R1-57

UNITED STATES GOVERNMENT FISH AND WILDLIFE SERVICE

Memorandum

TO : Bob Behnke DATE: 7/27

FROM : J Mullan

SUBJECT:

The enclosed draft report concerning coho salmon may be of interest, particularly pages 26 & 28. I am convinced that the coho propagation program on the mid-Columbia failed out of deference to not using long-distance migrating stocks. As far as my implications I don't think anyone gives a damn — natural production that is. Hopefully, this coho paper will be published in Nat. Marine Review — perhaps, at the rate we are going, in the year 2000.

I have a similar Sears Roebuck catalog virtually done on sockeye, which is a lot more complex and involves about 10 times more "hard" data. On this species, seemingly there has been no impairment of genetic viability, despite much

Genetic pollution.

Please send along a copy of your most recent publication, also I believe you have another out on managing endangered trout stocks that I don't have. At least the local area biologists, Larry Brown, WDG, is much impressed with your work and it is having a very positive effect on his direction.

I'd sure like to sit down and kick things around with you, but I've got to run, due to living in "Alice in Wonderland".

Best wishes

John

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ENDANGERED AND THREATENED -- A recent publication, "Endangered and Threatened Fishes of the Upper Colorado River Basin," by R. J. Behnke and D. E. Benson provides basic life history information pertinent to the endangered and threatened fishes of the upper Colorado River basin. The publication presents plausible reasons for the present plight of these species (Colorado River squawfish, boneytail club, humpback club, razorback sucker and the Colorado River cutthroat trout), and what is and/or should be done to enhance their chances of survival. The authors' perceptive exposition in the Preface of the discrete differences between accelerated extinction caused by man and evolutionary change is noteworthy. Also, the publication provides a thorough discussion of the many ramifications of the endangered species act which should prove helpful. Gratis copies of this highly recommended publication are available from Colorado State University, Extension Service, Bulletin Room 171, Alyesworth Hale, Fort Collins, Colorado 80523.

PURDUE UNIVERSITY -- GRADUATE INSTRUCTORSHIP IN AQUACULTURE -- One Position -- A one-half time graduate instructorship is available for teaching research in Fisheries Biology/Aquaculture leading to the Ph. D. degree. The person selected will be responsible for teaching the laboratory in Fisheries Management and assisting in teaching Vertebrate Population Dynamics. Research will be in the area of inducing maturation and spawning of channel catfish, including in vitro maturation and ovulation of oocytes. Initial stipend will be $450 per month for 12 months with remission of all but approximately $70 in fees per semester. A maximum academic load of 12 credits per semester is permitted. Candidates must have met the requirements for the M.S. degree in Fisheries Biology or related field. Qualified candidates should contact: Dr. George S. Libey, Department of Forestry and Natural Resources, Purdue University, West Lafeyette, Indiana 47907. Phone: (317) 494-6113.

DRAFT

ECOLOGICAL OVERVIEW

Coho Salmon

(*Oncorhynchus kisutch*)

Propagation

Mid-Columbia River

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ACKNOWLEDGMENTS

I should like to thank Roy Wahle of the National Marine Fisheries Service; Dr. John McIntyre, Dr. Richard Whitney, and Bill Nelson of the U.S. Fish and Wildlife Service; Dr. Ned Horner of the Idaho Fish and Game Department; Dr. Don Chapman, private consulting biologist; and Mike Erho, Mike Dell and Bernie Leman of the mid-Columbia River Public Utility Districts for critical reviews of the manuscript and helpful suggestions. I would also like to thank Mike Erho, Mike Dell and Bernie Leman for furnishing various data.

INTRODUCTION

Leavenworth, Entiat and Winthrop hatcheries were authorized by 52 Stat 345, May 11, 1938 (amended August 8, 1946 - Interior 60 Stat 932). This public law, commonly referred to as the Mitchell Act, authorized and directed the Secretary of Commerce "...to establish one or more salmon cultural stations in the Columbia River Basin in each of the states of Oregon, Washington and Idaho." More specifically, the mid-Columbia[1/] hatcheries were constructed as mitigation for anadromous fish losses associated with Grand Coulee Dam on the upper Columbia River.

As an alternative to passing salmon and steelhead over Grand Coulee Dam, the Washington Department of Fisheries (WDF) in 1938 proposed trapping the runs at Rock Island Dam (1939-42), diverting them to the principal tributaries of the downstream Wenatchee, Entiat, Methow and Okanogan rivers, and constructing hatcheries on these streams (Figure 1).

Fish and Hanavan (1948) reported that the relocation of the upriver runs was a conclusive success, whereas only limited success was achieved in the propagation efforts at the three hatcheries constructed. Part of the problem was one of "the cart before the horse"--technology in raising salmon and steelhead was in its infancy. Other handicaps centered on the

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1/ In referring to the major sections of the Columbia River drainage, I have defined the lower river as the area below McNary Dam, the middle river as the area between McNary and Grand Coulee dams, and the upper river as the area above Grand Coulee Dam.

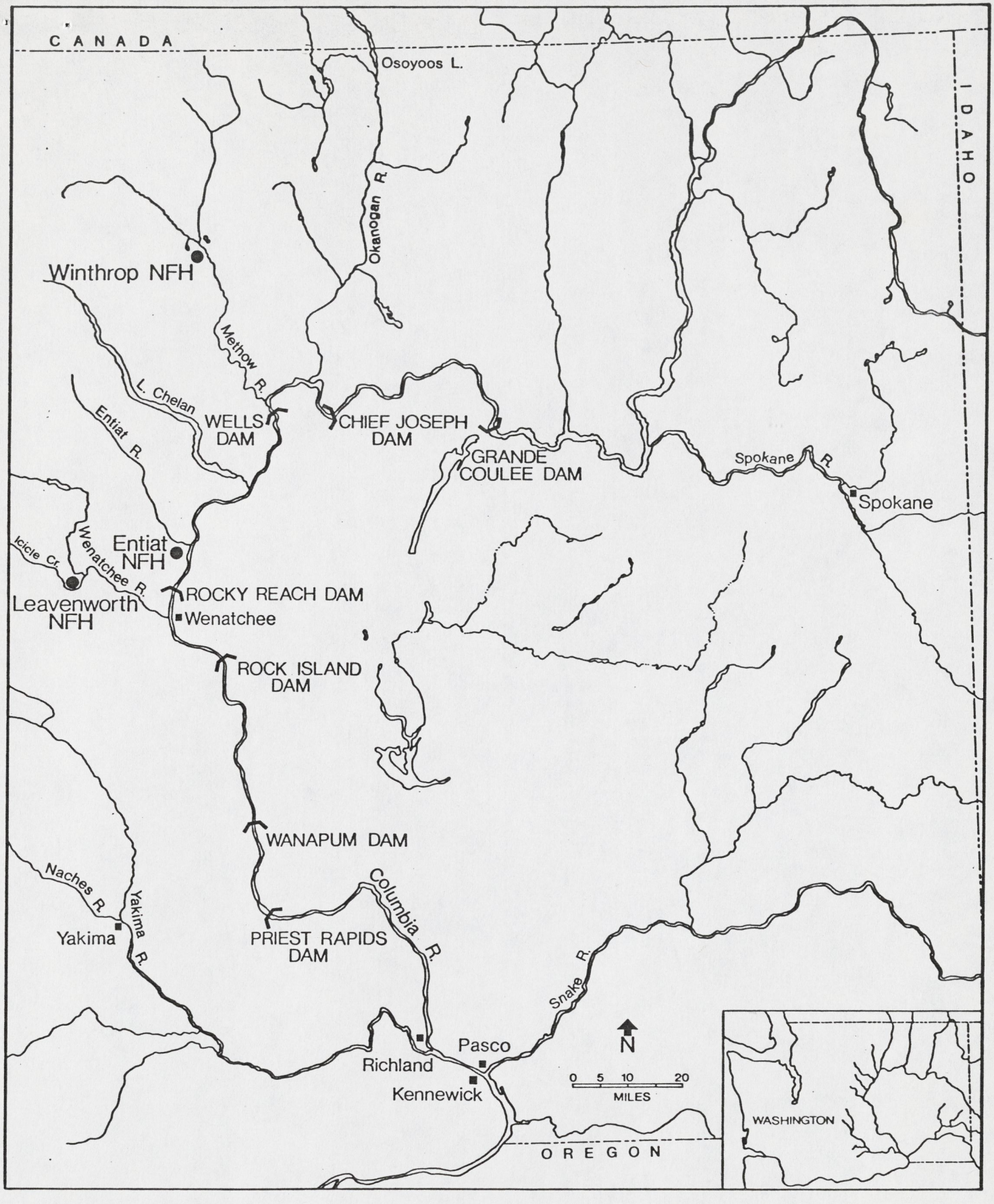


Figure 1. Portion of Columbia River Basin showing areas of past and present importance to coho salmon as described in text.

facilities and water supplies themselves. Accordingly, the species raised have varied over the past 40 years, depending on trends in management, advances in salmonid culture, and other particulars and problems of a given period.

The purpose of this report is two-fold: (1) to summarize and interpret observations regarding coho salmon (*Oncorhynchus kisutch*) propagation at the three mid-Columbia hatcheries before the records are completely obliviated by time; and (2) to assemble and collate information bearing on salmonid production of mid-Columbia River tributaries. Historical accounts by their nature tend to be exhaustive of observations while inclusive of principle or meaning to be drawn. Experience clearly demonstrates, however, that such records frequently do provide insight on ecological processes or limitations that were hardly considered during the years that the observations were routinely recorded.

