482	39	77,993	16	114,087	22
Average	106,893	17		34		21		24

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[a] Does not include all fish used for subsistence; data for years 1947-1950 are most complete and perhaps represent 90% to 100% of the actual harvest; data for years 1938-1946 are perhaps 64% to 81% complete, based on Schoning et al. (1951).

[b] From Bonneville Dam count, 50 miles downstream of Celilo Falls.

Wenatchee and Entiat rivers is about what one would expect based on the quantity of habitat available to salmon in each system. Second, current production may not be greatly different from primordial production of salmon in these streams, allowing that major harvest no longer occurs in-river and that more than 50% of the smolts are killed in dam turbines en route to the ocean.

HATCHERY ASSESSMENT

There is fascinating diversity in chinook salmon in regard to timing of spawning migrations, distance from the sea to spawning areas, time spent by young in freshwater, time of seaward migration, time spent maturing in the ocean, and ocean distribution. Questions concerning the range and complexities of these life history diversities and their significance for management challenge the imagination.

The origin of most chinook salmon released to the Wenatchee and Entiat rivers and all releases to the Methow River, through the late 1960's from the GCFMP hatcheries, can be traced to the comingled upriver stocks intercepted at Rock Island Dam. Imports were from the lower Columbia River (Tables 6, 7, and 8).

Records of two early hatcheries on the Wenatchee River (1899 to 1904 and 1913 to 1931) show releases of 9.8 million chinook salmon fry, which largely originated from hatcheries on the lower Columbia River (Craig and Suomela 1941). Two early (1899-1931) hatcheries on the Methow River also received shipments of chinook eggs from hatcheries on the lower Columbia River (Craig and Suomela 1941).

A second phase of chinook salmon propagation at Leavenworth NFH began in 1969, following 2 years (1967 and 1968) when no chinook were raised, and at Entiat and Winthrop NFH's in 1974, following 8 and 12 years respectively, when no chinook salmon were raised. The primary stock used in this effort was spring chinook from Carson NFH, although eggs from the Cowlitz River, and Little White Salmon and Spring Creek NFH's augmented efforts in establishing a continuing egg supply. Carson NFH stock was established from upriver spring chinook trapped at Bonneville Dam.

Spring chinook salmon from the Columbia River form at least three groups, on the basis of electrophoretic data: (1) West of the Cascade Mountains; (2) East of the Cascade Mountains, excluding; (3) Snake River above the Grande Ronde River (Schreck et al. 1986). A potential limitation of electrophoretic data for spring chinook salmon is that much of the data from the mid-Columbia River came from the Leavenworth, Entiat, and Winthrop NFH's, which received eggs from Carson NFH. It is possible that these hatchery stocks, because of transfers, differ from natural populations. Natural populations may not be typical of original populations of spring chinook as well, because of hatchery releases, translocation of stocks, or genetic alteration through overfishing. Electrophoresis suggests that the stocks of the same race from neighboring streams and or hatcheries in the mid-Columbia are more similar to each other than stocks of different races (e.g., springs vs. summers) from within the same stream system (Schreck et al. 1986). However, because electrophoretic studies fail to detect significant genetic differences between two closely related populations does not mean that there are no differences between them. Genetic diversity governing morphological, physiological, ecological, and behavioral aspects of differentiation cannot be detected by electrophoresis.

Because yardsticks upon which to gauge and compare current viability of chinook salmon stocks with those of the past are lacking, wild and hatchery stocks are characterized for difference and meaning. Chinook salmon are highly adaptable, as exemplified by the success of chinook introduced to the Great Lakes, with some stocks now spawning in the spring (Kwain and Thomas 1984). Plasticity also characterized the ascendancy of winter-run chinook salmon in the Sacramento River as a result of favorable water temperatures created by Shasta Dam (Moffett 1949; Slater 1968). It is these kinds of ecological and behavioral adaptations that would appear to have utility considering the dynamic transformation of the Columbia River from dam construction.

SPRING CHINOOK

The Wenatchee, Entiat, and Methow rivers are the last remaining drainages in the middle Columbia River that support runs of wild spring chinook salmon. Leavenworth NFH releases about 2.5 million spring chinook smolts annually to Icicle Creek, a tributary of the Wenatchee River. Entiat and Winthrop NFH's each release about 1.0 million smolts to the Entiat and Methow rivers.

Outmigration

Juveniles are released from the hatcheries as yearlings in the latter half of April at lengths of 117 to 178 mm (15-20/lb). Wild juveniles outmigrated from the Wenatchee River in 1955 and 1956 at lengths of 65 to 123 mm (mean 95 mm) during April-May with peaks in early May (French and Wahle 1959). Juveniles from Leavenworth NFH appear at Rock Island Dam, 71 km (44 miles) downstream, about two days after release (Olson 1982; BioSonics, Inc. 1984); peak passage generally occurs in the next few days.

Physiological indices of smoltification (e.g., silveriness, thyroxine levels, gill Na^+-K^+ ATPase levels) of Leavenworth NFH spring chinook salmon are usually not pronounced, through April (Weitkamp and Loeppke 1983). Juveniles at Entiat and Winthrop NFH's smolt in late winter and early spring, based on visual observations and limited physiological testing (Zaugg 1985).

Chinook juveniles released from the Winthrop NFH reach Wells Dam, 95 km (59 miles) downstream, in about two to five days (Johnson and Sullivan 1984). Generally, 80% of the spring outmigration passes Priest Rapids Dam (the last dam on the mid-Columbia, 294 km (183 miles) and 433 km (269 miles) downstream from Leavenworth and Winthrop hatcheries, respectively) during May, with peaks occurring mid to late May (CH_2M Hill 1980; Parametrix 1984a, 1984b); 95% of the outmigration occurs between May 2 and June 10 (Mid-Columbia

Coordinating Committee 1986). Median recapture in the Columbia River estuary, 724 km (450 miles) downstream, for four tagged groups released on April 25, 1978, and April 26, 1979, from Leavenworth NFH, was May 22-29 (Dawley et al. 1982).

Survival

Over four million juvenile spring chinook of the 1970 and 1971 broods from 21 Columbia River hatcheries were fin-clipped or coded wire tagged (CWT) Wahle et al. 1981). The 1970 brood year fish (97,000) from Leavenworth NFH resulted in a 0.89% return (catch and escapement). Only fish released from lower Columbia River hatcheries produced a higher return (1.8%). Returns from the Leavenworth NFH 1971 brood release (99,400) were negligible (0.01%).

Four CWT groups of Leavenworth NFH spring chinook, about 100,000 smolts from each brood year 1974 to 1977, were released to Icicle Creek. Total returns ranged from 0.06% to 0.16% (WDF 1982). A CWT study by National Marine Fisheries Service (NMFS) on spring chinook smolts of the Leavenworth NFH 1978 brood year also gave abysmally low returns (Slatick et al. 1984).

What these data (Table 12) suggested was that a survival (catch and escapement) of 1.0% for upriver hatchery spring chinook was very good. Total survival for more than four million spring chinook of the 1970 and 1971 brood years was only 0.6% (Wahle et al. 1981).

Twelve marking experiments involving 450,511 GCFMP hatchery chinook juveniles of brood years 1940-43 occurred prior to extensive hydroelectric power development of the Columbia River (Fulton and Pearson 1981). Return of fish released in the fall at one year of age ranged from 0.06 to 0.81%, and return of fish that were released in spring at 1-1/2 years of age ranged from 0.98 to 1.94%.

Run Size

Based on inter-dam counts, the adult run of wild spring chinook salmon averaged 5,065 to the Wenatchee River (1961-1985) (Table 13), 1,515 to the Entiat (1967-1985) (Table 14), and 2,955 to the Methow River (1967-1985) (Table 15). There are no obvious trends in escapements to these streams except for increasing numbers of hatchery fish in recent years (Tables 13, 14, and 15). Hatchery and wild spring chinook abundance fluctuated in much the same pattern. This suggests that similar factors affected their survival. The percentages of total escapement accounted for in spawning censuses range widely, with no evident trends (Tables 13, 14, and 15).

Catch Distribution

Wahle et al. (1981) pointed to changes in ocean fishing subsequent to their marking program that would affect the extrapolation of their results to the present. Historically, most upriver spring chinook salmon were harvested in the lower Columbia River (Fulton and Pearson 1981). But, since the early 1970's, fishing mortality has been negligible in the lower river. For example, a 68% exploitation rate was reported for Leavenworth NFH spring

Table 12. Percentage smolt to adult survival and percentage recovery distribution for stocks of spring chinook salmon from the Columbia River (adapted from Howell et al. 1985a).

Stock	Smolt to adult survival	Recoveries		
		Ocean	Columbia River	Tributary
Cowlitz River [a] (hatchery)	5.5	63	7	25
Willamette River (hatchery)	0.1 - 2.5	69	31	
Little White (hatchery)	0.2	<5 [b]	95	
Wind River (Carson Hatchery)	<0.1	<5	95	
Lewis River (Carson Hatchery)	2.0	<5	95	
Klickitat River (hatchery)	0.4	<5	95	
Deschutes River (wild)	1.3 - 3.2	35	31	34
Deschutes River (hatchery)	0.02-0.12	15	15	71
John Day R. (wild)	0.98-1.43	<5	95	
Kooskia Hatchery	0.03-0.30	<5	95	
Rapid R. Hatchery	0.02-0.87	<5	95	
Leavenworth Hatchery	0.06-0.89	11	4	85

[a] Includes Kalama and Lewis Rivers

[b] I have used 5% or less ocean harvest for all upper Columbia River spring chinook stocks (Howell et al. 1985a) when ocean harvest was believed to be minor based on tag recoveries, stock identification, etc.

Table 13. Estimates of spring chinook salmon to the Wenatchee River system, 1961-1985, based on the difference between counts at Rock Island Dam downstream and Rocky Reach Dam upstream.

Year	Total	Hatchery	(%)	~~Sport harvest~~	~~(%)~~	Stream Spawners Total	Stream Spawners Observed[a] spawning	Stream Spawners (%)
1961	3,662					3,662	697	(19)
1962	1,962					1,962	1,414	(72)
1963	1,250					1,250	1,168	(93)
1964	2,270					2,270	1,694	(75)
1965	1,570					1,570	1,324	(84)
1966	2,510					2,510	3,102	(124)
1967	1,895					1,89[illegible]	1,834	(97)
1968	4,820					4,82[illegible]	2,274	(47)
1969	2,898	37	[illegible]			2,86[illegible]	1,369	(48)
1970	1,501	140	[illegible]			1,36[illegible]	1,[illegible]68	(85)
1971	954	31	[illegible]			92[illegible]	669	(72)
1972	4,082					4,082	1,3[illegible]	(33)
1973	3,770	3	(tr)			3,767	2,7[illegible]	(73)
1974	5,164	1,700	(33)			3,464	1,25[illegible]	(36)
1975	2,909	29	(1)			2,880	1,95[illegible]	(68)
1976	5,636	2,000	(35)	465	(8)	3,171	1,44[illegible]	(46)
1977	13,038	3,000	(23)	1,207	(9)	8,831	1,23[illegible]	(14)
1978	12,946	1,587	(12)	1,694	(13)	9,665	1,786	(18)
1979	5,132	1,742	(34)			3,390	610	(18)
1980	5,545	2,452	(44)			3,093	818	(26)
1981	4,462	2,420	(54)	125	(3)	1,917	1,019	(53)
1982	5,428	2,799	(52)	110	(2)	2,629	759	(29)
1983	6,774	3,150	(47)	262	(4)	3,624	1,294	(36)
1984	8,603	3,594	(42)	429	(5)	4,580	1,033	(23)
1985	17,848	7,000	(39)	1,000	(6)	9,848	2,811	(29)
Average	5,065					3,601	1,473	(41)

[a]Based on 2.8 chinook per redd (Malm 1984).

Table 14. Estimates of spring chinook salmon to the Entiat River, 1967-1985, based on the differences between counts at Rocky Reach Dam downstream and Wells Dam upstream.

Year	Total	Hatchery	(%)	Stream Spawners Total	Observed[a] spawning	(%)
1967	4,027			4,027	706	(18)
1968	987			987	706	(72)
1969	531			531	238	(45)
1970	1,661			1,661	196	(12)
1971	960			960	380	(40)
1972	1,076			1,076	171	(16)
1973	1,115			1,115	638	(57)
1974	848			848	246	(29)
1975	1,167			1,167	437	(37)
1976	651			651	132	(20)
1977	2,132			2,132	479	(22)
1978	3,844			3,844	913	(24)
1979	1,300			1,300		
1980	942	305	(32)	637	300	(47)
1981	1,834	247	(13)	1,587	266	(17)
1982	517	247	(48)	270	300	(111)
1983	629	660	(105)	0	300	
1984	899	653	(72)	239	238	(100)
1985	3,671	793	(22)	2,419[b]	242	(10)
Average	1,515			1,414	383	(27)

[a] Based on 2.8 chinook per redd (Malm 1984).

[b] Corrected for an estimated illegal sport catch of 459 fish.

Table 15. Estimates of spring chinook salmon to the Methow River System, 1967-1985, based on count at Wells Dam.

				Stream Spawners		
Year	Total	Hatchery	(%)	Total	Observed[a] spawning	(%)
1967	960			960	1,064	(110)
1968	4,932			4,932	1,086	(22)
1969	3,713			3,713	790	(21)
1970	2,627			2,627	1,086	(41)
1971	3,172			3,172	865	(27)
1972	3,617			3,617	1,166	(32)
1973	3,006			3,006	1,389	(46)
1974	3,413			3,413	582	(17)
1975	2,221			2,221	913	(41)
1976	2,778			2,778	336	(12)
1977	4,212			4,212	1,008	(24)
1978	3,616	38	(1)	3,578	1,246	(35)
1979	1,088	102	(9)	986	305	(31)
1980	1,177	137	(12)	1,040	255	(24)
1981	1,834	389	(21)	1,445	272	(19)
1982	2,391	601	(25)	1,790	300	(17)
1983	2,870	902	(31)	1,968	501	(25)
1984	3,272	900	(28)	2,372	548	(23)
1985	5,239	1,200	(23)	4,039	622	(15)
Average	2,955			2,730	754	(28)

[a] Based on 2.8 chinook per redd (Malm 1984).

chinook of the 1970 brood, but 91% of the recoveries occurred in the lower Columbia River (Wahle et al. 1981); the remainder were caught off Alaska, British Columbia, and Washington. The 1974-77 Leavenworth NFH brood releases show only a 15% exploitation rate off British Columbia, Washington, and in the lower Columbia River (WDF 1982). Most of the marked chinook were recovered at Leavenworth NFH. Mortality rate from ocean fishing was recently estimated to be 5% or less for all upper Columbia River spring chinook stocks (Howell et al. 1985a; Table 12).

A limited sport fishing harvest (13% or less of runs) occurs in the Wenatchee River system (Table 13). The harvest consisted almost exclusively of hatchery fish when fishing was restricted to Icicle Creek (1981-1985). No Indian fisheries occur on spring chinook salmon above Rock Island Dam. However, adults surplus to Leavenworth NFH needs were distributed to the Yakima Indian Nation in 1983 (250), 1984 (350), and 1985 (3,340).

Migration and spawning

Upriver runs of spring chinook salmon peak at Bonneville Dam in mid to late April and about 50% of the mid-Columbia River run passes Priest Rapids Dam by mid May; peak passage at Wells Dam occurs a week to ten days later (Howell et al. 1985a). Leavenworth NFH fish to Icicle Creek peak in late May and early June. Arrival time is earlier in low flow years and later in high flow years.

Spawning at Leavenworth NFH commences about the second week in August and continues into the first week in September. Spawning is a few days to a week later at Entiat NFH, and almost two weeks later furthest upstream at the Winthrop NFH. As pointed out earlier, different temperature regimes cause the time of chinook salmon spawning to vary. Combs and Burrows (1957) defined the thresholds for deposition and normal development for chinook salmon eggs as 5.8^{o}C (42.5^{o}F) and 14.2^{o}C (57.5^{o}F). Hatching success declines acutely above and below this temperature range, although the eggs are not affected by colder water temperature after the 128-cell stage of development (Burrows 1963). Such a time-window for egg deposition and initial development prior to the near freezing water temperature of winter is illustrated by the different times spring chinook spawn in the upper Yakima and Naches rivers (Figures 6 and 7).

Age Composition

Chinook salmon scales collected at Leavenworth NFH during spawning cannot be aged with accuracy due to erosion. However, three-year-old fish are about $\leq$61 cm ($\leq$24 inches), four-year-olds about 61-81 cm (24-32 inches), and five year-olds about $\geq$81 cm ($\geq$32 inches) (Figure 8). This size-age separation is similar to that of other Columbia River stocks (Table 16).

