PASSAGE OF ADULT CHINOOK SALMON THROUGH BROWNLEE RESERVOIR, 1960-62

By Parker S. Trefethen and Doyle F. Sutherland, *Fishery Biologists*

Bureau of Commercial Fisheries Biological Laboratory

Seattle, Washington 98102

ABSTRACT

Adult chinook salmon (*Oncorhynchus tshawytscha*) were tagged and released in Brownlee Reservoir and upstream in the Snake River to determine if adults could pass through the reservoir and reach spawning grounds. Experiments with Petersen disk tags were performed by the Idaho Fish and Game Department in 1960–61 and by the Department and the Bureau of Commercial Fisheries in 1962. In addition, the Bureau marked salmon with sonic tags in 1961–62 to trace orientation and movement. Information was also obtained on the use of tributary streams for spawning and success of spawning.

Fish marked with Petersen disk tags and released in the 92.5-km.-long reservoir reached their spawning area as successfully as those transported above the impoundment and released in the river. Fish released during periods of constantly high water temperature in 1961–62 suffered losses, which may have been caused by stress during tagging. Some salmon with sonic tags were initially disoriented when released in the reservoir; those released in the river above the impoundment quickly oriented to the flow and resumed migration upstream.

Subpopulations of spring- and fall-run chinook salmon continued to use ancestral spawning areas in streams tributary to the impoundment after it was formed in 1958. No differences were noted between percentages of totally spent fall-run fish on the spawning grounds in the years before and after Brownlee Reservoir was filled.

Knowledge of the effect of impoundments on upstream migration is needed to plan the passage of adult salmon (*Oncorhynchus* spp.) and steelhead trout (*Salmo gairdneri*) at high dams. If mortality is high in the reservoir, or if delays or other factors associated with passage impair the ability of survivors to spawn, the fish may have to be transported around the impoundment. Transportation could prove difficult if spawners bound for several tributaries were intermingled below the dam. Subpopulations would then have to be separated before their release into respective tributaries—a difficult or impossible task. On the other hand, if anadromous fish can migrate up through the impoundment and spawn successfully, they can be passed directly to the forebay of the dam to continue their natural migration upstream.

Neither Brownlee Dam nor Oxbow Dam, which is 19.3 km. downriver from Brownlee, has a fishway leading up to its impoundment. Migrating adults enter a collection facility at Oxbow Dam where they are trapped and transferred to a tank truck; they are then transported 23.3 km., to a point 4.0 km. above Brownlee Dam, and released into Brownlee Reservoir to resume their migration. Release of fish in the reservoir was discontinued after these studies were completed; all fish were transported to hatcheries for artificial propa-

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gation. A small hatchery for fall chinook salmon (*O. tshawytscha*), 1 km. downstream from the trapping site, has been operated at Oxbow Dam from 1960 to the present by the Idaho Fish and Game Department.

Fishery agencies recognized that Brownlee Reservoir posed a number of problems. The impoundment is 92.5 km. long; it has almost no current except during periods of high river discharge and extreme drawdown; water temperatures are high and oxygen concentrations are low during summer and early fall when spawning migrations occur.

To learn if adults could pass successfully through Brownlee Reservoir and reach the spawning grounds, the Idaho Fish and Game Department tagged fall chinook salmon (with Petersen disk tags) in 1960–61. The Bureau of Commercial Fisheries, in cooperation with Idaho, continued the investigations in 1962. Petersen disk tags were used in all years; the Bureau also used sonic tags in 1961–62 to trace the orientation and movement of fish.

This report summarizes the results of the 1960–62 studies. It also contains information on (1) orientation and migratory behavior of sonic-tagged salmon, (2) observations of totally spent fish in the Snake River above Brownlee Reservoir, and (3) use of tributary spawning streams after completion of Brownlee Reservoir.

METHODS AND MATERIALS

The general plan was to capture adult chinook salmon in a trap at Oxbow Dam and transport them upstream for release either in Brownlee Reservoir or in the Snake River above the reservoir (fig. 1). Some of the fish released in the reservoir were either tagged or fin clipped; others were caught and released unmarked without additional handling. The relative numbers recovered on ancestral spawning grounds below Swan Falls provided data that enabled us to measure the ability of migrants to pass through Brownlee Reservoir. Sonic tags were applied to 59 fish in 1961–62 to obtain information on orientation and migratory behavior in and above the impoundment. A summary of data on tagging and release is shown in table 1.

CAPTURE AND HANDLING

Adult chinook salmon used in the experiments were taken at different stages of the spawning run in the different years. In 1960 and 1961 the fish were obtained after the peak of the run. Hauck (1961)[1], describing the work in 1960, mentioned "... that the selection of fish for tagging was not on a random basis; that some selection was made for better fish on the basis of appearance and physical vigor."

[1] Hauck, Forrest. 1961. Fall chinook salmon tagging studies, Snake River, 1960. Idaho Fish and Game Dept., 7 pp. [Processed.]

