EFFECT OF ENCROACHMENT OF WANAPUM DAM RESERVOIR ON FISH PASSAGE OVER ROCK ISLAND DAM, COLUMBIA RIVER

RICHARD L. MAJOR[1] AND GERALD J. PAULIK[2]

ABSTRACT

The filling of Wanapum Reservoir in 1964 flooded the lower sections of the three fish ladders at Rock Island Dam, 61 km upstream from Wanapum Dam on the Columbia River. To maintain fish passage under the new hydraulic conditions, the lower portions of the center and left-bank fish ladders of Rock Island Dam were rebuilt and a new sequence of spill patterns inaugurated. The effectiveness of these modifications was evaluated by comparing results from a series of tagging experiments conducted in 1964-65 on spring chinook salmon (*Oncorhynchus tshawytscha*) and sockeye salmon (*O. nerka*) with the results of similar experiments in 1954-55 before Wanapum Dam was built. These comparisons indicated fish passage over Rock Island Dam had improved substantially between 1954-55 and 1964-65; tagged fish traveled over the dam in a shorter time, and higher percentages of the tagged groups were sighted passing over the dam under postencroachment conditions.

Successful reproduction of Pacific salmon (*Oncorhynchus* spp.) and steelhead trout (*Salmo gairdneri*) requires that sufficient numbers of adults in suitable physical condition reach the spawning grounds. Serious consequences can result from delays en route. Thompson (1945), for example, showed that very few of the sockeye salmon (*O. nerka*) that were delayed more than 12 days by the Hell's Gate rock slide (Fraser River, British Columbia) reached their spawning grounds. Thompson also suggested that shorter delays reduced the reproductive capability of the survivors. Similarly, man-made facilities such as hydroelectric dams, even though equipped with fish-passage facilities, can act as barriers and thus delay or otherwise interfere with the migratory behavior of salmonids on their way to the spawning grounds.

One of the primary goals of the agencies responsible for conserving the fish resources of the Columbia River is to seek ways of minimizing the effects of dams on the migration and spawning success of the river's populations of salmonids. Although a variety of solutions to the problem of dams impeding the passage of migrating spawners have been proposed and a number of these have been tried in the field, the pool type of ladder has proven to be the only practical means of passing large numbers of adult salmonids over the dams on the Columbia River. Many research studies aimed at improving fish passage have been conducted over the past several decades. One result of this research has been the introduction of a number of improvements in design and operation of the pool-and-weir ladder. In some cases fish passage over ladders can be substantially improved by modification of spill patterns (Leman and Paulik, 1966).

The present study was designed to evaluate the effectiveness of modifications in the fish ladders at Rock Island Dam and changes in the spill pattern which were made after the lower portions of the ladders were flooded by the reservoir of Wanapum Dam. This type of problem is apt to become more common as all existing sites for hydroelectric dams are utilized and the reservoir of one dam begins to encroach on the tailrace of the dam immediately above.

Rock Island Dam, completed in 1934, was the first dam built on the Columbia River. It is in central Washington and about 725 km above the river's mouth (Figure 1). Originally, the dam

[1] National Marine Fisheries Service Fisheries Northwest Center, 2725 Montlake Boulevard East, Seattle, WA 98102.
[2] Center for Quantitative Science, University of Washington, Seattle, WA 98195.

Manuscript accepted July 1971.
FISHERY BULLETIN: VOL. 70, NO. 1, 1972.

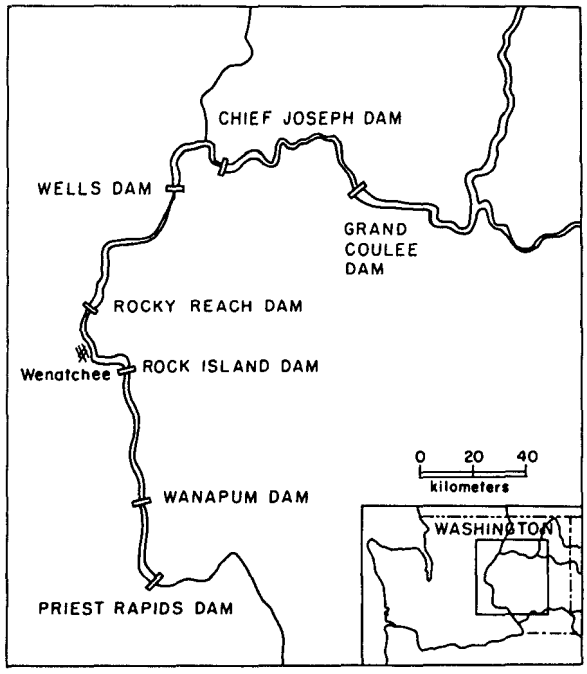

FIGURE 1.—The Columbia River and locations important to the present study.

was provided with two pool- and weir-type fish ladders, one adjacent to each bank. A third was added near the middle of the dam in 1936.

Rock Island Dam was modified during 1951-53. Six new generating units were added to the powerhouse (on the left side of the dam looking downstream), the reservoir was raised about 3.7 m, and regulating lift gates were installed in spillway bays 16-37 on the right side of the dam (Figure 2). Turbine discharge was increased from about 793 to 2,265 m^3 per sec, the fish ladders were altered to enable them to function at the new reservoir level, and the attraction flow at the entrance to the left ladder was increased to counteract the increased discharge from the turbines. Although the fishery agencies requested changes at the lower end of the right ladder to provide better entrance conditions and additional attraction flow, no immediate action was taken to implement these requests.

The Federal Power Commission, in granting permission for the modification of the dam, reserved the right to require alteration of the lower end of the right-bank ladder if substantial evidence were presented to show that alteration was necessary to protect runs of anadromous fish. Any such alteration was to begin before December 1, 1960.

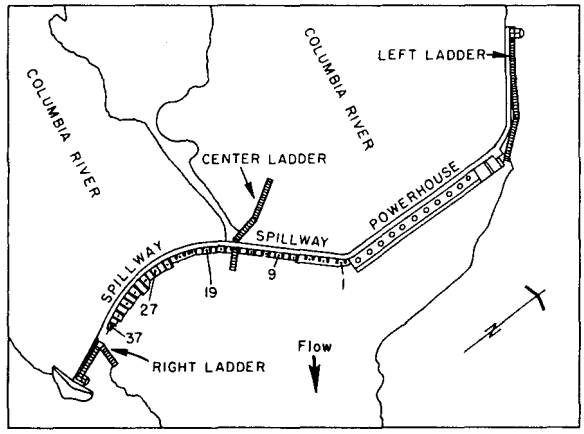

FIGURE 2.—Rock Island Dam showing locations of the fish ladders, powerhouse, and spillway bays.

To determine whether the dam caused loss or delay to the runs and whether loss or delay was associated with the right-bank fishway, tagging studies were conducted in 1954-56. French and Wahle (1966) summarized the results as follows:

> Point estimates of sockeye salmon losses ranged from 0 to 42 percent. Tagging results (one season only) on spring chinook salmon indicated a loss of fish released below the right bank ladder, but no loss when total tag returns from below and above dam releases were compared; data failed to show the dam caused losses of summer chinook. Tagged salmon released below the dam were delayed 2 to 4 days. Altering the right bank fishway may cause more fish to use it, but there is no clear evidence that such alteration will reduce overall loss or delay.[3]

Although the evidence did not indicate that a major overhaul of the right-bank ladder was justified, one relatively minor change was made. In 1956, a concrete wall was built at the entrance to the ladder. This wall replaced a cyclone fence

[3] Seasonal races of chinook salmon (*O. tshawytcha*) in the Columbia River system are classified as spring, summer, or fall chinook depending on the time of year that the adults enter the river to spawn.

which, at high tailwater elevations, appeared to impede the entry of fish into the ladder. The wall also eliminated the surging action across the ladder that occurred under certain combinations of spill pattern and tailwater elevation.

