CONTRIBUTION OF 1960-63 BROOD HATCHERY-REARED SOCKEYE SALMON, *ONCORHYNCHUS NERKA*, TO THE COLUMBIA RIVER COMMERCIAL FISHERY

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ABSTRACT

A 4-yr marking program was conducted at Leavenworth National Fish Hatchery, Leavenworth, Wash., to determine the contribution of hatchery sockeye salmon, *Oncorhynchus nerka*, to the Columbia River commercial fisheries and the economic feasibility of hatchery rearing of sockeye salmon. The study involved 1960 through 1963 brood-year fish. During the 4-yr period, 1961-64, a total of 11.5 million fish were released, of which 3.4 million were marked by the removal of the adipose fin and part of one of the maxillary bones—the right maxillary for 1960 and 1962 broods and the left maxillary for 1961 and 1963 broods. Trapping at the lake outlet in the spring for the first 2 yr indicated that less than 50% of the stocked fingerlings migrated. In 1964-67, recovery of marks from the commercial fishery on the Columbia below and the Indian fishery above Bonneville Dam showed that an average of 13.6% of the sockeye salmon catch was composed of fish raised at Leavenworth Hatchery. Adjusting for effects of marking, this represents an average fishery value per brood of $4,274.75. The average potential benefit/cost ratio for the 4 yr of the program was 0.04 to 1. Because preliminary data indicated such a low benefit/cost ratio, sockeye salmon rearing at Leavenworth was radically decreased in 1966 and terminated in 1969.

In the 1930's Grand Coulee Dam was constructed on the upper Columbia River, thus barring anadromous fish runs from 1,835 km of spawning and rearing area. The extreme height of the dam (106 m) precluded building passage facilities for both upstream and downstream migrants. To preserve the runs formerly utilizing the upper basin, a relocation of runs of affected species became necessary.

Basic data on existing fish populations were obtained from 1933 through the time of dam completion in 1941 (Fish and Hanavan 1948). The only relocation areas suitable for spawning and rearing were Columbia River tributaries below Grand Coulee Dam and above Rock Island Dam. The area was less than one-half the extent of that formerly available and on streams which, because of industrial diversion, were for the most part inaccessible to migrating fish. Because of general depletion of all the upriver salmonid runs, correction of fish passage problems was already underway in many areas. With the impetus of the relocation program, further rehabilitation was accomplished.

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The sockeye salmon, *Oncorhynchus nerka*, was seriously affected by the habitat changes as its development required a lake-stream environment which has been almost completely eliminated. Annual commercial catches of Columbia River sockeye salmon ranged from ½ to 2 million kg prior to 1900 (Gangmark and Fulton 1952). From then through the early 1920's annual catches varied from about ¼ million to over 1 million kg. Following one more good year in 1926, the ½ million kg figure was never again reached (Figure 1).

Estimates of escapement beyond the fishery were not possible until enumeration of migrating adults began in 1933 at Rock Island Dam, 755 km above the mouth of the Columbia River. An average of about 19,000 adults was counted annually until 1941, when only 949 adults passed upstream. The low escapement was caused by a large commercial catch, low flows, and retention of water behind Grand Coulee Dam (Fish and Hanavan 1948).

The relocation of runs began in 1939 for sockeye salmon as well as chinook salmon, *O. tshawytscha*; coho salmon, *O. kisutch*; and steelhead trout, *Salmo gairdneri*. Adult sockeye salmon were trapped at Rock Island Dam and were transported by tank trucks to the Wenatchee and Okanogan

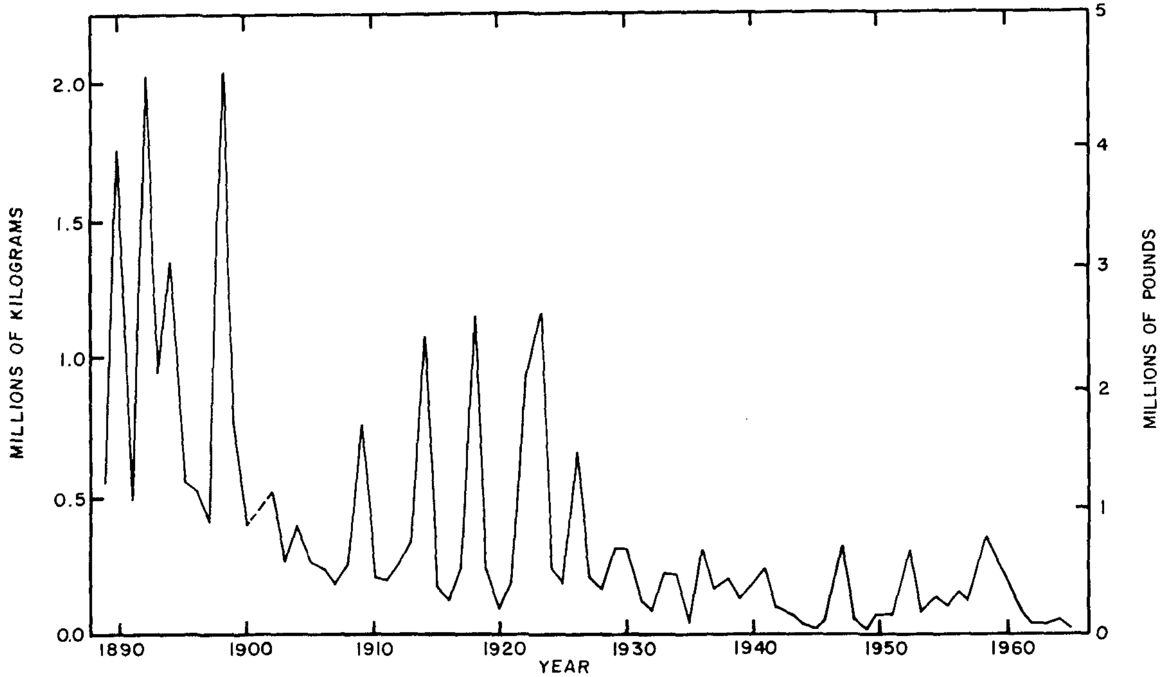

FIGURE 1.—Commercial catch of sockeye salmon in the Columbia River, 1889-1967. [Data for 1889-1936 from Craig and Hacker (1940), for 1937 from Ward et al. (1963) and for 1938-67 from Fish Commission of Oregon and Washington Department of Fisheries (1968).]

