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CONTENTS

FACTORS AFFECTING THE ABUNDANCE OF FALL CHINOOK SALMON IN THE COLUMBIA RIVER[1]

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ABSTRACT

The population of Columbia River fall chinook salmon (*Oncorhynchus tshawytscha*, Walbaum) was studied to determine the cause of a severe decline in the numbers of fish returning to the river in the late 1940's and early 1950's. Fluctuations in abundance of other major salmon runs in the North Pacific were examined to detect any coastwide pattern but none was apparent. Life history stages during marine life, upstream migration, reproduction and incubation, and downstream migration were examined for the pre-(1938-46) and post-decline (1947-59) year classes.

Salient points determined from the analysis were: (1) a change in the maturity and survival pattern occurred about 1950; (2) a significant negative correlation was found between sea-water temperature during the first year at sea and subsequent survival; (3) a large increase in the ocean fisheries occurred coincident with the decline in the run; (4) catch-effort and biological statistics of the ocean fisheries showed a near classic example of the effects of exploitation; (5) the contribution of Columbia River chinook to the ocean fisheries based on tag recoveries was probably greatly underestimated; (6) a significant inverse correlation between estimated ocean catch of Columbia River fall chinook and numbers entering the river was found for the post-decline period; (7) the gill-net fishery showed little selectivity by age, size, or sex; (8) fluctuations in abundance of hatchery stocks were related to differences in survival between fingerling and adult stages; (9) hatchery, lower river, and upriver populations fluctuated in abundance in much the same pattern; (10) optimum escapment was between 90,000 and 100,000 adults, a value that was exceeded during most years; (11) most of the early dams on the Columbia River had no direct effect on fall chinook and the decline in productivity occurred when river conditions were relatively stable; (12) temperatures at time of upstream migration and spawning had not increased enough to be a serious mortality factor; (13) river conditions at time of downstream migration of fingerlings were but slightly related to subsequent return of adults.

Variables that appeared to have some relation to fluctuations in abundance were submitted to multiple regression analysis. For the pre-decline period, sea-water temperature and ocean troll fishing effort were significant. For post-decline years, troll effort had the most influence on total returns with ocean temperature and escapement having lesser effects. For the combined years, troll intensity and ocean temperature were the significant variables. Equations were derived that predicted the returning run size in close agreement with the actual. Substituting a low and constant ocean fishing effort in the equation resulted in the predicted run maintaining the average pre-decline level.

[1] From a thesis submitted to Oregon State University in partial fulfillment of the requirements for the degree of Doctor of Philosophy, March 1968.

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The hypothesis of the increase in ocean fishing being the main contributor to the decline of Columbia River fall chinook run was confirmed by correlation, by analogy, and by the process of elimination. Due to several unique features in their life history, they are exposed to much more ocean fishing than other populations; thus other runs did not show similar declines. It is emphasized that these conclusions should not be extrapolated to the future or to other species or runs of salmon.

Introduction

The fall run of chinook salmon (*Oncorhynchus tshawytscha*, Walbaum) in the Columbia River supported a large and important commercial fishery for many years. This fishery had maintained itself at a high level of production, at about 10 million pounds annually, and even appeared to be improving in the early 1940's. In 1949, a sharp decline began which continued through 1953; the river catch then leveled off and stabilized at 2 to 3 million pounds per year through the 1950's (See Figure 1).

Many reasons have been offered for the cause of this decline. The most common is that dams have flooded spawning grounds, killed downstream migrants, and created slack water areas which harbor great numbers of predator fishes. However, no one has made a thorough study of the factors affecting abundance of the stock, attempted to prove or disprove any of the hypotheses, or demonstrated a probable order of importance of the causes of decline.

The purpose of this report is to bring together and analyze available information on the life history and ecology of fall chinook salmon to learn the possible cause or causes of the decline. It covers the 1938-59 brood years. Since 1959, more profound environmental changes have occurred in the Columbia and Snake rivers which this paper does not discuss. It analyzes only the cause of the decline in the early 1950's.

Life History and Racial Designation

Life History of Chinook Salmon

The literature, both scientific and popular, on chinook salmon is voluminous, and offered here is a summary to provide background. Chinook are commonly called king salmon or at times spring salmon. Three rivers in North America — the Sacramento, Columbia, and Yukon — are notable for their large chinook runs.

The age terminology proposed by Gilbert and Rich (1927) is used in this paper. Of the two numbers used in this system the first indicates the fish's year of life when captured and the second, subscript, the year of life at seaward migration. Brood year or year class refers to the fall of the year that the eggs were spawned. Except where noted, all reference to age will be to year of life expressed as an ordinal number, not the number of annuli or cardinal age.

The fish spawn typically in the fall with a considerable range from late summer to early winter. The spawning act is similar to that of other salmonid fishes and has been well described by Burner (1951). The eggs hatch after about 2

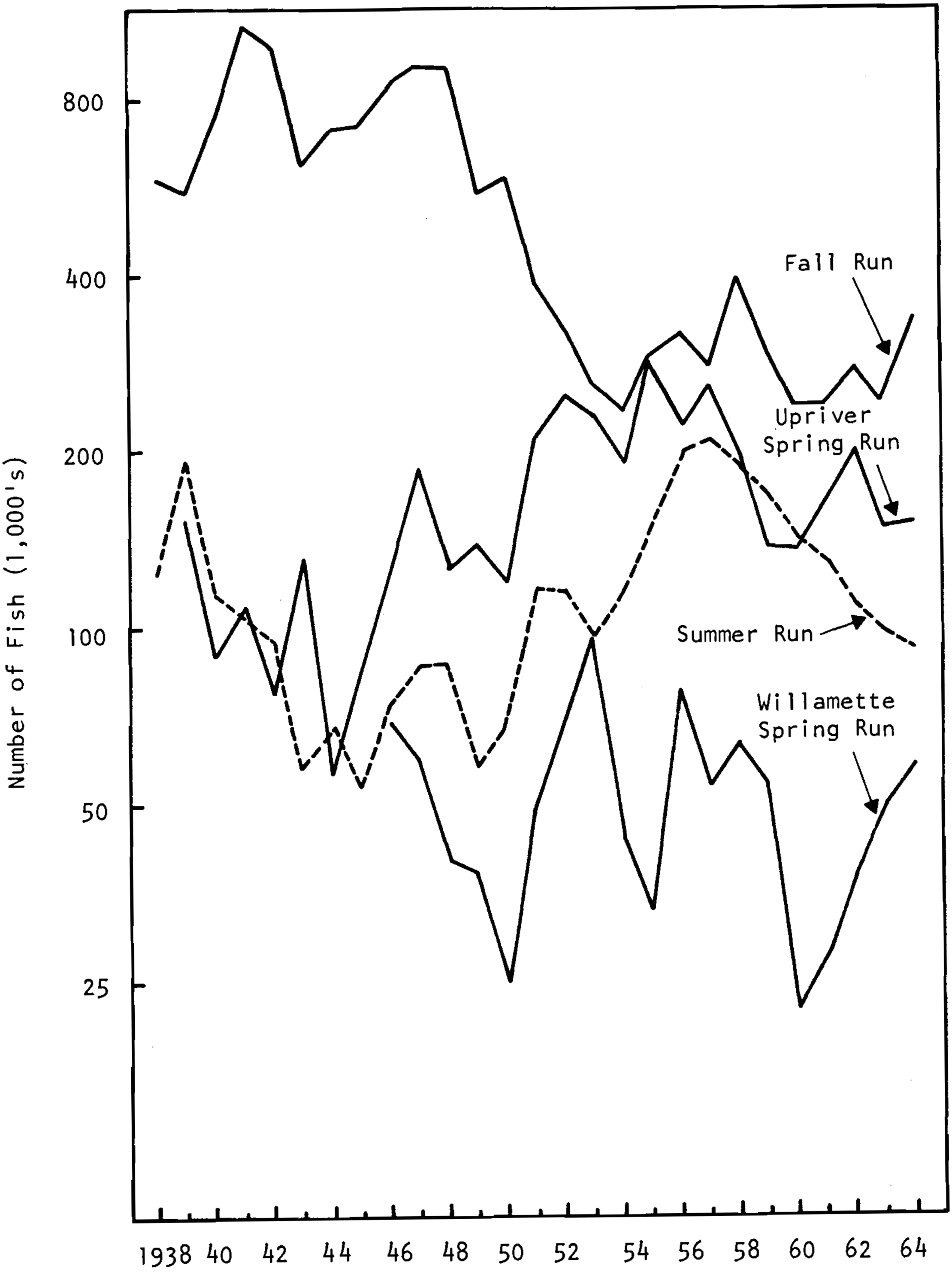


Figure 1. Trends of Columbia River chinook salmon abundance (numbers of fish on a log scale).

months and the young live in the gravel on the food in the abdominal yolk sac. In late winter or early spring the fish emerge as fry. The length of fresh-water residence and time of downstream migration varies greatly. The majority of fingerlings begin their migration in the spring, a short time after hatching; others remain in fresh water a full year and migrate to the sea in the spring of their second year.

Little is known about fish in the estuarine and marine environments until they are of sufficient size to be taken in the fisheries. During their stay at sea they grow rapidly, feeding voraciously on the larger planktonic organisms and pelagic fishes. The fish enter the ocean sport and commercial fisheries at 15 to 20 inches in length during their second year of life, but are generally released because of size limit regulations. Some precocious males or jacks mature at ages 2_1, 2_2, and 3_2 and enter the rivers. The rest of the fish mature at 3, 4, 5, or 6 years varying with race and area.

At sea the fish are exposed to the commercial troll fishery, which operates from central California through southeastern Alaska, and to an ocean sport fishery principally off California, Oregon and Washington. Chinook salmon migrate great distances at sea, returning to their stream of origin to spawn. The mature fish enter the rivers mainly from March through October, depending on race and area. Commercial gill-net fisheries operate in the estuaries of several streams, and Indians and anglers seek them in the rivers. Chinook that return to the river in the spring travel to the higher mountain streams and spend the summer in resting holes before spawning in late summer, while those entering fresh water in the fall generally travel shorter distances and spawn shortly thereafter.

Runs and Races of Columbia River Chinook Salmon

The terms "run" and "race" are often used interchangeably, but the definitions of Mason (1965) will be used in this paper: "a 'run' is defined as a seasonal appearance of chinook in a coastal or river area, first in small numbers which usually increase rather rapidly to a peak and then decline, with small numbers sometimes continuing to appear for extended periods of time. A 'race' is defined as a population of chinook salmon which will spawn in a particular river or tributary at a particular time of year. A single race may make up all or only part of a run."

The concept of self-sustaining groups of salmon that spawn in a particular area and at a definite time has become familiar. Cobb (1911) was perhaps the first to mention runs in the literature although he probably did not appreciate their biological significance. Run segregation can be shown by examining Columbia River dam counts. The U.S. Army Corps of Engineers (1963) shows how chinook passing Bonneville Dam are segregated temporally into spring (April-May), summer (June-July), and fall (August-September) runs and also that this segregation is maintained during the migration up river.

Although Columbia River chinook are now segregated into three distinct runs, Thompson (1951) presented evidence that in the early days of the fishery there may have been only one continuous run from February into September. He examined cannery landings and showed how the June-July run declined and by 1919-20 the August run was of overwhelming importance. Thompson believed this was due to intensive exploitation of the summer run while the fall run received the benefit of a closure from August 25 to September 10. Likewise, the early spring run, protected by a March-April closure, maintained itself. It was not until the great summer run was depleted that the spring and fall runs became clearly recognizable, according to Thompson.

The fall run is here defined as chinook entering the Columbia River from July 29 through November and passing Bonneville Dam from August 16 through November.

Population Fluctuations in Salmon Runs

The trends of abundance of other salmon runs are reviewed for two purposes: (1) to see if there is any detectable coastwide pattern of fluctuations in populations, or if other species, runs, or races have histories similar to that of fall chinook; and (2) to learn what factors other biologists may have proposed as being responsible for fluctuations or declines in abundance. Although only trends in Columbia River populations are presented, most of the available statistical data on North America salmonid runs have been examined (Van Hyning, 1968).

Chinook Salmon

The Columbia River originally had the largest chinook salmon run in the world. Annual catches of 20 to 40 million pounds were made from 1875 to the mid-1920's when a decline started that continued to the mid-1960's. Detailed information on the status of each segment of the run has been available since 1938 when fish counting began at Bonneville Dam. This count plus the commercial and sport catch below Bonneville is considered a reasonable estimate of the run for those races spawning mainly above Bonneville. The information on Columbia River runs since 1938 is taken from a joint Fish Commission of Oregon-Washington Department of Fisheries report, "The 1966 Status Report of the Columbia River Commercial Fisheries" (January 1967).

The trend of the upper Columbia River spring chinook run was sharply upward from 1944 to 1952 with a leveling off thereafter (Figure 1). This stock appears to be holding its own in the face of increasing adversities. The Willamette River supports a run of spring chinook averaging about 50,000 annually. Its size as shown in Figure 1 is computed by adding the sport catch in the lower Willamette, the estimated escapement into the Clackamas River, and the count at Willamette Falls fishway. This run appears to be maintaining itself despite previously poor passage facilities which have since been corrected, pollution problems, and loss of spawning areas.

The Columbia River summer chinook run was seriously reduced by overfishing in the late 1930's and early 1940's. A closure in late May and early June increased the escapement, and subsequently the stock improved until it reached a peak in 1957, then dropped steadily. The Columbia River fall run is shown in Figure 1 for comparative purposes and will be discussed in detail in later sections of this study. Obviously its trend bears no relationship to the other runs; in fact, the upriver spring and summer runs were increasing while the fall run was decreasing.

The status of most North American chinook runs at the time of writing is surprisingly good considering the loss of spawning and rearing areas, dam problems, and deterioration of the environment with the advent of civilization. Two notable exceptions are the Columbia River fall run and the runs to Cook Inlet, Alaska. Columbia River spring and summer runs have been the cause of concern only in rather recent years.

Coho Salmon

The coho salmon (*O. kisutch*) run in the Columbia River declined rather steadily from 1938 to 1959, but after reaching a low point showed a strong recovery.

Hatchery production has made an important contribution in recent years. The overall status of coho salmon is somewhat variable. Stocks in Oregon and Washington coastal rivers are apparently depressed from the early years, but are maintaining a satisfactory level of production and escapement, with substantial increases in some cases. Puget Sound and British Columbia stocks are generally considered to be healthy, while southeastern Alaska catches, which declined rather sharply since 1951, now appear to be recovering.

Chum Salmon

Chum salmon (*O. keta*) runs from Oregon through southeastern Alaska have generally declined, some rather severely and all quite uniformly, beginning in the early 1950's. Asian catches have also decreased in recent years. Only in central and western Alaska have stocks not declined. This suggests that in addition to overfishing an environmental change — most likely marine because of its widespread nature — has affected the species adversely. The steepest drop occurred at the southern limit of its range — Tillamook Bay and the Columbia — where the species may be least adapted and conditions marginal for the population to thrive under stress.

Pink Salmon

Pink salmon (*O. gorbuscha*) are native to streams from Puget Sound northward. Some are taken in the offshore troll fishery along the Washington and Oregon coasts. This species exhibits erratic and often unpredictable fluctuations by cycle and area. The coastwide United States catch of pinks has been decreasing since the late 1940's, although a rising trend has been noticeable in more recent years. Other areas, such as British Columbia and Asia, exhibit little decline. The causes for the fluctuations are not apparent, but according to some experts, overfishing played an important part.

Sockeye Salmon

Sockeye salmon (*O. nerka*) are found from the Columbia River northward through Bristol Bay. The Columbia River run is presently of small magnitude since the bulk of the spawning and rearing areas were lost with the construction of Grand Coulee Dam. No definite trend in run size appears since 1938. Total production of sockeye in the history of the fishery in North America has been downward, particularly in the northern part of the range, but production has increased in Washington and southern British Columbia, largely due to restoration of the Fraser River.

Summary

Although there have been many instances of declining runs, particularly over the long term, the decrease in Columbia River fall chinook has little parallel among Pacific salmon stocks in North America. Other large runs have decreased for a time, then built back to at least reasonably satisfactory levels if not to their historical highs; e.g., Columbia River spring chinook and coho, Fraser River sockeye, and Prince William Sound pinks. Others, such as Tillamook Bay and Columbia River chum, and Kodiak Island sockeye have declined and show little sign of recovery. The runs which evidence the greatest similarity to Columbia River fall chinook are Cook Inlet chinook, Tillamook Bay and Columbia River chum, Puget Sound chum, and southeastern Alaska pink, chum, and coho.

There seems to be little geographic pattern to fluctuations in abundance. Southeastern Alaska species are universally depressed, but areas to the north and south may or may not be. Chum stocks in both Asia and North America generally are declining and because of the widespread nature of this occurrence, changing oceanographic conditions have been blamed. Semko (1961) and other students of Asian fisheries, however, regard the heavy Japanese ocean fishing as a major cause. Japanese scientists disagree and it is noteworthy that the southern North American chum stocks, which are also declining, are not believed to be exposed to an ocean fishery.

Marine Life of Chinook Salmon

Range and Migration

Tagging

Many tagging experiments have been conducted along the Pacific Coast to show the origin and migration of chinook salmon found in various areas. These were discussed in detail in the thesis in order to trace the oceanic distribution of the stocks; only the most pertinent results are presented here.

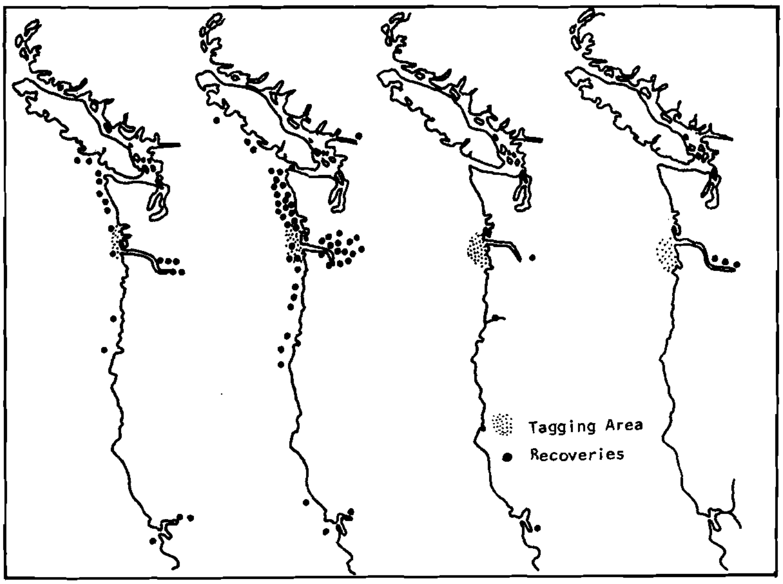
Very small numbers of Columbia River chinook appear to migrate to the California area (Fry and Hughes, 1951). The ocean fishery off Oregon south of Heceta Head is also of negligible importance (Van Hyning,1951).Two hundred thirty-three chinook were tagged in the Newport area north of Heceta Head (1948-62) and 43 were recovered. Twenty were stream recoveries and six were assignable as Columbia River fall chinook. Thus 28% of the fish of known origin tagged in the Newport area were Columbia River fall chinook.

A number of tagging experiments were completed in the area from Cape Lookout to Willapa Bay through the years 1948-62. Only some of the results will be summarized here. For convience the experiments can be grouped into two periods: (1) 1948-52 and 1955 and (2) 1958 and 1959-62.

Fish recovered the same year as tagged during 1948-52 and 1955 are shown in Figure 2 and recoveries made in the years following tagging are shown in Figure 3. Obviously chinook from the Columbia River dominate the tagging area, but fish from the Sacramento-San Joaquin, Alsea, and Fraser rivers are also found. Of the 50 river recoveries, 40 were from the Columbia and 36 of these were fall chinook. The proportion of Columbia fall chinook in the area, based on the assignable stream tag returns, is thus 72%.

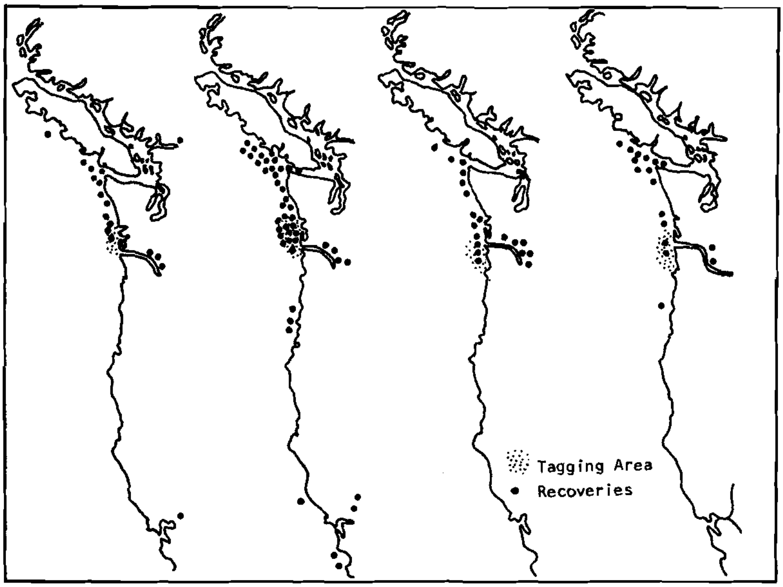
Both mature and immature Columbia River chinook are found in the Columbia area from April through September. The large number of recoveries one or more years after tagging shows that many fish were immature when tagged. The large ocean catch of tagged fish and the relatively few taken in the river in years following tagging is noteworthy. These fish show a predominant northward movement along the coast with a later return to spawning streams, principally the Columbia. This exposes the stock to an extended period of intense fishing as they move past the large sport and commercial fleets fishing out of Grays Harbor towards the feeding banks off Cape Flattery and Vancouver Island where American and Canadian trollers operate.

From March 15-April 15, 1959 and 1960, the Washington Department of Fisheries and Fish Commission of Oregon conducted a cooperative tagging program offshore between the Columbia River and Grays Harbor (Bergman, 1963). Distribution of returns from the 1959 experiment is shown in Figure 4. Certain similarities with previous tagging can be seen: the predominant movement northward with some fish going south, and large numbers entering the Columbia River. There is one striking difference; few recoveries were made in years following tagging. The Sacramento-San Joaquin system, Tillamook Bay, Columbia, and Fraser rivers were noted as streams of origin. Returns from the 1960 experiment were similar to 1959.



Tagged: April (134) May (453) June-July (137) Aug-Sept (151)

Figure 2. Recoveries, by month of tagging, from chinook salmon tagged in the Columbia area, 1948-52 and 1955, recovered same year as tagged. (Month of tagging and number tagged each period indicated.)



Tagged: April May June-July Aug-Sept

Figure 3 Recoveries, by month of tagging, from chinook tagged in the Columbia area, 1948-52 and 1955, recovered in years following tagging. (Month of tagging indicated.)

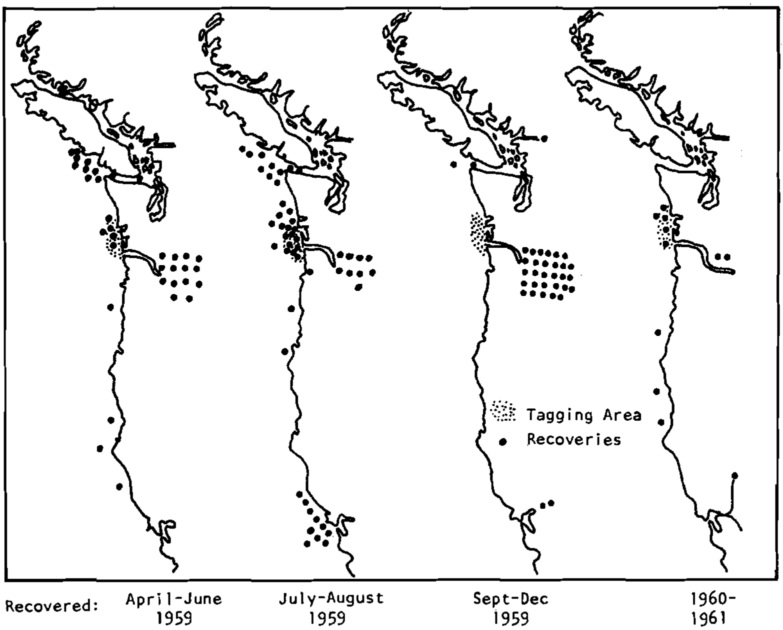


Figure 4. Recoveries from 422 chinook salmon tagged in the Columbia-Grays Harbor areas, March-April 1959.

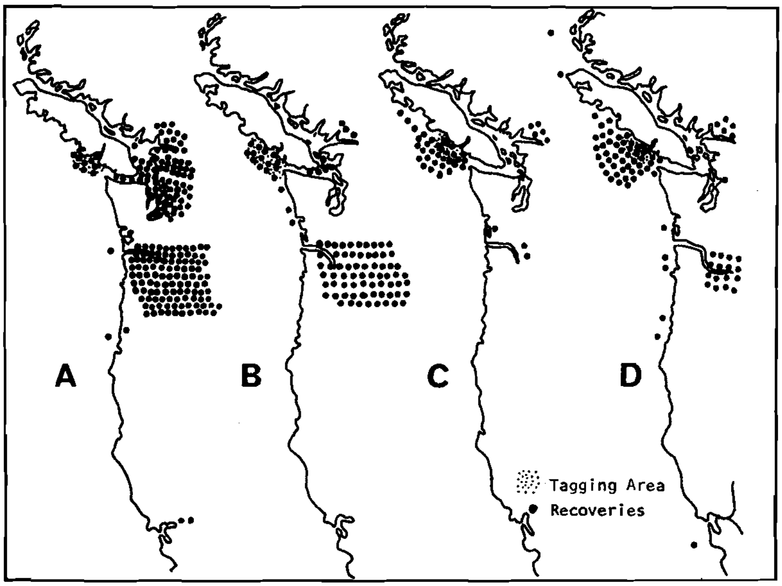


Figure 5. Recoveries from chinook tagged off Barkely Sound, Vancouver Island: 1925-30 (2,478 tagged), A — recovered same year as tagged, B — recovered in subsequent years; and 1949-50 (912 tagged), C — recovered same year as tagged, D — recovered in subsequent years.

One hundred sixty-eight chinook tagged in late May and early June 1961 between the Columbia River and Tillamook Head yielded an exceptionally high return. Only fish in good condition were tagged and they were mostly in their second and third years of life. During the 2 months following tagging, the center of abundance shifted to Grays Harbor with a return to the Columbia area in August and September. There was also a southern migration, but none went north of Cape Flattery even in the year following tagging. Only the Columbia, Sacramento, and Wilson rivers were represented. This population was fished intensively off and in the Columbia River and off Grays Harbor.

Kauffman (1951) gives the results of tagging experiments by the Washington Department of Fisheries in 1948-49. Recoveries from 200 chinook tagged near Umatilla Reef in June, July, and September 1948-49 included six from the Columbia River, all fall chinook, and they comprised half of the 12 stream recoveries. Other areas contributing to this sample were the Sacramento River, Willapa Bay, and Puget Sound. Tagging in the Swiftsure-Lennard Island area, in effect southern Vancouver Island, resulted in a large number of fish retaken in the vicinity the same year and the year after. According to Kauffman this area is apparently a major feeding ground where the fish remain for extended periods. Of the 15 stream recoveries, seven or 47% were from the Columbia (all fall chinook). If all recoveries in Puget Sound and the Strait of Georgia are considered to be fish nearing or destined for streams in that area, then the total "stream" recovery totals 19 and the proportion of Columbia River fall chinook drops to 37%.

In the period 1925-30 there was international impetus to tag salmon in the offshore fisheries of the Pacific Coast. The Canadians carried on a large program and published an excellent series of reports (reviewed by Milne, 1957) which offer a valuable comparison with more recent tagging experiments. Although tag loss was probably very high in these experiments, many fish were recovered more than 1 year after tagging.

Results of the 1925-30 tagging off southern Vancouver Island are shown in Figure 5, parts A and B, and Table 1. The overwhelming importance of the Columbia River fish in this experiment is obvious. Large numbers entered both Puget Sound and the Columbia River the same year as tagged, but in subsequent years more returned to the Columbia. This suggests that both mature and immature Columbia River fish were found in this area, but the Puget Sound-Fraser River stocks off southern Vancouver Island were largely mature.

Tagging in the same area in 1949-50 is shown in Figure 5, parts C and D. The change from a preponderance of recoveries in the river in the early period to more ocean returns in the later is striking, and the inference is clear that the large numbers recaptured in the tagging area resulted in fewer reaching the rivers. Again there is the tendency for Columbia River stocks to be more immature than the Fraser River-Puget Sound stocks. The greatly intensified fishing on immature, 3-year fish resulted in a greater decrease between the two periods for Columbia River than Puget Sound returns.

Tagging was also conducted off northern Vancouver Island (Kyuquot and Quatsino). The Columbia River fish found here in 1925-30 were largely mature, while Puget Sound fish were mostly immature. A comparison of spawning area recoveries for the two periods is shown in Table 1; a slight decline in the contribution of Columbia River fall chinook is indicated.

It is clear from these experiments that Columbia River chinook essentially do not use the inside waters of British Columbia or Alaska so these areas can be omitted from further consideration.