Even after these changes, fishery biologists continued to voice concern over the effectiveness of the right-bank ladder. Some held that hydraulic conditions at the entrance to the right-bank ladder impeded fish passage over the ladder. In 1958, in response to the continuing concern about the fish-passage conditions at Rock Island Dam, the owners of the dam—Puget Sound Power and Light Co. and Public Utility District No. 1 of Chelan County—financed a study to determine if fish passage could be improved by manipulating the spill pattern.

The study showed that fish could be guided to either the right or center ladders by spilling adjacent to the respective ladder. The experiment also indicated, but not conclusively, that when low tailwater elevations prevailed, spilling from gates 35, 36, and 37 (immediately adjacent to the right-bank ladder) confused the fish and interfered with their entry into the ladder (Leman and Paulik, 1966).

The construction in 1960-64 of Wanapum Dam, 61 km downstream, brought about a further change in fish-passage conditions at Rock Island Dam. The lower portions of the fish ladders at Rock Island Dam were flooded by Wanapum Reservoir. This condition, in the judgment of the Federal Power Commission, required certain modifications of the left and center fish ladders. The modifications were completed by 1963—1 year before Wanapum Reservoir was filled. The Commission also directed the owners of Rock Island Dam and of Wanapum Dam (Public Utility District of Grant County) to develop, in cooperation with representatives of the U.S. Department of the Interior and the Washington State Departments of Fisheries and Game, a program for the study and evaluation of the further effects of encroachment by Wanapum Reservoir on fish passage at Rock Island Dam.

It is important to note that the question at hand was the effect of the encroachment of Wanapum Reservoir on fish passage at Rock Island Dam and not the effects of Wanapum Dam on fish passage in the broader sense, i.e., passage over Wanapum Dam itself and passage through the newly formed forebay.

Representatives of the participating agencies formed the "Rock Island Study Group" and engaged the junior author as a consultant to serve as chairman of the group. A major segment of the research program, initiated and supervised by the study group, consisted of a series of tagging experiments conducted under postencroachment conditions. These experiments were so designed that the results would be comparable to results available from preencroachment tagging in 1954-55 (French and Wahle, 1966).[4] The field work was conducted by experienced personnel of the National Marine Fisheries Service (formerly the Bureau of Commercial Fisheries) under the supervision of the senior author.

In this paper we describe tagging experiments at Rock Island Dam in 1964-65 and compare the results to those obtained in the earlier (1954-55) study. The primary purpose is to estimate the differences between the times required for sockeye and spring chinook salmon (*O. tshawytscha*) to move from tagging sites below Rock Island Dam to the counting stations in the three (left, center, and right) fish ladders before encroachment and after encroachment.

EXPERIMENT RATIONALE

The basic experimental measures obtained from this type of tagging are (1) elapsed time from the release of tagged fish below Rock Island Dam to the sighting of tagged fish as they passed through a counting station near the top exit of the fish ladders and (2) the percentage of each release group passing over the dam. The elapsed times include (a) the time, if any, required for tagged fish to recover from possible effects of tagging, (b) the time required to locate and enter the fish ladders, and (c) the time required to ascend the ladders. A statistical analysis of the preencroachment tagging was employed to determine adequate sample sizes and release

[4] French and Wahle also tagged in 1956, but because the tagged fish were released in a different manner and at different locations than in any other year, the 1956 experiments were excluded from our comparisons.

frequencies needed in postencroachment tagging to be 95% certain of detecting a change of one-half day and 99% certain of detecting a change of a full day in elapsed times, if such changes occurred between 1954-55 and 1964-65. If we assume that the basic condition of the tagged fish and the time required for tagged fish to recover from possible effects of tagging did not differ significantly between the 1954-55 and 1964-65 experiments, it follows that changes in elapsed times could be attributed to the ability of tagged fish to find and ascend the fishways. The efficiency of the fish-passage system at Rock Island Dam could thus be compared under pre- and postencroachment conditions. Although travel times were expected to be the most sensitive measure of encroachment effects, it is obvious that any significant drop in the percentage of tagged fish passing over the dam would indicate severe stress under postencroachment conditions.

It might seem unrealistic at first to assume that tagged fish recovered from the possible effects of tagging equally well in the pre- and postencroachment phases of the study. One might expect, for example, that tagged fish were released into faster moving water in 1954-55 and into slower moving water in 1964-65 and that, accordingly, the tagged fish required longer to recover from the effects of tagging in the earlier phase of the study than in the latter. If this were true, we might have ended up measuring differences in recovery time of tagged fish rather than differences in the efficiency of the Rock Island Dam fish ladders.

Although water velocities were not measured at the release sites, velocities measured in a model of Rock Island Dam (Ward, 1965)[5] were not uniformly different under postencroachment conditions than under preencroachment conditions. In fact, velocities at the measuring point nearest the right-bank release site on the simulated model were generally higher after encroachment than before. On the other hand, at the station closest to the left-bank release site, velocities were higher at lower river flows and about the same at higher flows after encroachment.

Observations made during the 1964-65 experiments revealed that large numbers of tagged fish tended to remain close to shore in protective eddies. According to French, tagged fish behaved similarly during the 1954-55 experiments.[6] These observations tend to support the assumption that tagged fish recovered from tagging equally well in 1954-55 and 1964-65.

The flooding of the lower portions of the fish ladders at Rock Island Dam by Wanapum Reservoir was not the only factor affecting fish passage that changed between 1954-55 and 1964-65. Riprap was added to the left bank of the river below the dam, and the left and center fish ladders were modified extensively. Figures 3 and 4 show Rock Island Dam before and after Wanapum Reservoir had been filled. New spill patterns designed to enhance fish passage were in effect throughout most of the 1964 and all of the 1965 tagging. The basic pattern was developed from findings of the 1958 study (Leman and Paulik, 1966) and modified slightly after experiments with the model of Rock Island Dam (Ward, 1965, see footnote 5).

METHODS AND MATERIALS

The basic experimental procedure was as follows: salmon were trapped as they passed over the left ladder, transported to the release sites approximately 300 m below Rock Island Dam on either side of the river, then tagged and released. Fish counters at the dam recorded the tags as the tagged fish passed the counting boards after reascending the ladders.

TAGGING

Two different traps were used to capture the salmon. Sockeye were captured as they entered a trap placed at the upstream edge of the counting board in the left-bank fish ladder. Chinook salmon, which would not enter this trap, had to

[5] Ward, David A. 1965. Hydraulic model studies of the Rock Island fish attraction facilities. Wash. State Univ., Pullman, Div. Ind. Res., Inst. Technol., Res. Rep. 65/9-43. Vol. I—20 p., 29 fig., Append. I-II; Vol. II—23 fig. (Processed.)

[6] Personal communication, Robert R. French, Fishery Biologist, Natl. Mar. Fish. Serv., Northwest Fish. Cent., Seattle, Wash.