HISTORICAL PERSPECTIVE

Coho are second to chinook in being the most numerous salmon species in the Columbia River Basin. However, most coho salmon do not migrate far into fresh water to spawn. Current and historical abundance centered in lower Columbia River tributaries. The longest distance coho are known to have migrated in the Columbia River was to the Spokane River, 700 miles from the ocean (Fulton 1970). Coho also were reported (Fulton 1970) to have used the Yakima, Wenatchee, Entiat, and Methow river drainages. These runs had been decimated prior to completion of Grand Coulee Dam in

1941 by the construction of impassable mill and power dams, numerous unscreened irrigation diversions, and over-harvest in the lower Columbia River (Craig and Suomela 1941; Bryant and Parkhurst 1950).

Three-to-four million pounds of coho salmon were landed annually between 1866 and 1919 in the lower Columbia River (Craig and Hacker 1940). Peak catches occurred in the 1920's, with almost eight million pounds landed in 1925, after which the fishery experienced an almost-continual decline to the 1960's. Based on an average weight of 9.92 pounds per fish (Fulton 1970), the early, apparently equilibrium, annual harvest translates to between 300,000 and 400,000 fish. Apportionment of two-thirds of these as originating in tributaries of the lower Columbia and Snake rivers, coupled with a catch/escapement ratio of 5 or 4:1 (Mobrand et al. 1977), suggests population bounds of 120,000 to 166,500 fish originating in the mid- and upper Columbia River.

The abundance of coho salmon in the Columbia River during the 1800's and early 1900's, of course, cannot be estimated with accuracy. Nevertheless, there is some collateral evidence to suggest that a large portion of the coho in the middle and upper river originated in the Yakima River drainage.

Prior to 1880 about 600,000 salmon and steelhead have been estimated as migrating annually into the Yakima River System (U.S. Bureau of Reclamation and U.S. Fish and Wildlife Service 1976). If the 19% coho composition observed in the runs at Roza Dam (1940-67) held prior to run decimation, this would account for 114,000 coho or bewteen 68% and 95% of the calculated middle and upper Columbia River coho population.

Based on geographic distribution of known past and present habitat (stream miles) (Fulton 1970), 42% or 50,000-70,000 coho attributable to the upper Columbia River would have originated in the Yakima River drainage. Similar estimates for upriver rivers are: Wenatchee, 6,000-7,500 coho; Entiat, 9,000-13,000 coho; Methow, 23,000-31,000 coho; and Spokane, 32,000-45,000 coho.

Craig and Suomela (1941) examined three sources of information relating to the original salmon populations of the Wenatchee, Entiat, Methow, and Okanogan rivers: (1) records of WDF hatchery operations; (2) testimony of old-time residents; and (3) observations of biologists.

The affidavits of eight old-time Wenatchee River area residents, including the superintendent of the Dryden Power Station, read about as follows:

> Before construction of the Leavenworth mill dam in 1904 or 1905, the fall run appeared in the upper Wenatchee River in August-September, and was much larger than the spring run. This fall run was composed of chinook, silvers (coho), steelhead, and blueback (sockeye). Nason Creek was an especially attractive spawning ground, and nearly all the smaller creeks had runs of silvers and steelhead; however, very few salmon were found in Icicle Creek. This fall run continued until about 1914-15, after which it rapidly declined. Before the Leavenworth Dam was built, the Indians' fishing grounds were near the mouth of Tumwater Canyon and on Nason Creek. After the construction of this dam they fished below that structure.

Alex Saluski, a direct descendant of Chief Saluski of the Yakimas, as reported in Davidson (1966), recalled as a boy spending his summers and falls fishing the Wenatchee and Chiwawa rivers, along with many other Indians, where chinook, blueback and silver salmon were found in great abundance.

Craig and Suomela (1941) state that the salmon runs of the Entiat River had been practically exterminated for many years due to construction of impassable dams beginning in 1898. Therefore, there was very little information available, except for folklore, that chinook and coho salmon had once ascended the river.

Ten affidavits were obtained from interviews with old-time residents, including the sheriff of Okanogan County, relative to the Okanogan River salmon runs (Craig and Suomela 1941). Four of the recollections make no mention of coho salmon, four mention that some silvers (coho) accompanied the chinook run, and two mention large numbers of silvers and chinooks in the early 1900's. The latter affidavits also note the Methow River as a more important salmon spawning stream. A Washington Department of Game (WDG) warden (M.M. Fruit) corroborated the statements of the residents in a letter to the Bureau of Reclamation, April 1, 1942. He also emphasized, "The Methow River was much more important than the Okanogan River from the standpoint of salmon runs." Such a view was consistent with the early establishment of two hatcheries on the Methow River by the state and the Okanogan County Game Commission.

The first hatchery, located at the confluence of the Methow and Twisp rivers, was built in 1899 (Craig and Suomela 1941). This station was operated primarily as a coho hatchery. In the eleven years from 1904 to 1914 almost 12 million coho eggs were taken, representing an estimated range of 12 to 779 brood females (3,000 eggs/female; Table 1) annually, or an average of 360/year. In 1915, the Washington Water Power Company

Table 1. Available information on spawning of coho salmon at Leavenworth and Winthrop National Fish Hatcheries.

Leavenworth

Brood Year	Arrival Dates	Spawning Dates	No. Fish Spawned		Average No. Eggs/Female	Size (lbs.)
			Males	Females		
1940			4	2	3700	
1941		10/24-11/7	4	6	2600	8
1944	9/30-11/7	10/19-11/8	57	66	3077	
1945			3	1	2947	
1947		10/28-11/28	72	80	2635	
1950		--12/7--			2421	
1966			49	51	3078	
1967			7	11	2727	
1968	9/13--	10/2--	375	689	3027	12-15
1970	10/20--	11/18--	236	204	3317	
1971				408	3126	
1972				7	3143	
1973	8/30-10/29	10/29 *	28	39	3017	one female 30

*peak

Winthrop

Brood Year	Arrival Dates	Spawning Dates	No. Fish Spawned		Average No. Eggs/Female	Size (lbs.)
			Males	Females		
1947*		11/13-12/3			2092	
1950		10/25-12/10	9	7	3806	
1953			3	3	2824	
1954			2	1	2954	
1962**	10/9--	10/19--	64	119	2926	

*Returning adults reported in poor condition, some spawned out.

**Returning adults reported in excellent condition.

constructed a dam at Pateros near the mouth of the river which was not provided with fishways (Bryant and Parkhurst 1950). Since the dam was impassable, the upstream hatchery was moved downstream to the dam site. Substantial numbers of coho eggs continued to be taken; 3.5 million from 1915 to 1920. The average of 194 brood female fish/year for this period is suggestive of a minimum 50% decline in the run of coho between 1904-1914 and 1915-1920. No coho eggs were taken after 1920, although the hatchery continued to operate until 1931 with eggs and fry of steelhead and other salmon species shipped in.

Published and unpublished observations of Roger Burrows at the Entiat Hatchery and River suggest that voluntary return of spawners to holding ponds was no more than 10% effective without racking, that adjunct seining and/or mechanical racking raised recovery to perhaps 20% to 50%, and that use of an electrical weir was 100% effective in diverting the entire salmon run from the river (Burrows 1957). The 20% to 50% recovery level would seem to represent a likely upper limit for the earlier Twisp Hatchery operation on the much-larger Methow River. Like the Entiat operation, most of the spawning habitat was located upstream of the hatchery site and the stream channel was not blocked by any permanent barrier, such as the dam that was later built near Pateros. Circumstances of the latter situation are comparable to the Leavenworth Hatchery where upstream access is blocked by a diversion dam and, barring high water or other problems, 80% to 90% of the tailrace concentration of coho salmon have been collected.

A 20% to 50% recovery level for the Twisp Hatchery for the period 1904-1914 suggests an average spawning run for those years of 1,440 to 3,600 coho salmon (360 females + 360 males x 2 or 5). Means are primarily of interest as values around which animal populations fluctuate. Here we are most interested in what the maximum potential of the habitat might have been.

The peak egg take of 2.3 million in 1909, represented by an estimated 780 females, suggests a maximum run size of between 3,100-7,800 coho salmon (780 females + 780 males x 2 or 5). The magnitude of the average and maximum escapements to the Methow River fits fairly well with the estimate advanced of 23,000-31,000 coho for the drainage considering harvest. Furthermore, the range of average and maximum escapements results in estimates of 21, 53, 46, and 115 spawning coho per mile of stream (40 miles upper Methow River and 28 miles Twisp River, Fulton 1970). The values of 53 and 46 spawning fish per mile fall within the "normal" high range reported for wild coho spawning in Oregon coastal index streams (Gunsolus 1970), whereas the other values (21 and 115) represent indices of low and exceptionally high abundance (highest value reported by Gunsolus was 69 spawning fish per mile).

State hatchery operations on the Wenatchee River represent a considerable contrast to those on the Methow River (Craig and Suomela 1941). The earliest hatchery was constructed in 1899 near the Chiwaukin railroad station just above Tumwater Canyon. This hatchery was closed in 1904. The reasons given were extreme cold weather, heavy snow, isolated location and consequent expense of operation, freshets, and the fact that it was

too far up the river to secure the best variety of fish (chinook). A quotation from the 14th and 15th annual reports of the State Fish Commissioners of Washington reads as follows: "If it /the hatchery/ had been below the Tumwater Canyon, the early chinook could have been secured; as it is, it takes only an inferior run of silversides."

After the closure of this hatchery there was no activity connected with artificial propagation on the Wenatchee River until 1913, when a new hatchery was constructed at the town of Leavenworth. One of the reasons for the selection of this location was that it was thought that large numbers of spring chinooks could be taken. Very few eggs of spring chinook or any other species were secured by this hatchery until it was abandoned in 1931. The record shows two lots of coho eggs collected, 30,000 and 85,500, and one lot of 3.8 million fry planted (1903) which originated from lower Columbia River coho stocks.

Emphasis of the Wenatchee River hatcheries clearly was on chinook salmon. By contrast, emphasis of the Methow River hatcheries was on coho salmon despite the apparent low esteem for the species compared to chinook, apparently out of deference to a ready source of eggs from the river.

