EFFECTS OF TRANSPORTATION ON SURVIVAL AND HOMING OF SNAKE RIVER CHINOOK SALMON AND STEELHEAD TROUT

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ABSTRACT

The homing ability of adult fish that were captured during their seaward migration as juveniles and then transported downstream (from Ice Harbor Dam to Bonneville Dam) was not diminished. Data from returning adults indicated survival of adult fish that had been transported downstream as juveniles was higher than that of fish not transported. The percentage of increased survival ranged from 50 to 300% depending on the river environment during the time of transport. Information on the timing of the seaward migration and the extent of mixing of seaward runs of spring and summer chinook salmon, *Oncorhynchus tshawytscha*, was also obtained.

Losses to juvenile and adult Pacific salmon, *Oncorhynchus* spp., and steelhead trout, *Salmo gairdneri*, populations migrating in the Columbia and Snake Rivers have increased drastically in the last decade because of the effects of recently completed dams. The reservoirs formed by these dams have inundated some important spawning and rearing areas, have created new passage problems for both adult and juvenile migrants, and, in most cases, have significantly changed the aquatic environment to the detriment of salmonid fishes.

Gas bubble disease caused by high concentrations of dissolved nitrogen gas, resulting from the spilling of water at dams, has been pinpointed by the National Marine Fisheries Service (NMFS) (Ebel, 1969; Beiningen and Ebel, 1970; Ebel, 1971) as a major cause of salmon and steelhead trout mortalities. Nitrogen gas in the atmosphere is forced into solution as the water plunges into deep spill basins; the dissolved gas remains in solution in impounded sections of the river resulting in several hundred kilometers of water supersaturated with nitrogen gas through which fish must migrate. Another significant source of mortality can be due to passage of fish through turbines, particularly when indirect mortalities due to predation on fish emerging from turbines are included. These mortalities will persist even if nitrogen levels are reduced. Recent estimates (Raymond, 1970)[2] of losses to juvenile populations migrating downstream in the Snake and Columbia Rivers—that reflect losses from all sources, including nitrogen supersaturation—indicate that chinook salmon, *O. tshawytscha*, and steelhead trout from the upper Snake River drainage may be reduced to critically low numbers unless action is taken to reduce these losses.

NMFS has been conducting transportation experiments since 1965 to find ways of reducing these losses. Since 1968 we have been concentrating on an experiment where migrating juvenile salmon and trout—mostly spring and summer chinook salmon—are collected at Ice Harbor Dam and transported to two locations downstream. The experiment was designed to determine the effect of transportation on survival and homing.

Past information (Ellis and Noble, 1960; unpublished hatchery records of Washington,

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[2] Raymond, H. L. 1970. A summary of the 1969 and 1970 outmigration of juvenile chinook salmon and steelhead trout from the Snake River, Progress Report. U.S. Dep. Commer., Natl. Oceanic Atmos. Admin., Natl. Mar. Fish. Serv., Biol. Lab., Seattle, Wash. Unpubl. manuscr.

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Oregon, and California) concerning the effect of transportation of hatchery stocks of juvenile chinook salmon, coho salmon, *O. kisutch*, and steelhead trout on homing indicates that the homing mechanism is disrupted by the transportation process. In these experiments, the majority of the adults returned to the location of release and not to the hatchery of origin.

We recognized this in pursuing our experiments but felt confident that different results would be obtained because we were dealing with juvenile fish, captured during their seaward migration, that had an entirely different life experience before being collected and transported. The wild stocks among our captured fish had lived for a year or more in their parent stream, were actively smolting at the time of capture, and had traversed several hundred kilometers of stream before they were transported. Captured hatchery stocks also were actively smolting at the time of capture and had traversed many kilometers before being collected. Transport experiments done by others have been conducted with hatchery stocks taken directly with no stream experience from hatchery ponds. Previous experiments (Groves, Collins, and Trefethen, 1968; Hasler and Wisby, 1951; and others) on mechanisms used by fish for homing suggest that the experience during the time that the juvenile salmon migrates seaward is important in enabling the fish to receive olfactory and visual cues necessary for homing as an adult. Since we were eliminating only a portion of the fish's migration route by transporting, we hypothesized that a fish would be successful in seeking its home stream and that survival to the spawning grounds as well as to the fishery would be increased.

The adult returns from releases of juvenile chinook salmon in 1968 and 1969 and of juvenile steelhead trout in 1969 and 1970 were obtained in 1970 and 1971. This report describes the results of the experiment based on information compiled to date. Adult returns from chinook salmon releases in 1969 and steelhead trout releases in 1970 were insufficient because 2- and 3-ocean returns are needed from data that will be obtained in 1971 and 1972 and, therefore, are not included in this report. A supplementary report will be made as additional information is received in future years.

METHODS

General Experimental Design

Three groups (one control and two transported) of migrating chinook salmon (spring- and summer-run populations) and steelhead trout were collected from gatewells at Ice Harbor Dam. Gatewell dip net hauls were mixed, then the test and control groups were selected randomly from the pooled dip net hauls. These were marked by removal of the adipose fin and with a thermal brand and a magnetized wire tag. The control, or non-transported, group was released about 15 km above Ice Harbor Dam. The transported groups were released 5 km downstream from John Day Dam on the Oregon side of the Columbia River and 1 km downstream from Bonneville on the Washington side of the river (Figure 1). A separate brand was assigned to each group and was changed weekly. A distinguishing color-coded wire tag was also assigned to the control and to the experimental groups. In 1968 one color-code was used on both transported groups. In 1969 and 1970 separate codes were assigned to each transported group.