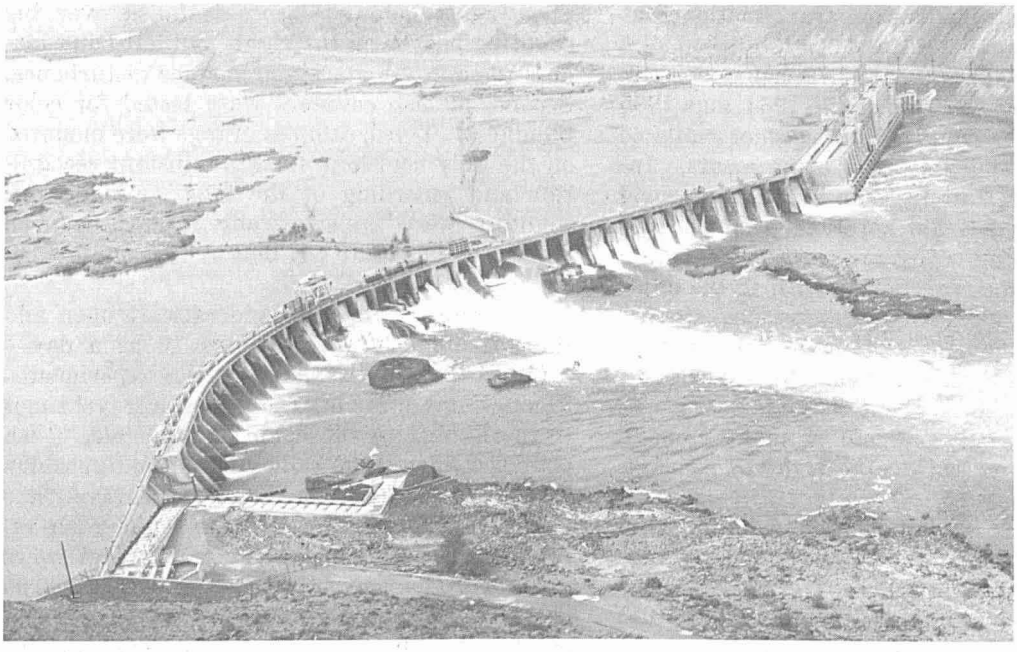

FIGURE 3.—Rock Island Dam before Wanapum Dam had been built.

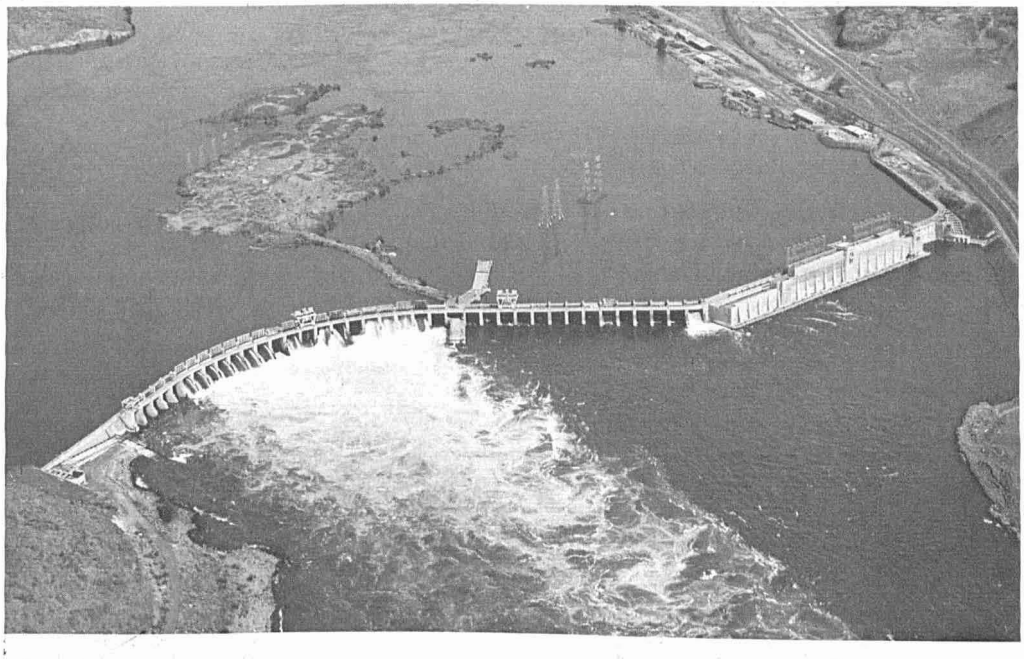

FIGURE 4.—Rock Island Dam after Wanapum Dam had been built. Note how the rocks and the lower portion of the right-bank fish ladder, visible below the dam in Figure 3, have been inundated in Figure 4.

be taken in a larger floating trap positioned at the upstream end of the ladder.

A conventional 1,000-gal (3.79-m^3) tank truck transported sockeye salmon in 1964 and 1965 and chinook salmon in 1965 but was not available for the 1964 chinook salmon experiments. Instead, we used 1.2 m by 1.2 m by 1.1 m plywood boxes, equipped with aeration systems and mounted on ¾-ton (680-kg) trucks. These units were suitable for transporting fish to the adjacent left-bank release site but inadequate for moving more than seven or eight fish per unit to the opposite bank via Wenatchee, Wash.,—a 48-km trip that took about ½ hr. Because of this limitation, only one-half as many chinook salmon were released on the right bank as on the left bank in 1964.

Each batch of fish liberated was distinctively marked. Several types and colors of tags were used. Petersen plastic disks were used either alone or in combination with plastic bars and vinyl streamers. Nickel pins, inserted through the body just below the dorsal fin, provided the attachment. Tags were applied in pairs, so that the same color and type of tag showed on both sides of the fish. Tagging time seldom exceeded 30 sec per fish.

ARTIFICIAL MANIPULATION OF SPILL PATTERN, AUGUST 3-5, 1964

The spill pattern throughout most of the 1964 and 1965 tagging was developed from results of experiments at Rock Island Dam in 1958 (Leman and Paulik, 1966) with subsequent refinements from a model study in 1964 and 1965 (Ward, 1965, see footnote 5). On August 3-5, 1964, however, gates 16 to 18 (adjacent to the center ladder) were closed and gates 34, 36, and 37 (adjacent to the right-bank ladder) were opened. This departure from the recommended spill pattern was undertaken to measure its effect on the passage of tagged fish over the dam.

TAG OBSERVATION AND DATA RECORDING

Four steps were taken to insure the accuracy of the tag observations: First, hydroscopes (floating "windows") were installed over the counting boards on the right- and left-bank ladders to suppress glare and surface disturbance. Second, all fish counters were tested for color blindness. Third, samples of tags were mounted on the tally boards to facilitate instant recognition and recording of the tags. Fourth, fish counters were systematically rotated between ladders to distribute any bias by the counters between the ladders.

The gates in the fish ladders were open and the passing fish were counted 16 hr a day—5:00 AM to 9:00 PM—during these experiments. The half-day units used to measure travel times were adapted to the counting schedule. Fish observed during the same 8-hr period in which they were released were assigned a travel time of one-quarter day or 0.5 half-day. Fish released just before noon (as most were) were given a travel time of 0.5 half-day, if observed the same day, or a time of 1.0 half-day if observed the next morning. Tag observations were grouped by tag combination, ladder, and travel time in half days. Data were punched on IBM cards—one card containing the release and recovery data for each fish. The numbers of tagged salmon released below Rock Island Dam and later observed passing the dam in 1954, 1955, 1964, and 1965 are summarized in Table 1.