Age composition of escapements of spring chinook to the Columbia River varies annually and between stocks (Table 17). Environmental influence on growth is indicated by year-to-year variability in size of the fish in individual stocks, and the fact that stocks tend to vary similarly (Ricker 1972).

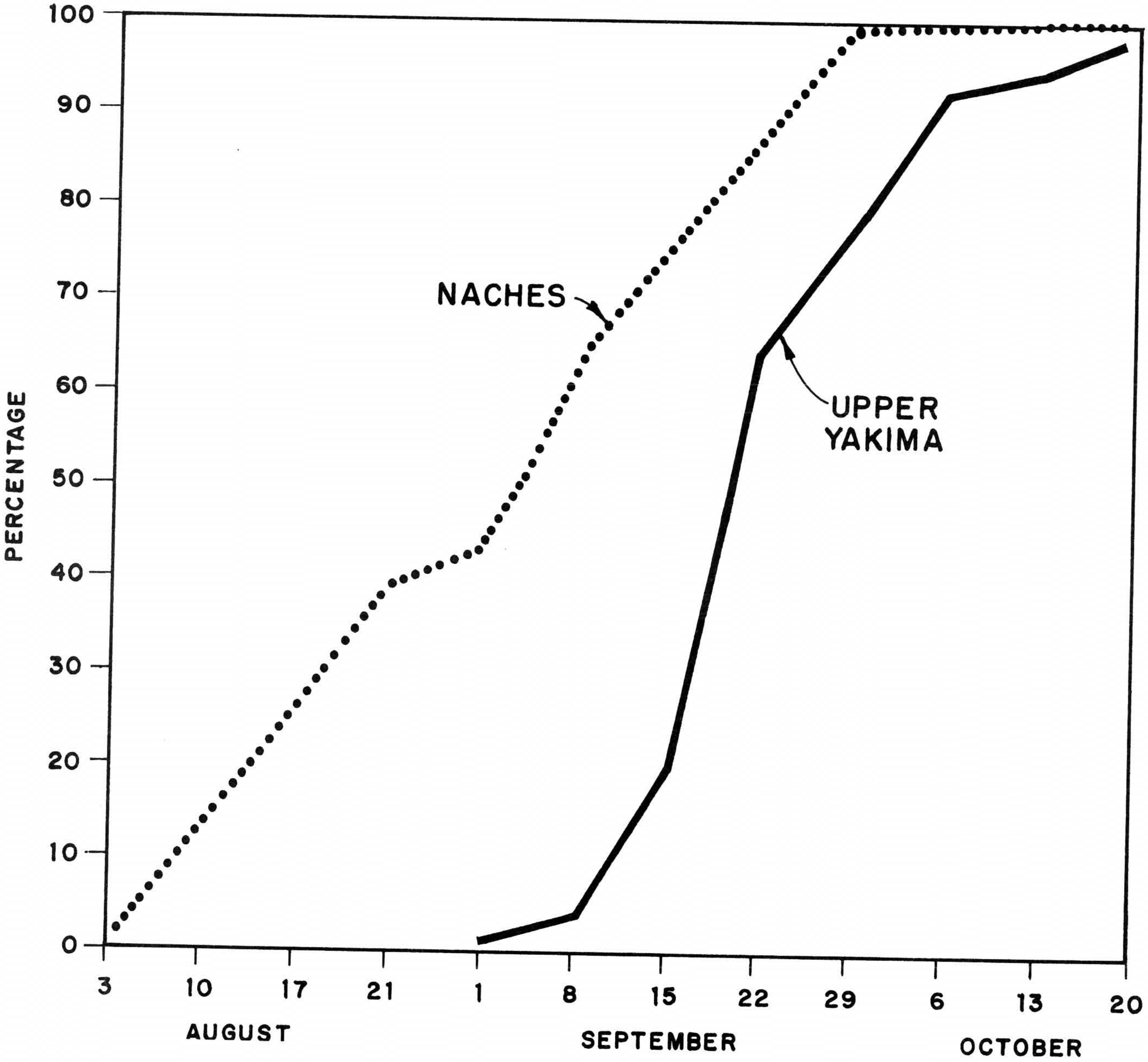

Figure 6. Cumulative percentage of spring chinook spawned by time in the upper Yakima and Naches rivers (from Hollowed 1983).

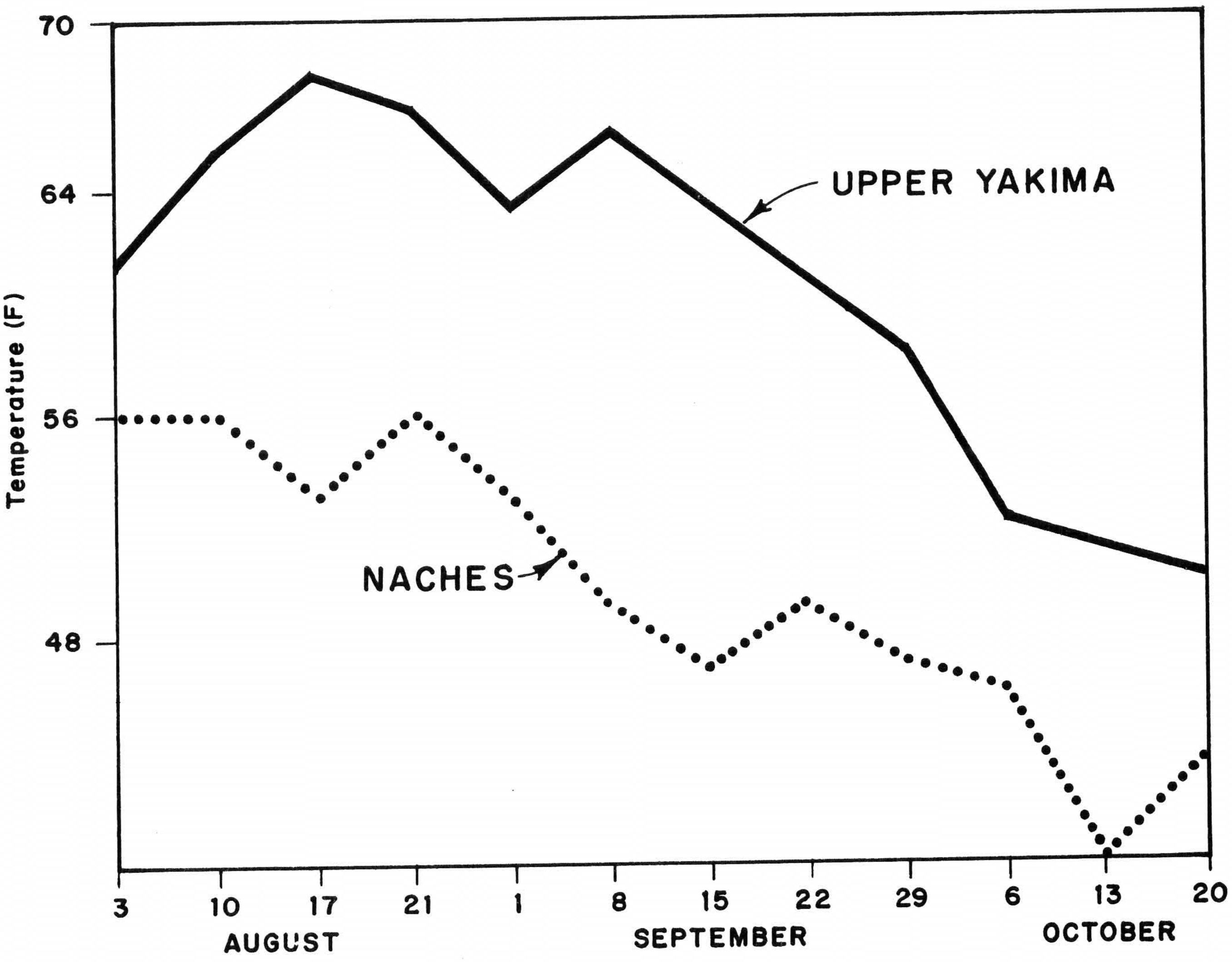

Figure 7. Water temperatures of Upper Yakima River at Cle Elum, Washington (USGS 1981) and Naches River at American River near Nile, Washington (USGS 1970).

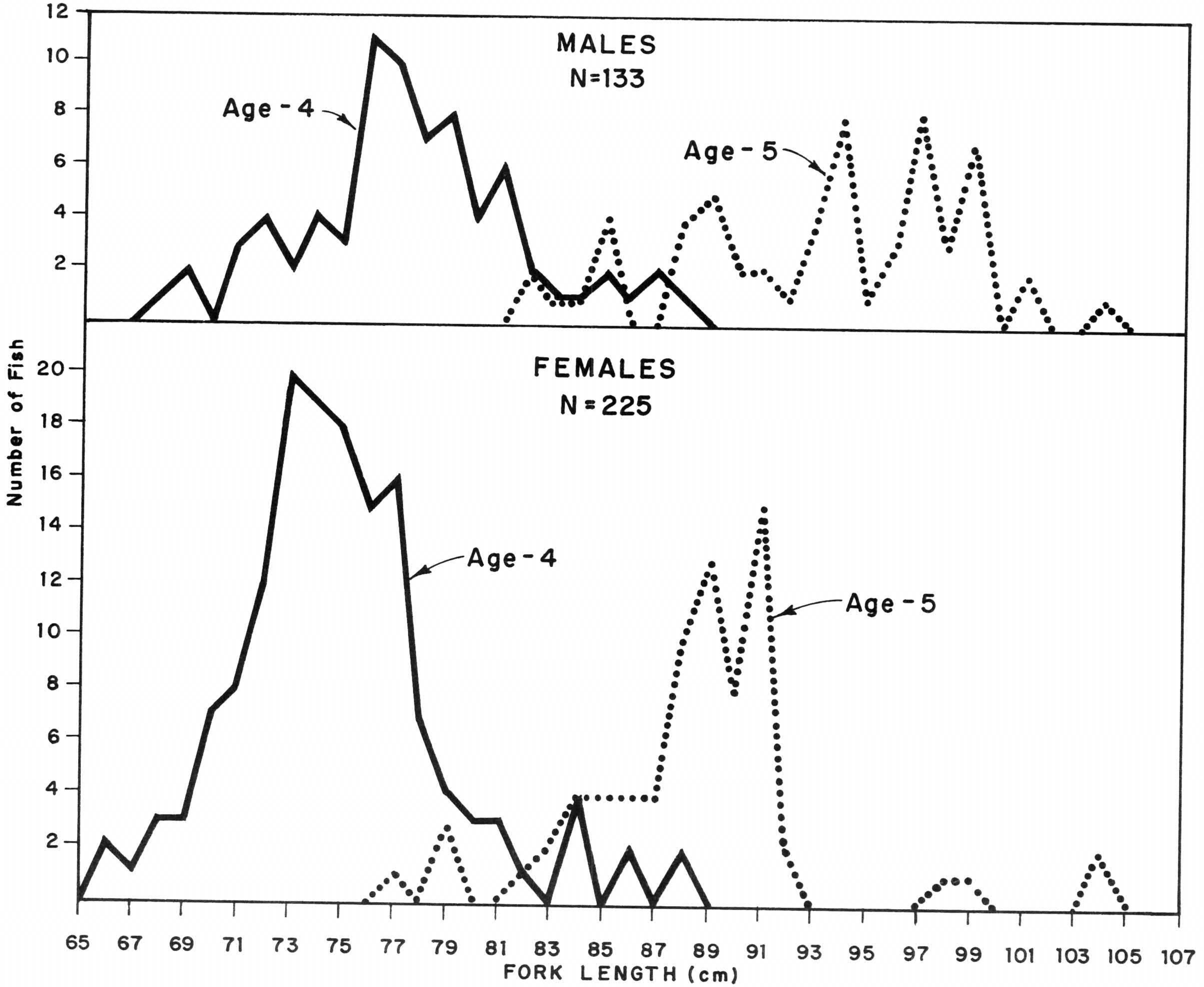

Figure 8. Age and fork length of 382 spring chinook salmon, Leavenworth Hatchery, 1982-84 (145 CW tagged fish 1982-83 and scale analysis of 237 fish sampled in mid June 1983 and 1984).

Table 16. Average and range (in italics) of fork length (cm) and corresponding age of spring chinook salmon stocks of Columbia River (adopted from Howell et al. 1985a).

Stock	Age in Years			
	2	3	4	5
Cowlitz River[a] (hatchery)	41 (28-50)	54 (43-64)	76 (50-93)	89 (75-105)
Willamette River (hatchery & wild)		46 (38-51)	73 (53-94)	88 (61-104)
Carson Hatchery		55 (44-69)	77 (66-94)	92 (76-98)
Deschutes River (wild)		47 (36-65)	69 (50-80)	82 (70-100)
Deschutes River (hatchery)		48 (31-65)		
John Day River (wild)		47 (35-63)	68 (44-95)	82 (65-95)
Kooskia Hatchery		53 (46-56)	76 (57-81)	91 (82-99)
Grand Ronde River (wild)			66 (64-69)	
Salmon River (wild)		51 (41-61)	71 (61-81)	91 (81-111)
Imnaha River (wild)			75 (61-86)	89 (74-111)
Wenatchee River (hatchery)		55 (40-63)	76 (65-89)	91 (76-110)

[a] Includes Kalama and Lewis rivers.

Table 17. Percentage and range (in italics) in age composition of Columbia River spring chinook salmon stocks (adapted from Howell et al. 1985a).

Stock	Years of Data	Age in Years				
		2	3	4	5	6
Cowlitz River[a] (hatchery)	8	27 (4-48)	11 (<1-23)	31 (10-53)	31 (17-40)	<1 (<1-2)
Willamette River (hatchery & wild)	9	4 (1-4)	2 (1-3)	44 (31-55)	48 (31-59)	2 (<1-3)
Carson Hatchery	14		5 (<1-25)	54 (3-98)	41 (2-91)	<1 (0-1)
Little White Salmon Hatchery	13		8 (<1-22)	48 (13-89)	42 (3-85)	<2 (0-6)
Deschutes River (wild)	10		3 (0-6)	77 (57-97)	20 (3-43)	
Deschutes River (hatchery)	6		28	72	<1	
Deschutes River (Warm Springs NFH)	2		7 (6-7)	86 (86-87)	7 (5-8)	
John Day River (wild)	7		3 (1-9)	76 (54-86)	22 (5-44)	
Kooskia Hatchery	10		11 (<1-17)	69 (38-91)	18 (1-54)	2 (0-4)
Rapid River Hatchery	13		11 (4-21)	71 (55-88)	18 (5-36)	
Imnaha River (wild)	16		5 (0-18)	44 (19-60)	50 (30-81)	<1 (0-3)
Grande Ronde River (wild)	16		10 (0-20)	67 (30-81)	23 (11-70)	<1 (0-<1)
Yakima River (wild)	4		9 (4-11)	7 (70-86)	14 (10-22)	
Wenathcee River (hatchery)	6		3 (1-6)	44 (28-70)	53 (24-70)	
Entiat River (hatchery)	4		<1 (0-2)	72 (62-81)	28 (19-38)	
Methow River (hatchery)	4		4 (2-8)	59 (31-85)	38 (13-66)	

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[a] Includes Kalama and Lewis Rivers

Size and sex ratio

Males are typically larger than females of the same age (Figure 9). Females consistently outnumber males about 2:1 (Table 18). There is little difference between the length-weight relationship of each sex, and most spawners return at weights of between 3.9 kg (8.5 lbs) and 8.3 kg (18.5 lbs) (Figure 10).

Hatchery Returns

The release to Icicle Creek of unmarked spring chinook smolts from brood years 1965-80 resulted in an average return of 0.21% of the number released (Table 19). This compares favorably with a 0.24% survival (catch and escapement) for Leavenworth NFH smolts of the 1970 brood year that were coded wire tagged (Wahle et al. 1981), but represents about a three-fold greater return over 1974-77 brood year CWT returns (0.08%) (WDF 1982).

Unmarked spring chinook smolts released from Rapid River Hatchery, Idaho have also consistently produced higher returns to the hatchery than have marked experimental fish (Parrish 1976; Levendofske et al. 1980). In only one of seven brood years at Leavenworth and two of ten brood years at Rapid River did hatchery returns of marked spring chinook equal or exceed the returns of unmarked fish.

SUMMER CHINOOK

Summer chinook salmon are managed primarily for natural production in the Wenatchee, Methow, Okanogan, and Similkameen rivers. However, summer chinook have been released annually from Wells Dam Hatchery and intermittently at Rocky Reach and Winthrop hatcheries in recent years (Howell et al. 1985a). Initial propagation centered on the Entiat NFH in the 1940's.

