STUDY OF LOSS AND DELAY OF SALMON PASSING ROCK ISLAND DAM, COLUMBIA RIVER, 1954–56

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ABSTRACT

To determine loss or delay of salmonids in passing Rock Island Dam on the Columbia River, and whether such loss or delay was associated with the right bank ladder, salmon were tagged and released both above and below the dam in 1954–56. They were subsequently observed passing through the fishways and recovered at upstream points. Most tagged fish released below the left and right bank fishway returned over the left, corresponding closely with the choice of ladders made by the untagged populations. 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 that 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 alterations will reduce overall loss or delay.

Rock Island Dam, completed in 1934, was the first dam built on the Columbia River. It is about 450 miles above the river's mouth in central Washington (fig. 1). A fishway was built at each end of the dam to pass anadromous fish and in 1936 a third was added near the middle of the dam to pass salmon observed congregating there. These ladders were the pool type, 20 feet wide, with a gradient of 1 to 10.

The dam was modified during 1951–53 by installing regulating gates in the spillway channel increasing the forebay elevation approximately 12 feet (fig. 2). Six new generating units were added in the powerhouse (located on the left side of the dam). These modifications necessitated changing the fishways to meet the new forebay level, and fish attraction flow was increased at the lower end of the left (looking downstream) ladder to counteract the effect of increased flow from the turbine units. Although fishery agencies requested changes at the lower end of the right ladder to provide better entrance conditions and additional attraction flow, nothing was done at the time. The entrance of the right ladder at three different water levels is shown in figure 3.

The Federal Power Commission, in granting a license amendment for the modification of Rock Island Dam, reserved the right to require altering the lower end of the right ladder if substantial evidence were presented that such alterations or modifications were required for effective conservation of fish life resources of the Columbia River. Any such altering was to begin before Dec. 1, 1960.

The size of anadromous fish runs passing Rock Island is shown in table 1. Fewer of the fish have used the right ladder since the dam was modified. During the period 1936–52, for example, the counts of salmon and steelhead at the three ladders were distributed as follows: Left ladder, 47.8 percent; center ladder, 22.5 percent; right ladder, 29.7 percent. For the period 1953–56 (after modification of the dam), the counts were these: Left ladder, 73.7 percent;

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center ladder, 11.6 percent; and right ladder, 14.7 percent.

This report describes tagging details and the results of experiments at Rock Island Dam to determine whether the dam caused loss or delay to these runs, and whether loss or delay was associated with the failure of fish to find and use the dam's right bank fishway.

TABLE 1.—*Chinook and sockeye salmon and steelhead trout counted at Rock Island Dam, 1933–56* [1]

Year	Number of fish counted		
	Chinook	Sockeye	Steelhead trout
1933	5,668	40,737	1,055
1934	7,115	2,227	583
1935	16,305	14,013	5,418
1936	7,290	16,500	2,373
1937	5,133	15,089	2,214
1938	5,795	17,095	2,399
1939 [2]	11,206	19,591	5,425
1940	9,512	27,008	5,220
1941	2,507	903	3,513
1942	6,833	16,340	3,693
1943	11,129	17,522	2,315
1944	3,364	5,035	1,338
1945	5,699	7,148	1,118
1946	9,981	45,030	1,779
1947	11,717	79,831	1,971
1948	7,083	84,184	2,360
1949	12,353	18,600	2,470
1950	10,348	50,134	1,852
1951	18,752	101,826	3,121
1952	20,121	114,349	2,883
1953	31,080	151,747	4,001
1954	33,283	91,234	5,406
1955	25,658	155,055	3,141
1956	25,085	92,443	1,540

[1] Silver salmon (*O. kisutch*) averaged about 60 fish per year during this period.
[2] Grand Coulee Dam blocked upriver migration commencing this year.

METHOD OF TAGGING

Preliminary experiments on tagging and methods of catching salmon were performed in 1953 followed by full-scale experiments in 1954 through 1956 on chinook (*Oncorhynchus tshawytscha*) and sockeye salmon (*O. nerka*). We planned to tag steelhead trout (*Salmo gairdneri*) but too few (17 to 32 each year) were captured and tagged for subsequent analysis.

Salmon were trapped at the upstream edge of the counting boards within the left and right fishways and at the upstream outlet of the left ladder. (Earlier attempts to catch quantities of fish for tagging below the dam were unsuccessful.) The trapped fish were transferred to tank trucks and hauled to the tagging sites located approximately 1,000 feet below the dam on each side of the river in 1954 and 1955. In 1956, tagged salmon were released off the downstream face of the dam close to the left or right ladder. The fish

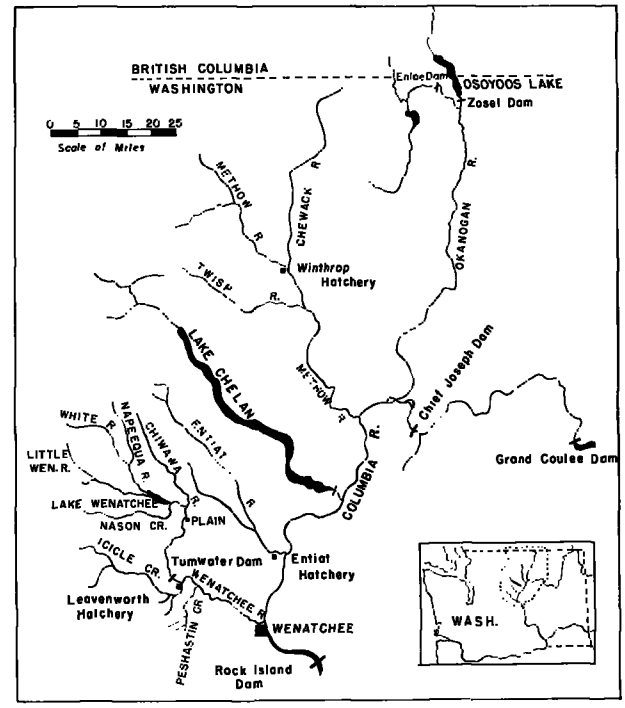

FIGURE 1.—Columbia River watershead between Rock Island and Grand Coulee Dams.

were lowered to water level in canvas bags filled with water (fig. 4). Forebay tag releases were from a trap located at the left ladder exit, and at sites on both sides of the river about 1 mile above the dam.

Various tag colors or shapes were used for the experiments at Rock Island Dam (fig. 5). Tags applied in the forebay differed from those used below the dam. Serially numbered plastic disks in combination with plastic bars formed one series of combinations, and serially numbered plastic disks with vinyl tubing and vinyl-coated nylon formed another series used below the dam. These were attached to each fish by nickel pins inserted through the body just below the dorsal fin. All tags were applied in pairs so that the same color or kind of tag showed on both sides of the fish. During 1954–55, the salmon were tagged while held in canvas-lined, cradle-type boxes. In 1956, the boxes were filled with water and the salmon were held under water during tagging.

Fish counters at the dam identified and recorded the tags as tagged fish crossed the counting boards. Display boards containing all tag samples were

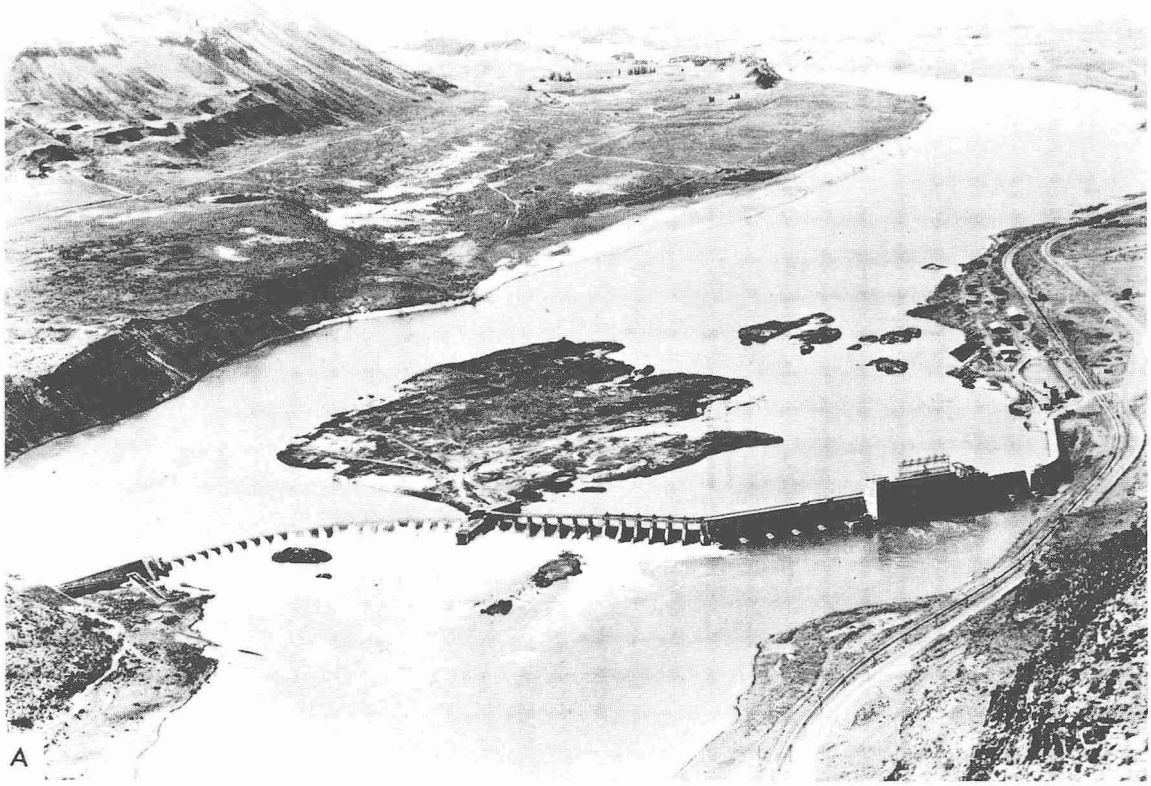

FIGURE 2a.—Rock Island Dam before modification.

placed in the counting rooms for reference but counters were not told of the tag applied each day.

Upstream tag recoveries were made from spawning ground surveys, at fish hatcheries, and from fish counters' observations at Tumwater and Zosel Dams (fig. 1). As different colors and combinations of tags were used for each experiment, a tag observed on a live fish provided the same information as an actual recovery, except for the identity of the particular fish. Therefore, upstream tag recoveries include both visual observations of tags and actual recoveries.

To determine mortalities at the dam, we analyzed and compared the percentage tag returns at Rock Island from releases below the left and right bank ladders; for upstream tag returns we compared recovery ratios from the different release areas above and below the dam. In addition, percentage tag returns from the two release areas below the dam were compared by date of tagging and by volume of water flow at Rock Island. To determine delay we computed the elapsed day-out (number of days between tagging and subsequent tag observations) periods of tag returns at Rock Island; for upstream returns we computed the difference in day-out periods for releases above and below the dam.

ESTIMATION OF TOTAL UPSTREAM RECOVERIES OF TAGGED SOCKEYE

Upstream tag recoveries and observations for the 1954–56 individual sockeye experiments at Rock Island are given in table 2. The numbers of tagged fish released are given by date, location, and age group. Releases at the four locations in the vicinity of the dam were designated as follows: below dam, left bank; below dam, right bank; above dam, left bank; above dam, right bank. The two age groups represented in the releases of tagged fish were 3-year-old sockeye, recognized by their small size, and sockeye over 3 years old. Most of the fish in the latter group were 4 years old; hence, this group is designated as 4-year-old sockeye.

The recoveries from each release lot are given by area of recovery above the dam: (1) Tumwater

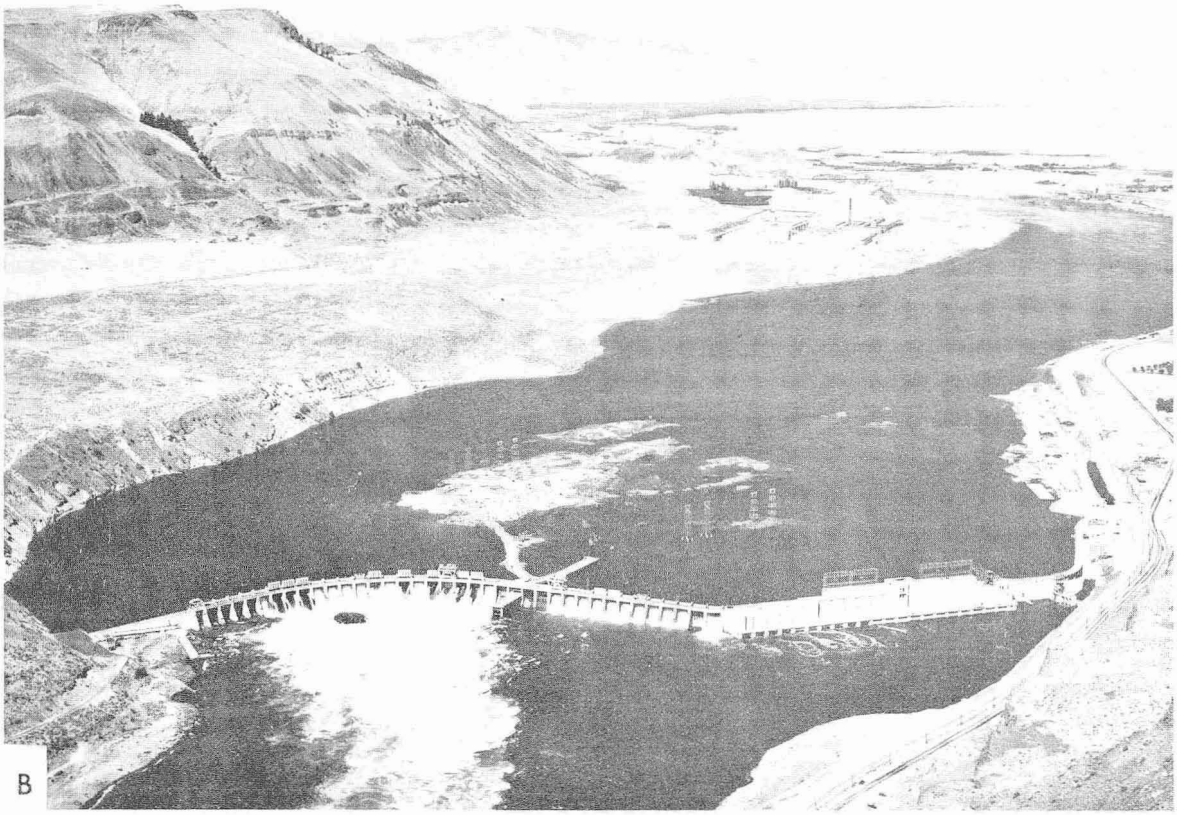

FIGURE 2b.—Rock Island Dam after modification.

Dam on the Wenatchee River; (2) Zosel Dam on the Okanogan River; (3) Okanogan River spawning grounds above Zosel Dam; and (4) all other areas combined.

In addition to the recovered tagged fish, numerous tagged sockeye were observed, but not recovered, in the recovery areas. These could be assigned to tagging date and release location, because different color combinations of tags were used for different release date-location combinations. They could not be individually assigned to age groups, however, hence, it is necessary to estimate the age composition of the tagged fish observed.