Lakes where they were allowed to spawn naturally (Figure 2).

Supplementary to adult relocation, an artificial propagation program was planned. A hatchery was constructed on Icicle Creek, a tributary of the Wenatchee River near Leavenworth, Wash. (Figure 3). Smaller substations were built on the Entiat and Methow Rivers. The sockeye salmon production program was to be concentrated at Leavenworth National Fish Hatchery.

Fish produced at Leavenworth were stocked into Wenatchee and Osoyoos Lakes. Success of the sockeye salmon relocation program was indicated in 1947 when the largest run recorded since 1926 appeared. This raised the question of whether the remaining available spawning habitat was overpopulated, prompting annual inventories that continued for many years (Gangmark and Fulton 1952).

How much of the apparent improvement in sockeye salmon runs was attributable to hatchery production was unknown. Importance of the Wenatchee system for total sockeye salmon production was obvious. Data indicated that an average of 33% of upper Columbia River sockeye salmon homed to the Wenatchee River in the 7 yr just prior to this study (French and Wahle 1965).

Wenatchee System Sockeye Salmon Stock

For over 25 yr Leavenworth Hatchery produced sockeye salmon which were stocked and reared in Wenatchee River tributaries. During this time, five major dams were built on the main Columbia River downstream. These structures, combined with growth and expansion in population and industry, added greatly to existing problems which confronted both downstream migrants and returning adults.

The Wenatchee River system was historically an excellent salmon producing system. It was comparable, for sockeye salmon production, to the Arrow Lakes, Yakima Basin, and Okanogan Lake areas, formerly the primary producers of this species in the basin (Figure 2). In the early 1900's the runs in the Wenatchee became severely depleted because of construction of impassable mill and power dams and unscreened irrigation projects. These conditions prevailed until the early 1930's, at which time about 85% of the Columbia

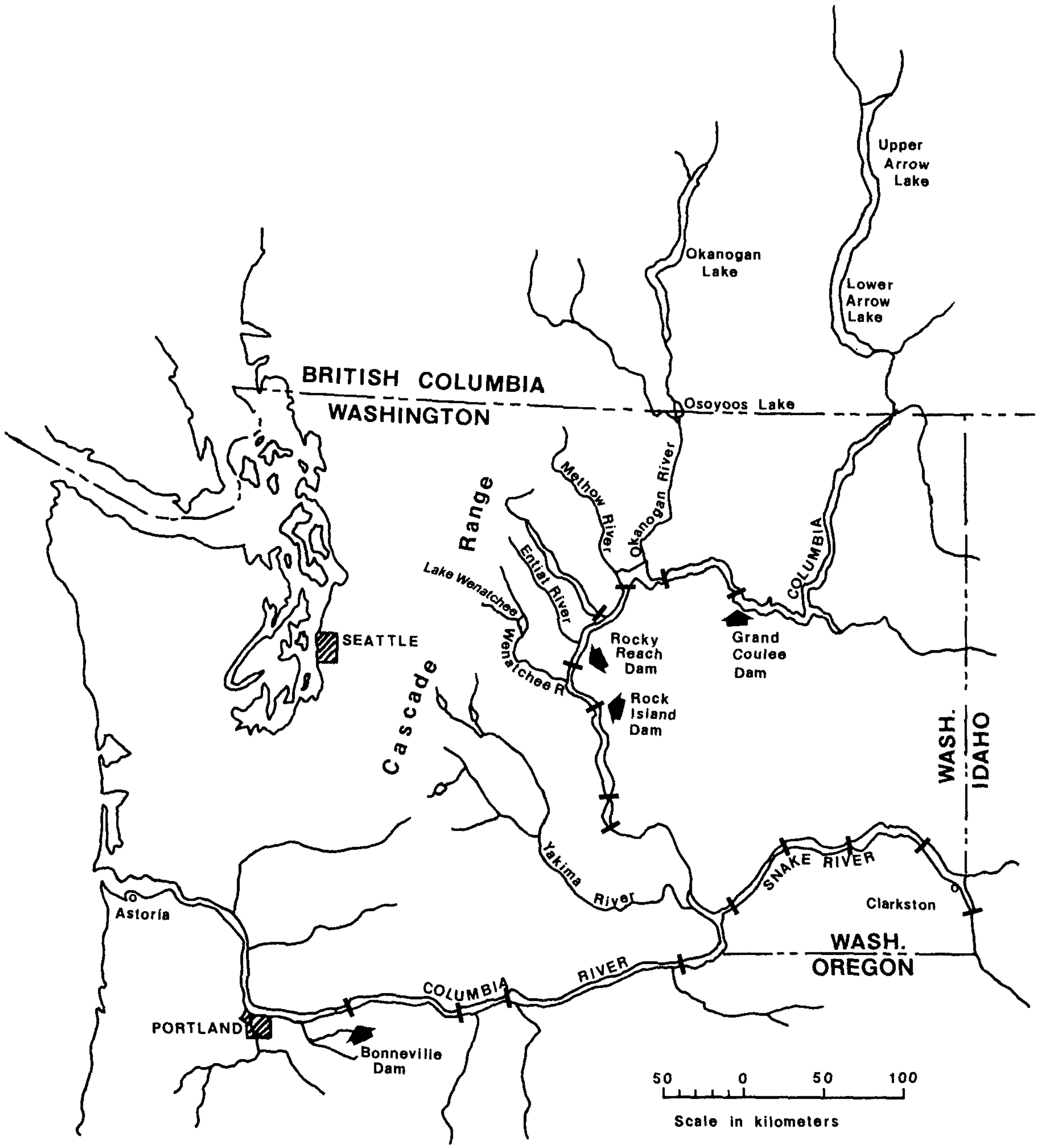

FIGURE 2.—Portion of Columbia River Basin showing areas of past and present importance to sockeye salmon as described in text.

River run was being produced in the Arrow Lakes area (Fulton 1970).