Milne (1957) emphasizes the decrease in Columbia River fish and increase in the contribution of the Fraser and other Canadian rivers to the Canadian troll fishery, as shown by tagged fish recovered in the respective areas from the 1925-30 and 1949-51 tagging. The Columbia River contribution to recoveries from the west coast of Vancouver Island tagging, dropped from 60 to 16% while the Fraser River fish increased from 5 to 12%, while total United States recoveries fell from 82 to 29% and Canadian recoveries jumped from 16 to 71%. However, the great increase in later years in ocean recoveries, which do not show origin, makes this conclusion questionable. The greatly accelerated ocean fishing reduced the number of fish that survived to reach fresh water.

Only tag recoveries showing stream of origin should be used in computing the contribution of a production area to a fishery. Furthermore, relative maturity of the tagged fish must be considered. Columbia River fish off southern Vancouver Island tended to be immature, while Fraser-Puget Sound stocks were mature. Since immature fish eventually would be reduced in numbers more than mature fish before returning to their home stream, the importance of the immature stock to the fishing area would be underestimated.

Tagging of chinook salmon off Alaska has been summarized by Parker and Kirkness (1956). From 30 to 50% of the fish recovered, which could be assigned to an area of origin, came from the Columbia River fall run.

Parker and Kirkness note: "The recovery of tags by locality suggests that the stocks Alaska is concerned with are of upriver (above Bonneville Dam) origin. Of 37 recoveries in the fall run, 12 were recovered at The Dalles or at Celilo." In comparison, tagging off the Columbia River and Washington coast yielded many recoveries of lower river origin, especially hatchery fish. No Alaska tags were found at Columbia River hatcheries. This suggests that the northern Gulf of Alaska may be a feeding area for certain

Table 1. Comparison of area of recovery for chinook tagged off Vancouver Island.

	1925-30		1948-51	
	No. Recoveries	%	No. Recoveries	%
TAGGED OFF SOUTHERN VANCOUVER ISLAND				
Area of Recovery				
Fraser River-Puget Sound Complex	87	32	26	50
Columbia River Spring and Summer Runs	45	16	4	8
Columbia River Fall Run	137	50	21	40
Other Stream Systems	5	2	1	2
	274	100	52	100
TAGGED OFF NORTHERN VANCOUVER ISLAND				
Area of Recovery				
Fraser River-Puget Sound Complex	20	24	8	57
Columbia River Spring and Summer Run	21	25	0	—
Columbia River Fall Run	34	41	5	36
Other Stream Systems	8	10	1	7
	84	100	14	100

chinook races where they feed almost unmolested. As maturity approaches the Fraser and Columbia river fish head southeastward along the coast. This speculation is reinforced by several factors: (1) from middle Vancouver Island north there is little northward movement as indicated by tagged fish; (2) from middle Vancouver Island north to Cape Spencer the fish are largely mature and are on a southern migration; and (3) the large numbers of fish in their fourth and fifth year caught off southeastern Alaska suggest that little ocean fishing has occurred on these stocks. Since tagging shows no northern migration to southeastern Alaska of catchable size Columbia River chinook, it follows that the young fish that migrated there did so before they reached this size. This contrasts to the area between the Columbia River and middle Vancouver Island, where fish seem to migrate back and forth.

In studies of offshore distribution and abundance of salmon, conducted under the auspices of the International North Pacific Fisheries Commission, chinook were found scattered across the North Pacific from 41°N latitude to the Aleutian Islands and into the Gulf of Alaska (Mason, 1965). Indications are that these are primarily immature fish from the northern rivers or early runs from the southern rivers.

Marking

Marking or fin clipping is another method of studying the migration of salmon at sea. Groups of hatchery-reared fingerlings are distinctively marked and the fisheries along the coast are sampled to recover the marked fish. If enough marks are recovered and certain assumptions made, it is possible to follow populations through their life cycle showing the areas where they were caught, return to the point of origin, etc. The marking of Columbia River salmon had been carried on for many years and sporadic recoveries were made, but it was not until the late 1940's, in a program coordinated by the Pacific Marine Fisheries Commission, that a concerted effort was undertaken in coastwide marking and recovery. Beginning with the 1949-brood year, hundreds of thousands of fingerling chinook were marked at various places along the coast and recoveries were made by sampling the fisheries at the principal ports.

Recoveries of marked 1949-brood fall chinook from the Washington Department of Fisheries Kalama River Hatchery were analyzed by Heyamoto and Kiemle (1955). This study generally confirms other tagging information showing a dispersion of fish from the mouth of the Columbia northward. None of these marked fish were taken in northern British Columbia or Alaska even though sampling was done there. Fish from the Kalama experiment were rather unusual because they matured almost exclusively at 4 years of age rather than at 2 to 5 years. A similar experiment with 1949-brood fish was conducted at Oxbow Hatchery of the Fish Commission of Oregon. These fish matured at both 3 and 4 years of age.

Preliminary results from the 1961-brood Columbia River hatchery evaluation program are available (Cleaver, 1969). Of the total production of over 54 million fingerlings at 12 principal hatcheries, over 7-1/2 million were marked. Estimates of marked fish taken by the various fisheries in 1963, 1964, and 1965, based on ratios between marked fish found in the samples and total number landed, are given in three Bureau of Commercial Fisheries reports (1964, 1966a and b). The 2-year fish in 1963 were taken only by sport fishermen, and they tended to have a center of abundance around the Columbia River. Three-year fish in 1964 were present off the Columbia in April and May, then virtually disappeared from there until August. The Washington coastal area (principally Grays Harbor) had peak numbers of marked fish in June, but some were present from April through August. Vancouver Island apparently had Columbia River fish all season with a peak in July; many remained into September and October. Four-year old recoveries do not show a well-defined pattern, but this age group was found all season off Vancouver Island and to a lesser extent off Neah Bay and the Washington coast, while none appeared off the Columbia River until August. The few marked fish recovered in northern British Columbia and Alaska were mainly 4- and 5-year olds. The northerly progression of 3-year fish along the Washington coast is again demonstrated, with the tendency for younger fish to be centered near their home stream, while the older ones are distributed to the north.

In comparing ocean migration patterns as shown by tagging and marking, both techniques showed that Columbia River fall chinook are found principally north of the Columbia River. Large numbers of marked fish were taken along the Washington coast and Vancouver Island, and tagging in these areas showed a predominant migration toward the Columbia River. However, tagging in northern British Columbia and Alaska revealed large numbers of Columbia River fish in those areas, but few marked Columbia River chinook were recovered there. This apparent dilemma can be explained if one recalls that Parker and Kirkness (1956) noted that upper river fall chinook were most important in the Alaska troll fishery. Oregon and Washington tagging indicated that lower river races predominate and hatcheries handle (and thus mark) only lower river stocks. Thus, most of the lower river hatchery populations must confine their ocean migration largely to the area between the Columbia River and Vancouver Island while the wild upper river stocks go north towards Alaska.

Growth and Maturity

Salmon are noted for their rapid growth at sea, and with chinook there is the added dimension of extremely variable life history patterns. The literature is summarized by Van Hyning (1968), and Table 2 presents generalized growth data on length and weight for average spring and fall chinook. Spring chinook in the Columbia as well as other rivers generally stay in fresh water their first year of life, migrating downstream in the spring of their second year. Most fall chinook, on the other hand, migrate to the ocean the first spring or summer. This difference in behavior causes a considerable difference in size and age at recruitment to the fishery, as will be discussed later.

Table 2. Average length and weight at completion of each winter for spring and fall chinook salmon.

		Age—Number of Annuli			
		I	II	III	IV
Spring	Fork Length—Inches	4	17	26	31
Chinook	Round Weight—Pounds	—	2.8	9.0	14.6
Fall	Fork Length—Inches	12	21	28	33
Chinook	Round Weight—Pounds	1.2	5.0	11.5	18.6

Reference has been made to the relative maturity of stocks in various areas in connection with ocean tagging results. These data can be further examined by size of fish when tagged and time out before recovery. Fish recovered in a stream the same year as tagged were obviously maturing when tagged; those recovered in subsequent years were immature. Nothing can be determined from those fish recovered in the ocean the same year as tagged; they are ignored in this analysis. Figure 6 compares the percentage mature fish plotted against length for all fish tagged in the Colum-

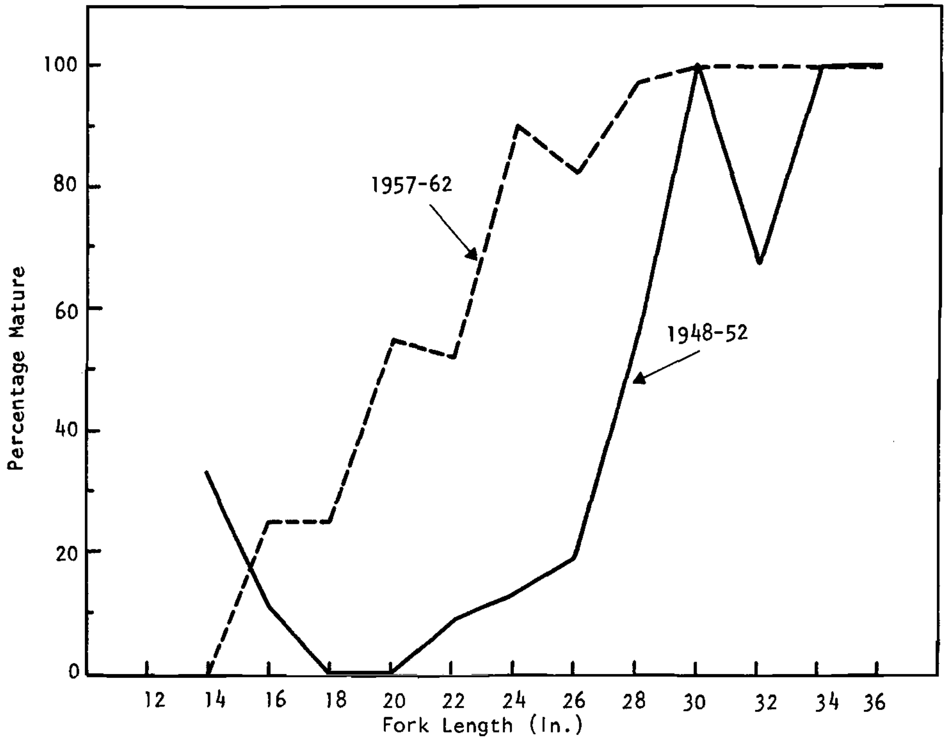


Figure 6. Maturity of chinook salmon as determined by ocean tagging, Columbia River-Grays Harbor, 1948-52 and 1957-62.

bia-Grays Harbor area for the periods 1948-52 and 1957-62. The percentage mature is that portion of the total recoveries, excluding first-year ocean recoveries, made in fresh-water areas the same year as tagged. One source of error is that immature fish are subject to an additional period of tag loss and mortality, thus reducing their numbers in relation to mature fish; but this should not affect the value of these data for comparative purposes. Obviously, more fish matured at a smaller size during 1957-62.

To explore further the relationship between age, size, and maturity, the length distributions of tagged fish known to be mature Columbia River fall chinook were plotted for two comparable periods, April-July 1948-52 and March-June 1959-61 (Figure 7). Recoveries showed that many more 19- to 23-inch 2-year fish and 24- to 27-inch 3-year fish matured in the later period than in the earlier years. The possible reasons for this change will be discussed later.

The relationship between maturity, age, and size was also studied from random samples of fish taken at sea in 1954-55. Maturity was determined by graphically comparing gonad weight with fish length and also by gonad weight-frequency distributions. In the late spring and summer mature fish of both sexes could be easly identified, but in March and April maturing fish were barely discernable. By working backward from the more distinct groups later in the season, the smaller gonads were assigned without too much difficulty. These data are presented in the thesis (Van Hyning, 1968) and only the important results will be discussed here.

Two-year fish ranged from 15 to 23 inches, and a few of the larger males were maturing. Three-year fish were the best represented age group, with most ranging from 21 to 30 inches. The larger fish were maturing, more males (44% mature) than females (15% mature). Four-year fish and a few 5-year olds were mostly between 25 and 35 inches; some of the smaller females would not have matured for another year. Maturity appears to be more a function of size and sex than age. Clearly an intense ocean fishery could alter the age and sex structure of the population as it enters the Columbia River. Almost one-half of the 3-year males were maturing and would not be available to the fishery as 4-year fish, but only 15% of the females were maturing and the remainder would be available for another year of fishing. An intense ocean fishery would in effect reduce the numbers of 4-year females entering the river and increase relatively the number of 3-year males.

Variation in Survival Rate

The recovery of fish that have been tagged or marked affords some measure of their survival rate between marking and recovery if allowances are made for changes in tagging, marking, and recovery techniques, size of fish, and fishing intensity. Likewise, return of adults to a hatchery from known numbers of fingerlings released gives a measure of their survival while free.

Tagging Experiments

The purpose of this section is to examine ocean tagging experiments to determine if any gross changes in marine survival can be detected. Tagging results

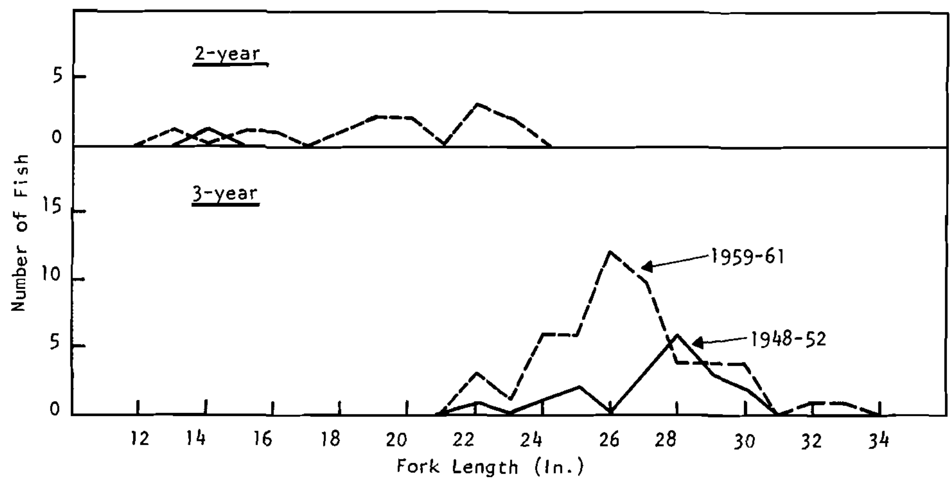


Figure 7. Comparison of size of mature 2- and 3-year Columbia River fall chinook tagged at sea during 1948-52 and 1959-61

discussed in previous pages, while primarily illustrating the migration and origin of the fish, showed a striking change in maturity pattern of stocks found near the Columbia River and in the numbers of second-year recoveries. The change in type of tags used could not account for this difference, suggesting a change in maturity schedule or a high mortality rate in the latter period (1957-62).

A summary of pertinent ocean tagging experiments is given in Table 3, which shows the number tagged and number and percentage recovered the same year as tagged and in subsequent years. Unlike the studies of maturity, first-year ocean recoveries are included. A perusal of the table shows that except for tagging off the Columbia River and Grays Harbor in 1959, 1960, and 1961, nearly all experiments yielded total returns of 10 to 20%. The three notable exceptions gave recovery rates of 28 to 47%. In contrast to this relatively constant recovery total, regardless of area or time, a distinct change in the pattern between years can be shown. This is particularly evident in taggings between the Columbia River and Grays Harbor. Contrast, for example, April-May 1948-52 (12% recoveries first year: 11% subsequent years) with March-April 1960 (30:1), and June-September 1948-51 (1:12) with May-June 1961 (40:7). The Newport area also shows a similar pattern (9:10 in earlier period, 11:3 in later period). The instances cited are roughly comparable with regard to tagging.

To explore this change further, the size of the fish tagged and recovered in the two periods was examined. The size of fish tagged and recovered from the Columbia River-Grays Harbor experiment in April-May 1951 was compared with March-April 1960, being approximately similar in area and time, and with adequate numbers of fish handled (Figure 8).

The fish tagged in 1960 were slightly larger than in 1951 (A), but the total recoveries the same year as tagged were almost identical for the 2 years (B) Breaking down the same year recoveries into ocean (C) and stream (D), shows

Table 3. Return of chinook salmon tagged in the ocean, by year of recovery.

Area Tagged	Tagging Time of	Tagged Number	Recovered Same Year As Tagged		Recovered in Years Following Tagging		Total Re-covered		Remarks
			No.	%	No.	%	No.	%	
Newport	June-Sept 1948-51	196	18	9.2	20	10.2	38	19.4	
Newport	June- Aug. 1959-62	37	4	10.8	1	2.7	5	13.5	
Columbia River	April-May 1948-52	575	70	12.2	62	10.8	132	23.0	
Columbia River	June-Sept. 1948-51	168	2	1.2	21	12.5	23	13.7	Mostly small fish
Columbia River	April-Sept.	132	4	3.0	17	12.9	21	15.9	All sublegal (<26 in.)
Columbia River	May-Aug. 1957	71	7	9.9	4	5.6	11	15.5	(Heyamoto, 1963), 82% sublegal
Columbia River	May-June 1961	168	67	39.9	12	7.1	79	47.0	
Columbia River-Grays Harbor	June-Sept. 1958-62	114	5	4.4	9	7.9	14	12.3	All sublegal when tagged
Columbia River-Grays Harbor	March-April 1959	422	108	25.6	11	2.6	119	28.2	
Columbia River-Grays Harbor	March-April 1960	343	103	30.0	4	1.2	107	31.2	
Grays Harbor	May-June 1961	97	14.	14.4	5	5.2	19	19.6	

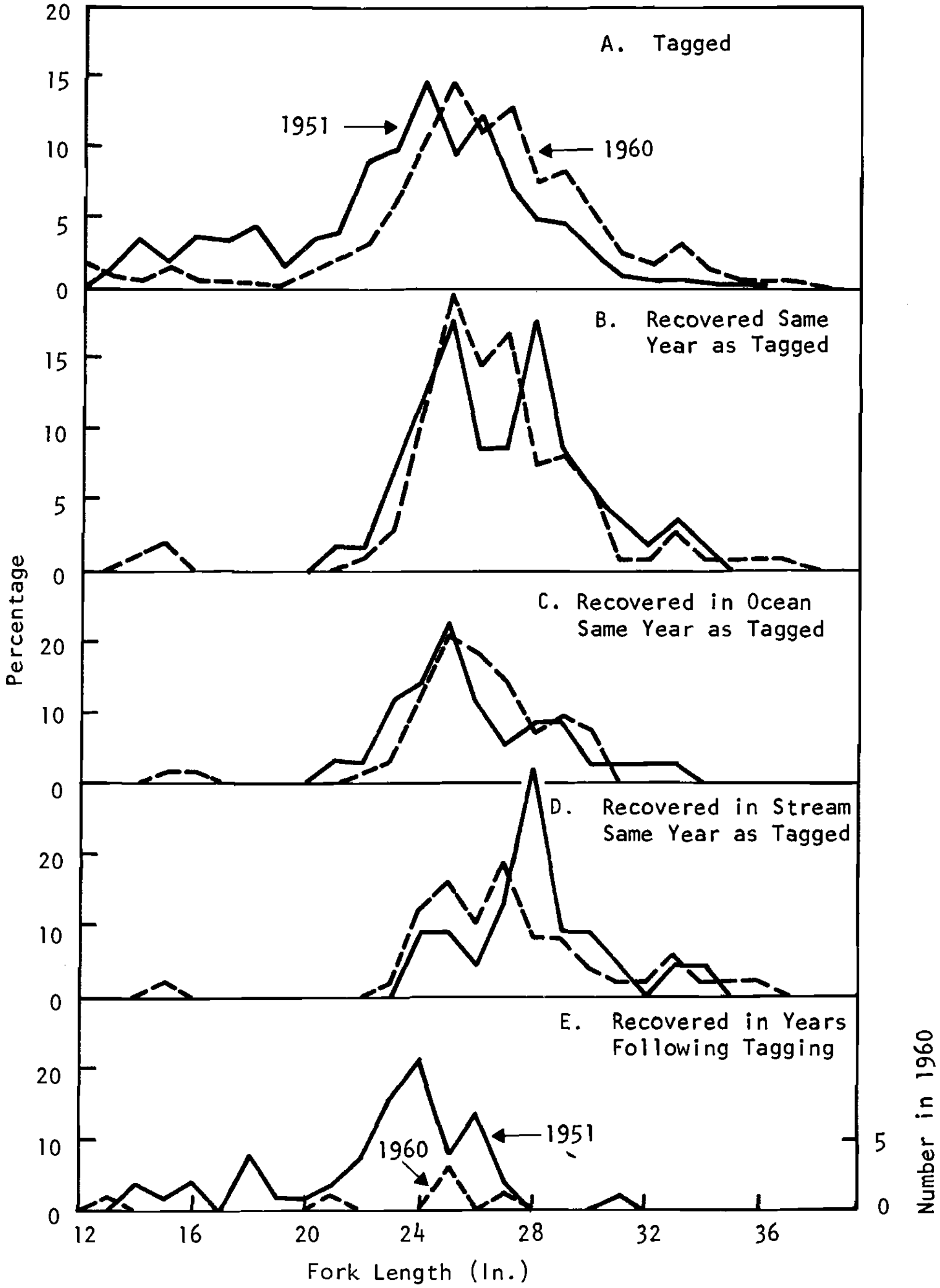


Figure 8. Length-frequency distributions of chinook tagged in the Columbia area in April-May 1951 and March-April 1960 by time and area of recovery (1951, 475 tagged; 1960, 343 tagged).

that the size distributions of ocean recoveries for the two periods were similar, but the river recoveries were different. In 1951, 63% of the stream recoveries were from fish 28 inches in length and over, while in 1960 only 39% were over 28 inches. Fish recovered in years following tagging (E) in 1951 were considerably smaller than those recaptured in a stream the same season as tagged, but only slightly smaller than same year ocean recoveries. Second-year recoveries in 1960 were too few to be meaningful. Clearly, the 1960 tagged fish matured at a smaller size than in 1951. A comparison of June-July 1948-51 with May-June 1961 tagging gave similar results. Generally small fish were not recaptured the same year as tagged in 1948-51, but they were in 1960 and 1961.

The conclusion is that there has been a real change in the survival or maturity of chinook salmon stocks in the Columbia River area in spring and early summer. It is also reasonable to assume that the majority of chinook becoming available to the ocean sport and commercial fisheries in this area, and remaining there, are either caught, or mature and enter the river the same year. A few facts can be presented to support this hypothesis. Table 4 is a composite of previously mentioned tagging experiments, showing the recovery by size at tagging, year, and whether taken in the ocean sport or commercial fishery, or in the river. River recoveries include both fishery and hatchery returns. The size categories are rough approximations of the size limits in the fisheries: the sport limit has varied for many years, from none to 22 inches (20-inches fork length) while the commercial limit has remained at 26 inches (approximately 24-inches fork length). The smallest size group (12-20 inches) would generally not be available to the sport fishery at the time of tagging but many fish would grow large enough by midsummer; the middle size group (21-24 inches) would be fully available to the sport but not commercial fishery until some growth had been made, while the largest size (25-37 inches) would be fished on by both fisheries. Assuming that tag loss the first year is not serious, certain conclusions can be drawn from this table. Particularly striking is the increase between the two periods of ocean

Table 4. Recovery of tagged chinook salmon by size at tagging, April-July 1948-51 and March-June 1960-61, Columbia River area. (Percentage recovered in parentheses.)

Fork Length (Inches)	No. Tagged	Recovered Same Year As Tagged			Recovered in Subsequent Years		
		Ocean Sport	Ocean Commercial	River	Ocean Sport	Ocean Commercial	River
April-July 1948-51							
12-20	205	1 (0.5)	1 (0.5)	1 (0.5)	2 (1.0)	15 (7.3)	5 (2.4)
21-24	233	0	10 (4.3)	3 (1.3)	4 (1.7)	27 (11.6)	4 (1.7)
25-37	277	4 (1.4)	25 (9.0)	27 (9.8)	3 (1.1)	11 (4.0)	3 (1.1)
Total	715	5 (0.7)	36 (5.0)	31 (4.3)	9 (1.3)	53 (7.4)	12 (1.7)
March-June 1960-61							
12-20	87	10 (11.5)	2 (2.3)	7 (8.0)	2 (2.3)	8 (9.2)	2 (2.3)
21-24	122	15 (12.3)	11 (9.0)	15 (12.3)	0	0	1 (0.8)
25-37	302	26 (8.6)	32 (10.6)	51 (16.9)	0	2 (0.6)	2 (0.6)
Total	511	51 (10.0)	45 (8.8)	73 (14.3)	2 (0.4)	10 (2.0)	5 (1.0)

sport returns the same year as tagged, from 0.7 to 10%. Troll recoveries rose from 5 to 8.8%, and river returns from 4.3 to 14.3%. The increase in ocean fishing intensity was proportionally greater on the smaller than larger size group, and the same was true in river returns. In 1948-51 fish under 24 inches were lightly exploited in the ocean (2.7% return) while in 1960-61 at least 18.2% of those available were taken during the fishing season. Subsequent year recoveries were less for the later group in all categories.

Table 5 shows the hypothetical return of tagged chinook based on an assumed tagging mortality and unreported tags for two periods, 1948-51 and 1960-61. The 30% tagging (hooking) mortality rate used is within the range suggested by Parker and Black, 1959. Further, it assumes a constant natural mortality, that 30% of the tags taken in the ocean are not turned in (probably minimal), and that 50% of the tagged fish entering a river are caught and reported (probably maximal).

Although the assumed values are used for comparison purposes only, and are valid only if they did not change, this example shows that the paucity of second-year recoveries in the later period can be attributed to increased ocean fishing intensity and greater numbers of fish maturing at a smaller size. Note also in Table 4 that the 12- to 20-inch group gave approximately the same subsequent year return from the 1960-61 and 1948-51 experiment, the only size category to do so. It appears that in the 1960-61 group only the smallest fish survived in significant numbers. Most of these fish, still largely immature (see Figure 6), would be below legal or desirable size for the ocean sport fishery, and thus were not recovered the same year as tagged.

The hypothesis that the majority of chinook becoming available to the fisheries between the Columbia River and Grays Harbor will either be caught or mature thus seems realistic. It should not be construed, however, that this applies to chinook stocks other than in the study area, which may be unique. Without corrections for tagging mortality, tag loss, and unreported tags, returns of 28 to 47% in more recent years from troll-caught chinook indicate they are subjected to an intense fishery.

The Vancouver Island area offers another comparison: viz., 1925-30 and 1949-51 (Milne, 1957). Recoveries of fish tagged at Barkely Sound, off southern Vancouver Island, during the two periods were almost identical, 12%, but

Table 5. Hypothetical return of tagged chinook salmon based on assumed tagging mortality and unreported tags, 1948-51 and 1960-61.

	1948-51	1960-61
Number tagged	715	511
Less tagging mortality (30%)	501	358
Tags recovered in ocean, year 1 (+30% unreported)	59	137
Ocean fishing mortality, year 1	12%	38%
Number left after ocean fishing, year 1	442	221
Number entering river during fall of year 1 (twice the tags actually recovered)	62	146
Available for year 2	380 (53% of original number tagged)	75 (15% of original number tagged)
Recovered in year 2	74 (20% of available)	17 (23% of available)

the proportions of first and subsequent year recoveries were reversed (8:4% in 1925-30 compared with 4:8% in 1949-51). Unfortunately, there was a great difference in the age of fish and tags used in the two periods, making a comparison (as in the previous discussion) difficult. Milne comments: "In the 1950 experiment all the fish were small but the relatively high return suggests that an intensive fishery must have exploited these immature fish throughout much of their ocean life."

These tagging experiments illustrate the increase in ocean fishing as a factor in the poor survival, but the phenomenon of increasing numbers maturing at the smaller sizes is still perplexing.

Marking Experiments

Return to the river or hatchery of fish marked and liberated as fry or fingerlings is a measure of their stream, estuary, and marine survival. Pertinent marking experiments are summarized in Table 6 and while the objectives were as varied as the methods of recovery, some conclusions can be drawn regarding changes in survival.

An index of survival can be determined from the fish captured by the commercial river fishery, but this is subject to changes in the proportion of the run removed by the fishery. The differences in recovery between the two periods are far greater than can be accounted for by changes in fishing rate, however. Table 6 shows that average return to the river fishery for the 1919-43 brood years was 0.29% but only 0.02% for 1949-57. Even including hatchery returns in the later period, which should comprise the bulk of surviving fish, the survival rate is only 0.04%. Obviously there was not only a catastrophic reduction in return to the river of marked hatchery-reared fall chinook during the period, but a great, and largely unexplained, variability in survival in different lots of fish (the question of disease will be discussed later). If we take calculated ocean recoveries for the 1949-brood experiments and assume that if the fish had not been caught at sea all would have returned to

Table 6. Return of marked hatchery-reared fall chinook.

Location	Brood Year	Number Marked (thousands)	Calculated Return to River Fishery (%)	Calculated Return to River Fishery and Release Site (%)	Reference
Little White Salmon Hatchery	1919	24	0.13	0.18	Rich & Holmes (1929)
Big White Salmon Hatchery	1922	100	0.35	0.45	Rich & Holmes (1929)
Spring Creek, Oxbow, Bonneville, and Little White Salmon hatcheries	1938-42	1,212	0.29	—	Holmes (1952)
Oxbow and Kalama hatcheries	1949	402	0.07 (0.29)①	0.13 (0.45)	Pulford (1964a); Heyamoto and Kiemle (1955)
Kalama Hatchery	1951	305	0.003	0.003	Kiemle (1962a)
Bonneville and Oxbow hatcheries and Gnat Creek Weir	1952-57	1,246	0.01 (0.02)	0.04 (0.06)	Pulford (1964a)
Klickitat, Kalama, and Toutle hatcheries	1952-57	1,571	0.02	0.03	Kiemle (1962)
All Columbia River	1961	7,515	0.10 (0.22)	0.16 (0.40)	Bureau of Commercial Fisheries (1964 and 1966a and b)

① Figures in parentheses are computations of number surviving if all marked fish calculated to have been caught in ocean fishery had returned to river.

the river, we can arrive at survival rates of 0.29% for the river fishery and 0.45% for the total return — remarkably similar to the 1922 and 1938-43 broods.