TABLE 1.—*Summary of data on tagging and release during tests on passage of fall-run chinook salmon through Brownlee Reservoir, 1960–62*

[*Unmarked fish were released in the reservoir during normal transport to maintain run; all fish were taken from trap at Oxbow Dam (fig. 1)*]

Year and kind of mark	Released in reservoir			Released in river		
	Date	Number	Anesthetized[1]	Date	Number	Anesthetized[1]
1960						
Petersen tag	Sept. 20–21	108	No	Sept. 23–30	267	No
Do	Oct. 4–7	253	No	---------------	----	----
None	Aug. 4–Dec. 12	4,282	No	---------------	----	----
1961						
Petersen tag	Sept. 18–Oct. 31	686	Yes	Sept. 18–Oct. 31	688	Yes
None	Aug. 9–Dec. 10	3,272	No	---------------	----	----
Sonic tag	Sept. 20–Oct. 21	15	No	---------------	----	----
1962						
Petersen tag	Aug. 27–Oct. 21	444	Yes	Aug. 27–Oct. 21	340	Yes
None	Aug. 20–Dec. 11	342	No	---------------	----	----
Fin clip	Aug. 27–Oct. 21	365	Yes	---------------	----	----
Sonic tag	---------------	----	----	Sept. 24–Oct. 8	44	Yes

[1] Anesthetized for tagging, but not during transport to release site.

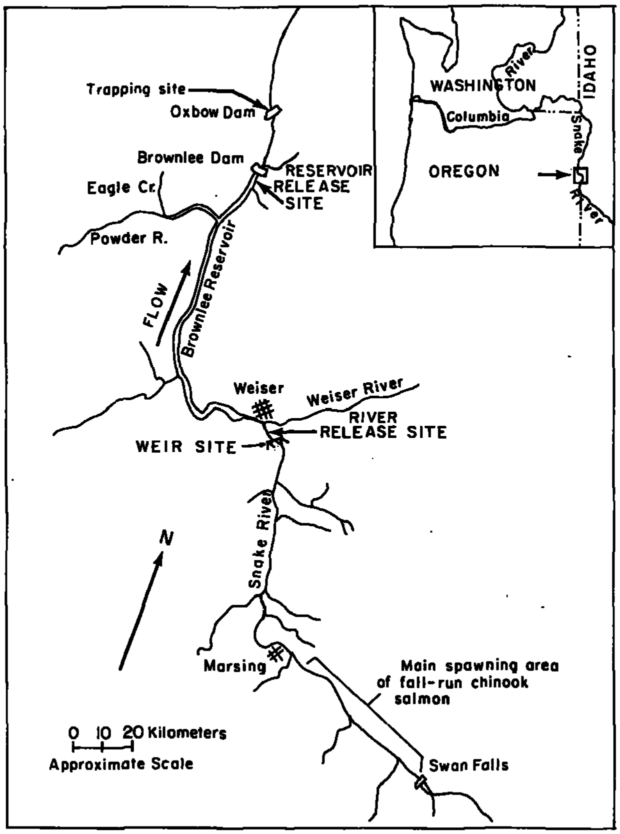

FIGURE 1.—Map showing trapping site below Oxbow Dam, release sites in and above Brownlee Reservoir, weir site, and main spawning area of fall-run chinook salmon in the Snake River, 1960–62.

In 1961, fish were collected in the trap until numbers were sufficient for tagging. The trapping time ranged from a few hours, soon after the peak of the run (when the tests started), to 1 day in the later stages of the run. In 1962, the trapping to obtain fish for tagging and release was scheduled by stage of migration. In the early and late stages (August 20 to September 23 and October 15–21) fish were collected for 24 hours before they were removed to the tagging area, and during the peak of migration (September 24 to October 14) fish were removed from the trap for tagging after about 30 had accumulated.

Fish were transported in a tank truck (3,785-liter capacity); water was recirculated and, except for a few hauls in 1960, oxygenated. Ice was used to control water temperatures during the 3½-hour drive to the release site at the river, but not during the 1-hour drive to the release site at the reservoir.

All salmon were anesthetized (with tricaine methane sulfonate) for tagging in 1961–62, but not in 1960; none were anesthetized during transportation.

Prophylactic treatments, supervised by the Fish Commission of Oregon, were used in 1962 to attempt to minimize the transmission of disease among fish during tagging and close confinement in the tank trucks. Prophylactics included tincture of iodine, roccal, ethanol, and malachite green. Tagging equipment was sterilized in a 70 percent solution of ethanol; the tagging area on the fish was treated with iodine. Wounds, abrasions, and infected areas were treated by topical application of a 15 percent solution of malachite green. In addition, all fish were treated for 1 hour with 1 p.p.m. (parts per million) of malachite green while being transported to the release sites. At the end of a day's operation, fish tanks on the hauling trucks were sterilized with roccal.

Skin discoloration and formation of blisters early in the experiment indicated that the iodine treatment might be affecting the fish adversely. As a precautionary measure, a 15 percent solution of malachite green was used in lieu of the iodine after the third week of tagging. On one occasion the fish tank was inadequately rinsed and the remaining roccal killed a load of fish. Thereafter malachite green at a concentration of 2 p.p.m. was used instead of roccal for sterilization.

TAGGING AND RELEASE

Petersen disk tags, sonic tags, and adipose fin-clips were used to mark adult chinook salmon before they were released. Personnel of the Idaho Fish and Game Department applied all disk tags (fig. 2), which were numbered or multicolored for identifying individual fish. The Bureau of Commercial Fisheries attached all sonic tags; only fish over 61 cm. were tagged. The Bureau also excised the adipose fins.