Spawning ground surveys of the Columbia River tributaries above Rock Island Dam indicated that 3-year-old sockeye migrate only to the Okanogan system, where they are found in varying numbers and proportions. On the basis of these surveys, together with the absence of recoveries of tagged 3-year-old sockeye in recovery areas 1 and 4, it is reasonable to assume that all the tagged fish observed in recovery areas 1 and 4 were 4-year-old sockeye.

The age composition of the tagged fish observed in recovery areas 2 and 3 can be estimated from proportions of 3-year-old sockeye in the recoveries from areas 2 and 3. Multiplying the proportions of 3-year-old sockeye in the recovery samples by the number of tagged fish observed provides estimates of the numbers of 3-year-old sockeye among the tagged fish observed. The numbers of 4-year-old sockeye among the tagged fish observed are obtained by subtraction. Table 3 shows the estimated numbers of 3- and 4-year-old sockeye observed in recovery areas 2 and 3.

In a number of instances, tagged sockeye recovered at Zosel Dam (recovery area 2) and released again after being checked for tag number and tag color were recovered a second time on the spawning grounds above Zosel Dam (recovery area 3). It is likely, therefore, that other tagged fish recovered or observed at Zosel Dam also were observed or recovered in recovery area 3. It is likely also that some tagged fish observed on the

spawning grounds subsequently were recovered. Such double recoveries or observations result in a tagged fish being counted two or more times in recovery areas 2 and 3.

To estimate the number of tagged individuals in the recovery-observations totals, we use the following expression:

$$S=R_2+R_3+O_2+O_3-R_{23}$$

$$-\frac{R_{23}}{R_2}(O_2)-\left(\frac{O_3}{R_3}\right)\left(\frac{R_{23}}{R_2}\right)(R_2+O_2)$$

Where, for each tag release group (age-release area-year combination),

R_2=number of tagged fish recovered at Zosel Dam
R_3=number of tagged fish recovered in area 3
O_2=number of tagged fish observed at Zosel Dam
O_3=number of tagged fish observed in area 3
R_{23}=number of tagged fish recovered at Zosel Dam and also in area 3

The first negative term corrects for double recoveries of tagged fish; the second negative term corrects for recoveries in area 3 of tagged fish observed at Zosel Dam; the last negative term corrects for observations in area 3 of tagged fish recovered or observed at Zosel Dam. The quantity, S, is referred to as the estimated total single recoveries.

Table 4 shows the recoveries, double recoveries, observations, estimated duplicate recovery-observations, and estimated total single recoveries for each release group.

TABLE 2.—*Sockeye salmon tagging data at Rock Island Dam*

[1954]

Area and date	Number released [1]			Number recovered								Number observed, age undetermined			
				3-year				4-year							
				Area of recovery				Area of recovery				Area where observed			
				1	2	3	4	1	2	3	4	1	2	3	4
Below dam, left bank:															
July 16	44	(2	42)	0	1	0	0	2	3	3	0	1	3	0	0
20	73	(7	66)	0	3	0	0	5	4	6	0	3	4	0	0
22	135	(27	108)	0	2	1	0	10	3	5	0	10	19	0	1
23	131	(21	110)	0	2	2	0	9	3	5	1	18	9	0	0
28	110	(20	90)	0	0	0	0	2	1	0	1	22	7	0	0
30	135	(62	73)	0	17	1	0	5	1	4	2	10	13	0	0
Aug. 6	125	(73	52)	0	6	2	0	3	0	0	1	6	16	1	0
11	31	(18	13)	0	0	0	0	2	0	0	0	1	0	2	0
13	18	(14	4)	0	1	0	0	0	0	0	1	0	2	0	0
Total	802	(244	558)	0	32	6	0	38	15	23	6	71	73	3	1
Below dam, right bank:															
July 1	1	(0	1)	0	0	0	0	0	0	0	0	0	0	0	0
7	7	(0	7)	0	0	0	0	1	0	0	0	0	0	0	1
8	14	(0	14)	0	0	0	0	0	0	0	0	1	0	1	0
21	126	(38	88)	0	2	0	0	2	3	2	1	7	23	1	0
22	25	(4	21)	0	0	0	0	1	0	0	1	2	2	1	0
27	83	(37	46)	0	2	1	0	0	0	1	1	10	18	0	0
29	63	(17	46)	9	4	1	0	3	1	0	1	6	9	0	0
Aug. 3	89	(43	46)	0	5	1	0	3	0	1	2	5	11	0	0
5	139	(82	57)	0	7	1	0	1	1	3	1	8	17	0	1
10	75	(43	32)	0	2	0	0	1	2	0	1	1	2	3	0
12	43	(25	18)	0	2	1	0	0	0	0	0	2	1	0	0
17	4	(1	3)	0	0	0	0	0	0	0	0	0	0	0	0
19	1	(0	1)	0	0	0	0	0	0	0	0	0	0	0	0
Total	670	(290	380)	0	24	5	0	12	7	7	8	42	83	6	2
Above dam, left bank:															
July 23	70	(14	56)	0	0	0	0	4	0	1	0	11	8	0	0
30	32	(8	24)	0	0	0	0	0	0	0	0	5	1	1	1
Aug. 4	30	(10	20)	0	0	1	0	1	0	0	0	7	4	0	0
6	13	(4	9)	0	0	0	0	0	0	0	0	1	0	0	0
13	8	(2	6)	0	0	0	0	0	0	0	1	0	0	2	0
20	2	(0	2)	0	0	0	0	0	0	0	0	0	0	0	0
27	2	(1	1)	0	0	0	0	0	0	0	0	0	0	0	0
Total	157	(39	118)	0	0	1	0	5	0	1	1	24	13	3	1
Summary:															
Below dam totals	1,472	(534	938)	0	56	11	0	50	22	30	14	113	156	9	3
Above dam totals [2]	157	(39	118)	0	0	1	0	5	0	1	1	24	13	3	1

See footnotes at end of table.

TABLE 2.—*Sockeye salmon tagging data at Rock Island Dam*—Continued

[1955]

Area and date	Number released [1]			Number recovered								Number observed, age undetermined			
				3-year				4-year							
				Area of recovery				Area of recovery				Area where observed			
				1	2	3	4	1	2	3	4	1	2	3	4
Below dam, left bank:															
July 21	59	(0	59)	0	0	0	0	9	2	8	0	1	0	2	0
26	111	(3	108)	0	0	1	0	14	2	9	1	3	0	1	1
28	95	(4	91)	0	0	0	0	24	1	5	0	2	0	1	1
29	92	(4	88)	0	0	0	0	20	3	4	1	1	0	1	0
Aug. 2	50	(3	47)	0	1	0	0	4	0	3	1	0	0	0	1
3	79	(3	76)	0	0	0	0	26	4	3	0	6	1	1	0
5	71	(11	60)	0	3	0	0	12	4	2	2	3	0	3	0
10	22	(4	18)	0	1	0	0	2	1	0	0	3	0	0	0
Total	579	(32	547)	0	5	1	0	111	17	34	5	19	1	9	3
Below dam, right bank:															
July 19	67	(1	66)	0	0	0	0	4	1	11	0	2	2	1	0
20	55	(2	53)	0	1	0	0	2	3	9	1	1	2	0	0
22	45	(4	41)	0	2	0	0	6	0	3	0	2	0	1	0
26	78	(5	73)	0	0	0	0	10	5	4	0	3	0	3	0
27	73	(3	70)	0	0	0	0	12	2	8	2	3	1	0	0
28	76	(5	71)	0	0	1	0	4	4	9	3	4	1	2	0
Aug. 2	24	(5	19)	0	0	0	0	4	1	1	0	1	0	1	0
4	101	(14	87)	0	1	0	0	16	5	1	1	1	0	2	0
9	41	(5	36)	0	0	0	0	6	1	2	0	2	0	0	1
11	37	(9	28)	0	1	0	0	5	0	0	0	3	0	0	0
Total	597	(53	544)	0	5	1	0	69	22	48	7	22	6	10	1
Above dam, left bank:															
July 21	61	(1	60)	0	0	0	0	8	4	8	1	7	0	0	0
29	60	(3	57)	0	0	0	0	5	2	5	0	2	0	2	0
Aug. 3	64	(1	63)	0	0	0	0	14	3	1	2	5	0	1	0
5	8	(1	7)	0	0	0	0	1	0	1	0	0	1	1	0
12	17	(5	12)	0	0	0	0	1	0	0	0	0	0	1	0
Total	210	(11	199)	0	0	0	0	29	9	15	3	14	1	5	0
Above dam, right bank:															
July 20	44	(1	43)	0	0	0	0	1	6	5	0	5	2	1	1
22	49	(2	47)	0	0	0	0	3	1	5	1	3	0	1	0
27	50	(3	47)	0	0	0	0	5	0	6	0	0	0	1	0
Total	143	(6	137)	0	0	0	0	9	7	16	1	8	2	3	1
Summary:															
Below dam total	1,176	(85	1,091)	0	10	2	0	180	39	82	12	41	7	19	4
Above dam total	353	(17	336)	0	0	0	0	38	16	31	4	22	3	8	1
[1956]															
Below dam, left bank:															
July 13	90	(1	89)	0	0	0	0	13	0	5	2	7	1	2	0
19	75	(15	60)	0	0	1	0	10	1	5	0	2	0	2	0
28	91	(38	53)	0	1	1	0	26	0	1	0	2	2	0	1
25	47	(9	38)	0	0	0	0	8	0	1	1	2	0	3	1
Aug. 1	41	(19	22)	0	0	1	0	4	1	1	0	0	2	0	0
3	49	(27	22)	0	2	0	0	2	0	0	1	3	2	4	0
Total	393	(109	284)	0	3	3	0	63	2	13	4	16	7	11	2
Below dam, right bank:															
July 10	24	(0	24)	0	0	0	0	2	0	0	1	1	0	3	0
12	20	(0	20)	0	0	0	0	0	0	0	0	0	0	5	0
17	80	(4	76)	0	0	0	0	10	0	5	0	3	1	9	0
24	75	(34	41)	0	2	2	0	15	0	2	0	1	0	1	0
26	96	(30	66)	0	0	0	0	27	0	2	0	2	0	1	0
31	33	(15	18)	0	0	1	0	4	0	0	0	1	1	2	0
Aug. 2	30	(24	6)	0	2	1	0	2	0	0	0	0	2	0	0
Total	358	(107	251)	0	4	4	0	60	0	9	1	7	4	21	0
Above dam, left bank:															
July 11	41	(0	41)	0	0	0	0	3	0	5	1	5	0	0	0
20	98	(21	77)	0	0	0	0	30	0	3	2	5	0	0	0
25	90	(36	54)	0	1	0	0	15	0	3	0	6	1	0	0
27	73	(26	47)	0	1	2	0	21	0	0	1	2	0	1	1
31	35	(19	16)	0	2	0	0	4	0	0	1	1	1	1	0
Aug. 1	19	(5	14)	0	0	1	0	5	0	0	0	0	0	0	0
2	46	(25	21)	0	1	1	0	4	0	0	0	0	1	1	1
Total	402	(132	270)	0	5	4	0	82	0	11	5	19	3	3	2
Above dam, right bank:															
July 18	19	(3	16)	0	0	0	0	3	0	1	0	0	0	0	0
Total	19	(3	16)	0	0	0	0	3	0	1	0	0	0	0	0
Summary:															
Below dam totals	751	(216	535)	0	7	7	0	123	2	22	5	23	11	32	2
Above dam totals	421	(135	286)	0	5	4	0	85	0	2	5	3	19	3	2

[1] Figures in parentheses represent the number of 3- and 4-year-old fish, respectively, making up the total.
[2] No tagged fish were released above dam, right bank, in 1954.

Table 5 contains a summary of releases of tagged sockeye by age group and release area and recoveries at Tumwater Dam, in the Okanogan River, and in other areas combined. The estimated total recoveries of 3- and 4-year-old tagged sockeye in the Okanogan system also are shown.

DETERMINATION OF MORTALITIES AT ROCK ISLAND

If there were a substantial loss of fish below Rock Island Dam, whether caused by a failure of fish to find a fish ladder or for other reasons, there should be a greater upstream recovery of fish tagged and released above the dam than of fish similarly tagged and released below the dam. Mortalities also should be reflected by the number of tagged fish passing the dam compared to the number released. We found, as shown later, that the fish counters' records of tagged fish passing Rock Island Dam from releases below the dam did not give completely reliable data on fish mortalities (assuming unaccounted-for tags as mortalities caused by the dam). Results of the upstream tag recovery comparisons are presented first, followed by the results obtained at Rock Island Dam.

RETURNS FROM UPSTREAM

Sockeye

Analysis of the tagging data to estimate mortalities is complicated by the presence of different races of sockeye in the tagging groups, by different age groups, and by the unequal effort expended recovering tags from different races and age groups. The sockeye run separates a short distance above Rock Island Dam, with some fish going into the Wenatchee River system and some fish up the Columbia River to the Okanogan River system. A few sockeye show up at the Entiat and Winthrop fish hatcheries and in Icicle Creek below the Leavenworth fish hatchery. As stated previously, 3-year-old sockeye are restricted to the Okanogan system and 4-year-old fish are found in all areas. We could effectively observe or recover all tagged fish passing Tumwater Dam on the Wenatchee River while on the way to spawning areas. In the Okanogan system, however, tag recoveries were made during stream surveys of the spawning areas and sampling at Zosel Dam on the Okanogan River, Thus, the recovery effort for tags on fish in the Wenatchee and Okanogan systems was not equal. Adding to these complications is the very probable loss of some tagged fish due to a tagging mortality or to straying.

Taking a simple approach, we have estimated the mortality rates from the ratios of the recovery proportions of tagged fish recovered from above- and below-dam releases. We made the following general assumptions: (1) The chance of recovering tagged fish is the same regardless of tagging date and tagging site, (2) racial proportions in the tagging lots are the same for the different areas of release, and (3) the chance of a tag recovery or observation is independent of tag type or color.

TABLE 3.—*Estimated numbers of 3- and 4-year-old tagged sockeye salmon in recovery areas 2 and 3, by year and release area*

Year and release area	Recovery Area 2										Recovery Area 3									
	Number recovered			Percent 3's	Number observed	Estimated numbers observed		Estimated totals			Number recovered			Percent 3's	Number observed	Estimated numbers observed		Estimated totals		
	3's	4's	Total			3's	4's	3's	4's	Totals	3's	4's	Total			3's	4's	3's	4's	Total
1954																				
Below dam, left bank	32	15	47	68	73	50	23	82	38	120	6	23	29	21	3	1	2	7	25	32
Below dam, right bank	24	7	31	77	83	64	19	88	26	114	5	7	12	42	6	2	4	7	11	18
Above dam, left bank	0	0	0	-------	13	~7	~6	7	6	13	1	1	2	50	3	1	2	2	3	5
1955																				
Below dam, left bank	5	17	22	23	1	0	1	5	18	23	1	34	35	3	9	0	9	1	43	44
Below dam, right bank	5	22	27	18	6	1	5	6	27	33	1	48	49	2	10	0	10	1	58	59
Above dam, left bank	0	9	9	0	1	0	1	0	10	10	0	15	15	0	5	0	5	0	20	20
Above dam, right bank	0	7	7	0	2	0	2	0	9	9	0	16	16	0	3	0	3	0	19	19
1956																				
Below dam, left bank	3	2	5	60	7	4	3	7	5	12	3	13	16	19	11	2	9	5	22	27
Below dam, right bank	4	0	4	100	4	4	0	8	0	8	4	9	13	31	21	6	15	10	24	34
Above dam, left bank	5	0	5	100	3	3	0	8	0	8	4	11	15	27	3	1	2	5	13	18
Above dam, right bank	0	0	0	-------	0	0	0	0	0	0	0	1	1	0	0	0	0	0	1	1

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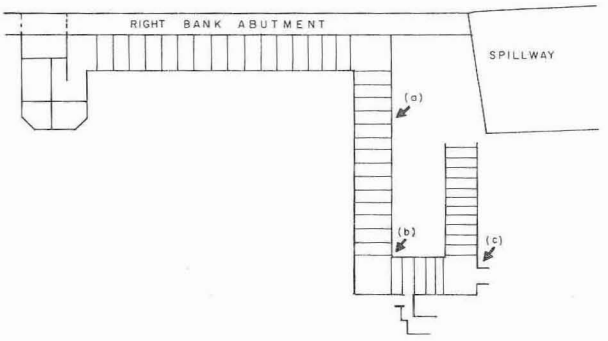


FIGURE 3.—Lower end of right ladder at different water levels. Diagrammatic sketch shows photo areas: (a) high flows; (b) intermediate flows; and (c) low flows.