The Grand Coulee Fish-Maintenance Project (Fish and Hanavan 1948) began in 1933. Under this project, obstructions were removed, dams were provided with passage facilities, and irrigation diversions were screened. These measures were necessary to establish suitable habitat for the relocated runs in tributaries between Grand Coulee and Rock Island Dams.

To reintroduce sockeye salmon to the spawning areas above Lake Wenatchee and provide eggs for

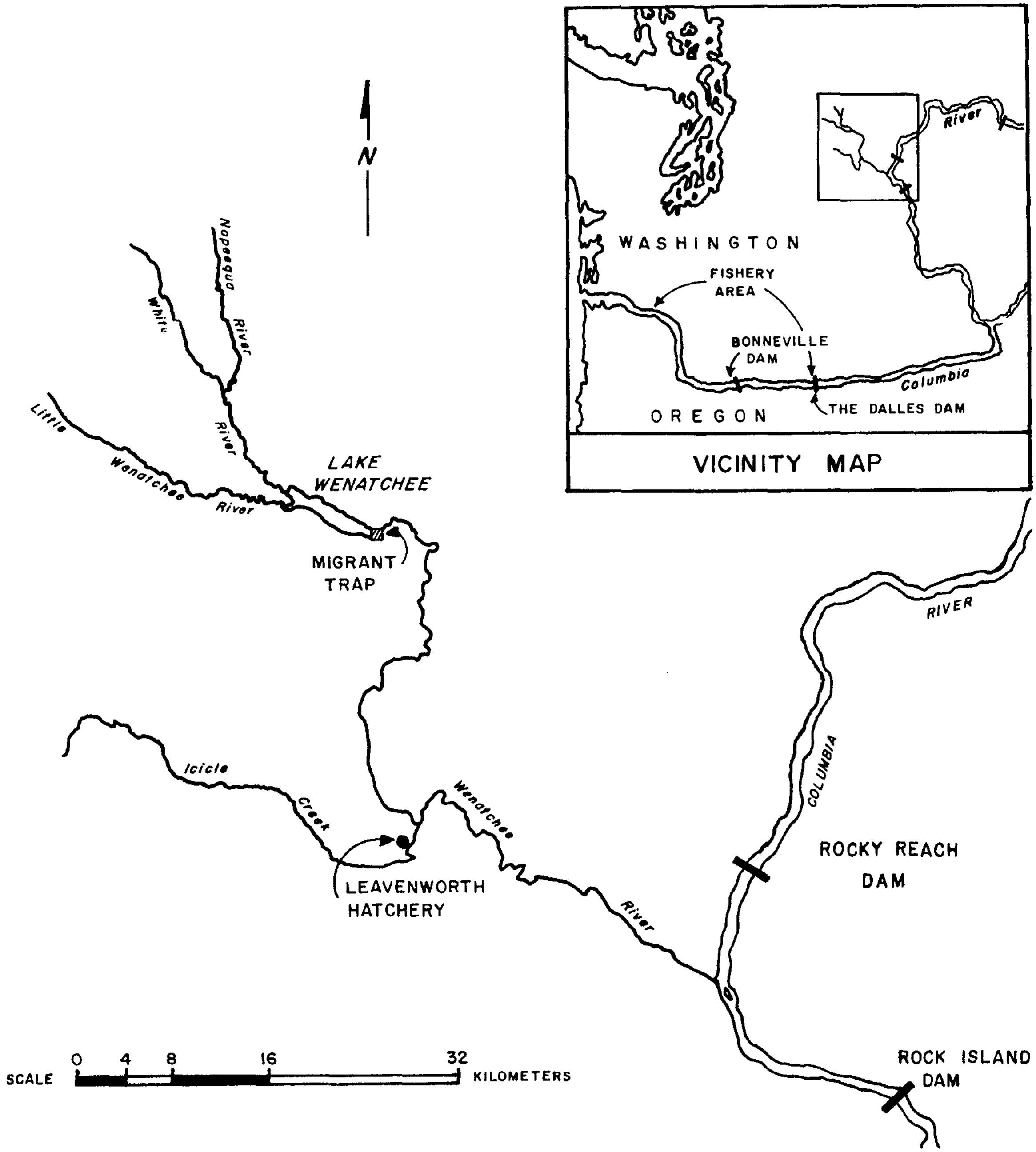

FIGURE 3.—The Wenatchee River system and location of Leavenworth National Fish Hatchery.

Leavenworth Hatchery, adult fish were trapped from 1939 through 1943 at Rock Island Dam on the main Columbia. Because the proposed hatcheries would not be available to handle fish until 1940, adults of all displaced species were released for natural spawning in predetermined locations. Separate areas were selected for each species to prevent overcrowding and mixing. Most of the sockeye salmon transplanted undoubtedly originated in the Arrow Lakes, but fish from the Okanogan and Wenatchee systems were certainly included (Fulton 1970).

Under the Grand Coulee Fish-Maintenance Project, sockeye salmon adults were trapped in July and August and hauled by tank truck to Lake Wenatchee, 113 km above Rock Island Dam, where a barrier was installed at the outlet. When spawning time approached, the fish ascended the White and Little Wenatchee Rivers where they spawned. When eggs were later needed for hatchery use, weirs were installed and adults trapped to supply the required ova. Surplus adults were allowed to pass upstream and spawn naturally. The offspring of these natural spawners homed back to the system to establish the new Wenatchee stock.

Spawning occurred in September and October. The fry emerged from the gravel in spring and drifted back down to the lake to rear until the following year. Outmigration occurred in April and May, with a peak reached in early May prior to the heavy spring run-off period (French and Wahle 1959). Following 2, or occasionally 1 or 3, yr at sea, the adults entered the Columbia River in late spring. The run passed Bonneville Dam in late June and early July, and several weeks later ascended the Wenatchee River to renew the cycle.

The Hatchery

Leavenworth National Fish Hatchery was completed in 1940 as the primary station to provide hatchery-reared fish to supplement the newly established natural runs. Sockeye salmon were to be produced there and adults of other species were spawned to obtain stock to supply the satellite stations on the Entiat and Methow Rivers (Figure 2). The hatchery capacity was approximately 3.5 million eggs and 2.4 million fingerlings (Fish and Hanavan 1948).