FIGURE 2.—Personnel of the Idaho Fish and Game Department attaching disk tag to chinook salmon. Fish is partially submerged in water supplied by hose in left foreground. Canvas cover over head of salmon helps quiet it during tagging.

Petersen Disk Tag

Tagging and release of disk-tagged fish differed in certain details during the 3 years of the study. In 1960, fish were tagged at the Oxbow trap and transported directly to release sites in the river or the reservoir. In 1961, untagged fish were transported to the release site and discharged into a holding pen; individual fish were then removed, anesthetized, tagged, and released at the site. In 1962, fish were taken from the Oxbow trap in groups of as many as 30, anesthetized en masse, tagged, put in a tank truck with fresh water to recover, hauled to the river or reservoir release site, and discharged into an open-ended holding pen. They swam over a submerged weir at the open end of the pen to resume migration. Individuals that did not leave the pen in 24 hours were eliminated from the experiment.

Releases of tagged and untagged fish in 1962 varied between migration periods. During the early and late stages of migration, fish were released daily for 6 successive days at a single site. For example, tagged fish were released in the Snake River on the first day of a week and in the reservoir on the next day. On the third day of the series, only untagged fish were released in the reservoir. This sequence was repeated over the next 3 days. No tagging was done on the seventh day, but fish captured in the trap at Oxbow Dam were transported and released in the reservoir by the Idaho Power Company as part of their usual fish-passage work. At the peak of migration (September 24 to October 14), tagged fish were released daily at both sites for 5 days a week. No more than 30 fish with Petersen tags were released at either site on any day. (In this same period, fin-clipped fish were released in the reservoir along with untagged fish that were excess to the tagging needs.) On the other 2 days of the week, only untagged fish were released in the reservoir.

Fin Clip

Fish marked by an adipose fin clip were released at the reservoir site only in 1962. These fish had been anesthetized and inspected during selection for spawn taking at the Oxbow hatchery but were not retained for that purpose. They were fin clipped to differentiate them from untagged fish that were released during the early stage of the 1962 experiment (September 10–16), but most were released during the peak stage of migration (September 24 to October 14).

Sonic Tag

Each sonic tag, used in 1961–62, was fastened by a metal clip or hog-ring which was crimped into the flesh behind the dorsal fin. The battery-powered tags emitted 132-kc. signals, detectable by receiving equipment within a range of about 1 km.; the operational life was about 5 days.

Salmon bearing sonic tags were released only in the reservoir in 1961 and only in the Snake River in 1962. In 1961, they were tagged at the reservoir release site and allowed to resume their migration from an open-ended holding pen. In 1962, the fish were tagged in groups of 6 to 14 at the Oxbow trap, coincident with the Petersen-disk tagging, and transported with the other tagged fish to an open-ended holding pen at the Snake River release site.

The sonic tags enabled us to obtain detailed

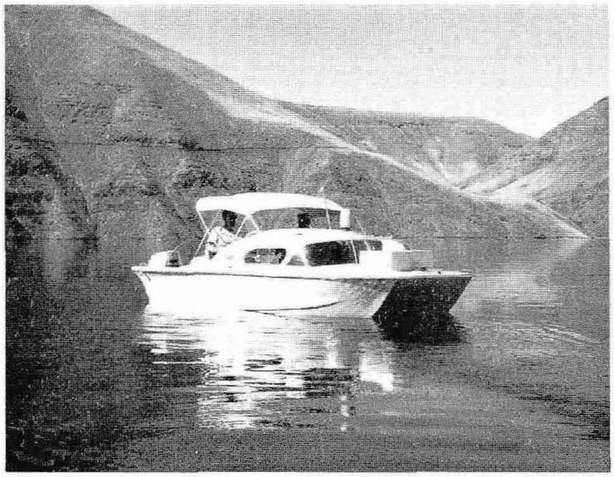

FIGURE 3.—Boat following chinook salmon with sonic tag in Brownlee Reservoir. Electronic tracking equipment provided precise data on day and night movements of tagged fish.

information on movements of individual fish in the reservoir by tracking them in a boat equipped with receiving equipment and plotting their positions on a chart at about 5-minute intervals (fig. 3). In the Snake River, the date and time of passage of fish with sonic tags past specific points was automatically recorded on time-event charts connected to fixed monitors [2] placed along the shoreline (fig. 4). Information on movement of individuals and groups of tagged fish between monitoring stations was obtained with portable hydrophones on a skiff propelled by an outboard motor.

RECOVERY

Marked and unmarked chinook salmon were recovered from the spawning area in periodic surveys from October to mid-January. The surveys were made monthly for the 1960 spawning run by the Idaho Fish and Game Department and weekly for the 1961 and 1962 runs, when the Bureau of Commercial Fisheries assisted the Department.

During the surveys, observers drifted downstream in a small boat or waded through shallow areas to search the entire known spawning area for carcasses. The dead salmon were ex-

[2] Johnson, James H. 1963. Development and use of sonic tracking as an aid to Pacific salmon conservation studies, 13 pp. [Processed.]