The estimating equation for survival rate (k) is given by

$$\frac{R_b/T_b}{R_a/T_a}$$

where

T_b=Number of tagged fish released below dam

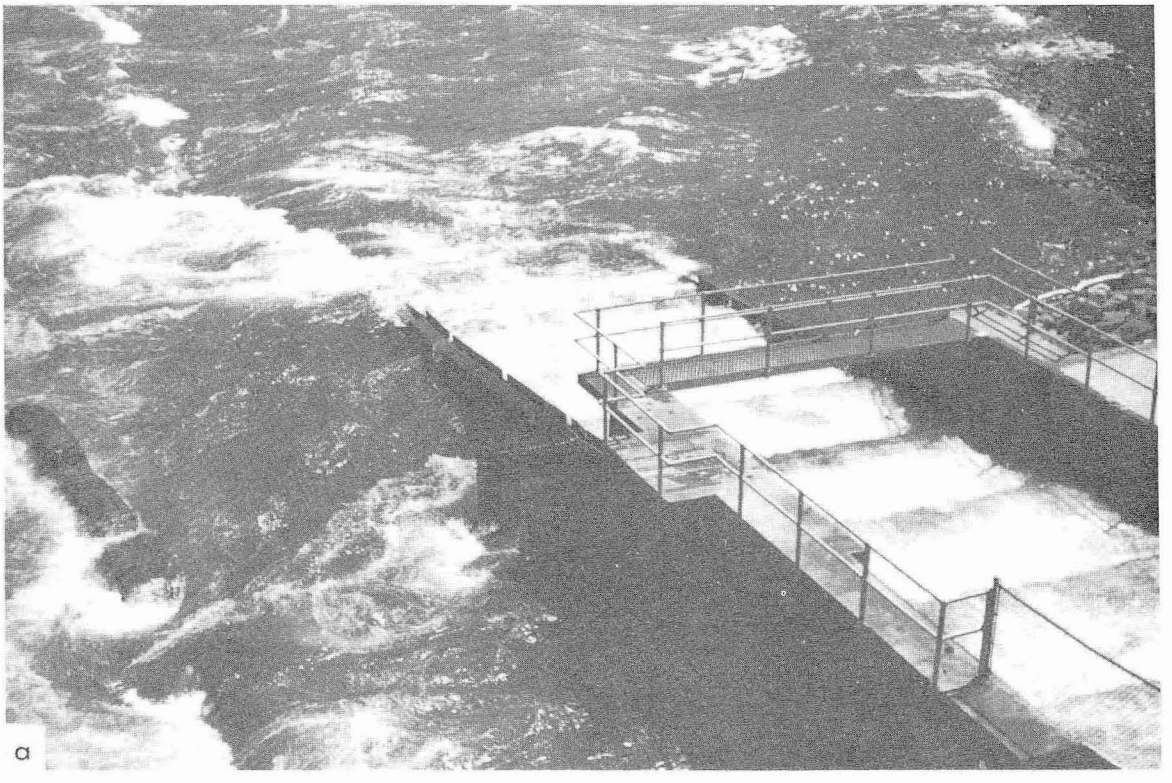
R_b=Number of tagged fish recovered from T_b

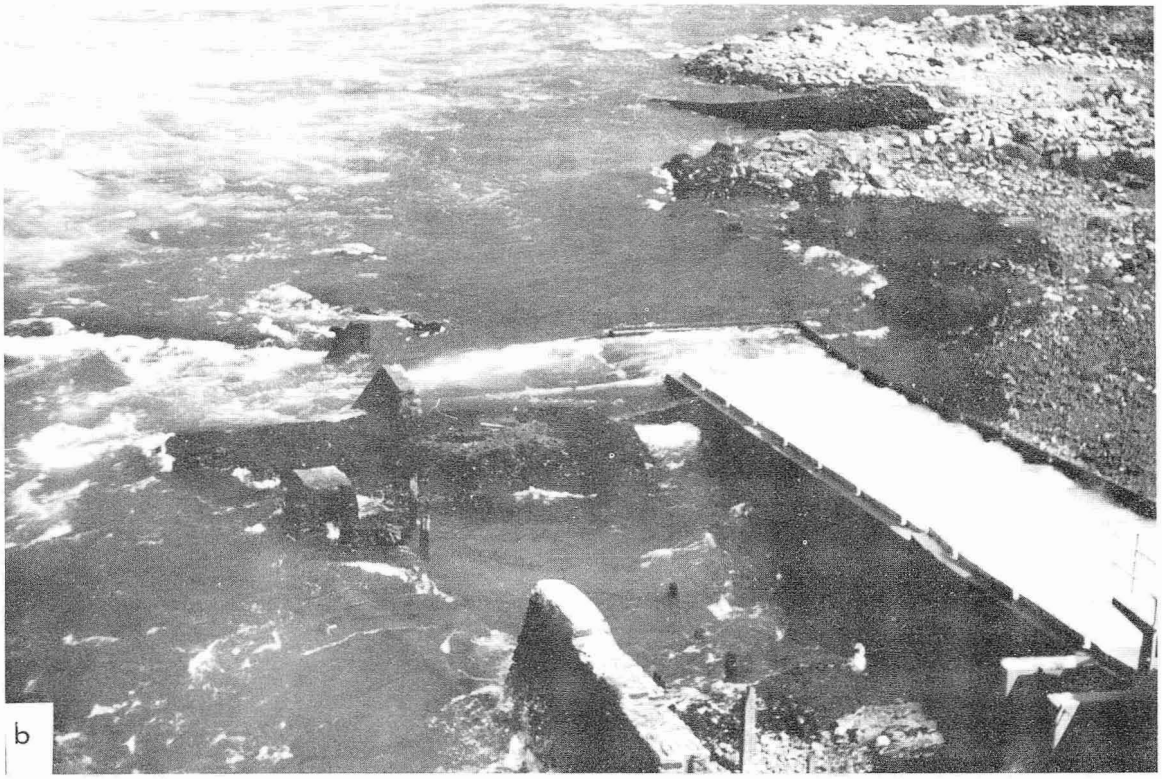
T_a=Number of tagged fish released above the dam

R_a=Number of tagged fish recovered from T_a

If the value of the ratio is one then mortality is zero. Where the value of this ratio is less than one, then the corresponding mortality rate is given by $1-k$.

The results of tagging experiments on the 3-year-old sockeye are shown in table 6. It is apparent that too few 3-year-old sockeye were tagged above the dam to afford meaningful comparisons between above and below dam experiments and to give estimates of mortality rates. No mortalities were evident from the limited data available. A comparison of the recovery proportions of tagged fish released below the left and right fishways shows right bank releases having a higher recovery rate in 2 of the 3 years. For all years combined the two recovery rates were nearly identical.





b

c

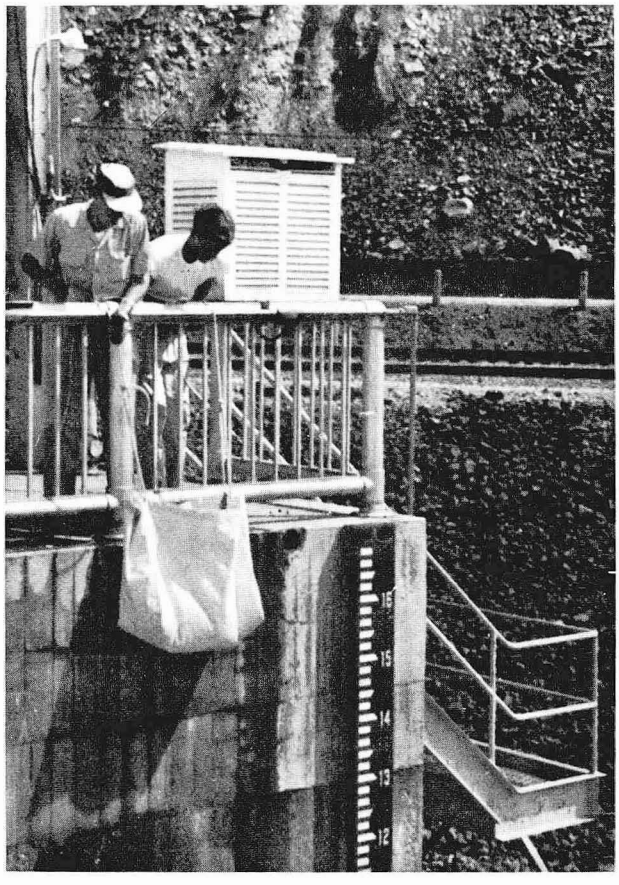


FIGURE 4.—Lowering tagged fish off the deck of the dam.

In table 7 are listed the estimates of mortalities based on all 4-year-old sockeye recoveries.

Compared with the proportions of tagged fish recovered from the area AL (left bank above the dam) releases, tagged fish released on the left bank below the dam suffered mortalities of about 10, 6, and 16 percent in 1954, 1955, and 1956, respectively. Tagged fish released on the right bank below the dam suffered mortalities of about 22, 12, and 18 percent in the corresponding years. We would conclude from these point estimates that tagged fish released below the dam suffered a mortality due to the dam, and that the mortality rate was greater for fish released on the right bank below the dam than for fish released on the left bank below the dam.

Compared with the proportions of tagged fish recovered from the AR (right bank above the dam) releases, tagged fish released on the left bank below the dam suffered no mortality due to the dam in either 1955 or 1956. Neither did tagged fish released on the right bank below the dam. The point estimates for 1956, it should be recognized, are based on a release of only 16 fish in area AR.

In combining the data for the 3 years, we could conclude, on the basis of recoveries from area AL releases, that tagged fish released on the left bank below the dam suffered a mortality of about 16 percent because of the dam, and that tagged fish released on the right bank below the dam suffered a mortality of about 21 percent because of the dam. Little or no mortality was indicated on the basis of releases in area AR (0 and 2 percent).

When comparing proportions of tagged fish recovered from total releases below the dam with all releases above the dam, we obtained point estimates of mortalities due to the dam of about 15 percent in 1954, 4 percent in 1955, 15 percent in 1956, and 15 percent for all years.

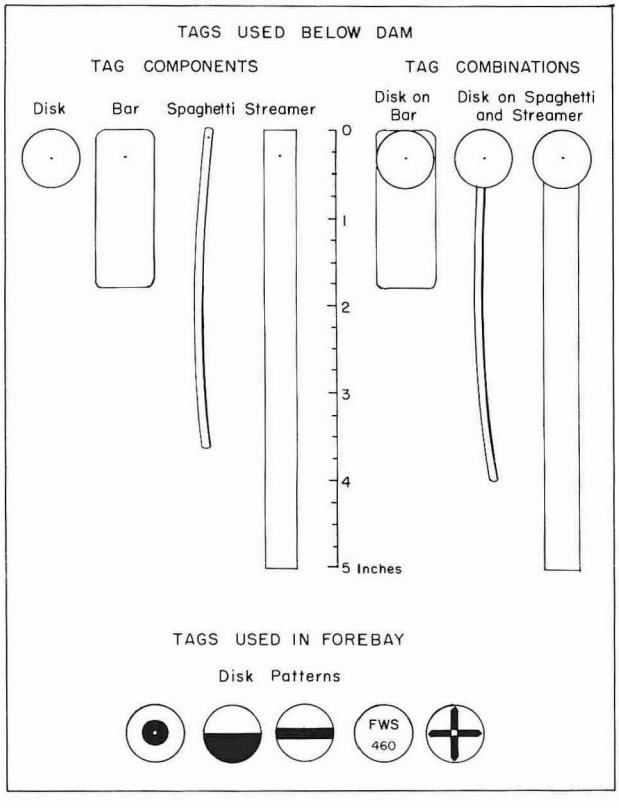


FIGURE 5.—Kinds of tags used during the Rock Island tagging experiments.

TABLE 4.—*Estimates of total single recoveries in the Okanogan system by age group and release area, Rock Island Dam sockeye tagging, 1954–56*

Year and release area	Number recovered area 2 (R_2)	Number recovered area 3 (R_3)	Number observed area 2 (O_2)	Number observed area 3 (O_3)	$R_2+R_3+O_2+O_3$	Number recovered second time in area 3 (R_{23})	$\frac{R_{23}}{R_2}(O_2)$	$\frac{O_2}{R_3}\left(\frac{R_{23}}{R_2}\right)(R_2+O_2)$	Total correction	Estimated total single recoveries (S)
	3-year-old sockeye									
1954										
Below dam, left bank	32	6	50	1	89	1	2	0	3	86
Below dam, right bank	24	5	64	2	95	0	0	0	0	95
Above dam, left bank	0	1	7	1	9	0	0	0	0	9
1955										
Below dam, left bank	5	1	0	0	6	0	0	0	0	6
Below dam, right bank	5	1	1	0	7	0	0	0	0	7
Above dam, left bank	0	0	0	0	0	0	0	0	0	0
Above dam, right bank	0	0	0	0	0	0	0	0	0	0
1956										
Below dam, left bank	3	3	4	2	12	0	0	0	0	12
Below dam, right bank	4	4	4	6	18	0	0	0	0	18
Above dam, left bank	5	4	3	1	13	0	0	0	0	13
Above dam, right bank	0	0	0	0	0	0	0	0	0	0
	4-year-old sockeye									
1954										
Below dam, left bank	15	23	23	2	63	3	5	1	9	54
Below dam, right bank	7	7	19	4	37	0	0	0	0	37
Above dam, left bank	0	1	6	2	9	0	0	0	0	9
1955										
Below dam, left bank	17	34	1	9	61	2	0	1	3	58
Below dam, right bank	22	48	5	10	85	1	0	0	1	84
Above dam, left bank	9	15	1	5	30	0	0	0	0	30
Above dam, right bank	7	16	2	3	28	1	0	0	1	27
1956										
Below dam, left bank	2	13	3	9	27	1	2	2	5	22
Below dam, right bank	0	9	0	15	24	0	0	0	0	24
Above dam, left bank	0	11	0	2	13	0	0	0	0	13
Above dam, right bank	0	1	0	0	1	0	0	0	0	1

We observe from the estimated confidence limits that the lower limits bracket zero in most instances and range to about 5 percent. The upper limits range from 20 to about 46 percent.