The source of eggs for the first 5 yr of operation was fish that had been hauled to Lake Wenatchee from Rock Island Dam as part of the relocation project. After this period the adult transportation was terminated and spawning operations continued using fish returning to the lake naturally.

After the eggs were taken and fertilized, usually in September, they were transferred to the hatchery for incubation. Hatching began in January and the fry began to feed about 6 wk later. Initial rearing took place inside the hatchery, and when water temperatures became suitable, they were placed in outside rearing ponds. In September or October, upon reaching an average weight of 9 to 10 g, the fingerlings were trucked to the lake. Survival from egg to stage at release ranged from 62 to 96%. After wintering over until the following April or May, the smolts migrated out of the lake.

From general observations, it appeared that the hatchery operation was a success: proper rearing techniques were followed, hatchery migrants were observed leaving the lake, adults returned to the area in adequate numbers, and fish were available for commercial harvest. Data obtained through spawning surveys and downstream migrant counts at the dams indicated that the sockeye salmon population was being satisfactorily maintained. However, it was not possible to determine whether the wild stock or the hatchery fish contributed most to the runs. Downstream migrant studies by Anas and Gauley (1956) pointed out the impossibility of identifying the separate stocks.

There were indications that the costs of conducting a sockeye salmon hatchery program were significantly higher than the values contributed to the fishery. Despite complexities of measurement of runs, some means of assessment seemed necessary. Thus, a study was designed to evaluate the economic feasibility of continuing artificial propagation of sockeye salmon at the hatchery.

The study involved the marking of a proportion of the hatchery sockeye salmon production for a period of 4 yr, observations on the rearing and migration of the fingerlings, and estimation of the contribution of returning adults to the commercial fishery. An analysis of production costs and the monetary benefits to the fishermen was included.

FIELD OPERATIONS

Estimating Procedures

The procedures used in making estimates of numbers of fish are similar to those described in reports by Worlund et al. (1969) and Wahle et al. (1974). Estimates of the potential contributions and value of hatchery sockeye salmon required four steps: 1) estimation of marked and unmarked hatchery releases, 2) estimation of catch of marked adults, 3) estimation of total contribution of hatchery fish to the catch, and 4) application of dollar values to the estimate of contribution.

Marking and Release Procedure

The study began in July 1961, using 1960-brood fingerling sockeye salmon. Each year, approximately one-third of the total Leavenworth Hatchery stock was marked. In each year except the first, a circular net pocket with a metal sleeve and a tub sampler were used to obtain a sample of fish for marking. Two types were employed: a 3-pocket sampler which gave an approximate 33.3% sample for marking, and a 10-pocket sampler (Worlund et al. 1969; Wahle et al. 1974) which provided a 10% sample for population estimate. In 1961, the one-third sample was obtained by marking every third pond, and in the other 3 yr the fish to be marked were selected as described above.

In 1961, hatchery personnel marked 1,008,310 1960-brood sockeye by removing the adipose fin (Ad) and part of the right maxillary bone (RM). In 1962, the 1961-brood fish (600,036) were marked by removal of the adipose fin and part of the left maxillary bone (LM). The 1962-brood fish (1,146,485) were marked the same as the 1960-brood, and the 1963-brood (606,578) repeated the 1961-brood mark.

In 1961 the marked and unmarked fish were kept in separate ponds and mortality records kept for each group. The number of unmarked fish for release was estimated by using the number of eggs and the percentage of hatch, and subtracting the number marked plus pond mortality. As the fish were stocked, in order to avoid bias, the marked and unmarked fish were mixed in each truck load.

In the three following years, by knowing the actual number of fish marked for each brood year, and the postmarking mortality, the total population at release time was estimated. Using the 10-pocket sampler on a random group of fish from a pond, a 10% sample was obtained. Repeating this procedure on the 10% sample provided a 1% sample, and a Peterson index of sample size was calculated (Table 1). The fingerlings were transported by tank truck and released into Lake Wenatchee each fall.

TABLE 1.—Numbers of sockeye released into Lake Wenatchee, Wash., during marking program.

Brood	Mark[1]	No. marked	No. unmarked	% marked	Total released
1960	Ad-RM	1,000,725	1,760,319	36.24	2,761,044
1961	Ad-LM	571,726	1,327,878	30.10	1,899,604
1962	Ad-RM	1,247,755	2,554,809	32.81	3,802,564
1963	Ad-LM	570,735	2,504,344	18.56	3,075,079
Total		3,390,941	8,147,350	29.39	11,538,291

[1]Ad = adipose fin; RM = right maxillary bone; LM = left maxillary bone.

In the spring of 1962 and 1963, a trap was operated at the lake outlet to monitor the outmigration. Data obtained at the trap indicated that <50% of the marked fish migrated downstream. This amounted to 38.4% of the marked fish of the 1960-brood and 47.9% of the 1961-brood.

Marked Fish Recovery

Sampling for returning marked adults began in 1964 and continued through 1968. Earlier returns were not expected because prior studies at Lake Wenatchee indicated that few, if any, adults would return in their third year (Major and Craddock 1962). The search for marks was confined to the two commercial fishing areas in the lower Columbia River: zones 1-5, the gill net fishery below Bonneville Dam, and zone 6, the Indian set net and dip net fishery above the dam (Figure 3). Other fisheries were not sampled as Columbia River sockeye salmon rarely occur in the ocean commercial catch and are seldom taken by sport anglers (Koski 1964).

We looked for marked fish during the commercial seasons. The zone 6 catch was monitored at Washington and Oregon Indian fishery buying stations. Commercial canneries in the lower river were sampled for the zones 1-5 gill net catch. Unfortunately for the study, the commercial gill net season in zones 1-5 was closed in 1965 and 1966, and opened only for 5 days in 1964 (Fish Commission of Oregon and Washington Department of Fisheries 1968). The zone 6 catch was also limited by this restriction, severely reducing the total catch (see Table 4). The catch in the 7 yr previous to the study averaged 90,900 fish. During the study period the average was only 22,500 ranging from 4,361 to 56,200 (Figure 4).