Chinook salmon runs to the Entiat River had been extirpated prior to the GCFM Project (WDF 1938; Craig and Suomela 1941; Bryant and Parkhurst 1950). Apparently, the Entiat River had never supported runs of summer chinook salmon, although a run of spring chinook reportedly existed before the turn of the century (Craig and Suomela 1941). Both races were introduced (or re-introduced) beginning in 1939, the summer run by relocation of adults intercepted at Rock Island Dam (Table 5) and the spring run by releases of hatchery fry (Tables 6 and 7).

Outmigration

At the Wells Dam spawning channel, fry emergence occurred from January through April during 1968-1971 (Howell et al. 1985a). Conversion of the spawning channel to a hatchery was transitional, with releases from late winter through early summer of fish ranging in size from emergent fry to reared juveniles (Table 20). Young-of-the-year (y-o-y) fish are currently released from the Wells Dam Hatchery in May and June (30-70 fish/lb), and yearlings are released in March-May (7-15 fish/lb) (Howell et al. 1985a). Releases at Entiat NFH in earlier years were March-July of small fish (49-467

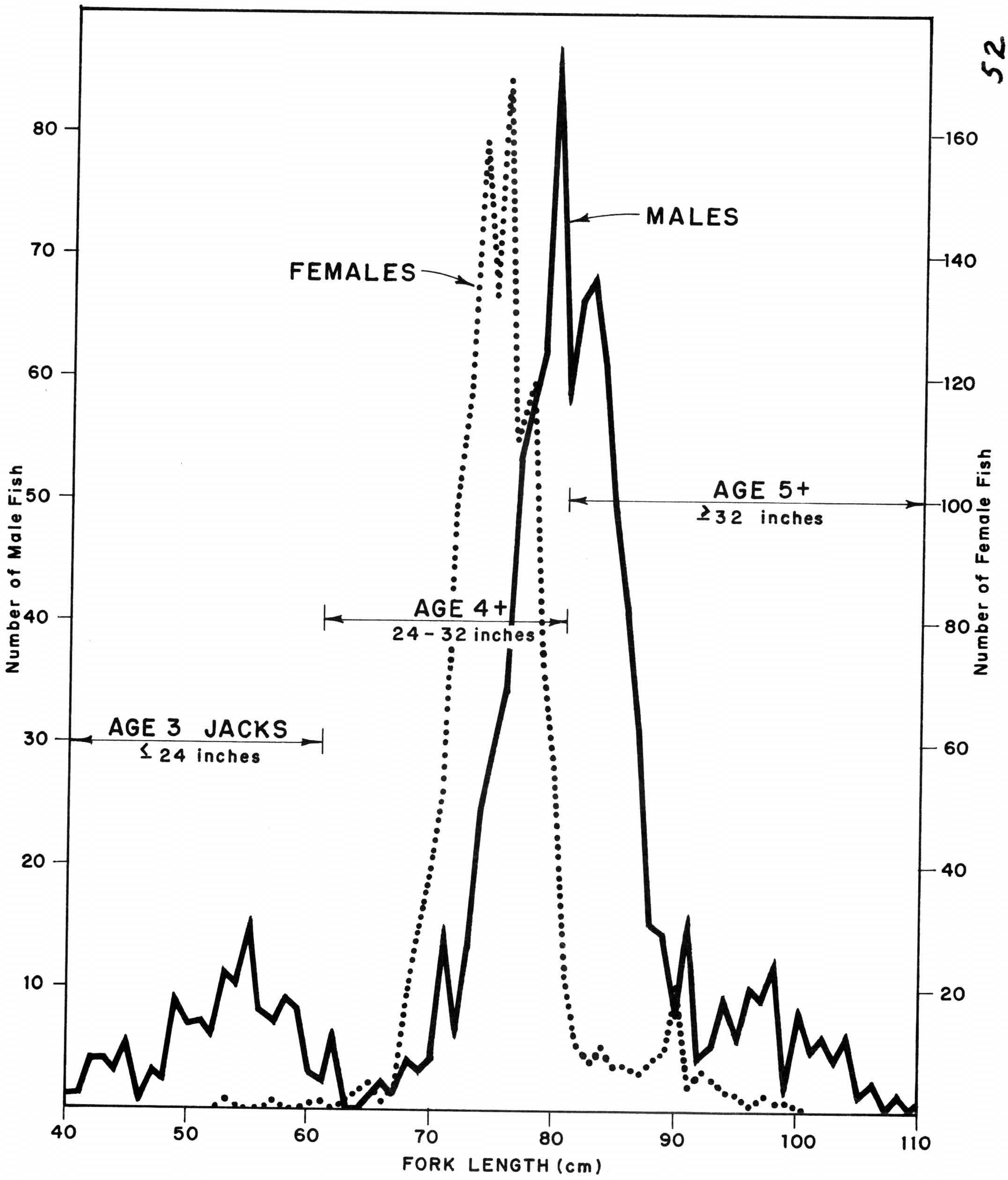

Figure 9. Length frequency distribution of spring chinook salmon escapement, Leavenworth Hatchery, 1984.

Table 18. Percentage of males and females in stocks of Columbia River spring chinook salmon (adapted from Howell et al. 1985a).

Stock	Years of data	Age 4 and 5 years		All ages	
		Male	Female	Male	Female
Cowlitz River (hatchery)	8	43	57	64	36
Willamette River (hatchery)	12	55	45	57	43
Carson Hatchery	17	42	58	44	56
Little White S. Hatchery	11	37	63		
Deschutes River (wild)	4			38	62
Kooskia hatchery	10	40	60		
Grande Ronde River (wild)	2	39	61		
Rapid River Hatchery	5	44	56		
Upper Salmon River (wild)	1			57	43
Yakima River (wild)	3	44	56		
Leavenworth Hatchery	7	40	60	44	56
Entiat Hatchery	6	34	66	35	65
Winthrop Hatchery	5	39	61	40	60
Average or Total	91	42	58	48	52

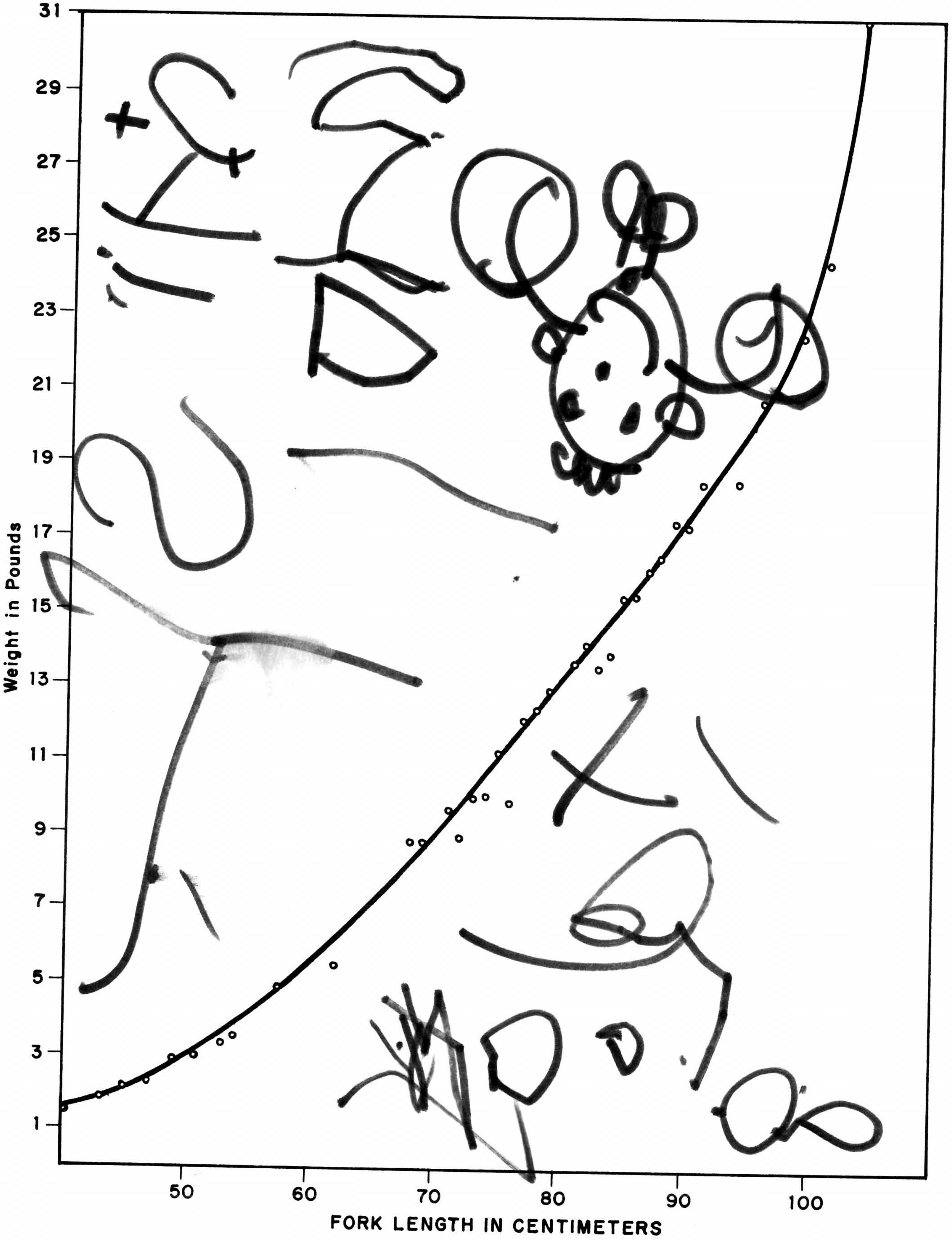

Figure 10. Length-weight relationship of spring chinook, Leavenworth Hatchery, June 1983-84 (230 males and 244 females, with each dot represented by average of five or more fish).

Table 19. Summary of returns of spring chinook salmon to Leavenworth Hatchery from smolts released to Icicle Creek.

Brood Year	Number released (000)		Hatchery escapement	
	Marked	Unmarked	Number	Percent
1965		251.0	116	0.05
1966		86.0	84	0.10
1969		64.0	969	1.51
1970		193.0	467	0.24
	97.0		213	0.22
1971		423.6	1,277	0.37
	99.4		4	0.00
1972		480.0	2,510	0.70
1973		717.0	2,304	0.46
1974		1,182.7	1,733	0.18
	100.4		120	0.11
1975		1,634.2	2,385	0.15
	99.6		124	0.12
1976		1,689.4	2,116	0.14
	95.2		89	0.09
1977		956.1	2,840	0.31
	97.5		2	0.00
1978		1,924.0	3,150	0.16
	98.6		46	0.04
1979		2,177.0	2,019	0.09
1980		1,779.4	6,916	0.38
Total or average	687.7		598	0.08
Total or average		13,557.4	28,886	0.21

A

Table 20. Releases[a] and estimated escapement of summer chinook salmon from the spawing channel and hatchery at Wells Dam.

Brood Year	Releases (000)	Size (fish/pound)	Return Estimated %[b]	Return Estimated no.
1967	2,077	430-719	0.018	374
"	61	100	0.039	24
1968	2,141	231-476	0.018	385
"	1,314	190-243	0.018	237
1969	2,763	290	0.018	497
"	519	71	0.039	202
1970	1,425	400-131	0.018	256
"	359	19	0.039	140
1971	1,801	222	0.039	702
"	573	27	0.05	287
1972	1,287	139	0.039	502
"	808	139	0.05	404
1973	1,575	107	0.039	614
"	873	25	0.05	437
1974	1,342	112	0.039	523
"	285	17	0.05	143
1975	40	17	0.167	67
"	54	8	0.154	83
1976	248	128	0.039	96
"	501	36	0.05	250
"	347	8	0.154	534
1977	100	100^+	0.039	39
"	350	50	0.05	175
1978	550	44	0.05	275
"	587	89	0.039	229
"	1,172	130	0.039	457
"	236	9	0.154	363
1979	2,324	61	0.039	906
1980	2,271	60	0.039	886
1981	40	714	0.018	1[c]
"	1,071	44	0.05	85[c]
"	1,500	42	0.05	120[c]
1982	758	31	---	---
"	675	38	---	---
1983	1,240	46	---	---

[a] From WDF, Wells spawning channel annual reports.
[b] From Seidel 1983.
[c] Includes only jacks (3-year olds).

fish/lb) and September-October of large fish (18-39 fish/lb) (Table 7); yearlings (10-23 fish/lb) were released in March in only two years.

French and Wahle (1959) showed two size groups of chinook salmon outmigrating in the Wenatchee River in April-May 1955. The larger juveniles (95 mm average) were identified as yearling spring chinook smolts and the newly emerged fry (41 mm average) either as spring, summer, or fall chinook. Recently emerged chinook fry have been commonly sampled in the Wenatchee River through early summer (Figure 11). Beak (1980) demonstrated a major exodus of y-o-y emigrants from the Wenatchee River through June 1980 (Figure 12). Downstream at Rock Island Dam, the summer migration begins in mid June and is primarily composed of y-o-y, presumably summer chinook. Larger y-o-y are present in mid July, with migrants continuing to pass the dam through August (Figure 13).

CWT y-o-y summer chinook released from Wells Dam Hatchery (1978 brood) migrated downstream slower (8 miles/day) than yearling releases (23 miles/day). Median date of recovery in the Columbia River estuary was in early August for y-o-y released in June (52 fish/lb), and in early June for yearlings released in mid May (9 fish/lb) (Howell et al. 1985a).

Survival

Returns to all fisheries and escapement averaged 0.3% for 10 CWT groups of subyearlings released from Wells Dam Hatchery (Howell et al. 1985a). Ten marking experiments involving summer chinook from the GCFM Project hatcheries for brood years 1940-43 gave an average return of 0.36% (Table 21).

Run Size

The summer chinook run to the Wenatchee River appeared relatively stable over time (Table 9). However, these data do not consider the possible effects of jacks and fall-run chinook on escapement.

There are no clear differences between summer-run and fall-run chinook salmon in the mid-Columbia, as explained earlier. The convention is that summer chinook salmon spawn earlier than fall chinook, despite the fact that all chinook races spawn at about the same water temperature--an environmental and not a genetic influence. Insofar as differences in run-timing are concerned, the fall chinook salmon run at Rock Island Dam would seem to be no more than the tapering off of the summer run, especially considering that the fall run consists mostly of jacks (Table 3) that commonly run later than older fish (Figure 14). Isozyme gene frequencies showed no significant differences between summer chinook from the Okanogan River, Methow River, and Wells Dam Hatchery and fall chinook from Priest Rapids Hatchery and the Hanford Reach (Schreck et al. 1986). Isozymes show summer chinook salmon in the Okanogan differ, however, from those of Wenatchee and Wells.

More adult summer chinook salmon were surveyed on spawning grounds (Table 22) above Wells Dam than had actually passed the dam (Table 23). This is not possible, especially considering the Indian snag harvest below Chief Joseph Dam further upstream. Estimates of harvest range from 215 chinook in

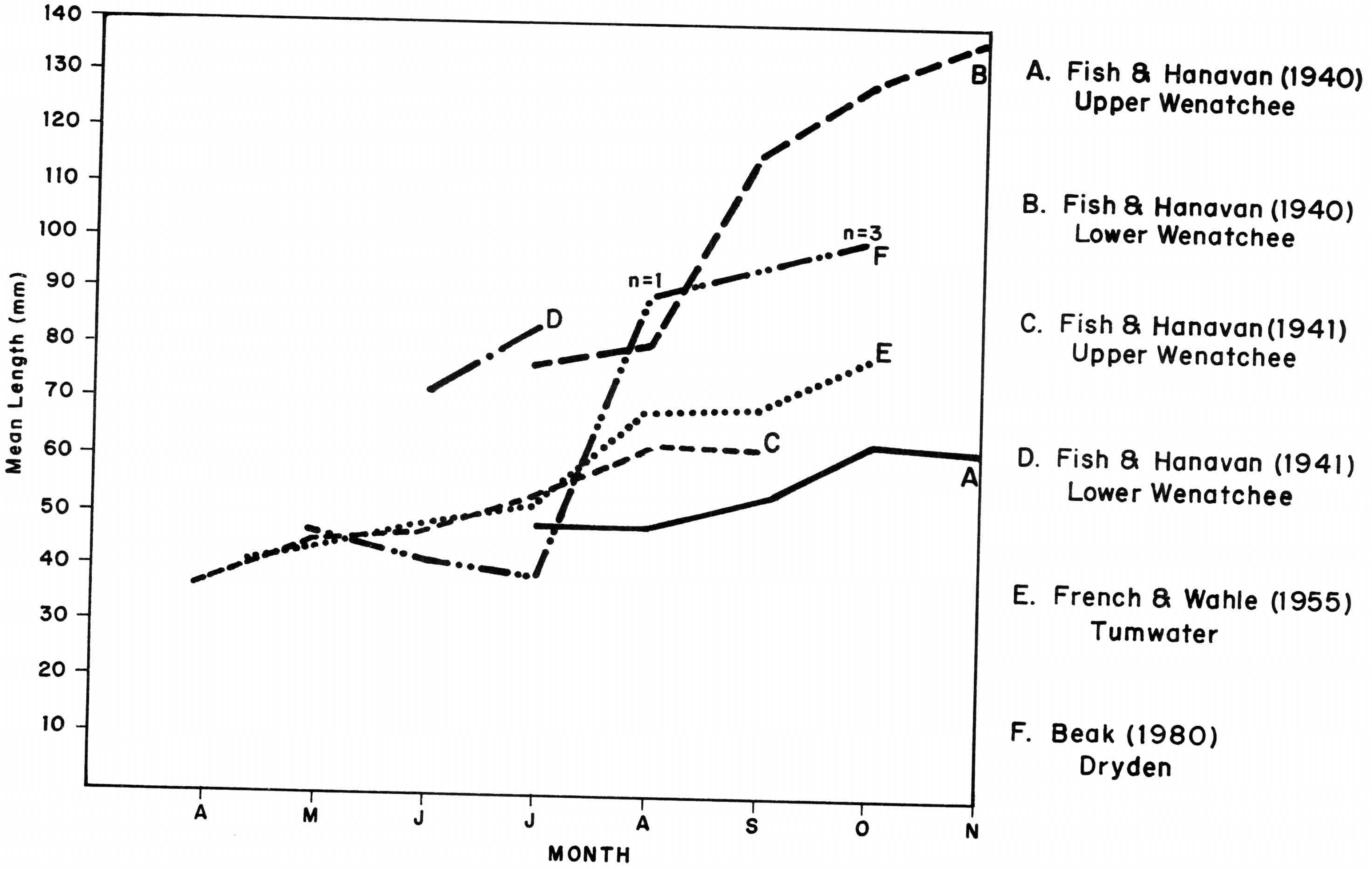

Figure 11. Sizes of young-of-the year chinook salmon sampled from the Wenatchee River by various investigators as related to time (Beak 1980).