Calculated total mark returns from the 1961-brood fall chinook contribution study are available through 1965; 1966 returns were estimated by assuming a 25% sampling rate in all fisheries. Return to the river for this brood is low (0.16% of the number released); by including ocean recoveries the survival rate rises to the magnitude of earlier years.

Hatchery Returns

The number of adult salmon returning to a hatchery from known or estimated numbers of juveniles released is a measure of their ultimate survival. Here again, river, estuarine, and marine survival cannot be differentiated, and the data gathered through the years have at times been only rough estimates. Other complicating factors are the variable age at maturity and the straying of adults into nonhatchery streams.

Junge and Phinney (1963) made a thorough study of the return of fall chinook to the U.S. Fish and Wildlife Service Spring Creek Hatchery a few miles above Bonneville Dam. Spring Creek is unique because the run is believed to be entirely artifically produced; it is one of the most successful chinook hatcheries in the Columbia River system. The study was primarily concerned with isolating the factors influencing the relatively high return to Spring Creek. It is rather surprising to learn "that survival rates since 1950 have been greatly reduced. When the pounds of fingerlings released are taken into consideration, even the large returns in 1958 and 1959 do not exhibit survival rates comparable to those maintained in the 1940's." The high production has been maintained by large increases in pounds of fingerlings released, but the return per pound has decreased. The authors consider the incidence of tuberculosis, coagulated yolk disease, and increased crowding, without coming to any firm conclusion as to the cause of the decrease.

Wallis (1964a and b) reviewed the records of the Bonneville and Oxbow hatcheries maintained by the Fish Commission of Oregon just below and above Bonneville Dam, respectively. In general, both show a similar high level of production for the 1945-46 broods followed by a decline to a very low level for the 1951-55 broods, then an increase beginning with the 1959 brood but not up to the 1945-46 level — trends very similar to Spring Creek.

For Oxbow Hatchery Wallis notes:

> "The number of adults handled at the hatchery since 1948 have shown the same trends of abundance as noted on the spawning grounds and in counts over Bonneville Dam. This suggests that similar factors are involved in the survival of the fish returning to Herman Creek and in the total run, and that hatchery operations have had little influence on the trends of abundance."

There is a suggestion that the survival rate for the 1943-45 broods was exceptionally high at both Spring Creek and Oxbow compared with earlier and later years. A similar pattern is given by return of adults as a percentage of fry and fingerlings released at all hatcheries in the Bonneville area (from Maltzeff and Zimmer, 1963).

It has been shown that the survival rate (return to the hatcheries) of both marked and unmarked chinook, from above and below Bonneville Dam, apparently declined during the early 1950's. This has been ascribed to disease, but the fact remains that wild stocks, relatively free of disease, also decreased during the same period. Clearly some other factor or factors were controlling the survival rate and size of the population.

Ocean Temperature

In the thesis I describe the oceanography of the region inhabited by Columbia River chinook and examine several aspects of marine ecology that might be related to ocean survival. Only ocean temperature appeared to bear any relationship. Several serial measurements of temperature are examined in the following section to determine what correlation with abundance may exist for Columbia River chinook. The dependent variables in this analysis are total return to the river of a given brood-year stock and return per spawner, and they will be correlated with independent variables such as water temperature.

Fluctuations or declines in abundance of salmon runs have been blamed on changes in marine survival, but little is known about the mechanisms involved. Vernon (1958), for example, examined the factors influencing the abundance of pink salmon in the Fraser River and found that abundance of year classes was closely and inversely correlated with water temperatures encountered by the juveniles in Georgia Straits. Birman (1964) noted that the warming of Asiatic coastal water by the Kuroshio current was correlated with decreased numbers of pink salmon, and that hydrological conditions were not responsible for the decline of Asian chum salmon although they may cause some fluctuations in abundance.

Columbia River fall chinook migrate downstream shortly after hatching, but since they often hatch far upriver, the trip may take weeks or even months. May is probably the month when most of them arrive at or near the mouth of the Columbia, but there is a considerable migration in June (refer to section on downstream migration). Varying periods of downstream migration and weather conditions suggest that the time of arrival of young fish at sea may be quite variable, and that they encounter different conditions. Little is known about how long the downstream migrants remain in the estuary or the conditions they face which might affect survival.

The average ocean temperature during the first May and June of life of a given year class was chosen as a critical period during which any relationship between water temperature and survival should be revealed. Serial water temperature data are scarce, but an excellent series of air temperatures is available for the North Head Lighthouse (U.S. Weather Bureau Climatological Data) located about 5 miles north of the Columbia River and directly facing the ocean. Several authors comment on the similarity of sea and air temperatures in such situations (for example, Roden 1961). Weather records at this station were discontinued in 1953, but beginning in 1949 daily water temperatures were taken in the surf at high tide at the Seaside Aquarium about 17 miles south of the mouth of the Columbia River (Kujala and Wyatt, 1961). They are representative of actual temperatures and salinities the young salmon encounter in leaving the river.

Examination of North Head air temperature data suggested better runs occurred with lower May and June temperatures; however, a calculated correlation coefficient for the years 1938-46 of $r = -0.396$ was nonsignificant ($r_{.05} = 0.666$ with 7 *d.f.*).

Seaside water temperatures show pronounced warm temperatures in 1956-58 characteristic of the North Pacific. These data also suggest that perhaps warm years produce poorer runs than cold years. The correlation coefficient was $r = -0.360$ ($r_{.05} = 0.576$ with 10 *d.f.*). Seaside data cover a period when the run had stabilized at a low level. Salinity at Seaside seemed to be the inverse of temperature with no obvious relationship with salmon abundance.

Another available series of water temperatures is from Neah Bay, Washington, near the tip of Cape Flattery (U.S. Coast and Geodetic Survey, 1962). May, June, and July mean water temperatures were plotted; they showed much fluctuation with no apparent relation to salmon abundance or other temperature records. The sheltered location of this station, along with strong tidal currents, may account for the variability.

The Fisheries Research Board of Canada has for many years maintained temperature and salinity records at a number of light stations on the British Columbia coast (Hollister, 1964). Amphitrite Point is particularly good for our purpose because records go back to 1934, it faces the open ocean, and is in an area inhabited by large numbers of Columbia River chinook. Pickard and McLeod (1953) note that Amphitrite is representative of the water of the open coast. Plotting a scatter diagram of total salmon returns by brood year with June Amphitrite temperatures (Figure 9) reveals a significant inverse correlation at the 5% level for the brood years 1938-46 ($r = -0.754$, $r_{.05} = 0.666$ with 7 *d.f.*). A negative, but nonsignificant, relationship is observed for more recent (1947-59) years. Taking return per spawner, 1938-46 gave $r = -0.583$ ($r_{.05} = 0.666$ with 7 *d.f.*) and 1947-59 gave $r = -0.517$ ($r_{.05} = 0.553$ with 11 *d.f.*), both approaching significant values.

In summary, an exploratory examina-

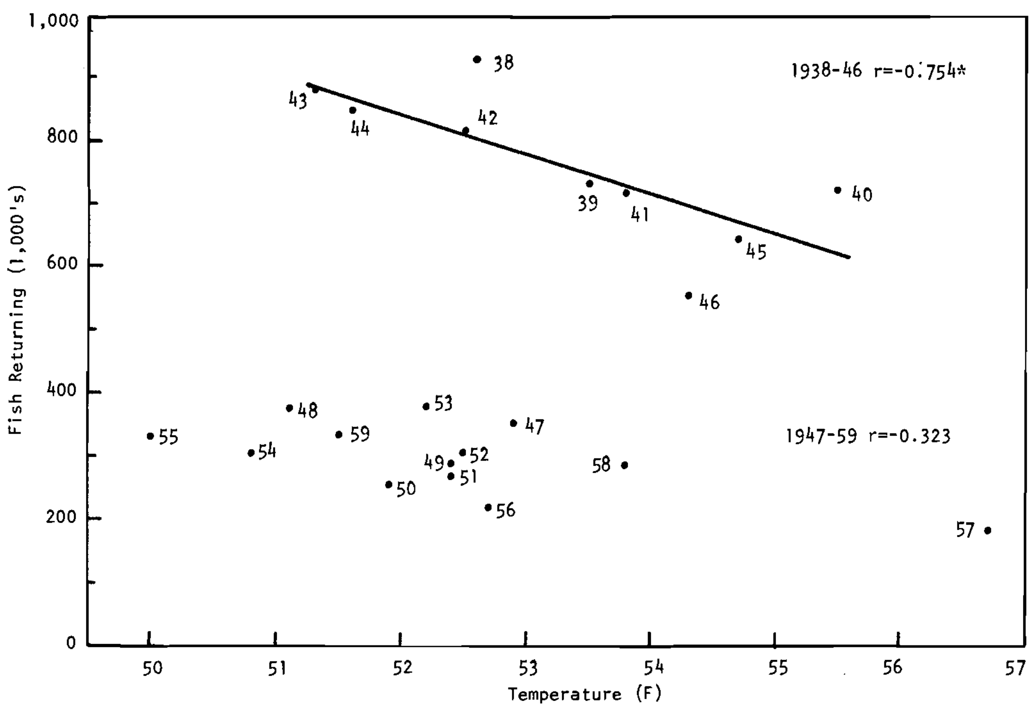


Figure 9. Relationship between Amphirite Point water temperature in June and return of fall chinook to Columbia River, 1938-46 and 1947-59-brood years.

tion of marine factors that could affect the abundance of chinook salmon revealed a correlation between ocean water temperature during the brood's first spring and rate of survival. The mechanism involved is not known, but higher temperatures may perhaps reflect unfavorable ocean current patterns rather than exert a direct effect.

Ocean Fisheries

Commercial Troll Fishery

The history of the Pacific Coast ocean troll salmon fishery has been documented by Parker and Kirkness (1956), Milne and Godfrey (1964), Kauffman (1951), and Van Hyning (1951 and 1968).

Regulation of the early troll fishery consisted of size limits to protect immature fish and prevent the landing of a poor quality product for the market. Size limits for chinook varied from 20 to 28 inches (total length) through the years, but since 1957 a 26-inch limit has generally applied in offshore waters. In 1949 a March 15 to November 1 open season for chinook trolling was enacted by Oregon and Washington. In 1956 the opening date was moved up to April 15, primarily to protect Columbia River fall chinook. British Columbia and Alaska followed within a year or two, so that now the April 15-November 1 season is standard on the Pacific Coast. Certain exceptions exist on the inside waters of British Columbia and Alaska, but they are of little consequence to Columbia River stocks.

Since Columbia River fall chinook are taken primarily in outside waters from central Oregon north through southeastern Alaska, the following discussion will be confined to that area. Data on pounds of troll-caught chinook landed are available from records of fishery agencies, but these are a composite of salmon from many rivers. As noted, however, Columbia River fall chinook dominate most areas and production statistics give at least an index of the harvest of this stock. Numbers of fish are given in some records, but these are usually converted from pounds, using a constant conversion factor or sampling data, both subject to error.

The reader is referred to the thesis (Van Hyning, 1968) for analysis of catch statistics for individual troll fishing areas and an explanation of source material and adjustments. Briefly, some areas have shown increasing landings, others decreasing, and all indicate severe fluctuations. Central Oregon (Newport) landings showed an upward trend until 1957, then a sharp decline while those from off the Columbia River (Oregon and Washington combined) exhibited a rising trend until 1952, then a gradual decline to a very low level. The Washington coastal area had a rapid increase until 1955, then a sharp decrease. Landings at Puget Sound ports for the area off Cape Flattery as well as the west coast of Vancouver Island indicated a long-term downward trend while landings for the west coast of Vancouver Island showed a striking increase to 1948, a high level of production until 1959, then a drop to former levels. Both northern British Columbia and southeastern Alaska had long-term declines.

Three geographically related areas — Newport, Columbia River, and Washington coast — revealed a similar trend of increasing landings followed by a drop. The increase occurred during a period when most of the trolling fleet adopted electronic and other devices and greatly improved their fishing ability. In addition, albacore were scarce or absent in northwest waters during 1952-55, causing the fleet to concentrate on salmon. It is suggested that stocks in this area were unable to sustain the high level of catches that developed in the early and mid-1950's.

The contrast between the American

and Canadian fishery off Cape Flattery and Vancouver Island was striking; i.e., Washington troll landings gradually declined while Canadian increased rather spectacularly.

Northern British Columbia troll catches exhibited a gradual downward trend. Milne and Godfrey (1964) state: "The low catch and effort expended in recent years (1955-57) suggest a decline in the abundance of chinook salmon in this area, which is associated with the recent decline in Columbia River stocks."

Alaska troll catches after 1937 evinced a very sharp downward trend. According to Parker and Kirkness (1956) some important trolling grounds, such as Cape Ommaney and the west coast of Prince of Wales Island, ceased to be productive: "We are able to see, then, the virtual disppearance of important king salmon trolling grounds during a period of exploration, expansion, and technological development. It is not remarkable that such events should occur in almost perfect correlation with the destruction of the Columbia River spawning grounds." This may seem a logical conclusion, but other explanations must also be considered.

During the period of greatly reduced Alaska catches, 1935 to 1950, the Columbia River spring and summer chinook runs were declining, but not the fall run. This presupposes that the spring and summer stocks were of prime importance to the Alaskan fishery at that time, which may not be the case. The destruction of Columbia River spawning grounds will be covered in a later section, but fall chinook were relatively unaffected by spawning ground loss in this watershed during the early period of Alaskan decline. The picture is thus more complex than suggested by Parker and Kirkness and could reflect the interaction of changes in abundance of different races. Although these authors suggest that dam building on the Columbia was the principal cause of the decline of Alaska's troll chinook fishery, overfishing cannot be excluded. An intense fishery could have developed on certain races which rendezvous at a coastal location en route to their home stream. For example, 373,000 chinook were landed in the Cape Ommaney area in 1924 compared to "normal production" of 144,000 in 1927. By 1951 and 1952 landings had fallen to 12,000 and 17,000, respectively. Catches in the magnitude of 150,000-350,000 chinook in only one area must have had an important effect in reducing the numbers entering rivers to which they were destined. Information is not available to study the near demise of the Alaska troll chinook fishery, but the inference is rather strong that overfishing was an important factor, perhaps more important than spawning ground destruction.

The oceanic life of Columbia River fall chinook may be conveniently divided into two areas: southern (from central Oregon to and including the west coast of Vancouver Island) and northern (northern British Columbia and Alaska). The southern area contains both upper and lower Columbia River stocks, mature and immature, while in the northern area mostly mature fish of upper-river origin are caught. Catch statistics can be summed up for the two areas separately, as shown in Figure 10, and compared with the estimated pounds of fall chinook entering the Columbia (commercial landings plus number escaping over Bonneville Dam[1], assuming 20 pounds average weight).

The total catch in the southern area increased substantially until 1952, leveled off until 1957, then fell sharply dur-

[1] The years 1935-37, prior to Bonneville counts, were computed from the ratio between pounds landed and total size of the run for 1938-40.

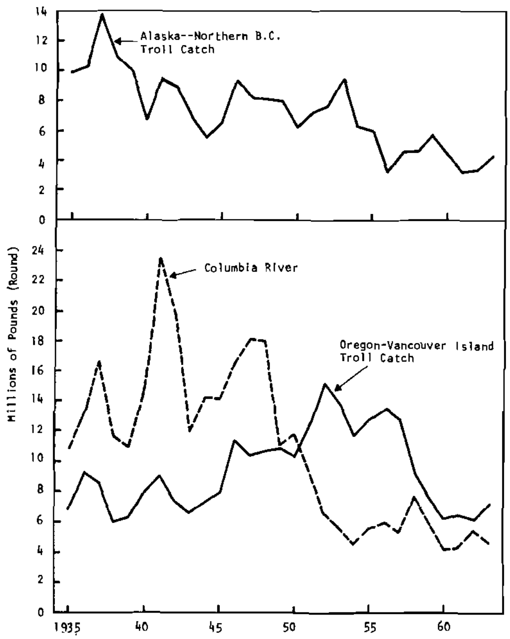


Figure 10. Ocean troll chinook salmon landings by area compared to pounds of fall chinook entering the Columbia River, 1935-63.

ing the remainder of the period studied. Since Columbia River fall chinook was the single most important component of the fishery, the total ocean catch of this stock must have followed a somewhat similiar trend.

Northern British Columbia and Alaska combined show a long-term decline. Unlike the southern fishery, which could increase its catch up to a point by improving efficiency of gear and exploiting different areas and younger age groups, the northern fishery, dependent to a large extent on mature upper-river stocks, was fully developed by 1937 and could only decline along with the general decrease in the runs. The correspondence between peaks and nadirs in catches in the two areas and in the Columbia River in the earlier years implies that they are dependent, to a high degree, upon a common stock.

Since there seemed to be an agreement between catches in the two ocean areas and runs entering the Columbia during the earlier years, while an inverse relationship existed in later years, correlation analysis was used to study the relationships. In the period 1935-48 a significant positive correlation was evident ($r = 0.59$, $r_{.05} = 0.53$ with 12 *d.f.*); increasing ocean catches were associated with larger runs into the river. The fishery was then merely sampling the run without a major impact. Beginning in 1949, a change occurred, corresponding with a declining run entering the Columbia; we now see a negative but nonsignificant relationship for 1949-58 ($r = -0.54$, $r_{.05} = 0.63$ with 8 *d.f.*) between an increasing ocean catch and decreasing return to the river. A transition occurred in 1958, and from 1959-63 another level was formed marked by low ocean catches and low runs to the river. The close correlation between total ocean catches and magnitude of the Columbia fall run in the early years shows the dependence of the fishery on Columbia River fish, and confirms the tagging studies that revealed the presence of a majority of Columbia River stocks in most ocean troll areas.

In conjunction with catches, another vital statistic is the amount of fishing effort. Unfortunately effort data for the troll fishery are not uniform and are difficult to evaluate. The best series is for the Washington troll fishery (unpublished data provided by the Washington Department of Fisheries) and consists of numbers of troll landings by month, year, and area which, with some adjustment (Van Hyning, 1968), give the number of trolling trips off Washington and adjacent areas each year.

This tabulation, shown in Figure 11, indicates a rapid increase in the number of trips until 1948, a high level until 1957, and a slight reduction in more recent years. Part of the reduction is caused by shortening the open season by 1 month (March 15 to April 15) in 1956. For the previous 5 years, an average of 2,117 landings had been made from March 15 to April 15. The very low value in 1960 was occasioned by a scarcity of both chinook and coho. There was a substantial increase in trolling off Washington: from an average of 16,400 trips in 1935-44 to 28,100 in 1948-57.

After 1951, British Columbia recorded the number of boat days of fishing (Milne and Godfrey, 1964). This period was well into the era of exceptionally high catches off Vancouver Island, and thus did not depict any increase in intensity. Milne and Godfrey also give the number of troll licenses issued in British Columbia (Figure 11). The excellent agreement between number of days fished and number of licenses suggests that the latter may be a good measure of fishing effort. In combination, the two measures indicate that fishing effort increased materially after World War II and has remained high.

Intensity of the Washington fishery is used as an index of fishing effort because it is the best such data available and I feel that similar changes in effort for Oregon and British Columbia are reflected in these statistics. The Washington troll fishery is not singled out for special attention; reference to troll fishing effort will be to Washington but applies to the other areas as well.

Figure 12 shows three vital aspects of the Washington troll chinook fishery—catch, effort, and abundance (catch-per-unit effort). Total catches increased slowly but steadily until 1952 then declined sharply. Effort (trips) reached a peak in 1954 then decreased slightly, while catch-per-unit effort fell steadily throughout the period. As can be seen,

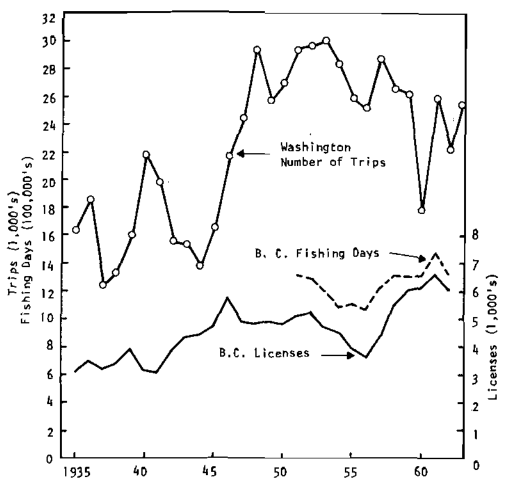


Figure 11. Troll fishing effort off Washington and British Columbia.

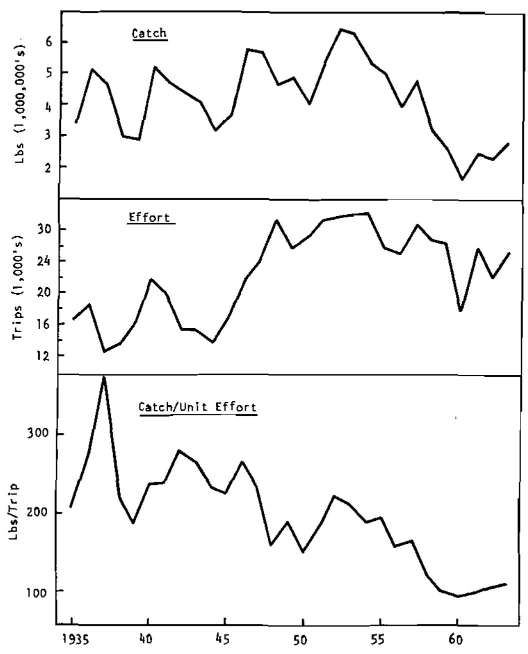


Figure 12 Statistics of the Washington troll chinook fishery, 1935-63.

a large increase in intensity resulted in an only modest rise in yield. Fitting a visual trend line from 1935 to 1954 suggests that a doubling of effort (15,000-30,-000 trips) resulted in a 58% increase in catch (from 3.5 to 5.0 million pounds). Undoubtedly rising competition between gear has been a factor in reducing the catch-per-unit effort, but there is little question that abundance has declined, especially since 1955. That troll fishing effort probably has an effect on the abundance of chinook is shown by a significant negative correlation between effort and catch-per-unit effort ($r = -0.52$, $r_{.05} = 0.37$ with 27 *d.f.*).

If chinook salmon are considered strictly a marine species, an almost classic example of the effect of exploitation is shown in Figure 12: an increase in effort results in a rise in catch up to a point, then more intensive fishing brings a decline in yield. The troll chinook fishery would be uneconomical if there were not other species of salmon, albacore, and halibut to be harvested. The abundance of these fish keeps trolling intensity at a high level.

Increasing fishing effort results in reduced runs returning to the Columbia River. This hypothesis hardly needs proving, but is further examined by correlating the return of fish by brood year with the fishing effort to which that group was exposed. (Since fall chinook are present in the fishery for substantially 2 years, as 3- and 4-year fish, the number of trips during the years when the fish were in their third and fourth years were summed up in order to arrive at a measure of fishing effort on a brood year.) A significant negative linear correlation ($r = -0.562$, $r_{.05} = -0.423$ with 20 *d.f.*) was found for all years combined. Taking only the brood years 1938-50, a curvilinear pattern was detected. A curve was fitted to these years ($\hat{y} = 144.9158X - 1.7699X^2 - 2042.77$) and the R value of 0.91 was significant, showing that an increase in effort on a brood year up to 40,000 trips resulted in a greater return to the river (probably a greater abundance induced increased fishing). Fishing effort above this level brought a rapid drop in the returning run.

Changes in the size and age composition of a population often indicate the effects of fishing. Long-term declines in either reflect increasing fishing pressure as older groups are removed and younger ones support the bulk of the fishery. Systematic sampling of the troll fishery did not begin until the late 1940's and early 1950's when the fishery had already reached its peak, so that the composition of the catch prior to 1940 is not known and hence cannot be compared under different levels of fishing intensity. An exception is fish tagged in British Columbia in 1925-30 for which scales were taken; they can be compared to catch sampling in 1952-57 (Milne, 1957). The best comparison is the fishery off southern Vancouver Island. In general, 3-year fish increased from 25 to 50% of the catch while 4-year fish dropped from 50 to 25% and 5-year fish declined to negligible numbers. In more recent years, the 3_1 group constituted as much as 65% of the catch in this area. Catches in northern British Columbia also show a change in age composition. A shift of modal age from 5 to 4 and an increase in the number of 3-year olds is indicated.

When samples taken in the period 1919-30 are compared with those from 1949-63, a marked decrease is seen in average age of chinook entering the troll catch from the Columbia River to northern British Columbia. Generally the modal age moved in the southern areas from 4 to 3 and in the northern from 5 to 4. Young fish became more important in the landings while the older ones virtually disappeared. Combined with this was a drop in average size. These trends indicate the typical reaction of a population to exploitation and show that the ocean fishery is exerting a measurable effect on the chinook population. Size and age composition of fall chinook as they enter the Columbia River will be discussed in another section.

Japanese Fishery

Ever since the Japanese began their post-war high seas mothership fishing in the North Pacific they have been blamed for declines in some American salmon runs. There is no evidence to indicate, however, that this fishery has had any influence on Columbia River stocks.

Japanese fishing is restricted by international agreement to the Pacific Ocean west of 175°W longitude. According to Mason (1965) limited chinook tagging in the vicinity of the treaty line resulted in the recovery of one spring chinook from the Salmon River, Idaho, one from a northern Alaska river, one from the Siberian coast, and two recaptured on the high seas. The lack of fall chinook recoveries does not preclude their presence in the area. A more convincing argument, however, is that the Japanese mothership catch consists almost entirely of fish with sub-two or stream-type scales. Since Columbia River fall chinook are predominantly fish which spent less than 1 year in fresh water there can be few if any in the Japanese catch. Furthermore, the Japanese mothership catches averaged only 40,000 chinook per year in 1952-61 (Kasahara, 1963).

Sport Fishery

Ocean sport fishing for salmon is mainly a development of the 1950's (Wendler, 1960). Mass production of suitable boats and reliable outboard motors resulted in a tremendous upsurge in this sport, especially off the mouth of the Columbia and Grays Harbor. Oregon sport fisheries also expanded, but the catch includes so few Columbia River chinook that it can be ignored in this analysis.

Both the Columbia River estuary and Neah Bay had fisheries in existence before catch sampling began but they were at a low and steady level. Prior to 1951, the fishery at the mouth of the Columbia was entirely in the estuary and consisted almost solely of mature chinook. Subsequently it moved offshore, and coho and immature chinook became more important. The estuary sport fishery in 1946-51 followed the general trend of the fall chinook run, as might be expected, since it operated on the peak of the run between mid-August and early September. After 1951, the sport catch increased to between 20,000 and 30,000 fish per year. Prior to 1950 the catch at Westport, Washington, was negligible but rose rapidly from 1950 to 1952, reaching a peak of 69,000 in 1956, and then leveled off. A small fishery developed at LaPush, Washington, which took generally 2,000 to 3,000 chinook per year, but because of its isolation did not expand as in other areas. Sport fisheries on the inside waters of Puget Sound, British Columbia, and Alaska probably do not take many Columbia River salmon, but these fish are important to the Neah Bay and western Strait of Juan de Fuca fishery. Numerous marked Columbia River fish have been taken as far as Sekiu.

The estimated ocean sport chinook catch in the Columbia River estuary and off the coast of Washington increased from about 35,000 in 1949 to nearly 130,000 in 1956 and then leveled off at around 100,000. Also, during this period (1949-64) the number of angler trips rose from about 80,000 to over 400,000. The charter fleet at Westport increased from 8 in 1952 to 91 in 1953 and over 200 in 1964, and at Ilwaco from less than

10 in 1954 to over 90 in 1964. According to Haw, Wendler, and Deschamps (1967): "Westport is now dominated by a wide-ranging charter fleet, one of the largest charter fleets in North America." The intensity of the fishery is still increasing, but the catch has leveled off, suggesting that the available stocks are being fully utilized.

Hooking Mortality

Another factor related to ocean fishing is the number and mortality of small chinook that are released by trollers; this varies greatly by area and season, from zero to 100 per day. For a number of trolling trips in 1954-55 between Grays Harbor and Newport, 17% of the ocean-type chinook caught were under 24 inches fork length and would have been discarded. Tagging experiments conducted off the Columbia River from 1948 to 1952 showed that of the 938 fish caught, 394 or 42% were below legal size. In tagging off the Columbia River-Grays Harbor area in March-April 1959 and 1960, 27 and 28%, respectively, were sublegal. Heyamoto (1963) found that 82% of the chinook caught off the mouth of the Columbia River from May to August 1957 were sublegal. In a commercial operation in June 1962 off Grays Harbor, 38% of the chinook caught were undersized, while in September 1962 off the Columbia, 84% were so designated.