Sampling Results

Nearly one-half of the Columbia River commercial sockeye salmon catch was inspected for marks each year, except in 1966 when only a 4.2% sample was obtained because of the erratic nature of landings. The extremely small sample undoubtedly biased the estimation of catch for the brood years involved. For most brood years, the majority of fish were caught in their fourth year (Table 2). For all broods except the 1962 group an average of 94% was caught at age 4_2 (4 - total age, 2 - seaward migration age). This age-group represented only 4% of the total 1962-brood fish caught in 1966, evidence that the age 4_2 fish were almost entirely missed by the fishery, although undoubtedly available.

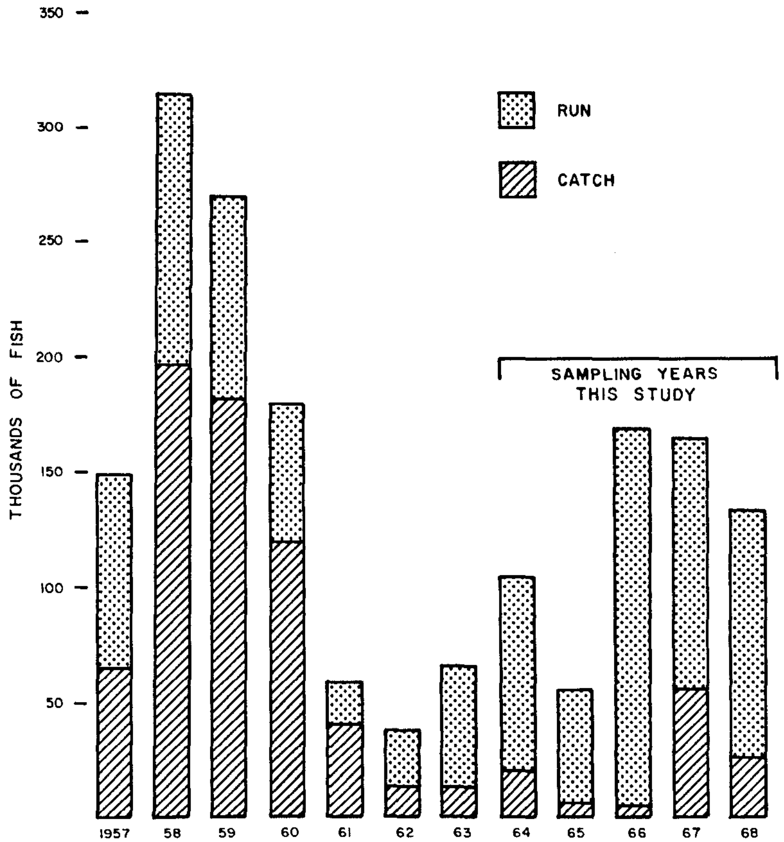

FIGURE 4.—Columbia River sockeye salmon commercial catch in thousands, as part of the total run, 1957-68. [Data from Fish Commission of Oregon and Washington Department of Fisheries (1968).]

TABLE 2.—Sampling rate and marks observed in Columbia River commercial fishery for sockeye 1960-63 broods.

Catch year	Fishery zone[1]	Total catch	Number sampled	Percent sampled	No. of marks observed by brood year			
					1960	1961	1962	1963
1964	1-5	4,950	3,307					
	6	15,820	7,195					
	Total	20,770	10,502	50.6	265	1		
1965	1-5	70	24					
	6	5,773	3,024					
	Total	5,843	3,048	52.2	22	43		
1966	1-5	157	27					
	6	4,204	158					
	Total	4,361	185	4.2		1	8	
1967	1-5	21,218	7,993					
	6	35,002	13,885					
	Total	56,220	21,878	38.9			191	294
1968	1-5	20,300	9,689					
	6	5,000	2,632					
	Total	25,300	12,321	48.7				16
				Total	287	45	199	310

[1]Zone 1-5 (below Bonneville Dam); Zone 6 (above Bonneville Dam).

The number of fish in the catch, the number sampled and the number of marks recovered from zones 1-5 and zone 6, were combined.

CALCULATIONS

Because the marks used to distinguish the groups of hatchery fish have a negative effect on survival, two different steps were employed to calculate the hatchery fish contribution. The determination of the level of contribution required an estimation of the number of hatchery fish in the catch for each year sampled. This was calculated from the estimated number of marked fish plus the estimated number of hatchery unmarked after a correction for differential mark mortality. Potential catch is that which would be expected if marking did not cause postrelease mortalities.

Differential Mark Mortality (Survival Factor)

We suspected that there would be adverse effects on the survival of the fish because of the excised fin and maxillary bone. Foerster (1968) reported that marked sockeye salmon at Cultus Lake had an estimated return of only 38% of the unmarked return.

To obtain a mark survival factor, a modification was made to the procedure for marking the 1961-brood fish. In addition to the group that received an Ad-LM, a second group received only a chemical (tetracycline) mark, while a third had both marks. In sampling returning adults, a comparison of the three groups showed that only 40% of Ad-LM fish expected, returned (Weber and Wahle 1969). Because we believe that tetracycline had no effect on survival, we considered that the difference between returns was caused by mortality due to marking by excision.

Marks in Catch

To calculate the number of marks in the catch for a certain year, the number of n marks in the sample was divided by the sampling ratio:

$$n \text{ marks (catch)} = \frac{n \text{ marks (sample)}}{n \text{ fish (sample)}/n \text{ fish (catch)}}.$$

This assumed a random sample of the catch. The mark survival factor was not considered in this equation.

Hatchery Contribution to the Fishery

To determine the percent of sockeye caught in a specific year that originated at Leavenworth Hatchery, the number of (n) unmarked hatchery fish in the catch was estimated by using the number of (n) marked fish in the catch and dividing by the sampling ratio and the marked/unmarked ratio at release, corrected by the mark survival factor. The correction was necessary because this ratio changes from the time of release to time of catch due to the effects of marking:

$$n \text{ unmarked hatchery catch} = \frac{n \text{ marks (catch)}}{\dfrac{n \text{ fish (sample)}}{n \text{ fish (catch)}} \times \dfrac{n \text{ marked release}}{n \text{ unmarked release}} \times \text{survival factor}}.$$

Summing the marked and unmarked hatchery fish for a catch year and dividing by the total catch gave the estimated percent produced by the Leavenworth Hatchery. For 1964-67, contributions averaged 13.6% of the total catch (Table 3). The 21.6% figure for 1966 may not be representative as the sample size that year was small.