The fact that the early Wenatchee River hatcheries did not turn to the production of coho when the supply of chinook brood stock failed to materialize can be interpreted to mean that the supply of coho brood stock was likewise in short supply. Such a deduction lends credence to the least coho abundance for the Wenatchee River system compared to the

other drainages. On the other hand, such a deduction is at odds with the testimony of old timers interviewed by Craig and Suomela (1941), who without exception noted that "silvers" were numerous and spawned in nearly all the small creeks.

Fulton's (1970) description of coho habitat in the Wenatchee River system is vague, underlies the coho estimates cited, and appears to have been tinged by the promise of the Leavenworth Hatchery rehabilitation program of the 1960's:

> Formerly large runs entered Wenatchee system to spawn. Icicle and Nason creeks were the only known productive areas but other tributaries were probably contributors. Leavenworth National Fish Hatchery, which reared coho salmon many years ago, resumed the work in 1963. Restocking has begun. Some returns from plants in Icicle Creek realized as noted in text. In 1968 most spawners used the main Wenatchee River downstream from Leavenworth.

The key to the enigma appears to lie in -- "Icicle and Nason creeks were the only known productive areas but other tributaries were probably contributors." Contradictorily, the old timers interviewed by Craig and Suomela (1941) emphasized that very few salmon were found in Icicle Creek. The point here is not a highlighting of inconsistencies (others mentioned were reports of coho runs to the Chiwawa and Okanogan rivers) but to illustrate an impression derived from the inconsistencies.

It will be recalled that Craig and Suomela (1941) could find only second-hand information relative to the coho run to the Entiat River, apparently out of deference to the fact that the run had been extirpated early (1898).

Bryant's and Parkhurst's (1950) stream surveys of the Columbia River system, precursor to Fulton's work, likewise tend to illustrate that coho were gone from many of the smaller tributary streams long before chronicling began, particularly in the Yakima River drainage. Furthermore, these would have been stocks consisting of relatively few fish/stream, but making up an appreciable total, which would not have seemed overly impressive as bits and pieces of an ecosystem mosaic masked by a remaining abundance of other salmon. The causative agent in the early demise of the coho in situations such as the Entiat River -- an impassable mill dam at the mouth -- needs no elaboration. Nor does the usurpation of coho habitat in small tributary streams for irrigation by the large influx of settlers in the last three decades of the 19th century need explanation, except for ecological ramifications.

Originally the Columbia River was the greatest salmon and steelhead river in the world. The fish originated in the thousands of miles of inland streams, migrated to the ocean, grew to adults, and migrated back to the natal streams to complete the life cycle. Such a cycle represented a virtually fail-safe, energy-efficient system representing many thousands of years of evolution. The population did not consist of one large mass of fish that randomly distributed itself throughout the system, with free interbreeding occurring between all fish (Horner and Bjornn 1980). Instead, a unique faunal complex, featuring species and stocks within species, evolved specialized adaptive features in behavior and physiology so as to maximize efficiency of energy conversion (detailed examples for the Columbia

River and elsewhere can be found in Thompson 1951). With this came habitat and/or food partitioning which segregated the various species and stocks.

Historically the upriver population of coho salmon may have been composed of several stocks of fish, each adapted to its own particular environment (Horner and Bjornn 1980). Functionally the evidence suggests one stock of fish that spawned in the lower portions of first order streams and another in the upper reaches of second order streams, a dichotomy that could be encompassed by a single headwater-type stream designation. In any event, the former were largely gone by the early 1900's, due to the relative ease by which the habitat could be altered for irrigation purposes, and the latter lingered into the 1920's on the Methow River, and perhaps to the present on the Yakima River, because the larger stream habitat proved less amenable to drastic alteration unless blocked by dams.

The foregoing explanation of causative factors possibly responsible for the early demise of upriver coho abundance could be overly simplistic and obscure an important consideration in any rehabilitation program for the species. Apart from the obvious hazards of habitat loss, more than likely the upriver population of coho salmon was composed of several stocks of fish with different productivities affecting response to commercial harvest. Ricker (1973) described the theoretical dynamics of such impact:

> It is the nature of animals of whatever sort, to penetrate into every habitat where they can eke out a living. Hence it is to be expected that there once existed salmon stocks (even fairly large ones) in marginal situations that needed almost the whole of their recruitment for spawning in order to survive....

> Such stocks would disappear during the developmental period of the fishery. On the spawning grounds this disappearance would scarcely be noticed amid the general abundance of breeding fish in those days (mostly before 1900), when in any event the information available was poor or lacking. While they lasted, however, such stocks may have contributed importantly to the large runs and easy catches that were then available in the commercial fishing areas.

Marginal habitat can be defined as habitat that is biologically precarious due to chronic or recurring environmental restraint(s), which periodically inhibit expression of population potential of a species (Binns 1978). Manifestation of such phenomenon commonly takes the form of erratic fluctuations in abundance of species occupying habitat peripheral to principal areas of abundance. As discussed, current and historical abundance of coho salmon in the huge Columbia Basin (260,000 square miles) centered in lower mainstem tributaries. This can be taken as evidence that the survival rate is highest for such stocks, and that the time and distance of their migration ties together in the best manner the periods of favorable conditions in the different environments utilized. Conversely, biological potential of upriver coho stocks could have been compromised, possibly to levels encompassed by that of Ricker's "marginal situations," long before the circumscription of habitat imposed by the modern dam era.

LIFE HISTORY

Coho salmon from the Columbia River are separated into early and late run stocks. Early run coho enter the Columbia River during August and September, peaking in early September, and spawning takes place between October and November, generally in larger tributaries. Late run coho enter the Columbia between October and November, peaking in mid-October, and spawning, generally in the smaller tributaries, takes place any time from late October through March (Horner and Bjornn 1980).

The old-timers cited implicate native coho in the Wenatchee, Methow, and Okanogan drainages as having consisted of early run stocks, especially considering upriver location, but, at least in the Wenatchee drainage, of having spawned in the smaller tributaries.

Records of arrival and spawning dates for coho salmon returning to the Leavenworth complex hatcheries are incomplete and inconsistent (Table 3). Native coho at Leavenworth Hatchery were spawned in late October-early November in 1941 and 1944. Non-native stocks in later years apparently spawned about the same time. However, non-native stock returning to Winthrop Hatchery, 72 miles further upstream, were spawned into December some years, with the coho reported in poor condition and partially spawned out. Likewise, fish counting in the 1970's was extended into late November or mid-December at Rock Island and Rocky Reach dams out of deference to passage of large numbers of coho during this period.

Juvenile coho usually spend about 18 months in fresh water before migrating to the ocean in May of their second year of life. Early run coho tend to migrate south after entering the ocean, whereas late run coho tend to migrate north, although there is considerable overlap (Horner and Bjornn 1980). Leavenworth Hatchery releases of 1965 brood year coho from Cascade Hatchery eggs tended to migrate north, whereas 1966 brood year releases from Little White Salmon Hatchery eggs tended to migrate south (Lander and Henry 1973). Columbia Basin coho salmon do not migrate far in the ocean and are harvested primarily off the coasts of Washington, Oregon and California (Horner and Bjornn 1980; Lander and Henry 1973).

Jack coho salmon spend about six months in the ocean and return to spawn in the fall of their second year of life (two-year-olds). Most adult coho spend about 18 months in the ocean and return to spawn in their third year of life (three-year-olds). The percentage of Columbia Basin coho maturing in their fourth or fifth year of life is small. Although jack coho are functionally adults, primarily precocious males, the terms *jack* and *adult* are used throughout this report to differentiate between two-year-olds and older age coho, primarily three-year-olds.

Coho salmon, like all Pacific salmon, die after spawning and the cycle is then complete. Scott and Crossman (1973) estimate that about 85% of the spawners home to their natal stream. Egg number is variable with size of female, area, and year, and has been reported in Washington to be 1,440-5,700 for females 17.3-28.3 inches in length and in British Columbia from 2,100-2,789, where the usual size of fish in the commercial catch is eight

pounds, ranging from 5-12 pounds, with 20-pound fish not uncommon (Scott and Crossman 1973).

The record of average number of eggs per female spawned at Leavenworth and Winthrop hatcheries is relatively complete, but data on size of fish spawned is almost totally lacking (Table 1). Fulton (1970) reported coho returning to Leavenworth Hatchery in 1968 as larger than usual (12-15 pounds) for the Columbia River (9.9 pounds). Although none returned to Leavenworth Hatchery, 1942 brood releases of marked Lewis River coho stock recovered as adults in the lower river commercial fisheries were smaller; 89 females averaged 9.6 pounds and 27.0 inches in length and 121 males averaged 9.3 pounds and 26.3 inches in length (Fulton, Pearson and Hanavan, in press). Average number of eggs per females taken in 1968 was about 3,000, which represented about a median value for the 13 years of record.

HATCHERIES, RIVERS AND DAMS

All three federal mitigation hatcheries are of relatively conventional design and were originally constructed for production of over 100 million salmon and steelhead fry or fingerlings, with Leavenworth constituting the main cultural unit and Entiat and Winthrop operated as satellite stations. Although there have been many changes over the years, Leavenworth is still the largest, with a production of about 2.5 million smolts (about 18/lb.), followed by Winthrop (1 million smolts) and Entiat (0.6 million smolts). Currently, production is almost exclusively devoted to spring chinook in meeting the goal of a comprehensive management plan for the mid-Columbia River developed by the inter-agency Grand Coulee Fish Rehabilitation Committee.

Leavenworth Hatchery is located on Icicle Creek, a tributary of the Wenatchee River, about 497 miles from the ocean (3 miles Icicle Creek; 26 miles Wenatchee River; 468 miles Columbia River) (Figure 1). Entiat Hatchery is located to the north on the Entiat River about 490 miles from the ocean (6 miles Entiat River; 484 miles Columbia River). Winthrop Hatchery lies farthest north on the Methow River about 569 miles from the ocean (45 miles Methow River; 524 miles Columbia River).