All groups were hauled in a tank truck of 18,900-liter (5,000-gal) capacity that has been

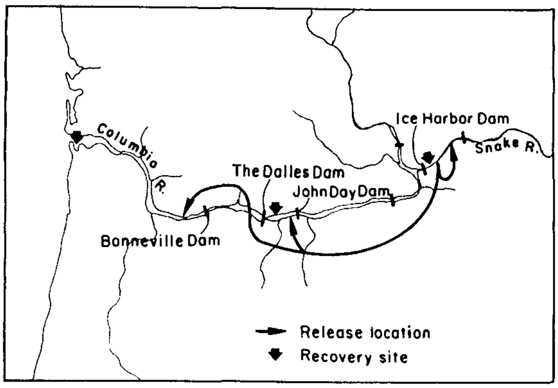

FIGURE 1.—Columbia and Snake Rivers, showing release and recovery sites of migrating chinook salmon and steelhead trout.

described by Ebel (1970). All releases were made at dusk. Records were kept of mortality during marking and at time of release.

This general procedure has been repeated during three downstream migrations—from 1968 through 1970. Each year our goal was to mark at least 50,000 fish per group but, because of low collection efficiency at the gatewells in 1969-70, this goal was reached only in 1968. In 1969 and 1970, steelhead trout were also included in the experiment.

Collection, Marking, and Hauling Procedures

In 1968-69 fish were obtained for the experiment by dipnetting them from gatewells (Bentley and Raymond, 1969). An orifice bypass system (Park and Farr, 1972) was completed in 1970 by the U.S. Army Corps of Engineers; we used this system as a source of fish in the spring of 1970. In 1969 and 1970, fish collected in the above manner were hauled by tank truck to a holding facility where they were held for about 24 hr before marking in denitrified water which had been pumped from the Snake River. Minor gas bubble disease subsided during the holding period, and presumably our holding procedure relieved some of the stress from this disease caused by the newly constructed dams upstream. In 1968, the disease was not a problem, and the fish were held and marked on the intake deck of the dam.

Fingerlings were brought into a marking building where they were anesthetized, examined for marks, and sorted by species. Marked fish were returned to the river; each of the remaining unmarked fish was cold-branded with liquid nitrogen (Mighell, 1969), the adipose fin was excised, and a magnetized wire tag was inserted in the snout (Jefferts, Bergman, and Fiscus, 1963). Before being placed into the transport truck, each fish went through a magnetic field (to magnetize the tag) and a detection coil; an improperly tagged fish was automatically rejected and returned to the marker for retagging. Steelhead trout and chinook salmon were kept in separate compartments in the truck whenever both species were hauled simultaneously. Load densities were governed by the size of a day's catch which never exceeded 10,000 fish. Thus loads were less than 60 g of fish per liter (½ lb. per gal) of water, which allowed a large margin of safety without loss of fish.

Water chemistry measurements were taken at the time of release for every load transported in 1968; in 1969 and 1970 only occasional water chemistry checks were made. Concentrations of ammonia, nitrogen, dissolved oxygen, carbon dioxide, pH, and total alkalinity were recorded.

Evaluation of Downstream Survival of Juveniles

Comparisons of the downstream survival of juvenile chinook salmon and steelhead trout released in the pool above Ice Harbor Dam and at John Day Dam were based on the proportions of these groups recovered from the gatewells by dipnetting at The Dalles Dam. Additional sampling with beach seines and purse seines was attempted in the Columbia River estuary. Samples from the estuary were to be used to evaluate survival to the sea.

Evaluation of Returning Adults

The effect of transportation on the survival and homing of adult fish was evaluated by comparing recoveries of transported and non-transported groups at various sites in the river system. These included returns to the sport, commercial, and Indian fisheries in the lower Columbia River; to Ice Harbor Dam on the lower Snake River; to Rapid River Hatchery (Idaho); and to the spawning grounds.

At Ice Harbor Dam about 80% of the run of adult fish ascends the south ladder enroute to the spawning grounds. We installed in this ladder a tag detector and adult separator device that intercepted tagged salmon and trout (Durkin, Ebel, and Smith, 1969) and diverted them into a holding pen (Figure 2). The tagged fish from our study were readily identified by the missing adipose fin. These were anesthetized and further examined for brands. If the brand was recognizable, the origin of the fish could be determined without having to extract the magnetic tag from the snout. Fish with recognizable brands were then dart-tagged and released so that further information might be obtained upon recapture upstream or to identify the fish in case it fell back over the dam and ascended the ladder a second time. If a fish was known to be tagged but the brand was indistinguishable, it was tagged with a serially numbered dart and hauled to the Rapid River Hatchery where the fish was allowed to mature for spawn taking. The tag was then extracted after spawning, and the test or control group was determined from the color code.

The Columbia River gill net fishery below Bonneville Dam, the Indian fishery above the dam, and the sport fishery (primarily below the dam) were sampled throughout the spring chinook salmon run to provide information concerning the returns of our marked fish to the lower river. Closure of the summer fishery on chinook salmon prevented sampling of this segment of the run in the lower river. Steelhead trout were sampled in the sport and commercial fisheries of the lower river, but first year returns of fish from those marked in 1969 were insignificant.

Surveys of spawning grounds were conducted with the cooperation of the Washington Department of Fisheries, Fish Commission of Oregon, and the Idaho Fish and Game Department. Most of the surveys were in the Snake River drainage of Idaho, but hatcheries and spring and summer chinook spawning grounds in the upper Columbia River were also checked for strays.

RESULTS

Effect of Transport Mortality and Tag Loss on Analysis

Two factors that have bearing on the assessment of effects of transportation are transport mortality and tag loss.