TABLE 3.—Estimated numbers and percent of hatchery sockeye in Columbia River commercial catch.

Catch year	Brood year	Hatchery fish Marked	Hatchery fish Unmarked	Hatchery fish Total	%	Total catch all fish
1964	1960	517	1,504	2,021		
	1961	2	8	10		
Total		519	1,512	2,031	9.8	20,770
1965	1960	42	123	165		
	1961	82	316	398		
Total		124	439	563	9.6	5,843
1966	1961	24	90	114		
	1962	189	638	827		
Total		213	728	941	21.6	4,361
1967	1962	500	1,692	2,192		
	1963	751	5,443	6,194		
Total		1,251	7,135	8,386	14.9	56,220
1968	1963	31	226	257	([1])	25,300

[1]Not applicable as no 1964 brood hatchery fish were marked.

Potential Hatchery Catch

A potential hatchery catch figure is a theoretical number that represents what could have been caught in a given fishery assuming the same effort and no marking program and was required to calculate benefit/cost ratios. It allows for the large number of fish failing to survive because of the mark. Potential hatchery catch (Table 4) was calculated by dividing the number of marks in the catch by the mark survival factor and adding the

TABLE 4.—Potential number and weight of hatchery sockeye by brood year and catch year.

Brood year	Catch year	No. with marks in sample	Hatchery fish in catch: Estimated no.	Potential no.	Potential wt[1] (kg)
1960	1964	265	2,021	2,359	4,122
	1965	22	165	192	342
Total		287	2,186	2,551	4,464
1961	1964	1	10	11	16
	1965	43	398	451	802
	1966	1	114	130	234
Total		45	522	592	1,052
1962	1966	8	827	950	1,706
	1967	191	2,192	2,518	4,085
Total		199	3,019	3,468	5,791
1963	1967	294	6,194	6,684	10,733
	1968	16	257	277	479
Total		310	6,451	6,961	11,212
Grand total		841	12,178	13,572	22,519

[1]The average weight of commercially caught sockeye ranged from 1.5 to 1.8 kg during the study.

number of unmarked hatchery fish in the catch:

$$\text{potential hatchery (catch)} = \frac{n \text{ marks (catch)}}{\text{survival factor}} + \text{unmarked hatchery (catch)}.$$

ECONOMIC EVALUATION

A primary purpose of this study was to determine the economic feasibility of rearing sockeye salmon at Leavenworth National Fish Hatchery. An oft-employed measure of financial worth of a program is the benefit/cost ratio which compares the dollar value (benefit) of the fish returned to the amount spent (cost) in their production. Normally a favorable ratio should exceed 1:1.

Cost Accounting

Production costs for each brood of sockeye salmon in this study were derived in the same manner as in Wahle et al. (1974) and consisted of two categories, amortized construction costs or capital costs and operational costs.

The "annual imputed capital charge" was computed by amortizing the capital expenditures at the hatchery into 30 equal annual payments using an interest rate of 3.5%. This rate was the average 3- to 5-yr government bond interest rate weighted by the total annual capital outlay at Columbia River Program Development hatcheries from 1949 to 1970. As the hatchery reared other species in addition to the study fish, the capital charge was apportioned by applying a percentage based on the ratio of manpower time charged specifically to sockeye salmon care.

Operation and maintenance costs were divided into fish food and drugs, and other operational costs. Fish food and treatment costs were apportioned according to the pounds of study fish produced as a percentage of the total production. Other operational costs including labor, personal services, travel, equipment, supplies, and administration were apportioned, as with capital, according to the percentage of time allotted to the care of each brood.

Benefits

In other economic studies involving Columbia River salmonids (Worlund et al. 1969; Wahle et al. 1974) benefits included the accrued values from exvessel prices received by commercial fishermen engaged in the variety of catch methods, i.e., offshore troll, purse seine, gill net, set net, etc. In addition, benefits were calculated for sport-caught fish and for sale of adult carcasses to processors. Our study included only the benefits to commercial fishermen on the Columbia River in the gill net (zones 1-5), and tribal dip net (zone 6) fisheries. Sport catch values were not considered as there are virtually no sockeye salmon caught by anglers in the river.

The simple exvessel price paid to fishermen is a reasonable estimate of benefits as explained by Richards,[2] although some inadequacies exist in more intensive and complicated fisheries. For the minor fishery involved in this study, this method

[2]Richards, J. A. 1969. An economic evaluation of Columbia River anadromous fish programs. U.S. Dep. Int., Fish Wildl. Serv., Bur. Commer. Fish., Working Pap. 17, 274 p.

of valuation seemed satisfactory. The commercial price paid to fishermen during the sampling years ranged from $0.68 to $0.82/kg depending on the area of catch. The benefit/cost ratio averaged 0.039:1, or approximately 4 cents returned for each dollar spent (Table 5).

TABLE 5.—Benefit-cost ratios for Leavenworth sockeye 1960-63 broods.

Brood year	Total catch (kg)	Hatchery fish in catch: Potential wt (kg)	Hatchery fish in catch: Potential value ($)	Production cost ($)	Potential benefit-cost ratio
1960	41,327	4,464	3,062	114,123	0.027:1
1961	49,160	1,052	858	86,823	.010:1
1962	97,228	5,791	4,456	124,321	.036:1
1963	75,579	11,212	8,723	113,541	.077:1
Total	263,294	22,519	17,099	438,808	.039:1

DISCUSSION

As our results clearly show, hatchery fish did not appear significantly in the commercial catch, averaging only 13.5% of the total harvest. Considering that the hatchery fish may have utilized almost one-half of the natural rearing space available, we expected their contribution would be greater. We also expected a larger proportion of hatchery fish in the returning adult run based on the ratio of hatchery to wild smolts emigrating from Lake Wenatchee. In a concurrent study, Craddock[3] determined that hatchery fish made up 53% and 72% of the 1962 and 1963 total outmigration, respectively.