Another procedure was to estimate mortality rates based on recoveries of 4-year-old sockeye at Tumwater Dam (table 8). Compared with the proportions of tagged fish recovered from area AL (left bank above the dam) releases, tagged fish from left bank-below releases suffered mortalities of about 21, 0, and 26 percent, respectively, for 1954, 1955, and 1956. Tagged fish released on the right bank below the dam suffered mortalities of about 42, 23, and 29 percent, respectively, for the same 3 years.

Compared with the proportions of tagged fish recovered from the area AR releases (right bank above the dam), the tagged fish released at the right and left banks below the dam suffered no mortalities.

Combining the data for the 3 years, we observe on the basis of area AL releases that tagged fish released below the left fishway suffered a mortality of about 22 percent and that tagged fish released below the right bank fishway suffered a mortality of about 39 percent. No mortality was indicated on the basis of releases in area AR; however, comparatively few fish were released there.

Point estimates of mortality rates, obtained from comparisons of proportions of tagged fish recovered from total releases below the dam with all releases above the dam are about 29 percent in 1954, 0 percent in 1955, 25 percent in 1956, and 21 percent for all years.

Considering the confidence limits of these mortality rates based on Tumwater Dam recoveries, we observe the lower limits to bracket zero in two instances and range to 28 percent. The upper limits range from about 32 to 66 percent.

It is readily apparent that the analyses of the sockeye tagging data gave conflicting results of mortalities caused by the dam. On the one hand, many experiments indicated substantial mortalities, and mortalities apparently were greater for fish released below the right bank fishway. On

TABLE 5.—*Summary of Rock Island Dam sockeye tagging data by age group, 1954–56*

Year and release area	Total number released	3-year-old sockeye		4-year-old sockeye				Estimated total Okanogan recoveries
		Number released	Estimated number recovered in Okanogan	Number released	Number recovered			
					Tumwater	Estimated in Okanogan	Other areas	
1954								
Below dam, left bank	802	244	86	558	109	54	7	140
Below dam, right bank	670	290	95	380	54	37	10	132
Total	1,472	534	181	938	163	91	17	272
Above dam, left bank	157	39	9	118	29	9	2	18
Total	157	39	9	118	29	9	2	18
1955								
Below dam, left bank	579	32	6	547	130	58	8	64
Below dam, right bank	597	53	7	544	91	84	8	91
Total	1,176	85	13	1,091	221	142	16	155
Above dam, left bank	210	11	0	199	43	30	3	30
Above dam, right bank	143	6	0	137	17	27	2	27
Total	353	17	0	336	60	57	5	57
1956								
Below dam, left bank	393	109	12	284	79	22	6	34
Below dam, right bank	358	107	18	251	67	24	1	42
Total	751	216	30	535	146	46	7	76
Above dam, left bank	402	132	13	270	101	13	7	26
Above dam, right bank	19	3	0	16	3	1	0	1
Total	421	135	13	286	104	14	7	27
Totals 1954–55–56								
Below dam, left bank	1,774	385	104	1,389	318	134	21	238
Below dam, right bank	1,625	450	120	1,175	212	145	19	265
Total	3,399	835	224	2,564	530	279	40	503
Above dam, left bank	769	182	22	587	173	52	12	74
Above dam, right bank	162	9	0	153	20	28	2	28
Total	931	191	22	740	193	80	14	102

the other hand, many of the experiments indicated no mortalities caused by the dam.

Returns from below the dam by date of tagging.—The upstream recoveries of tagged sockeye, released below the dam, indicated a fairly uniform pattern of returns for all experiments (figs. 6,7, and 8). As tagging experiments were alternated between left and right banks on alternate days, these graphs show a fairly consistent pattern of returns for both release areas and for the duration of the tagging season. The percent-recovered curve in 1954 assumed the shape of the numbers-tagged curve, with fewer returns from the tails of the experiments. Percentage returns for 1955 and 1956 show a remarkably uniform pattern. The large numbers tagged, shown for July 26 and 28 in 1955 and for July 24 in 1956, are the result of combining left and right bank experiments, as experiments were conducted on both banks on those dates. Returns of nearly 50 percent from the August 3, 1955, experiment (fig. 7) are a result of observing a large number of that day's tagged fish passing Tumwater Dam, more fish observed than for any other single experiment. It might be that this particular sample contained relatively more Wenatchee fish than the other samples.

Returns from below dam compared with water flow.—In order to determine the influence of different water levels on fish passage at Rock Island Dam, tag recoveries from releases at each bank below the dam were compared with water flow (figs. 9, 10, and 11). In general, the tag returns from both banks showed a fairly consistent pattern despite large changes in flow during the experiments.

The returns for 1954 merit attention, since fewer returns are indicated for experiments on August 10–13 during the low river flows (fig. 9). These

TABLE 6.—*Estimated mortality rates due to Rock Island Dam based on 3-year-old sockeye tag recoveries*

Year and release area	Number released	Estimate number recovered	Proportion recovered r_i	Estimate of mortality rates				
				$1-\frac{r_{BL}}{r_{AL}}$	$1-\frac{r_{BL}}{r_{AR}}$	$1-\frac{r_{BR}}{r_{AL}}$	$1-\frac{r_{BR}}{r_{AR}}$	$1-\frac{r_{BL}+r_{BR}}{r_{AL}+r_{AR}}$
1954								
Below dam, left bank	244	86	0.352	−0.524				
Below dam, right bank	290	95	.328			−0.420		
Total	534	181	.339					−0.468
Above dam, left bank	39	9	.231					
Total	39	9	.231					
1955								
Below dam, left bank	32	6	.188					
Below dam, right bank	53	7	.132					
Total	85	13	.153					
Above dam, left bank	11	0	0					
Above dam, right bank	6	0	0					
Total	17	0	0					
1956								
Below dam, left bank	109	12	.110	−.122				
Below dam, right bank	107	18	.168			−.714		
Total	216	30	.139					−.448
Above dam, left bank	132	13	.098					
Above dam, right bank	3	0	0					
Total	135	13	.096					
Totals *1954–55–56*								
Below dam, left bank	385	104	.270	−1.231				
Below dam, right bank	450	120	.267			−1.207		
Total	835	224	.268					−1.330
Above dam, left bank	182	22	.121					
Above dam, right bank	9	0	0					
Total	191	22	.115					

fewer returns undoubtedly are related to a diminished effort to recover tags from these experiments. Fish counting and tag observing were discontinued at Zosel Dam from August 20 to August 26, at a time when tagged fish were still passing and when the number of tags from the August 10–13 experiments should have peaked there. Therefore, with comparable recovery effort, tag returns from these experiments probably would have been greater than indicated. It is noted that the 1955 returns from this same time period, August 9–11, and for comparable water flows (fig. 10), were consistent with returns from earlier experiments occurring at high flows. It is evident, as shown by upstream tag returns, that changes in flows at Rock Island Dam had little effect on the ability of sockeye to pass the dam.

Chinook

In order to compare recovery ratios of chinook salmon tagged above and below the dam, it was necessary to separate the chinooks by race. Races at Rock Island Dam were reported by Fish and Hanavan (1948) as spring and summer chinook. Spring chinook, passing Rock Island Dam earlier in the season than summer chinook, migrated to smaller, more remote spawning streams. In these streams, tagged fish were much easier to observe and recover than in larger streams, such as the Wenatchee and lower Methow Rivers (the summer chinook spawning areas). Thus, recoveries from spring chinook tagging experiments were much greater than from experiments on summer chinook.

Upstream tag recoveries for all chinook experiments are given in table 9. Many samples were too small to compare returns statistically. Only in 1956 were sufficient fish obtained to release at the two banks below the dam and above the dam. Returns of spring chinooks tagged below the dam were virtually the same (27 percent) for the 3

TABLE 7.—*Estimated mortality rates due to Rock Island Dam based on total 4-year-old sockeye recoveries*

[95 percent confidence limits]

Year and release area	Number released	Estimate number recovered	Proportion recovered r_i	Estimates of mortality rates				
				$1-\frac{r_{BL}}{r_{AL}}$	$1-\frac{r_{BL}}{r_{AR}}$	$1-\frac{r_{BR}}{r_{AL}}$	$1-\frac{r_{BR}}{r_{AR}}$	$1-\frac{r_{BL}+r_{BR}}{r_{AL}+r_{AR}}$
1954								
Below dam, left bank	558	170	0.305	0.100 (−0.159 to 0.359).				
Below dam, right bank	380	101	.266			0.215 (−0.028 to 0.458).		
Total	938	271	.289					0.147 (−0.089 to 0.383).
Above dam, left bank	118	40	.339					
Total	118	40	.339					
1955								
Below dam, left bank	547	196	.358	0.064 (−0.136 to 0.264).	−0.065			
Below dam, right bank	544	183	.336			0.120 (−0.071 to 0.311).		
Total	1,091	379	.347					0.044 (−0.116 to 0.204).
Above dam, left bank	199	76	.382					
Above dam, right bank	137	46	.336					
Total	336	122	.363					
1956								
Below dam, left bank	284	107	.377	0.158 (−0.014 to 0.330).	−.508			
Below dam, right bank	251	92	.366			0.183 (0.008 to 0.358).	−0.464	
Total	535	199	.372					0.149 (0 to 0.298).
Above dam, left bank	270	121	.448					
Above dam, right bank	16	4	.250					
Total	286	125	.437					
Totals *1954–55–56*								
Below dam, left bank	1,389	473	.340	0.158 (0.053 to 0.263).	−.040			
Below dam, right bank	1,175	376	.320			0.208 (0.103 to 0.313).	0.022 (−0.221 to 0.265).	
Total	2,564	849	.331					0.147 (0.054 to 0.240).
Above dam, left bank	587	237	.404					
Above dam, right bank	153	50	.327					
Total	740	287	.388					

years. In 1956, returns from tagging at the right bank were considerably lower than those from the left bank; however, the reverse was true for 1955. No reasonable explanation can be offered for these differences. Perhaps conditions which may have caused low recoveries from the right bank one season were not present the other season, or it may have been chance that upstream recoveries varied as they did in the 2 years.

The data for 1956 indicated a loss of fish released below the right bank fishway when recovery proportions were compared to recovery proportions of fish released above the dam (19.5 percent compared to 24.4 percent). In terms of mortality rates, in the same manner as was done for the sockeye, this would indicate a 20 percent mortality for fish tagged below the right bank. No mortalities were indicated when comparing total returns from below the dam with returns from above the dam.

While summer chinook tag returns are comparatively few, the recovery ratios are consistent over the years and for the different areas of release. Only in 1954 was there an indication of mortalities for right bank tag releases (7.1 percent recovered compared with 7.8 percent recovered from above the dam). In the other 2 years there was no indication of mortalities. There was no indication

TABLE 8.—*Estimated mortality rates due to Rock Island Dam based on Wenatchee sockeye recoveries*

[95 Percent confidence limits]

Year and release area	Number released	Estimate number recovered	Proportion recovered r_i	Estimates of mortality rates and confidence limits				
				$1-\frac{r_{BL}}{r_{AL}}$	$1-\frac{r_{BL}}{r_{AR}}$	$1-\frac{r_{BR}}{r_{AL}}$	$1-\frac{r_{BR}}{r_{AR}}$	$1-\frac{r_{BL}+r_{BR}}{r_{AL}+r_{AR}}$
1954								
Below dam, left bank	558	109	0.195	0.207 (0.08 to 0.497).				
Below dam, right bank	380	54	.142			0.423 (0.186 to 0.660).		
Total	938	163	.174					0.293 (0.044 to 0.542).
Above dam, left bank	118	29	.246					
Total	118	29	.246					
1955								
Below dam, left bank	547	130	.238	−0.102	−0.919			
Below dam, right bank	544	91	.167			0.227 (−0.030 to 0.484).	−0.347	
Total	1,091	221	.203					−0.134.
Above dam, left bank	199	43	.216,					
Above dam, right bank	137	17	.124,					
Total	336	60	.179					
1956								
Below dam, left bank	284	79	.278	0.257 (0.072 to 0.442).	−.479			
Below dam, right bank	251	67	.267			0.286 (0.099 to 0.473).	−.420	
Total	535	146	.273					0.250 (0.089 to 0.411).
Above dam, left bank	270	101	.374					
Above dam, right bank	16	3	.188					
Total	286	104	.364					
Total, *1954–55–56*								
Below dam, left bank	1,389	318	.229	0.224 (0.099 to 0.349).	−.748			
Below dam, right bank	1,175	212	.180			0.390 (0.280 to 0.500).	−.374	
Total	2,564	530	.207					0.207 (0.092 to 0.322).
Above dam, left bank	587	173	.295					
Above dam, right bank	153	20	.131					
Total	740	193	.261					

TABLE 9.—*Upstream returns of tagged spring and summer chinook by area of released at Rock Island Dam, 1954–56*

Year and release area	Spring chinook			Summer chinook		
	Tagged	Recovered		Tagged	Recovered	
	Number	*Number*	*Percent*	*Number*	*Number*	*Percent*
1954						
Below dam, right bank	150	40	26.7	113	8	7.1
Below dam, left bank	------	------	------	80	7	8.8
Total below dam	150	40	26.7	193	15	7.8
Above dam	------	------	------	217	17	7.8
1955						
Below dam, right bank	122	38	31.1	66	10	15.2
Below dam, left bank	70	13	18.6	34	2	5.9
Total below dam	192	51	26.6	100	12	12.0
Above dam	3	1	33.3	99	9	9.1
1956						
Off dam, right side	159	31	19.5	92	11	12.0
Off dam, left side	154	53	34.4	113	11	9.7
Total off dam	313	84	26.8	205	22	10.7
Above dam	168	41	24.4	199	21	10.6

of mortalities when comparing total returns from above and below the dam.

In view of these similar recoveries of tagged chinook salmon released above and below Rock Island Dam, we cannot conclude that there is a substantial mortality caused by the dam. For spring chinooks, there are indications of a loss of fish released below the right bank ladder in 1956. Data are not available for determining if this loss exists for the other 2 years.

RETURNS AT ROCK ISLAND

Identity of Tags and Species

The correct identity of tag returns at Rock Island Dam depended upon the fish counters'

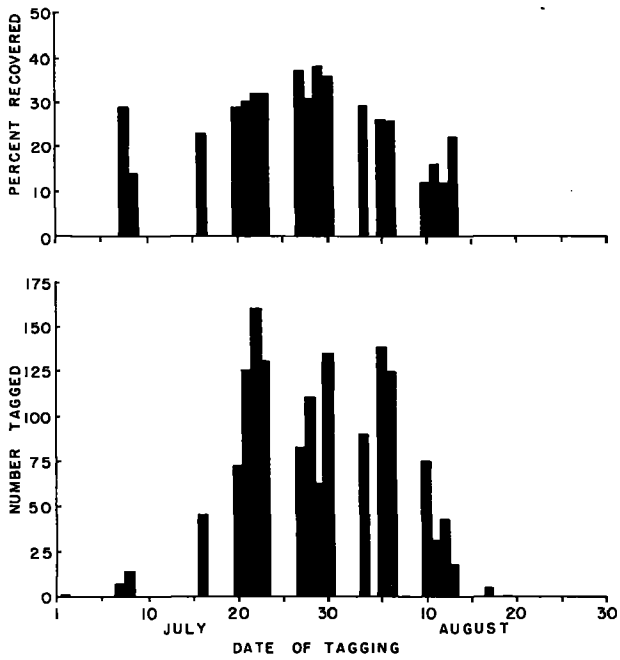


FIGURE 6.—Numbers of sockeye tagged below Rock Island Dam, and recoveries of tagged fish upstream, expressed as percentages of the number tagged each day, 1954.

identifying accurately the various tags and species of fish as the fish crossed counting boards. The tags were more difficult to identify at Rock Island than at upstream points because of the need for counting large numbers of fish while simultaneously identifying tags, and because of the speed the fish moved across the counting boards. The misidentification of both tags and species was a source of error in the Rock Island tag return data as exemplified in the following illustrations:

1. In some of the 1954 experiments, fish counters recorded as tagged species which had not been tagged. In other experiments, they recorded greater numbers of tag observations of species than fish tagged, and on several occasions they counted fewer jack chinook in the traps than were tallied during subsequent tagging. We revised our tagging procedure for some experiments in 1954 to determine the magnitude of error in species identification. Instead of tagging all species with one color combination as was usually done, we tagged the various species with different color combinations and noted the returns as identified by the counters (table 10). Many chinooks (obviously jacks) were called sockeye. Jacks are precocious male chinooks, and are similar in size to sockeye. The error in mistaking sockeye for chinooks was relatively small. No tagged steelhead were reported by the counters at Rock Island Dam; one tagged steelhead, however, was observed upstream at Tumwater Dam. Similar errors were made in 1955 and 1956, although the fish counters were asked to keep the counting boards at the minimum depth consistent with efficient fish passage. The magnitude of error was not determined for these years.