The Wenatchee, Entiat, and Methow rivers are second-order streams, with base flows of about 3,000 cfs, 500 cfs, and 1,400 cfs, respectively. The three rivers flow southeasterly from the Cascade Mountains and are primarily maintained by melting snow and glaciers. There is about a 50-inch difference in precipitation between the subalpine forests of the headwaters to the semi-arid, pine-grass associations at the confluences with the Columbia River in north-central Washington. These are freestone rivers, which are characteristically droughty, with floods common, due to climate and geology.

Holding ponds at Leavenworth for retaining adult fish between the time of their arrival and the onset of sexual maturity were formed in a three-quarter-mile section of Icicle Creek bypassed by a diversion canal. Construction of four dams created three separate river-holding areas. Retrieval of fish was by seining or various trapping schemes either in the holding areas or the tailrace of the bypass diversion canal dam. No provision for holding adult fish to secure a continuing egg

supply were made in the original plans for Entiat or Winthrop stations. To remedy this deficiency, small adult fish holding ponds connected to the Entiat and Methow rivers by short fish ladders were constructed during World War II. In subsequent years these facilities were upgraded on a year-by-year basis, including various racking of the rivers to divert runs into the holding ponds. Efficiency of collection varied widely and is discussed in the Historical Perspective section.

The period of operation of these hatcheries (1940 to the present) corresponds to the time of extensive development of hydroelectric power on the Columbia River. Rock Island, Bonneville and Grand Coulee dams began operation in 1933, 1938 and 1941, respectively, and these dams were followed by additional dams (Table 2; Figure 1). While all of these dams have had a detrimental cumulative effect on natural runs and returns from hatchery releases, they have also served as counting fences, recording the demise or enhancement of the resource (Salo and Stober 1977). The inherent limitations of dam fish counts are discussed by Bell et al. (1977).

RELEASES

Propagation of coho salmon from the Leavenworth (Table 3), Entiat (Table 4) and Winthrop (Table 5) hatcheries was in two phases. The first began with the completion of the hatcheries in the early 1940's in implementing the integrated program of natural and artificial propagation envisioned in the Grand Coulee Fish Maintenance Project. A project report (USFWS) for 1944 states:

Table 2. Chronology of hydroelectric power dam construction on the Columbia River.

Years Constructed	Dam Name	River Mile	Reservoir Length (miles)	Reservoir Area (acres)
1930-33	Rock Island	453	21	2,500
1933-38	Bonneville	145.5	46.2	20,400
1933-41	Grand Coulee	597	150	80,000
1947-54	McNary	292	61	38,100
1950-55	Chief Joseph	545	52	7,800
1952-57	The Dalles	191.7	23.9	10,500
1956-59	Priest Rapids	397	18	7,000
1956-61	Rocky Reach	474	42	9,200
1958-68	John Day	215.6	76.4	50,000
1959-63	Wanapum	415	38	13,800
1963-67	Wells	515.8	29.2	10,700

Table 3. Leavenworth National Fish Hatchery coho salmon stocking history.

Brood Year	Egg Source [1]	Releases			
		Area	Number	Date	Fish/Pound
1940	Rock Island [2]	Icicle Cr	5,470	1942	11.4
1941	Rock Island [2]	Icicle Cr	11,050	1943	11.4
1942	Lewis River	Icicle Cr	40,370	1943	91.0
	Lewis River	Icicle Cr	69,627	1944	91.0
1943	Lewis River	Icicle Cr	112,267	1944	91.0
1944	Icicle River	Icicle Cr	133,703	1945	47.0
	Lewis River	Icicle Cr	28,954	1945	24.8
1945	Icicle River	Icicle Cr	1,896	1946	26.0
1946	---	---	0	---	---
1947	Icicle River	Icicle Cr	114,652	1948	60.2
1948	---	---	0	---	---
1949	Lewis River	Wenatchee R [3]	229,969	Oct 1950	27.6
1950	Lewis River	Icicle Cr	98,786	1952	16.6
	Icicle River	Icicle Cr	16,850	1952	16.6
1951	Lewis River	Icicle Cr	47,607	1953	23.2
1952	Lewis River	Icicle Cr	93,909	1954	42.4
1953	Icicle River	Icicle Cr	2,419	1954	142.3
1954	Quilcene	Icicle Cr	11,750	1955	50.0
	Icicle River	Icicle Cr	3,222	1956	25.4
	Quilcene	Icicle Cr	12,499	1956	38.0
1955	---	---	0	---	---
1956	---	---	0	---	---
1957	Icicle River	Icicle Cr	2,884	Mar 1959	27.7
1958	---	---	0	---	---
1959	---	---	0	---	---
1960	---	---	0	---	---
1961	---	---	0	---	---
1962	Eagle Creek	Icicle Cr	455,713	Aug 1963	118.0
1963	Eagle Creek	Icicle Cr	871,000	Oct 1964	62.0
1964	Cascade	Icicle Cr	769,000	Sep 1965	41.0
	Cascade	Icicle Cr	656,000	Mar 1966	16.0
1965	L. White Salmon	Icicle Cr	1,734,000	Mar 1966	706.0
	Cascade	Wen.R.+Tribs	4,170,000	July-Sep '66	54.0
	Cascade	Icicle Cr	536,000	Mar 1967	19.2
	Cascade	Snake R	708,000	Apr 1967	16.0
1966	L. White Salmon	Icicle Cr	125,000	Mar 1968	23.0
	L. White Salmon	Icicle Cr	550,000	Mar 1968	18.0
	L. White Salmon	Snake R	700,000	Apr 1968	20.0
	L. White Salmon	Wenatchee R	3,701,000	Apr 1967	150.0
	Spring Cr and L. White Salmon	Wenatchee R	7,900,000	?	eyed eggs

Table 3. (continued)

Brood Year	Egg Source 1/	Releases			
		Area	Number	Date	Fish/Pound
1967	Icicle River	Icicle Cr	26,000	Apr 1969	18.0
	L. White Salmon	Wenatchee R	4,397,000	July 1968	412.0
	L. White Salmon	Icicle Cr	701,000	Apr 1969	18.0
	L. White Salmon	Snake Cr	102,000	May 1969	18.0
1968	Icicle River	Icicle Cr	2,231,000	Sep 1969	47.0
	L. White Salmon	Icicle Cr	908,000	Apr 1970	16.0
1969	Willard	Icicle Cr	2,001,000	Feb 1970	1190.0
	Willard & Icicle	Icicle Cr	1,457,000	Mar 1971	15.0
1970	?	Icicle Cr	1,102,000	Mar 1972	15.0
1971	Icicle Cr	Icicle Cr	233,000	May 1972	313.0
	Icicle Cr	Icicle Cr	341,000	May 1972	195.0
	Icicle Cr	Icicle Cr	734,000	Apr 1973	18.0
1972	Willard	Icicle Cr	156,000	Apr 1974	16.0
1973	Eagle Creek	Snake R	645,000	Apr 1974	21.0
1974	Eagle Creek	Icicle Cr	659,000	Apr 1975	15.0

1/ Refers to either river of origin or hatchery located on river of origin as listed in Wahle and Smith 1979.

2/ From brood stock intercepted at Rock Island Dam.

3/ Stocked in Wenatchee River below Dryden Dam.

Table 4. Entiat National Fish Hatchery coho salmon stocking history.

Brood Year	Egg Source [1/]	Releases			
		Area	Number	Date	Fish/Pound
1943	Lewis River	Entiat R	28,954	1944	91.0
1944	Lewis River	Entiat R	99,485	Oct 1945	30.0
1963	Lower Columbia	Entiat R	106,425	Mar 1965	29.0
1964	Lower Columbia	Entiat R	367,457	Sep 1965	31.0
1965	Lower Columbia	Entiat R	275,000	June 1966	250.0
	Lower Columbia	Entiat R	299,855	Sep 1966	52.0
1966	Lower Columbia	Entiat R	703,146	Oct 1967	22.0
1967	Lower Columbia	Entiat R	1,672,106	Feb 1968	913.0
	Lower Columbia	Entiat R	430,564	Apr 1968	644.0
	Lower Columbia	Entiat R	452,929	Oct 1968	32.0
1968	L. White Salmon	Entiat R	588,745	July 1969	167.0

[1/] Aside from Lewis River and Little White Salmon National Fish Hatchery, source only listed as lower Columbia River hatcheries in annual reports. Undoubtedly, specific source was same as for Leavenworth NFH in same brood year.

Table 5. Winthrop National Fish Hatchery coho salmon stocking history.

Brood Year	Egg Source [1/]	Releases			
		Area	Number	Date	Fish/Pound
1944	Carson	Methow R	40,082	Nov 1945	91.0
1947	Methow River	Methow R	6,203	1949	24.0
1950	Methow River	Methow R	21,255	1952	20.0
	Lewis River	Methow R	149,578	1952	20.0
1951	Lewis River	Methow R	90,000	1953	15.0
1952	Lewis River	Methow R	94,514	1954	20.0
1953	Methow River	Methow R	6,840	1954	91.0
1954	Methow River	Methow R	1,493	1956	20.0
1958	Quilcene	Methow R	183,691	1959	19.0
1959	Eagle Creek	Methow R	638,039	Sep 1960	28.0
1961	Eagle Creek	Methow R	327,653	1962	37.0
1962	Eagle Creek	Methow R	1,448,447	1963	44.0
1963	Big Creek	Methow R.	824,045	1964	30.0
1964	Eagle Creek	Methow R	1,306,901	1965	40.0
1965	L. White Salmon	Methow R	449,400	1966	1,672.0
	L. White Salmon	Methow R	1,623,178	1966	58.0
1966	L. White Salmon	Methow R	382,176	1967	833.0
	L. White Salmon	Methow R.	600,284	1967	48.0
1967	L. White Salmon	Methow R.	418,750	1968	444.0
	L. White Salmon	Methow R	400,844	1968	24.0
1968	L. White Salmon	Methow R	113,778	1969	30.0

[1/] Refers to either river of origin or hatchery located on river of origin as listed in Wahle and Smith 1979.