From the economic viewpoint we feel that the study produced an accurate assessment of the benefits provided to the commercial fishermen by the addition of hatchery fish to their catch. We are confident that the method of determining the production costs of the hatchery sockeye salmon provided a valid estimate for that portion of the benefit/cost ratio.

Benefits as a measure of value in this study applied specifically to those received by the commercial fishery. Not considered were intangible benefits derived from the preservation, maintenance, and enhancement of the Columbia River sockeye salmon. The return of adults to the system for a hatchery egg source is another value. Another unmeasured benefit was the contribution to the Indian subsistence and ceremonial fisheries. In short, the total benefits from the Leavenworth Hatchery sockeye salmon program were obviously greater than the value derived within the specific confines of the study.

From the catch results it is apparent that the study period was one of an abnormally low harvest. The river below Bonneville Dam was closed completely for two of the catch seasons and only 5 days fishing allowed in another, with almost all of the small catch taken in the Indian fishery. As the benefits were based on the number of fish provided the commercial fishery, and the zones 1-5 fishermen were almost completely denied the opportunity to harvest these fish, then little in the way of value could be expected under these conditions. It should be noted that the regulatory measures were in effect specifically for the protection of low runs of summer chinook salmon and summer steelhead trout which can be netted at the same time in the area.

Another indication of the unusually low harvest of sockeye salmon during the study period is noted in catch/escapement ratios (C/E), which in the 5 yr preceding the study were 1/1 - 2.6/1. During the study the ratio did not exceed 0.5/1 and ranged downward to 0.02/1 (Fish Commission of Oregon and Washington Department of Fisheries 1968).

In addition to the low rate of return associated with adult harvest, we suspected that poor survival of the released fish through various stages was a primary cause of low adult returns. Problems confronting the young sockeye salmon are discussed below.

We could not assess any effect on the released fingerlings caused by rearing practices at Leavenworth Hatchery, as there was no comparable rearing of sockeye salmon elsewhere. We assumed that the produced fish were of good quality, as the rearing techniques, disease control, and nutrition in effect at the hatchery were essentially the same at other Columbia River salmon hatcheries raising other species.

A possible hatchery-related effect on the quality of the stocked fish may have been undetected disease. As reported by Guenther et al. (1959), a filterable virus disease transmitted by feeding of sockeye salmon carcasses at Leavenworth Hatchery caused extreme mortalities prior to 1954 when the practice was discontinued. Losses from undetected diseases could have had significant effect on survival following release of the fingerlings. Although kidney disease was not detected at the hatchery, prior to release, the senior author observed it in fish held in saltwater during the mark

[3]D. R. Craddock, Northwest and Alaska Fisheries Center, National Marine Fisheries Service, NOAA, Mukilteo, WA 98272, pers. Commun. April 1964.

retention phase of the project. Cumulative long-term effects on outmigrants may have been substantial. Other viral diseases, about which little was known at the time, may have been present.

Lake Existence

A high rate of mortality occurred in Lake Wenatchee during the period of lake rearing, and this was probably spread over the period from stocking until outmigration. Losses similar to the 62 and 51%, found where outmigrants were enumerated, undoubtedly occurred in the 2 yr in which outmigrants were not counted. Foerster (1968) reported that the average smolt migration from British Columbia and Alaska lakes where only fry were stocked was 44% and the survival to return ranged from 11 to 84%. The hatchery rearing at Leavenworth seemed an economic waste, as equal outmigration rates may have been obtained using fry plants.

There is an extensive sport fishery in Lake Wenatchee on Dolly Varden, *Salvelinus malma*, and kokanee, a nonmigrant strain of sockeye salmon. We monitored this fishery in order to determine the effect on released study fish.

Incidental to the trout catch, a fairly large number of sublegal (<6-in) hatchery salmon were taken. This was determined by the presence of marked fish in a sample of sublegal fish in the angler catch. The hatchery fish were caught during the early spring of their second year just prior to their outmigration. Most sublegals were released by the anglers, but mortality undoubtedly resulted from hooking and handling. Additionally, some of the marked sockeye salmon remained in the lake without migrating and were observed throughout the season in the creel checks of legal-sized trout. The percentage becoming resident was unknown, but in 1964 represented 1.4% of the calculated total kokanee sport catch of 17, 523 fish.

Sockeye salmon becoming resident in the lake and entering the sport fishery, based on 1964 data, accounted for <1% of the stocked fish. The mortality of sublegal fingerlings from angling was assumed to be small because of their rare occurrence in the sport catch. Health records of the hatchery fish did not indicate any expected loss from disease or parasites. Undoubtedly, the large loss of fingerlings was due to predation by larger fish and possibly starvation.

The heaviest loss of fingerlings in the lake was certainly caused by predation. Although precautions were taken during release, when fish were barged to avoid shoreline concentrations. Thompson and Tufts (1967) reported heavy predation both during and following release periods. Dolly Varden and northern squawfish, *Ptychocheilus oregonensis*, were sampled by gill net and trolling gear. During the weeks of release, the number of captured fish containing sockeye salmon ranged from 58 to 100%. Gangmark and Fulton (1952) during experiments in 1949-51 reported heavy predation by the same species. Our own observations of angler-caught fish from March through July 1962 showed an average of over one sockeye salmon per stomach. No estimate of the total predation loss was possible as the total number of predators was not known.

From our observations and those reported by Allen and Meekin (1973) the zooplankton production in the lake peaked in August and September each year. The hatchery fish, stocked in October, were faced with a declining food supply. Growth apparently stopped during the winter. Fingerlings of the 1961-brood averaged 97 mm FL when stocked in October whereas in the following spring, migrants trapped at the outlet, had a size range of 87-98 mm FL (Weber and Wahle 1969). Low food productivity of the lake, coupled with competition from natural resident fish for food, undoubtedly affected the fitness of the migrant sockeye salmon and possibly caused subsequent losses from stress on the seaward journey.