Transport mortality is actually a combination mortality resulting from stresses of handling, marking, and hauling. During this study, mortality prior to hauling was less than 2% of the total number of fish collected. Of those marked and transported, however, about 5% died. This mortality was subtracted from the tallies of release group data in this report. Attempts were made to determine a delayed mortality after transport. These tests failed because holding conditions were unfavorable

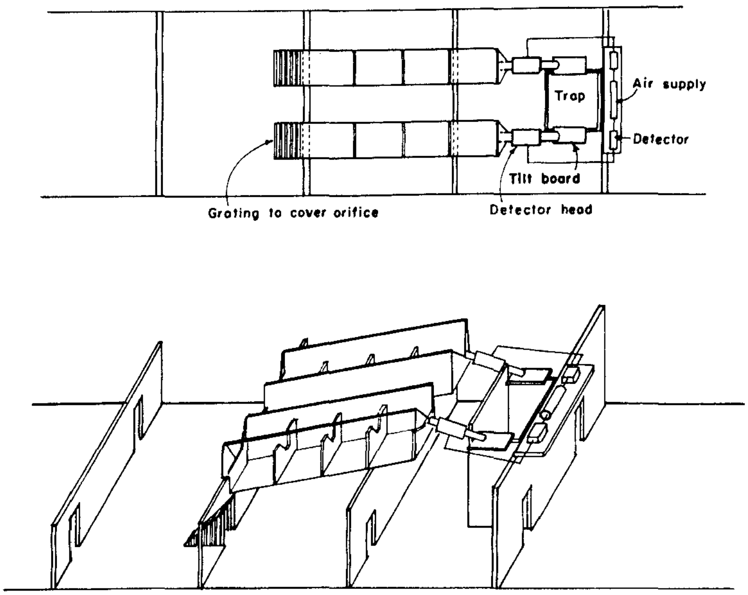

FIGURE 2.—Diagrammatic sketch of tag detector and separator device used for adult salmon and trout in south ladder of Ice Harbor Dam. Note trip board deflects tagged fish into trap.

and most fish probably died from factors other than stress from hauling.

One test, conducted with steelhead trout on 27-28 May, gives insight into the effect of transportation on smolts. Two groups of about 3,500 smolts each were released at the control group release site. Group I was treated similarly to that of our normal control group; i.e., the fish were hauled for about 1 hr before being released in the impoundment upstream from Ice Harbor Dam. Group II was treated in a like manner but was hauled for 7 hr before being released at the same site as group I. (This was approximately 2 hr longer than our typical hauls to date, but if transport tests in the future are made from points upstream, it is conceivable that 7 hr would be a minimum trip.) Upon examination of returns at Ice Harbor Dam, significantly ($\chi^2 = 4.300$; d.f. = 1) fewer fish returned from the long-haul group. More tests are required to establish an accurate posttransport mortality percentage.

Tag loss does not affect our information relating to effect of transportation on downstream survival. All data were adjusted for marking, handling, and transport mortality. Loss of tags is important when considering the results from returning adult fish. Insofar as affecting results of this study, apparent "tag loss" can occur in three ways: 1) Faulty machine operation—the smolt may never have been tagged; 2) the tag may be rejected at some time after being properly inserted in the snout; and 3) the fish can be tagged but the tag is not adequately magnetized. All have the same result—the returning fish cannot be detected. In 1968 our best information on initial tag loss was obtained from sampling at The Dalles Dam and from releases below Bonneville Dam. Although tag loss differed between release groups, overall weighted average tag loss on chinook salmon was 9.2%. Numbers of chinook salmon (transported and control) mentioned in this report have been adjusted on this basis. Tagging procedures were refined in 1969-70 so that tag loss is now less than 1% for both chinook salmon and steelhead trout.

Effect of Transportation on Downstream Survival of Juveniles

The best information concerning the effect of transportation on downstream survival of juveniles was obtained from catches in the gatewells of The Dalles Dam. The numbers of transported and nontransported (control) chinook salmon and steelhead trout that were marked and released are shown in Table 1. Recoveries at The Dalles Dam included only those fish transported to John Day Dam and the control releases above Ice Harbor Dam. Survival of the transported groups released at Bonneville Dam was estimated by recoveries in the estuary. Marked chinook salmon obtained from beach seine catches in the estuary were too limited (40 in 1968; none in 1969 and 1970) to reveal significant information. Table 2 compares recaptures of control and transported fish in 1968 that were released before and after heavy spilling began at The

TABLE 1.—Number of transported and nontransported (control) juvenile chinook salmon and steelhead trout that were marked and released, 1968-70 (figures adjusted for tag loss).

Release site and (in parentheses) experimental group of fish	1968	1969		1970	
	Chinook	Chinook	Steelhead	Chinook	Steelhead
Ice Harbor Dam (control)	80,335	24,217	25,313	8,624	18,347
John Day Dam (transported)	40,895	14,782	20,430	10,159	20,935
Bonneville Dam (transported)	42,420	13,529	—	10,173	31,282
Total	163,650	52,528	45,743	28,956	70,564

TABLE 2.—Releases and recaptures of transported and nontransported juvenile chinook salmon (transported fish were released below John Day Dam and nontransported fish were released above Ice Harbor Dam) that were recaptured at The Dalles Dam from releases before and after spilling began, 1968 (figures not adjusted for tag loss).

	Nontransported (control) fish					Transported fish				
Dates of release	Number released	Number recaptured	Dates of recapture	Percentage recapture	Recovery efficiency[1]	Number released	Number recaptured	Dates of recapture	Percentage recapture	Percentage increase in survival[2]
Before spill:										
4/2-4/5	425	13	4/22-5/8	—	—	0	0	—	0	—
	—	3	5/9-5/29	—	—	—	—	—	—	—
	—	16	—	3.76	5.74	—	—	—	—	—
4/8-4/12	4,128	175	4/22-5/22	—	—	1,352	67	4/16-5/16	—	—
	—	4	5/29-6/4	—	—	—	—	—	—	—
	—	179	—	4.34	4.56	—	—	—	4.96	—
4/15-4/19	7,843	1	4/26	—	—	7,305	416	4/22-5/25	—	—
	—	253	5/1-5/25	—	—	—	3	5/26-6/6	—	—
	—	17	5/26-6/14	—	—	—	0	—	—	—
	—	271	—	3.46	4.56	—	419	—	5.74	—
4/22-4/26	17,499	436	5/6-6/7	2.49	3.87	4,517	184	4/25-5/27	4.07	—
Totals	29,895	902	—	—	—	13,174	670	—	—	—
Cumulative average	—	—	—	3.02	5.09	—	—	—	5.09	69
After spill:										
4/28-5/4	15,711	241	5/9-5/30	—	—	9,222	347	5/1-5/25	—	—
	—	12	5/31-6/13	—	—	—	10	5/26-6/11	—	—
	—	253	—	1.61	3.88	—	357		3.87	—
5/5-5/11	21,964	190	5/16-6/11	0.86	3.88	8,730	340	5/8-6/12	3.89	—
5/12-5/17	11,371	48	5/22-6/12	0.42	2.64	6,446	212	5/16-6/14	3.29	—
5/18-5/22	5,200	—	—	—	—	2,791	27	5/22-5/30	—	—
	—	—	—	—	—	—	5	5/31-6/10	—	—
	—	7	5/27-6/6	0.13	1.15	—	32	—	1.15	—
5/23-6/7	2,290	0	—	0.00	0.00	3,601	4	6/5-6/12	0.11	—
Total	56,536	498	—	—	—	30,790	945	—	—	—
Cumulative average	—	—	—	—	0.88	—	—	—	3.07	249
Grand total	86,431	1,400	—	—	—	43,964	1,615	—	—	—
Cumulative average	—	—	—	1.62	3.67	—	—	—	3.67	127