TABLE 1.—Numbers of salmon that were tagged and released below Rock Island Dam in 1954, 1955, 1964, and 1965, and the numbers and percentages of tagged fish that were later observed passing over the dam's fish ladders.[1]

Species of salmon	Year	Fish tagged and released below dam	Tagged fish observed passing dam	
		no.	*no.*	*%*
Spring chinook	1954	155	60	38.7
	1955	157	94	59.9
	1964	103	93	90.3
	1965	311	285	91.6
Sockeye	1954	1,485	1,176	79.2
	1955	1,176	793	67.4
	1964	951	895	94.1
	1965	679	623	91.8

[1] The numbers of spring chinook salmon released in 1954 and 1955 differ from those reported by French and Wahle (1966). They used the July 13 date suggested by Fish and Hanavan (1948) as the termination of the spring run and the beginning of the summer run. We used the scale method described by Koo and Isarankura (1967) to determine that the dates of least overlap between the two races were July 30, 1954, and July 8, 1955. We believe that our separations, based on the more recent study, are the more accurate.

TAG OBSERVATIONS AT ROCK ISLAND DAM, 1964 AND 1965

The 1964 and 1965 data are treated by species—spring chinook salmon first, followed by sockeye salmon. In a later section these data will be compared to the 1954 and 1955 results to determine the effects of encroachment of Wanapum Reservoir on fish passage at Rock Island Dam.

SPRING CHINOOK SALMON

The tag release and tag observation data for 1964 and 1965 are presented in Table 2. Included are the date and location of release, the number of fish tagged, the release area, and the number and mean travel time of tagged fish subsequently observed passing Rock Island Dam. Logarithmically transformed data are used throughout this paper for analysis of travel time; means are geometric means.

Three times as many chinook (311) were tagged in 1965 as in 1964 (103). The small number released and the short duration of the tagging period in 1964 (May 19-27) can be attributed to difficulties in completing the access roads, difficulties with the trapping and transportation systems, and a shortage of fish in the left-bank ladder—the ladder where the trap was located. Tagging was from May 16 to June 9, 1965. The 1965 data are grouped, somewhat arbitrarily, into five time periods.

Percentage Observed

The overall percentages of tagged chinook salmon subsequently observed passing over Rock Island Dam were 90.3 in 1964 and 91.6 in 1965. Variability among the release groups was high, ranging from 67 to 129% in 1964 and 60 to 115% in 1965. It is noteworthy that the number observed exceeded the number released for 6 of the 24 releases over the two tagging seasons.

TABLE 2.—Numbers of chinook salmon that were tagged, released below Rock Island Dam and the numbers and mean travel times of tagged fish that were later observed passing over the dam's fish ladders, 1964 and 1965.

			Number of fish tagged and released below dam		Number and mean travel time in half-days of tagged fish observed passing dam							
					Left ladder		Center ladder		Right ladder		Total[1]	
Year	Period	Date	Left bank	Right bank	No.	Travel time	No.	Travel time	No.	Travel time	No.	Travel time
1964		May 19	17	--	10	14.8	5	16.8	7	8.5	22	12.8
		May 19	--	15	6	6.0	6	8.7	1	4.0	13	6.9
		May 20	13	--	7	13.2	6	13.4	2	14.8	15	13.5
		May 20	--	17	6	18.1	3	5.3	4	6.6	13	10.0
		May 21	27	--	9	10.5	7	4.2	4	8.1	20	7.2
		May 21	--	5	1	7.0	3	12.6	0	--	4	10.9
		May 27	9	--	4	9.9	0	--	2	8.7	6	9.5
1965		May 16	5	--	1	2.5	3	3.4	1	2.5	5	3.0
	I	May 18	5	--	2	11.5	2	4.0	1	2.0	5	5.3
		May 21	--	19	12	6.8	4	2.7	3	4.0	19	5.1
		May 22	41	--	33	5.4	9	15.8	5	5.7	47	6.6
		May 23	--	11	8	7.0	3	5.2	0	--	11	6.4
	II	May 24	9	--	4	4.7	0	--	2	2.5	6	3.8
		May 24	--	25	17	7.7	6	4.7	3	2.5	26	6.0
		May 25	8	--	5	3.1	2	22.5	2	12.5	9	6.6
		May 26	15	--	8	4.8	0	--	1	0.5	9	3.7
	III	May 27	--	30	23	8.2	4	5.9	5	3.9	32	7.0
		May 28	28	--	16	9.1	4	15.5	5	3.7	25	8.3
	IV	May 31	21	--	10	6.7	2	5.2	2	6.5	14	6.5
		June 1	--	27	14	6.4	4	4.1	4	2.4	22	4.9
	V	June 4	10	--	5	2.7	3	8.0	0	--	8	4.1
		June 4	--	22	11	6.9	2	6.6	5	2.3	18	5.0
	VI	June 8	--	22	12	3.9	3	5.1	5	3.2	20	3.9
		June 9	13	--	8	6.5	1	20.5	0	--	9	7.3

[1] The total number observed may exceed the number tagged. See text (p. 132) for explanation.

Possible explanations include the misidentification of tags by the counters and multiple observations of the same tagged fish that passed over the dam, fell back, and survived to pass over the dam again. The "falling back" of salmon over dams is a frequent occurrence on the Columbia River (Johnson, 1965),[7] although recent studies[8] have shown the magnitude of such fallback is not large (usually less than 5%).

The percentages of tagged fish recovered by release location (releases pooled by location within years) were not consistent for the 2 years. In 1964 the percentage of tagged fish released on the left bank and subsequently observed exceeded that of the right bank—95.5 to 81.1. In 1965 the comparable percentages were 88.4 and 94.9, respectively.

Distribution by Ladder

Of the tagged fish sighted in 1964, nearly one-half (46.2%) chose the left ladder; the center and right ladders lured 32.3 and 21.5%, respectively. In 1965, 66.3% chose the left ladder, 18.2% the center ladder, and 15.4% the right ladder. Distribution between ladders was basically the same for each release site within, but not between, years. The percentages observed in the left ladder were 47.6 and 43.3 for the left- and right-bank releases in 1964 but considerably higher (67.2 and 65.5) for fish released from the left and right banks, respectively, in 1965. However, in both years similar percentages of the fish not using the left ladder chose the center ladder (60.0 in 1964 and 54.1 in 1965).

Between-period comparisons are possible for 1965 only when the percentage of tagged fish using the left-bank ladder remained very consistent from period to period, varying only from 61.5 to 69.0.

[7] Johnson, James H. 1965. Fallback of adult chinook salmon at Ice Harbor Dam spillway, May 1964. Final Report to U.S. Army Corps of Engineers for Research Contract No. DA-45-164-CIVENG-63-286. Bur. Commer. Fish., Fish-Passage Research Program, Seattle, Wash., 16 p. (Processed.)

[8] Personal communication with Charles Junge of the Oregon Fish Commission with regard to experiments with tagged chinook salmon at Bonneville Dam during 1970.

Travel Time from Release to Observation in Fish Ladders

Travel times—by date of release, release location, and ladder in which the tagged spring chinook salmon were sighted—are presented in Table 2. Because of the small numbers of fish involved in the 1964 tests, their value is limited. The 1965 experiments provided the most sensitive analysis of the time required for tagged fish to pass over Rock Island Dam under encroachment conditions.