2. The disproportionate returns of the different types of tags used gave evidence of errors in tag identity at Rock Island Dam. A far greater percentage of bar tags was observed at Rock Island in 1954 and 1955 than of spaghetti tags (table 11). Upstream, however, the percentage returns of the two tags were approximately the same for both years. The streamer tag was substituted

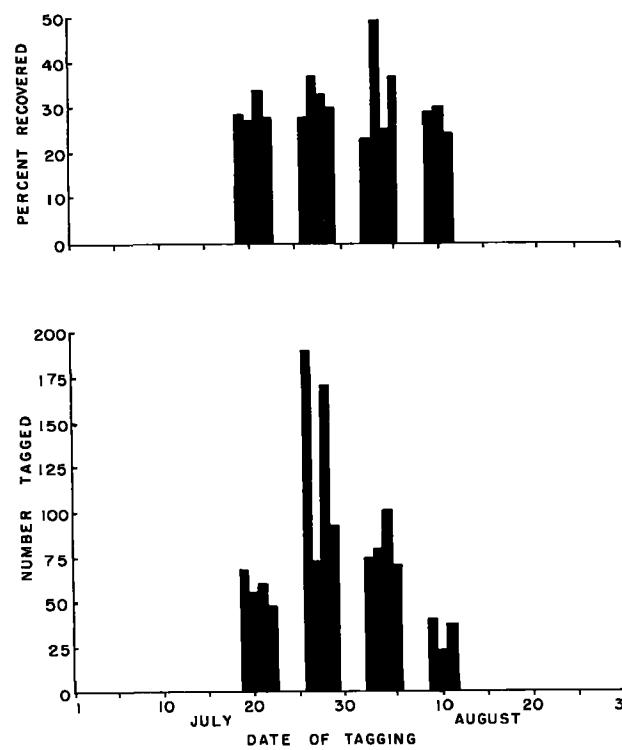


FIGURE 7.—Numbers of sockeye tagged below Rock Island Dam, and recoveries of tagged fish upstream, expressed as percentages of the number tagged each day, 1955.

for the spaghetti tag in 1956, and, as observed, returns were similar at Rock Island Dam and upstream for the two tags. It is evident, therefore, that the counters at Rock Island Dam did not discriminate between the tags in 1954 and 1955.

These errors in species and tag identification thus affected the reliability of the tag return data at Rock Island Dam, and the data must be used with caution.

TABLE 10.—*Errors in species identification at Rock Island Dam in 1954*

Species and date tagged	Tagged	Species reported by counters	Error
Chinook:	*Number*	*Number*	*Percent*
Aug. 5 [1]	6	0	
6	11	2 chinook, 4 sockeye	66.7
10	20 chinook, 2 steelhead	4 chinook, 9 sockeye	69.2
11	13 chinook, 2 steelhead	2 chinook, 10 sockeye	83.4
Total	50 chinook, 4 steelhead	10 chinook, 24 sockeye	70.5
Sockeye:			
Aug. 5	139	136 sockeye, 1 chinook	0.7
6	125	90 sockeye	0
10	75	71 sockeye [2], 8 chinook	10.1
11	31	22 sockeye, 2 chinook	8.3
Total	370	319 sockeye, 11 chinook	3.3

[1] The color and tag combination used here was also used 15 days previous. Some returns may have been attributed to the previous experiment.
[2] The total of 79 fish observed is an obvious error in tag identity.

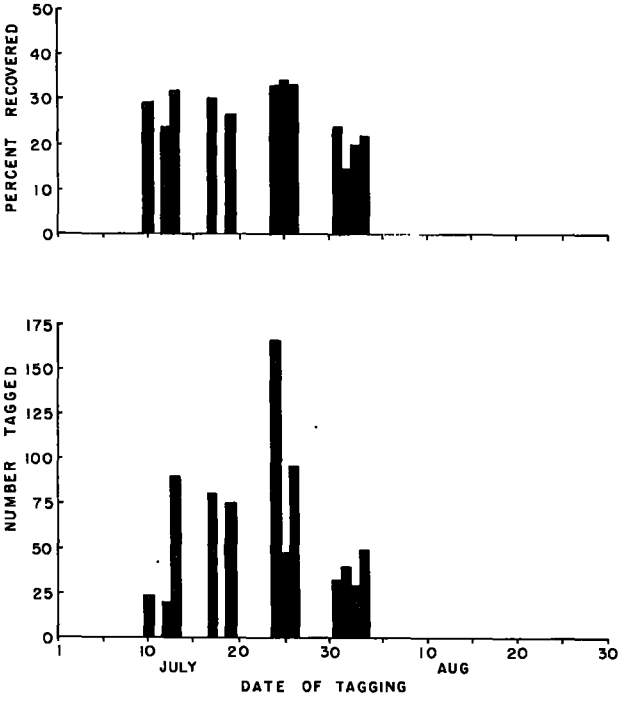


FIGURE 8.—Numbers of sockeye tagged below Rock Island Dam, and recoveries of tagged fish upstream, expressed as percentages of the number tagged each day, 1956.

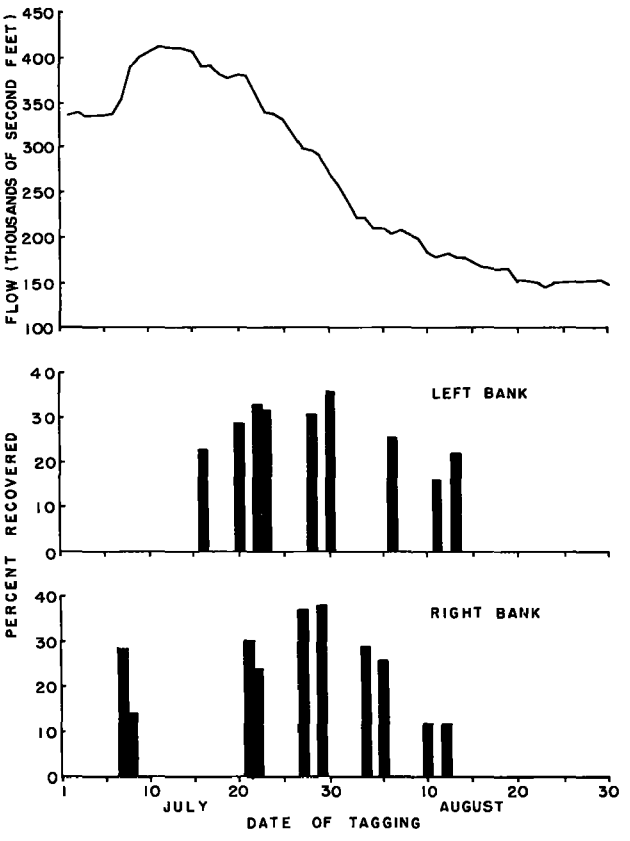


FIGURE 9.—Recoveries of tagged sockeye upstream expressed as percentages of the number tagged at each bank below, compared with water flow, 1954.

Sockeye and Chinook

The results of the fish counters' observations of tagged fish (including the few steelhead tagged) crossing the counting boards for the four seasons of tagging are shown in table 12. Although the salmon were released below the dam at various places on both sides of the river, most of the tags were observed at the left ladder. Comparatively few were recorded at the right ladder, even though roughly half of the salmon were released a short distance away. The counters observed 85 percent

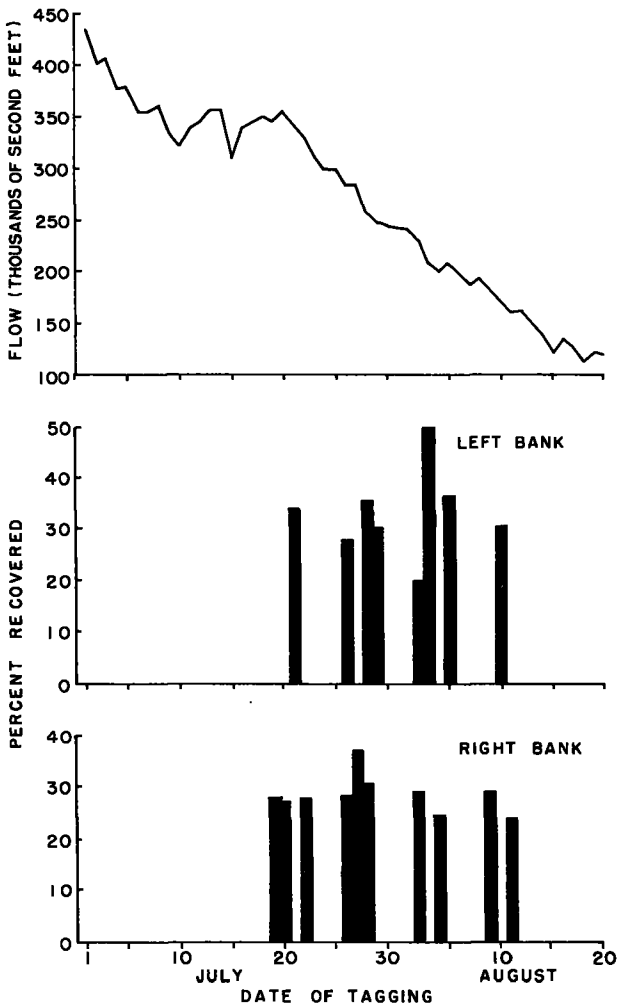


FIGURE 10.—Recoveries of tagged sockeye upstream expressed as percentages of the number tagged at each bank below, compared with water flow, 1955.

TABLE 11.—*Returns at Rock Island Dam and upstream of different kinds of tags used*

Year and kind of tag	Tagged	Returns at Rock Island		Tagged[2]	Returns upstream	
		Observed [1]			Recovered	
1954	*Number*	*Number*	*Percent*	*Number*	*Number*	*Percent*
Bar	1,284	1,121	87.3	1,260	320	25.4
Spaghetti	565	241	42.7	556	155	27.9
1955 [3]						
Bar	1,174	855	72.8	1,000	317	31.7
Spaghetti	310	123	39.7	179	50	27.9
1956						
Bar	770	671	87.1	764	197	25.8
Streamer	509	423	83.1	506	128	25.3

[1] Undetermined tag observations at Rock Island not identified as bar, spaghetti, or streamer are omitted.
[2] Steelhead and those tagged fish removed at Rock Island for other experiments were omitted from this column.
[3] Only sockeye are included in the upstream returns in 1955 because of the unequal recovery effort spent on chinooks tagged with the two kinds of tags.

of the tags at the left and center ladders for the 4 years. While only 64 to 86 percent of the fish released below the dam were observed at the counting boards, we cannot say with certainty that these missing tags indicated mortalities caused by the dam.

These are some possible reasons for the apparent tag losses:

1. Counters did not identify tagged fish crossing the counting boards.
2. Tagging harmed the fish.
3. Fish lost the tags.
4. Tagged fish refused to re-pass the dam.
5. The dam itself caused mortalities.

The counters did overlook tagged salmon. On a few occasions when the forebay trap was fished, we captured tagged fish the counters had not reported. In some experiments, we recovered more tags upstream than the counters reported at

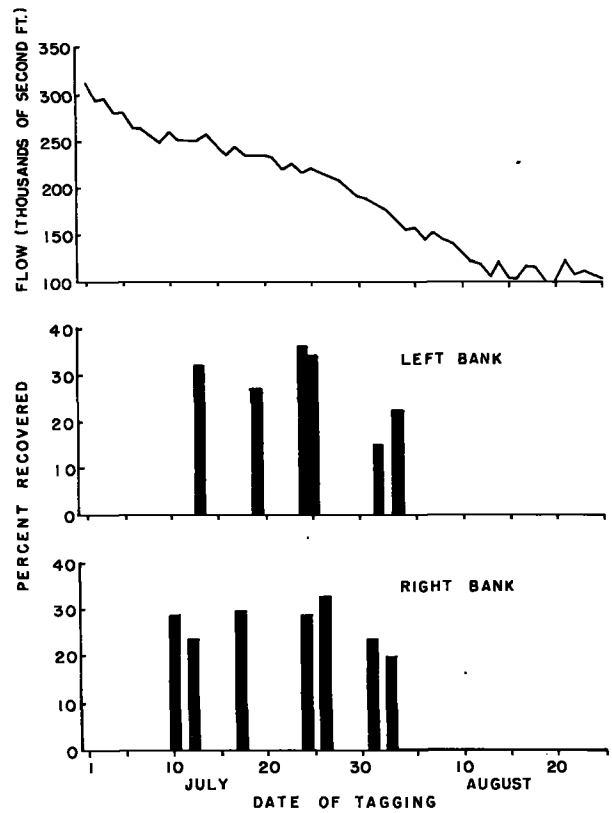


FIGURE 11.—Recoveries of tagged sockeye upstream expressed as percentages of the number tagged at each bank below, compared with water flow, 1956.

TABLE 12.—*Returns of tagged fish at Rock Island Dam by ladder, 1953–56*

Year	Tagged below Rock Island[1]	Observations by ladder						Total tag observations	
		Left		Center		Right			
	Number	Number	Percent	Number	Percent	Number	Percent	Number	Percent
1953	764	298	39.0	87	11.4	106	13.9	491	64.3
1954	1,849	788	42.6	399	21.6	188	10.2	1,375	74.4
1955	1,484	656	44.2	205	13.8	127	8.6	988	66.6
1956	1,279	724	56.6	214	16.7	156	12.2	1,094	85.5
Total	5,376	2,466	45.9	905	16.8	577	10.7	3,948	73.4

[1] Tagged members included chinook, sockeye, and steelhead.

Rock Island Dam. An illustration was the Bonneville experiment (app. p. 366) where a distinctive copper and black disk tag was used; only 6 of these tags were reported at Rock Island, but 14 were recovered upstream. In view of these examples, it was undoubtedly true that the counters missed tagged fish.

Tagging operations have caused mortalities. Schaefer (1951) concluded that there was a serious differential mortality among the tagged and untagged fish during the long migration between the Harrison trap and the Birkenhead River. Nelson[1] found a differential mortality between tagged and untagged sockeye migrating between Karluk River weir and weirs on the tributary spawning streams of Karluk Lake.