> Very few silver salmon now reach Rock Island Dam, but in earlier years the tributaries now being used for the Grand Coulee fish-salvage program supported large runs of this species. Consideration accordingly is being given to the re-establishment of this species to compensate for the reduction in the supply of other species. Interest in silver salmon is increased by the observation that this species appears to respond more favorably than any other salmon to artificial propagation.

The major emphasis in species rearing, nevertheless, was on sockeye and chinook salmon and not on coho. This initial phase, lasting into the 1950's, has been typified for all Columbia Basin hatcheries by Cleaver (1969) as featuring a short rearing period, poor nutrition, and low survival.

Fish culture improved markedly in the early 1960's, especially nutritionally, as typified by pelletized diets, resulting in release of larger, healthier fish and improved returns to the fisheries. These developments revived emphasis in coho and put them on center stage. This second phase lasted until 1969 at Winthrop and Entiat, and until 1975 at Leavenworth, after which coho production was abandoned.

Approximately 31.7 million coho (818,093 pounds), representing 27 brood years, were released from Leavenworth Hatchery, primarily to the Wenatchee River system (Table 3). Just over 5 million coho (78,161 pounds), representing 8 brood years, were released from the Entiat Hatchery into the Entiat River (Table 4). Slightly more than 9.1 million coho (216,714 pounds), representing 17 brood years, were released from the Winthrop Hatchery into the Methow River (Table 5).

The majority of coho released were from lower Columbia River stocks (Tables 3, 4, 5). Even a few Quilcene coastal stock eggs were propagated and released. Dependence on non-native sources of coho eggs was because of virtual depletion of indigenous upriver runs. In the years 1933-1939 from 10-183 coho were recorded annually passing Rock Island Dam. In 1940, 1941 and 1942, when the hatcheries became operational and coho eggs were most needed in getting started, coho counts at Rock Island Dam were 12, 29, and 1, respectively.

Two females were spawned from the 12 brood stock collected in 1940, resulting in a release of 5,470 smolts (11.4/lb.) from Leavenworth Hatchery into Icicle Creek in spring, 1942. Six females were spawned from the 29 fish intercepted at Rock Island Dam in 1941 and 11,050 smolts (11.4/lb.) were released to Icicle Creek in spring, 1943. The run consisted of one fish in 1942 and the 22 fish collected in 1943 died, so no eggs were taken in these years.

First returns to Icicle Creek and Leavenworth Hatchery occurred in 1944, with 128 coho out of an up-until-then record run of 186 passing Rock Island Dam. Although 125 of these coho were not marked (the 3 additional coho were marked jacks from Lewis River stock released in 1944), there is no reason to doubt, based on a three-year life cycle, that these fish were not the progeny of the 11,050 smolts released in spring, 1943, and originating with the six females spawned in 1941. Sixty-six females were spawned in 1944 for an egg take of 203,093, with 133,700 fingerlings (47/lb.) released into Icicle Creek in 1945. Had this second generation

of upriver hatchery coho been reared for 18 months prior to release, as the first generation had been, the re-establishment of coho salmon to the mid-Columbia River might have turned out differently. In wild and hatchery salmon stocks, it is well known that larger juveniles survive better and contribute more to catches and escapement, other factors being reasonably equal, than small juveniles.

Subsequent returns to Leavenworth Hatchery are masked by coincidental releases of lower Columbia River stocks. For example, 166 coho returned to Leavenworth in 1947, again out of an up-to-then record count (229) at Rock Island Dam, and these fish could be attributable to either the Icicle Creek stock in 1944 or 28,954 fingerlings (24.8/lb.) originating from Lewis River stock released in 1945. However, 80 females were spawned in 1947 resulting in a release of 114,652 fingerlings (60.2/lb.) in 1948. Thus, there is the likelihood that the initial runs of coho to the Leavenworth Hatchery were weighted in favor of native stock, and was the root of the oft-cited comment in annual reports thereafter that "Leavenworth coho runs only occurred every three years and that all attempts to fill in the blank years with imported stocks was to no avail."

It can only be assumed that the value of using native coho in re-establishing the runs was recognized. The 22 coho noted as passing Rock Island Dam in 1943, after the initial interception and relocation phase of the Grand Coulee Fish Maintenance Project was completed, were trapped for spawning purposes, but died while being held for sexual maturation. Early run coho passing Bonneville Dam were collected and held at the Carson National

Fish Hatchery for spawning but these, too, died. The WDF Director's initial offer of Lewis River coho as a substitute for native stock was accepted with reluctance. In the 1942 annual report, District Supervisor Kemmerick, plagued by disease problems at the Leavenworth Hatchery, noted:

> The small lot of silver salmon fingerlings produced from eggs of two females spawned in the fall of 1940 were liberated on April 28 and never became affected with any disease. Likewise the silver salmon fingerlings produced from the small lot of eggs taken in the fall of 1941 have outgrown any other fish on hand and have never required a treatment of any kind.

The point to be emphasized here in relation to re-establishing coho runs by artificial propagation is the differential survival between native and non-native stocks of salmonid fishes documented by Ricker (1972). Coho stocks, like all anadromous salmonid stocks, have been selected for thousands of years to make the most effective use of a drainage basin by evolving discrete populations homing to specific areas and each with subtle life history differences. Such populations are not genetically homogeneous, however, and viable populations usually contain a high level of genetic variability or diversity, which is a normal equilibrium condition in most natural animal populations. The capability of a population to rebound from perturbations of environment and/or depletion depends heavily on the amount of genetic variability remaining in the population. Possibly the remaining upriver coho stocks at the time of the Grand Coulee Fish Maintenance Project represented too limited a gene pool to prevent extinction.

Essentially only a handful of female coho remained, regardless of whether one counts only the ones that were spawned or includes also the ones that might have been spawned with better luck. Over-exploitation inevitably reduces

genetic diversity, but particularly the more productive components of the stock (Ricker 1973; Thompson 1951). Furthermore, it is well known that the roles of natural selection and random drift are complimentary in bringing about a reduction in overall diversity in small and isolated animal populations. Accordingly, it is reasonable to assume that only a relatively low level of genetic variability -- "founder effect" -- would or could have been maintained even without subsequent genetic swamping by non-native introductions.

CATCH AND ESCAPEMENT

The return of 125 adult coho salmon in 1944 from the 1941 brood year release (11,050 smolts) of native stock, discussed previously, was clear-cut and respectable (1.13%). However, the apparent lack of any returns from the similar but smaller plant (5,470 smolts) of the 1940 brood year presents an enigma (Table 6). Returns become even more enigmatic in latter years with releases of non-native stock. Nevertheless, a distinctive correlation does exist between annual coho counts at Rock Island Dam, which rose from less than a few hundred fish into the thousands beginning in the mid-1960's, and the second phase of more numerous hatchery releases beginning in the early 1960's (Figure 2; Table 6).

The fragmented record of coho escapement to Icicle Creek and Leavenworth Hatchery associated with major coho production has been reconstructed as follows: 1966 — 1,025 adults trapped with another 5,000 jacks estimated; 1967 — a good run estimated but only 461 coho collected due to washout

Table 6. Chronological year, dam counts, Wenatchee River escapement, Icicle Creek escapement, and pounds of coho salmon released from Leavenworth Hatchery three years before into Wenatchee River drainage.

Year	Rock Island Dam Count	Rocky Reach Dam Count	Wells Dam Count	Wenatchee R Escapement Estimate	Icicle Creek Escapement			Releases (pounds) 3 yrs before
					trapped	observed/ estimated	comment	
1933	183							
1934	69							
1935	10							
1936	--							
1937	58							
1938	78							
1939	13							
1940	12							
1941	29							
1942	1							
1943	22							480
1944	186				128			969
1945	166				4			1,209
1946	32				1			1,234
1947	229		41 trapped Winthrop NFH		166			4,012
1948	29							73
1949	40				1			
1950	72		23 trapped Winthrop NFH		22			1,905
1951	8							
1952	22							
1953	40		6 trapped Winthrop NFH		4			12,900
1954	43		3 Winthrop		3			2,055
1955	51							2,231
1956	29							17
1957	33				5			456
1958	76							
1959	118							
1960	94							104