[1] Recovery efficiency based on average percentage recapture of transported fish at The Dalles Dam for the recovery period shown. One hundred percent survival assumed between release site below John Day Dam and The Dalles Dam.
[2] Percentage increase in survival of transported groups equal to [(recovery efficiency) (100)/(% recapture of control)] - 100.

Dalles Dam. Recovery rates of survivors to The Dalles Dam varies tremendously depending on flow condition. Because the controls released at Ice Harbor Dam often took several days to reach The Dalles Dam, the recapture rate varied and was spread out over a longer period than the test groups. The recapture rate computed for the controls was therefore based on average recapture rate measured throughout the recovery period of the controls. As the table indicates, this rate was based on average percentage recovery rate of the test groups released during that period. It should be stressed that spilling also occurs at upstream dams once steady spilling begins at The Dalles. Before heavy spilling, the data indicate that survival of fish transported to John Day Dam was increased about 69% ; the ratio of recapture of transport/control fish was 1.7:1. After heavy spilling, survival was increased by about 250% or 3.5:1.

In 1969 (Table 3), heavy spilling occurred throughout the recapture period at The Dalles Dam. The overall average recovery of chinook salmon indicates that transportation increased survival by about 90%, or a ratio of about 1.9:1. Recapture data from steelhead trout indicated a 245% increased with a ratio of about 3.5:1. No downstream survival data were obtained in 1970.

Returns of Adult Spring and Summer Chinook Salmon to Ice Harbor Dam

Table 4 lists the number of adult salmon successfully detected, separated, and identified at the automatic separator in the south ladder at Ice Harbor Dam. It should be stressed that the observed return represents only a fraction of the total return of marked fish to Ice Harbor Dam. The observed tally is low for the following reasons: 1) Approximately 20% of the run at Ice Harbor passes up the right bank (North) fishway which did not have a tag detection device; 2) the tag detection system in the left bank (South) fishway was less than 100% efficient; 3) the system was operated less than full time during salmon runs; and 4) some tag losses had occurred between tagging and recovery.

The combined adult returns of spring and summer chinook salmon at Ice Harbor Dam to 31 July 1971 from juveniles marked in 1968 (Table 4) indicate that survival from releases at Bonneville Dam were significantly (χ^2 = 33.184; d.f. = 1) greater (2.0:1) than those from control releases at Ice Harbor. When these returns at Ice Harbor are divided into spring and summer seasonal races and

TABLE 3.—Releases and recaptures of transported and nontransported juvenile chinook salmon and steelhead trout transported fish were released below John Day Dam and nontransported fish were released above Ice Harbor Dam) that were recaptured at The Dalles Dam, 1969 (figures not adjusted for tag loss).

Species and dates of release	Nontransported (control) fish					Transported fish				
	Number re-leased	Number recap-tured	Dates of recapture	Percent-age recapture	Recovery effi-ciency[1]	Number re-leased	Number recap-tured	Dates of recapture	Percent-age recapture	Percentage increase in survival[2]
Chinook salmon:										
4/11-4/19	5,297	43	4/22-5/7	0.81	1.88	5,159	35	4/17-4/29	0.68	—
4/20-4/27	6,977	68	4/28-5/15	0.97	2.19	2,301	24	4/23-4/29	1.04	—
4/28-5/4	2,844	15	5/8-5/14	0.53	1.35	4,538	105	4/29-5/12	2.31	—
5/5-5/11	4,312	17	5/13-5/23	0.39	0.94	666	9	5/8-5/16	1.35	—
5/12-5/18	3,553	15	5/19-5/27	0.42	1.07	521	3	5/15-5/19	0.58	—
5/19-5/25	1,947	12	5/23-6/2	0.62	1.07	1,497	16	5/21-6/2	1.07	—
5/26-6/1	561	1	6/4	0.18	.80	878	7	6/3-6/5	0.80	—
Total	25,491	171	—	—	—	15,560	199	—	—	—
Cumulative average	—	—	—	0.67	1.28	—	—	—	1.28	91
Steelhead trout:										
4/11-4/19	1,184	8	4/23-5/2	0.68	—	0	0	—	—	—
4/20-4/27	3,812	11	4/28-5/8	0.29	1.59	0	0	—	—	—
4/28-5/4	2,379	14	5/8-5/21	0.59	1.36	4,207	67	5/2-5/16	1.59	—
5/5-5/11	6,036	27	5/9-5/23	0.45	1.46	4,635	63	5/7-5/20	1.36	—
5/12-5/18	7,497	25	5/16-6/2	0.33	1.24	6,785	106	5/15-5/27	1.56	—
5/19-5/25	4,421	14	5/23-6/9	0.32	0.74	3,441	32	5/21-6/4	0.93	—
5/26-6/1	1,316	1	6/4	0.08	—	2,437	14	5/28-6/4	0.57	—
Total	26,645	100	—	—	—	21,505	282	—	—	—
Cumulative average	—	—	—	0.38	1.31	—	—	—	1.31	245

[1] Recovery efficiency based on average percentage recapture of transported fish at The Dalles Dam for the recovery period shown. One hundred percent survival assumed between release site below John Day Dam and The Dalles Dam.
[2] Percentage increase in survival of transported groups equal to [(recovery efficiency) (100)/(% recapture of control)] - 100.