The loss of tags from tagged fish apparently was not a reason for the missing tags at Rock Island Dam. No tag-scarred salmon were reported by the counters at Rock Island Dam, and neither were any caught in the traps, though many tagged fish were captured there.

Tagged salmon may have refused to reenter the fishways after tagging. In 1956, five tagged salmon were observed in the Oregon Fish Commission's trap at McNary Dam, located approximately 160 river-miles downstream from Rock Island Dam. Also, a tagged sockeye was observed at the Redfish Lake weir in Idaho, about 700 river-miles from Rock Island Dam. Howard (1948) reported that handling during tagging operations at Cultus Lake, British Columbia, apparently caused some of the tagged sockeye to remain in the area immediately above the tagging location, rather than continue their migration. Undoubtedly some of the missing tags at Rock Island Dam could be attributed to straying.

Finally, mortalities could be caused by the dam. Mortalities were indicated for some experiments but not for others when comparing upstream recovery ratios from tagged fish released above and below the dam.

Returns by area of release.—The results of tag returns by ladder are shown in table 13. These data show a consistent pattern of passage over the ladders for the 3 years and for the two release areas. Only 6 to 12 percent of the fish used the right ladder.

The observed differences in returns from the two banks over the 3 years would indicate that right bank tag releases were not as successful in passing the dam as left bank releases.

TABLE 13.—*Tag returns by area of release and ladder, 1954–56*

Year and release area	Tagged	Observations by ladder[1]							
		Left		Center		Right		All ladders	
	Number	Number	Percent	Number	Percent	Number	Percent	Number	Percent
1954									
Right bank	950	389	40.9	192	20.2	80	8.4	661	69.6
Left bank	899	352	39.2	187	20.8	92	10.2	631	70.2
1955									
Right bank	793	311	39.2	91	11.5	47	5.9	449	56.6
Left bank	691	302	43.7	104	15.1	70	10.1	476	68.9
1956									
Right bank	616	331	53.7	94	15.3	76	12.3	501	81.3
Left bank	663	385	58.1	119	17.9	77	11.6	581	87.6

[1] Unidentifiable tags were excluded.

Since almost all of the fish were trapped in the left ladder or in the forebay trap at the head of this ladder, and since they were released at both banks below the dam, it was important to know whether these fish had learned the route for their second passage of the dam. Accordingly, the tag returns were listed by trapping site and by area of release (table 14). Regardless of where the fish were trapped or released, they returned in approximately the same ratio over the three ladders with the least returns always at the right ladder. It is evident that the salmon did not learn a route and then repeat this route for a second passage over the dam. Neither were they necessarily frightened away from a ladder, since the majority of fish returned to the left ladder, where most were trapped previously.

[1] Nelson, Philip R., unpublished data 1947 and 1948. U.S. Fish and Wildlife Service, Seattle, Wash.

TABLE 14.—*Tag returns by ladder of salmon trapped at both ladders and released at both banks below Rock Island Dam, 1954–55*

Year and trapping area	Area released	Tagged	Observations by ladder [1]					
			Left		Center		Right	
1954		*Number*	*Number*	*Percent*	*Number*	*Percent*	*Number*	*Percent*
Right ladder	Right bank	178	56	64.4	20	23.0	11	12.6
Left ladder	Right bank	748	331	57.9	172	30.1	69	12.1
Left ladder	Left bank	923	354	55.9	187	29.5	92	14.5
1955								
Right ladder	Right bank	363	169	72.5	49	21.0	15	6.4
Left ladder	Right bank	430	142	65.7	42	19.4	32	14.8
Left ladder	Left bank	691	302	63.4	104	21.8	70	14.7

[1] The percentage by ladder is based on total observations.

Tagged and untagged fish movements.—Table 15 shows the comparison of choice of ladders between tagged and untagged salmon for each season of tagging. Chinooks and sockeye were combined because of the error of confusing chinooks (jacks) with the sockeye. The percentage returns at the right ladder agreed closely with those of the untagged run. A somewhat larger proportion of the untagged run, compared with the tagged fish, chose the left ladder for passage. The percentage returns at the middle ladder were greater than the proportion of untagged fish at this ladder. This may be because right bank releases, failing to enter the right ladder, were attracted by the center ladder before the left ladder. Generally speaking, however, the tagged and untagged salmon were similar in their patterns of passage.

During the years of the tagging experiments, the four spillway regulating gates nearest the right ladder were kept closed so the high-velocity flows would not interfere with fish approaching along the right bank. In 1957, in order to test their influence on fish passage, these gates (one or more) were opened when most of the fish passed the dam. The percentage of chinooks and sockeye using this ladder in 1957 increased to 24 percent, compared to an average of 15 percent for 1953–56. This was the pattern of fish passage at the right ladder by species—chinooks, 19.8 percent; sockeye, 26.8 percent; and steelhead, 16.6 percent. No tagging was done in 1957, and a comparison of tagged fish movements could not be made. Apparently the salmons' choice of ladders can be influenced by manipulating the regulating gates and by the resulting changes in flow patterns below the dam.

TABLE 15.—Combined chinook and sockeye counts of the tag returns and the untagged runs by ladder, 1954–56

Year	Combined chinook and sockeye counts						Total
	Left ladder		Center ladder		Right ladder		
1954	*Number*	*Percent*	*Number*	*Percent*	*Number*	*Percent*	*Number*
Tagged	787	57.3	399	29.0	188	13.7	1,374
Untagged	86,439	70.0	17,144	13.9	19,892	16.1	123,475
1955							
Tagged	654	66.3	205	20.8	127	12.9	985
Untagged	139,555	77.4	22,415	12.4	18,448	10.2	180,418
1956							
Tagged	724	66.2	214	19.6	156	14.2	1,094
Untagged	88,154	75.0	18,697	15.9	10,677	9.1	117,528
Total 1954–1956.							
Tagged	2,165	62.7	818	22.7	471	13.6	3,454
Untagged	314,148	74.5	58,256	13.8	49,017	11.6	421,421

DETERMINATION OF DELAY AT ROCK ISLAND

In this paper delay means the period of time that Rock Island Dam checks the migration of salmon under present conditions.[2] Delay may cause salmon mortalities prior to spawning. Some causes of delay may be flood waters in rivers, low flows, high water temperatures, areas of difficult passage (as in precipitous canyons), or dams in rivers. Delay here is measured as days elapsing between release of tagged fish and subsequent observations at the counting boards. The delay also is assessed by comparing, at upstream points, the time of arrival of tagged fish released above and below the dam. The difference in time of arrival at an upriver point would be a measure of delay at the dam, and this difference should correspond to the delay observed at Rock Island Dam. It will be shown that this was true.

[2] An argument advanced is that studies of delays at dams should consider comparisons of travel rates before and after a dam is built. This has seldom been accomplished; subsequent to this study, comparisons of travel rates were made before and after Rocky Reach dam was built. Major, Richard L. and James L. Mighell. A study to measure delay to upstream migrating salmonids at Rocky Reach Dam. Manuscript. Bureau of Commercial Fisheries Biological Laboratory, Seattle, Wash.

RETURNS FROM UPSTREAM

Sockeye Salmon

It was necessary that days-out of tagged fish at upstream points be measured at a point where a minimum of mixing of (1) chronological order of movement and (2) delay might occur. Zosel Dam, on the Okanogan River, approximately 145 river miles above Rock Island Dam, appeared the best place for measuring the period of migration of tagged sockeye salmon. The sockeye passing this dam were headed for Lake Osoyoos and the spawning areas above the lake. They passed the dam easily, either through fishways or through the spillway. Unfortunately, not many tagged fish were released in the forebay at Rock Island in 1954, the year many sockeye and tags were observed at Zosel Dam. In 1955 and 1956, larger samples were released above the dam at Rock Island but most fish passed Zosel Dam unobserved. These data, at Zosel Dam, however, did allow us to compare the migration period of different lots of tagged fish.

Tumwater Dam on the Wenatchee River, the only other fish-passage observation point, presented a delay and mixing problem which precluded a reliable comparison of time periods for different tagged lots. At this dam, all fish had to find and ascend the ladder to pass the dam, and this offered chances for mixing and delaying of various parts of the salmon runs. The data obtained at Tumwater Dam are given for comparative purposes.

Figure 12 shows the days-out period at Zosel Dam for sockeye released at three areas at Rock Island. Looking at the modal values, we note a 2-day difference between forebay and left bank below the dam releases for both 1954 and 1955. The right bank modes, however, show a 3-day difference for 1954 and a 4-day difference for 1955. This would indicate right bank releases were delayed longer than left bank releases. The mean values do not indicate this difference between banks. Since the means are influenced by extreme values, however, the modal values should be preferred when making comparisons, provided the data are sufficient for forming smooth distribution curves. The number of observations leave something to be desired, but they indicate a delay of from 2 to 4 days at Rock Island, and a greater delay for right bank releases than left bank releases below the dam.

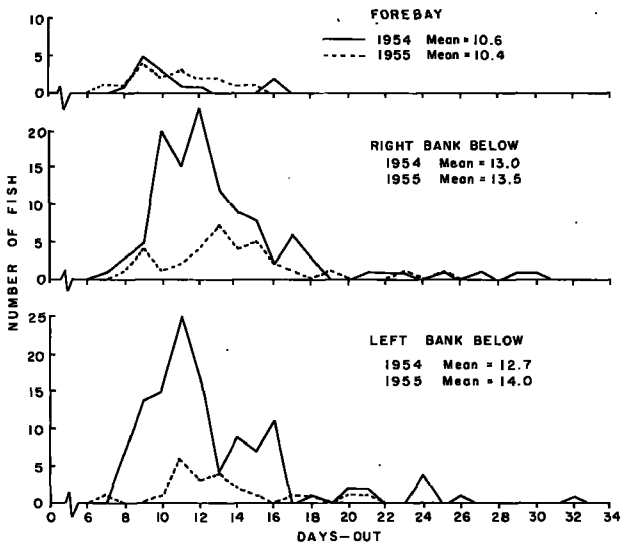


FIGURE 12.—Number of days out at Zosel Dam of tagged sockeye released at three different areas at Rock Island, 1954–55.

At Tumwater Dam, the difference in days-out between above- and below-dam experiments averaged 2 to 3 days in 1954 and 1955 (table 16). We observed that for these 2 years right bank releases took longer to pass than left bank releases. The 1956 results may have been affected by changed flow patterns at Tumwater Dam, the entire river was spilled over the dam and no water was diverted for power production as in previous seasons. The great range in individual days-out of tagged sockeye is indicated by the large standard deviations shown for the data.

Chinook

Our only upstream measure of the days-out period of tagged chinook salmon was obtained at Tumwater Dam. All other tag recoveries were from the spawning grounds or hatcheries,

TABLE 16.—*Means and standard deviations of days-out at Tumwater Dam of tagged sockeye released at different areas at Rock Island Dam, 1954–56.*

[Figures in parentheses are standard deviations]

Year	Release area at Rock Island Dam				Difference between above and total below
	Left bank below	Right bank below	Total below	Above dam	
1954	23.5	24.7	23.9	20.8	3.1
	(7.3)	(7.0)	(7.2)	(5.9)	
1955	21.6	22.1	21.8	19.9	1.9
	(7.5)	(7.1)	(7.3)	(8.2)	
1956	21.5	21.5	21.5	20.3	1.2
	(8.0)	(9.4)	(8.4)	(7.9)	

where the chronological order of the arrival of tagged fish could not be determined. At Tumwater Dam, moreover, migrating chinooks were subject to delay, and conclusive data of the time-out period for fish from the different tagging areas were not obtained. The days-out at Tumwater Dam for individual chinooks ranged from 11 to 65 days, and there was no evidence that any one group of releases was different from another group.

RETURNS AT ROCK ISLAND

Sockeye

As hypothesized previously, the difference in days-out at upstream points between above- and below-dam releases should equal the days-out period at Rock Island Dam of below-dam releases. The results at Rock Island Dam (fig. 13) confirm the hypothesis. The majority of fish passed through the fishways within 2 to 4 days after being released below the dam. In 1953, the peak of the days-out curve occurred a day earlier than in 1954-56. This may have been because the majority of fish in 1953 were tagged during a 3-day period near the end of the run in contrast to the season-long tagging of the later years.

The comparisons of days-out by area of release at Rock Island are shown in figures 14, 15, and 16. At first glance we have a fairly consistent picture of passage from the two areas of release, with the exception of the right bank releases in 1956. A better comparison of the days-out period for each release area is gained from the following

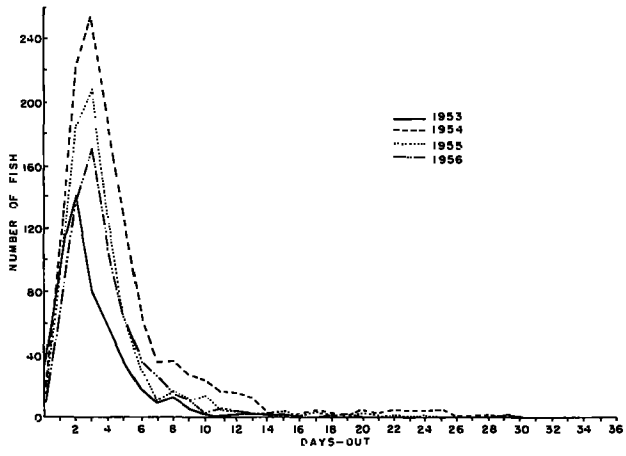


FIGURE 13.—Comparison of days-out at Rock Island of tagged sockeye released below the dam, 1953-56.

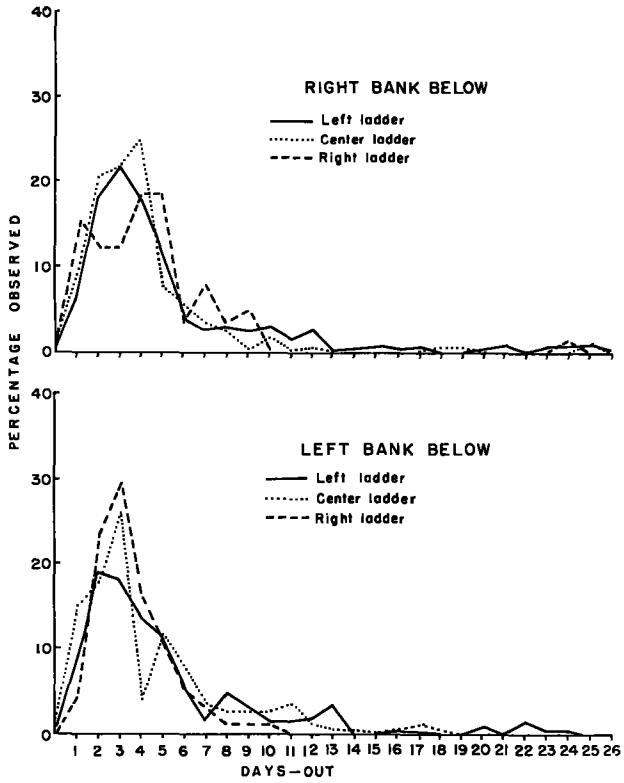


FIGURE 14.—Days-out of tagged sockeye at Rock Island for each area of release expressed in percentages of total observations by ladder, 1954.

array of modal values of days-out for each tag release area and the ladder of passage (table 17).