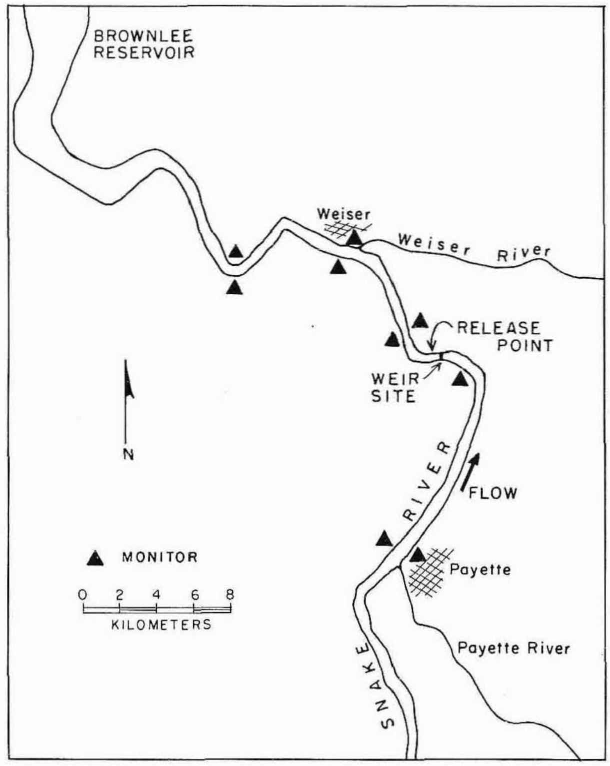

FIGURE 4.—Locations along Snake River between Brownlee Reservoir and the mouth of Payette River where fixed monitors recorded the passage of upstream-migrating chinook salmon carrying sonic tags.

amined for tags, fin clips, and spawning stages and then marked with spaghetti-type tags to identify them on future surveys. SCUBA diving was added in 1962 for investigation of deep pools where the spent fish might accumulate and remain unobserved. The greater recovery effort in 1962—plus experience gained in searching for fish in 1960–61—may have led to higher rates of recovery of untagged fish in 1962 (24.9 percent) than in 1960 (5.1 percent) or 1961 (14.3 percent). Water level and clarity appeared to be about the same for the 3 years.

PROPORTIONS OF FISH REACHING SPAWNING GROUNDS

In evaluating recoveries from both release sites, we considered the possible effect of differences in hauling time and post-release environment on the eventual passage of chinook salmon to the spawning grounds. Differences in hauling time, however, did not appear to be an important factor in survival. Although fish transported to the Snake River were confined in a tank truck about 2½ hours longer than those transported to the reservoir, they appeared to be in excellent condition at release. Other investigators have also indicated that prolonged transportation is not detrimental to adult chinook salmon. Parker and Hanson (1944) successfully transported adult salmon for 2 hours, and Fish and Hanavan (1948) reported hauls of about 4 hours without adverse effects. Groves (personal communication[3]) transported adult chinook salmon for about 5 hours to a test area in 1961 and followed this at a later date by a 5-hour return haul to a hatchery. He reported no mortalities directly attributable to the prolonged transportation.

Differences in postrelease environment also had no apparent effect on survival in the present experiments. Differences between recoveries of tagged fish released in the reservoir and of those released in the river were not significant in any year (table 2).

TABLE 2.—*Numbers of marked and unmarked fall-run chinook salmon released in Brownlee Reservoir and the Snake River and numbers recovered on the spawning grounds, 1960–62*

Year and release site	Mark[1]	Fish released	Fish recovered on spawning grounds	
		Number	*Number*	*Percent*
1960[2]				
Reservoir	Tag	361	23	6.4
	None	4,282	218	5.1
River	Tag	267	16	6.0
1961[3]				
Reservoir	Tag	686	70	10.2
	None	3,272	467	14.3
River	Tag	688	83	12.1
1962				
Reservoir	Tag	444	13	2.9
	Fin clip	365	31	8.5
	None	342	85	24.9
River	Tag	340	11	3.2

[1] Tag indicates Petersen disk; none of the 59 fish tagged with sonic tags were recovered.
[2] Hauck, Forrest. 1961. Fall chinook salmon tagging studies, Snake River, 1960. Idaho Fish and Game Department, 7 pp. [Processed.]
[3] Graban, James R. 1964. Evaluation of fish facilities, Brownlee and Oxbow Dams, Snake River. Idaho Fish and Game Dept. 60 pp. [Processed.]

The effect of tagging on survival of fish released in the reservoir apparently varied in different years. In 1960, the percentages of tagged and untagged fish recovered in the spawning areas were closely similar; in 1961, more untagged than tagged fish were recovered; and in 1962 the percentage recovery was higher for untagged fish than for either fin-clipped or tagged fish, and higher for fin-clipped than for tagged fish (table 2).

A high mortality of tagged fish was apparent in the early phase of the 1962 experiment. No recoveries were made of tagged fish released in the reservoir or in the Snake River during the first 4 weeks of tagging, August 27 to September 23 (table 3), and only one recovery was made from fish released in the first 5 days of the following week of tagging. This lack of tag recoveries coincided with a period of sustained high water temperature at both release sites. The average temperature of surface water was 22.1° C. (range, 21.1° to 23.9°) in Brownlee Reservoir and 18.4° C. (range, 16.6° to 20.6°) in the Snake River.