For southern Vancouver Island, Neave (1951) gives a table showing the size composition of 1,204 chinook taken from May to August 1949. Fish under 24-1/2 inches fork length comprised 15 to 34% of the catch in May and June, and 6 and 9% on July 1 and August 5, respectively. Off northern Vancouver Island (Quatsino) the percentage varied in July from zero to eight.

Milne (1964) gives length-frequency distributions of fish received at the buying stations in the British Columbia troll fishery from 1952 to 1959. A measure is obtained from the 1952-56 data on fish taken between 18 and 24 inches which would have been discarded had the larger size limit been in effect. On the west coast of Vancouver Island fish under 26 inches (total length) varied from 21 to 36% with an average of 29%. Undoubtedly, numerous fish under 18 inches were also discarded. For north and south Hecate Straits the percentages were 16 and 17, respectively, and for the Queen Charlotte Islands, only 5. Sampling off southeastern Alaska in 1950-52 showed between 2 and 16% under 23.75 inches fork length.

Thus, for the area between central Oregon and Vancouver Island 25% might be a conservative estimate of the average proportion of the troll chinook catch returned to the water. For northern British Columbia and Alaska, it would be only about 5%.

Some small chinook are released in the ocean sport fisheries but little information on this matter is available. Prior to 1958, size and bag limits were so lenient that few were discarded, but in 1958 20- and 22-inch total length size limits were instigated in Washington and Oregon which prevented the retention of small chinook. In addition, the bag limit was reduced, probably causing anglers to be more selective. Sampling at Westport and the mouth of the Columbia in 1955-57 showed that from 11 to 17% of the chinook landed were below 20 inches.

Mortality of released fish may be quite high. Based on physical damage alone, Van Hyning and Naab (1957) estimated that 30% of a large sample of troll-caught chinook under 24 inches would probably die if released. Milne and Ball (1956) suggest a hooking mortality of one-third to one-half for small chinook and coho, based on holding in live pounds. Parker and Black (1959) bring up another point, that of death through exhaustion or hyperactivity associated with high blood lactate levels. They estimate a mortality rate of 71% with 95% confidence limits of 40 and 86% for troll-caught chinook. There is a suspicion, however, that such high mortality may have been partially caused by confinement and stress in a live box (Ellis, 1964). With some recent tagging experiments giving returns as high as 47% (Table 3), a hooking mortality greatly in excess of 40% can hardly be accommodated when considering tag loss, tags recovered but not turned in, natural mortality, and tagged fish undetected on the spawning grounds. An estimated hooking mortality of 40% appears reasonable after considering the foregoing information. Additional numbers of legal-sized fish are hooked but escape with torn mouth parts and gills. Their mortality rates are unknown.

The crux of this discussion is that the number of fish landed does not represent the entire fishing mortality. For example, in 1957, when over 1 million chinook were landed in the troll fishery from central Oregon to Vancouver Island, perhaps an additional 250,000 were discarded at sea, of which 100,000 may have died. Thus, catches since 1948 for Oregon and Washington and since 1957 for British Columbia could be increased by approximately 10% over those reported. The unrefined estimates do not warrant further analysis at this time, but do show that there is fishing mortality beyond that recorded in the landing statistics.

Combined Influences of Ocean Fisheries

Biologically, the marine habitat of Columbia River fall chinook has been divided into southern and northern areas. The northern shows a long-term decline in production, the southern an increase until 1952 then a sharp decrease. This is seen in Figure 10 where the troll catch in pounds within each area was summed up and compared with the estimate (in pounds) of fall chinook entering the Columbia River each year. The ocean catch was correlated with the run in the Columbia until the catch in the southern area increased markedly; then the number entering the river decreased.

Since the fish are being cropped at a younger age and smaller size, the poundage landed in more recent years no longer reflects the production of which the stock is capable, nor what was produced by the same number of fish in earlier years. For this reason, numbers of fish taken should be considered. Such estimates were compiled from a variety of sources and showed a trend similar to Figure 10, but with a much more rapid buildup of the catch by the ocean fishery and higher peak coincident with the decline in the fall run to the Columbia River.

An accurate estimate of the number of Columbia River fall chinook landed in the ocean fishery is badly needed, but data are not available. Attempts based on ocean tagging and subsequent tag recovery in the rivers have been criticized on the ground that the chance of recovery in the Columbia is greater than in other rivers without intense fisheries or hatcheries. Silliman (1948), in making an estimate of the troll catch of Columbia River chinook from the early British Columbia offshore tagging results, succinctly stated the problem:

"It is well to recognize that their suitability for this purpose is entirely dependent upon the fishing intensity and recovery effort in the various regions. For instance, we assume a stock of 1,500 tagged salmon, composed of 1,000 British Columbia and 500 Columbia River fish. Disregarding other mortality, and assuming 100 per cent recovery of tagged fish caught, a fishing intensity of 25 per cent in British Columbia and 50 per cent in the Columbia River would result in 250 recoveries of tags in each region, and evidence from recoveries alone would point to 50 per cent Columbia River instead of the true 33-1/3 per cent. When efficiency in recovering the caught fish, as well as fishing intensity itself varies, the situation is further complicated."

Although a number of tagging programs have since been conducted and we have refined catch statistics, there is still a lack of information on fishing intensity in the various recovery areas outside the Columbia River. A further complication is the much larger sea recoveries from more recent tagging than early tagging. If one race of chinook is more available or vulnerable to ocean fishing than another, tagged fish of that race would be selectively reduced before they reached their natal stream, while the less available race would not, tending to distort the estimates of importance. Likewise, if a tagging area contains mostly mature fish from one river but immature from another, the immatures would be exposed to a longer fishing period and tag loss, reducing their apparent importance to the area as compared to maturing fish which returned to the river sooner. That such a situation may exist is shown in Figure 5, where both mature and immature Columbia River chinook were found off Barkely Sound whereas the Puget Sound-Fraser River chinook were largely mature. Milne and Godfrey (1964) stated that the average gill-net catch of chinook in the Fraser was 150,000 and the escapement about 100,000. This gives a fishing mortality of 60%, similar to the Columbia River in more recent years. Milne (1957) stated that the Columbia River contribution to the southern Vancouver Island fishery was probably about 30% and the Fraser 20%. Later this was changed to "one-quarter or less" for the Columbia (Milne and Godfrey, 1964). No clear basis for these estimates is given and they must be regarded as opinions or educated guesses.

Returns of marked fish suggest a substantial contribution of Columbia River hatchery chinook to the ocean fisheries but past marking experiments were not designed to accurately produce such statistics. Preliminary results of returns under the Columbia River Fishery Development Program, which evaluates the contribution of hatcheries are presented in Table 7. The 1962 brood experienced poor survival compared to broods in 1961 and following years, but in 1965 Columbia River hatchery fall chinook alone constituted 16 to 31% of the ocean catch off Washington and Vancouver Island. The 1961 brood showed a high survival rate and the proportion of hatchery fish in the catches was likewise high (29 to 43%) in the 2 years covered. Furthermore, the estimates are not corrected for differential survival rates of marked and unmarked fish.

Table 7. Estimated percentages of Columbia River hatchery fall chinook in selected fisheries.

	Estimated Contribution by Age				
	1961 Brood			1962 Brood 1965 Catch	
Fishery	As 3-Year Fish in 1964	As 4-year Fish in 1965	(1) + (2)	As 3-Year Fish in 1965	(2) + (4)
	(1)	(2)	(3)	(4)	(5)
	%	%	%	%	%
Vancouver Island Troll	17.3	11.4	28.7	4.9	16.3
Washington Troll	30.0	12.6	42.6	18.5	31.1
Washington Sport	24.1	9.0	33.1	10.3	19.3
Columbia River Gill Net	18.8	21.8	40.6	30.9	52.7

Cleaver (1969) states: "It appears that the marks caused a reduction in number returning to the hatcheries of from 52 to 72 per cent." A disproportionate number of hatchery fall chinook may be caught by the ocean and river fisheries because they are more available than wild stocks; but, on the other hand, hatchery fish were less abundant than wild fish returning to the Columbia. For example, in 1965, 76,000 wild fall chinook escaped over McNary Dam while 18,000 were enumerated at Columbia River hatcheries. In addition, wild populations spawn below McNary Dam and in lower tributaries. In any event, Columbia River fall chinook are a major component of the catch and the use of tag returns may give a conservative rather than exaggerated estimate of the proportion present in various areas.

Attention should be called in Table 7 to the relative change in the percentage of 3- and 4-year fish in the ocean catch of the 1961 brood. Thus the Washington troll contained 30% 3-year fish and 13% 4-year fish. This could mean that Columbia River fish are more available as 3-year olds than 4-year olds and are replaced by other stocks of 4-year fish. The other ocean fisheries show the same trend while the Columbia River catch ratio of 3's and 4's remains basically the same. The significance of this difference will be developed later.

All tagging and marking results indicated that Columbia River fall chinook were an important, and sometimes dominant component of the offshore catch from central Oregon through southeastern Alaska. The agreement in fluctuations in ocean catches and size of the fall chinook run during 1935-48 illustrates the dominant effect of this population and conversely the effect of the ocean fishery on the stock.

In spite of uncertainties, some measure of the offshore catch seems desirable, even though only an estimate of magnitude is possible. To do this I applied the proportion of Columbia River fall chinook found in the various areas, as shown by tagging results, to the number landed by area. For central Oregon, Columbia River, and Washington coastal ports, 28, 72, and 62%, respectively, were used. For areas around Cape Flattery, tagging off the northern Washington coast (Umatilla Reef) showed 50% and Swiftsure Bank 37%; the average, 44%, was used to estimate the number of Columbia River fall chinook landed at Neah Bay and other Puget Sound ports. For the Canadian fishery, Southern Vancouver Island showed 40% and Northern Vancouver Island 36%; 38% was the average used. For the ocean sport fishery, a value of 65% was assigned. For northern British Columbia and Alaska outside fisheries, 19 and 40%, respectively, for the percentage of Columbia River fall chinook. These proportions were based on early Canadian tagging, as noted, and on Alaska tagging which showed 31% Columbia River fall chinook in southern and middle Alaska catches and 52% in northern catches. The results are shown in Figure 13.

Assuming these values are acceptable as an index of Columbia River fall chinook taken at sea, combining them with the number actually entering the Columbia gives the population size. It is clear that the drop in the late 1940's was less drastic than previously shown, but there has been a gradual decline followed by a second major drop in the late 1950's coincident with a reduced ocean catch.

Although the increase in the ocean take appears to account for much of the decrease in stocks, one aspect is still puzzling. In general, the annual harvest of Columbia River chinook at sea increased by 200,000 in the period 1935-50, but the run entering the river declined by perhaps twice that much after 1950. A possible explanation is an underestimate of the ocean harvest of Columbia River chinook. Previously I noted the effect of one race of fish being more available or vulnerable to ocean fishing than another, and how this could distort abundance calculations using tagging results. I also noted that Columbia River fall chinook of hatchery origin composed 16-43% of the catch off Washington and Vancouver Island. Examining mark returns from another point of view corroborates this conclusion. For example, 1949-brood fish marked at Kalama and Oxbow hatcheries were taken at sea and entered the river in the ratio of 2.4:1 and 2.0:1, respectively (Heyamoto and Kiemle, 1955, and Pulford, 1964a). Compare this with a computed ocean catch-to-escapement ratio of 1.7:1 for the years 1952 and 1953, when these fish were taken, as shown in Figure 13. For the 1961 brood, all hatchery marking, the ratio of ocean catch to return to river was 1.5:1 (Bureau of Commercial Fisheries, 1964 and 1966a and b). Figure 13, based on tagging results, shows a 1:1 ratio in 1961, however. Knowing the ocean catch and return of marked fish, and assuming they are representative of the run, it appears that using tag returns underestimates the number of Columbia River chinook taken at sea possibly by as much as 40%.

The ocean catch of Columbia River fish appears to have decreased from the high levels in the mid-1950's. Trollers probably were fishing less on concentrations of Columbia River chinook — the March 15 to April 15 closure would have had this effect. Also, with the decline in the runs, the fish may not have been as abundant in their former haunts causing boats to deploy elsewhere. This possible lessening of the ocean catch may explain why the number entering the river maintained a relatively level trend after the initial decline.

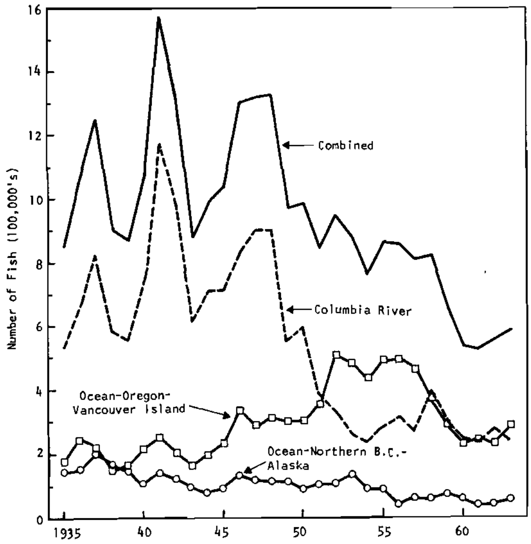


Figure 13. Estimated number of Columbia River fall chinook taken in the ocean fisheries and number entering the Columbia River, 1935-63.

Thus the evidence is rather conclusive that the increase in ocean fishing was an important cause of the drop in the fall chinook run. The rest of the paper will explore the fresh-water environment to detect factors there which might have altered productivity of the stock.

River Life of Chinook Salmon

River Fisheries

Commercial Fishery

The history of the Columbia River commercial fishery is well documented by Craig and Hacker (1940) and others.

Salmon canning on the Columbia began in 1867 when William Hume and his partners moved their operations from the Sacramento River. The river fishery, developing on virgin stocks of spring and summer chinook, reached a peak of over

40 million pounds in 1883. In 1889, spring and summer chinook catches dropped to 18 million pounds. There is small wonder that the opportunity to process fall-run chinook was quickly seized in order to maintain production; there were also warnings even then that the runs might be overfished.

The early industry was based entirely on the highest quality spring and summer chinook, but as they became less abundant and demand for canned salmon increased, other and less desirable runs and species were utilized. By 1900 coho and chum were being canned in considerable volume, indicating that the fall run of chinook was also being harvested. The exact time when the fall run was fully utilized is not known, but in 1892 9% of the chinook catch was made in August (Smith, 1895), reaching 37% by 1912 (Rich, 1942). By World War I, with the increasing demand for food, all salmon runs were heavily utilized. In 1919 and 1920 the August run was of overwhelming importance, comprising 66 to 70% of the total chinook catch (Smith, 1921).

To understand the relation between the fall, spring, and summer runs, we should review briefly the historical trend of catches since the inception of the river fishery. Figure 14 shows total chinook landings from 1866 to 1963, broken down into run components where possible. Data for 1866-1927 are from Craig and Hacker (1940); 1928-37, from Gangmark (1957); and 1938-63, from Fish Commission of Oregon and Washington Department of Fisheries. The catches are estimated by run in some early years using the proportional catch by month as given by Smith (1895) and Rich (1942).

A rapid buildup in the fall fishery occured between 1890 and 1920. At the peak of the fishery, during and immediately after World War I, probably between 16 and 20 million pounds of fall chinook were harvested annually. Another period of high production occured during World War II. Probably the lower production from 1922 to 1940 was due to the depression (Gangmark, 1957).

The chinook fishery was maintained at a high level for about 50 years, from 1870 to 1920. Figure 14 shows that this was due to the fall chinook catches increasing at about the same rate as the summer run catches were decreasing. Beginning in 1920 a steady downhill trend in total catch started. Evidently by 1920 the fall run was being harvested at or near its maximum and contribution to the fisheries could not be increased by further fishing effort, while the harvest of the summer run continued to fall off. The spring run has shown a much less rapid rate of decline than the summer run. Between 1940 and 1950, the fall run virtually supported the Columbia River fishery, but it subsequently fell to a low level while the spring and summer runs had modest increases for a brief period.

This analysis tends to support Thompson's (1951) hypothesis that the effect of fishing on Columbia River chinook changed the character ot the run in that it seriously reduced the main summer run, leaving the spring and fall runs, which had received some protection, dominant.

After the initial development, the history of the river fishery has been marked by increasing restrictions on gear. In the early days every conceivable form of fishing apparatus was used: drifting gill nets, set gill nets, drag seines, purse seines, fish wheels, traps, trolling, and dip nets. Gradually through gear fights and legislation, drift gill nets became the only legal form of commercial fishing in the lower river. Dip nets and set gill nets are still used by Indians above Bonneville dam. Unlike other salmon fisheries which show an increased fishing effort despite decreasing runs, the number of licensed gill-net fishermen on the Columbia River declined steadily—from 1,191 in 1938 to 683 in 1965. In addition, elimination of fixed gear further reduced the fishing effort; but Johnson, Chapman, and Schoning (1948) conclude: "It appears that the elimination of any one type of gear on the Columbia River has served only to increase the catch by other gears rather than increase the escapement." They believe the beneficial effect of removing traps and seines, if any, was in favor of the fall run.

Recent regulations have shortened both seasons and areas open to commercial fishing in an attempt to maintain the runs (Wendler, 1966). Of particular importance was the closure of the area above Bonneville Dam in 1957. When the decline of the fall run became evident in the early 1950's, stringent regulations were imposed on the August-September fishery which included reducing the open periods and increasing the weekend clo-

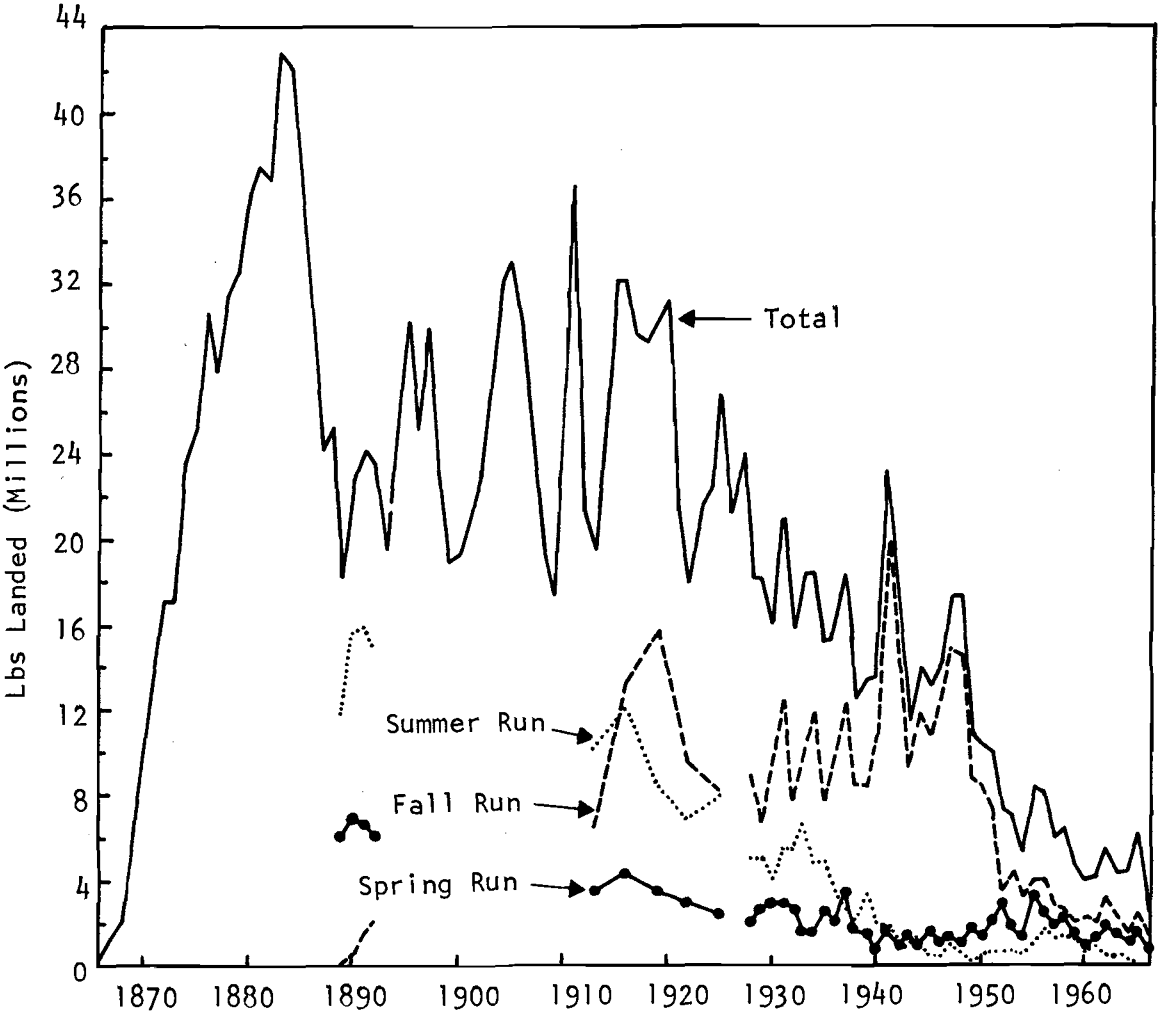


Figure 14. Chinook salmon landings by the Columbia River commercial fishery, 1866-1966.

sures. In recent years only Indians have been permitted to fish commercially above Bonneville Dam.

Even some of the earliest observers were concerned about the effect of the intense fishery on the Columbia River resource. Smith (1895) wrote:

> "It being generally recognized that the decline in the abundance of chinook salmon is due to the fact that the length of the fishing season and the avidity with which the fishery is prosecuted prevent a sufficient number of salmon reaching the spawning grounds to repair the annual destruction by man . . ."

Smith was speaking primarily of the summer run, since the season closed on August 10 in those years. However, he noted the August run in 1893 was extraordinarily heavy and obviated what would have been a poor season. The continued decline in the June-July run resulted only in opening most of August, to partially compensate for loss of summer chinook.

That the fishery seriously reduced the spawning population is well documented. Gilbert and Evermann (1895) toured the Columbia and Snake River basins in 1891-93 and McDonald (1895) quoted Evermann as follows:

> "Salmon were abundant in the Columbia River at Kettle Falls as late as 1878. Since then there has been a great decrease. They have been scarce since 1882. Since 1890 there have been scarcely any at Kettle Falls. Essentially the same information was obtained regarding the decrease of salmon in other parts of the upper tributaries of the Columbia, viz: at Spokane, in both the Big and Little Spokane rivers, and in the Snake River and its various tributaries."

McDonald states:

> "There is no reason to doubt — indeed, the fact is beyond question — that the number of salmon now reaching the head waters of streams in the Columbia River Basin is insignificant in comparison with the number which some years ago annually visited and spawned in these waters."

The remarkable coincidence of the shortage of salmon in the upper areas following the high annual production of 36 to 43 million pounds between 1880 and 1885 cannot be easily discounted.

An estimate of escapement became available when counting began in 1938 at Bonneville Dam. Rich (1942) summarized the first year and revealed the rather startling fishing mortality on some runs:

> "Percentages of chinook salmon escapement are less than 15 during May; 17 during June and July; and 33 during the remainder of the year. The June and July runs are now greatly depleted, and an important part of these runs spawns above Rock Island Dam . . . Main runs of salmon to the Columbia River are practically unprotected and are fished with destructive intensity."

Rich did not have a complete count of the 1938 spring run and subsequent counts in 1939-41 showed an average escapement of 45%. His concern for the summer run was fully justified and escapements from 1938-40 were only 11% of the run. As escapements increased in the mid-1940's the run showed a healthy response until 1957 when another decline began. The recent decline in the summer run is not associated with the spawning escapement which has been maintained at a relatively high level.

To conclude: there can be little doubt that the summer run was literally "fished out" and the fall run took its place in maintaining production. Nothing inherent in the river fishery, however, seems related to the decline of the fall run. Since 1935 it has had a history of decreasing rather than increasing fishing effort, and there was no regulation change associated with the drop in production. As the poor fall run continued, regulations to maintain or augment escapement had little or no effect. Further information on escapement will be given in a later section.

Indian Fishery

Salmon was the staff of life of the primitive northwest Indians; many early explorers commented on the large numbers of Indians gathered at fishing encampments along the Columbia River. Craig and Hacker (1940) estimated that 50,000 Indians in the Columbia Basin caught 18 million pounds of salmon annually before white men made their appearance. Although 18 million pounds is considerably more than landings in recent years, it is much less than white men caught between 1870 and 1920. Indians were efficient fishermen; Craig and Hacker record them using weirs, dip nets, basket nets, spears, hook and line, seines, and set gill nets.

Through thousands of years of adaptation the Indian population might be expected to have come into balance with its principal food supply. One can speculate that 18 million pounds may have been near the maximum sustainable yield for Columbia River salmon (see Figure 14). The Indians succumbed in large numbers to the white man's diseases and by 1850 there were perhaps only 8,000 left in the Columbia River basin outside the upper Snake River Valley. Thus, while primitive Indians must have maintained a fairly large fishery which could have exerted some influence on the runs, by the time the canning industry began the Indian tribes had declined to one-sixth of their former numbers with a consequent reduction in the fish catch.

Most of the Indian catch was probably chinook because it was the largest and most abundant species. Studies from 1947 to 1950 at Celilo Falls (Schoning, Merrell, and Johnson, 1951) showed that the bulk of the fish caught came from the upriver fall run. Although spring and summer chinook were more available on the smaller upper tributaries, high water conditions in the main Columbia during spring and summer often made fishing at the usual main river sites ineffective. Fall chinook, on the other hand, migrating during the low-water period, were extremely vulnerable at such places as Celilo Falls. In addition, the closed season in late August and early September in the lower river allowed significant numbers to reach Celilo. Probably summer chinook were more important before the white man's fishery emerged to crop the runs before they reached the upriver sites.

The Indians soon realized that the fish they caught could be sold for a profit and a commercial dip-net fishery developed in the vicinity of Celilo Falls and at a few other places. The picturesque fishery has been described in the literature cited. From 1889 to 1892 an average of only 101,000 pounds was landed at Celilo (Smith, 1895). This level probably persisted until about 1930 when catches began to increase, reaching 2.5 million pounds by 1941 (Schoning, Merrell, and Johnson, 1951), due in large part to elimination of fish wheels in Oregon in 1927 and all fixed gear in Washington in 1934-35. Landings fluctuated greatly but maintained a level trend until 1948 when they declined coincident with the general drop in the fall run. In 1957 the reservoir was filled behind The Dalles Dam, thus flooding out the historic fishing sites at Celilo Falls and all commercial fishing above Bonneville Dam was halted. In the years 1938-56 the Indians accounted for 12% of the total commercial landings of fall chinook on the Columbia and 68% of the landings above Bonneville Dam.

There was also a large personal-use fishery during the closed commercial season. Schoning, Merrell, and Johnson (1951) sampled this fishery from 1947 to 1950, and the U.S. Fish and Wildlife Service (1955) from 1951 to 1954, and estimated that the Indians took each year an average of 380,300 pounds of fall chinook for their own use and sale to tourists in addition to 1,150,100 pounds sold commercially. The personal-use total remained near 1/2 million pounds (404,000-536,000) from 1947 to 1952. This amount apparently filled their need. It dropped to 127,000 in 1953 and 64,000 in 1954.

After the loss of Celilo Falls, Indian landings fell to almost nothing for a few years; then a few enterprising Indians discovered that salmon could be caught by set gill nets and a new fishery rapidly developed. This new fishery is somewhat different from the previous in that much effort is concentrated in the Bonneville pool where many hatchery fall chinook congregate. The gill nets also take upriver stocks that are passing through. At Celilo Falls few hatchery-reared fish were taken. A legal technicality has allowed the Indians to sell their "closed-season" gill-net catch. This fishery is increasing and is approaching the level of the dip net catch at Celilo Falls before 1957.

Sport Fishery

The river sport fishery on fall chinook occurs above the estuary, from Tongue Point, Oregon upstream. The estuary catch was considered with the ocean sport fishery.

Fishing for fall chinook along the Columbia River is intensive but the catch is low. Surveys by the Washington Department of Fisheries on the main stem up to Klickitat River indicated that 5,507 fall chinook were caught by sportsmen in 1963 and 5,200 in 1964 (Stockley and Fiscus, 1965). The catch consisted mostly of 2- and 3-year males. The river sport fishery is newly developed and the catch probably never exceeded the most recent figures.

There is also a minor fishery in lower Columbia tributaries which takes mostly jack salmon. Fall chinook are generally dark and sexually mature when they enter the spawning streams, hence are not particularly desirable for either sport or food.

In the upper areas fall chinook spawn in the main stem of the Columbia and Snake rivers and are largely unavailable to sportsmen. In contrast to spring and summer chinook, there has apparently never been a sport fishery of consequence on fall chinook in Idaho. We must conclude that the river sport fishery has had no measurable impact on the fall chinook run.

Size and Age Composition of the Run

Knowledge of the age composition of the adult fall chinook run entering the Columbia is basic to understanding year-class survival and changes in the stock. Unfortunately, only sporadic data are available prior to 1957 in the form of spot age samples, marked fish returns, and length-frequency distributions. For a discussion of the method used in estimating the age composition of the run from 1938 to the present and documentation of changes, see the original thesis.

The percentage of fish returning at each age from any brood differs from the ages found in a random sample of a season's catch. Seasonal catches or runs are composites of several brood years with differing survival rates and total production and age compositions between successive years are variable. Age compositions from separate brood years, on the other hand, are much less variable if the age at maturity is assumed to be relatively constant. Table 8 summarizes observations on age composition of Columbia River fall chinook on both a run and a brood-year basis.