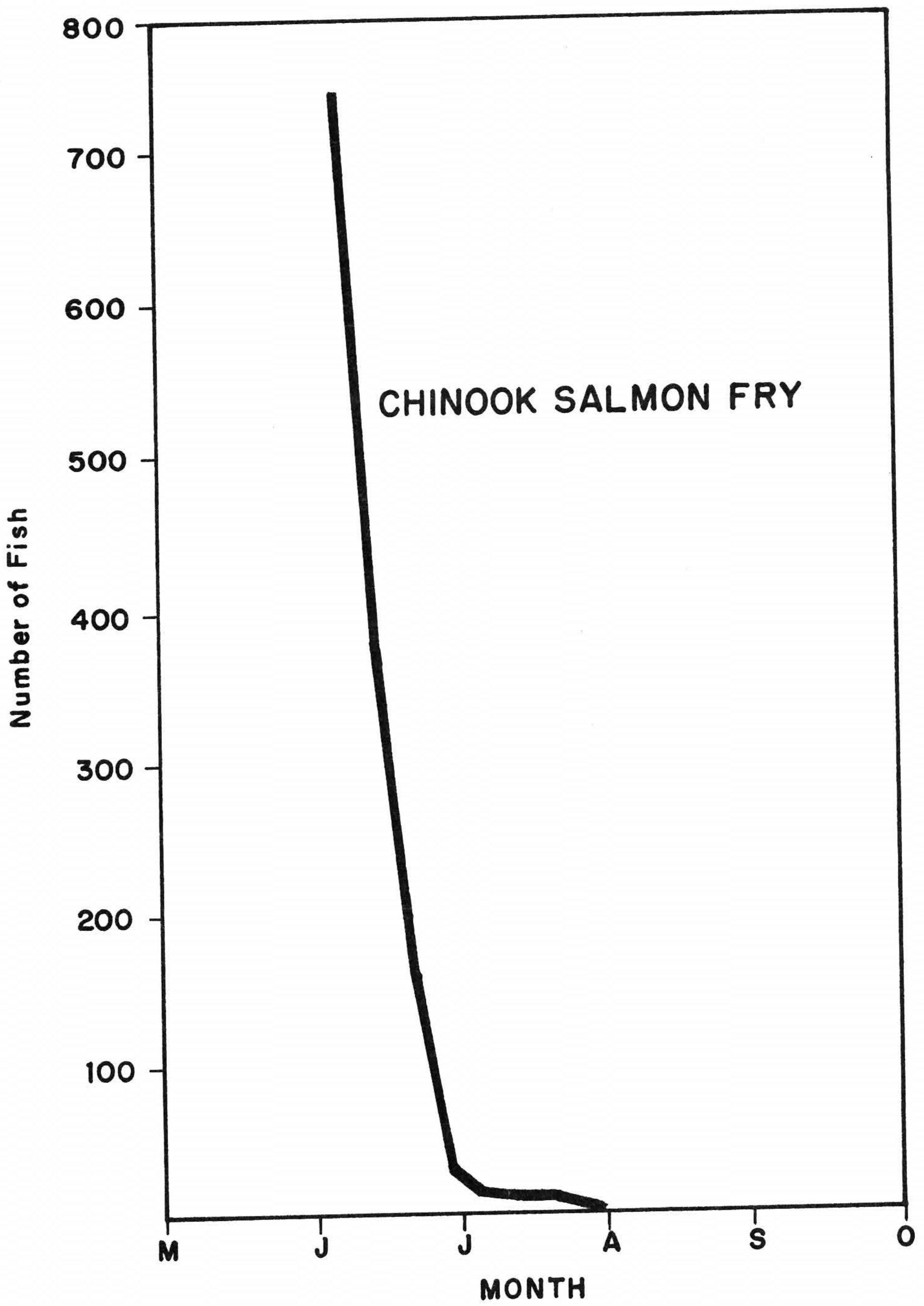

Figure 12. Kvichak trawl (mounted upstream from Dryden Canal intake) catch of downstream emigrating chinook salmon fry, Wenatchee River, 1980 (Beak 1980).

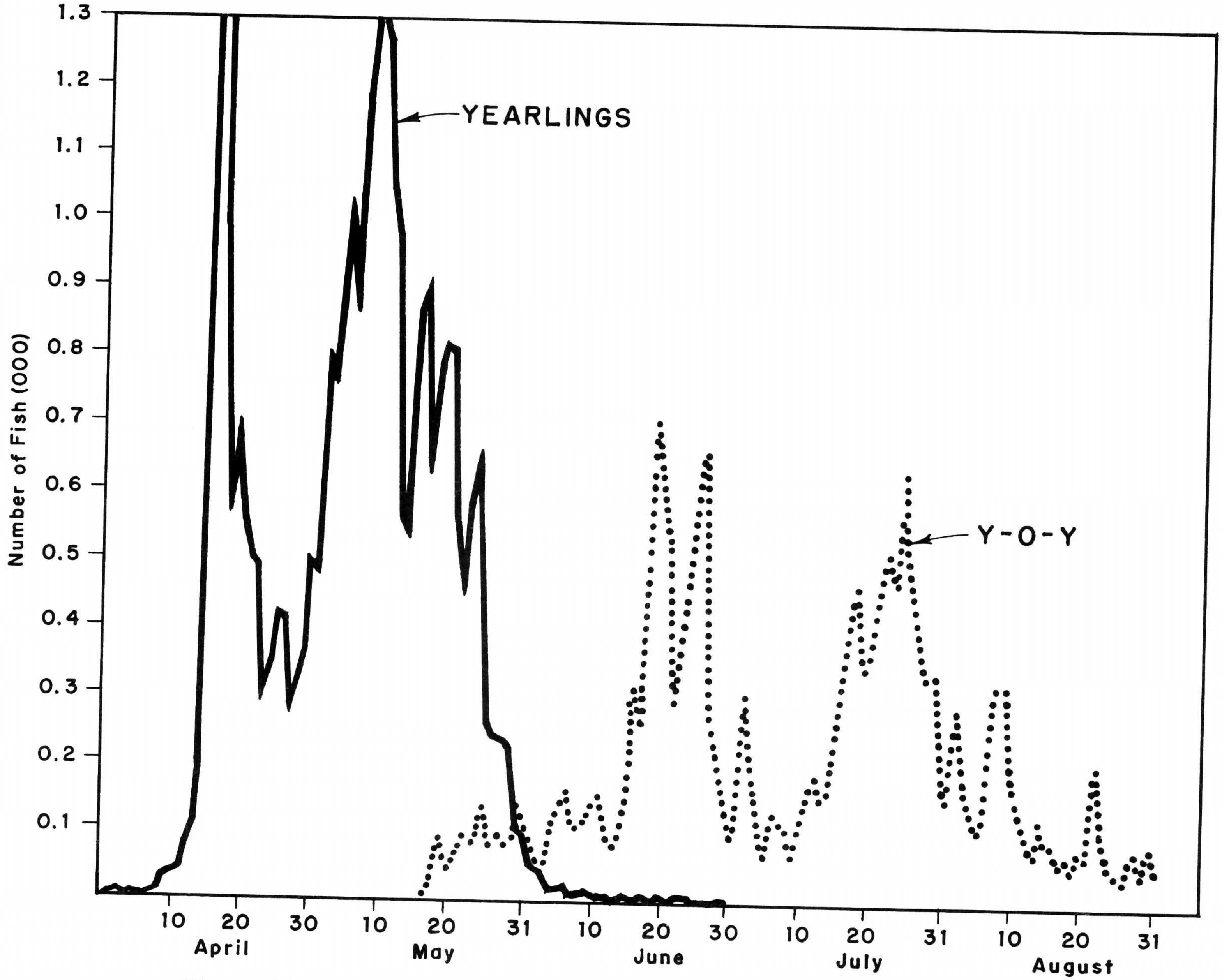

Figure 13. Seasonal distribution of juvenile chinook salmon captured during their seaward migration at Rock Island Dam bypass trap 1985 (adapted from Truscott 1985).

Table 21. Survival of 1940-43 brood, fin-clipped chinook salmon from mid-Columbia River hatcheries (Fulton and Pearson 1981).

Experiment number (race)[a]	Brood year	Egg source	Releases			
			Number	Area	Date	Percent recovery
23(SU)	1940	Rock Is. Dam	100,000	Entiat R.	7-8/41	0.06
24(SU)	1940	Rock Is. Dam	50,008	Entiat R.	10/41	0.18
25(S&SU)	1940	Rock Is. Dam	24,982	Entiat R.	3/42	1.70
26(S&SU)	1940	Rock Is. Dam	25,400	Entiat R.	5/42	0.98
31(SU)	1942	Rock Is. Dam	40,015	Methow R.	10/43	0.43
32(SU)	1942	Rock Is. Dam	10,579	Methow R.	4/44	1.94
33(SU)	1943	Rock Is. Dam	24,916	Entiat R.	10-11/44	0.81
34(SU)	1943	Rock Is. Dam	25,654	Entiat R.	3-4/45	1.30
29(S)	1941	McKenzie R.	50,435	Icicle Cr.	10/42	0.09
30(F)	1942	Big White	48,522	Icicle Cr.	10/43	0.76
27(SU)	1940	Rock Is. Dam	25,000	Icicle Cr.	5/42	0.10
28(SU)	1940	Rock Is. Dam	25,000	Methow R.	5.42	0.11
Total or Average			450,511			0.489

[a] Spring = S; Summer = SU; Fall = F (Cut-off date for spring chinook at Rock Island Dam during these years was June 30).

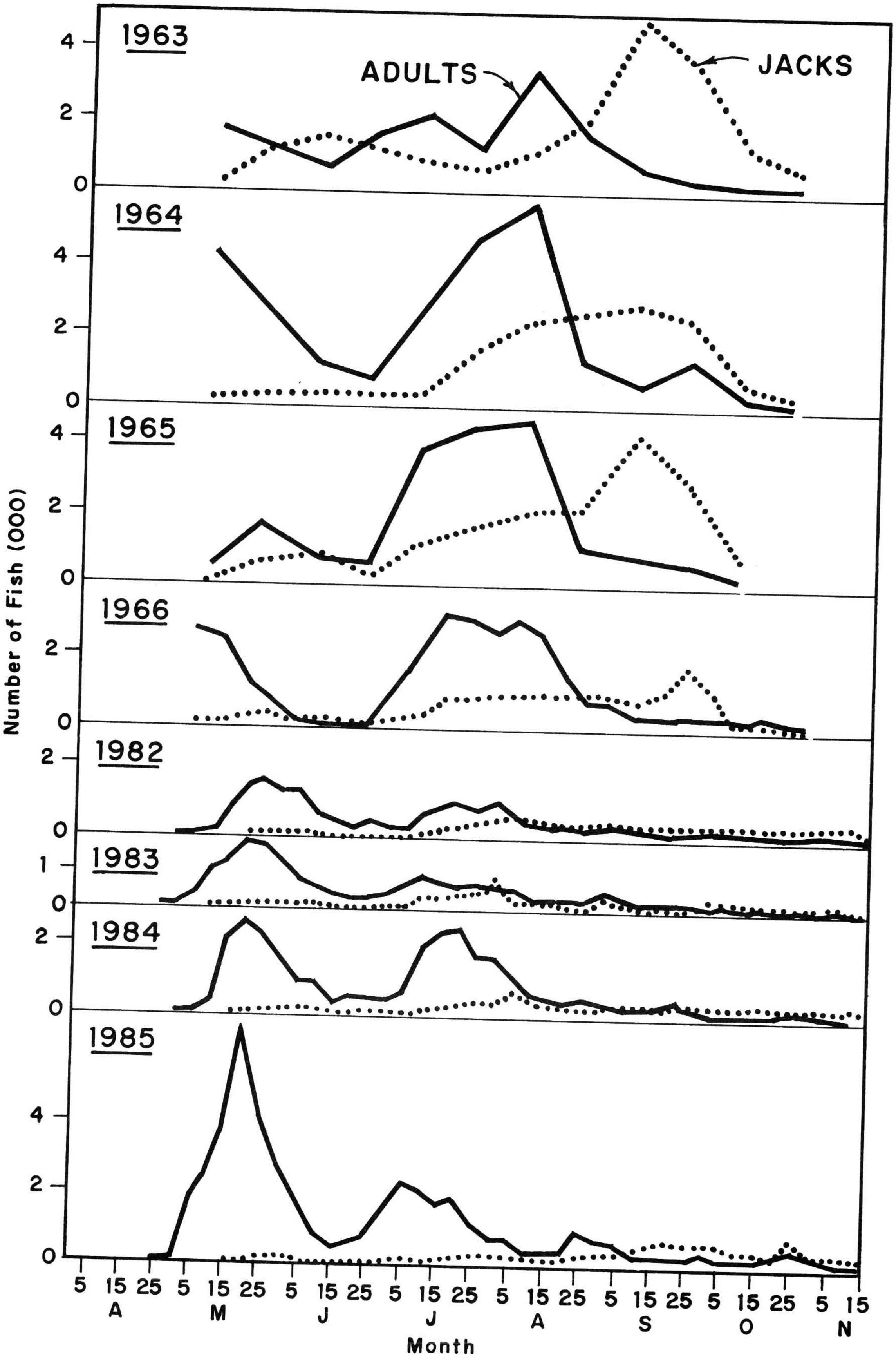

Figure 14. Seasonal distribution of chinook salmon counted ascending Rock Island Dam for selected years. Dashed lines are jacks (≤24 inches); solid lines are adults.

Table 22. Escapements of summer chinook salmon to and above Wells Dam.

Year	Wells Dam count		Retained at Wells Dam Hatchery (%)	Spawning ground counts[a]		
	Total	Adults		Methow R.	Okanogan R.	Similkameen R.
1957				1,398	164	93
1958				1,039	291	93
1959				402	155	96
1960				601	90	71
1961				372		
1962				2,102		
1963				924	27	53
1964				2,465	770	158
1965				1,742	338	108
1966				3,952	1,190	477
1967	12,266	8,412	2,004 (23)	2,272	462	239
1968	8,918	4,798	2,277 (47)	2,043	719	332
1969	6,854	2,978	2,873 (94)	1,020	319	257
1970	8,041	4,474	1,745 (39)	2,186	2,034	1,107
1971	6,007	3,862	1,793 (46)	1,742	961	651
1972	4,058	2,525	1,694 (67)	1,008	564	171
1973	5,089	2,737	2,088 (76)	1,135	428	198
1974	4,572	2,979	2,893 (97)	691	350	403
1975	8,532	3,866	3,253 (84)	1,339	846	623
1976	7,889	5,363	2,518 (47)	592	332	415
1977	7,526	5,054	2,628 (52)	1,132	856	431
1978	6,422	5,128	2,259 (44)	1,606	605	831
1979	9,506	6,696	2,095 (31)	1,928	536	428
1980	5,520	4,206	1,827 (43)	1,070	366	533
1981	4,241	3,103	1,533 (49)	605	171	406
1982	3,258	2,166	700 (32)	440	71	183
1983	2,763	1,975	848[b] (43)	202	112	177
1984	5,885	4,765	1,185[b] (25)	502	729	933
1985	4,379	4,032	1,387[b] (34)	508	428	958

[a] Aerial redd counts x 3.1 adult spawners (Meekin 1967).