Results of analysis of variance tests of the hypothesis of no difference in mean travel time between fish released on the right and left banks in 1965 are summarized in Table 3. Regardless of how the data were grouped—whether travel times of the right-bank and the left-bank releases were compared period by period, whether adjacent periods were combined, or whether all periods were pooled—no statistically significant differences were found. It is noteworthy, however, that the mean passage time for fish released from the right-bank site was less than for fish released at the left-bank site. Thus, fish released from the right bank were finding and passing over the ladders at least as fast as, if not faster than, those released from the left bank.

TABLE 3.—Analysis of variance tests of the hypothesis that spring chinook salmon, tagged and released on the left bank below Rock Island Dam in 1965, traveled over the Rock Island Dam fish ladders equally as fast as fish released on the right bank below the dam.

Periods	Mean travel time in half-days, all ladders combined		*F*-statistics (1 and 268 df)
	Left-bank releases	Right-bank releases	
I	6.081	5.130	0.32 N.S.[1]
II	4.630	6.159	0.93 N.S.
III	8.249	7.009	0.29 N.S.
IV	6.454	4.940	0.48 N.S.
V	4.054	5.048	0.21 N.S.
VI	7.342	3.855	2.03 N.S.
			F-statistics (1 and 279 df)
I and II	5.609	5.789	0.03 N.S.
III and IV	7.553	6.078	0.84 N.S.
V and VI	5.553	4.380	0.50 N.S.
			F-statistics (1 and 283 df)
I-VI	6.097	5.486	0.63 N.S.

[1] N.S. = Not significant.

TABLE 4.—Analysis of variance tests of the hypothesis that spring chinook salmon, tagged and released below Rock Island Dam in 1965, traveled over the right fish ladder at Rock Island Dam equally as fast as those traveling over the left and center ladders.

Ladders compared	Mean travel time in half days, release areas combined			F-statistics[1] (1 and 268 df)
	Left ladder	Center ladder	Right ladder	
Right vs. left	6.210	--	3.396	10.60**
Right vs. center	--	6.929	3.396	9.86**

[1] ** = Highly significant at the 0.01 level, reject hypothesis of equal travel times, and conclude that travel time was significantly less through the right ladder.

We also analyzed the 1965 data on a ladder by ladder basis. Although the data, even when compared on a period by period basis, are too limited to provide a sensitive comparison of the mean passage times between fish using the different ladders, they did reveal that in every period fish moved over the right ladder faster than over either the center or left ladder. Mean passage times for right ladder versus the left ladder and right ladder versus the center ladder (all periods and both release sites pooled) are compared in Table 4.[9] The data have been adjusted for simultaneous tests according to the method described by Dunn (1961). The differences shown in Table 4 are highly significant. Thus the hypothesis that spring chinook salmon traveled from the tagging sites over the right ladder equally as fast as over the left ladder is strongly rejected as is the same hypothesis for the right versus the center ladder. In both cases the mean passage times are significantly less for fish using the right ladder. This means that ladder choice was the only observed factor clearly affecting passage time. Similar trends were noted in 1964. Mean passage time over the right ladder was less than for either the left or center ladders.

The overall travel time in 1965 (5.8 half-days) was shown by an analysis of variance test to be significantly less than that of 1964 (9.8 half-days). The F-value for this test was 17.72 with 1 and 165 degrees of freedom.

[9] Because the passage of fish over the right-bank fish ladder had been a source of controversy among fishery biologists, we directed special attention to the right-bank ladder in the present study.

SOCKEYE SALMON

Fewer sockeye salmon were tagged in 1965 than in 1964. Analysis of the 1964 data revealed that the precision desired could still be achieved if sample sizes were reduced from 100 to 75 fish per release in each year. The tagging season was divided into five periods. With one exception, each of these periods contained releases from the left and right banks. During period IV in 1965, both releases were from the left bank.

Tagging was from July 15 to August 5 in 1964 and from July 14 to August 4 in 1965. Tag release and tag observation data are presented in Table 5.

Percentage Observed

The percentages of tagged sockeye from individual releases observed passing Rock Island Dam were similar for 1964 and 1965. The percentage ranged from 84.3 to 120.8 in 1964 and from 81.2 to 98.8 in 1965. Overall, 94.1% of the tagged fish were observed in 1964 and 91.8% in 1965. Percentages observed from left-bank releases were not significantly different from those released on the right bank in either year—94.8 (left bank) versus 93.3 (right bank) in 1964 and 91.5 (left bank) versus 92.0 (right bank) in 1965.

Distribution by Ladder

Distribution by ladder was similar in both years. Of the tagged fish sighted, 55.6% used the left ladder in 1964 and 53.1% in 1965. The center ladder took 20.7 and 23.6% and the right ladder 23.7 and 23.3% in the 2 years, respectively. For the left- and right-bank releases, respectively, the percentages using the left ladder were 54.1 and 57.4 in 1964. Comparable percentages were 55.4 and 50.7 in 1965. Fish not choosing the left ladder were fairly evenly distributed between the center and right ladders in both years.

The between-period consistency of the percentage of tagged sockeye salmon using the preferred left ladder was less evident than for chinook salmon. For sockeye salmon, the

TABLE 5.—Numbers of sockeye salmon that were tagged, released below Rock Island Dam and the numbers, and mean travel times of tagged fish that were later observed passing over the dam's fish ladders, 1964 and 1965.

			Number of fish tagged and released below dam		Number and mean travel time in half-days of tagged fish observed passing dam							
					Left ladder		Center ladder		Right ladder		Total[1]	
Year	Period	Date	Left bank	Right bank	No.	Travel time	No.	Travel time	No.	Travel time	No.	Travel time
1964		July 15	76	--	21	2.7	16	2.2	40	2.4	77	2.4
	I	July 16	24	--	16	2.2	9	1.9	7	2.0	29	2.1
		July 17	--	113	48	5.9	29	4.8	29	6.8	106	5.8
		July 21	--	70	35	4.9	8	4.9	16	3.0	59	4.3
	II	July 22	104	--	59	3.4	16	2.8	15	4.1	90	3.4
		July 23	--	89	48	5.7	20	3.3	16	4.8	84	4.8
	III	July 28	92	--	45	1.6	25	1.3	19	3.2	89	1.7
		July 30	--	80	56	5.0	20	3.3	11	5.5	87	4.6
	IV	July 31	85	--	53	2.3	16	3.4	13	3.3	82	2.7
		August 3	70	--	38	4.4	10	2.8	15	5.6	63	4.4
	V	August 4	--	96	53	4.8	13	3.3	16	5.6	82	4.6
		August 5	52	--	26	4.1	6	2.8	15	3.1	47	3.6
1965	I	July 14	71	--	38	3.1	8	3.8	23	2.4	69	2.9
		July 15	--	68	38	4.2	9	2.3	20	3.5	67	3.7
	II	July 19	81	--	51	4.6	7	4.2	22	4.7	80	4.6
		July 20	--	76	43	4.1	6	2.9	23	2.9	72	3.5
	III	July 27	75	--	36	3.7	19	2.8	13	3.4	68	3.4
		July 28	--	75	28	2.5	28	2.1	16	1.9	72	2.2
	IV	July 29	69	--	25	4.3	18	4.5	13	4.1	56	4.3
		July 30	--	66	25	2.0	19	2.7	13	2.6	57	2.4
	V	August 3	60	--	29	2.0	19	3.0	1	2.5	49	2.4
		August 4	--	38	18	3.1	14	3.5	1	2.0	33	3.3

[1] The total number observed may exceed the number tagged. See text (p. 132) for explanation.

percentage varied from 40.1 to 62.8 in 1964 and from 44.2 to 61.8 in 1965. For chinook salmon, the range was 61.5 to 69.0% in 1965, the only year in which adequate data were obtained.