TABLE 4.—Percentage of transported and nontransported (control) juvenile chinook salmon (released in 1968) that were recaptured as adults at Ice Harbor Dam, 1 April through 30 September 1970 and 1971.

Release site and (in parentheses) experimental group of fish	Number of juveniles released[1]	Number recaptured as adults	Percentage return as adults	
			Observed	Estimated[2]
Ice Harbor Dam (control)	80,335	117	0.14	4.3
John Day Dam (transported)	40,895	64	0.16	4.7
Bonneville Dam (transported)	42,420	128	0.30	9.0
Total	163,650	309	0.19 Ave.	5.6

[1] Adjusted for initial tag loss.
[2] Based on a comparison of the known recovery of fish with magnetized wire tags at Ice Harbor Dam and the subsequent recovery of these and other marked fish at a hatchery upstream from Ice Harbor. Returning fish identified at the dam were marked with dart tags and released to continue their migration upstream. Numbers of dart-tagged fish arriving at Rapid River Hatchery were compared with the recovery of other wire-tagged fish not previously detected and identified at Ice Harbor Dam.

compared (Table 5), benefits from transportation are defined by time. Returns of spring chinook salmon are in a ratio of 1.8:1 (transport/control) and summer chinook salmon in a ratio of 2.8:1.

TABLE 5.—A comparison between transported and nontransported groups of chinook salmon based on numbers of transported and nontransported juvenile fish (released at Bonneville and John Day Dams) that were recaptured as adults at Ice Harbor Dam in 1970 and 1971.

Release site (of juveniles) and seasonal race of salmon[1]	No. of salmon recaptured[2] as adults at Ice Harbor Dam		Transport/control ratio of fish
	Transported	Nontransported (control)	
Below Bonneville Dam:			
Spring chinook salmon	161	88	1.8:1
Summer chinook salmon	82	29	2.8:1
Below John Day Dam:			
Spring chinook salmon	92	88	1.05:1
Summer chinook salmon	36	29	1.24:1

[1] Seasonal races of chinook salmon in the Columbia River system are classified as spring, summer, or fall chinook depending on the time of year that the adults enter the river to spawn. We classified adult salmon captured at Ice Harbor Dam prior to 2 June as spring chinook and those taken from 2 June through 31 July as summer chinook.
[2] *Numbers recaptured adjusted in relation to numbers re*leased (Table 1).

Combined adult returns from the John Day release were only slightly more than returns from the controls. Although the poorer returns from releases at John Day are unexplained at this time, it is possible that the stress on the fish from having to pass two dams (The Dalles and Bonneville) plus the stress of being hauled may have eliminated any benefit from transport prior to spilling. If returns from this release are again separated into seasonal races, however, the ratio of transport to control of the summer chinook salmon is about 1.3:1.

A comparison of adult returns to Ice Harbor Dam from the Bonneville releases with estimates of juvenile survival at The Dalles Dam indicates a correspondence. Prior to heavy spilling when the majority of the spring chinook salmon migrated, the recovery ratio of juveniles released before spilling began was 1.7:1 (transport/controls); adult return ratio at Ice Harbor was 1.8:1 for spring chinook salmon. After heavy spilling when the majority of the summer chinook salmon migrated, the recovery ratio of juveniles released then was 3.5:1; adult return ratio of summer chinook salmon was 2.8:1.

Logically, the adult return ratios indicated from those transported to Bonneville Dam should show more benefit from transport than the juvenile ratios showed at The Dalles Dam because the controls still had to pass two dams, The Dalles and Bonneville, before reaching the ocean. This is not the case; only the spring chinook salmon show a greater ratio; the summer chinook salmon transport/control return ratios for juvenile migrants were higher than the adult ratios established at Ice Harbor Dam.

Returns of Adult Steelhead Trout to Ice Harbor Dam

The first adults returning from control releases and those transported to John Day in 1969 appeared at Ice Harbor Dam in the fall of 1970; in the following year, a second group of older fish returned. We detected 143 steelhead trout with coded wire tags and identified them in the trap at Ice Harbor Dam in 1970 and 1971. Of these, 46 were from the control release, 97 from the transported release—a ratio of 2.1:1 of transport/control. This return ratio is higher than that shown for the returns of summer chinook salmon transported and released at John Day. Although the juvenile fish migrated downstream in different years (1968 for chinook salmon; 1969 for steelhead trout), environmental conditions were similar. During both years, heavy spilling prevailed at the time of release and concentrations of dissolved nitrogen gas were very high.

If gas bubble disease caused by supersaturation of nitrogen was the main factor determining survival of these groups, susceptibility of the salmon and trout to lethal levels of nitrogen gas in the river must have been similar or the ratios of returning adults would not have been similar. This, of course, is merely a hypothesis; several other factors which cause change in survival could also have been responsible for the similarity of the ratios.

This return ratio also indicates that the ability of steelhead trout to return or "home" to Ice Harbor Dam was not appreciably affected by transporting the seaward migrants around a portion of their downstream route.

Recovery of Marked Chinook Salmon in Commercial and Sport Fisheries

Returns to the commercial and sport fisheries in the lower Columbia River (Table 6) are based on the spring fishery and indicate a definite benefit from transportation. The return ratio of transported fish (John Day-Bonneville releases combined) to control fish was 1.4:1. The marked increase in the transport/control ratio for summer-run adults taken at Ice Harbor Dam is not reflected in the commercial fishery because of the closure on summer-run chinook salmon.