TABLE 3.—*Numbers of tagged fall-run chinook salmon recovered on the spawning grounds after release above Brownlee Dam in 1962, by week of release*

Week of release	Fish released in reservoir	Fish recovered on spawning grounds	Fish released in river	Fish recovered on spawning grounds
	Number	*Number*	*Number*	*Number*
Aug. 27–Sept. 2	11	0	7	0
Sept. 3–9	30	0	29	0
Sept. 10–16	33	0	31	0
Sept. 17–23	96	0	85	0
Sept. 24–30	74	2	46	3
Oct. 1–7	158	7	80	5
Oct. 8–14	34	3	41	2
Oct. 15–21	8	1	21	1

The high temperature, however, apparently was not the direct cause of mortality. The good recovery of untagged fish in 1962 (highest of the 3 years) suggests that a fair number of untagged fish from the early releases must have survived and reached the spawning grounds in spite of the high water temperatures. Possibly the additional stress on fish during handling, anesthetizing, and tagging produced the mortalities.

Mortality from tagging was also indicated in 1961 by the differences in percentage recov-

[3] Alan B. Groves. 1963. Fishery Biologist, Biological Laboratory, Bureau of Commercial Fisheries, Seattle, Wash.

ery of tagged and untagged fish released in the reservoir. Graban (1964)[4] observed that tagging mortality approached 30 percent. Although total recoveries of tagged and untagged fish in the 1960 experiments did not differ appreciably—possibly because of the selection of large, healthy fish for tagging—Hauck (see footnote 1) reported, "A decrease in survival (recovery) rates is indicated with increasing water temperatures at release site. . . ."

Recoveries of fish from the fin-clipped group in 1962 also give evidence of stress from handling: the percentage of returns was only about one-third that of returns from untagged salmon (table 2). The percentage of recoveries was higher from fin-clipped fish than from tagged fish (even though handling procedures were about the same for both lots), but most of the fin-clipped fish were released when water temperatures were declining and, hence, becoming more favorable for survival.

SPAWNING SUCCESS

Annual surveys by Richards[5] and Pirtle and Keating (1955)[6] provided percentages of totally spent fish on the spawning grounds from inspection of gonads and counts of eggs retained before and after the filling of Brownlee Reservoir in 1958 (fig. 5). These observations showed that passage through the reservoir did not affect the ability of fall-run chinook salmon to spawn successfully. The difference between percentages of totally spent fish in the preimpoundment and postimpoundment years was not significant.

Information on the use of specific areas for spawning by various salmonids was obtained from surveys before and after the impoundment was formed and from discussions with personnel of the Oregon State Game Commission, who annually surveyed spawning fish in the Powder River and its major tributary—

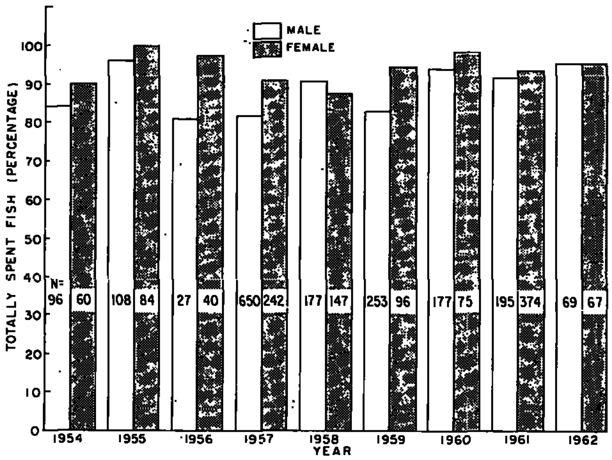

FIGURE 5.—Percentage of totally spent fall-run chinook salmon recovered on spawning ground surveys in the Swan Falls area, Snake River, 1954–62. Numerals in each bar indicate number of fish. Brownlee Reservoir was filled in 1958.

Eagle Creek; the Idaho Fish and Game Department carried out similar spawning surveys upstream from the impoundment in the Snake and Weiser Rivers. Records of State fishery agencies and of the Bureau of Commercial Fisheries on the capture of juveniles migrating from these various spawning areas also verified previous spawning.

The formation of Brownlee Reservoir apparently did not affect the ability of anadromous salmonids to use specific spawning areas. Fall-run chinook salmon passed through the impoundment after construction of Brownlee Dam and spawned in their accustomed area near Swan Falls. Because no tagged fall-run chinook salmon were observed in other spawning streams in 1960–62, straying evidently was slight or nil. Spring-run chinook salmon and steelhead trout, as evidenced by surveys on spawning grounds and by catches of their progeny in sampling traps, continued to use widely separated spawning areas after the reservoir was filled. Some spring-run populations entered the Powder River about 32 km. above Brownlee Reservoir and migrated into Eagle Creek to spawn (fig. 1), whereas others passed through the entire length of the impoundment and continued into spawning grounds in the Weiser River system.