A series of 13 marking experiments from the 1938-43 brood years at Spring Creek, Oxbow, and Bonneville hatcheries were summarized by Holmes (1952). The purpose of his study was to ascertain the loss of fingerlings in passing Bonneville Dam as measured by return of adult fish from fingerlings released above and

Table 8. Summary of observations on age composition of Columbia River fall chinook.

Year	Percentage at Age					Source
	2	3	4	5	6	
1919 run	1	18	62	16	3	Rich (1925), trap and seine fishery samples.
1919 and 1922 broods	1	16	60	23		Rich and Holmes (1929), marked fish returns to river fishery and hatchery.
1938-43 broods	tr.	16	68	15	tr.	Holmes (1952), marked hatchery fish returns to river fishery.
1947-48 runs	15	13	72			Length-frequency of lower river trap catch and length-age of troll sample (Van Hyning, 1968).
1949 brood	tr.	15	84	tr.		Kiemle (1962) and Pulford (1964a), marked hatchery fish returns to river fishery and hatchery.
1954-57 broods	6	44	45	5		" " "
1955-59 broods	8	43	43	6		Average age composition of gill-net catch.
1957-64 runs	7	38	47	8		" " "

below the dam. The preponderant age at maturity of hatchery stock during this period was 4 (68%), with lesser numbers of 3-year (16%) and 5-year fish (15%). Two- and 6-year fish were scarce. Except for 1939 the numbers returning at each age were remarkably constant, with 3-year fish varying from 11 to 20% and 4-year fish from 63 to 72%. Compared with the 1919 and 1922 experiments (Rich and Holmes, 1929), the 1938-43 work showed an increase in percentage of 4-year old, and a decrease in 5-year olds while the 3-year fish remained the same.

In 1957 the Oregon and Washington fishery agencies began a systematic sampling program of the Columbia River commercial gill-net fishery. On a run-year basis, considerable fluctation in age was noted, with 3-year fish ranging from 19 to 53% and 4-year fish from 34 to 66%, averaging 38% 3-year and 47% 4-year fish. On a brood basis the fluctuation was much less, with 3-year olds ranging from 40 to 47% and 4-year olds from 36 to 48%, averaging 43% each.

In order to prorate each year's run prior to 1957 to the proper escapement year, the average age compositions shown in Table 9 were used. Although figures for years prior to 1957 are estimates, it is preferable to use them rather than assume a 4-year cycle, as used in the past, or the 1957-64 average for years before 1950. Samples of the catch are assumed to represent the age composition of the run; it will be shown later that this is not an important source of error.

Table 9. Average age composition of Columbia River fall chinook.

Year	Percentage at Age			
	2	3	4	5
1951-56①	7	38	47	8
1938-50	10	15	60	15

① Average of 1957-64 samples.

Table 10 shows the estimated number of fish at each age in the Columbia River fall chinook run from 1938 to 1964. Despite the unrefined and incomplete age data for earlier years, there was a sharp decline in 4-year fish while 3-year olds remained constant. The question might be asked if the decline in older age groups is due to ocean fishing, as suggested, why did not the 3-year fish decrease since they were also exposed to increased fishing? A possible answer is the increase in fish maturing as 3-year olds in recent years. This might balance the increasing catch of 3-year olds and further reduce the number left to mature as 4-year olds.

The average weight of fall chinook

Table 10. Estimates of number of fish at each age in Columbia River fall chinook run, 1938-64

Year	Total Run (Thousands of Fish)	Thousands of Fish			
		2 Year	3 Year	4 Year	5 Year
1938	582	58	87	349	87
1939	550	55	83	330	83
1940	743	74	111	446	111
1941	1,176	118	176	705	176
1942	979	98	147	587	147
1943	601	60	90	361	90
1944	710	71	106	426	106
1945	712	71	107	427	107
1946	832	83	125	499	125
1947	904	90	136	542	136
1948	899	90	135	540	135
1949	551	55	83	330	82
1950	588	59	88	353	88
1951	386	27	147	181	31
1952	323	23	123	152	26
1953	257	18	98	121	21
1954	232	16	88	109	19
1955	282	20	107	132	23
1956	313	22	119	147	25
1957	277	25	53	183	17
1958	393	8	130	197	55
1959	296	6	101	157	30
1960	238	43	86	95	14
1961	232	19	121	84	9
1962	277	19	144	102	8
1963	240	17	60	144	19
1964	325	18	172	111	26

caught should reflect to some degree changes in age composition. Average weight data have been collected for many years and are summarized by Pulford (1964b). In the early period (through 1954) the August weights fluctuated arounds 26 pounds per fish; since 1955 they have been around 22 pounds. This suggests that age composition remained relatively constant in the early years of the fishery. In 1955 older and heavier fish became relatively less abundant, and the average weight declined. September values dropped more than August values. Pulford found a significant decrease in average weight of fall chinook between the 1918-39 and 1951-61 periods and a significant downward trend in the 1951-61 period. Spring chinook, on the other hand, did not show a significant change in average weight.

In summary, there has been a pronounced change in age composition of the fall chinook run during the period of this study. Sporadic observations in the years 1919-48 indicated that age composition was relatively stable with 4-year fish dominant, comprising from 60 to 68% of the run, 5-year olds 15 to 23%, and 3-year olds 13 to 18%. Two-year fish were apparently of negligible importance. More recent sampling of the gill-net fishery and marked fish returning to the river has shown an increased proportion of 2- and 3-year olds, and fewer 4- and 5-year fish with considerable fluctuation between 3- and 4-year olds. Of particular interest and facility for comparison are returns of marked fish from the 1938-43 and 1954-57 broods. In the earlier period the returns comprised a trace of 2-year fish, 16% 3-year fish, 68% 4-year fish, and 15% 5-year fish; in the later period, the figures were 6%

44%, 45% and 5%, respectively. Data on a brood year basis in a more recent study confirm this change, as does the sketchy early age work. Thus, one can say that 2-year fish have increased from negligible numbers to perhaps 10% of the run, 3-year olds from 15 to 40%, 4-year fish dropped from 60 to 40%, and 5-year olds from 15 to less than 10%. The changes resulted in a drop in average weight. Increased ocean fishing could be a logical and major contributor to this phenomenon. That an increase in fishing intensity reduces the number of older fish is axiomatic in fishery management. The period of transition appeared to coincide approximately with the decline in the fall run beginning in 1949. It is suggested that increased ocean fishing was largely responsible for the decrease in average size and age.

Escapement

Dam Counts

The advent of dams has provided counts of anadromous fish going upstream

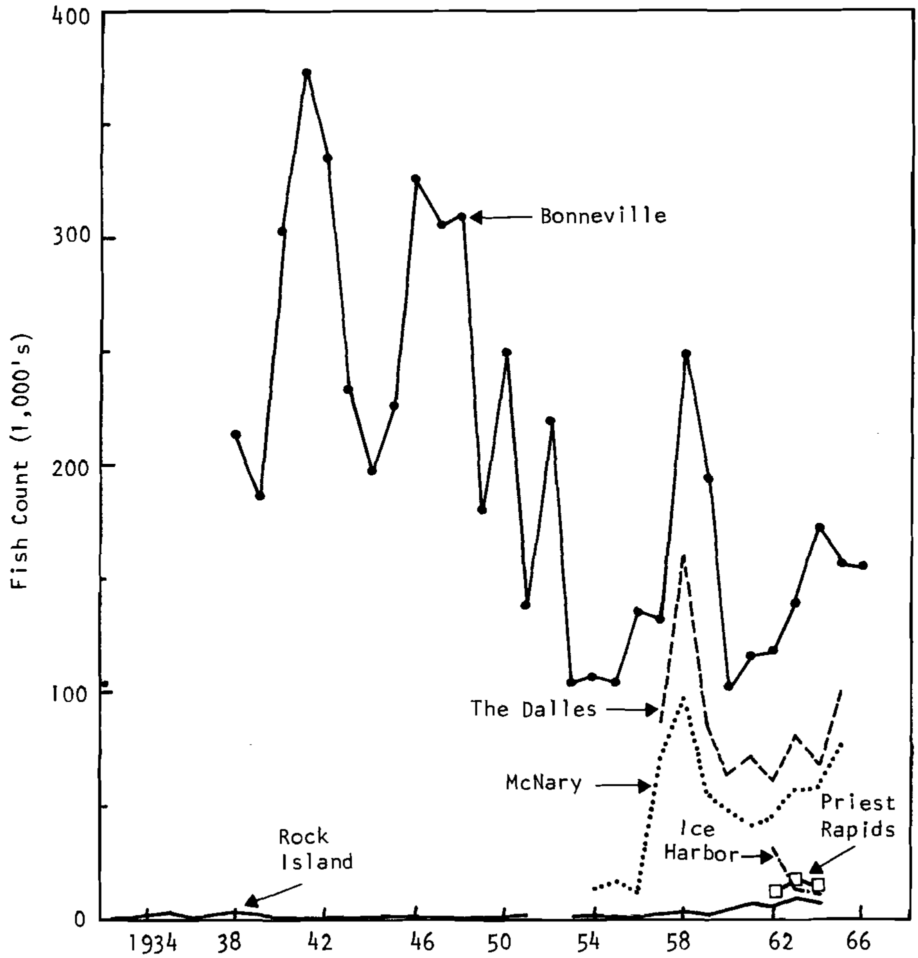


Figure 15. Counts of fall chinook salmon at Columbia River dams. (Rock Island Dam count in hundreds of fish.)

and thus has given us information on population size and escapement.

Rock Island Dam near Wenatchee, Washington (453 miles from the mouth) was the first on the main stem of the Columbia and the first to pass and count fish. Fish and Hanavan (1948) considered that the run passing Rock Island was composed only of spring and summer chinook, although they showed passage over the dam into October. French and Wahle (1960) present evidence on the fall run which they consider passes Rock Island after August 27. Here, unlike other dams, there is no sharp distinction between summer and fall runs. Counts of fall chinook at Rock Island Dam (chinook counted after August 27) and other Columbia River dams are shown in Figure 15. Apparently, by the time counting began in 1933, not many fall chinook were using the upper Columbia for spawning, usually less than 1,000, and often only a few hundred. Rock Island counts continued at a low level until 1957 then began to rise. This might be associated with the cessation of Indian fishing at Celilo Falls, but French and Wahle (1965) also offer another possible reason: the pool behind Priest Rapids Dam (56 miles below Rock Island) formed in 1960 "may have displaced some fall chinook formerly spawning there and caused them to move upstream to spawn."

A factor to be considered in all dam counts is the number of "jacks" or 2-year-old precocious males. At Rock Island, fish under 22 inches are considered jacks. Separate adult and jack counts are available only since 1959, and the percentages of jacks in the September-October count were as follows: 1959, 51%; 1960, 35%; 1961, 43%; 1962, 23%; 1963, 88%; and 1964, 73% (Zimmer and Broughton, 1965). There is considerable fluctuation but an increase occurred in the last 2 years. For example, the very large count in 1963 of 8,800 consisted of only about 1,500 adults, and the remainder jacks. The reason for the increase in jacks is not clear. Perhaps they are more prone to wander and seek different areas if their limited spawning areas are saturated. Obviously the total chinook count does not give a realistic picture of the productive element of the population.

Counts began at Bonneville Dam in 1938, as shown in Figure 15. These figures, less the recorded commercial catch above Bonneville, have been used by management as representing the escapement. Actually this is not the case. Many small male chinook under 24 inches are included in the count. Furthermore, a substantial Indian personal-use fishery which existed prior to 1957, amounting to 22,000-30,000 fish annually between 1947 and 1952, is not considered. Thus the counts even with the above-Bonneville landings subtracted do not represent the true reproductive potential but are a considerable overestimate.

Since the Bonneville count does represent the status of the run as it reaches the dam the decline of fall chinook from 1948 to 1953 is again evident. Except for the unusual years 1958 and 1959, the counts have leveled off but with a modest upward turn in more recent years, probably due mostly to increasing restrictions on the commercial fishery below Bonneville.

Bonneville counts record the number of chinook under 18 inches as jacks (Corps of Engineers Annual Fish Passage Reports and Donaldson, 1965, personal communication). These are only a portion of the true number since many jacks are up to 24 inches in length. A comparison with length frequencies taken at Bonneville in 1948, 1950, and 1956 suggest that an average of 73% of the jacks were counted as jacks in August but only

35% in September (Van Hyning, 1968). The values appear consistent in reflecting changes in the relative numbers of jacks, however. In other words, these counts are a fairly good indication of the number of fish under 18 inches and, comparing the number counted with the percentage under 24 inches, a relative index of the total number of jacks.

To obtain an escapement index, conservatively corrected for jacks, I subtracted the recorded number of jacks at Bonneville from the total count, and then subtracted the recorded above-Bonneville commercial catch from this value. The resulting figure while an improvement still includes jacks between 18 and 24 inches and does not correct for the Indian personal use catch, thus is still an overestimate of the actual escapement. Since few fish under 18 inches enter hatcheries, or are of any consequence in the fisheries, they can be safely excluded from consideration in the above-Bonneville picture. Bonneville counts and escapements are detailed in Table 11, separating the above-Bonneville catch and the return to hatcheries from the upriver escapement. This table shows a slightly increasing trend until 1948, a sharp decline until 1954, then a rise. The 1952 peak was caused by a fishermen's strike which permitted a larger than usual part of the run to escape, and the peaks in 1958-59 were caused by late runs which entered and passed upriver during the closed season, when there was almost no fishing above Bonneville.

McNary Dam, 146 miles above Bonneville, which began counting in 1954, offers a good index of escapement in the upper Columbia and Snake Rivers. The

Table 11. Bonneville dam counts of fall chinooksalmon and adjusted escapement, 1938-65.

	Thousands of Fish					
	Bonneville Count			Adjusted Adult Escapement		
Year	Jacks	Adults	Zone 6 ② Landings	Hatchery	Upriver	Combined
1938	30	204	77	31	96	127
1939	50	136	59	23	54	77
1940	75	228	103	35	90	125
1941	39	334	188	32	114	146
1942	42	294	163	32	99	132
1943	15	219	93	18	108	125
1944	30	168	79	22	67	89
1945	27	200	59	22	118	140
1946	34	293	125	31	138	169
1947	22	286	156	37	92	129
1948	44	354	150	53	152	204
1949	9	172	69	30	72	102
1950	28	222	96	46	81	126
1951	8	130	57	41	31	73
1952	18	202	77	40	85	125
1953	9	95	49	22	24	46
1954	24	83	44	24	14	39
1955	21	84	30	21	34	55
1956	26	111	38	26	47	72
1957	10	122	2	37	83	120
1958	7	242	3	78	160	239
1959	18	177	1	54	122	176
1960	11	91	2	28	61	89
1961	17	100	6	21	73	94
1962	9	109	5	24	80	104
1963	28	111	23	25	62	87
1964	17 ①	155	23	28	104	132
1965	44 ①	113	29	13	72	85

① Jacks are under 22 inches compared to 18 inches in previous years.
② Zone 6 is the area above Bonneville Dam.

low level to which upper river fall chinook descended was apparent when counting began, as only 12,000 to 17,000 of these fish passed the dam in 1954-56 (Figure 15). In 1955 and 1956 a reference length of 24 inches was established for jacks, thus providing a good measure of adult escapement. In all other years the jack size was 18 inches. In 1957-58 the count increased tremendously then dropped to a median level. This increase has been directly associated with the cessation of fishing at Celilo Falls.

In 1957 The Dalles Dam was completed and counts here are intermediate between Bonneville and McNary. Hatcheries between Bonneville and The Dalles account for much of the discrepancy in counts between these two locations; also there was considerable natural spawning between The Dalles and McNary. In 1957 counts began at Brownlee-Oxbow complex on the middle Snake River (not shown). Here numbers of fall chinook declined steadily from 15,160 in 1957 to 945 in 1963 (Haas, 1965) reflecting failure of fish passage. The Brownlee-Oxbow counts dropped from 29 to 2% of the McNary count.

In 1962, counts at Ice Harbor Dam, near the mouth of the Snake River, and Priest Rapids Dam on the Columbia, allowed an inventory of the escapement into the Snake and upper Columbia Rivers. The Ice Harbor fall chinook count dropped from 30,000 to 11,000 in 3 years, while the Priest Rapids escapement increased slightly. There is considerable spawning between McNary pool and Priest Rapids Dam, but the Ice Harbor count accurately estimates the numbers entering the Snake River. In 1962 the Ice Harbor count was nearly 75% of the McNary count, but in 1963-64 only 25%.

Spawning Fish Counts

The counting of spawning salmon or redds in streams is a traditional method of establishing an index of abundance. Although this procedure does not give a total count, it is better in some respects than dam counts because only fish reaching the spawning grounds are inventoried and observations can be made on sex ratio, size, and spawning success. Spawning fish surveys on the Columbia River are many and varied, but little has been published. Much of the material presented here is taken from files of the Fish Commission of Oregon.

Two series of redd counts were studied: (1) in the main Columbia from Rock Island Dam to the mouth of the Snake River or head of McNary Reservoir, and (2) the formerly important Snake River area from Swan Falls to Marsing. Although subject to error due to water conditions, visibility, and variable timing, the redd counts depict actual spawning activity. The Columbia counts show a general decline from 1946 to 1956, a sharp rise coincident with the flooding of Celilo Falls, then a return to a low level. These data are probably not meaningful after 1959 because of the flooding of spawning areas by Priest Rapids, Rocky Reach and Wanapum Dams. The upper Snake had a very high redd count in 1947, a drop to a lower level which continued until the increase in 1957, then a steady decline until this race was exterminated by Brownlee-Oxbow Dam operations. Counts in both areas reflect in a general way counts at the main-stem dams (Figure 15): they show a decrease from the high in 1947 to a very low level in 1954-56, again a high level in 1957-59, followed by a return to an intermediate level.

Spawning fish surveys are of special importance in the tributaries below Bonneville because there are no dams where the salmon must pass and be counted. The Washington Department of Fisheries has a good series of observations on the

Kalama River, one of the most important fall chinook spawning streams (Wendler and Junge, 1955). Both fish-per-mile index counts and a population estimate based on stream survey information, hatchery counts, and some tagging are available. Both measures show a high level of spawning fish in 1945-52, then a sharp drop in 1953, continuing to 1964, except for 1958. The year 1952 is unusual because of a fishermen's strike; if fishing had been normal the downward trend between 1948 and 1955 would have been continuous. The agreement between the Kalama population estimate and Bonneville count is good.

Systematic surveys have been made since 1947 on five small Oregon tributaries of the lower Columbia River (Youngs, Lewis and Clark, Clatskanie, and Hood Rivers and Lindsey Creek) to determine fall chinook abundance. Although each is of a minor importance, these streams collectively contribute an appreciable number of fish to the stock. They show the same kind of fluctuation inherent in all stream surveys but a general agreement is evident with the Kalama counts.

An important facet of the escapement is not only quantity but quality. That is, has there been a change in sex ratio and a reduced number of females, or a size reduction causing lowered fecundity? Although a vital question, there are almost no data to throw light on the issue. With a decrease in size and increase in number of 3-year fish (high proportion of males), a decline could occur in egg potential more dramatic than that shown by mere fish counts. Analysis of hatchery records may supply information on this point.

Hatchery Returns

Fall chinook are reared at hatcheries on the Columbia River and the returning adults are inventoried. Returns to five hatcheries at Spring, Eagle, and Herman Creeks and Big and Little White Salmon Rivers in the Columbia Gorge are shown in Figure 16 (from Fish Commission of Oregon-Washington Department of Fisheries, 1967). The general trend is stable, but several periods of relatively high and low escapements are recorded: average escapements are indicated for 1938-46, followed by an increase and high level from 1947-52 then a drop in 1953-56, good numbers in 1957-59 and again a drop. If the three exceptional years 1957-59 are overlooked, a general decline since 1948 would be evident for the five hatcheries. The numbers of fall chinook handled at Bonneville Hatchery, just below Bonneville Dam, is also shown in Figure 16 (Wallis, 1964a). Fish were not counted in 1946-48 but egg takes were near record highs so undoubtedly over 10,000 fish per year were handled. The trend after 1949 is similar to the hatcheries above Bonneville except that the high response in 1958 is not shown.

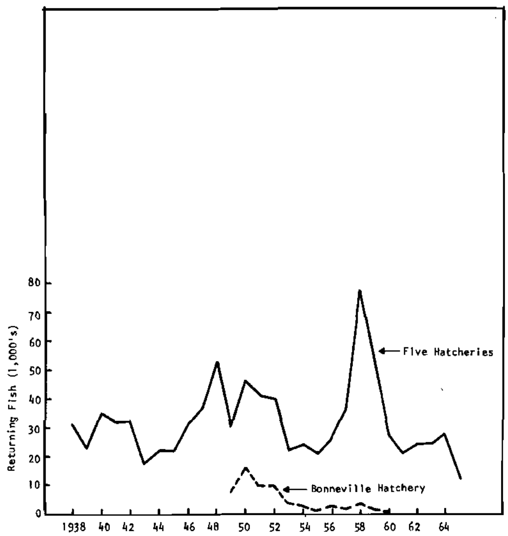


Figure 16. Numbers of fall chinook entering five hatchery streams above Bonneville Dam and Bonneville Hatchery.

In a previous section it was noted that there was a sharp decline in survival rate for hatchery fish from fingerling to returning adult from the 1946- to 1953-brood years, an increase for the 1954-56 broods, then a decrease to an intermediate level. This coincides with fluctuations in the number of adults reaching hatchery streams, and it follows that the abundance of adults is primarily an expression of the survival rate. It was also pointed out that the number of adults returning to Fish Commission of Oregon hatcheries shows a trend similar to that noted on the spawning grounds and the Bonneville count.

Salmon egg takes would be a good measure of the change in potential production of a stock of fish, except that they often do not reflect the number of females present. In some years, hatchery capacity was reached or weirs were flooded out and many fish were allowed to spawn naturally; also expansion in facilities and changes in practices and procedures have occurred. It is noteworthy, however, that substantial increases in fall chinook eggs taken and fingerlings released resulted in the hatcheries merely maintaining their status quo as far as returning adults is concerned.

In the discussion of the commercial river fishery, we noted that there has been a decrease in size and age composition in the catch of fall chinook. This change is even more pronounced when considering only the hatchery population. In the early work with marked hatchery fish (Rich and Holmes, 1929; Holmes 1952), 4-year olds comprised 60-68% of the returns and 3-year fish 16%. In the period 1954-57 this ratio had changed to almost equal number of 3- and 4-year fish (44-45%). In more recent years (1960-64) systematic hatchery samples show the proportion of 3-year fish to be even higher, generally dominant, and occasionally approaching 80%, while 5-year fish have virtually disappeared from the hatchery scene. Two-year fish have increased, but in an erratic manner.

Junge and Phinney (1963) give length-frequency measurements at Little White Salmon Hatchery for 1955-59 and Spring Creek Hatchery for 1959. During these 5 years the females showed a decrease in size, suggesting a shift in modal age of return from 4 to 3 years. Cleaver (1969) shows differences in age and length at return for various hatcheries and implies that life in the ocean is not the same for all hatchery stocks. He believes that the change in maturity is due to changes in genetic makeup, caused by the selective pressures of increased fishing and hatchery environment.

An interesting facet of the change in age composition of hatchery returns is the great number of 3-year females now present. Rich and Holmes (1929) showed that 19% of the returns of the 1922-brood at Big White Salmon Hatchery were 3-year fish, with 23% being females. In 1963 and 1964 most of the returns to Columbia River hatcheries were measured, sexed, and aged under the federal hatchery evaluation program (Bureau of Commercial Fisheries, 1964 and 1966a). In 1963, 54% of the 3-year fish were females and in 1964, 51%. In 1963 and 1964, 65% and 71% of the 4-year fish were females, compared to 51% in the Rich and Holmes' experiment. Even a few 2-year females are present among fall chinook hatchery stocks. For the eight major hatcheries 3-year females outnumbered 4-year females by some 3,000 fish each year. Thus even though the average size and age of the population has been reduced, the ratio of females has perhaps increased. Furthermore, since the size of the 3-year fish is approaching that of the 4-year olds, the average fecundity remains about the same at about 5,000 eggs per female (Bureau of Commercial Fisheries, 1964, and Fish Commission of Oregon hatchery records).

Spring Creek Hatchery records (Junge and Phinney, 1963) show that eggs per female remained steady from 1941 to 1958, at about 4,800, while eggs per fish handled (a reflection of the number of males and jacks) also remained constant, at about 2,000. The rather attractive hypothesis that the decline in size and age has caused a reduction in productivity through lowered fecundity is thus disproved, at least for hatchery stocks.

Gear Selectivity

Gill-net fishing is well known for its selectivity of size, species, and sex. Since fall chinook are exposed to a gauntlet of gill nets as they migrate through the lower Columbia, it is possible that the size, age, and sex composition of the escapement could be substantially altered. If the gill nets selected large, old females, for example, the potential fecundity of the population could be reduced even though there might be little change numerically.

In some years the age composition of the hatchery escapement was considerably different from that of the commercial river catch. For example, in 1963, the gill-net fishery age composition was 2-year fish, 7%; 3-year fish, 25%; 4-year fish, 60%; and, 5-year fish, 8%, while the weighted hatchery age composition was 6%, 61%, 32%, and 1%, respectively. In 1964, the fishery comprised 5% 2-year olds, 53% 3-year fish, 34% 4-year fish, and 8% 5-year fish while the hatchery composition was 1%, 66%, 33%, and trace. Hatchery returns thus favor 3-year fish, suggesting net selectivity on the larger and older specimens. However, the age composition of wild and hatchery races might be different, and they cannot be distinguished in the fishery unless marked.

In 1965, 3 brood years (1961-63) of marked fish returned to the Columbia River from the Bureau of Commercial Fisheries hatchery evaluation program as 2-, 3-, and 4-year fish. This may be regarded as a random sample since approximately 10% of each brood year was marked at each hatchery. An unusual feature of 1965, however, was the relatively small return of 3-year fish, caused by poor survival of the 1962 brood. Plotting gill net and hatchery length frequencies by age group (Figure 17) shows that the fishery tends to take larger 2- and 3-year fish than those which arrive at hatcheries; with 4-year fish the situation is reversed, the fishery taking smaller specimens than the hatcheries. The fishery took a relatively greater proportion of 28 to 35-36-inch fish than escaped, but above and below that size, the proportion returning to hatcheries increased.

In 1965 the age composition of marked fish taken by gill nets was 2% 2-year fish, 19% 3-year fish, and 79% 4-year fish, while at the hatcheries comparable groups were 10%, 13%, and 77%. Thus the hatchery returns leaned heavily toward 2-year fish but the other age groups were not disproportionally represented. The fishery took relatively more 3- and fewer 4-year olds than returned to the hatchery.

There is some indication of selectivity toward males in the gill-net fishery. The 1964 fishery took marked 3-year fish at the ratio of 68:32 males to females; but the 3-year fish at the hatcheries had a sex ratio of nearly 50:50. In 1965 the difference was slight 64:36 in the fishery and 61:39 at the hatchery. Likewise 4-year fish in 1965 showed little difference, 38:62 fishery and 34:66 hatchery. Part of the selectivity may be due to age 3 males being larger than age 3 females; but run timing may be equally or more

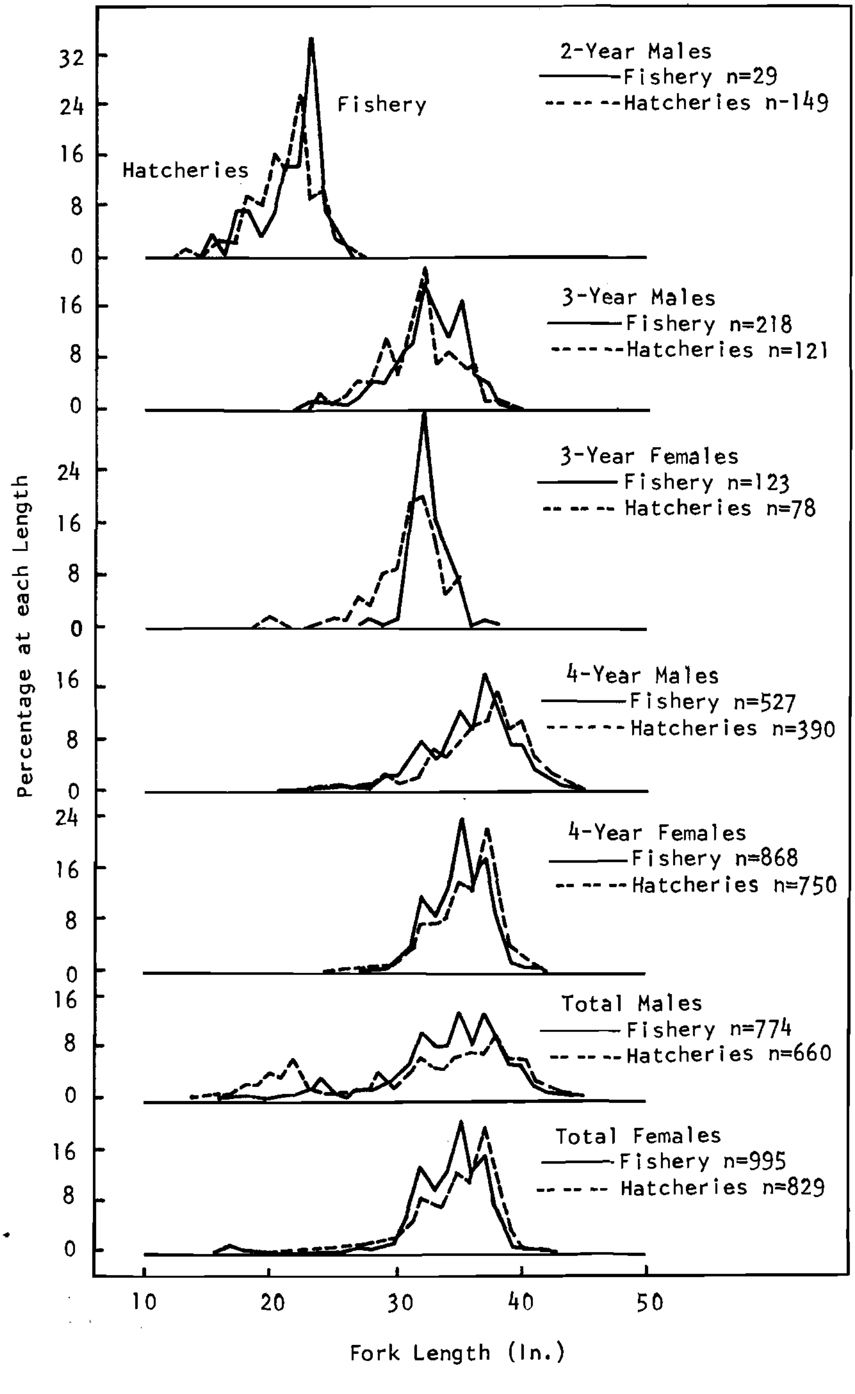


Figure 17. Length-frequency distribution of marked Columbia River fall chinook salmon in the gill-net fishery and at the hatcheries, 1965.

important. It is well known that males precede females in arrival at the hatcheries (this is particularly true of jacks). In the 1964 gill-net fishery, for example, the proportion of fish under 28 inches (mostly males) decreased from 74 to 24% between the first and last weeks of the August fishing season (July 29 to August 25). In 1965 the change was less: from 39 to 22%. Since the fishery closes for almost 3 weeks after August 25, it can be seen how this could alter the sex ratio of the escapement. Since females migrate later than males, they have the advantage of greater protection during the closed season. Variation in timing could thus cause considerable variation in the sex ratios in the fishery and at the hatcheries.