It was not possible to distinguish between returns to the fishery from releases at Bonneville and John Day because of the loss of the identifying brands. Brands which would have enabled identification by release site were obliterated by gill-net abrasion. Transported and control groups could be distinguished by magnetic tags, but only two codes were used —one for the controls and one for the transported fish. However, if the percentage of adult returns obtained at Ice Harbor—where brands of fish returning from releases at Bonneville and John Day were visible—is applied to the total transport returns obtained in the commercial fishery, the ratio of transport/control becomes 1.7:1 for fish transported to Bonneville Dam.

TABLE 6.—A comparison between transported and nontransported groups of chinook salmon based on numbers of transported and nontransported juvenile fish that were recaptured as adults by commercial and sport fisheries in the lower Columbia River, 23 February through 11 August 1970 and 1971.

Location of fisheries	No. of salmon recaptured as adults: Transported	No. of salmon recaptured as adults: Nontransported (control)
Upstream from Bonneville Dam (Indian fishery)	37	16
Downstream from Bonneville Dam	95	78
Total	132	94

Returns of Adults to Spawning Grounds

Spring and Summer Chinook Salmon

Spawning ground surveys (Figure 3) and examination of tagged adult fish at Rapid River Hatchery near Riggins, Idaho, provided further information concerning the ratios of transport/control spring and summer chinook salmon at their "home" destination. During the study, 65 tagged fish were recovered from Rapid River Hatchery; an additional 29 were from sport fishermen and spawning ground surveys. Of these fish, 52 were from the transported groups and 42 from the control group. By adjusting for the ratio of John Day to Bonneville returns, we estimated that 36 of the 52 transported fish were from the group released at Bonneville Dam. The ratio, then, of transport/control fish for the group released at Bonneville becomes 1.7:1 when computed on the basis of the number of juveniles released per group. This is nearly identical to

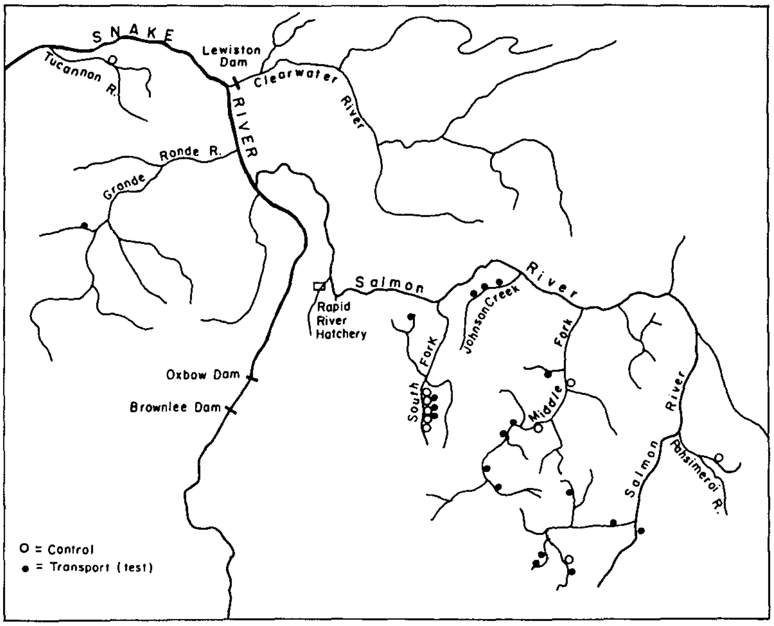

FIGURE 3.—Location of tagged adult chinook salmon returns from spawning ground surveys and returns of tags from sport fishermen in the Snake River drainage.

the ratio at Ice Harbor Dam for the Bonneville release, indicating no straying or loss of homing between Ice Harbor Dam and the spawning grounds.

The chinook salmon spawning grounds of the Okanogan and Methow Rivers and the hatcheries on the Columbia River above and below the mouth of the Snake River were checked for returning tagged adults, but no tagged fish were found. Thus, if straying to these areas did occur, it was too small to detect.

Steelhead Trout

Information on the return of adult steelhead trout to their spawning ground is based solely on recoveries of dart tags by sport fishermen. To date (January 1972) only nine tags have been recovered—two from the control group and seven from the transported group.

Timing of Seaward Migration of Juvenile Fish in Relation to Adult Returns

Spring and Summer Chinook Salmon

During marking of juveniles in 1968, a distinctive brand was used each week for the transport and control groups. These identifying brands provided a means of comparing the timing of the downstream migration of the juvenile fish with the timing of the upstream (spawning) migration of the adult fish. Only a small number (57) of adult returns could be used for this comparison because the brand on the adult fish had to be absolutely legible to determine the time of downstream migration. Returns from the control group could not be used because poor environmental conditions caused by supersaturation of dissolved nitrogen gas apparently wiped out whole groups of juvenile fish that were released during the highest nitrogen concentration. For example, over 37,000 fish were marked for the control group and released between 5 May and 27 May; only 1 adult fish was recovered from those marked during that period.

Adult returns of juveniles marked and transported between 12 April and 13 May indicate that the juvenile population at that time is mixed, with juvenile summer and spring chinook salmon evenly dispersed. Of 37 adult returns from groups marked and transported during this period, 20 were spring chinook and 17 were summer chinook salmon.

Adult returns (14 of 20) from those marked and transported after 13 May indicated that about 70% of the juveniles migrating seaward after that date were summer chinook salmon. All returns (11) from those marked after 19 May were summer chinook salmon—again indicating that the latest juvenile outmigrants are from summer chinook salmon populations.

This, in part, explains why the benefit from transport (2.8:1 ratio of transport/control fish) was so much higher for summer chinook salmon than for spring chinook salmon. After heavy spilling at dams, from early May on, a higher proportion of the juvenile population consisted of summer chinook salmon. The obvious implication is that the control groups released from this time on were largely wiped out by gas bubble disease, caused by high concentrations of nitrogen gas from the heavy spillway discharges.

Steelhead Trout

Juvenile steelhead trout were transported from 28 April to 1 June 1969, each group being marked with a distinctive weekly brand; 90% of those that returned as adults in 1970 arrived at Ice Harbor between 24 September and 14 October. There was no particular relation between time of seaward migration and time of return. Adult returns from juveniles marked between 28 April and 1 June were equally distributed throughout the return period, 24 September-14 October.