In 1954, right bank releases took a day longer to pass at each ladder than the left bank tag releases. This difference was not noted for other years except in 1955, in the center ladder. In 1956, right bank releases passed sooner than left bank releases. The 1956 tagged fish, it is recalled, were released off the face of the dam close to the fishways. Apparently the few sockeye using the right ladder moved into the ladder immediately after tagging and the remainder moved downstream or across the river. Those sockeye using the right ladder possibly moved up sooner upon finding the ladder because of the absence of resting areas below the ladder.

Measuring the number of days-out for tagged salmon at Rock Island Dam depended on the ability of the counters to distinguish the kinds and colors of tags used. As previously pointed out, the counters made many errors. To test if the counters were approximately correct in identi-

fying most tags upon which the days-out data were derived, the occurrence of tagged salmon, regardless of tag color or kind, was plotted by date and compared with the total number of salmon tagged (fig. 17). An examination of the graphs reveals that the peaks and troughs of the tag occurrence curve occur 2 to 4 days after the start and finish of a tagging period. This 2- to 4-day lag compares with the days-out curve of figure 13 and indicates the counters were approximately correct in identifying most of the tags from which the days-out data were derived.

TABLE 17.—*Modal values in days out for each tag release area and ladder of passage*

[Data from figs. 14, 15, and 16]

Releases	Ladder		
	Left	Center	Right
1954			
Left bank	2	3	3
Right bank	3	4	4–5
1955			
Left bank	3	2	2
Right bank	2	3	2
1956			
Left bank	3	3	3
Right bank	3	2	1

Undoubtedly the difference in time required for salmon released above and below Rock Island Dam to reach an upstream point reflects the amount of time required for the below-dam releases to pass the dam. Thus, it is reasonable to conclude that tagged sockeye were delayed 2 to 4 days below Rock Island Dam. Assuming that tagged and untagged salmon migrate at similar rates, Rock Island Dam delays sockeye approximately 2 to 4 days.

Chinook

At Rock Island Dam spring chinook peaked after 1 day-out and summer chinook on the third

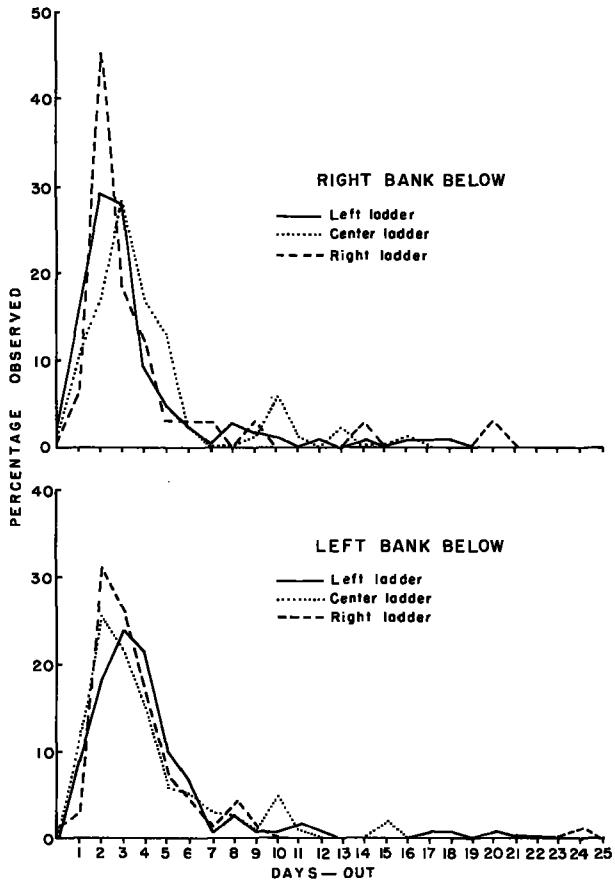


FIGURE 15.—Days-out of tagged sockeye at Rock Island for each area of release, expressed in percentages of total observations by ladder, 1955.

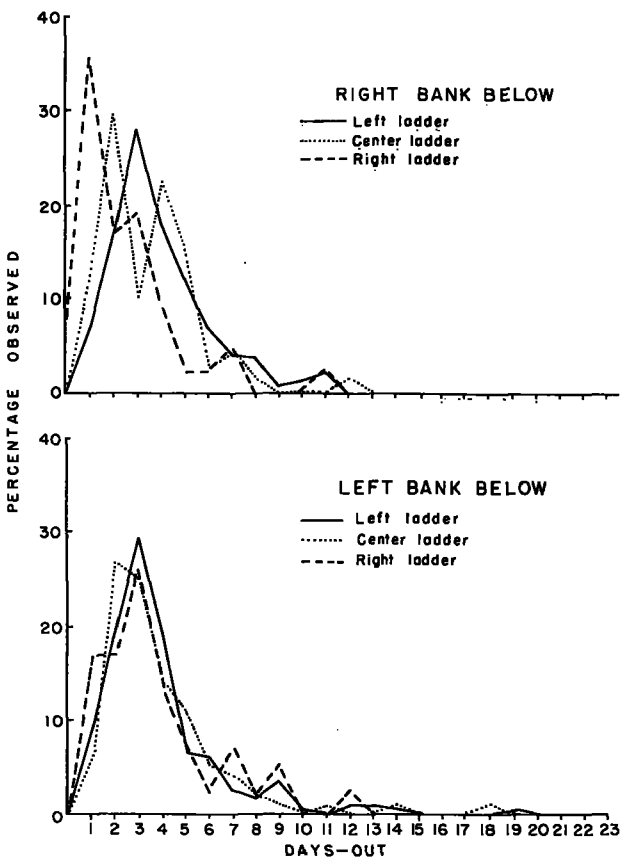


FIGURE 16.—Days-out of tagged sockeye at Rock Island for each area of release, expressed in percentages of total observations by ladder, 1956.

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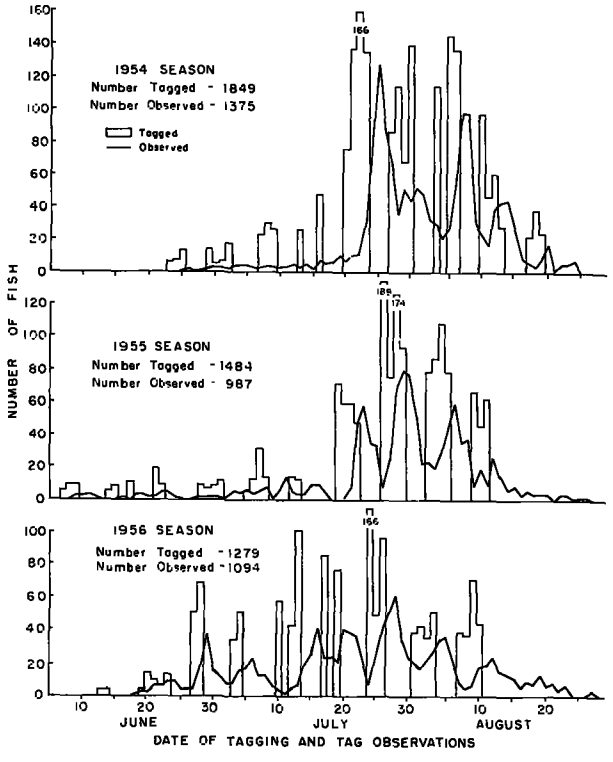

FIGURE 17.—Numbers of salmon tagged below Rock Island, and numbers of daily tag observations at the counting stations.

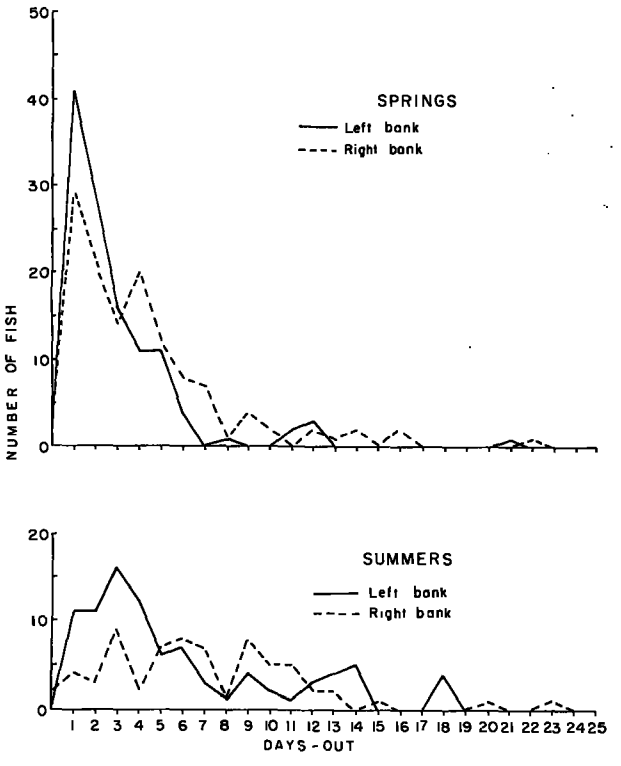

FIGURE 18.—Comparison of days-out at Rock Island of tagged spring and summer run chinook, by area of release, 1956 season.

day after tagging (fig. 18). The drawn-out time period noted for many summer chinooks may have resulted from errors in species identification as this run coincides with sockeye, or it may be characteristic of the summer chinook to take longer to pass the dam.

DISCUSSION

EXPERIMENTAL SITUATION

In view of conflicting results for different years and for different tagging areas, it is pertinent to review briefly the experimental situation and sources of error of the tagging experiments.

We have assumed that the likelihood of recovering or observing a tagged fish in a given recovery area was the same regardless of the area of release or time of tagging. This seems a reasonable assumption, because recovery efforts on spawning grounds were directed to all parts of the spawning areas and throughout the period of spawning. Tagged fish also were recorded as they passed Zosel Dam on the way to the spawning grounds, although sockeye could pass Zosel Dam without passing through counting traps. At Tumwater Dam, all fish, in order to pass the dam, had to pass through a trap where tagged fish were easily observed and counted.

We have assumed also that proportions of tagged fish migrating to different spawning areas were the same for the different release lots. In sampling fish for tagging, salmon were trapped throughout the duration of the run and usually during the height of the daily migration. In many instances, individual truck loads of fish were divided between above-dam and below-dam taggings. Other times, successive loads of fish were divided between left and right bank releases and above and below-dam releases. On this basis we feel that the above assumption is reasonable.

Another factor relating to experimental control was the kind of tag used for the various experiments. All the fish released above the dam were tagged with paired plastic disks. Different color combinations or single colors were used for different release groups. Tags used on fish released below the dam consisted of disks of single colors

in combination with plastic bars, nylon streamers, or vinyl tubing (spaghetti). Tags used below the dam were larger than the tags used above the dam. It might be argued that a larger, different shaped tag would aid recovery or observation of a tagged fish released below the dam. In considering the conditions for tag recoveries and observations, we do not agree with this argument. At Tumwater Dam all tags were observed in clear water from a distance of 3 or 4 feet. Most tags were read for numbers; thus, differentiation of tags from above and below the dam should have been readily apparent. This also holds true for tag observations at Zosel Dam. On the Okanogan River spawning grounds, tags were recovered from dead spawned-out fish or were observed during surveys of the river. In the latter case, biologists identified tags from 5 to 25 feet away and recognition was easy. In fact, when viewing tagged fish from the Tumwater Dam suspension bridge and from the railroad bridge just below Zosel Dam, both suspended 20 to 30 feet above the water, we could easily discern sizes and shapes of tags. Biologists observing fish at Rock Island distinguished, from about 40 feet away, shapes, sizes, and colors of tags on fish in the tailrace just below the fishway.

So far as tag colors are concerned, all tags used below the dam had single-colored disks and single-colored bars, streamers, or spaghetti. Tags used above the dam had single or bicolored patterns on the disks. It is difficult to say what the differences in colors or color combinations mean in terms of likelihood of recovery. Based on our observations of hundreds of tags under many circumstances, we believe that the tags, when seen, can be differentiated by color and kind.

ALTERNATIVE MODELS FOR ESTIMATING MORTALITY

Several models were considered for estimating mortalities in addition to the one used (ratios of recovery proportions of tagged fish from different release areas). We were unable, however, to accept the assumptions necessary for some. In others, dubious and conflicting results were obtained; hence, they are not given in detail in this paper. Two models are discussed briefly.

In one model we determined the racial composition of sockeye salmon in the tagged sample by estimating the number of 4-year-old upriver fish from the relative abundance of 3-year-old Okanogan fish in the tagged lots, and using the ratio of fishway counts to numbers released, as an adjustment factor in estimating the relative abundance of Wenatchee tagged fish in different release groups. Another model estimated racial composition from the differences in the proportions of 3-year-old sockeye in the populations at Rock Island Dam and in the Okanogan River, caused by a segment of the 4-year-old sockeye population splitting off and entering the Wenatchee system. In neither of these two models were definitive results obtained regarding mortalities caused by the dam. Mortalities were indicated for some years and areas, not for others. Because of these conflicting and nondefinitive results, we feel the best approach to the problem is that given.

MORTALITIES

Populations of anadromous salmonids lose some members passing large dams. For years, dead salmon have been observed floating down the Columbia River below Bonneville Dam, apparently fish which failed to pass the dam. Using the results of experiments involving the marking and recovery of dead salmon carcasses, Merrell and Collins [3] estimated a salmon loss at Bonneville Dam. Thompson (1945) found that a serious decline in Fraser River sockeye salmon runs was related to an area of difficult passage and to an obstruction in the river, even though salmon were known to pass this area each season. In a later paper on the Fraser River sockeye salmon, Talbot (1950) found that fish delayed longer than 14 days at Hells Gate did not reach their spawning grounds.

The tagging experiments at Rock Island gave conflicting results of mortalities caused by the dam. We found no mortalities for 3-year-old sockeye salmon when comparing recoveries of tagged fish released above and below the dam. We found mortalities in many experiments for 4-year-old sockeye when comparing tag returns from above and below dam releases. In other experiments involving these 4-year-old fish, no mortalities were indicated. Most experiments

[3] Merrell, Theodore R., and Melvin D. Collins. An investigation of adult chinook salmon mortality in the vicinity of Bonneville Dam, 1954 and 1955, on the Columbia River. Fish Commission of Oregon, August, 1960. 150 p. (Contract No. DA-35-026-eng-20892, U.S. Department of Interior, Fish and Wildlife Service.)

with chinook salmon indicated no mortalities caused by the dam.

Results show that mortalities caused by the dam are neither substantial nor consistent over the years, or that our tagging methods could not detect mortalities accurately. Confidence limits for the point estimates of mortalities ranged from zero (in many instances) to about 28 percent for the lower limits; upper limits ranged from 20 to 66 percent.

Comparatively few tagged fish used the right ladder (also observed for untagged runs), even when they were released near it. Apparently, the majority of these salmon ascended other ladders. An increased percentage of the salmon was attracted to the right ladder in 1957 when spillway gates on the right side of the dam were opened during the fish migration season. Previously these were closed to reduce water turbulence near the right ladder entrance. It may be that the added flow attracts fish to this bank and into the fishway.

While altering the right bank fishway might induce more fish to use the right ladder, we cannot say it would result in markedly improved facilities with respect to mortalities.