To summarize: gill nets do not evince a damaging selectivity in taking the larger, most fecund members of the population. On the contrary, they seem to select the medium-sized members or most abundant size groups. Using age composition data in the fishery to estimate age composition of the total run does not introduce serious errors for most years, and no correction is necessary for gear selectivity. The number of 2-year fish in the population would be underestimated, but they are of minor importance, both numerically and reproductively.

Optimum Escapment.

The relationship for fall chinook between spawning stock and subsequent return of progeny (recruitment) has been published elsewhere (Van Hyning, 1970). Optimum escapement for Columbia River fall chinook was shown to be about 90,000-100,000 spawners, a value that was realized or exceeded during most years of study. Escapement remained relatively stable compared with the large drop in returns, and there was no evidence of underspawning during the period of the decline.

Dams

Major obstacles facing upstream migrants are the large power dams on the Columbia and Snake Rivers. Fish ladders to pass adults are part of these projects and are generally considered successful. Yet there is evidence that mortality and delay is experienced at the dams. A list of dams which might have significance in fall chinook passage are given in Table 12. Many of these projects are far up the tributaries, beyond usual fall chinook migration, but could affect water quality; for example, through storage which reduces flow in the early fall.

The early dam builders were primarilv reclamationists concerned with supplying water for irrigation of dry lands in eastern Oregon, Washington, and Idaho. During the period 1910-37 many storage dams were built on tributaries of the Columbia and Snake; for example, Black Canyon on the Payette River (1924) and Tieton on the Yakima River (1925). Most of them were high, had no fish ladders, and subsequently killed off runs of spring and summer chinook, sockeye, and steelhead. In addition, innumerable small irrigation dams were built on streams which frequently took most of the flow in the dry season. Fall chinook spawn primarily in the main stem or large tributaries and are believed less affected by dams on the smaller tributaries. Two early dams—Swan Falls (1910) and Rock Island (1933)—may have had some adverse effects, but the former was near the upper limit of fall chinook migration on the Snake while relatively few fall chinook utilized the upper reaches of the Columbia and these seemed to pass Rock Island successfully. The main development of hydroelectric power by "run-of-the-river" dams started with Bonneville and ushered in a new era of fish versus dam problems.

Table 12. Important dams in the Columbia River Basin possibly affecting fall chinook.

Date①	Name	Stream	Miles from Mouth of Columbia	Structural Height② (Feet)	Gross Head③ (Feet)	Reservoir Capacity④ (Acre Feet)	Reservoir Length (Miles)	Comments
1910	Swan Falls	Snake, Ida	780		24		8	Inadequate fishway, few if any fall chinook passed above.
1910	Estacoda	Clackamas, Ore.		110				Now called River Mill; could have affected fall run in upper Clackamas.
1910	Lower Salmon	Snake, Ida.	896	88	59	2,400	6	Above Swan Falls, probably at upper limit of migration.
1913	Condit	White Salmon, Wn.		125		1,081		Impassable, run maintained by hatchery.
1915	Long Lake Dam	Spokane, Wn.	679		37	253,000	22	
1915	Arrow Rock	Boise, Ida.	793		111	286,000	17	
1919	Warm Springs	Malheur, Ore.	801		79	192,400	8	
1923	Powerdale	Hood River, Ore.		30				Flow fluctuations have adverse effect.
1924	Black Canyon	Payette, Ida	731		277	425,060		No fishway.
1925	Dee Dam	Hood River, Ore.						
1929	Clearwater	Clearwater, Ida.		76				Inadequate fishway eliminated spring and summer chinook runs, few if any falls involved.
1931	Merwin-Ariel	Lewis, Wn.	108	313	162	650,000	12	No fishways, made large part part of river inaccessible.
1932	Owyhee	Owyhee, Ore.	744		200	1,120,000	52	
1932	Thief Valley	Powder, Ore.	680			17,400		
1933	Rock Island	Columbia, Wn.	453	100	51	4,500	21	
1935	Agency Valley	Malheur, Ore.	789		77	60,000	3	
1937	Unity	Burnt, Ore.	694			25,000		
1938	Bonneville	Columbia, Ore.-Wn.	146	197	59	537,000	45	
1940	Roza	Yakima, Wn.		67		2,200		May have involved a few fall chinook, has fish ladder.
1941	Grand Coulee	Columbia, Ore.-Wn.	597	550	343	9,402,000	151	No passage facilities; upper Columbia runs trapped and transferred to tribs below.
1950	Bliss	Snake, Ida.		120	70	1,000	5	Initial service 1949. Above Swan Falls Dam; few if any fall chinook affected.
1952	Albernia Falls	Pend Orielle, Ida.	836		35	1,542,000	67	
1952	C. J. Strike	Snake, Ida.	816	132	88	250,000	32	Above Swan Falls Dam; few if any fall chinook affected.
1953	McNary	Columbia, Ore.-Wn.	292	183	86	1,345,000		
1955	Chief Joseph	Columbia, Wn.	545	205	175	518,000	61	No passage facilies blocked remaining runs.
1957	The Dalles	Columbia, Ore.-Wn.	192	260	86	330,000	31	
1957	Pelton	Deschutes, Ore.		204	155			Few fall chinook above this point.
1958	Brownlee	Snake, Ida.-Ore.	609	395	272	1,470,000	57	Ineffective passage facilities decimated run above.
1959	Priest Rapids	Columbia, Wn.	397	180	84	200,000	18	
1961	Ice Harbor	Snake, Wn.	334	186	97	417,000	32	
1961	Oxbow	Snake, Ore.-Ida.	597	205	122	52,500	12	Same as Brownlee.
1961	Rocky Reach	Columbia, Wn.	474	123	93	390,000	42	
1963	Wanapum	Columbia, Wn.	415	170	80	600,000	38	
1963	Mayfield	Cowlitz, Wn.	120	235	185	127,000		

① Date of initial service or date it first affected fish runs.
② Verticle distance from the lowest point of the foundation to the top or crest elevation.
③ Difference in elevation between forebay and tailwater.
④ Full pool.

Completed in 1938, Bonneville Dam incorporated a complex fish passage facility which apparently worked satisfactorily. The dam seemed to have had no detrimental effect on the run. For 8 years, 1938-45, large numbers of fall chinook passed upstream and produced at a high level. Grand Coulee Dam, with no fish passage facilities, followed in 1941 but it probably had little direct effect on fall chinook production since so few utilized the upper Columbia. McNary Dam in 1953 signaled the phase of increased activity and Chief Joseph, The Dalles, Brownlee, Priest Rapids, Ice Harbor, Oxbow, Rocky Reach, and Wanapum dams followed in rapid succession. All of these projects had or will have some effect on fall chinook and other salmon stocks.

The important thing is that the decline in the fall run occurred when river conditions were stable—that is, in the 1946-50 runs which had only to pass Bonneville, a feat they successfully accomplished the previous 8 years. By the time McNary went into service, the run had already stabilized at a much reduced level.

In spite of the apparently successful passage of hundreds of thousands of salmon over the low-head main-stem dams, there was increasing awareness of fish passage difficulties. Schoning and Johnson (1956) showed a 2.5 to 3.0-day delay in migration of fall chinook at Bonneville Dam in 1948, and French and Wahle (1966) a 2- to 4-day delay for chinook and sockeye at Rock Island Dam in 1954-56. On occasion, numbers of dead salmon were noted below the impoundments. Merrell and Collins (1960) summarized these observations and conducted a tagging experiment to determine how many chinook died in attempting to pass Bonneville during a certain period. They estimated a mortality of between 18 and 21% of the Bonneville count for the period June 28-July 8, 1955. This high mortality coincided with peak flows in the Columbia and they presented evidence of a relationship between spillway discharge and mortality rate. Fortunately for fall chinook, they pass during the period of low flow and are not subjected to high flows. Still, substantial numbers of dead adult fall chinook were observed below Bonneville in certain years. While Merrell and Collins made no estimate of this mortality, the implication was that it was not serious compared with other species and runs subjected to higher flows.

A problem that has plagued biologists in recent years is the discrepancies in fish counts at successive dams. This is attributed to mortality, passage through navigation locks, and species misidentification. Fredd (1966) analyzed variations in counts at Columbia River dams since 1957, and after subtracting known between-dam losses, concluded that counting error and spawning escapement to intermediate tributaries was inadequate to explain most of the differences. Average unaccounted differences for the period 1957-65 for fall chinook were 24,000 between Bonneville and The Dalles, 23,000 between The Dalles and McNary, and 31,000 between McNary and Priest Rapids-Ice Harbor. Virtually 100% survival between dams was shown by sockeye and jack summer chinook also exhibited excellent survival; thus suggesting that most mortality may be inflicted on the larger fish.

Gangmark (1957) compared abundance and production rates (return per spawner) for chinook before and after construction of Bonneville Dam, using catch-per-unit effort of the gill-net fishery as the index of abundance. He found the spring run to be better after dam construction, the summer run worse, and the fall run about the same, resulting in "no special decline in trend after the construction of Bonneville Dam."

In summary, the fact that adult fall chinook can suffer mortality in passing dams is well documented. There is not, however, any relationship between dam construction on the Columbia and the period of fall chinook decline. Furthermore, lower river and hatchery populations, unaffected by dams, showed the same fluctuations in abundance as the upper-river stocks, thus indicating that some other factor was responsible for the decline. A direct mortality at one dam might be considered in the same light as fishing mortailty. As long as only the harvestable surplus is killed, no harm may result to the stock. Junge (1970) shows that theoretically an adult kill has much less of an effect on yield than a smolt kill of the same magnitude. This was further borne out in the escapement-return relationship where production was shown to be largely independent of escapement. Thus, it is likely that any adult mortality at dams which occurred prior to completion of McNary (1953) had a negligible effect on the fall chinook stock. Whether such a conclusion can prevail under the cumulative effect of the number of successive dams that exist today is open to question. Further consideration will be given to the effect of dams in the sections on reproduction and downstream migration.

Parasites and Diseases

Adult salmon entering the river to spawn are subjected to a number of diseases (Rucker, 1963) Columnaris (*Chondrococcus columnaris*) can become serious if the water is warm, and has accounted for high losses in spring and summer chinook and sockeye. Furunculosis (*Aeromonas salmonicida* and *A. liquefaciens*) may cause losses among prespawning fish. The myxosporidian *Ceratomyxa* creates lesions in the intestine and extensive damage to the organs and is associated with prespawning deaths. Some of the bacterial diseases such as fish tuberculosis (*Mycobacterium salmoniphilum*) and kidney disease (*Conynebacterium sp.*) may be important. On the spawning grounds adults are subject to fungus (*Saprolegnia parasitica*) infections because of primary infections and injuries and inability to repair damaged tissue due to senescence. "Ich" (*Ichthyophthirius multitilus*), *Trichodina* sp., and *Costia* sp. are common parasites on the gills and body surfaces of prespawning adults. Bacterial gill diseases are caused by a variety of myxobacteria; with high fish density death of adults may result. The thesis summarizes information on salmon diseases up to 1967; Columnaris is considered to be the only potentially important one in the fall chinook decline. It has accounted for some spectacular fish kills, but an actual record of significant prespawning loss in natural fall chinook populations has not been documented. Columnaris affects fish when temperatures rise above 60 F and causes high losses when they approach 70 F (Rucker, 1963). Columnaris has killed spring chinook which enter the river in the spring and remain in the upper areas through the warm summer months before spawning in early fall, and also summer chinook and sockeye which enter during the warmest months of the year. Fall chinook, on the other hand, enter in the fall, proceed directly to the spawning areas, and spawn without a long resting and maturing period in warm water.

Burrows (1963) gives the optimum temperatures for salmon during upstream migration and maturation as between 45 and 60 F. In this regard an examination of water temperature records when the fall chinook run passes Bonneville Dam is of interest; Figure 18 shows temperatures for the period August 16 to September 20 by 5-day averages for the years 1938-62. Although they generally averaged 66-67 F during early September, and in some years approached 70 F, there is no indication of an increase in recent years or during the period of fall chinook decline. Thus, it is unlikely that the chance of acquiring Columnaris in passing through the lower river has increased. Furthermore, temperatures started to decline by the time the peak of the run passed Bonneville (September 6-16).

Davidson (1964) reports on Columbia River temperature data taken at Rock Island Dam from 1933-60. He demonstrates that there has been no increase in average water temperature during September and October (the principal month of spawning). In fact, there was a general decrease in September from 1940 to 1954. October shows a level trend fluctuating around 60 F after 1940. As far as adult fall chinook are concerned, the chief effect of Grand Coulee Dam was to delay the drop in temperature in late fall and raise the September-October temperature by perhaps 4 degrees from pre-1940 levels; this did not have any apparent effect on the reproductive success of the 1940-46 fall chinook runs.

An examination of mean October water temperatures at Rock Island Dam and production and return per spawner by brood year showed a complete lack of relationship.

The Snake River, meandering through the desert area of southern Idaho and eastern Oregon and Washington, has been considered a warmer river than the Columbia which heads in the mountainous area of British Columbia, Idaho, and Montana. This is especially true in sum-

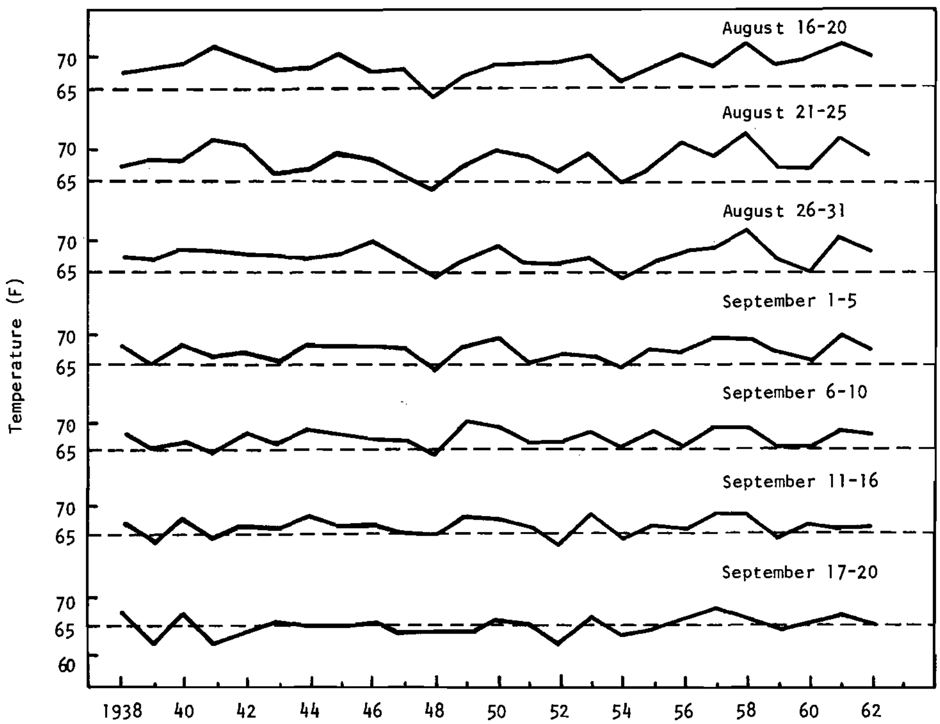


Figure 18. Five-day average water temperatures at Bonneville Dam, August 16-September 20, 1938-62.

mer, but the difference rapidly disappears in the fall. The average September 1954-56 temperature of the Snake River at its mouth was 66.8 F and for October 60.8 F, compared with 62.7 and 60.0 F at Rock Island for the same period (Sylvester, 1959). Although the Snake in September and early October seems a poor environment for salmon, this system historically produced large runs and was little changed until Brownlee Dam was completed in 1958.

The tributaries below Bonneville Dam in which fall chinook spawn flow through mountainous, forested areas and are generally cool. For example, in the Cowlitz River near Mayfield, Washington, maximum temperature for August 1953 never exceeded 65 F, and the mean daily maximum was 62 F. For September the mean maximum was 58 F. For Big Creek, Oregon, mean maximum temperatures were 59 and 58 F in August and September 1953 and never exceeded 61 F (U.S. Geological Survey, 1958).

The artificial spawning channel below McNary Dam was plagued by prespawning losses (Chambers, 1965). This was an unnatural situation in which both local and upriver races were held until they spawned in water coming largely from the dam forebay. Columnaris was considered the principal cause of premature death but furunculosis, *Ceratomyxa*, and death from injuries were also noted. The local fish started spawning in mid-September with a peak in late September and early October while the upriver race began to spawn in mid-October and peaked in early November. Maximum water temperatures were near 68 F in early September but dropped to 65 F by the end of the month and below 60 F by mid-October. Survival of females to the spawning stage ranged from 38 to 89% for the local race and 12 to 78% for the upriver race.

Although adult fall chinook are host to a variety of parasites and diseases, there is no evidence of large or catastrophic mortality except for a few instances under artificial conditions. Granted that a mass mortality could occur in the main stem of the Columbia or Snake, it is unlikely that extensive spawning ground surveys and other observations would not detect it. Furthermore, numerous examinations of dead and moribund fall chinook have revealed few fish that were not spawned out or nearly so. It seems unlikely that disease could affect the fall chinook upriver, lower river, tributary, and hatchery races simultaneously so as to cause a general decrease in each and the total run as well at about the same time.

Water Quality

Temperature, turbidity, and pollution in the Columbia River would be expected to have an effect on the upstream migration of adult salmon. Turbidity has lessened in the Columbia in recent years (Junge and Oakley, 1966) but the effect, if any, on upstream migrants is unknown. In general, adult salmon migrate faster in clear than turbid water and can avoid nets better, both of which would appear to be advantageous. During the fall chinook run the Columbia is at its lowest and clearest and the effect of any changes in turbidity would be minor.

Sylvester (1958 and 1959) studied water quality in the Columbia River Basin for the years 1952-57 and was able to make comparisons with 1910-11 data. He concluded (1958): "An analysis of water quality data shows that these pollutants have had no serious overall effect on the water quality of the Columbia River itself." Except for the Willamette River, no serious dissolved oxygen deficiencies were observed in any of the streams. Between 1910-11 and 1952-56 there was a general increase in alkalinity, hardness, dissolved solids, sulfate, $Ca+$

Mg, Na+K, iron, chlorides, and nitrate, but in no case did a constituent increase to the point that the water was nearing the upper limit for the propagation of fish. Most of the changes were considered to be due to return water from irrigation and domestic consumption rather than from dams. He further states: "In summary, the Columbia River, as it enters the survey area, is a cool, moderately soft, low alkalinity stream with no quality characteristics making it unsuitable for aquatic life."

The discharge of pulp mill wastes and attendant growth of *Sphaerotilus* bacteria and low dissolved oxygen values is a serious problem in many northwestern rivers. On the main stem of the Columbia, however, with its large flow and abundant oxygen, there does not yet appear to be an oxygen depletion problem; the waste and *Sphaerotilus* give no evidence of being toxic to adults in the concentrations encountered, although the slime interferes with the successful prosecution of the fishery at times. It is quite possible that the fall chinook run in the Clackamas River was exterminated by excessive pollution and oxygen depletion in the lower Willamette River, but this happened long before the depletion of the main fall run. There is no evidence that fall chinook ascended the Willamette River beyond Willamette Falls.

Reproduction and Incubation

Spawning Areas

Assuming that the fall chinook population was in harmony with its pre-civilization environment, any substantial change in environmental conditions could reduce the reproductive potential of the stock. As noted, the most obvious change has been the construction of dams on the main stem. These could have had various effects on successful reproduction through: (1) delay of adult migration, (2) mortality of adults, and (3) submergence of spawning areas by the reservoirs. We have seen in previous sections that delays and losses do occur, and probably will become increasingly severe as the number of dams increase, but these cannot explain the decline in fall chinook in the early 1950's.

The loss of spawning areas will be discussed in this section; it is assumed that chinook cannot spawn successfully in streams covered by reservoir waters. A summary of former and present chinook salmon habitat is given by Fulton (1968).

Fall chinook originally went approximately 900 miles up the Snake River to Shoshone Falls. Approximately 170 miles of the upper Snake were lost in 1910 with the construction of Swan Falls Dam, and another 170 miles in 1958 by unsuccessful fish passage at the Oxbow-Brownlee complex. Ice Harbor Dam inundated 32 miles in 1961. Little is known about present spawning activity in the lower Snake from Oxbow Dam to the mouth because of turbidity and turbulence, but production of some consequence remains. In 1962 when counting began at Ice Harbor Dam, 30,000 fall chinook entered the Snake, of which only 2,400 arrived at Brownlee-Oxbow. It has been estimated that in recent years over 42,000 fall chinook have utilized the Snake River from the mouth of the Salmon River to Swan Falls Dam (Haas, 1965).

Fall chinook also utilized the upper Columbia, probably as far as the Pend Oreille and Kootenay rivers, but by the time Rock Island Dam was built (1933) this run had been reduced to only a few thousand fish. Grand Coulee Dam in 1941 and Chief Joseph in 1955 blocked the few fish that remained. The main stem of the Columbia from the mouth of the Snake River to Chief Joseph Dam

(220 miles) has been an important and productive spawning area, although much is now lost due to dam construction. From 1933 to 1959 there was no construction in this area, but 98 miles were inundated after Priest Rapids was built. Fish spawning in this area are being handled in large spawning channels, but the success of this operation is uncertain at this time.

The main stem of the Columbia from the upstream end of The Dalles reservoir to the mouth of the Snake River was undoubtedly an important spawning area, the bottom consisting of many riffles and gravel bars. McNary Dam (1953) inundated 61 miles of this section. The area between The Dalles and Bonneville was not believed to be important for spawning because the river was swift, deep, and rocky prior to dam construction.

In the lower Columbia River below The Dalles Dam spawning is entirely in tributaries and hatcheries. These tributaries differ greatly from the main river, varying from large streams like the Cowlitz to very small ones such as Plympton Creek. In the early 1900's lumbering was concentrated in the lower Columbia River valley, and destructive logging practices severely damaged many streams with impassable log jams and siltation. These watersheds now have second growth timber and their productive capacity may improve. Fulton (1968), using a variety of sources for the period 1957-60 estimated the average lower tributary (below Bonneville) escapement as 63,000; middle Columbia (mostly hatcheries) 72,000; John Day Dam site to McNary Dam 34,000; McNary to Chief Joseph Dam 15,000; and Snake River 41,000. Historically upper river areas were more important and productive than the lower, but their gradual loss increased the relative value of the lower reaches. It was noted earlier that abundance of adult fish in the lower tributaries and above Bonneville show the same fluctuations, indicating a common factor affecting survival. The similarity between abundance trends in lower and upper river areas, and the fact that little spawning area was lost until the mid-1950's, precludes assigning the loss of spawning grounds as a major factor in the fall chinook decline.

Spawning and Incubation Conditions

Time of Spawning and Emergence

An understanding of the relationship between success of spawning, incubation, and emergence of fry with environmental conditions can be gained by examining the literature on the timing of these events. At McNary spawning channel the "local" fish spawned over a period of 1 month beginning in mid-September, with a peak in late September and early October, while the upriver race usually began spawning in mid-October, peaking in early November (Chambers, 1965). In the Hanford area spawning reached a peak the 1st week of November 1962; in 1963 spawning started October 8, reached a peak around November 12 (1 week later than usual), and ended November 21. In 1964 spawning had just started on October 21 and was completed by November 16 (Watson, 1965). Aerial surveys in the John Day to McNary area show heavy spawning throughout October with little evidence of a consistent peak (Smith, 1966).

In contrast, hatchery stocks spawn much earlier. Egg taking operations at the three principal fall chinook hatcheries operated by the Fish Commission of Oregon (Bonneville, Cascade, and Oxbow) in 1965, a typical year, ranged from September 18 to October 11 with the peak from September 21 to 25. The alevins have completed their yolk absorption and are placed in hatchery ponds usually in February.

Shelton (1955) studied the hatching

and emergence of fall chinook in simulated spawning beds at a Columbia River hatchery under different levels of flow, gravel size, and depth of planting. The eggs were taken the last of September, hatching was completed by January 6, and the first fry emerged on February 2. By April 7, 50% of the fry had emerged and emergence continued until May 18. Some fry remained in the gravel about 4 months after hatching. The first fry had a portion of their yolk sac visible, but by March only 10% had visible yolk sac, and the remainder had the abdominal wall completely closed.

Although information is scanty, natural-run fall chinook in the lower tributaries may spawn somewhat later than hatchery fish.

Temperature

A review of the thermal requirements of incubating fall chinook eggs showed that temperature during the initial period was a critical factor. Less than normal survival can be expected if initial temperature falls below 42 F or goes above 55 F. Degree of mortality attributable to temperature is a function of duration of exposure .

Considering October as the important month for egg deposition in the main stem, average October temperatures at Rock Island Dam for 1933-60 were examined (Davidson, 1964). From 1933-39 they were below 57 F, but after 1940 they increased to about 60 F. In no case, however, did the average exceed 62 F and there has been no upward or downward trend since 1940. In November, temperatures were well below 55 F. Depending on the time of spawning, some mortality of eggs could occur in warm years. The warm Octobers (average temperature above 61 F) occurred in 1942-44, 1952, and 1958. The 1942-44 broods produced at a high level while the 1952 and 1958 broods produced poorly. Likewise the cool years—1938-39, 1946, 1948-49, 1954, and 1959—show a lack of correlation ($r = -0.095$) for initial incubation temperature vs. brood year production.

Average water temperature at McNary channel from 1957 to 1963 began at 64 F on October 1 but decreased rather rapidly to 56 F by November 1, with an average of about 60 F. High temperatures early in the fall and siltation were considered to be causes of reduced production from deposited spawn. No correlations are expressed in Chambers' (1965) report, but he notes that the lowest percentage yields occurred when high temperatures persisted into late October (1958 and 1963). Eggs deposited during late September and the 1st week of October in the McNary channel could have high mortality. For the Columbia River at McNary Dam the average temperature for October 1950-55 was 57.8 F and did not exceed 60 F in any year (Sylvester, 1958). Since salmon spawn through October and into November in this area, only a small portion of the potential egg deposition may be lost in an average year.

Another critical period may be during the winter when extremely cold temperatures could kill or inhibit embryo development. Silliman (1950) showed a positive relationship between winter water temperatures in selected spawning streams and chinook returning 4 years later (all runs combined), but the correlation was not statistically significant. Grand Coulee Dam has made the upper Columbia River warmer during the winter months (Davidson, 1964). Prior to 1940 the water temperatures decreased to 32 F during severe winters and it was not unusual for the river to be frozen over. Since 1941, the temperature has never dropped to 32 F even in the coldest weather; in mild winters it remains above 40 F and the river does not freeze. This warmer temperature and lack of ice, which could cause scouring of eggs and gravel, should have a beneficial effect on the run, offsetting perhaps some of the detrimental effects of the dams.

The warmer fall and winter temperatures would hasten the development of eggs and cause early hatching and emergence. What effect this might have on the survival of fry is unknown. Early emergence before food supplies become abundant in the spring might cause a migration to the ocean before the smolts were physiologically ready or ocean plankton began to bloom. On the other hand, fry might benefit from an early migration by leaving before predatory fishes became active with warming temperatures. Chambers (1965) noted that at the McNary channel eggs hatched and fry emerged in December and January, but most fish apparently did not choose to migrate until April-June, the optimum time. Mains and Smith (1964) observed the downstream migration of fry in the Snake River primarily in March and April and in the Columbia from March through June. This difference would not be expected if incubation temperatures influenced the time of downstream migration, since the Snake is colder than the Columbia during the winter (Sylvester, 1958).