[4] Graban, James R. 1964. Evaluation of fish facilities, Brownlee and Oxbow Dams, Snake River. Idaho Fish and Game Department, 60 pp. [Processed.]

[5] Richards, Monte. 1956–62. Snake River fall-chinook spawning ground surveys. Idaho Fish and Game Department. Various pagination. [Processed.]

[6] Pirtle, Ralph B., and James Keating. 1955. Annual report: The size and timing of runs of anadromous species of fish in the Columbia and Snake Rivers and their tributaries above the confluence of the Snake River, 1954. Idaho Fish Game Dept., Contract DA 35-026-eng-20608, for U.S. Army, Corps Engrs., 30 pp. [Processed.]

RATES OF MIGRATION OF FISH MARKED WITH PETERSEN TAGS

The rate of movement of chinook salmon in Brownlee Reservoir in 1960 was estimated by Hauck (see footnote 1) from tagged fish that sport fishermen recovered on the spawning grounds. Eight fish released in the reservoir and five released in the river were recovered; the elapsed time from release to recovery averaged 32.0 days (range, 17 to 42) for fish released in the reservoir and 25.8 days (range, 18 to 30) for those released in the river 16 km. above the reservoir. On the basis of the difference between the averages (6.2 days) and the distance between the reservoir and the river release sites (104.5 km.), he estimated the average rate of movement in the reservoir as 16.8 km. per day.

Rates of migration were not studied in 1961, but in 1962 the rate of movement through the reservoir was estimated from data on five tagged fish that were identified as they migrated through a gate in a weir in the Snake River (fig. 6). The weir was 20 km. above the reservoir and 1 km. above the river release site, which was 19 km. above the reservoir in 1962. (Midway through the experiment, it became evident that the weir was delaying upstream migration; the structure was removed at the end of September to allow free passage of adult migrants.) The total elapsed time between release of the five fish above Brownlee Dam and recapture at the weir (108.5 km. upstream) ranged from 3.2 to 9.9 days and averaged 6.7 days. Thus, the average rate of upstream movement from release to passage through the weir was 16.1 km. per day. The true rate of movement may have been somewhat faster than indicated because the calculation does not take into account any possible delays at the weir.

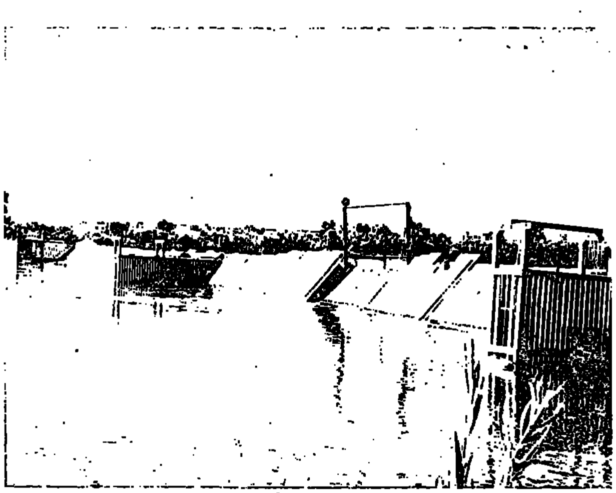

FIGURE 6.—Snake River weir (upstream view) with fish traps for identification and release of migrating salmon. Site is about 20 km. above Brownlee Reservoir.

Thirteen tagged salmon released in the Snake River in 1962 were observed passing through the weir, 1 km. upstream, in elapsed time that ranged from 2.2 hours to 6.6 days and averaged 2.8 days (or about 0.36 km. per day). The delaying effect of the weir undoubtedly accounted for the low rate of movement in this stretch of river. As is shown in the next section, more than half of the sonic-tagged fish reached the weir in less than 1 hour; hence, they moved up this short section of stream at about 19 km. per day.

ORIENTATION AND MOVEMENT OF SONIC-TAGGED FISH

Because the sonic tags we used transmitted identifiable signals for only about 5 days, our experiments were limited to a study of initial behavior after release. In such a study, it is essential that the attachment of the tag not affect the behavior of the fish. We were unable to detect any immediate effect of the tag from visual observations of tagged and untagged fish released in the same area. Although the long-term effect on behavior is unknown, previous work by the Bureau of Commercial Fisheries during the past 10 years suggests that the effect may be slight (Johnson, 1957).

BROWNLEE RESERVOIR

Most of the chinook salmon with sonic tags released in Brownlee Reservoir in 1961 were initially disoriented and spent considerable time in the lower end of the reservoir before resuming migration upstream. The movement of an obviously disoriented fish is shown in figure 7. A track of one fish that resumed migration upstream soon after release is shown in figure 8.

The initial aimless wandering of most of the sonic-tagged fish may also have been characteristic of untagged fish released in the reservoir; if so, they eventually recovered because a high percentage of fish arrived on the spawning grounds from releases in the reservoir. In 1962, for example, nearly 25 percent of the untagged fish released in the reservoir were recovered in the spawning areas. In view of the size of the Snake River (flow more than 365 c.m.s.) and the extent of spawning grounds (over 25 river km.), we can be certain the percentage of fish that reached the spawning grounds was far greater than the percentage recovered.