Travel Time from Release to Observation in Fish Ladders

Travel time by date of release, release location, and ladder for the 1964 and 1965 experiments are presented in Table 5. Following analysis of the 1964 data, we will examine the 1965 experiments (p. 135).

Analysis of variance tests of the hypothesis of no difference in travel time between left- and right-bank releases (all ladders combined) are given in Table 6. Because there were no releases from the right bank in period IV, the test compares the two left-bank releases. Within-release group variances were pooled to form an overall pooled estimate of the variance with 883 degrees of freedom. Because the mean travel times did not differ significantly between the July 15 and 16 left-bank releases, these releases were combined. The July 21 and 23 right-bank releases were similarly tested and combined. Note that in periods I to III, travel times for the left-bank releases were significantly less than

TABLE 6.—Analysis of variance tests of the hypothesis that sockeye salmon, tagged and released on the left bank below Rock Island Dam in 1964, traveled over the Rock Island Dam fish ladders equally as fast as fish released on the right bank; the testing period IV involves two left-bank releases.

Period	Release locations compared	Mean travel time in half-days, all ladders combined		F-statistics[1] (1 and 883 df)
		Left bank	Right bank	
I	Left vs. right	2.331	5.787	72.95 **
II	Left vs. right	3.394	4.617	8.71 **
III	Left vs. right	1.746	4.619	69.38 **
IV	Left (July 31) vs. Left (Aug. 3)	2.651 4.350	--	14.55 **
V	Left vs. right	4.628	3.604	3.11 N.S.

[1] ** = Highly significant at the 0.01 level, reject hypothesis of equal travel times, and conclude that travel time was significantly less for fish released from one bank than for those released on the other bank.
N.S. = Not significant at the 0.05 level, accept hypothesis of equal travel times.

for the right-bank releases. In period IV when both releases were from the left bank, the travel time of fish released on August 3 was significantly higher than that of fish released on July 31. Differences were not significant in period V when fish were released from both left and right banks.

There is little doubt then that in periods I to III (when the spill pattern recommended by the study group was in operation), fish released from the left bank were finding the ladders and traveling over the dam faster than those released on the right bank. During the last two periods (V and VI), the flows were intentionally switched from the center to the right and back again. The effects of this change on fish passage are discussed in greater detail in a later section.

Further examination of Table 5 reveals two additional characteristics about the movement of tagged sockeye salmon over Rock Island Dam in 1964. First is the consistency of the relative passage times between ladders for fish from a given tag release. This means that regardless of how rapidly or slowly fish from a particular release moved, they did so more or less uniformly at all three ladders. Spring chinook salmon (Table 2) varied much more than did the sockeye in this respect. Second, in five of six comparisons fish released on the left bank negotiated the right-bank fish ladder faster than did fish released on the right bank. Considered jointly, these two features suggest that sockeye were capable of rapid lateral movement in the area downstream from the dam and that the passage of fish released on the right bank was somehow delayed whether they chose the left, center, or even the adjacent right-bank ladder.

Table 7 depicts the travel times by period and ladder, ignoring release sites. Corresponding statistical tests of the hypothesis of no difference in travel times between the right and center and between right and left fish ladders are included. For these tests, a pooled estimate of the error variance with 880 degrees of freedom was computed from within-ladder variances for the 15 groups. Because we tested left versus right and center versus right ladders simultaneously, using the same within-period data, we modified the t-test to control the type I error according to the method suggested by Dunn (1961).

Only one difference is significant. In period III, the mean passage time through the center ladder was less than through the right ladder. In general, however, passage time does not appear to be influenced by the ladder chosen.

Analysis of variance tests of the hypothesis of no difference in travel time between fish released on the right and left banks (all ladders combined) in 1965 are presented in Table 8. The conclusions from these tests are mixed. Fish traveled over the dam faster from the left-bank release site than from the right-bank release

TABLE 7.—Analysis of variance tests of the hypothesis that sockeye salmon, tagged and relased below Rock Island Dam in 1964, traveled over the right fish ladder at Rock Island Dam equally as fast as those traveling over the left and center ladders.

Period	Ladders compared	Mean travel time in half-days, release areas combined			t-statistics[1]	Degrees of freedom
		Left ladder	Center ladder	Right ladder		
I	Left vs. right	4.018	--	3.530	0.981 N.S.	(1, 159)
	Center vs. right	--	3.358	3.530	−0.329 N.S.	(1, 125)
II	Left vs. right	4.453	--	3.887	0.967 N.S.	(1, 187)
	Center vs. right	--	3.324	3.887	−0.893 N.S.	(1, 89)
III	Left vs. right	2.989	--	3.874	−1.494 N.S.	(1, 129)
	Center vs. right	--	2.014	3.874	−3.321 *	(1, 73)
IV	Left vs. right	3.042	--	4.399	−2.043 N.S.	(1, 117)
	Center vs. right	--	3.155	4.399	−1.461 N.S.	(1, 52)
V	Left vs. right	4.547	--	4.211	0.434 N.S.	(1, 108)
	Center vs. right	--	3.132	4.211	−1.215 N.S.	(1, 48)

[1] N.S. = Not significant at the 0.05 level, accept hypothesis of equal travel times.
* = Significant at the 0.05 level, reject hypothesis of equal travel times, and conclude that travel time through the center ladder was significantly less than through the right ladder.

TABLE 8.—Analysis of variance tests of the hypothesis that sockeye salmon, tagged and released on the left bank below Rock Island Dam in 1965, traveled over the Rock Island Dam fish ladders equally as fast as fish released on the right bank.

Period	Mean travel time in half-days, all ladders combined		F-statistics[1] (1 and 613 df)
	Left-bank releases	Right-bank releases	
I	2.943	3.674	3.239 N.S.
II	4.589	3.543	4.915 *
III	3.374	2.182	12.867 **
IV	2.363	4.319	25.511 **
V	2.368	3.251	3.841 *

[1] N.S. = Not significant at the 0.05 level, accept hypothesis of equal travel times.
* = Significant at the 0.05 level, reject hypothesis of equal travel times, and conclude that travel time for fish released on one bank was significantly less than for fish released on the other bank.
** = Significant at the 0.01 level, reject hypothesis, and conclude as above.

site in period I but not significantly so. In periods II and III, fish released on the right bank moved over the dam significantly faster than their left-bank counterparts. In periods IV and V, statistically significant differences were found only in the other direction, e.g., left-bank releases were faster than right-bank releases.

Thus, there is no clear superiority of one release location over the other. The effect of release location on relative and absolute travel times changed from period to period. In contrast, tagged sockeye salmon released from the left-bank site in 1964, before the spill was intentionally modified, moved past the dam faster than their right-bank counterparts. The main difference between the 2 years seems to be the decreased passage time for the right-bank releases of 1965 which, for every comparable period, moved over the dam faster than their 1964 counterparts.