Oxygen and Flow

Literature on the effects of gravel permeability and dissolved oxygen concentration on survival and development of salmon eggs and embroys was reviewed. In general, reduced water velocity and oxygen in the redds have caused increased embryo mortality, retarded development and growth, and delayed hatching. Fry from embryos reared at low and intermediate oxygen concentrations were smaller and weaker than from high concentrations.

Little is known about conditions in chinook redds in the Columbia River. At McNary channel, water samples from nests had 8.1 to 12.5 ppm of dissolved oxygen while the surface water contained 11.0 to 13.4 ppm (Chambers, 1965). The range in subterranean water given by Chambers (1956) for natural chinook spawning areas was 5.7 to 9.1 ppm. He noted that fall chinook spawned in the main Columbia at velocities of 2.75-3.75 feet per second while in the tributary streams they spawned in 1.00-1.75 fps. While these values cannot be related to subterranean velocity, they suggest a rapid intra-gravel flow. The range of oxygen values cited falls within the area of good embryo survival and growth.

Shelton's (1955) experiments in planting eggs at selected depths and velocities showed that in all cases of flow (average water surface velocity of 2.2, 1.2, and 0.4 fps) and depth (3-18 inches) survival to the hatching stage exceeded 80%. Satisfactory survival was obtained when water velocity in the gravel was as low as 0.002 fps, and in spite of some silt problems. The percentage of emergence was much higher in beds with large gravel.

Siltation reduces gravel permeability and oxygen supply in spawning beds. Turbidity, that is, the amount of suspended sediment, is related to siltation. Shelton and Pollock (1966) showed that fall chinook eggs planted in an incubation channel in Abernathy Creek, a lower Columbia River tributary, suffered 85% mortality when 15 to 30% of the voids in the gravel were filled with sediment. Use of a settling basin reduced mortality to 10%.

There has been a noticeable decrease in turbidity of the Columbia and Snake rivers in recent years (Junge and Oakley, 1966). Dam construction has created extensive reservoirs which act as settling basins and remove much of the suspended matter. Thus the deposition of silt in the redds should have materially lessened.

Another important criteria for evaluating spawning success is flow; high water can wash out eggs, scour the gravel, and deposit silt loads while low water can expose eggs to freezing and desiccation. The Columbia River, however, is remarkably constant in flow during the winter months, with river discharge at Rock Island Dam varying little from year to year (Davidson, 1964). There is a trend for increased flows with less fluctuation. The Snake is more erratic, but winter floods are exceptional. Lower river tributaries are subject to high water during the winter but heavy floods are infrequent. Meekin (1965) observed chinook redds below Chief Joseph Dam that were periodically exposed and concluded that damage to buried eggs was negligible. Oxygen levels in the ground water were sufficient for the eggs to survive with as much as 38 hours exposure. Exposed redds had an egg mortality of 12% compared to 8% for unexposed redds. Meekin also noted large amounts of sand in the redds but survival was still good.

Since Columbia River water is near oxygen saturation, siltation is decreasing, flow is relatively constant and fast in the sections not dammed, and temperatures are for the most part below the critical level in the fall and warmer in the winter, conditions for successful spawning and incubation of eggs and development of alevins in the remaining spawning gravels should be even better than during the early period of high fall chinook productivity.

Pollution and Predation

It has been suggested that radioactive pollutants from the Hanford atomic plant could cause mortalities or abnormalities in developing embryos. Donaldson and Bonham (1964) studied this possibility by submitting chinook and coho eggs and alevins to low-level chronic irradiation in excess of that found in the Columbia River. No difference between the control and experimental groups could be detected in the first generation in survival, growth, or sex ratio. Even if there were damage, only a small part of the fall chinook population would be affected. Furthermore, large numbers of fall chinook have reproduced through a number of generations within the confines of the Hanford project without observable adverse effects.

It has also been suggested that macroorganisms found in the gravel could cause mortality to eggs. Thompson (1963) studied this problem in several Columbia Basin streams and concluded: "The observations made on the fauna of the streams studied indicate that salmon eggs buried under the gravel are in little danger of predation or damage."

Superimposition of redds and subsequent dislodging of deposited eggs may be a problem in heavily spawned streams in Alaska and other areas, but it has not been considered significant in the Columbia Basin with its large rivers and vast area. Still, the existence of a density-dependent reproduction curve in the earlier years of the study (Van Hyning, 1970) suggests that overspawning occurred at the large escapements.

To summarize: during the period of fall chinook decline there was no evidence of serious deterioration in the quality of available spawning areas or any factor that would reduce egg and larvae survival. Indeed, there is an indication of possible improvement in winter temperature, amount of siltation, and flow. Considerable spawning ground has been lost due to dam construction and inundation but this occurred largely after 1954 and in particular following 1960.

Stream Residence and Downstream Migration

Adult chinook are actively sought by fishermen. They can be counted, weighed, measured, aged, and sexed in the fisheries, at the hatcheries, and on the spawning grounds. In contrast, the juveniles, or smolts, slip downstream largely unnoticed. Available environmental data are reviewed in an attempt to find meaningful relationships between environmental factors at the time of downstream migration and subsequent return of a year class to the river. Several factors affecting adults also influence juveniles.

Timing

The timing of downstream migration may be a very important factor in survival as temperature, flow, and turbidity change seasonally. A review of available information indicates considerable variation. Some fry start downstream immediately after emerging in December and January, even with the yolk sac still present. At McNary spawning channel distinct movements occurred in December, January, February, April, May, and June. The early migrations appeared related to population density. In lower tributaries peak movements were in February and March in Gnat Creek and April and May in the Cowlitz River. Most hatchery fall chinook are now released after feeding for 90 days, which puts them into the river usually in May. Formerly, large numbers were released as unfed fry in February and March. In the Snake River peak counts were recorded in March, April, and May. In the main upper Columbia the fry migrated from March through June. April could be considered the peak month in both systems. Once the fingerlings reach the estuary (probably mostly in May and June) they apparently stay there for some time, some even through most of the early summer.

Predation

Although predators are considered an important factor in survival of young salmonids, little is known of their role in the Columbia River ecosystem. Thompson (1959a) studied the food of the squawfish (*Ptychocheilus oregonensis*), probably the major predator in the river. He concluded that they were omnivorous and somewhat sluggish, "taking the opportunity to feed on foods that are available." Juvenile salmon comprised 3.6% of the food in squawfish stomaches, and occurrence was related to releases from hatcheries. "The role of the squawfish as a predator on salmon was limited to time and place where juvenile salmon concentrations were high following release."

There has possibly been a decrease in abundance of squawfish in the Columbia, as shown by Bonneville Dam counts which indicated a sharp drop from 67,000 fish in 1938 to 15,000 in 1964. Likewise McNary Dam shows a decline of from 57,000 in 1955 to 5,000 in 1964 (U.S. Army Corps of Engineers, 1964). It is possible, however, that squawfish have not declined but merely ceased their former migrations due to the dams.

Thompson (1959b) also studied possible predation below McNary Dam in March 1956 when large numbers of fingerlings were being released in a dam mortality study. Of 106 squawfish stomachs examined, only three contained salmon. The stomachs of 18 sculpins (*Cottus* sp.) examined were empty. Thompson concluded that predation was slight and low visibility (Secchi disc readings average 1.15 feet with a range of 0.3-2.2) and low water temperature (39-40 F) minimized the effectiveness of the predators in finding fingerlings.

Many observers feel that a "population explosion" of scrap and warm water fish in the newly formed reservoirs is having a deleterious effect on salmonid fingerling survival. Neither the increase in numbers nor the effect on salmonids has been documented for the main-stem dams, however. At Brownlee Dam, bass

(*Micropterus* sp.) and squawfish were found to contain remnants of salmon in their stomachs during the 1960 migration season but not in 1959. Predation by bass was also noted at the release site below Oxbow Dam and by gulls downstream from Brownlee Dam. The gulls had apparently gathered below the dam to feed on fish that were killed, injured or stunned by passing through the turbines or spillway (Haas, 1965). April temperatures at Rock Island Dam show a considerable decrease through the years (Davidson, 1964); this should have an inhibitory effect on predatory fishes.

Junge and Oakley (1966) note the decrease in turbidity of Columbia River water with extensive dam construction, coincident with the decline in production rates of upriver salmon and steelhead runs, and suggest that clearer water may enable predators to be more effective. Turbidity-predation interaction is, of course, only one possible manifestation of changing environmental conditions caused by dam construction.

Although predation remains largely unknown, there is nothing to suggest that it has been an important factor in reducing the size of the fall chinook population, at least prior to extensive dam construction beginning in 1954.

Parasites and Diseases

Through the years a great deal of research has been done on the problem of producing healthy salmon and trout in hatcheries, but little is known about the health of native or wild fish. The sick and weak do not survive in the wild, but the survivors must harbor some diseases because wild fish are a reservoir of infection for hatchery stocks. Kidney disease and tuberculosis, contracted by feeding diseased carcasses to the young, were held responsible by some biologists for the poor return of adults to hatcheries in the early 1950's. This was contradicted, however, by the fact that hatchery and wild fish showed the same pattern of fluctuations in abundance and that omission of unpasteurized salmon products in the diet did not result in any great increase in return of fall chinook, despite large increases in numbers of fish reared.

A full discussion of juvenile salmonid diseases has been reviewed by Rucker (1963) and others. Most diseases affecting juveniles are also found in adults and these were covered in a previous section.

As mentioned earlier, temperature plays an important role in pathology. Fall chinook juveniles are well out of the streams before the summer warmup and thus are exposed to minimal warm-water disease conditions. An epidemic or catastrophic disease could have occurred in the early 1950's which decimated the fall chinook population and kept it at a low level of abundance, but there is no evidence that such an event took place.

Dams and Reservoirs

The main direct effect of dams on downstream migrants is mortality in passing through the turbines of power plants or over spillways. Holmes (1952) estimated an average loss of 3% in fingerlings passing the spillway and 11% in the turbines at Bonneville Dam. Schoeneman, Pressey, and Junge (1961) indicated a mortality of 11% for fingerlings passing through the turbines at McNary Dam, but only 2% for those going over the spillway. Obviously, mortality would depend on how many dams a group of fingerlings had to pass as well as what proportion of the water was diverted into the turbines. The higher the flow the greater the chance of survival.

The reservoir created by a dam can also be a cause of mortality. The slack water slows the fish's downstream migration, exposing it to a longer period of predation, causing a delay in reaching the ocean. Davidson (1965) in reviewing information on these possibilities shows that reservoirs cause a slowdown in current. For example, in the natural river near Celilo Falls the velocity at 150,000 cfs was 2.1 miles per hour, while after the construction of The Dalles Dam it decreased to 0.8 mph. The travel time of water from the Okanogan River to Bonneville Dam (393 miles) was estimated at 138 hours in the natural river and 352 hours in the impounded river. Higher flows increase velocity and should cause less delay. Davidson, using data from Anas and Gauley (1956), showed a relationship between timing of sockeye fingerlings passing Bonneville and river flow—the earliest peak migration occurred with the fastest river current.

A delay in downstream migration could affect survival of smolts by reducing their ability to make the transition to sea water. However, the occurence of fry and fingerlings in the estuary during the summer, before there were dams (Rich, 1922), and the wide range of migration time suggests that their movement to the ocean is not temporarily restricted. It is unlikely that the timing of fall chinook migrants is so critical that a delay of any magnitude could cause mortality or serious physiological disturbance.

Dam construction could possibly result in residualism, the phenomenon of anadromous fish taking up residence in lakes or reservoirs past their normal time of migration. It can be due to the downstream migrants becoming lost or confused in still water, unable to find the exit structures, or because limnological conditions are unsatisfactory for migration. If this condition persists, the fish may be delayed up to a year or more in going to sea, or they may not migrate at all. The consequences of the latter are obvious, but the effects of delay itself are not known. The exposure of migrants to an additional period of predation in the reservoir may be the most serious factor. Except for Brownlee Reservoir (Haas, 1965) there is no evidence of residualism for fall chinook. The perceptible current and rapid flushing rate (range 1/4 to 4 days, average 3) of main-stem reservoirs would indicate that it is not a problem (Sylvester, 1959). Furthermore, reservoirs of low-head main-stem dams do not have thermoclines and their temperature varies only a few degrees with depth.

Flow, Turbidity, and Temperature

In considering factors that might affect the survival of downstream migrants, two items are crucial: (1) flow as it influences the relative amount of water passing through the turbines and over the spillway, the velocity and thus the time necessary for passage, and the spatial relationship between predator and prey; and (2) turbidity as it influences predation. High flow and high turbidity (low Secchi disc reading) would be regarded as representing the most favorable conditions. April was considered the peak month of juvenile migration, but May was also examined.

Mean daily discharge in cubic feet per second (cfs) and mean daily Secchi disc readings at Bonneville Dam for the months of April and May of the year following spawning were the variables compared to total return and return per spawner by brood year. In Figure 19 turbidity (taken only since 1945), average discharge, and fall chinook return are plotted on an annual basis. There has been a tendency for the Columbia to become clearer, especially since 1956, and April and May turbidities are very similar. Discharge has remained level but with marked fluctuations. Characteristically, flow in April is relatively steady, but increases rapidly in May and peaks in late May or early June. In general, high flow and turbid water and low flow and clear

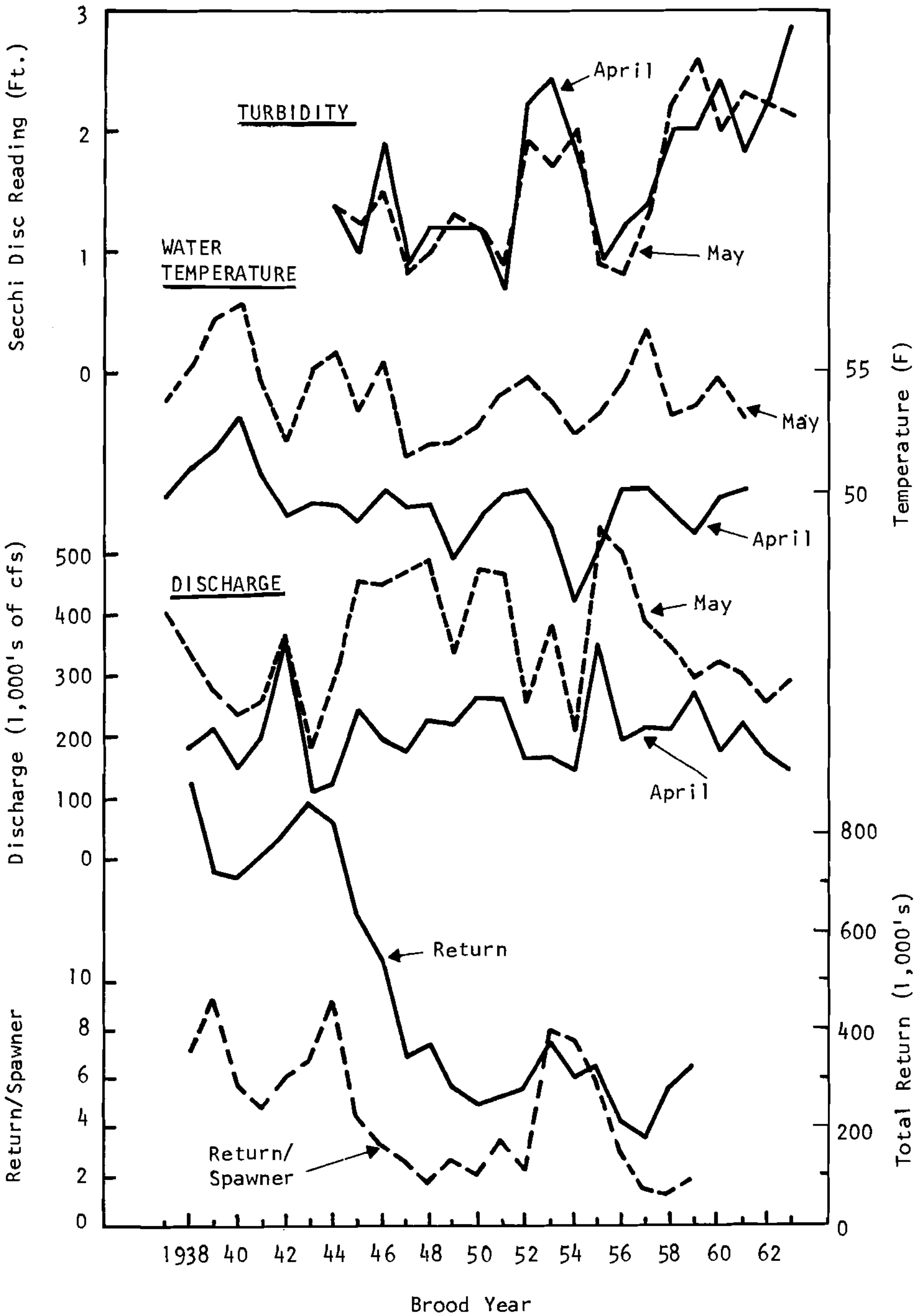


Figure 19. Mean daily water turbidity, temperature, and flow during April and May at Bonneville Dam and return of fall chinook salmon.

water are associated although there is a good deal of variation (see Figure 20A, for 1948-60 $r = -0.723$, $r_{.01} = 0.684$ with 11 *d.f.*).

There appears to be little relationship between the return of the fall chinook and water flow conditions at time of downstream migration. The good return for the 1944-45 and 1954-55 downstream migrations was associated with low flows, and the time of fall chinook decline (1946-52 broods) was during a period of relatively high May discharge and high turbidity. A series of scatter diagrams (Figure 20B, C, D) show little relationship between flow, turbidity, and return of fish but during certain series of years the suggestion of an inverse relationship can be discerned. For example, total return of brood years 1938-46 was negatively, though not significantly, correlated with mean April-May discharge (Figure 20B, $r = -0.45$, $r_{.05} = 0.666$ with 7 *d.f.*). No relationship is shown for the 1947-49 broods. On a return-per-spawner basis (Figure 20D), this suggestion of an inverse relationship for the earlier years is again noted.

Turbidity showns no relationship whatever to return of fish (at least partly because of a shorter time series), although Junge and Oakley (1966) concluded that there was some relationship between clear water and reduced sockeye salmon survival and suggested it might also apply to other upriver runs. Junge and Oakley consider Secchi disc readings of 2.5 or greater as clear water and 1.0 or less as turbid but this adds little to the analysis. For the 1948-51 broods, all days in April were turbid but production ranged from 252,000 to 378,000 fish or 1.8 to 3.6 per spawner. For the 1953 and 1954 broods there were no turbid days and production was 287,000 and 376,000 and 2.3 and 8.2 fish per spawner. For 1955-57 there were again no clear days and production varied from 184,000 to 326,000 and 1.5 to 6.0 fish per spawner. The 1954-56 broods all produced at about the same high level yet turbidity ranged from all clear days to all turbid.

Water temperature at the time of downstream migration (April-May) is generally between 48 and 56 F, probably near optimal. Burrows (1963) reports that for maximum productivity of fingerling salmon water should be between 50 and 60 F. There was a slight tendency toward cooler temperatures during the years examined, but no obvious relationship exists between water temperature and return.

One may conclude that the survival of fall chinook was for the most part unrelated to conditions of flow, turbidity, and temperature at the time of downstream migration, even though in the early years of the study there was a suggestion of an inverse relationship between flow and return. In any event, and contrary to expectations, high flow and turbid water were not associated with good survival.

Estuary Conditions

Estuarine conditions may affect juvenile survival, but almost nothing is known about variations in the Columbia River estuarine environment or how they might influence salmon survival. Evidence previously noted suggests that most of the fall chinook fingerlings arrive in the upper estuary in May and substantial numbers reside there through July. Temperature and salinity measurements have been taken at Tongue Point near Astoria for many years (U.S. Coast and Geodetic Survey, 1962). This station is 18 miles above the mouth of the river and salinity rarely exceeds 3‰ and during the spring is almost 0. Although a salt-water wedge extends upstream near the bottom (Burt and McAlister, 1959), surface waters at this point are essentially fresh.

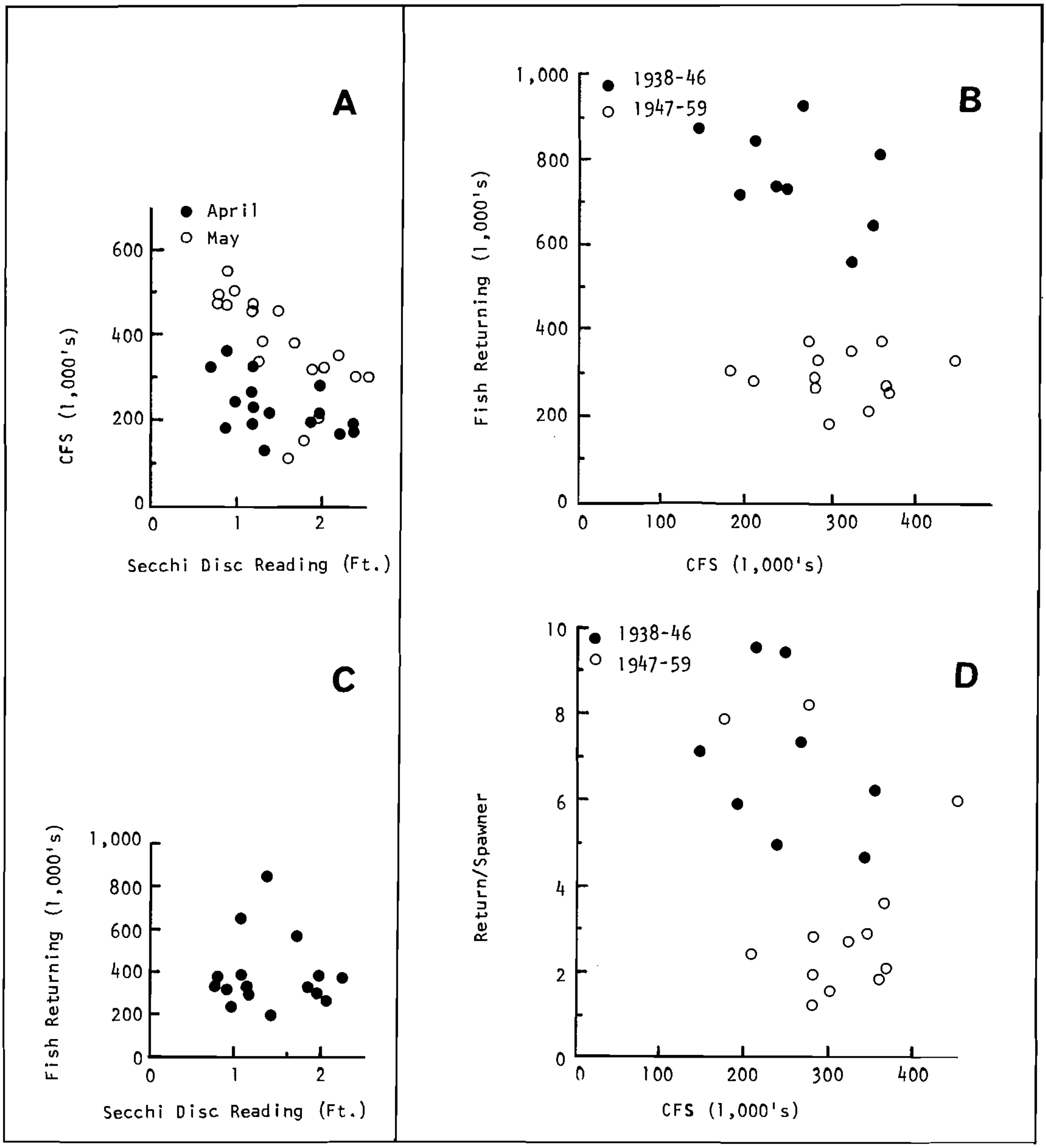


Figure 20. Correlations between mean daily flow and turbidity at Bonneville Dam and fall chinook return by brood year: A. April-May turbidity vs. flow; B. April-May flow vs. total return; C. April-May turbidity vs. total return; D. April-May flow vs. return per spawner.

A comparision of Bonneville and Tongue Point April-May temperatures showed that Tongue Point was generally 2 to 3 F higher than Bonneville. Average May water temperatures at Tongue Point were compared to return of fall chinoon broods exposed to that temperature; correlation coefficients for the 1938-46, 1947-59, and combined broods were —0.219, —0.631, and 0.101, respectively. The 1947-59 regression was significant at the 5% level. For return per spawner, the r values were all in the 0.1 bracket. There is thus some indication of a poorer return with higher river or estuary water temperatures in some years.

Multiple Regression and Response Surface Analysis

The various environmental and survival data in this study were submitted to regression analysis by means of standard programs at the Oregon State University computer center.

A correlation matrix was constructed relating every independent variable with every other and with the two dependent variables, total return to the river and return per spawner, by brood year. The two brood year periods 1938-46 and 1947-59 were done separately and also combined. Most of these correlations have been discussed in appropriate sections of the preceding text, but a brief review of significant correlations will provide background for the ensuing discussion.

For the early period 1938-46 the total return was inversely correlated with the ocean temperature at Amphitrite Point. Return per spawner vs. escapement gave a highly significant negative correlation and return per spawner was also negatively related to the index of ocean catch of Columbia River fall chinook.

In the second period, 1947-59 brood years, return to the river was positively correlated with troll effort and negatively with Tongue Point water temperature. The return vs. Tongue Point correlation is in accord with the general finding that warm temperatures at the time of downstream movement are somehow detrimental. Significant negative correlations are noted between Seaside and Amphitrite water temperatures and troll effort and catch of Columbia River fish. Unlike the 1938-46 period, increased survival due to colder water at Amphitrite is not reflected in the return to the river during the later period. Seaside Beach and Tongue Point water temperatures were positively correlated with each other. An expected correlation between troll effort and ocean catch is shown. Bonneville flow and turbidity are closely related. The return per spawner is only correlated with number of spawners.

Combining all the years and dropping a number of values that did not appear related, or for which data were not continuous, shows total return to be negatively correlated with troll intensity and ocean catch of Columbia River chinook. For the first time, a correlation exists between the two dependent variables, total return and return per spawner, although it was almost significant for the 1938-46 period. This would be expected since they should both reflect the same environmental factors, although the very high correlation between escapement and return per spawner ($r = -0.96$ in 1938-46) overshadows the effect of the other variables. Return per spawner was negatively correlated with escapement and positively with total return. Troll effort was again correlated with ocean catch.

In multiple regression it is important to strengthen the analysis by reducing the number of variables to the most important and eliminating those related to each other. Since troll effort and ocean catch of Columbia River fish were correlated, ocean catch was dropped.

Since the various temperatures at the time of downstream migration were generally related (although not all significantly), Amphitrite Point was chosen as best suited to describe the early ocean environment. It had the further advantage of being continuous through the entire time series. Bonneville Dam flow and turbidity were correlated, so only flow was used. In the overall view, the factors which were deemed most worthy of further study as affecting the total return and return per spawner of fall chinook were: (1) escapement, (2) a measure of ocean and estuary water temperature at the time of downstream migration, and (3) index of ocean fishing intensity. Fresh-water environmental factors did not show any significant relationships, but based on other work and opinions, I felt that water temperature at time of spawning and river flow during downstream migration should also be included. With the variation in the run caused by the first three items removed, the residual of river temperature and flow might then show some relationship.

Some judgment decisions are necessary in interpreting computer results. The variables are inserted stepwise and arranged and printed out in decreasing order of contribution to the total R^2. As additional variables are inserted, the degrees of freedom are reduced and variables change in significance. Therefore a step was chosen which gave the maximum number of significant variables along with a reasonably high R^2. In some cases nonsignificant variables were included because they contributed appreciably to the R^2. The reader is referred to the original paper for detailed tables of the analysis.

The first step was a multiple regression analysis with the four variables being escapement (X_1), ocean temperature (X_2), troll intensity (X_3), and river flow (X_4) vs. total return (Y_1) for the 1938-46 period. Considering only ocean temperature, a multiple correlation coefficient (R^2) of 0.569 is realized ($R = 0.754$). This means in effect that 57% of the variability in the returning run can be accounted for by the ocean temperature at downstream migration and that there is good fit to the regression plane. Including troll fishing intensity in the regression brought R^2 up to 0.74 and $R = 0.859$. The addition of escapement and river flow brought R^2 only to 0.75, indicating they played an insignificant role in influencing return and were not significant variables as shown by low t values.

If the relationships are actually curvilinear rather than linear, or if interaction occurs between the variables, then the introduction of quadratic and interaction terms through a response surface program gives a better fit. In this case, no benefit is realized, with the R^2 of 0.74 almost identical to the linear model.

The same procedure was followed with the other dependent variable, return per spawner for the early period. Due to the very high correlation between escapement and return per spawner, the other factors assume a rather unimportant position. For example, escapement and return per spawner gave a R^2 value of 0.924 ($R = 0.961$). Including ocean temperature brought R^2 to 0.980 and this was still a significant factor, but troll intensity and river flow were not significant. The introduction of quadratic and interaction terms on only escapement and sea-water temperature did not improve the relationship.