SNAKE RIVER

More than half of the 44 fish with sonic tags that were released in the Snake River covered the 1.0 km. stretch to the weir in less than an hour. Other fish moved more slowly. A few fish remained in the release area up to 24 hours, and one stayed 4 days before moving upstream. Only one fish moved downstream; this salmon drifted 2.4 km. below the release site, lingered about 2 hours, and then resumed its migration upstream. Distributions that show the delaying effect of the weir are given in figure 9.

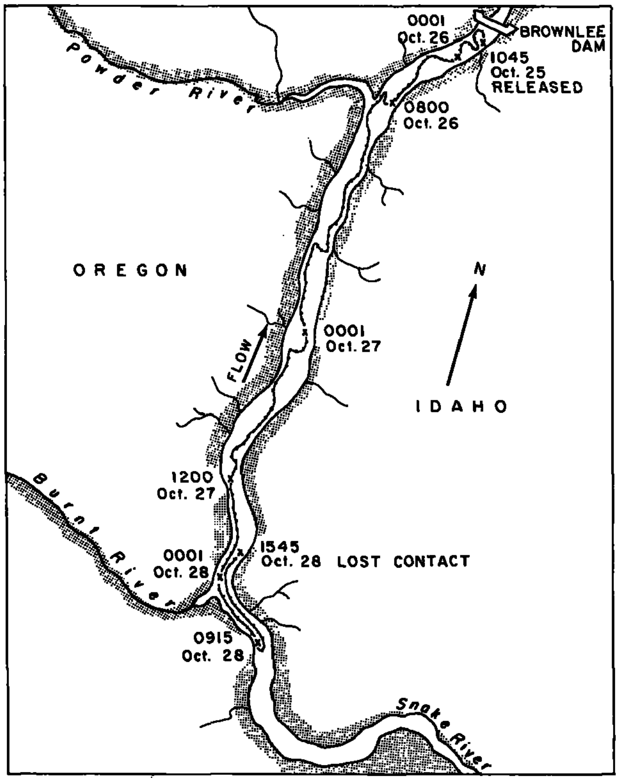

FIGURE 8.—Chronological record (diagrammatic) of a 77-hour track of well-oriented adult chinook salmon moving 81 km. upstream in Brownlee Reservoir. Fish carried a sonic tag.

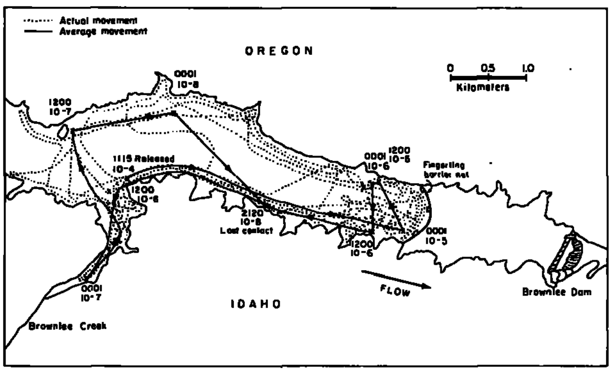

FIGURE 7.—Disoriented movement of an adult chinook salmon tagged with a sonic tag and released in Brownlee Reservoir. This fish, tracked for 106 hours, moved almost continuously day and night and traveled about 81 km. Travel was confined to area within 3.2 km. of the release point.

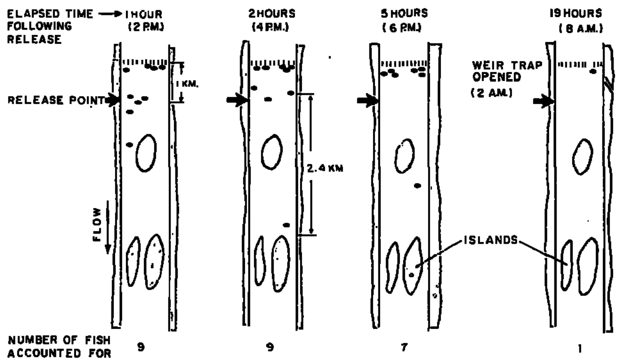

FIGURE 9.—Diagram of the changing distribution of a group of nine chinook salmon tagged with sonic tags and released in the Snake River above Brownlee Reservoir. Two fish presumably passed through the weir between 4 and 6 p.m. No fish were found farther than 2.4 km. downstream from the weir.

In a similar, earlier release from the same site, all but one of seven fish moved up to the weir during the afternoon. Some fish then dropped downstream about 1 km. after dark but returned to the weir in the morning, at which time only two were counted through the gates. In three releases (total of 25 fish) after the weir was removed, the fish moved past the vacated site without hesitation.

Sonic tags provided additional information on rates of movement in the river. Fish took from 26 to 120 hours to move upstream from the release point to the monitor at the Payette River mouth, which was 24 km. upstream. The maximum rate of movement for the distance was, therefore, slightly more than 0.8 km. per hour, or 19 km. per day. The slowest fish recorded by the monitor moved 13 km. upstream in 6 days; this was the same fish mentioned earlier, which had spent 4 days in the release area before resuming migration.