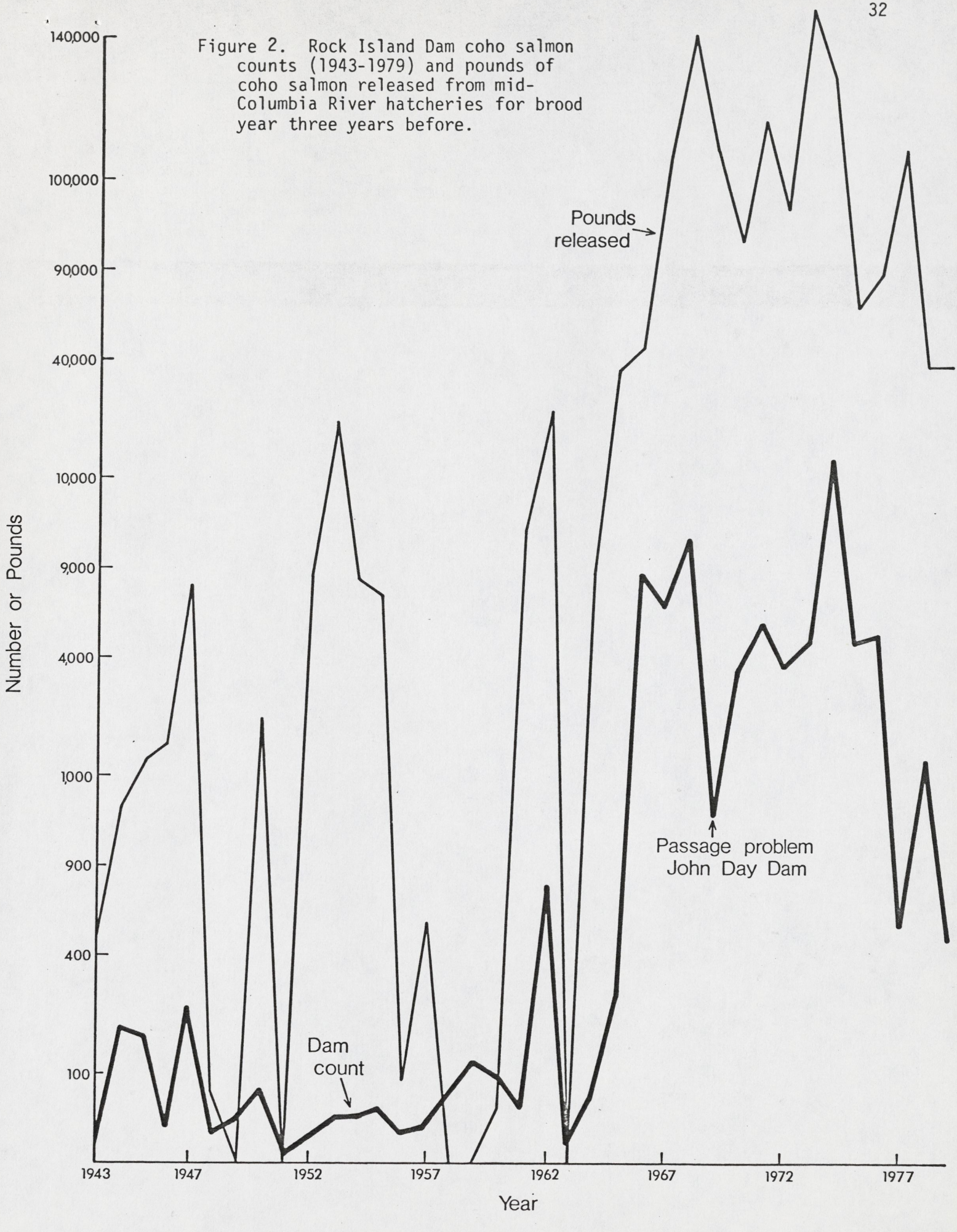
Table 6. (continued)

Year	Rock Island Dam Count	Rocky Reach Dam Count	Wells Dam Count	Wenatchee R Escapement Estimate	Icicle Creek Escapement			Releases (pounds) 3 yrs before
					trapped	observed/ estimated	comment	
1961	50							
1962	737	500	250 trapped Winthrop NFH	237				
1963	18	2		16				
1964	61	100			15	150		
1965	258	304						3,861
1966	8,342	879		7,463	1,025	6,025	5,000 jacks	14,118
1967**	6,222	688	257	5,534	461	good run	trap washout	58,737
1968**	9,259	735	221	8,524	2,286	2,350		107,490
1969**	947	179	27	768	12	poor run	pass.blocked John Day Dam	60,767
1970**	3,483	207	54	3,276	1,031	1,231		50,689
1971**	5,423	0	154	5,269	2,778			100,895
1972**	3,661	3,312	584	349	7			93,632
1973	4,605	745	322	3,860	477	good run	trap futile	77,655
1974	13,000	10,788	110	2,212	67	good run	incidental	43,130
1975	4,610	6,979*	26				to chinook	9,596
1976	4,996	5,685*	97					30,632
1977	518	927*	70					42,276
1978	1,229	1,438*	73					
1979	465	244	63	221				

*Counting at Rocky Reach Dam extended longer into fall in years when counts for that dam exceeded those of Rock Island.

**Computed estimates from Priest Rapids counts.

Figure 2. Rock Island Dam coho salmon counts (1943-1979) and pounds of coho salmon released from mid-Columbia River hatcheries for brood year three years before.



of the trap; 1968 — 2,286 coho trapped out of an estimated total run of 2,350 fish; 1969 — run largely blocked because of construction at John Day Dam in the lower Columbia River; 1970 — 1,031 coho trapped with about 100 adults and 100 jacks estimated remaining in Icicle Creek; 1971 — 2,778 coho trapped; 1972 — some coho observed but only a few fish entered the trap (this attributed to higher-than-normal stream flow); 1973 — large numbers of coho observed spawning in Icicle Creek but only 477 collected; 1974 — observations of a good run but trapping for coho abandoned with only 67 fish collected incidental to the recovery of chinook salmon spawners.

It can be seen from the foregoing that coho escapement to Icicle Creek can be reasonably quantified only for the years 1966, 1968, 1970 and 1971 (Table 7). These data permit an estimate of escapement to Leavenworth Hatchery of adult (three-year-old) coho of 0.049% and escapement of jacks (two-year-olds) and adults for the 1968 brood release of 0.042%. Assuming that all the jacks were of the same brood years as the adults increases the escapement to 0.175%. Fulton (1970) suggests that coho runs in the Columbia River during the 1960's may have averaged 40% jacks. Use of this percentage rather than the 72% observed and/or estimated lowers escapement to 0.081%.

A better measure of escapement would be the fish counts at mid-Columbia River dams. Counts at Rock Island Dam generally reflected coho abundance and impact of hatchery releases in early years when runs and releases were small. Completion of upstream Rocky Reach Dam and commencement of

Table 7. Coho salmon escapement to Leavenworth Hatchery for the years 1966, 1968, 1970 and 1971.

	Icicle Creek Escapement			Wenatchee River Escapement	Releases to Icicle Creek			
Year	Adults	Jacks	Total		Brood Year	Number	No./lb (date)	Total Pounds
1966	1,025	5,000	6,025	7,463	1963	871,000	62 (10/64)	14,118
1968	1,086	1,200	2,286	8,524	1965	1,734,000	706 (3/66)	2,456
						536,000	19 (3/67)	27,930
1970	540	691	1,231	3,276	1967	727,000	18 (4/69)	40,017
1971	778	2,000	2,778	5,423	1968	2,231,000	47 (9/69)	47,129
						908,000	17 (4/70)	53,766
Total	3,429	8,891	12,320			7,007,000		
Percent	28%	72%						

Estimated escapement of adults (three-year-olds) = 0.049%.

Estimated escapement of adults and jacks for 1968 brood year = 0.042%.

Assumption that all jacks were of same brood years as adults raises estimated escapement to = 0.175%.

Use of an average 40% jack composition, after Fulton 1970, lowers estimated escapement to = 0.081%.

fish counting there in 1962 provided an improved measure of coho escapement to the Wenatchee River. Coho salmon passing Rock Island Dam could either proceed up the Columbia River over Rocky Reach Dam or enter the Wenatchee River (Figure 1). Of major credence is that when coho production at Leavenworth Hatchery was abandoned and subsequently initiated at Wells Dam and Turtle Rock hatcheries, located in the upstream Rocky Reach impoundment, coho runs to the Wenatchee River ceased for all practical purposes and the runs were then documented passing Rocky Reach Dam (Table 6).

Fairly obviously, the implications of the change in homing is that the coho salmon runs to the Wenatchee River in the 1960's and early 1970's were largely, if not entirely, hatchery-dependent, just as they had been earlier. This is not to say that there was no natural spawning of some hatchery fish. In any case, the dam counts could be expected to more adequately reflect the contribution of outplants from Leavenworth Hatchery to the Wenatchee River and tributaries which could not be expected to return to Icicle Creek. Also, such an accounting more adequately reflects returns from releases of fry-fingerling size coho released into Icicle Creek itself, but requiring additional rearing before smolting. Homing of these fish to rearing areas not necessarily located in Icicle Creek could be expected.

The difference in fish counts between Rock Island and Rocky Reach dams for the years 1966-1973, minus the possibility of 200 wild spawned fish

annually, indicated an average escapement of hatchery coho salmon to the Wenatchee River of 0.129% (Table 8). This figure is similar to the 0.173% Leavenworth Hatchery escapement reported by Wahle, Vreeland and Lander (1973) for the 1965 brood year, and the 0.175% Leavenworth Hatchery escapement previously calculated by assuming comparability between average jack:adult ratios not involving the same brood year.

In the Wahle et al. study, marked coho smolts of the 1965-66 broods were released from 20 hatcheries on four sections of the Columbia River and tributaries to determine costs/benefits. Unfortunately, few Leavenworth Hatchery returns of the 1966 brood were obtained because of passage difficulties at John Day Dam due to construction of fish ladders and mortalities caused by trapping at Priest Rapids Dam (Wahle et al. 1973). The 1965 brood release amounted to 101,734 smolts of which 176 were recovered in Icicle Creek. Thirty-eight of these were recovered as jacks in 1967. Trapping of coho was poor that year due to a wash-out of the trap at Leavenworth Hatchery. However, even if some reasonable adjustment is made for non-recovery of marked jacks in 1967, the low hatchery escapement for the 1965 brood is little altered.

In 1968, all of the coho returning to Leavenworth Hatchery were accounted for (2,286 trapped, with another 90-100 adults and 90-100 jacks observed remaining in Icicle Creek). Of those trapped, 1,086 were adults and 138 of these consisted of marked fish from the 1965 brood year. The remaining unmarked adults originated either with 434,266 production fish, the same lot of fish as those marked, or a release of 1.7 million fry (706/lb.).

Table 8. Estimated coho salmon escapement to Wenatchee River (1966-1973) based on differences in fish counts between Rock Island and Rocky Reach dams, from brood year releases (1963-1970).