[b] About 10% jacks used in propagation, but not included in these figures.

Table 23. Escapements of summer and fall chinook salmon above Wells Dam.

	Summer Chinook		Fall Chinook[c]	Summer/Fall Chinook Combined	
Year	Adults[a]	Spawning Counts[b] (%)	Adults	Total Adults	Spawning Counts (%)
1967	6,408	2,973 (46)	648	7,056	2,973 (42)
1968	2,521	3,094 (123)	752	3,273	3,094 (95)
1969	105	1,596 (1520)	646	751	1,596 (212)
1970	2,729	5,327 (195)	1,109	3,838	5,327 (138)
1971	2,069	3,354 (162)	748	2,817	3,354 (119)
1972	831	1,743 (209)	522	1,353	1,743 (129)
1973	649	1,761 (271)	767	1,416	1,761 (124)
1974	86	1,444 (1679)	446	532	1,444 (271)
1975	613	2,808 (458)	650	1,263	2,808 (222)
1976	2,845	1,339 (47)	1,221	4,066	1,339 (33)
1977	2,425	2,419 (100)	1,151	3,576	2,419 (68)
1978	2,869	3,042 (106)	856	3,725	3,042 (82)
1979	4,601	2,892 (63)	1,070	5,671	2,892 (51)
1980	2,379	1,969 (83)	477	2,856	1,969 (69)
1981	1,570	1,182 (75)	438	2,008	1,182 (59)
1982	1,466	694 (47)	786	2,252	694 (31)
1983	1,127	491 (44)	593	1,720	491 (30)
1984	3,578	2,164 (60)	903	4,481	2,164 (50)
1985	2,645	1,894 (72)	1,083	3,728	1,894 (51)
Total	41,516	42,186 (102)	14,866	56,382	42,186 (75)
Average	2,185	2,220 (102)	782	2,967	2,220 (75)

[a] Wells Dam count minus hatchery spawners (Table 22).

[b] Aerial redd counts x 3.1 adult spawners (Meekin 1967).

[c] There is no known spawning of fall chinook salmon as a separate race because they mix with summer chinook and spawn at the same time.

1980 (Paul Kucera, Colville Confederated Tribes; pers. comm.) to about 2,000 in 1977 (Richard Laramie, WDF; pers. comm.), although numbers caught perhaps rarely exceed 200 per year (Meekin and Allen 1974). However, if counts of fall chinook passing Wells Dam are combined with counts of summer chinook, the relationship between dam and spawning counts becomes closer (Table 23).

Chinook salmon spawned in the mainstem Columbia River upstream of Wells Dam prior to its construction in 1967 (Table 10), and early dam counts, included returning progeny (Figure 15). The Wells Dam Hatchery usurped a large portion of the summer chinook adults in some years (e.g., 94% in 1969) (Table 22). Prespawning mortality of adult spawners at the hatchery, resulting from warmwater columnaris disease (Flexibacter columnaris), was the cause of this stock reduction (Figure 15)[3]. The problem was largely corrected beginning in 1980 by using cooler well water to hold spawners (McGee 1981).

There is no indication that the inundation of the Columbia River by the Wells Dam impoundment resulted in the translocation of mainstem summer chinook spawners to upstream tributaries. About the same number of adults (2,220) now appear on tributary spawning grounds each year than before (2,033) Wells Dam was built (Table 22). However, 74% of the upstream escapement spawned in the Methow River before Wells Dam was built compared to 52% after the dam was built.

Historically, the Methow River primarily supported runs of coho salmon, followed by steelhead trout, with some chinook salmon (Craig and Suomela 1941). These authors could find no evidence that the chinook run consisted of anything but spring chinook, although they pointed out that it was possible some summer chinook spawned in the lower Methow River. However, the Okanogan River and the Similkameen, the major tributary, had supported summer chinook (Craig and Suomela 1941). Forty chinook were observed spawning in the Similkameen in 1934, 20 in 1935, and 50 in 1936. These populations were intercepted at Rock Island Dam 1939 to 1943, but there is no evidence that any adults or their progeny were ever reintroduced (Tables 6, 7, 8; Fish and Hanavan 1948).

Inter-dam escapement of adult summer/fall chinook adult salmon to the Rocky Reach impoundment has averaged only a little less (2,808) than the escapement above Wells Dam (2,967) (Tables 23 and 24). Most of these fish cannot be accounted for by numbers spawning in streams tributary to Rocky Reach Reservoir.

Peak spawning counts on the Entiat River amounted to only 3% to 12% of the summer/fall adult escapement between Rocky Reach Dam and Wells Dam (Table 24). Aerial survey of chinook redds in the Entiat River is difficult because of its small size and obscuring riparian vegetation, which leads to under-

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[3] Between 1967-1980, 31,947 adults were trapped out of runs at Wells Dam for artificial propagation. Theoretically, based on the tagging data of Seidel (1983), escapement of progeny back to the dam totaled 2,701 jacks and 4,131 adults.

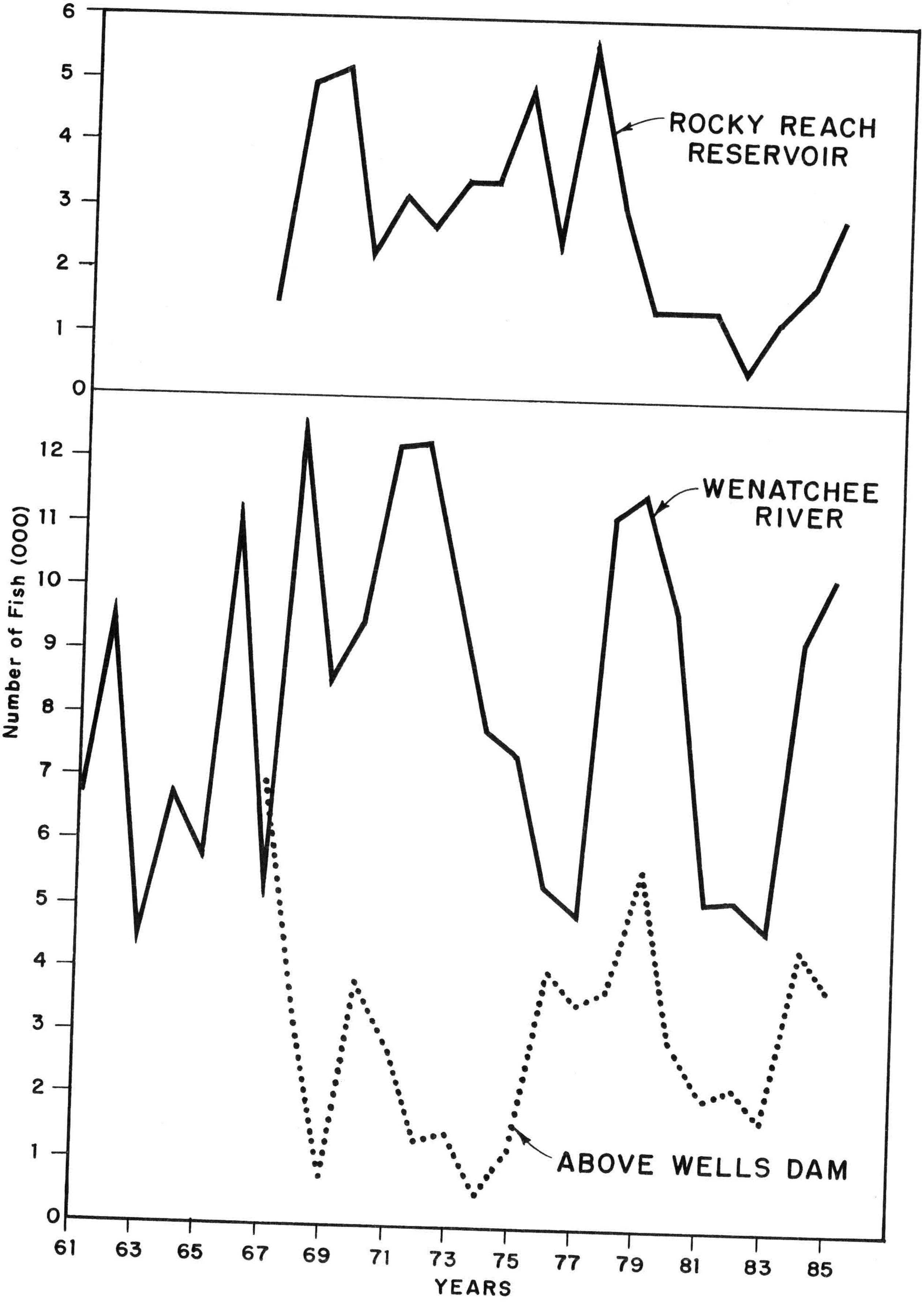

Figure 15. Inter-dam escapements of summer/fall chinook salmon to the Wenatchee River, Rocky Reach Reservoir, and above Wells Dam.

Table 24. Inter-dam counts of summer and fall chinook salmon to Rocky Reach Reservoir, 1967-1985.

Year	Summer Chinook		Fall Chinook		Total	Spawning ground surveys			
	Adults	Jacks	Adults	Jacks	Adults	Turtle Rock Hatchery	Entiat River	Chelan River	Percent of total escapement
1967	1,451	2,414	0	0	1,451	106	167	0	18
1968	4,943	1,363	0	0	4,943		167		3
1969	5,127	1,171	0	666	5,127		127		2
1970	2,278	1,590	0	1,402	2,278		81		4
1971	3,130	894	0	1,267	3,130		56		2
1972	2,637	494	68	969	2,705		16		1
1973	3,474	1,083	0	2,111	3,474		74		2
1974	3,443	283	38	523	3,481		0		0
1975	4,882	1,262	41	558	4,923		0		0
1976	2,400	1,595	0	441	2,408		19		1
1977	5,539	2,309	0	937	5,539		12		
1978	2,967	843	0	515	2,967		40		1
1979	1,427	0	0	0	1,427		19		1
1980	1,126	0	314	357	1,440		25		2
1981	1,231	0	175	254	1,406			143	10
1982	539	305	17	360	556			56	10
1983	802	147	499	207	1,301			50	4
1984	1,100	4	704	722	1,804			84	5
1985	1,905	497	1,091	1,977	2,996			71	2
Total	50,409	16,254	2,947	13,266	53,356	106	803	404	2
Average	2,653	855	155	698	2,808				

estimates of spawners. However, this is of small consequence in the accounting. Chinook eggs incubated at temperatures below 5.8°C (42.5°F) from first deposition suffer abnormally high mortalities (Combs and Burrows 1957). Such temperatures prevail in the Entiat River before the middle of October each year. The spawning period of summer chinook in the Entiat River was from early September to late November, with a peak in late October (Burrows 1954). Burrows concluded that the summer chinook run was largely an artifact of hatchery propagation; this was verified after propagation of summer chinook at Entiat NFH was abandoned, by the decline in natural spawning (Table 24).

The only other tributary of any consequence in the Rocky Reach Reservoir area is the Chelan River. The river flows 6.4 km (4 miles) from Lake Chelan, but in that distance it drops 119 m (390 feet) and passes through a power house shortly before joining the Columbia River. Chinook salmon spawning below the power house has been noted back to 1937 (Chapman 1941). The largest number of spawners observed was 143 in 1981, which was 10% of the escapement to Rocky Reach Reservoir that year (Table 24).

Considering the large number and persistence (19-year average of 2,808 adults) of the escapement of summer/fall chinook salmon to Rocky Reach Reservoir, it would seem that most of these fish spawn in the reservoir. Rocky Reach Reservoir retains the characteristics of a flowing river in its upstream portion where chinook salmon redds (maximum of 57 in 1968) have been observed (Table 10). It was believed that relatively few chinook salmon spawned in the area inundated by Rocky Reach Dam (Meekin et al. 1971). However, it was not recognized at the time that chinook may spawn in the mainstem Columbia River to a depth of 35 feet. Chinook redds in water deeper than about 8 feet generally are not visible from the air (Chapman et al. 1983).

Inter-dam escapement of summer/fall chinook salmon to the Wenatchee River has averaged 8,278 adults (range 4,691 to 12,445; Table 25). Fluctuations appear to be within the bounds of natural variation (Figure 15). About 60% of the total escapement of summer/fall chinook above Rock Island Dam returns to the Wenatchee River, with the remainder about equally divided between the Rocky Reach area (20%) and above Wells Dam (20%).

Catch Distribution

Commercial harvest of marked summer chinook for brood years 1940-43 from the GCFM Project hatcheries primarily occurred in the lower Columbia River (Fulton and Pearson 1981). Since 1970, harvest of summer chinook salmon in the Columbia River has been limited to incidental commercial and recreational catches (50 to 4,450 fish total) or to tribal ceremonial and subsistence fisheries (200 to 1,050 fish documented) (Howell et al. 1985a). A harvest profile for two broods (1974 and 1976) of CWT fingerlings released from Wells Dam Hatchery revealed that 78% of the catch occurred in Alaska and British Columbia waters (Howell et al. 1985a).

Table 25. Escapement of summer and fall chinook salmon to the Wenatchee River.

	Summer Chinook		Fall Chinook[a]	Summer/fall chinook combined	
Year	Adults[a]	Spawning counts (%)	Adults	Total adults	Spawning counts (%)
1961	2,412	2,722 (113)	3,936	6,348	2,722 (43)
1962	5,063	3,351 (66)	4,494	9,557	3,351 (35)
1963	4,433	4,232 (95)	156	4,589	4,232 (92)
1964	4,535	4,099 (90)	2,239	6,774	4,099 (61)
1965	4,666	7,245 (155)	1,147	5,813	7,245(125)
1966	8,673	3,906 (45)	2,418	11,091	3,906 (35)
1967	4,282	5,264 (123)	1,146	5,428	5,264 (97)
1968	10,605	5,559 (52)	1,840	12,445	5,559 (44)
1969	7,120	4,293 (60)	1,457	8,577	4,293 (50)
1970	8,094	4,199 (52)	1,346	9,440	4,199 (44)
1971	10,450	4,399 (42)	1,774	12,224	4,399 (36)
1972	10,531	4,228 (40)	1,737	12,268	4,228 (34)
1973	5,902	3,546 (60)	4,132	10,034	3,546 (35)
1974	3,220	3,580 (111)	4,544	7,764	3,580 (46)
1975	7,394	2,868 (39)	0	7,394	2,868 (39)
1976	4,582	3,489 (76)	743	5,325	3,489 (65)
1977	4,574	4,855 (106)	401	4,975	4,855 (97)
1978	10,684	6,184 (58)	566	11,250	6,184 (55)
1979	10,967	5,348 (48)	594	11,561	5,348 (46)
1980	9,192	6,456 (70)	545	9,737	6,456 (66)
1981	4,947	4,771 (96)	202	5,149	4,771 (92)
1982	4,169	4,380 (105)	1,019	5,188	4,380 (84)
1983	4,125	2,251 (55)	566	4,691	2,251 (48)
1984	8,647	4,098 (47)	463	9,110	4,098 (45)
1985	8,304	3,445 (41)	1,922	10,226	3,445 (34)
Total	167,571	108,768 (65)	39,387	206,958	108,768 (53)
Average	6,703	4,351	1,575	8,278	

[a] There is no known spawning of fall chinook as a separate race because they mix with summer chinook and spawn at the same time.

Migration and Spawning

The return migration of summer chinook salmon begins in late May or early June with peak counts at Bonneville Dam during early July. About 50% of the run has migrated past Priest Rapids Dam in mid-July, and past Wells Dam in late July. Frequently, summer chinook do not enter the Methow and Okanogan rivers until September (Meekin et al. 1966; Meekin 1967). Rather, they hold in the cooler water of the Columbia River below Chief Joseph Dam. At this location, they are vulnerable to the Indian snag fisheries mentioned and, before the problem was alleviated in the early 1970's, to mortality from dam induced nitrogen supersaturation (Meekin and Allen 1974). Spawning occurs during late September through early November, depending on water temperatures.

Age Composition

Jack salmon are much more numerous in the summer-run chinook (24%) than in the spring-run (12%), and even more abundant in the fall-run (48%) at Rock Island Dam (Tables 1, 2, 3). Spring chinook generally stay in fresh water their first year of life, migrating downstream in the spring of their second year. Most summer/fall chinook migrate to the ocean during the first year of life. This difference in behavior causes a considerable difference in age and size at maturity.

Jack salmon may be age types 3_2 or 2_1 (of the two numbers used, the first indicates the fish's year of life when captured and the second, or subscript, the year of life at seaward migration). In contrast to spring chinook, most 3-year-old fall chinook are not jack salmon because they have had 2 years of ocean growth (Young and Robinson 1974).