Overall travel times (3.6 half-days in 1964 and 3.2 half-days in 1965) did not differ significantly despite the better performance by the right-bank releases.

Next, it is appropriate to examine the effect of ladder choice on mean travel time in 1965 by period and with release areas pooled. The basic data and the corresponding tests of significance are given in Table 9. No significant differences were found. Ladder choice did not appear to influence travel time. The same result was noted in 1964.

SPILL PATTERN MANIPULATION

On August 3, 4, and 5, 1964, spill was shifted from gates adjacent to the center ladder to the gate on the far right side of the dam. During this 3-day period, two groups of tagged fish (August 3 and 5) were released from the left bank and one (August 4) from the right bank. We will consider the left-bank releases first. The release of August 3 was subjected to 3 days of the modified spill condition, whereas the release of August 5 was subjected to 1 day of the same condition. The left-bank release of July 31 provided a crude "control" (no effect of modified

TABLE 9.—Analysis of variance tests of the hypothesis that sockeye salmon, tagged and released below Rock Island Dam in 1965, traveled over the right fish ladder at Rock Island Dam equally as fast as those using the left and center ladders.

Period	Ladders compared	Mean travel time in half-days, release areas combined			F-statistics[1]	Degrees of freedom
		Left ladder	Center ladder	Right ladder		
I	Right vs. left	3.642	--	2.868	3.051 N.S.	(1, 117)
	Right vs. center	--	2.906	2.868	0.004 N.S.	(1, 58)
II	Right vs. left	4.354	--	3.639	1.903 N.S.	(1, 137)
	Right vs. center	--	3.577	3.639	0.006 N.S.	(1, 56)
III	Right vs. left	3.096	--	2.502	1.766 N.S.	(1, 91)
	Right vs. center	--	2.340	2.502	0.155 N.S.	(1, 74)
IV	Right vs. left	2.946	--	3.288	0.402 N.S.	(1, 74)
	Right vs. center	--	3.464	3.288	0.080 N.S.	(1, 71)
V	Right vs. left	2.400	--	2.236	0.019 N.S.	(1, 47)
	Right vs. center	--	3.201	2,236	0.472 N.S.	(1, 33)

[1] N.S. = Not significant at the 0.05 level, accept hypothesis of equal travel times.

spill) for the two "experimental" releases on August 3 and 5.

The percentages of the tagged fish observed in the right ladder were 15.9, 23.8, and 31.9 for the releases of July 31 (0-day modified spill), August 3 (3-day modified spill), and August 5 (1-day modified spill), respectively. Comparable percentages were 19.5, 15.9, and 12.8 for the center ladder and 64.6, 60.3, and 55.3 for the left ladder. Travel times for the three releases averaged 2.7, 4.4, and 3.6 half-days respectively. Thus, it appears that spilling from the right side tended to attract fish released on the left bank to the right ladder but at the expense of increasing overall travel time.

The change in the spill pattern did not have a significant effect on tagged fish released on the right bank. For the July 30 "control" release, mean travel time was 4.6 half-days; for the August 4 "experimental" release it was 4.6 half-days. Slightly more fish from the August 4 release (19.5%) were attracted to the right ladder than from the July 30 release (12.6%).

Most striking is the similarity between the left-bank release of August 3 and the right-bank release of August 4. The percentages of tagged fish using various ladders for the releases of August 3 and 4 were: (see Table 5) left, 60.3 and 64.6; center, 15.9 and 15.9; and right, 23.8 and 19.5. Overall travel times were 4.4 and 4.6 half-days. Travel times by ladder were similar —4.4 and 4.8 half-days for the left, 2.8 and 3.3 for the center, and 5.6 and 5.6 for the right ladder.

In summary, the departure from the basic spill pattern tended to attract fish to the right-bank ladder, especially those released on the left bank and in so doing, increased the overall travel time. These experiments support the efficacy of the basic spill pattern as compared to the other pattern tested.

COMPARISON OF PREENCROACHMENT AND POSTENCROACHMENT TAGGING STUDIES

The effect of the encroachment of Wanapum Reservoir on fish passage at Rock Island Dam is best measured by comparing the results of the pre- and postencroachment tagging studies. We shall consider spring chinook salmon first, followed by sockeye salmon. Three measurements—percentage observed, distribution by ladder, and travel time—provide the basis of our analysis.

SPRING CHINOOK SALMON

The results of the 1954 and 1955 tagging studies with spring chinook salmon are presented in Tables 10 and 11. Comparable data for 1964 and 1965 are in Table 2.

Percentage Observed

The overall percentages of tagged spring chinook salmon observed passing Rock Island Dam were 38.7 and 59.9 in 1954 and 1955; they were 90.3 and 91.6 in 1964 and 1965. Although some of the significant increase may represent better tag retention or increased survival brought about by improved conditions for fish passage during the postencroachment study, it is likely that the precautions we took to improve the tag observations also were important.

It is interesting to note that the greatest increase occurred for fish released from the right-bank site. In 1954 and 1955, sightings from right-bank releases were only 37.5 and 51.9%, whereas in the postencroachment years—1964 and 1965—they were 81.1 and 94.9%. Few fish were released on the left bank in 1954, but the increase in the percentage of tagged fish observed for the other years (from 77.6 in 1955 to 95.5 and 88.4 in 1964 and 1965) while significant, is not as dramatic as for the right-bank releases.

Distribution by Ladder

The percentages of tagged spring chinook salmon in the left-bank fish ladder were 61.7, 74.5, 46.2, and 66.3 in 1954, 1955, 1964, and 1965, respectively. For the right ladder the percentages were 25.0, 16.0, 21.5, and 15.4 for the 4 years, respectively. This means that 13.3% used the center ladder in 1954, 9.6% in 1955, 32.3% in 1964, and 18.2% in 1965. Thus, there was no

TABLE 10.—Tag release and observation data for spring chinook salmon seen passing over fish ladders at Rock Island Dam, 1954 and 1955.[1]

Date	Tagging location	Number of fish tagged and released	Number of tagged fish observed			
			Left ladder	Center ladder	Right ladder	Total
1954						
June 23-25	Right bank	26	6	3	7	16
June 29-July 2	Right bank	36	5	2	2	9
July 7-9	Right bank	57	7	1	5	13
July 13	Right bank	26	15	2	0	17
July 16-22	Left bank	3	3	0	0	3
July 29-30	Right bank	7	1	0	1	2
1955						
June 7-9	Left bank	8	3	0	1	4
	Right bank	14	7	1	1	9
June 14-15	Right bank	13	7	1	2	10
June 17-21	Left bank	9	10	0	2	12
	Right bank	19	6	1	2	9
June 28-29	Right bank	15	10	0	0	10
June 30-July 1	Right bank	19	3	2	2	7
July 5-6	Left bank	17	8	3	1	12
July 7-8	Right bank	43	16	1	4	21

[1] The total number observed may exceed the number tagged. See text (p. 132) for explanation.

TABLE 11.—Travel time of tagged spring chinook salmon from tagging areas below Rock Island Dam to the Rock Island fish ladders, 1954 and 1955.