We examined scales to determine whether the adults were predominantly 1- or 2-year freshwater smolts at the time of their downstream migration. All adults had lived 2 years or more in fresh water. Only 19 scale samples, however, had legible freshwater annuli. The size of these fish was of interest. After spending only 1 year in the ocean, they averaged 61 cm and 2.6 kg. No significant difference was found between size of control fish and transported fish.

Retention of Cold Brand and Magnetic Tag

We were particularly interested in determining the percentage of brand retention on adult fish that had been cold branded as juveniles during the course of this study. Both cold (Mighell, 1969) and hot (Groves and Novotny, 1965) brands have been used successfully as short-term marks on chinook salmon and steelhead trout; up to the time of this study, however, no information was available concerning the retention of the brand to adulthood by chinook salmon and steelhead trout.

Clifford Long (National Marine Fisheries Service, Pasco, Wash., pers. comm.) determined that the brand was retained by 70% of the jack coho salmon marked for his studies; the Fish Commission of Oregon had similar results with coho salmon they had branded (Groves and Jones, 1969). Although we attempted to duplicate the techniques used by the above authors, the salmon and trout that we branded did not retain brands as well as the retention reported for coho salmon. Forty percent of our brands were not detectable on the spring and summer chinook salmon when they returned as adults (Table 7). The brand was legible (Figure 4) on 38% but only partially legible on 22%. Of the steelhead trout brands, 64% were legible, 24% illegible, and 12% partially legible. The size and physiological condition of the fish at the time of marking may have affected brand retention. The chinook salmon and steelhead trout we marked were smolting. Size range of the chinook salmon was 80-140 mm and of the steelhead trout, 160-250 mm.

Average overall tag loss for all groups was determined by comparing returns to Rapid River Hatchery of: 1) adults with adipose fin clips and wire nose tags with 2) adults with adipose fin clips only.

Approximately 27% of the juvenile chinook

TABLE 7.—Quality of marks ("cold" brands) on adult chinook salmon and steelhead trout that had been branded as juveniles during their downstream migration.

Species	Total no. of fish examined	Fish with legible marks		Fish with partially legible marks		Fish without readily identifiable marks	
		No.	%	No.	%	No.	%
Chinook	212	80	38	46	22	86	40
Steelhead	115	74	64	13	12	28	24

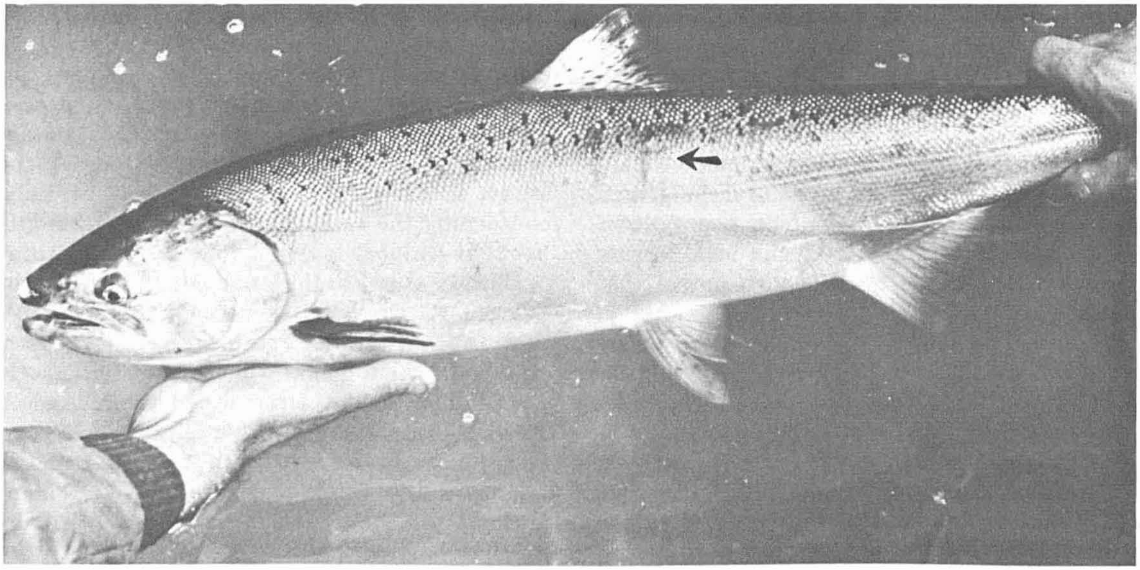

FIGURE 4.—Spring chinook salmon with legible brand (arrow) captured at Ice Harbor Dam, spring 1970.

salmon we tagged lost their tags between the time they were released as juveniles and returned as adults. The weighted average initial tag loss of all groups measured after release of juveniles in the river was 9.2%. This was computed by checking recaptured juveniles with brands and clips at The Dalles Dam and by checking samples of fish released below Bonneville Dam. Obviously an additional 18% tag loss occurred sometime after the 9.2% figure was established. This is much higher than the loss (0.31%) determined by Bergman et al. (1968). There are several possible explanations for this high loss: 1) The population we marked had a much wider size range than the hatchery stock Bergman et al. used, and this could have resulted in poor placement of the tag in those fish that were either too large or small for the tagging machine; 2) our fish taggers were inexperienced in operation of the machine; or 3) the Snake River has a high incidence of pathogens which could cause infection of the tag wound, resulting in rejection of the tag at a later date.

A combination of the above factors probably accounts for the high tag loss in our initial experiments. We believe that continued training and experience of the tagging personnel will result in a major reduction of tag loss in the future. For example, initial tag loss in 1969 was reduced to 5% and in 1970, to less than 1%. Although the loss was high in 1968, it could be compensated for mathematically. The basic information we needed from the data was not affected.