EXAMPLES OF PASSAGE THROUGH LARGE NATURAL LAKES

Because Brownlee Reservoir provides the only evidence of chinook salmon passage through a long, deep impoundment, we searched for other examples of their passage capabilities under comparable conditions. Passage of chinook salmon through large, shallow impoundments, such as those formed by low-head dams on the Columbia River, has long been established. These impoundments pass tremendous volumes of water and normally provide strong directional currents that are usually absent in large, deep reservoirs, such as Brownlee. What was needed were examples of passage through large bodies of water having low or no directional currents. Although large lakes with inlets and outlets may differ from reservoirs, the flow of water and limnological conditions can be similar to those in large, deep impoundments.

We discussed the passage of adult chinook salmon through large, natural bodies of water with biologists familiar with chinook salmon runs in Alaska, British Columbia, and the Yukon Territory. They estimated the sizes of sustained runs and provided data on the sizes of lakes through which the species migrates to reach spawning areas.

We concluded that the size of a body of water may not influence greatly the upstream migration of this species. In Bristol Bay, Alaska, chinook (king) salmon have been observed in the upper Wood River Lakes (Burgner, personal communication[7]). To reach this area, the fish migrate through three connecting lakes—about 30 km. through Aleknagik Lake, about 56 km. through Lake Nerka, and about 24 km. through Lake Beverly. An average of 5,000 adults entered in 1957–62 and spawned in tributaries to Naknek Lake (about 64 km. long) (Jaenicke, personal communication[8]). Some of these fish were observed at the Brooks Lake weir in a tributary stream about 48 km. above the outlet of Naknek Lake.

In British Columbia (Fraser River system), researchers[9] estimated that 500 to 1,000 adult chinook salmon pass through Harrison Lake (80 km.) into the Birkenhead River; about 5,000 migrate through Kamloops Lake (24 km.) and continue for 72 km. through Shuswap, Eagle, and Mara Lakes to spawn. Some chinook salmon pass 72 km. through Quesnel Lake into the Mitchell River. Before Coulee Dam was constructed on the Columbia River, large runs of chinook salmon were reported by local residents (Bryant and Parkhurst, 1950) to have migrated through the lower Arrow Lake (72 km.) and upper Arrow Lake (56 km.) to spawn below Windermere Lake, 128 km. farther upriver.

More than 3,600 chinook salmon are estimated by Elliott (personal communication[10]) to enter LaBerge Lake on the Yukon River, Yukon Territory. A small number enter a tributary about halfway through the 56-km. lake, but most continue through the lake to the Takhini and McKlintock Rivers. Another run

[7] Robert L. Burgner. 1963. Fisheries Research Institute, University of Washington, Seattle, Wash.

[8] Herbert W. Jaenicke. 1964. Fishery Biologist, Bureau of Commercial Fisheries, Auke Bay, Alaska.

[9] J. R. Brett, Fishery Research Board of Canada, Nanaimo, B. C.; and W. R. Hourston, D. McKinnon, and B. M. Chatwin, Department of Fisheries, Canada, Vancouver, B. C.

[10] W. K. Elliot. 1964. Fishery Officer, Department of Fisheries, Canada, Whitehorse, Yukon Territory.

of 2,000 fish migrate up the Teslin River, tributary to the Yukon River below LaBerge Lake, and continue 72 km. into Teslin Lake before entering the Nisutlin River; from here the fish continue for another 153 km. to a spawning area at the outlet of Nisutlin Lake.

IMPLICATIONS OF PRESENT RESEARCH

Our experiments indicated that adult fall-run chinook salmon can migrate through large impoundments. This ability apparently does not require previous reservoir experience in the juvenile stage; adult salmon returning upstream through Brownlee Reservoir in 1958–60 had passed downstream through this area as juveniles when it was still a river. The results point to the feasibility of passing adult chinook salmon directly through large storage reservoirs, thus eliminating the need for extended transport around impoundments.

The successful passage of fall chinook salmon through Brownlee Reservoir has special significance because the environment for the survival of upstream migrants is perhaps as poor as any found in the present freshwater range of this species. Surface temperatures over 21° C. are common in the reservoir until mid-September, and oxygen concentrations in the deeper, cooler water generally are 4 p.p.m. or less [11] during the fall migration. Despite the marginal environment for survival of salmonids in the reservoir, adult migrants apparently suffered no greater losses than the fish bypassed upstream to the river, where water temperatures and oxygen concentrations were much more favorable.

[11] Ebel, Wesley J., and Charles H. Koski. Physical and chemical limnology of Brownlee Reservoir. Bureau of Commercial Fisheries Biological Laboratory, Seattle, Wash. Manuscript in preparation.

CONCLUSIONS

The studies on chinook salmon in the Brownlee Reservoir area support the following conclusions:

1. Evidence of successful passage by chinook salmon through Brownlee Reservoir and of their sustained migration through large lakes in Alaska, British Columbia, and Yukon Territory suggests that the large size of an impoundment may not be detrimental to upstream migration of this species.
2. Despite initial disorientation, chinook salmon released in the reservoir were able to reach spawning areas as successfully as those transported and released in the river above the impoundment. In the river, fish resumed migration shortly after release.
3. The ability of fish to spawn successfully was not affected by passage through the reservoir.
4. Ancestral spawning grounds in the Snake River above the reservoir continued to be used after the impoundment was formed.

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