DELAY

Delay of migrating adult salmon runs is very important to the survival of the runs. As Thompson (1945) and Talbot (1950) pointed out, delays to sockeye salmon runs in the Fraser River caused mortalities and a serious decline in the runs. Schoning and Johnson (1956), in a study at Bonneville Dam on the lower Columbia River, reported that migrating chinook salmon were delayed 2.6 to 3 days. The 2- to 4-day delay at Rock Island Dam may not be important in itself, but if the delay is multiplied by a series of dams, serious losses of anadromous fish populations may result.

We do not know if upper river salmon runs would survive the series of delays in migration that may result when all Columbia River dams are completed. It may be that delays, if short-termed would be compensated for by easier and faster travel through the reservoirs created by the dams. These salmon do not spawn immediately upon reaching the spawning areas. There is an interval before spawning, of from 1½ to 2½ months after the salmon pass Rock Island Dam. This ripening period has been noted on other river systems. Howard (1948) found that the period for sockeye in Cultus Lake, British Columbia was about 1 month. Schaefer (1951) noted the time for sockeye in the Harrison River system of British Columbia, was a month or less. The ripening period for sockeye in Lakelse Lake, British Columbia, averaged 54 days (Fisheries Research Board of Canada, 1954). In the Bristol Bay area of Alaska, some sockeye remain in the lakes up to 3 months before spawning. The ripening period evidently is a necessary adjunct to the migration time.

In this study at Rock Island Dam, we discovered a 2- to 4-day delay to migrating salmon. Upstream tag observations at Zosel Dam indicated that fish tagged and released below the right ladder were delayed longer than fish tagged and released below the left ladder. This was confirmed by comparing returns of left and right bank tag releases at Rock Island for 1954. The longer delay was absent in 1955 and 1956. Thus, while we do not have positive evidence of a greater delay for fish released below the right ladder, such a delay is indicated.

Altering the right-bank fishway may lessen delay at the dam because of the possible increased chances of salmon finding a ladder sooner. However, the same delay pattern was noted at Bonneville Dam (app.), where ladders at both sides of the dam were designed to be equally attractive. From this study, we cannot conclude that altering the right bank fishway would decrease materially the overall delay at Rock Island Dam.

SUMMARY AND CONCLUSIONS

We conducted a tagging program at Rock Island Dam during 1953–56 to determine whether the dam caused loss or delay of salmon passing the dam, and whether such loss or delay was associated with the failure of fish to find and use the dam's right bank fishway. In this study, tagged salmon were released below the left and right bank fishways and above the dam. Fish counters at the dam identified different tag groups by noting the different colors and kinds of tags on salmon crossing the counting boards. Tags also were identified at upstream points on migration routes and during spawning surveys.

A comparison of upstream tag recoveries from the different release areas gave conflicting results regarding losses of fish. Point estimates of losses, for some combinations of years and release areas

(left or right bank below the dam), ranged from 0 to 42 percent, with mortalities greatest for fish released below the right bank ladder. Tagging data on chinook salmon indicated a loss of spring chinooks released below the right ladder in 1956; no loss was indicated, however, in comparing total returns from below the dam with returns from above the dam. For summer chinooks, tagging data failed to show losses due to the dam.

Total tag returns at Rock Island Dam, as identified by fish counters, ranged from 64 to 86 percent of the number released below the dam during the experiments. Straying and mortalities may have accounted for many of the missing tags; it was probable also that the counters missed many of the tags, and total returns were greater than indicated.

Tag returns at Rock Island Dam from below-dam releases showed that although salmon were released at both banks, the majority returned over the left ladder. Only 12 to 14 percent of the tagged salmon returned over the right ladder. The tag returns corresponded closely with the choice of ladders of the untagged populations, of which the majority chose the left ladder for passage and 10 to 17 percent the right ladder. Although the salmon were taken from the ladders for tagging, they did not learn a particlar route in re-passing the dam; neither were they frightened from a particular ladder during repassage of the dam.

Tagged salmon released above Rock Island Dam arrived at upstream points 2 to 4 days earlier than fish released below the dam. This difference in days out corresponded to the time required for most fish to pass Rock Island Dam after tagging, and is termed the delay at the dam. Fish released below the right ladder apparently were delayed 1 to 2 days longer in reaching upriver points than fish released below the left ladder.

The days-out period at Rock Island Dam, for sockeye released at the two banks below the dam, was essentially the same, with most of the salmon passing in 2 to 4 days, and the peak occurring the third day after tagging. In 1954, right-bank releases were delayed 1 day longer than left-bank releases. This greater delay of right-bank releases was not evident in 1955 and 1956. Spring chinook peaked after 1 day-out, with the majority passing the dam by the fourth day. The peak day for summer chinook was the third day after tagging. No apparent difference in days-out period at Rock Island Dam was indicated for chinooks released at the two banks below the dam.

An increased percentage of the run used the right ladder in 1957, following a change in spillway-gate operating procedures. Evidently attraction to this ladder was increased by opening gates on the right side of the dam next to the fishway.

On the basis of these tagging studies we found that Rock Island Dam delayed migrating salmon from 2 to 4 days. There is conflicting evidence of a greater delay to fish released below the right ladder than to fish released below the left ladder. Data regarding mortalities gave conflicting results; some experiments indicated substantial mortalities while others indicated none. While altering the right-bank fishway may attract more fish to the fishway, we cannot say it will necessarily improve passage considering overall loss and delay. The delay of 2 to 4 days may be significant when similar delays at a series of dams are considered.

ACKNOWLEDGMENTS

Many persons in addition to staff members at the Seattle Biological Laboratory contributed to the tagging experiments at Rock Island Dam. The Washington State Department of Fisheries helped in planning the project, and provided equipment for the investigations. The Puget Sound Power and Light Company, and Chelan County Public Utility District No. 1 gave valuable assistance by providing equipment and facilities. R. A. Fredin and D. D. Worlund of the Bureau's Biological Laboratory in Seattle assisted with the statistical analyses.

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APPENDIX

BONNEVILLE TAGGING EXPERIMENTS

At the conclusion of the Rock Island tagging experiments in 1954, we were confronted with the apparent loss at the dam of many tagged fish. What was the meaning of observing only approximately 75 percent of the tags released below the dam in 1954 and 64 percent in 1953? In the following years, 65 percent in 1955 and 86 percent in 1956 of all tags released were subsequently recorded by fish counters. Were these percentage returns due to conditions associated with the Rock Island fishways or could low percentage returns from tagging be expected at any dam? In an attempt to answer these questions we decided to tag, on a small scale, below another dam in the same manner as at Rock Island. The objectives were to determine the percentage and pattern of tag returns at Bonneville Dam and compare them with the Rock Island tagging data.

On July 14 and 15, 1955, 293 fish were tagged and released below Bonneville Dam located on the Columbia River approximately 140 miles above the river's mouth. The procedure at Bonneville was the same as at Rock Island. Fish were trapped in a ladder, transported by truck, and tagged and released below the dam. The experiments differed somewhat from those at Rock Island in that the fish were released about one mile below Bonneville on only one bank while at Rock Island they were released about, 1,000 feet below the dam at both banks. Also, fish at Bonneville were tagged with paired disks and not the combination tags applied at Rock Island.

TABLE A–1.—*Returns at Bonneville Dam of tagged salmon and steelhead released below the dam in 1955*

Species	Tagged	Returns by ladder			Returns No. tagged
		Washington shore	Bradford Island	Total	
	Number	*Number*	*Number*	*Number*	*Percent*
Sockeye	160	47	25	72	45.0
Chinook	17	9	30	[1] 39	229.4
Steelhead	116	36	16	52	44.8
Totals	293	92	71	163	
Percent by ladder		31.4	24.2	55.6	

[1] This is an obvious error in species identification.

Tag Returns at Bonneville

The number tagged and the returns at Bonneville are shown in table A–1. Far more steelhead were tagged at Bonneville than during the Rock Island experiments. Tag returns of 55.6 percent reported over Bonneville Dam by the fish counters were less than for any season at Rock Island, where percent returns ranged from 64 to 86 for the seasons 1953–56. Nine tags were returned from below Bonneville, six from dead fish found on the beaches and three from fishermen. At Rock Island the largest number of recoveries from below the dam occurred in 1956 when seven were recovered. Of these, five were from McNary Dam where a trap was installed for other tagging projects, one was returned by a sports fisherman, and one was observed in Redfish Lake in the Snake River system.

One feature found at Bonneville and not at Rock Island is the ship locks through which it is possible for fish to pass. There was no way of knowing whether or not any tagged fish passed the dam by this means.

As at Rock Island, the returns indicated fish counters had trouble identifying species. This is evident when 39 tagged chinook were reported by the counters and only 17 had been tagged. This same kind of error was noted at McNary Dam where fish counters reported 23 tagged chinooks from this same experiment.

The time-out period (time elapsing between tagging and observation at the counting boards) for tagged fish at Bonneville was similar to results obtained at Rock Island. Figure A–1 shows the number of days-out for all tagged fish observed at Bonneville. The majority of the fish passed in 2 to 5 days after tagging. There is an inherent error in the figure because days-out were computed from July 14, the first day of

tagging, although half the fish were tagged on July 15. There was no way for the counters to distinguish between the two lots. Correctly then, many fish passed 1 day sooner than indicated. It is notable that these results are similar to those from the Rock Island experiments in which the majority of fish passed in 2 to 4 days.

Figure A–2 shows the days-out by ladder at Bonneville. Many fish (44 percent) crossed the river to pass upstream through the Bradford Island ladder, although the fish were trapped and released on the Washington shore. The mean days-out time for fish passing through the two ladders was approximately the same: 6.6 days for the Washington shore ladder and 6.8 days for the Bradford Island ladder. Again, these results were similar to those obtained at Rock Island.

Tag Returns—Bonneville to McNary Dam

Tag recoveries were obtained above Bonneville Dam from the commercial fishery, sports fishermen, the Celilo Falls fishery, at McNary Dam, at Rock Island Dam, and also from spawning ground surveys above Rock Island. For the area between Bonneville and McNary Dams, 28 sockeye and 3 steelhead tags were returned by commercial fishermen and the Indian dip net fishery at Celilo Falls. Sports fishermen fishing in the various tributaries returned tags from seven tagged steelhead.

At McNary Dam, approximately 120 miles above Bonneville, 84 of the Bonneville tagged fish were recorded at counting stations. This was 28.7 percent of the number tagged and 51.5 percent of the number recorded over Bonneville Dam. The total number of tags accounted for from Bonneville to and including McNary counts was 122, or 41.6 percent of the number tagged and 74.8 percent of the number reported over Bonneville.

Figure A–3 shows the days-out for tagged fish at McNary Dam. The double mode is pronounced for each species and the modes are 5 days apart for chinooks and sockeye. It is doubtful that the 5-day interval is the result of computing days out from the first day of tagging when tagging occurred on 2 successive days. It is more likely that some short-term delay affected a group of fish, possibly those tagged the second day. The figure shows that the majority of tagged fish took from 12 to 20 days to pass McNary Dam after being tagged below Bonneville Dam.

Tag Returns Above McNary Dam

The Rock Island fish counters were alerted to the particular tag applied at Bonneville and recorded its appearance on fish. The tags used were paired disks of a copper color with a black bullseye, a very distinctive color, and much

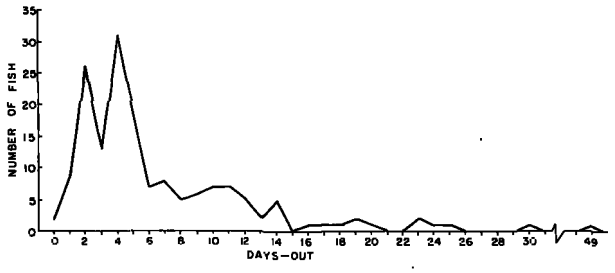

FIGURE A–1.—Number of days-out at Bonneville of tagged fish released below the dam, 1955 season (days-out dated from July 14).

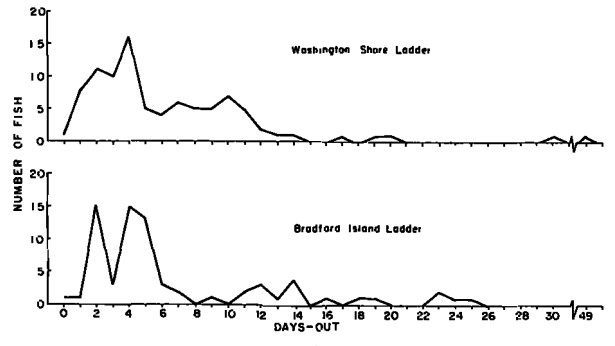

FIGURE A–2.—Number of days-out by ladder at Bonneville of tagged fish released below the dam in 1955 (days-out dated from July 14).

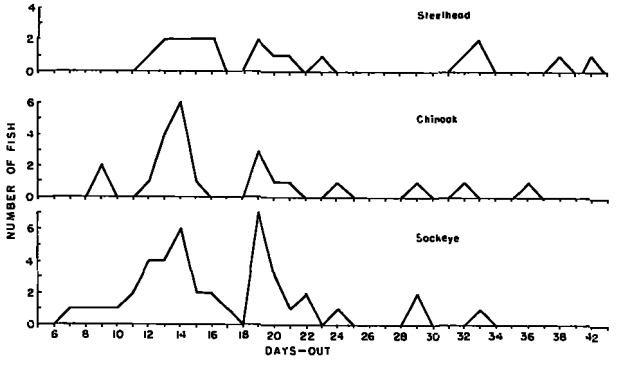

FIGURE A–3.—Number of days-out at McNary Dam for the three species tagged below Bonneville Dam in 1955 (days-out dated from July 14).

different from the tag combinations used below Rock Island. The counters reported five sockeye and one chinook tag of this group between August 3 and August 21. However, the counters were apparently unable to observe and identify this particular tag easily, for 14 tags (11 sockeye, 2 chinooks, and 1 steelhead) were recovered during spawning ground surveys above Rock Island.

If many of the Bonneville tags (8 of 14 or 57 percent) passed Rock Island undetected, where counters were alerted for tags of various colors and combinations, it is likely tagged fish could pass unnoticed at any dam. Unaccounted-for tags, which have been released below a dam, may not represent true mortalities of tagged fish occurring below a dam. These data are dependent upon the ability of fish counters to observe all tags, and for various reasons this may not be possible.

SUMMARY AND CONCLUSIONS

A small-scale tagging experiment below Bonneville Dam on July 14, and 15, 1955, and patterned after the Rock Island experiments, gave results similar to those obtained at Rock Island Dam. Total tag returns at Bonneville Dam were 56 percent, or somewhat less than the 64–86 percent returns at Rock Island for 1953–56. It is not known if tagged fish passed Bonneville by way of the navigation locks, thus reducing the number available for passage through the fishways. Fish released on one shore below Bonneville passed the dam through both fishways with only a slight majority passing through the Washington shore ladder on the side they were released.

The days-out period at Bonneville compared closely with the results obtained at Rock Island. The majority of tagged fish passed in 2 to 4 days at both dams. As at Rock Island Dam, the fish counters at both Bonneville and McNary Dams had difficulty in identifying species. More tagged chinooks were reported at Bonneville and McNary Dams than had been tagged.

The returns at Rock Island of the Bonneville releases were featured by the apparent inability of the counters to identify these tags. Six tags were reported at the dam and 14 were recovered on the spawning grounds above the dam. It is suggested, therefore, that tags may pass undetected at any dam and caution must be used in relating unaccounted-for tags to mortalities occurring below a dam.