Date	Tagging location	Mean travel time in half-days, all ladders combined
1954		
June 23-25	Right bank	12.3
June 29-July 2	Right bank	7.4
July 7-9	Right bank	14.9
July 13	Right bank	13.8
July 16-22	Left bank	15.8
July 29-30	Right bank	10.6
1955		
June 7-9	Left bank	6.5
	Right bank	19.4
June 14-15	Right bank	12.4
June 17-21	Left bank	24.2
	Right bank	21.8
June 28-29	Left bank	20.3
June 30-July 1	Right bank	9.2
July 5-6	Left bank	19.6
July 7-8	Right bank	12.8

marked and repeatable difference in distribution by ladder between the postencroachment years, 1964 and 1965, and the preencroachment years, 1954 and 1955. The center ladder took a disproportionate share of the fish in 1964 (at the expense of the left ladder), but this was less pronounced in 1965.

Travel Time from Release to Observation in Fish Ladders

Apparently no large-scale mortalities and no great losses of tags were caused by encroachment (these assumptions are supported by the high percentages of tagged fish subsequently seen passing Rock Island Dam). The overall effect of encroachment is then best measured by comparing the travel times between the pre- and postencroachment tagging studies. Although we have already shown that the 1965 travel time (5.8 half-days) was significantly less than the 1964 travel time (9.0 half-days), this difference does not overshadow the fact that both values are well below the comparable figures (12.4 and 16.0 half-days) for 1954 and 1955, respectively. We can only conclude that travel time of spring chinook has decreased markedly since encroachment.

SOCKEYE SALMON

Results of the 1954 and 1955 tagging studies with sockeye salmon are given in Table 12. Comparable data for 1964 and 1965 are presented in Table 5.

TABLE 12.—Tag releases, tag observations, and travel times for sockeye salmon seen passing over fish ladders at Rock Island Dam, 1954 and 1955.

Period	Date	Tagging location	Number of fish tagged and released	Number of tagged fish observed[1]	Mean travel time in half-days
1954					
I	July 7-8	Right bank	22	22	23.3
II	July 16, 20	Left bank	119	168	12.5
	July 21-22	Right bank	155	151	10.1
III	July 22-23	Left bank	272	196	8.4
	July 27-29	Right bank	146	75	7.7
IV	July 28-30	Left bank	246	111	7.3
	August 3	Right bank	89	80	6.6
V	August 6-12	Left bank	174	128	4.8
	August 5-12	Right bank	262	245	6.4
1955					
I	July 19-20	Right bank	123	118	7.3
II	July 21	Left bank	59	46	7.0
	July 22	Right bank	46	6	14.9
III	July 26-29	Left bank	298	224	7.0
	July 26-28	Right bank	227	151	5.2
IV	August 2-3	Left bank	129	119	7.1
	August 2	Right bank	24	12	3.8
V	August 5-10	Left bank	93	38	7.1
	August 4-11	Right bank	177	79	7.5

[1] The number observed may exceed the number tagged. See text (p. 132) for explanation.

Percentage Observed

The overall percentages of tagged sockeye salmon observed passing Rock Island Dam in 1964 and 1965 (94.1 and 91.8, respectively) were significantly higher than those recorded in 1954 and 1955 (79.2 and 67.4). A similar change was noted for chinook salmon. As we mentioned earlier in discussing the results with chinook salmon, two factors—increased tag retention and improved facilities for observing and reporting tagged fish—probably contributed to the increased percentages of tagged fish that were observed. Unlike chinook salmon, for which a greater part of the increased percentage of fish sighted could be attributed to fish released on the right bank, the improvement in sockeye salmon was of the same magnitude for releases made on both banks.

Distribution by Ladder

Percentages of tagged sockeye salmon in the left ladder were 55.3, 64.3, 55.6, and 53.1 in 1954, 1955, 1964, and 1965, respectively. For the right ladder, the percentages were 13.2, 12.4, 23.7, and 23.3; for the center ladder they were 31.5, 23.3, 20.7, and 23.6. As with chinook salmon then, the distribution of tagged sockeye salmon by ladder in postencroachment years, 1964 and 1965, did not differ significantly or at least consistently so from that observed in preencroachment years, 1954 and 1955.

Travel Time from Release to Observation in Fish Ladders

Comparisons of the mean travel times by period and area of release for 1954 versus 1964 and 1965 and for 1955 versus 1964 and 1965 are presented in Figure 5. On only 1 of 34 occasions was the travel time in the preencroachment tagging year less than for the corresponding postencroachment tagging year. The difference was not significant.

As with chinook salmon then, we found the time required by tagged sockeye salmon to pass the fish ladders at Rock Island Dam was considerably less after the onset of encroachment than before.

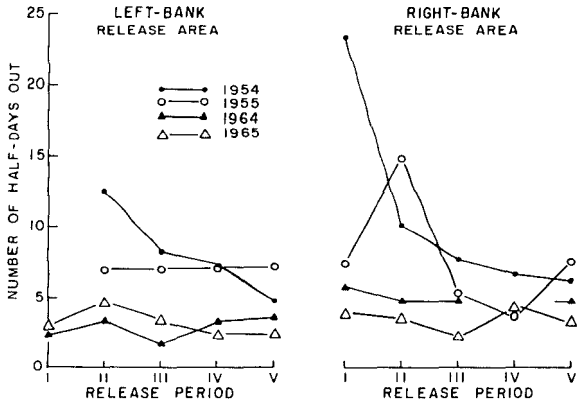

FIGURE 5.—Time required for tagged sockeye salmon to move over the Rock Island Dam fish ladders from the tagging areas below the dam, 1954, 1955, 1964, and 1965.

SUMMARY AND CONCLUSIONS

The lower portions of the fish ladders at Rock Island Dam were flooded by the reservoir of Wanapum Dam. At the direction of the Federal Power Commission, the fish ladders were modified to maintain or enhance fish passage and a study was developed to evaluate the adequacy of the modifications.

In 1964 and 1965 over 2,000 spring chinook and sockeye salmon were tagged and released below Rock Island Dam; their subsequent movement over the fish ladders was noted. Three features—travel time, the percentage of tagged fish observed, and the distribution of tagged fish by ladder—were compared with data obtained in a similar tagging study in 1954 and 1955.

Results clearly indicate that the fish passage over Rock Island Dam was better in 1964 and 1965 than in 1954 and 1955. Travel times were significantly shorter and higher percentages of tagged fish were sighted passing over the ladders under postencroachment conditions.

LITERATURE CITED

DUNN, O. J.
1961. Multiple comparison among means. J. Am. Stat. Assoc. 56(293): 52-64.

FISH, F. F., AND M. G. HANAVAN.
1948. A report upon the Grand Coulee fish-maintenance project 1939-1947. U.S. Fish Wildl. Serv., Spec. Sci. Rep. 55, 63 p.

FRENCH, R. R., AND R. J. WAHLE.
1966. Study of loss and delay of salmon passing Rock Island Dam, Columbia River, 1954-56. U.S. Fish Wildl. Serv., Fish. Bull. 65: 339-368.

KOO, T. S. Y., AND A. ISARANKURA.
1967. Objective studies of scales of Columbia River chinook salmon, *Oncorhynchus tshawytscha* (Walbaum). U.S. Fish Wildl. Serv., Fish. Bull. 66: 165-180.

LEMAN, B., AND G. J. PAULIK.
1966. Spill pattern manipulation to guide migrant salmon upstream. Trans. Am. Fish. Soc. 95: 397-407.

THOMPSON, W. F.
1945. Effect of the obstruction at Hell's Gate on the sockeye salmon of the Fraser River. Int. Pac. Salmon Fish. Comm., Bull. 1, 175 p.