The summer chinook run is the only run entering the Columbia River where both sub 1 and sub 2 age types are abundant in each age group. When age at seaward migration is plotted by week for the summer return, sub 2 age types prevail during the early part of the run in mid June and sub 1 age types are predominant during the latter part of the run in late June and July. Counts at Ice Harbor and Priest Rapids Dams indicated that most of the early part of the summer chinook run (sub 2 age type) is destined for the Snake River, while most of the later migrants (sub 1 age type) are destined for the mid-Columbia (Young and Robinson 1974).

Jacks in the run of summer chinook salmon to the mid-Columbia River above Priest Rapids Dam primarily consist of 3-year-olds with 2 years in freshwater (Table 26) (Fulton and Pearson 1981). In contrast, jacks in the run of fall chinook that spawn in the unimpounded Hanford Reach below Priest Rapids Dam consist of 2-year-olds that average 37% of the run. Jacks are entirely males, although 3-year-old fish are predominantly males as well (83% average in 1979-1983) (Howell et al. 1985a).

Table 26. Percentage and range (in italics) in age composition of summer chinook salmon stocks from the Columbia River.

Stock	Years of Data	Age in years 2	3	4	5	6
Rapid River[a] (wild)	2		46 (36-51)	39 (35-41)	15 (8-29)	
S.F. Salmon R.[a] (wild)	8		26 (6-54)	64 (34-89)	10 (3-22)	
Wells Dam[a] Hatchery	4	4	16	48	30	2
Leavenworth[b] hatcheries	4		18	48	30	4

[a] From Howell et al. 1985a; Wells Dam Hatchery from four CWT brood years (1974-77).

[b] From Fulton and Pearson 1981; fin-clipped fish from four brood years (1940-43).

Size and Sex Ratio

Mature chinook of all races, primarily 4- and 5-year-old fish[4], are significantly weighted toward females (Table 27). However, there is usually a surplus of males on the spawning grounds due to the high incidence of jacks in runs (Table 27).

Race-specific differences are indicated, however, in the tendency for summer chinook salmon to be larger than springs and fall chinook salmon to be larger than summers (Figure 16). Larger fish select larger gravel size for spawning, which in turn is determined by current velocity. Thus, larger chinook spawn in higher velocity water found in the lower reaches of major tributaries and in sections of the mainstem Columbia River. Of most importance, the fecundity of larger spawners is greater than that of smaller spawners (Galbreath and Ridenhour 1964; Matthews and Meekin 1971).

Hatchery Returns

The number of adult salmon returning to a hatchery from juveniles released is a measure of their survival. Here again, as in dam counts, survival rates of fish in the river, estuary, and ocean cannot be differentiated. Other complicating factors to such survival estimates are the variable age at maturity, obtaining an estimate of age class mix in each year's return examined, and the sometimes uncertain recovery of adults at the hatchery.

Enough is known about escapements of summer chinook salmon to Entiat NFH to make reasonable estimates of escapements by brood years 1940 to 1957 (Table 28). This information includes 100% effective racking of the Entiat River with an electric weir 1953 to 1691 (Burrows 1957); known-age marked fish from brood releases 1940, 1943, 1949, 1950; and 3-year-old jacks clearly differentiated based on lengths. The data show an overall return to the hatchery of 0.20% (range 0.00 to 1.43). Return to the Wells Dam Hatchery for brood year releases 1967 to 1981 appears to be about 0.03% (Table 20).

FALL CHINOOK

Fall chinook salmon spawned in the unimpounded Hanford Reach represent one of the most viable chinook stocks remaining in the Columbia River. Aerial surveys of fall chinook redds have been made in the Hanford Reach annually since 1947 (Watson 1976). Initial counts reflected limited spawning prior to construction of Priest Rapids Dam. However, the number of redds increased dramatically from about 300 in 1960 to 7,310 in 1984 (Becker 1985; Howell et al. 1985a).

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[4] Older fish are uncommon in the Columbia River and can be ignored. Of 67,771 chinook salmon of all races examined by Young and Robinson (1974) in the commercial harvest from the lower river 1960 to 1969, only 141 or 0.2% were estimated to be 6-year-old fish.

Table 27. Percentage of males and females in races of Columbia River chinook salmon.

		Ages 4 and 5		All ages	
Location	Race	Male	Female	Male	Female
Lower Columbia R.[a]	Early springs[b]	43	57	43	57
Lower Columbia R.[a]	Springs	46	54	48	52
Average, Table 18	Springs	42	58	48	52
Lower Columbia R.[a]	Summers				
outmigration as y-o-y		41	59	56	44
outmigration as yearlings		43	57	59	41
Leavenworth hatcheries	Summers	54	46	76	24
Lower Columbia R.[a]	Early falls	38	62	55	45
Lower Columbia R.[a]	Late falls	36	64	54	46

[a] Based on commercial catch (Young and Robinson 1974).

[b] Destined primarily for tributaries below Bonneville Dam (e.g., Willamette R.).

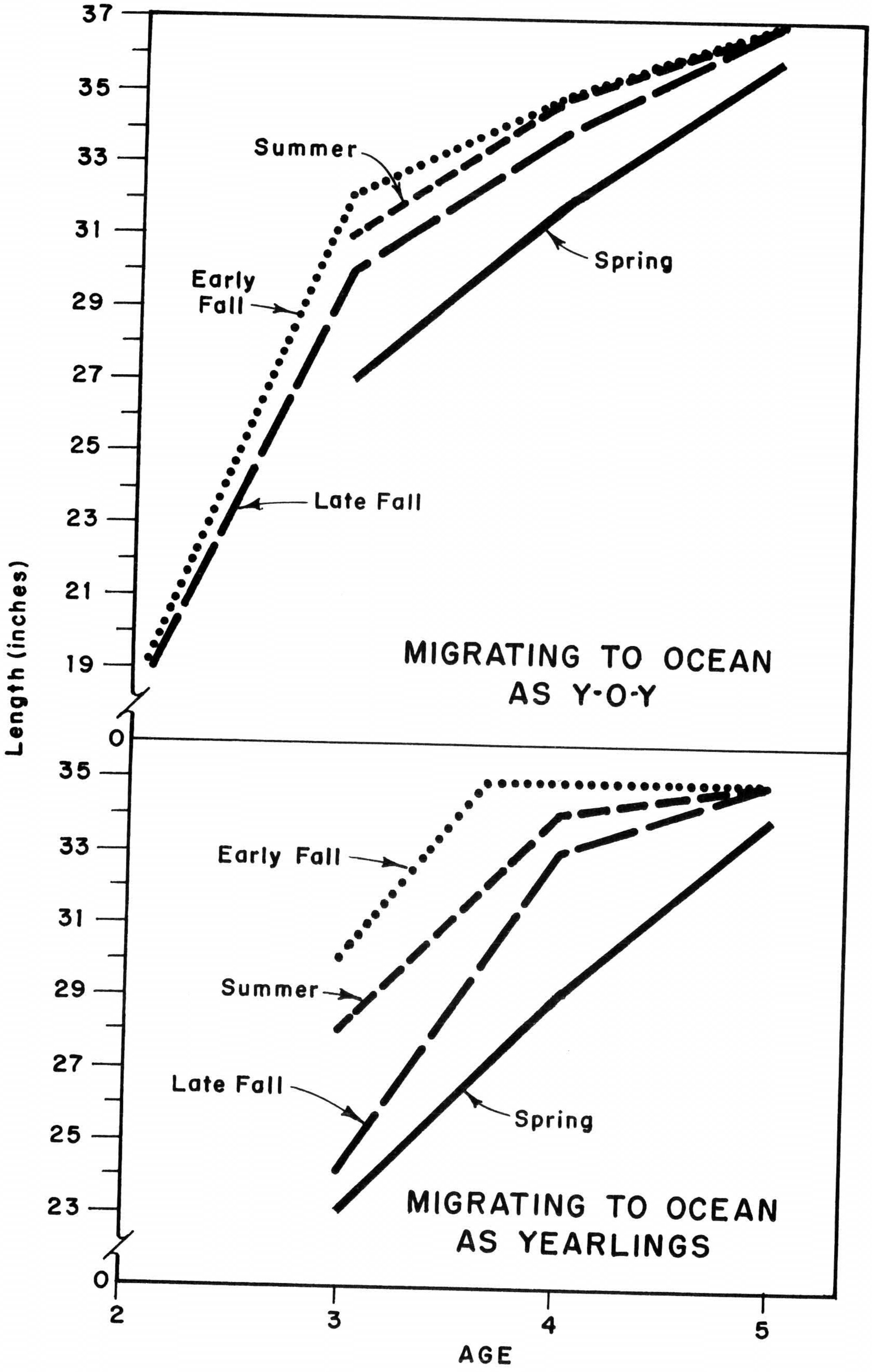

Figure 16. Average length of female chinook salmon returning to lower Columbia River by age group, season, and year of migration to ocean (Data from Young and Robinson 1974).

Table 28. Returns of chinook salmon to Entiat Hatchery from releases to Entiat River, 1940-1957 brood years.

Brood year	Releases				Escapement	
	Number (000)	Race[a]	Size (no/lb)	Date	No.	%
1940	100.0^b	SU	--	7/41	1	0.00
1940	50.0^b	SU	--	10/41	5	0.01
1940	25.0^b	S&SU	--	3/42	27	0.11
1940	25.4^b	S&SU	--	5/42	16	0.06
1941	85.5	SU	215	9/42	483	0.56
1942	55.9	SU	77	10/43	804	1.43
1943	591.0	S	467	3/44	271	0.05
1943	24.9^b	SU	--	10/44	55	0.22
1943	25.7^b	SU	23	3/45	96	0.37
1944	8.2	SU	10	3/46		
1944	27.0	SU	14	12/45	361	0.83
1944	8.2	SU	23	10/45		
1945	22.3	SU	81	3/46		
1945	184.2	SU	19	10/46	541	0.26
1946	177.7	SU	215	5/47		
1946	73.7	SU	37	9/47	551	0.22
1947	241.6	SU	116	5/48		
1947	155.1	SU	38	9/48	591	0.15
1948	235.2	SU	39	9/49	595	0.25
1949	64.1	SU	75	7/50		
1949	318.5	SU	32	9/50	530	0.14
1949	25.0^b	SU	69	7/50	4	0.02
1949	25.0^b	SU	31	9/50	4	0.02
1950	462.1	SU	70	7/51		
1950	84.3	SU	--	10/51	1,284	0.24
1950	26.4^b	SU	--	7/51	12	0.05
1950	26.0^b	SU	--	10/51	15	0.06
1951	281.0	SU	36	10/52	1,136	0.40
1952	404.5	SU	115	7/53		
1952	254.6	SU	24	10/53	818	0.12
1953	212.0	SU	22	10/54	504	0.24
1954	228.8	SU	116	7/55		
1954	212.0	SU	19	10/55	895	0.20
1955	250.5	SU	24	10/56	588	0.34
1956	32.9	SU	52	7/57		
1956	273.9	SU	24	10/57	709	0.23
1957	270.2	SU	53	6/58		
1957	113.8	SU	49	7/58	469	0.09
1957	137.5	SU	18	10/58		
Total	5,819.7				11,365	0.20

[a] Race: Summer = SU; Spring = S.
[b] Experimental, fin-clipped fish.

Two hatchery facilities on the Hanford Reach also contribute juvenile chinook salmon to the outmigration. Priest Rapids Hatchery releases averaged 2.6 million (range 1.2 to 5.5 million) y-o-y fall chinook annually from 1947 to 1982, but increased to 10.3 million fish in 1983 and 1984. The Ringold Hatchery also releases up to 2.5 million fall chinook each year to the Hanford Reach. In addition, juvenile chinook reared at downstream hatcheries are released in the Hanford Reach (e.g., 3.8 million fall chinook from the Bonneville Hatchery in 1984). Hatchery production of fall chinook above Priest Rapids Dam has been limited to Rocky Reach Hatchery in 1984-1985 (Howell et al. 1985a) and the unsuccessful spawning channel in 1960-1967 at the same location.

Outmigration

Peak numbers of 0-age fry from spawning in the Hanford Reach appear along the shoreline in April and May, but some are present in March (Gray and Dauble 1977). Most emergents reside inshore only briefly. Small numbers of 0-age fry linger in slackwater areas until early July, before temperatures peak, but they are absent later.

The outmigration of 0-age fry of summer/fall chinook salmon from upriver through the Hanford Reach typically peaks from July 26 to August 13 at Priest Rapids Dam (Becker 1985). These fish are larger than 0-age fry emerging earlier at Hanford because of additional growth. Hatchery fish released at Hanford are also larger than natural fry (e.g., 60-100 fish/lb and 100-130 mm) (Howell et al. 1985a).

Allen and Meekin (1973) reported that marked 1965, 1968, and 1969 y-o-y released at Priest Rapids spawning channel in May and June did not arrive at McNary Dam (105 miles down stream) until July and early August, with some arrivals continuing into September. Nichols (1979) showed that peak abundance of fall chinook juveniles occurred in late July. In 1984, downstream passage indices at McNary Dam indicated a somewhat earlier migration pattern with peak passage during late June and early July. This earlier timing in 1984 was associated with greater hatchery releases of 15 million fall chinook in the Hanford Reach upstream, over the 1.5 million released 1971-1982 (Howell et al. 1985a).

The available information indicates that peak outmigration of hatchery fall chinook juveniles occurs in July and lesser numbers migrating in June, August, and September. Based on CWT Priest Rapids Hatchery releases, median date of recovery in the estuary was about a month after release (Howell et al. 1985a). Thus, while the larger hatchery fall chinook quickly exit the river, the outmigration of naturally produced fry is much less clear.

Survival

Smolt to adult survival averaged 0.8% for three CWT groups (1975 and 1976 brood years) released from Priest Rapids Hatchery (Howell et al. 1985a). Exploitation of fall chinook at sea and in the Columbia River has been extensive, reaching 90% in some years (Chapman et al. 1982).

Run Size

The adult run of upriver "bright" fall chinook has averaged about 100,000 since 1970 (Howell et al. 1985a). Spawning escapement to the Hanford Reach (about 73% of the McNary Dam count) has ranged between 15,000 to 47,000 adults (excluding precocious males). Hanford Reach fall chinook are genetically distinct from other upriver bright fall chinook stocks (e.g., Snake River) (Utter et al. 1982).

Other Characteristics

Hanford Reach fall chinook have different ocean distribution, maturity schedules, and other characteristics than do lower river fall chinook populations (Table 29, 30, 31).

Table 29. Percentage distribution of catch of Hanford Reach (URB), lower river wild (LRW), Bonneville pool hatchery (BPH), and lower river hatchery (LRH) fall chinook salmon (Howell et al. 1985a).

Area	Population[a]			
	URB	LRW	BPH	LRH
Alaska	33	18	<1	5
British Columbia	51	39	30	54
Washington (marine)	5	8	44	21
Oregon (marine)	<1	1	5	1
Columbia River	11	34	20	19
California			<1	

[a] URB = 1974-1977 brood fingerlings released from Priest Rapids Hatchery.
LRW = 1977 brood North Lewis River wild fingerlings.
BPH = 1971-1972 brood fingerlings released from Spring Creek Hatchery.
LRH = 1976 brood released from Kalama Falls, Toutle, Washougal, and Bonneville hatcheries.

Table 30. Percentage and range (in italics) in age composition of Columbia River fall chinook salmon populations (data from Howell et al. 1985a).

Stock	Years of data	Age in years				
		2	3	4	5	6
Upriver bright	27	34	24	34	8	<1
	15	(23-46)	(7-42)	(18-47)	(3-35)	
Lower river (wild)	27	23	18	44	15	<1
	14	(7-40)	(11-28)	(20-61)	(4-21)	
Bonneville Pool Hatchery	14	7	56	35	2	
		(1-16)	(22-77)	(21-66)	(<1-6)	
Lower river[a] Hatchery	27	5	35	52	8	
	14	(3-8)	(21-58)	(33-65)	(3-17)	

[a] Average of entire run; generally, however, returns to Oregon hatcheries have a greater portion of 3-year-old adults than do Washington hatcheries. During 1982 through 1984, 3-year-old adults returning to Oregon hatcheries averaged 62% of total returns compared to 33% at Washington hatcheries (Howell et al. 1985a).

Table 31. Average and range (in italics) of fork length (cm) and corresponding age of Columbia River fall chinook salmon populations, 1981-1982 (data Prom Howell et al. 1985a).