For the brood years 1938-46 then, return to the river was strongly and inversely correlated to ocean temperature at the time of downstream migration and less so but still significiantly with the intensity of the troll fishery. The production rate or return per spawner was influenced by the number of spawners and

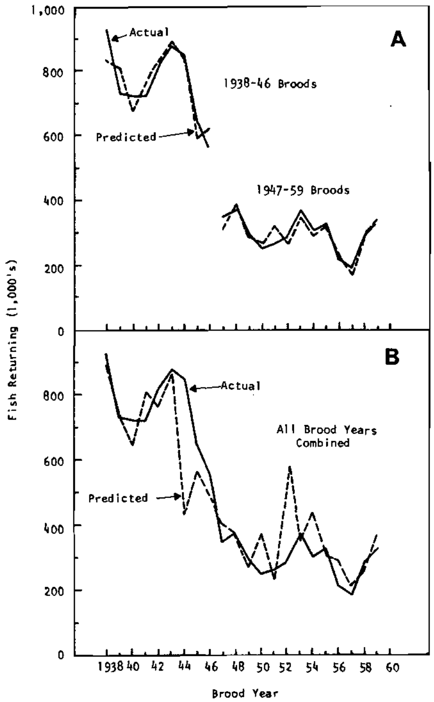


Figure 21. Actual and predicted return of fall chinook salmon to the Columbia River based on multiple regression equations, by early and late years and all years combined.

the ocean temperature.

With such a high level of correlation, prediction of the dependent variables becomes possible. This is the ultimate aim of such research. The predicting equation of the form

$$\hat{Y} = 4471.560 - 0.293X_1 - 65.274X_2 - 4.073X_3 - 0.107X_4$$

was used for the 1938-46 period. A comparison of predicted and actual return to the river for the early period is shown in Figure 21A. The agreement is rather remarkable and adds confidence in the conclusions reached.

The same procedure was followed for the 1947-59 brood years but with the addition of a few more independent values. Considered first in the multiple regression were escapement (X_1), Amphitrite Point June water temperature (X_2), Washington troll fishing effort (X_3), April-May Bonneville Dam flow (X_4), Seaside June water temperature (X_5), and Rock Island Dam October temperature (X_6) vs. total return. The only significant variable was troll intensity and it accounted for only 31% of the variation. Including all other variables added only 5% to the regression.

Reducing the problem to three variables: escapement, Amphitrite temperature, and troll intensity, and introducing quadratic and interaction terms greatly improved the relationship, indicating that nonlinear relationships existed between one or more of the variables. In order of contribution to the R^2 were troll intensity, troll intensity squared, interaction of escapement and ocean temperatures, escapement squared, interaction of escapement and troll intensity, and escapement. Amphitrite Point water temperature had a negligible effect by itself. Actual and predicted returns for the 1947-59 broods are also shown in Figure 21A. Again an excellent prediction is illustrated.

Considering the above six variables on return per spawner, only escapement had a significant effect. Escapement accounted for 0.605 and sea-water temperature only 0.045 of the total R^2 of 0.705. Introducing quadratic and interaction terms on escapement, ocean temperature, and troll intensity gives a total R^2 of 0.949 with escapement contributing most to it.

Next I grouped all the brood years for the period 1938-59 into one program and tested escapement (X_1), Amphitrite Point June water temperature (X_2), troll intensity (X_3), April-May Bonneville Dam flow (X_4), Tongue Point water temperature (X_5), and Rock Island Dam October water temperature (X_6) against return (Y_1). Troll intensity and Amphitrite water temperature were the only significant variables, with troll intensity highly so, but river flow and escapement contributed to the R^2. The total R^2 was only 0.47, however.

Adding quadratic and interaction terms on X_1 to X_4 and carrying through six steps gave a R^2 of 0.572. Interaction of Amphitrite water temperature and troll intensity and water temperature squared, were significant variables at the 5% level. Entering the other variables, although they were not significantly related, brought the final R^2 to 0.754.

Taking the six variables against return per spawner (Y_2) showed significant relationships for escapement, river flow, sea-water temperature, and troll intensity. Escapement and troll effort were significant at the 5% level, the other two at 10%. Spawning and estuary temperatures were not significant. With the early and late periods combined, the linear correlation coefficient between escapement and return per spawner is lower ($r = -0.589$) than when treated separately ($r = -0.961$ and -0.778), thus permitting the other variables to enter into the regression. This is the first time that river flow has assumed a significant role in this analysis. However, the negative slope indicates that it is not the expected one; i.e., high flows give high returns. The total R^2 of 0.634 ($R = 0.798$) is lower than when the periods were separate but still high.

Entering quadratic and interaction terms on variables X_1 through X_4 on Y_2 gives a R^2 of 0.796. The three significant variables — escapement-troll interaction, temperature-flow interaction, and temperature squared— built up a R^2 of 0.60, but the addition of more variables increased it to 0.80, even though they were not significant.

The response surface program allows a predicting equation to be formulated for the whole period which should depict the numbers of fish in the returning run based on the relationship between troll fishing effort, ocean water temperature, river flow at time of downstream migration, and number of spawners.

The results of the predicted return compared to the actual return is shown in Figure 21B. The agreement is good except for 2 years, 1944 and 1952. The reason for these discrepancies is not clear; however, the equation does depict the history of the run fairly accurately and substantiates that ocean fishing effort played a major part in determining the numbers of fall chinook returning to the Columbia River. Further confirmation could be obtained by predicting the outcome of keeping the fishing effort low and constant. This was accomplished by substituting the mean value of fishing effort for the 1938-42 brood years (32,-900 trips) for the actual value into the equation. Mathematically, keeping one variable constant exaggerates the effect of the others, resulting in wide fluctuation in the predicted values. Still it was clear that if the troll fishing intensity had remained low, the predicted returning runs would have been, on the average, at the predecline level.

The multiple regression analysis yielded predicting equations which made accurate "hindcasts" of returning runs. One of the major problems and goals in salmon management is to predict runs with some degree of accuracy. A logical extension of the present work would be to forecast returning runs based on analysis of environmental factors. Such an approach is beyond the scope of this report, but it is suggested that a predicting equation be computed beginning with the 1948 brood and extending as far as possible into more recent years. This would permit inclusion of British Columbia and Oregon troll fishing, sport fishing effort and the effect of dams built in recent years. The most meaningful variables appear to be ocean fishing intensity, escapement, ocean water temperature during a brood's first summer, and river flow during downstream migration. Loss of spawning area may be a factor to consider in the future and also the increased contribution of hatchery-reared fish. To predict a year's run, it is necessary to prorate brood-year production into run years; i.e., a run would consist of elements from 4 brood years. However, 3- and 4-year olds comprise most of the run, and the ratio is relatively constant; thus no appreciable error should be introduced.

Discussion

Ocean Habitat of Various Chinook Populations

The hypothesis that increased fishing effort in the ocean was largely responsible for the decline in the fall chinook run in the early 1950's has been confirmed by direct correlation, by the classic effects of exploitation of a population, and by the process of elimination of environmental variables shown to have no effect. Still, one question remains: why have not other chinook runs declined in a like manner? This might be explained by examining ocean habitat of different populations, fishing intensity by area, and growth rate.

In the section on ocean life we showed that the oceanic migrations of lower river fall chinook are largely confined to the area from the Columbia River to mid-Vancouver Island, with some individuals scattering southward to mid-Oregon and others going as far as northern Vancouver Island. Upper river fall chinook are also found in this region, but many go to the northern Gulf of Alaska and are taken only on their southward migration during the summer. Columbia River spring and summer chinook for the most part migrate into northern latitudes where they reside until approaching maturity sends them south. Undoubtedly some are taken by the troll fishery but the main migration is over before the fishery reaches its peak. Fall chinook from the Sacramento River migrate north along the California and Oregon coast with numbers decreasing rapidly along the Washington coast. Chinook from Oregon coastal rivers were shown to be in fair abundance off Alaska, northern British Columbia, and Oregon (Van Hyning, 1968). Possibly some races of coastal chinook migrate long distances while others are more restricted in their movements — like Columbia River fall chinook. Puget Sound chinook are found from Cape Flattery north through southeastern Alaska but there was a definite tendency for immature Puget Sound fish to be relatively less available to the fishery than immature Columbia River stocks off Vancouver Island.

Ocean Fishing Effort by Area

If fishing intensity varies between areas, then some stocks could be subjected to greater mortality than others. This concept was explored by examining fishing days by area. Table 13 is a tabulation of fishing effort in 1963 by area for California to northern British Columbia (no effort data were available for Alaska). Days fished are given in British Columbia catch statistics but for the other areas it was necessary to convert trips to days by tabulating sampling data from the various ports, giving the following values for average number of fishing days per trip; southern Oregon — 1.5; central Oregon — 1.6; Columbia — 2.6; Grays Harbor-LaPush — 1.6; and Neah Bay — 3.3.

Since sampling at Columbia River ports probably did not representatively cover the day boats, the value of 2.0 was used to convert to days fished. Since the California fishery is similar to that of

Table 13. Ocean fishing effort by area, 1963

Area	Commercial Days	Sport Days	Sport Commercial Equiv. Days	Nautical Miles of Coast Line	Combined Comm. and Sport Days	Total Fishing Days Per Mile	Combined Areas Days	Combined Areas Miles	Combined Areas Days Per Mile
N. British Columbia (District 2)	29,782	0	0	300	29,782	99.3	54,598	450	121.3
N. Vancouver Island (Areas 24-27)	24,816	0	0	150	24,816	165.4			
S. Vancouver Island (Areas 20-23)	32,699	0	0	70	55,560	793.7	106,593	250	426.4
Cape Flattery	20,691	43,400	2,170						
Washington Coast (LaPush, Grays and Willapa harbors)	22,174	157,300	7,865	95	30,039	316.2			
Columbia River	14,868	122,530	6,126	85	20,994	247.0			
Central Oregon	5,251	80,951	4,048	75	9,299	124.0	91,126	585	155.8
Southern Oregon	14,876	111,898	5,595	135	20,471	151.6			
California	55,592	115,283	5,764	375	61,356	163.6			

southern Oregon, the figure of 1.5 days per trip was used. Sport fishing intensity in angler days is also shown. The sport fishery off Vancouver Island is assumed to be negligible. In order to arrive at a common unit of measurement, sport days were equated to commercial days, using the value of 20 sport days as equal to one commercial day. This may have some relation to reality because commercial boats commonly fish about 20 hooks. These effort figures are not meaningful unless related to some measurement of area. Therefore the miles of coastline in each division were considered and the number of days of fishing per mile was computed. Southern Vancouver Island and Cape Flattery areas were combined because they are continuous and most of the effort is on the fishing banks off southern Vancouver Island.

An examination of Table 13 shows that considerable differences exist in fishing effort among areas. The lowest intensity occurred off northern British Columbia with about 100 fishing days per mile while the greatest off Cape Flattery and southern Vancouver Island at almost 800 days per mile. This explains why a large proportion of the chinook tagged in the latter area were recovered in the same vicinity.

Grouping the areas into (1) northern Vancouver Island and northern British Columbia, (2) southern Vancouver Island to the Columbia River, and (3) Oregon and California coast, reveals fish occupying area (2) are exposed to almost three times the fishing intensity of those in area (3). This corresponds roughly to the ocean domain of Columbia River and Sacramento River fall chinook, respectively. Stocks migrating into northern British Columbia are exposed to a relatively low fishing effort. Although no data are given for Alaska with its long and rugged coastline, it is probably similar to northern British Columbia. Furthermore, fish migrating northwest of Cape Fairweather, as many upper Columbia River, British Columbia, and Alaska stocks do, are exposed to virtually no fishery while there.

Growth Rates

Additional information on selective ocean fishing mortality can be obtained by examining the life history and growth rates of different stocks (see section on Growth and Maturity). Fall chinook become available to the ocean fisheries earlier than spring chinook. For example, spring chinook would be largely unavailable to a sport fishery with a 20-inch size limit (18 inches fork length) in their second year, whereas fall chinook would be available in midsummer. Likewise, spring chinook would not be retained by the troll fishery with a 26-inch size limit (24 inches fork length) until near the end of their third summer, whereas fall chinook could be retained much earlier in the season. Many spring chinook mature in the spring of their fourth year and are thus exposed to no further ocean fishing. A 4-year-old fall chinook would be exposed to another full season of fishing before maturity in the late summer.

Taking a cohort of fall chinook destined to mature at 4 years, about one-half would be large enough to be exposed to a sport fishery in their second summer; all would be available to the sport fishery and most to the troll fishery in the 3rd year; and all would be exposed to virtually a full season of ocean fishing before entering the river in the fall of their 4th year. A similar cohort of spring chinook, maturing in April of their 4th year, would not be subjected to fishing until their 3rd year; most of them would be recruited into the sport fishery but only the larger ones into the troll fishery. Thus the lag in growth for spring chinook benefits them to the extent that they are exposed to a full year's less fishing than fall chinook.

An analogy can be made between chinook and coho salmon. Coho spend their 1st year in fresh water, migrating to sea early in their 2nd year. Only jacks are taken as 2-year olds. The 3-year old adults appear on the fishing grounds usually around mid-June and are fished intensively until mid-September, when they slacken feeding and begin their spawning migration. Thus, a year class is exposed to only 3 months of ocean fishing. Even though large numbers are taken during this brief period, the condition of the resource is considered good.

The differing availability to the fishery of 3- and 4-year fish was discussed in reference to Table 7. It was shown that the proportion of 3-year Columbia River hatchery fish (1961 brood) in the total Washington troll catch was 30% in 1964, but dropped to 13% as 4-year fish in 1965. This further shows that Columbia River hatchery fish are more available as 3- than 4-year olds and are replaced by other stocks of 4-year fish that had probably been less available as 3-year olds.

Comparison with a Puget Sound Run

Further confirmation of differing marine rates of exploitation and how they affect abundance of various stocks can be determined from an examination of mark recoveries from different hatchery stocks. Heyamoto and Kiemle (1955) analyze recoveries for several fall chinook marking experiments on Puget Sound streams as well as the Kalama River experiment previously mentioned. Two 1949-brood experiments are particularly pertinent: 204,000 fall chinook were marked and planted in the Deschutes River (tributary to southern Puget Sound) in June 1950 and 199,000 fall chinook were marked and planted in the Kalama River (tributary to the

Table 14. Comparison of returns from two 1949-brood fall chinook marking experiments, Deschutes River (Puget Sound) and Kalama River (Columbia River).

	YEAR OF RECOVERY																	
	1952①						1953③						Combined					
	Ocean		Puget Sound or Columbia R.		Escape-ment	Total	Ocean		Puget Sound or Columbia R.		Escape-ment	Total	Ocean		Puget Sound or Columbia R.		Escape-ment	Total
	Comm.	Sport	Comm.	Sport			Comm.	Sport	Comm.	Sport			Comm.	Sport	Comm.	Sport		
Deschutes R.	141	3	146	2,172	550②	3,012	514	1	5	599	828	1,947	655	4	151	2,771	1,378	4,959
Percentage													13.2	0.1	3.0	55.9	27.8	
Kalama R.	668	44	0	0	4	716	253	4	172	43	176	648	921	48	172	43	180	1,364
Percentage													67.5	3.5	12.6	3.2	13.2	

① Includes a few 2-year olds recovered in 1951.
② Corrected from original publication.
③ Includes a few 5-year olds recovered in 1954.

lower Columbia River) the same month (Table 14). Although the fact that many Deschutes River fish stayed in the Sound and were exposed to a sport fishery of considerable magnitude presents a complicating factor, the important thing is the reversal of the ocean take on 3- and 4-year fish: relatively few 3-year Deschutes fish were captured and proportionately more Kalama fish were taken at sea in their 3rd year. The authors' comment: "Most of the marked fish captured by the troll fisheries were 4-year olds. Perhaps their early life existence in Puget Sound delayed their entrance as a group into the ocean areas." This may be true, since few 3rd year Deschutes chinook were taken in the ocean before July while many Kalama fish were caught in the spring of their 3rd year. On the other hand, many 3-year-old Puget Sound fish may have been in offshore areas not visited by the troll fleet. If Puget Sound fish went farther north to northern Vancouver Island and the Queen Charlottes (there was little mark recovery effort there), they would have been exposed to considerably less fishing than if they remained off southern Vancouver Island or turned south (Table 13). Tagging indicates that this situation does in fact occur. Different growth rates could also be an important factor here in determining availability. If Puget Sound fish remained in inside waters for up to 2 years they would show a depressed growth compared with stocks that went to the ocean shortly after leaving fresh water and would thus not be available to the troll gear, or could not be retained if caught until later in life. This certainly is the case with Puget Sound coho where two distinct size groups can be differentiated. In any event, Puget Sound chinook were less available to the ocean fishery and the survival rate to the spawning stage improved.

Considering the combined returns, 13% of the Deschutes fish and 71% of the Kalama fish were taken at sea. The total catch-to-escapement ratios were approximately 3:1 for the Deschutes and 9:1 for the Kalama — or three times more for Columbia River than Puget Sound stock. The apparently intense inside sport fishery had less effect on ultimate survival than the outside troll; in effect, Puget Sound may offer a somewhat protected environment. This difference in fishing mortality logically explains why some Puget Sound hatcheries produced near record runs of chinook while Columbia River hatcheries seemingly produced little.

Conclusion

The chief conclusion of this paper is that during the period of study fluctuations in size of the Columbia River fall chinook run were to a large extent related to the intensity of the ocean fishery and that the decreased numbers of fish entering the river was caused by an increased ocean harvest. This constituted a shift in catch, but the reproductive potential of the run was not reduced since the river fishery was curtailed to maintain adequate escapement.

The results of this study apply only to the years of investigation (1938-59 broods) and to the fall chinook run and should not be extrapolated to other years, other species, or runs. During these years fresh-water factors appeared to have little influence on abundance, and during most of the period the environment changed relatively little. Bonneville, Grand Coulee, Rock Island, and Swan Falls dams were in existence, but for a period of 15 years following 1938 no other dam was built affecting fall chinook. McNary went into operation in 1953, Chief Joseph in 1955, The Dalles in 1957, Brownlee in 1958, and Priest Rapids in 1959. Rocky Reach, Ice Harbor, and Oxbow dams were completed in 1961 and Wanapum in 1963. John Day Dam became operative in 1968 and additional dams have been completed or are under construction on the Snake River. Thus the effect of the recent era of intensive river development was hardly covered in this analysis. All these later projects have, or will have, some detrimental effect on fall chinook through direct mortalities or flooding of spawning areas. The combined effects of passage over a number of dams may reveal a serious reduction in returns of fall chinook and other species of salmon that was not evident for the dams completed through 1959. Since prospects for continuing a high level of natural production do not appear optimistic, reliance on maintaining fall chinook stocks must be increasingly placed on hatcheries, spawning channels, and better fisheries management. It behooves us to examine carefully our management policies to determine if we are making the best possible use of this limited and valuable natural resource.

Summary

1. Columbia River fall chinook salmon were studied to determine the cause of the serious decline in numbers returning to the river in the early 1950's.
2. Population fluctuations in other major salmon runs were examined to detect any coastwide pattern. Other chinook runs were remarkably stable or their fluctuations were out of phase with Columbia River fall chinook. Chum salmon runs from Oregon through southeastern Alaska have generally declined since the early 1950's, in most areas a few years following that of Columbia River fall chinook.
3. Ocean tagging and hatchery finmarking experiments were reviewed to show the areas inhabited by Columbia River chinook and their migrations at sea. The fish were rarely found south of the cental Oregon coast. Tagging off and north of the Columbia River showed that Columbia River fish predominated. Fish tagged off the Columbia River in the spring demonstrated a northerly movement along the Washington coast to Vancouver Island. Tagging off Cape Flattery and southern Vancouver Island indicated that 40-50% of the stream tag recoveries were from fall chinook in the Columbia River. Both immature and mature Columbia River fish were tagged in this area, but the majority of the Puget Sound stocks were mature. Off northern Vancouver Island and the Queen Charlotte Islands, Puget Sound-Fraser River stocks predominated but many Columbia River fall chinook were also found. Off southeastern Alaska 31-52% of the stream recoveries were Columbia River fall chinook. In northern British Columbia and Alaska only upper Columbia River fall chinook were found, while lower Columbia River fish were confined largely to the area between the Columbia River and Vancouver Island. Marked recoveries of lower Columbia river hatchery stocks confirmed the tagging results in that few went south of the Columbia or north of Vancouver Island.
4. Growth and maturity of Columbia River chinook was briefly discussed. Fall chinook were larger at each age than spring chinook and the fastest growing fish matured at the earliest age. A change in maturity pattern was shown for fish tagged in the Columbia-Grays Harbor areas between 1948-52 and 1957-62.
5. Variations in survival rate were found in ocean tagging and marked fish and hatchery returns. Tag returns from the late 1940's and early 1950's contrasted with the late 1950's and early 1960's. Total returns were approximately the same but in the early period about as many fish were recovered in years following tagging as during the tagging season. In later years few fish were recovered after the first season. It was demonstrated that increased ocean fishing, plus the tendency for the fish to mature at a smaller size could easily account for this change. Analysis of adult returns to river fisheries and hatcheries indicated that survival was high in the mid-1940's, followed by a decline to a low level in the mid-1950's, and then an increase, but not to former levels. Trends of abundance were similar at the hatcheries, on the spawning grounds, and in numbers passing over Bonneville Dam, suggesting that all are influenced by some common factors.
6. Data on chinook salmon abundance

were compared with various air and ocean water temperatures and salinities during various months of a brood's 1st year at sea. A significant negative correlation between return to the river of a given brood and average June Vancouver Island water temperature was found.

7. The ocean troll and sport fisheries for chinook salmon from southeastern Alaska to central Oregon were examined. Historically, the northern troll fisheries showed a rapid increase to a high level then a long-term decline. The southern area, Vancouver Island to Oregon, presented a picture of increasing landings until 1952, a high and level trend until 1957, then a decline. In the earlier years (1935-48) ocean catches were significantly correlated with runs entering the Columbia River, but this relationship broke down in later years. Catch-effort statistics for the Washington troll fishery showed an increase in effort, an increase in catch for a time then a drop, and a steady decrease in catch-per-unit effort. Effort was negatively correlated with catch-per-unit effort, indicating that the fishery influenced the abundance of fish. A decrease in size and age of chinook taken by the troll fishery between the periods 1919-30 and 1949-63 was demonstrated, further confirming that the ocean fishery had a measurable effect on the offshore chinook population. The Japanese high-seas salmon fishery was absolved of blame in the decline of fall chinook.

8. The rapid growth of the ocean sport fishery off the mouth of the Columbia and Washington coast since 1950 was documented. Hooking mortality of small salmon was discussed in the light of the literature on the subject. Converting total ocean landings to numbers of fish emphasized the increase in ocean catch and decrease in return to the river. Using ocean tagging data, the contribution of Columbia River fall chinook to the ocean fishery was estimated. It was demonstrated that such a method could under—rather than overestimate the actual contribution, as has been suggested. Considering both the total estimated ocean take and numbers entering the river, there was no decline in the population in the early 1950's. The evidence from several sources was rather conclusive that the increase in ocean fishing was an important cause of decline in the fall run to the Columbia River.

9. The 100-year history and production of the Columbia River fishery was reviewed for spring, summer, and fall chinook. After dropping from a high peak in the 1880's, total chinook landings remained steady from 1890 to 1920. This was due to increased catches of fall chinook compensating for declining summer chinook. After 1920, landings of fall chinook remained level while summer chinook continued to decrease. Evidence strongly indicates that overfishing was largely responsible for the long-term decline of the summer run. The drop in fall run in the 1950's cannot be related to any factor in the river's commercial or Indian fisheries. The recent history of regulation has been one of reduction in types of gear, areas, and open seasons. The river sport fishery was of negligible importance.

10. A study of the age composition of the fall chinook run into the Columbia River showed a decrease in percentage of 4- and 5-year fish and increase in 2- and 3-year fish. This change occurred during the period of the fall

chinook decline. Size compositions were different between August and September at Bonneville Dam, and hatchery-reared 2- and 3-year fall chinook were larger than wild fish of the same age. Sizes of 2- and 3-year fish in the runs fluctuate considerably, but remain relatively constant for 4-year fish. Some evidence was presented showing the relationship between faster growth and earlier age at maturity. Average weight of fall chinook landed by the river fishery evidenced a significant decrease. A cause and effect relationship between increased intensity of ocean fishing coinciding with the decrease in average size and age, and possibly faster growth and earlier maturity, was suggested.

11. The escapement of fall chinook as measured by counts at several Columbia River dams was discussed. Bonneville Dam counts were adjusted for numbers of jacks and the commercial catch above Bonneville to arrive at an index of above-Bonneville escapement. Spawning ground surveys in the upper Columbia and Snake rivers and in tributaries below Bonneville reflect the counts at the mainstem dams. The number of adult fall chinook returning to Columbia River hatcheries show a pattern similar to that at Bonneville Dam as well as spawning ground counts for both upper and lower river populations. For hatchery stocks, fluctuations were shown to be related to survival rate between fingerling and adult, and it can be inferred that this also applies to wild stocks. Hatchery populations have changed in composition from a predominantly 4-year to 3-year age at maturity. Even though the average age has been reduced, fecundity has been maintained because now over half the 3-year fish are females and are almost equal in size to 4-year fish. Comparisons of size frequencies and age compositions for the gill-net fishery and hatchery and wild escapements show a minor amount of gear selectivity for age, size, or sex.

12. The optimum escapement of Columbia River fall chinook was examined with respect to return per spawner and the stock-recruitment relationship. The total return as well as return per spawner decreased in a similar manner over the period studied, while the number of spawners remained relatively constant. Highly significant negative correlations between number of spawners and return per spawner in both the early and late periods indicated a density-dependent factor operating on the population. Ricker-type reproduction curves suggested that the optimum escapement index was between 90,000 and 100,000 fish, a value exceeded during most years of the study. Underescapement was obviously not a factor in the decline of fall chinook entering the Columbia.

13. Columbia and Snake river dams as they influenced upstream-migrating fall chinook were reviewed. Most of the early dams had no direct effect on fall chinook, although they blocked other species and races. Damming of the lower main stem began in 1938 with completion of Bonneville but for the next 12 years no major dam was completed. The decline in productivity of fall chinook stocks thus occurred when river conditions were stable and hence cannot be related to dam construction. Furthermore, populations below the major dams show trends similar to upriver stocks. Information on delay and mortality to

upstream migrants was reviewed, but these factors were considered of minor importance in causing fluctuations in fall chinook abundance.

14. The loss of spawning areas through dam construction cannot be considered a major factor in the decrease of fall chinook. Some areas were lost in the years 1910-41, and more in the period following 1953 and particularly after 1960, but the major change in abundance occurred when spawning grounds were still extensive and little damaged.
15. The literature on parasites and diseases revealed a wide variety of organisms causing morbidity and mortality in adult salmon, particularly in hatchery or holding situations. Diseases are specially virulent at high temperatures but an analysis of temperature records at Bonneville Dam during the time of upstream migration gave no indication of a rise through the years studied.
16. Water temperature at time of spawning and early incubation is critical in survival and during certain years temperatures in the main stem of the Columbia in late September and early October would be detrimental, but most spawning occurs from mid-October through early November. Temperatures in the tributaries are generally low and satisfactory. There was no correlation between mean October temperatures at Rock Island Dam and brood-year production. Since Grand Coulee Dam was completed there has been an increase in winter water temperature and a more constant flow. The literature gave no indications of detrimental change in water quality during the period of study.
17. April is the most important month for downstream migration of juveniles and arrival in the estuary peaks in May. Predation in large reservoirs was suspected as a serious mortality factor, but there is no evidence that this had an impact on fall chinook populations in run-of the river reservoirs. The loss of migrants in passing low-head dams was not serious until accelerated dam construction began in 1957. Delay and residualism did not appear to be serious except in isolated localities. Correlation of river flow and turbidity at time of downstream migration with subsequent return gave no clear result although a tendency was noted for an inverse relationship; i.e., higher flows were correlated with poorer returns than lower flows. The Columbia River is becoming notably clearer as reservoirs are created, but this was not shown to affect fall chinook survival. There was a suggestion of an inverse relationship between May estuary temperatures and return of adults.
18. A multiple regression analysis was made of selected environmental factors in relation to brood-year return. The most significant variables were chosen from a correlation matrix. For the 1938-46 brood years June seawater temperature at Amphitrite Point (Vancouver Island) and troll fishing effort accounted for 74% of the variability in the returning run. Escapement and flow at time of downstream migration were nonsignificant. Return per spawner during this period was influenced only by escapement and ocean temperature. For the 1947-59 period troll intensity had the greatest influence on total returns; escapement and ocean temperature also had some effect. For return per spawner escapement alone had a significant effect during this period. For the two periods combined, troll intensity and seawater temper-

ature were the significant variables in total return. The return per spawner for the entire study period was dependent on escapement, troll effort, flow, and sea-water temperature. Multiple regressions were used to derive predicting equations which agreed very closely with the actual run. Substituting a low and constant troll fishing effort in the equation resulted in the predicted run maintaining the average predecline level, substantiating the conclusion that ocean fishing played a major role in influencing the number of fall chinook returning to the Columbia River.

19. The hypothesis that the increase in ocean fishing was the main contributor to the decline in returns was shown to be true by correlation, by analogy with the effects of exploitation on this and other fish populations, and by the process of elimination. To answer the question why other chinook runs have not declined in a like manner, I studied the ocean habitat of different populations, fishing effort, and growth rate to demonstrate that Columbia River fall chinook probably were exposed to much more ocean fishing than any other population. It must be emphasized that these conclusions cannot be extrapolated to the future and may not apply to other species, runs, or races of salmonids.

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