DISCUSSION

All comparisons between the returns of transported and control groups of spring chinook salmon indicate that survival was definitely increased by transporting juvenile fish to a release site downstream from Bonneville Dam. The ratios varied from 1.7:1 in the commercial fishery to 1.8:1 at Ice Harbor Dam. Comparison between the control and transported groups of summer chinook salmon can be made only at Ice Harbor Dam. No returns were obtainable in the sport and commercial fishery because direct fisheries on these fish have been restricted in recent years due to decline in the size of run; only nine returns were obtained on the spawning grounds. The return ratio (2.8:1) at Ice Harbor Dam, however, clearly indicates a definite increase in survival of transported summer chinook salmon.

These ratios also provide information on the effect of transportation on homing and straying. A steadily decreasing ratio of transport/control numbers from the commercial fishery below Bonneville to the spawning grounds would indicate a loss of homing ability, straying, or differential mortality between groups. The ratios established for the test group released at Bonneville were 1.7:1, 1.8:1, and 1.7:1 for the commercial fishery, Ice Harbor Dam, and the spawning grounds, respectively. This indicates that no loss of the transport group occurred between Astoria (Oreg.), Ice Harbor Dam, and the spawning grounds. The same relation between ratios exists if the returns from releases at John Day and Bonneville Dam are combined; i.e., no loss of the transport groups occurred between Astoria and Ice Harbor Dam. If the homing ability of some fish was lost, any loss of fish due to straying was compensated for by an increase in survival and return of transported fish to both the fishery and spawning grounds.

Certain assumptions have been made to determine, and then compare, ratios and percentage returns of fish from transported and control groups. These are:

1. No differential mortality occurred between control and transported fish as they moved upstream from the mouth of the river to the spawning grounds; i.e., adult return ratios of the numbers of transport/control fish in the commercial and sport fishery in the lower river can be directly compared with the observed ratios at Ice Harbor Dam and the spawning grounds to provide an indicator of the effect of transportation on homing or straying.

2. The adult return ratio of John Day/Bonneville transported fish remained constant after these fish entered the Columbia River. We must assume this when the ratio is used to determine the actual number of fish of the John Day and Bonneville groups in returns to the commercial fishery and to spawning grounds (where the brands were not visible) and when it is then necessary to rely on the single tag code to calculate return data for the two transported groups.

3. Native and hatchery stocks in our control and transported groups were recovered at the same rate by the detector and separator at Ice Harbor Dam. This assumption is necessary inasmuch as the estimated percentage return of all adults to Ice Harbor (Table 4) was based solely on the ratio of observed recoveries of a hatchery stock (Rapid River stock) at Ice Harbor and those subsequently recovered at the hatchery. Recoveries of native fish on the spawning grounds from fish identified at Ice Harbor were insufficient for use in this application.

4. Rate of maturity and timing of migration is the same for transport and controls. Since ocean and river fishing rates are not the same on fish maturing early and returning early as they are on fish maturing late and returning late, this assumption is required.

The most significant result of this study is that the ability of the chinook salmon and steelhead trout to return to Ice Harbor Dam was not destroyed or even seriously affected by transporting seaward migrants around a major part of their downstream route. Overall returns from transported groups, except those from the early releases at John Day Dam, were significantly greater than those from the control group. These results are radically different from any achieved to date in other experiments (Ellis and Noble, 1960; unpublished hatchery records of Washington, Oregon, and California) where hatchery stocks exclusively had been transported. We are therefore convinced that our original hypothesis is acceptable—namely, that a fish's experience from the period beginning with smolting to the time the fish is collected for transport is critical. Our understanding of the mechanisms of homing is still limited, however, and much more must be learned to fully understand what the critical factors are in determining what is needed to provide anadromous salmon and trout with homing cues. Experiments to pinpoint the critical requirements for imprinting are needed. If these factors can be determined, it might be possible to provide the necessary experience in a hatchery prior to transport which would enable transport of fish directly from the rearing areas to locations downstream and thus eliminate much of the usual downstream mortality and still achieve satisfactory returns to the hatchery concomitant with greater returns to the fishery.

The information we have to date is sufficient to consider the feasibility of a major collection and transportation system on the Snake and Columbia Rivers. An evaluation of a prototype system was initiated at Little Goose Dam on the Snake River in the spring of 1971. The results of that study, we believe, should lead to a determination of whether collection and transportation of juvenile salmon and trout is, indeed, feasible and can provide substantial protection for runs from upriver areas.

CONCLUSION

1. The homing of adult fish that were captured during their seaward migration as juveniles and then transported (from upstream of Ice Harbor Dam to below Bonneville Dam) downstream was not reduced by the transportation operation. A comparison of the transport/control ratios of returning adults in the lower river with those at Ice Harbor Dam and the spawning grounds indicated that no loss to the transport groups occurred between the estuary, Ice Harbor Dam, and the spawning ground. Straying of either the transported or control groups was not indicated in surveys of hatcheries and spawning grounds.

2. Data from adult returns indicated that transportation of naturally migrating juvenile spring- and summer-run chinook salmon and of steelhead trout from upstream of Ice Harbor Dam to below Bonneville Dam definitely increased returns (50-300%) to the fishery and to Ice Harbor Dam, depending on the river environment during the time of transport.

3. Transportation of juvenile spring chinook salmon to the release site below John Day Dam did not increase their survival (as evidenced by adult returns) during the period before the dams began heavy spilling but did increase survival about 15% after heavy spilling began.

4. The juvenile population of chinook salmon migrating seaward past Ice Harbor Dam from 12 April to 13 May in 1968 was of mixed seasonal races—with juvenile summer and spring chinook salmon mixed and evenly dispersed throughout the period. After 13 May, about 70% of the juvenile chinook salmon were summer-run fish.

5. Quality of brands on adult fish that had been marked as juveniles (using tools that were chilled with liquid nitrogen) varied between species—38% of the marks on spring and summer chinook salmon were legible compared with 64% on steelhead trout.

6. Relative effects of transport over controls is demonstrated, but effects of handling on both groups has not been evaluated. Thus, the survival of transported fish needs to be compared with survival of undisturbed migrants and is currently being studied.

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