		Releases Leavenworth Hatchery			
Year	Wenatchee R. Escapement	Brood Year	Number	No./lb	Total Pounds
1966	7,463	1963	871,000	62	14,118
1967	5,534	1964	769,000	41	18,747
			656,000	16	39,990
1968	8,524	1965	1,734,000	706	2,456
			4,170,000	54	77,104
			536,000	19	27,930
1969	768	1966*	125,000	23	5,543
			550,000	18	30,556
			3,701,000	150	24,668
1970	3,276	1967	26,000	18	1,444
			4,397,000	412	10,672
	5,269		701,000	18	38,573
1971	5,269	1968	2,231,000	47	47,129
			908,000	16	53,766
1972	349	1969	2,001,000	1,190	1,682
			1,457,000	15	91,950
1973	3,860	1970	1,102,000	15	77,655
Total	35,043		25,935,000		
	-1,600 (200 possible wild fish per year)				
	33,443 = 0.129% escapement.				

*7.9 million eyed eggs planted in tributaries ignored.

Assuming the same escapement for the unmarked smolts as the marked smolts leaves 358 returning adults (0.02%) attributable to the 1.7 million fry release.

The 1965 brood year releases from Leavenworth Hatchery represented an all-time record, both in numbers and weight, and included 4.17 million fingerlings (54/lb.) outplanted to the Wenatchee River and tributaries. Returns from these record releases were reflected in a record count (9,259 coho) over Rock Island Dam and a record escapement (8,524 coho) to the Wenatchee River in 1968. About 28% (2,350 coho) of the escapement to the Wenatchee River returned to Icicle Creek, with about one-half consisting of jacks. If about the same percentage of the Wenatchee River escapement consisted of jacks, this would have resulted in a return of about 3,000 adults (0.07%) that could have originated with the outplant of 4.17 million fingerlings. Again, it will be noted that any reasonable adjustment(s) to the jack:adult ratio does little to alter the premise of low hatchery escapement within the bounds of the hard data of Wahle et al. (1973). Furthermore, the various escapement estimates are all consistent with respect to the Wahle-et al. conclusion of a fraction of one percent escapement and decreasing return with release of smaller fish.

There is no record of any coho salmon ever having returned to the Entiat Hatchery. More than likely this can be largely explained by the fact that the period of maximum releases of coho occurred after the use of the electrical weir was abandoned, which previously had proved so effective in collecting

other salmon species. Differences in fish counts between Rocky Reach Dam and upstream Wells Dam for the years 1967-1970 suggest a possible average escapement of hatchery coho to the Entiat River of 0.029%, or between 150 and 500 fish annually (Table 9).

The record of coho salmon returning to the furthermost upstream Winthrop Hatchery was also far from spectacular, but perhaps with good reason. The Methow River also was not racked during most of the years of maximum coho releases from Winthrop Hatchery. The exception, 1962, shows a record 250 coho collected, correlated with an up-until-then record count of 737 coho passing Rock Island Dam and 500 passing Rocky Reach Dam (Table 6).

Correlation of returns at Winthrop Hatchery with coho counts at Rock Island Dam was also good in the earlier years, although the number of coho involved was small. As already discussed, 229 coho were counted over Rock Island Dam in 1947, of which 166 returned to Leavenworth Hatchery. However, another 41 returned to Winthrop Hatchery, which accounts for 90% of the coho run passing Rock Island Dam that year. In 1950, 72 coho were counted passing Rock Island Dam, of which 22 returned to Leavenworth Hatchery and another 23 to Winthrop Hatchery for a combined hatchery contribution of 62%. While the numbers of fish involved and percentage contributions are much smaller, the same relationship holds for the coho runs of 1953-1954 (Table 6).

Small numbers of coho were observed by WDF personnel to spawn in the Methow River below the Winthrop Hatchery in the 1960's (Fulton 1970). If all

Table 9. Estimated coho salmon escapement to the Entiat River (1967-1970), based on differences in fish counts between Rocky Reach and Wells dams, from Entiat Hatchery brood year releases (1964-1967).

		Releases Entiat Hatchery			
Year	Entiat River Escapement	Brood Year	Number	No./lb.	Total Pounds
1967	431	1964	367,457	31	11,853
1968	514	1965	275,000	250	1,100
			299,855	52	5,766
1969	152	1966	703,146	22	31,961
1970	153	1967	1,672,106	913	1,831
			430,564	644	668
			452,929	32	14,154
TOTAL	1,250		4,201,057		

0.030% escapement

coho salmon passing Wells Dam in the years 1967-1971 were of Winthrop Hatchery origin, this would represent an escapement of only 0.013% or between 25 and 250 fish annually (Table 10). Meekin (1967) counted a run of 25 coho passing an electrical weir located near the mouth of the Methow River from October 4-28, 1966 and reported observing no coho at the weir in 1965.

The Public Utility Districts (PUD's) of Chelan and Douglas counties, in cooperation with the WDF, essentially took over the propagation of coho for the mid-Columbia about where the federal effort on the species ended in the late 1960's and early 1970's (Table 11). Initially coho eggs were hatched at Leavenworth Hatchery and transferred to the PUD-WDF Wells Dam and Turtle Rock Island fish cultural facilities for rearing, but in later years eggs or fry were shipped in from WDF hatcheries on the lower Columbia River. After initial shake-down and with release of large-sized smolts (9-15/lb.), success was reflected in dam fish counts, particularly the all-time record run of 10,800 coho tallied over Rocky Reach Dam in 1974 (Table 6). Differences in coho salmon counts between Rocky Reach Dam and upstream Wells Dam, where the Wells and Turtle Rock hatcheries are located, suggest an average escapement of coho to this reach of the Columbia River of 0.58% for the years 1973-1979. This represents about a three-fold higher escapement than from the earlier federal releases.

It is well documented that coho salmon populations, like all animal populations, fluctuate on an annual as well as a long-term basis. An upward trend in Washington and Oregon coho stocks followed the low level

Table 10. Estimated coho salmon escapement to Methow River, assuming that all coho passing Wells Dam in the years 1967-1971 originated with Winthrop Hatchery brood year releases of 1964-1968.

		Releases Winthrop Hatchery			
Year	Methow River Escapement	Brood Year	Number	No./lb.	Total Pounds
1967	257	1964	1,306,901	40	32,672
1968	221	1965	449,400	1,672	269
			1,623,178	58	27,985
1969	27	1966	382,176	833	459
			600,284	48	12,506
1970	54	1967	418,750	444	943
			400,844	24	16,701
1971	154	1968	113,778	30	3,792
TOTAL	713		5,295,311		

0.013% escapement

Table 11. Chronological year, dam counts, estimated escapement to Rocky Reach Impoundment and coho salmon releases from Wells Dam and Turtle Rock Island hatcheries, 1970-1979.

Year	Rocky Reach Dam Count	Wells Dam Count	Escapement Rocky Reach Impoundment	Releases			
				Brood Year	Number	No./lb.	Hatchery
1970	207	54	153	1967	190,000	26	Wells
1971	0	154	?	1968	916,185	fry	Turtle Rock
1972	3,312	584	2,728	1969	3,000,000	eggs & fry	Turtle Rock
1973	745	322	423	1970	738,000	9.4	Turtle Rock
1974	10,783	110	10,788	1971	735,000	9	Turtle Rock
1975	6,979	26	6,953	1972	393,000	13	Wells
					388,000	15	
1976	5,685	97	5,588	1973	260,000	14.7	Wells
					571,519	14.2	Turtle Rock
1977	927	70	857	1974	548,500	13.4	Turtle Rock
					400,000	18	Wells
1978	1,438	73	1,365	1975	500,000	13.4	Turtle Rock
1979	244	63	181	1976	500,000	13.4	Turtle Rock

in abundance reached between 1940 and 1960, correlated with the improved hatchery production of the 1960's. This trend leveled off in the 1970's despite an increase in the number of smolts released from hatcheries (Gunsolus 1978). Within the long-term trend there was also wide annual fluctuations in coho abundance. Oregon's commercial landings of coho in 1977 dropped to their lowest level since 1961 and the ocean sport harvest was the lowest on record (Gunsolus 1978). The decline of coho in 1977 followed all-time record catches in 1976. Mid-Columbia River dam fish counts mimicked these gyrations in coho abundance (Table 6; Figure 1).

Gunsolus (1978) suggests that a limit to ocean survival of young coho, associated with upwelling, was reached in the 1970's. He further suggests that the 1970's level of ocean abundance may have been as great during the peak harvest period of the 1920's, and that there was no historical evidence that numbers of fish produced could be increased above these levels. From this it can be seen that the federal coho program of the 1960's coincided with a cycle of favorable environmental conditions in the ocean, whereas the PUD-WDF coho program of the 1970's did not. In the former period, production of smolts was the prevailing limiting factor, where in the latter period ocean survival was most critical.

Naturally enough, the foregoing does not explain, and is inconsistent with, why the PUD-WDF coho program was so much more successful than the earlier federal effort, at least as reflected in dam counts. When catch and escapement records are combined, they represent the total production of adults less natural mortality. Up until this point, we have relied on

escapement records as an indicator of return from coho releases because harvest data was generally lacking.

In the only major harvest study available from the mid-Columbia River, Wahle et al. (1973) reported a catch of 2.65% and 0.93% for marked coho of the 1965-1966 brood year released from Leavenworth Hatchery. While these harvest data are generally in the lower quartile of recovery values reported by Wahle et al. (1973) for downstream areas of the Columbia River and by Mobrand et al. (1977) for coastal streams, there are no data to suggest that these catch levels were not representative of other releases of the 1960's. Most of the Columbia River dams were in place (Table 1) just as now, although there was much more spill for smolt outmigration, a fact supported by only a slight difference between the recovery of marked coho of the 1966 brood year released at Leavenworth (0.93%) and a similar lot trucked and released below Bonneville Dam (1.16%). Currently a 1-to-2-percent escapement and harvest of steelhead trout, not subject to ocean exploitation, to the Columbia River from upstream releases is considered good (Eldred 1979). Furthermore, a case can be made that while the harvest returns of Wahle et al. (1973) are low, they represent an improvement over returns of earlier years when propagation technology was less advanced. The percentage return of adults to the lower river commercial fisheries from Leavenworth Hatchery 1942 and 1943 brood year releases of fin-clipped coho salmon reared for 12 months (N=32,562 and N=25,217) and released in the fall (79/lb. and 54/lb.) was 0.40% and 0.34%, and 0.64% and 1.05% for fish (N=29,222 and N=26,478) that had been reared for 17 months and released in the spring (56/lb. and 25/lb.) (Fulton, Pearson and Hanavan, in press).