Population	Age in years 2	3	4	5
Upriver bright (Hanford Reach)	48 (33-68)	70 (46-84)	89 (64-115)	100 (77-118)
Lower river wild	45 (34-67)	70 (49-95)	87 (66-100)	99 (80-125)
Bonneville Pool hatchery	62 (47-69)	83 (58-102)	92 (73-110)	
Lower river Bonneville Hatchery	60 (37-68)	81 (58-99)	91 (65-109)	
Cowlitz Hatchery	46 (38-55)	71 (52-92)	86 (66-108)	93 (69-110)
Kalama Hatchery		77 (50-94)	90 (63-109)	96 (76-121)

DISCUSSION

SALVAGE OF UPRIVER CHINOOK SALMON

Was the trapping of returning adult chinook salmon at Rock Island Dam for release in other streams a salvage operation which in the long run salvaged nothing (Ricker 1972)? In the short term, the salvage operation expedited restoration of runs in tributaries below Grand Coulee Dam. In the long term, the genetic diversity that characterized runs presumably was maintained to some unknown extent.

A major problem confronting restoration of Atlantic salmon (Salmo salar) is the limited genetic diversity left to work with. Currently, 15 New England rivers are part of the Atlantic salmon restoration project. From millions of fry and smolts stocked, runs estimated at about 7,000 fish are maintained (Behnke 1986).

By the early 1900's, only residual runs of Atlantic salmon remained in a few Maine rivers. The largest river, the Penobscott, lost all its native runs by 1958, because of pollution. When conditions in the Penobscott improved sufficiently to allow salmon reintroduction, eggs were taken from remnant runs that had persisted in the Narraguagus and Machais rivers. The establishment of the new Penobscott salmon has been the most successful restoration of any of the New England rivers stocked with Atlantic salmon, but returns have been less than 1% (Behnke 1986).

In other words, the great range of adaptive genetic diversity once represented in the various races of 28 Atlantic salmon rivers of New England is gone. In contrast, Sweden has attempted to maintain its native Atlantic salmon in tributaries to the Baltic Sea after they were blocked by dams. Each major river has its own hatchery (17 in all) propagating the native runs of each river in an attempt to preserve the original genetic diversity. Smolt to adult survival has typically ranged from 10% to 20% (Behnke 1986).

HATCHERY PROPAGATION

Has artificial propagation of chinook salmon by the GCFMP hatcheries generally been ineffective as compensation for upriver losses, as so frequently alleged (e.g., Chaney 1978)? There are many hatchery programs (e.g., steelhead trout, coho salmon) that refute blanket indictment of hatchery programs, yet there can be little doubt that hatchery propagation of chinook salmon in the mid-Columbia has not achieved its full promise. In what follows, I look for clues on how to integrate hatchery and natural production without deleterious effects on wild stocks (Lichatowich and McIntyre, in press), while achieving survival of hatchery fish that equals or exceeds survival of wild fish.

Low Returns of Spring Chinook

There are two possible scenarios to explain poor returns of spring chinook salmon to the middle Columbia River: (1) Coded wire tag returns underestimate the number of hatchery fish taken at sea, or (2) escapements to hatcheries do approximate total survival.

Chapman et al. (1982) discuss the enigma posed by mark-recovery data in their analysis of factors that determine abundance of Columbia River chinook salmon. With data not subject to the bias of marking mortality, they document that ocean harvest and power dams are both responsible for losses in upriver Columbia River chinook salmon:

> Quoting Walters et al. (1982), "Tagging studies as far back as the 1920's show that a large share of our (Canadian) chinook harvest has come from U.S. rivers, particularly the Columbia and their enhancement programs have been instrumental in maintaining our catches in recent years."

and

> "It has been argued that since spring and summer chinook appear to comprise a small part of the ocean catch compared to fall chinook, these fish are not heavily impacted by ocean fishing...This is a fallacious reasoning when applied to a mixed-stock fishery (particularly with harvest rates of 60% to 90% and insatiable demand). Spring chinook can be identified by the stream-type nuclei on their scales and stream-type fish comprise generally 10% of the catch as determined by sampling and scale analysis. Wright (1976) further suggests that 10% of the Washington troll catch is composed of Columbia River spring chinook. Say for example, while only 10% may be spring chinook, this is still 100,000 fish (plus shaker loss) and the majority would probably be of Columbia River origin, since other Pacific Coast streams have relatively small spring chinook runs. This equals (or exceeds) the upriver spring chinook run in recent years."

finally:

> "The mark recovery program reported on by Wahle et al. (1981) showed about 7 spring chinook being taken at sea for every 3 entering the river."

Currently, an average catch to escapement ratio of 3:1 for spring chinook returns to Leavenworth NFH can be argued. This ratio is the same as that reported for the 1970 marked brood (Wahle et al. 1981). Hatchery escapement of unmarked fish of the 1970 brood was virtually identical (0.22%) with that of marked fish (0.24%), eliminating the confounding effect of mortality induced by marking. Furthermore, a hatchery escapement of 0.22% is virtually identical with the average hatchery escapement of unmarked fish for brood years 1965-80 (Table 19). However, 90% of the catch of the marked 1970 brood occurred in the river and not the ocean. Low return to the river and curtailment of the river fisheries was logically a consequence of increased ocean harvest in the 1970's as hatchery output expanded and sea-going vessels became more efficient (Chapman et al. 1982).

If we factor in turbine mortality of 10% to 13% per dam for seven mainstem dams, this results in losses of between 52% and 62% of the Leavenworth NFH smolts before they reach the sea. Subsequent total survival then increases from 0.89% to the 1.0% to 2.0% range cited for chinook salmon released from GCFM Project hatcheries prior to extensive hydroelectric development of the Columbia River (Table 21, Experiments 25, 26, 32, 34).

The hypothetical total survival of about 0.89% for Leavenworth NFH spring chinook salmon has one distraction. Spring chinook may not be exposed to the same high exploitation rates in the sea as summer and fall chinook because their ocean distribution is different.

Although chinook are the least numerous of all Pacific salmon species, they are the most widely distributed. Adults spawn in rivers from California north to Alaska and west to Japan and Russia (Scott and Crossman 1973).

Chinook salmon in the ocean can only be distinguished as ocean-type and stream-type fish. Stream-type chinook have one or more freshwater annuli on their scales. Stream-type fish, presumably spring chinook, are least common and apparently distributed in the open sea. The more common ocean-type chinook are primarily found in coastal waters off Washington northward to Alaska where the major fisheries occur (Healey 1983).

Because tag recovery data are lacking, the ocean distribution of upriver spring chinook salmon from the Columbia River is unclear. Relatively good information exists for upriver summer and fall chinook, however. Catch distribution of the two stocks is virtually identical, and most harvest occurs in coastal southeast Alaska, northern British Columbia, and the west coast of Vancouver Island (NPFMC 1982).

Spring chinook salmon from the undammed Fraser River bear many similarities with spring chinook from the Columbia River. Fraser River stream-type chinook, averaging adult runs of 19,000 to 31,500 fish, pass through Georgia Strait as 1+ smolts and thereby avoid exploitation as immature one year ocean fish in inside waters. As returning adults, they move through major coastal fishing areas in early spring prior to heavy fishing pressure, and through the lower Fraser River prior to most sockeye fishing (US/Canada 1984).

As with Columbia River spring chinook salmon, little information exists regarding the interception of Fraser River spring chinook in ocean fisheries. Tagging of wild spring chinook salmon on upper Fraser River drainages have generated only modest returns. The few marked fish recovered show a general, far north ocean distribution (US/Canada 1984).

The difference between hatchery-reared and wild salmonids has been measured many times. Survival of hatchery fish is usually less than that of wild fish of comparable size, species, and circumstance (e.g., Cooper 1959). It is known that hatchery-reared trout, when superimposed on a resident fish population, suffer very heavy mortalities. Investigations in streams have demonstrated that the bulk of this mortality occurs in the first two weeks after planting (Miller 1958). The northern squawfish is a highly opportunistic omnivore (Brown and Moyle 1981), and it is possible that their ingestion of hatchery salmonids in the Columbia River largely amounts to a form of scavenging.

Migration and Smoltification

The juvenile outmigration of chinook salmon in the mid-Columbia River is now believed to occur later than before extensive dam construction (Mains and Smith 1964; Park 1969). Impoundments are believed to delay the seaward migration (Park 1969; Raymond 1979). A normal, unrestrained outmigration is presumably timed to correspond with physiological changes (smoltification) that lead to development of seawater tolerance (Wedemeyer et al. 1980). Delay may impair the ability of smolts to adapt from fresh to salt water (Mahnken et al. 1982).

With the increase in hatchery salmonids to the Columbia River in recent years (395 million smolts weighing 6.6 million pounds in 1983, GAIA 1986), concern regarding the optimal time of release to minimize stress due to migration delay, predation, and other perceived problems has increased. There is widespread belief that the optimal time for juveniles to reach the estuary is in May-June (Diamond and Pribble 1978). Rich (1920, 1925) showed that the historical juvenile salmon migration occurred year-round in the Columbia River and that the height of 0-age fish to the estuary was late summer and early fall, even though yearlings exited the river by June.

Entrance to the estuary and entrance to the ocean, however, are not synonymous. Many anadromous salmonids may initiate migration before they are able to adapt to full strength seawater. Smoltification is the coordination of several, not fully understood, physiological and behavioral processes, including downstream migration, resulting in the ability to continue to grow and develop in the ocean (Wedemeyer et al. 1980).

Hatchery releases have generally been timed to mimic the outmigration of naturally produced salmon. However, changes in the environment of the Columbia River may render historical migration times inappropriate. Moreover, there is some evidence that certain wild populations of chinook salmon may have now responded to environmental changes.

First, a period of rapid growth accompanies the smolting process; second, salinity tolerance is likely influenced by size; third, ocean-type chinook life histories almost invariably include a significant amount of residence in a river or estuary (e.g., Reimers and Loeffel 1968; Reimers 1973; Sibert 1974). Lastly, one can deduce that the Hanford Reach stock of wild fall chinook rears in downstream reservoirs. Naturally produced fry disappear from the unimpounded Hanford Reach in spring (Becker 1973), followed by an increasing abundance of larger 0-age chinook through fall downstream (Nelson 1981; Zimmerman and Rasmussen 1981; Miller and Sims 1984). Large numbers of 0-age chinook rearing in John Day Reservoir reached a mean fork length of 166 mm in mid-December 1983 (Miller and Sims 1984).

Wild chinook salmon in the Columbia River do move downstream shortly after hatching, but the trip may take weeks or even months since they often hatch far upriver. Thus, it is essential that they feed and grow en route to obtain a minimum size for successful transition from fresh to salt water. Apparently, the threshold size for smoltification is about 80-90 mm (Wedemeyer et al. 1980), a prerequisite recognized by releasing larger hatchery fish in recent years. However, because hatchery fish are generally larger than wild fish of comparable age, and they generally approach or exceed a minimum length of 80-90 mm, the practice of correlation of hatchery releases with seaward migration of naturally produced fish may be voided.

Growth, Age, and Sex Ratios

Because smolt age appears to be a significant feature of different life history patterns of chinook salmon, the factors controlling smolt age are worth review. There is a general trend for extended duration of the juvenile stage in rivers toward the northern extreme of distribution because of a shorter growing season and slower growth (Rich 1920). This also occurs in Atlantic salmon (Symons 1979; Behnke 1986). Production of stream-type chinook is also correlated with altitude (Healey 1983). Stream-type chinook typically dominate in the higher, harsher rearing environments of Columbia Basin streams, and are usually distinguished as spring chinook based on timing of the adult run. In Snake River tributaries, the typological distinction is that of summer-run chinook. Stream-type summer chinook of the Snake River are believed to originate primarily in the South Fork and mainstem Salmon River above 1,364 m MSL (Don Chapman Consultants, Inc., McCall, Id., pers. comm.).

There is no evidence that the phenotype of stream-type smolts is under control of anything but environmental influences (Ricker 1972). Smolt transformation and seaward migration in 0-age progeny of adult spring chinook that were matured early by control of photoperiod (Zaugg et al. 1986) provide evidence that stream-type chinook are not under inflexible genetic control. In fact, adult life history patterns in chinook salmon may be controlled by environmental priming factors in fresh water, though a heritable component is likely as well.

The predominant distribution of ocean-type chinook along the coast and the distribution of stream-type chinook offshore has been mentioned. While environmental conditions that result in longer freshwater residence seem unlikely to influence oceanic distribution (Healey 1983), partitioning of the grazing resources of the North Pacific is not unreasonable (Larkin 1980). Solving the riddle of how salmon find their way back to natal steams may not be nearly as important as how salmon find their way around the ocean (Larkin 1980).

Stock case histories show how difference in one development stage might relate to difference in another (Howell et al. 1985a). Two-and 3-year fall chinook salmon returning to hatcheries are larger than wild fish of the same age. Three-year adults returning to Oregon hatcheries averaged 62% of total returns compared to 33% at Washington hatcheries, presumably because of differing culture practice. Conversely, spring chinook that spawn later in the warmer Yakima River are primarily 4-year fish vs. 5-year fish that spawn earlier in the colder Naches tributary (Figures 5 and 6; Major and Mighell 1969; Hollowed 1983).

Ultimate adult size is related to number of years salmon spend in the ocean. Accelerated rearing of large size smolts in hatcheries normally increases the number of small 1-year ocean salmon and steelhead (i.e., jacks) (e.g., Bilton 1980). Fertilization of Great Central Lake in British Columbia increased the number of jacks in wild sockeye runs (Stockner 1976).

The percentage of jacks in runs of Columbia River chinook salmon, as measured in dam counts, increases as the season advances. Spring chinook generally have the lowest jack components and fall chinook the highest. This disparity in jack-adult ratios could have at least three explanations; (1) selective harvest, (2) effects of artificial propagation, and (3) environmental cluing of young.

Evidence indicates that selective harvest of chinook salmon could be a reality. Age at sexual maturity has both an environmental and hereditary component (Ricker 1972), and selection for jacks should increase the proportion of genes that cause early maturation. The problem has been of particular concern with Atlantic salmon. More and more juvenile male parr have become sexually precocious and the population structure has changed recently in some streams in eastern Canada, with grilse (jacks) dominating because of overfishing of the larger, older fish (Montgomery 1983). However, three lines of evidence suggest that the increase in jacks was not solely due to harvest of large fish: (1) jacks tend to beget jacks; (2) absolute numbers of jacks increased; and (3) stocks from different rivers but in similar habitats and geographic areas often have different age structures. This indicates that genes at least partly control the age at which Atlantic salmon return from the sea (Montgomery 1983).

A cause-and-effect relationship between increased ocean fishing coinciding with the decrease in average size and age, and possibly faster growth and earlier maturity, was suggested for wild fall chinook in the Columbia River in the late 1940's and early 1950's (Van Hyning 1973). Hatchery returns changed from a predominantly 4- to 3-year fish. Even though the average age was reduced, fecundity was maintained because over half of the 3-year fish were females which were almost equal in size to 4-year fish. When size frequencies and age compositions for the gill-net fishery, hatchery, and wild escapement were compared, only a minor amount of gear selectivity for age, size, or sex was indicated.

Cause-and-effect relationships between hatchery propagation and artifacts in salmon runs are legion and need not be repeated. Nevertheless, it is likely that there is more in the early development of salmon relating to subsequent behavior than has been realized (Larkin 1980). In fresh water, juvenile salmon imprint the odor characteristics of their environment. Prior imprinting is implicit in the homing of salmon.

Large returns of jacks are used as a predictor of high survival of older salmon of the same brood year. Although the jack predictor is not infallible, it has a good record for spring chinook from hatcheries in the lower Columbia River (Tables 32 and 33). It does not hold at mid-Columbia hatcheries, where the jack component of escapements is low (Table 17) and total survival is low (Table 12). Highest known survival for spring chinook was from the Cowlitz Hatchery (5.5% average, Table 12; 6.4% and 7.7% for CWT releases, Wahle et al. 1981), located below all dams on the Columbia River. Accordingly, the high return of 2-year "minijacks" to the hatchery is of interest. Released in February-March to April as large yearlings (4.7/lb), these fish hardly could have migrated beyond the estuary before returning in June-August at a weight of about one pound (Hugh Fiscus, WDF, pers. comm.). Release of smaller yearlings (6.5/lb) beginning with the 1977 brood year substantially reduced the number of returning "minijacks." Obviously, there is an optimum smolt size and or growth rate range that will maximize return of older and larger fish. However, returns of 4- and 5-year fish from releases of large smolts were not inconsequential, although less than at other hatcheries (Table 17).

Unlike returns to Cowlitz Hatchery, females consistently outnumber males about 2:1 in returns of spring chinook salmon to upriver hatcheries; inexplicably, jacks (males) are uncommon (Table 18). Skewed sex ratios could reflect differential mortality of male fish.