It is highly improbable that any hatchery production program utilizing an additional rearing period in Lake Wenatchee could succeed. However, even if no loss had occurred during lake residence, thus doubling the number of hatchery outmigrants, no more than a twofold increase in adults could be expected. Even with such an improvement, still more than 10 times that number of adults would be required for a favorable benefit/cost ratio.

Downstream Migrant Problems

With a large portion of the production sacrificed in the lake, the remaining smolts were still faced with great problems. Until recently, little was known of the causes and extent of downstream losses of sockeye salmon, although much information has been obtained for chinook salmon and steelhead trout smolts. Anas and Gauley (1956) studied the seaward migration of sockeye salmon smolts and their data suggested a wide range in travel time and in size and age of migrants. No estimates of mortality of any given group of sockeye salmon could be made from their data or from other studies conducted at the various dam projects. However, we have assumed that extremely large losses occur in each annual outmigration of sockeye salmon, comparable to those documented for chinook salmon and steelhead trout.

Losses can occur in but a short distance during the seaward journey. Ellis and Noble (1960) reported losses of fall chinook salmon of 12.2 to 29.7% in the Klickitat River in a distance of only 64 km. The Wenatchee stock sockeye salmon smolts had to navigate 844 km in their seaward migration and were subjected to injuries and possible death at each of seven dams, plus the myriad effects of altered flows and water quality.

Major direct causes of mortality in juvenile migrants are gas bubble disease, a result of high dissolved nitrogen concentrations which occur throughout the river and death or injury by passing through turbines (Ebel et al. 1973). At high flows with excessive spill the fingerlings are subjected to the nitrogen problem, while the turbine caused losses are most severe at low flows. Chaney and Perry (1976) reported that the juvenile losses averaged 15 to 20% at each mainstem dam from combined causes. At low flows, cumulative fish losses just from turbine mortality at a series of seven dams may exceed 90%.

Additional mortality can be expected from several other causes. The delay of stream flow in the impoundments has reduced migration rates of juveniles by one-third according to Raymond (1969). The fish are then subject to increased predation, possible loss of marine adaptability, and may become residual in the reservoir. Undoubtedly but a small part of the outmigrants ever reach the sea in some years.

Adult Problems

We surmise that the sockeye salmon suffer losses comparable to the other species in the ocean, but there is no appreciable fishery harvest. The few tagging returns that have been reported for Columbia sockeye salmon (Margolis et al. 1966) indicate a more southerly distribution than for Canadian or Washington sockeye salmon, and there is no inshore marine fishery to intercept the adults.

The relatively few remaining adult sockeye salmon, after surviving the perils of sea life, still must face serious obstacles on the spawning migration. Aside from the commercial harvest, a substantial mortality occurs which cannot be measured precisely. In early reports of upriver fish passage, Schoning (1948) pointed out that annually an average of 36% of the Bonneville Dam count could not be located after subtracting the known harvest. "Fall-back" contributes to the loss and obscures the actual number passing the dam. Later accounts corroborate these losses (Chaney and Perry 1976). Bonneville Dam mortalities would reduce the number of fish available for harvest only in the zone 6 portion of the fishery.

SUMMARY

1. The Columbia River system produced large runs of sockeye salmon prior to 1900, providing an annual commercial harvest reaching 2 million kg.
2. Deterioration of spawning areas and blockage of tributaries caused a severe decline in the sockeye salmon population early in this century.
3. Construction of Grand Coulee Dam in 1941 blocked the sockeye salmon from 1,835 km of spawning and rearing areas, virtually eliminating all natural production.
4. Compensatory measures intended to replace the lost production included relocation of the sockeye salmon runs to suitable areas below Grand Coulee Dam and construction of hatcheries for additional production.
5. Leavenworth National Fish Hatchery on the Wenatchee River was activated in 1940 as the primary fish production station and an annual stocking program of sockeye salmon fingerlings was started.
6. For over 20 yr Leavenworth Hatchery reared sockeye salmon, releasing the fingerlings into the Wenatchee system augmenting the natural production.
7. No assessment had been made of the actual contribution of hatchery fish to the commercial fishery, thus the subject study was initiated using the 1960-63 broods of sockeye salmon.
8. During the initial 4 yr of the study, a total of 11,538,291 fish were released, of which 3,390,941 were marked by removal of the adipose fin and a part of the maxillary bone.
9. The stock used was adult sockeye trapped in tributaries of Lake Wenatchee. Fingerlings were reared at the hatchery until fall, then released into Lake Wenatchee.
10. Surviving smolts migrated out of the lake in the spring. Outmigrant trapping in the first 2 yr

revealed that <50% of the stocked fish migrated downstream.

11. From 1964 through 1968, sampling for marked adults was conducted in the two Columbia River fisheries: the gill net area below Bonneville Dam (zones 1-5), and the Indian set net and dip net fishery above the dam (zone 6). An average of 43.5% of the commercial catch was examined for marks.

12. The commercial harvest was atypical during the study because of regulation restrictions. The average annual harvest for the period was only 22,500 fish compared with average landings of 90,900 for the prior 7 yr. The C/E ratio did not exceed 0.5/1.

13. Almost all hatchery fish in the catch were in their fourth year of life. The average weight of fish in the catch ranged from 1.5 to 1.8 kg.

14. A mark mortality correction factor was included in calculations of hatchery fish in the catch as it was shown that the marked fish survival was only 60.52% of the unmarked fish.

15. During the study, hatchery fish composed an average of 13.6% of the total commercial catch.

16. The exvessel price to fishermen, used to determine benefits in this study, ranged from $0.68 to $0.82/kg.

17. Production costs were determined by a previously developed method utilizing both capital and operational charges.

18. The benefit cost ratio for the study broods was 0.039:1 or about 4 cents returned for each dollar spent.

19. Factors contributing to poor survival of juvenile fish were: high mortality from predation and angling during lake rearing, probable disease and nutritional problems, losses during migration from turbine injury and gas bubble disease, and delay in reservoirs.

20. Reasons for the low return of adults to the fishery include: unknown ocean mortality, losses incurred while ascending Bonneville Dam, and the erratic opportunity of harvest because of season restrictions.

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