What is difficult to reconcile in the coho salmon production equation (catch *plus* escapement *minus* natural mortality) is the meaning of high ratios between returning jacks and adults in upriver areas of the mid-Columbia River in some years.

Jack and adult coho salmon were counted separately at Priest Rapids Dam from 1967-1978 (Table 12). While total counts do not agree very well with some counts at the upstream Rock Island and Rocky Reach dams (for various reasons, i.e., counting in recent years has been extended into late November or mid-December at Rock Island and Rocky Reach dams, while counting is normally terminated at Priest Rapids in late October) or with some of the estimates for Leavenworth Hatchery, they do depict jack:adult ratios (72.2%, 68.2%, 63.0%, 69.6%, 89.1%) for some brood years (1966, 1970, 1972, 1973, 1974) that are completely out-of-line with that reported by Wahle et al. (1973). In the latter study, percentages of jacks in coho spawning cohorts by river section for the 1965-1966 brood year releases were: lower river, 46% and 54%; middle river, 32% and 28%; upper river, 37% and 36%; and uppermost river (Leavenworth Hatchery), 22% and unknown.

Logically, the apparent distortion in upriver jack:adult coho ratios could be dismissed out of deference to interactions of multiple variables, especially the vagaries (i.e., misidentification) of fish counts at dams as discussed by Bell et al. (1977). A less complex speculation would be simply that varying portions of hatchery coho released in the mid-Columbia do not go to sea. High residualism of hatchery coho released to the

Table 12. Jack-adult coho salmon counts, Priest Rapids Dam, 1967-1978, and percentage jacks in brood year cohort.

Year	Adult	Jack	(%)	Brood Year	Adult	Jack	(%)
1967	2,998	5,881	(66.2)	1964	2,998	---	(--)
1968	11,475	1,737	(13.0)	1965	11,475	5,881	(33.9)
1969	668	683	(50.5)	1966	668	1,737	(72.2)
1970	2,402	2,569	(51.7)	1967	2,402	683	(22.1)
1971	6,897	841	(10.9)	1968	6,897	2,569	(27.1)
1972	2,288	2,937	(56.2)	1969	2,288	841	(26.9)
1973	1,364	212	(13.5)	1970	1,364	2,937	(68.2)
1974	1,136	645	(36.2)	1971	1,136	212	(15.7)
1975	378	1,815	(82.8)	1972	378	645	(63.0)
1976	792	1,483	(65.2)	1973	792	1,815	(69.6)
1977	182	188	(50.8)	1974	182	1,483	(89.1)
1978	153	444	(74.4)	1975	153	188	(55.1)

Columbia in some years is not inconsistent with the propagation of short (late) run coho stocks 500 or more miles from the ocean, where the intervening river has been largely altered to a series of impoundments (Table 2). Besides representing potential habitat, impoundment and accompanying regulation of flow has also been demonstrated as being highly disruptive of the normal migration-smoltification timing processes, particularly in years of low flow (Raymond 1976). Accelerated rearing of large size smolts in hatcheries characteristically increases the number of precocious males in salmon and steelhead having a propensity to residualize in freshwater as well. Bilton (1978, 1980) clearly demonstrates that atypical large coho smolts, released to a stream on Vancouver Island, B.C., returned much more heavily as jacks than corresponding typical, but smaller, smolts.

Release of large size smolts (Table 11) made possible by use of the warmer Columbia River water at the Wells Dam and Turtle Rock Island rearing facilities, apparently underlies much of the three-fold higher escapement noted for the PUD-WDF propagation of coho on the mid-Columbia in comparison to earlier federal propagation using colder tributary water. Also, in all fairness, it should be noted that many of the smaller coho released from the federal hatcheries were not production fish scheduled in meeting program goals, but rather were merely surplus to needs. Nevertheless, it also follows that a higher percentage of the escapement from PUD-WDF releases consisted of jacks (two-year-olds) or "jack"-size coho (three-year-olds) that experienced much lower growth in fresh water compared to brethren that

sojourned in the comparatively food-rich ocean. Although coho salmon returning to Rocky Reach Impoundment were never aged, observations of PUD biologists were that the runs were heavily weighted towards 10-14 inch "jacks", especially the all-time record escapement of close to 11,000 coho passing Rocky Reach Dam in 1974 (Bernie Leman, Chelan County PUD and Mike Erho, Douglas County PUD, personal communications).

SUMMARY AND CONCLUSIONS

1. Leavenworth, Entiat and Winthrop National Fish Hatcheries, located on the Wenatchee, Entiat, and Methow rivers, respectively, were built (1939-1941) as part of a comprehensive plan to mitigate loss of 1,140 miles of anadromous salmonid spawning and rearing habitat blocked by construction of Grand Coulee Dam on the upper Columbia River. Essentially the plan (Grand Coulee Fish Maintenance Project) consisted of relocating the anadromous fish runs of the upper Columbia River to the four major tributaries entering below the Grand Coulee dam site, with hatcheries built on these streams.

2. An interim report issued by the U.S. Fish and Wildlife Service in 1948 concluded that the relocation of the upriver runs was a conclusive success, whereas only mixed results were achieved in the propagation of chinook, sockeye, coho salmon and steelhead trout at the three hatcheries constructed. The current report summarizes and interprets observations pertaining only to coho salmon. Hopefully this first in a series of historical assessments by species sheds light on interactive, integrative and emergent properties of habitat and species making up part of the total ecosystem.

3. Coho salmon runs to the mid-Columbia River had been decimated by the construction of impassable mill and power dams, numerous unscreened irrigation diversions and over-harvest in the lower Columbia prior to completion of Grand Coulee Dam in 1941. In the years 1933-1940, only 10 to 183 coho were recorded annually passing Rock Island Dam located downstream of the major tributaries.

4. Despite plantings of 46 million (1.1 million pounds) fry, fingerlings and smolts from the three mitigation hatcheries in the period from 1942-1975, and correction of most local causes of early coho depletion, there is no evidence to indicate development of a self-sustaining population above threshold levels recorded in the 1930's. In fact, there is no discernible evidence to suggest that natural spawning of hatchery coho either temporarily or tokenly contributed to increasing run size. However, hatchery coho did make significant contributions to the ocean and river sport and commercial fisheries.

5. The failure to re-establish, by salmon culture, permanent sizeable populations of coho salmon in any of the tributary streams of the mid-Columbia River appears to have been related primarily to being forced to rely on stocks lacking in genetic variability and/or genetic suitability to the habitat remaining. The value of using native coho stocks in re-establishing runs was recognized, and a concerted effort made in obtaining remanent native coho for propagation in the initial years of the hatcheries. However, numbers were so depleted that only eight females were spawned

and none were available for relocation and wild spawning. While the returns of the progeny from the eight female coho showed promise, there is some reason to believe that only a relatively low level of genetic variability -- founder effect, which could have included genetic contamination with non-native stock in 1903 -- would or could have been perpetuated even without subsequent genetic swamping by late, short-run stocks from the lower Columbia River and a Puget Sound coastal stream.

6. Failure to re-establish coho salmon in tributary streams of the mid-Columbia River carries with it the implication of an unfilled species niche in the habitat remaining. This would seem particularly true of the Methow River, where the abiotic integrity of the habitat appears reasonably good and which originally supported a sizeable coho salmon run. Salmonids, including resident species, in addition to having comparatively rigid life history requirements and adaptations to particular habitats, also can be highly resilient to changes in environment if no critical factor(s) are violated, such as the early impassable dams, now removed, on the Methow River. A manifestation of such adaptation apparently involved the residualization of large coho smolts, originating from late, short-run stocks released from upstream hatcheries in Columbia River impoundments in recent years. We can never know, of course, how virgin populations of anadromous and resident fishes may have affected each other's abundance and/or production in tributary streams such as the Methow River, but we can be pretty well assured that interactions produced adaptations and shaped a fish community different in structure and function than that existing today.

7. Inasmuch as the emphasis of this review has been at the species level, when the decisions concerning anadromous salmonids in the Columbia River decidedly lie at the ecosystem level, extending the analysis to recommendations has been purposely avoided. However, assuming it is deemed holistically desirable to re-establish naturally reproducing populations of coho salmon to historical habitat of the mid-Columbia River Basin, certain precepts are evident from the track record: (1) sufficient donor stock should be selected with high genetic variability, preferably from several populations with differing gene frequencies, and restricted to stocks from similar habitats requiring long-distance homing; (2) the same donor stock should be used for a minimum of three years; (3) propagation should be with survivors of releases from this donor stock and returning adults should not be mixed with the donor stock in the egg take; (4) survivors of initial introductions should be protected from needless exploitation because in all likelihood they will need the whole of their recruitment for spawning in order to survive and improve genetic adaptation; (5) chances for success and quality of resulting population will turn to an appreciable extent on the cardinal consideration of consistency, involving, at a minimum, several generations of fish.

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— Coho program initiated at Rocky Reach Rearing channel in 68 w. 74-75 returns of 12,000 & 5,000 to Rocky Reach. These were later running Cowlitz stock — most pass thru lower Col. after mid Oct. — we have since changed to an earlier running stock — but there are also some serious doubts about the advisability of maintaining a coho program in the upper Col. — (WD, Dept. Fish)

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