Precocious male chinook salmon (≤6.0 inches) are not abundant in tributary streams of the mid-Columbia (Leman 1968; Griffiths 1985). However, in July 1983, I observed a high number of precocious males from an earlier outplanting of fry from Leavenworth NFH to Icicle Creek (Mullan and McIntyre 1986). Gametogenesis may have been stimulated in these fish because they had been fed a hatchery diet and had experienced rapid growth before being released. Fall die-offs of precocious male spring chinook salmon in GCFMP hatcheries are known.

Outmigrations of Atlantic salmon smolts have shifted towards greater domination by females in recent years in some streams of eastern Canada. Precocious parr use more energy forming testes and have less body fat than nonmaturing juveniles, which is believed to lead to more wintertime deaths and insure a surplus of females in smolt runs (Montgomery 1983). Precocious chinook salmon produce viable sperm and have been reported to survive and subsequently migrate to sea (Robertson 1957; Ricker 1972), as well as to die following maturation (Burck 1966).

Disease and Stress

A variety of environmental stress factors predispose hatchery salmonids to diseases (Wedemeyer et al. 1984). Unfortunately, tolerance limits are understood for only a few environmental stressors (e.g., unfavorable water temperatures, crowding, marking), and then only when they occur singly. More

Table 32. Brood year contribution by age[a], number, and percentage of total escapement by year for spring chinook salmon returning to Carson Hatchery, 1971-1984 (modified from data of T. Roth, USFWS, in Howell et al. 1985a).

Brood year	Age 3		Age 4		Age 5		Total	
	No.	%	No.	%	No.	%	return	(%)
1968	952	22.4	4,123	62.1	1,066	48.7	6,154	(0.79)
1969	49	0.7	1,022	46.7	261	16.7	1,332	(0.12)
1970	101	4.6	905	57.9	265	5.4	1,295	(0.11)
1971	384	24.6	4,630	94.4	5,025	91.4	10,039	(0.64)
1972	10	0.2	161	2.9	46	1.5	222	(0.10)
1973	288	5.2	2,907	97.7	2,361	79.3	5,556	(0.28)
1974	22	0.7	598	20.1	209	8.2	829	(0.04)
1975	12	0.4	2,328	91.6	2,730	81.1	5,105	(0.18)
1976	4	0.2	606	18.0	1,609	63.1	2,219	(0.08)
1977	32	1.0	901	35.4	550	33.2	1,483	(0.09)
1978	3	0.1	1,085	65.5	1,413	56.7	2,512	(0.10)

[a] 6-year-old fish not included due to small number (n=87).

Table 33. Brood year contribution by age[a], number, and percentage of total escapement by year for spring chinook salmon (Carson stock) returning to Little White Salmon Hatchery, 1970-1979 (modified from data of T. Roth, USFWS, in Howell et al. 1985a).

Brood year	Age 3		Age 4		Age 5		Total	
	No.	%	No.	%	No.	%	return	(%)
1967	38	15.9	688	85.1	175	43.9	904	(0.34)
1968	96	11.9	199	50.1	81	45.3	382	(0.08)
1969	24	6.0	86	48.0	35	50.0	157	(0.02)
1970	9	5.0	16	22.2	214	15.2	239	(0.04)
1971	14	19.4	1,154	82.0	1,321	43.3	2,498	(0.43)
1972	27	1.9	1,067	35.0	308	8.8	1,424	(0.10)
1973	664	21.8	3,103	88.9	1,275	68.7	5,051	(0.71)
1974	69	2.0	353	19.0	114	12.5	536	(0.10)

[a] 6-year-old fish not included due to small number (n=63).

commonly, environmental stressors are multiple. Stress that greatly exceeds tolerance limits tends to be self-evident because the fish rapidly die. Sublethal stress is more common but more insidious because it tends to be manifested by poor survival later in the wild (Wedemeyer et al. 1984).

There is consensus among fish disease specialists that latent bacterial or viral infections in hatchery juvenile salmon are probably activated by the stress of migration and saltwater adaptation resulting in substantial ocean mortality (Wedemeyer et al. 1980). The universal presence of bacterial kidney disease (BKD) in hatchery stocks is a prime suspect for the poor returns of chinook salmon--particularly spring chinook (Banner et al. 1982; Fryer 1984).

BKD is a chronic bacterial infection of salmon and trout. Although BKD causes mortality in both hatchery trout and salmon, it is now most severe in Atlantic salmon and chinook salmon -- particularly spring chinook (Bullock and Wolf 1986). The causative bacterium grows slowly and often requires two to three weeks to isolate in the laboratory. The disease, too, progresses slowly in fish and clinical signs may require several months to develop. Control of BKD is difficult because the bacterium grows intracellularly--a feature that reduces the efficiency of therapeutic antibiotics. Also, the bacterium is transmitted inside of developing eggs and thus, is passed from one generation to another (Bullock and Wolf 1986).

Various case histories suggest that spring chinook smolts released with even subclinical infections of BKD are likely to have the disease activated by the stress of migration and conversion to salt water, and will suffer a delayed mortality in the ocean (e.g., Wedemeyer et al. 1980; Bjornn et al. 1985). Considering the epidemiology of BKD, it may not be coincidental that releases of fall chinook normally provide better returns than releases of spring chinook. Fall chinook are spawned shortly after return to hatcheries and the young are normally released in 6 to 8 months. Spring chinook, on the other hand, are exposed to almost 2 years of hatchery stessors between return of adults and release of young. Juveniles are overwintered and released in early spring. Major BKD outbreaks occur before release, and may be induced by the stress of approaching smoltification. This seems to apply particularly to Entiat and Winthrop NFH's, noted for early smoltification and adult returns half (0.10%) that of Leavenworth NFH.

Virulent epizootics of infectious hematopoietic necrosis (IHN), or sockeye salmon disease, in steelhead at Columbia Basin hatcheries (e.g., Dworshak NFH) has overshadowed BKD in chinook salmon. More than 30 years ago, FWS personnel at Leavenworth NFH described a suspect viral disease that killed young sockeye salmon. A few years later, they described a viral disease of young chinook salmon. Their reports predated the general use of fish tissue culture for virus isolation and the disease of the two salmon species were considered as separate for nearly a decade. The situation changed when an FWS virologist headed a group that isolated a rhabdovirus from infected young rainbow trout and sockeye salmon, and described the pathology clinically as IHN. They noted that IHN resembled the so-called sockeye and chinook viral diseases--a concept that was soon substantiated by electron microscopy and serology. The IHN virus was traced to adult carriers that shed virus at spawning and thus ensured its continuity (Bullock and Wolf 1986).

IHN has never been a serious problem in chinook salmon at the GCFM Project hatcheries, though catastrophic losses occurred in sockeye from the virus. Interestingly, IHN has never been a problem in steelhead (though it is a problem in rainbow trout) at mid-Columbia River hatcheries. Perhaps of equal importance, because steelhead now provide greater returns than spring chinook, clinical signs of BKD in steelhead returning to mid-Columbia hatcheries are rare but common in spring chinook (Steve Roberts, WDG pathologist, pers. comm.).

CONCLUSIONS

Throughout the range of Pacific salmon there is enthusiasm for more hatchery programs (Larkin 1980). Regionally, the potential of existing Columbia River hatcheries has been identified at one billion smolts (GAIA 1986). There is no way that such massive hatchery production can be rationally integrated with production of wild stocks (Lichatowich and McIntyre, in press). A best estimate of original run size is only 7 to 9 million adults (Chapman, in press). Massive enhancement of remaining natural production by outplanting of hatchery fish (e.g., Pinkham 1984) is probably ill advised (e.g., McFadden 1969).

Chinook salmon survival from egg to smolt varies from location to location and from year to year depending on environmental factors. However, any naturally maintained stock of salmon has lower population limits below which survival cannot fall without threat of extinction. While the upper limit to survival is 100%, it is unlikely to ever be this high. There is, therefore, a range of survival rates through each life stage (egg, fry, fingerling, and smolt) within which any naturally maintained stock is likely to remain. This pattern of density-dependent mortality in the post-hatching or larval stages of fish, with adjustments at later stages occurring through regulation of body growth (Ricker 1954), generally results in full seeding of the habitat, assuming some threshold level of spawning.

I cannot be sure as to what constitutes full seeding of mid-Columbia River salmon habitats at this time. However, it does appear that late summer densities of 0-age chinook and steelhead are at least equal (Griffith 1985; Mullan, unpublished) to values for Northwest streams compiled by Smith et al. (1985). They found 0-age chinook at densities below 0.3 fish/m^2 and o-age steelhead at 0.01 to 0.7 fish/m^2. Also, as we have already seen, wild chinook escapements to mid-Columbia stream have hardly been near extinction since populations were reestablished under the GCFM Project. For example, the escapement of spring chinook alone to the mid-Columbia in recent years was about 7,745 wild adults, providing a theoretical deposition of about 19 million eggs (male:female ratio 42:58, Table 18, X 4,200 eggs/female). Wild smolts usually produce 4-5 times as many returning adults as hatchery smolts (e.g., Table 12). If 3.9 million hatchery smolts resulted in a return of 11,000 adults in 1985, then the 15,758 wild adults that also returned might have been represented by an outmigration of 1.4 to 1.8 million smolts. This is appreciable production from tributary drainages (i.e., Wenatchee, Entiat, and Methow) that constitute only 2% of the average flow of the Columbia River at Rock Island Dam (USGS 1975). Then there is the ethnographic hint that current natural production of smolts may not differ greatly from primordial production in these streams.

While none of these data are convincing alone, together they indicate that there are few vacant niches today to accommodate outplantings of fry as reflected in the rapid re-establishment of chinook salmon under the GCFM Project. More likely, there is an excess of young, normally, in relation to available rearing habitat, which leads us to the mechanisms that control the adjustment of the system.

Anadromy, like many forms of animal migration (e.g., caribou, waterfowl), is an evolutionary response for coping with seasonal environments. Anadromy occurs primarily in and north of the temperate zone, and the differences between ocean and river environments at these latitudes require some insight on fish migration and the evolutionary pay-off achieved by participation in such dissimilar ecosystems.

Streams in the temperate and more northerly latitudes are typically cold and well oxygenated, but with relatively low primary productivity. The result of a limited food supply is that such waters are incapable of supporting large secondary fish biomasses. The lack of a large secondary fish biomass means a reduction in potential competitors and predators upon salmon eggs and young fish, and the presence of abundant oxygen is conducive to their development (Schalk 1977).

Streams, unlike the oceans, are strongly influenced by the terrestrial ecosystems that surround them. There is much less seasonality in ocean environments in terms of primary productivity and water temperature than in stream environments at comparable latitudes. Primary productivity in the Pacific Ocean may remain high throughout the year as far north as 60°N latitude. The presence of thermal inversions at these latitudes and, more locally, the presence of upwelling and continental shelves, tends to even out productivity during an annual cycle. Recognizing these broad differences between oceans and streams of cold latitudes, it is apparent why anadromous salmonids are, in terms of energy, more than 95% the product of the ocean stage of life. It should also be evident, because of reproductive advantages of freshwater streams and feeding advantages of the oceans, that anadromy makes the best of both worlds (Schalk 1977).

The reproductive advantage of a stream is lost when it is impounded and trophic relationships are altered. Insects, upon which small salmonids are most dependent for food, are diminished. Primary production in mid-Columbia reservoirs depends on detritus, sessile algae, and macrophytes. This, in turn, results in a large secondary fish production consisting of fish that can use such foods (Mullan et al. 1986). Further, the acute seasonality that once characterized the environment of the Columbia River is dampened by impoundment, not unlike the ocean environment.

River systems are an integrating series of physical gradients and biotic adjustments, with ecosystem-level processes in downstream areas linked to those in upstream areas (Minshall et al. 1985). The types of chinook salmon life histories reflect such a continuum.

Spring chinook salmon typically ascend to headwaters during high water levels and the young rear in these harsher climes for a year before migrating to the ocean. Fall chinook are favored by spawning in the largest river reaches closest to the ocean, and the young typically leave these milder climes as y-o-y. Summer chinook have varied life history patterns. A mixed, but optimum strategy in use of the habitat lying between headwaters and mouth was reflected in summer chinook being the most productive segment of the original, world famous, chinook salmon run in the Columbia (Thompson 1951).

However, the erosion-to-deposition continuum of river systems does not extend uninterrupted from headwaters to mouth. Discontinuities or intermediate zones featuring sand and gravel sediments where salmonids spawn are invariably skewed in distribution, as shown for chinook spawning in the mainstem Columbia (e.g., Chapman 1943). Downstream dispersal of recently emerged salmonid fry, as well as larger juveniles, is commonly noted. For example, French and Wahle (1959) showed extensive downstream movement of 0-age chinook in the Wenatchee River from spring through fall. Bjornn (1978) showed similar movement of 0-age chinook from upstream to downstream in the Snake River system. Presumably this is how rearing habitat below spawning areas is seeded, with the dispersal induced by excessive densities of young in relation to available microhabitat (Chapman 1962, 1966). Before impoundment of the mid-Columbia River and disruption of trophic relationships, more of these surpluses of young fish likely survived and or overwintered in the mainstem than currently. Today, this "halfway" refugium is primarily evident in lower river reservoirs and estuary by the extended rearing of chinook juveniles that occurs there.

Recognizing these differences between yesterday and today, it should be obvious that mid-Columbia reservoirs may offer possibilities for anadromous salmonid management. Reduced spawning in reservoirs would seem of small consequence, considering current hatchery potential. Hatchery potential, in turn, is plagued by inherent disease problems (e.g., BKD) in raising full-term smolts. The relatively benign temperatures existing in reservoirs would seem suitable for wild conditioning of hatchery smolts. Biomasses of competitor and predator fishes could be removed from dam fish ladders during spawning migrations. It is likely, too, that wild fish spawned in the reservoirs and tributary streams would benefit from the latter.

The design of such a management strategy must reflect the complex interactions discussed. Chinook juveniles could be released in fall when the preferred water temperature range (45^{o}-60^{o}F) at GCFMP hatcheries was decreasing below the minimum but just reaching the maximum in reservoirs. Quick exodus to the reservoirs could be expected based on current spring releases. Hopefully, they would not immediately smolt and head seaward when they reach the more lacustrine reservoirs. Increasing water temperatures and photoperiod in spring are conductive to smoltification (Wedemeyer et al. 1980) and decreasing water temperatures and photoperiod in fall should inhibit the process.

Releasing chinook salmon from hatcheries early in their life cycle to reservoirs would not be unlike short-term rearing and preadaptation in saltwater and freshwater enclosures prior to release (e.g., Gould et al. 1985; Novotny et al. 1985). Benefits could be similar:

1. Greater flexibility in the use of hatchery facilities, i.e., multi-species propagation, advantageous use of thinning releases.
2. More economical rearing operations because more fish could be produced, or fish of better quality because of reduced exposure to hatchery stressors, e.g., crowding, disease.
3. Effective use of hatchery water supplies, which are frequently seasonally over-subscribed and limiting.
4. Higher survival of hatchery production.
5. Minimum effect on wild juvenile salmonids rearing in streams.
6. Possible amelioration of estuary density-dependent mortality on wild stocks if hatchery fish migrated of their own volition in a somewhat different time interval.

Studies to obtain information involving multiple variables are not usually likely to achieve clear-cut results. However, alternate-year spring and fall releases of all hatchery chinook for an eight-year period, involving no marking or handling stress, should help resolve the differences between natural variables (e.g., ocean survival) and a management strategy. Gross differences in results should be evident in adult counts at dams and escapements to hatcheries.

Interactions between resident fish and chinook salmon juveniles remain a major unknown to the success of the management sketched. A major problem is whether juvenile chinook salmon released in fall to reservoirs could find sufficient food, grow, and develop over winter before migrating to sea in spring. Intraspecific competition, both for food and space, causes stunting in crowded fish populations, and there are many examples of increased growth and survival rates in fishes following reductions in their numbers (Miller 1958). It is also possible for competition to alter populations of species that are not themselves sensitive to its direct influence in much the same way that the fluctuations in dominant species may influence subordinate species (Skud 1982).

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16. Abstract (Limit: 200 words)

Grand Coulee Dam barred anadromous salmonids from 1,835 km (1,140 miles) of the upper Columbia River drainage in 1939. To preserve the runs, returning salmon (Oncorhynchus spp.) and steelhead (Salmo gairdneri) were intercepted at downstream Rock Island Dam and transported to the upstream Wenatchee and Entiat rivers and released above temporary weirs, or to the new Leavenworth, Entiat, and Winthrop National Fish Hatcheries. This report examines the status and propagation of chinook salmon (O. tshawytscha) associated with the Grand Coulee Fish Maintenance (GCFM) Project through 1985.

The GCFM Project succeeded in maintaining genetic diversity of wild chinook salmon in the mid-Columbia River to some unknown degree. Only nominal success was achieved in hatchery propagation because survival to adult return was 1% or less. Low survival seems associated with latent bacterial kidney disease (BKD) in hatchery stocks, which is activated by the stresses of migration and saltwater adaptation.

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