IMPRINTING HATCHERY REARED SALMON AND STEELHEAD TROUT FOR HOMING, 1978-1983

VOLUME I: NARRATIVE

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PREFACE

Because of the scope of this report, it was prepared in three separate volumes. The Narrative is contained in Volume I, Volume II summarizes the data in tabular form, and Volume III contains the supplemental information on disease and physiology relating to the juvenile salmonids used in the study.

EXECUTIVE SUMMARY

The National Marine Fisheries Service (NMFS), under contract to the Bonneville Power Administration, began conducting homing research on Pacific salmon and steelhead in 1978. The juvenile marking phase of the study was completed in 1980, and adult returns were examined through 1985. Over 4 million juvenile salmon and steelhead were marked and released, and 23 individual experiments were conducted. The research had the following objectives: (1) develop the techniques for imprinting homing cues while increasing survival of hatchery reared salmonids and (2) provide fishery managers with the information necessary to increase the returns of salmon and steelhead to the Columbia River system and to effectively distribute these fish to the various user groups.[1/]

Our imprint methods were grouped into three general categories: (1) natural migration imprint from a hatchery of origin or an alternate homing site (by allowing fish to volitionally travel downstream through the river on their seaward journey), (2) single exposure imprinting (cueing fish to a single unique water supply with or without mechanical stimuli prior to transport and release), and (3) sequential exposure imprinting (cueing fish to two or more water sources in a step-by-step process to establish a series of signposts for the route "home"). With variations, all three techniques were used with all salmonid groups tested: coho salmon, spring and fall chinook salmon, and steelhead. For the single and sequential imprinting, fish were transported around a portion of their normal migration route before releasing them into the Columbia River.

1/ Imprinting is defined as a rapid and irreversible learning experience that provides fish with the ability to return to natal streams or a preselected homing site.

There were successes and failures with all the imprint techniques used. The sequential imprint concept, inherent in both the natural migration imprint and to a lesser degree the sequential exposure imprint using truck and/or barge transport, was most successful in imprinting fish. The natural migration imprint method (used for control releases) was generally effective in imprinting all stocks of salmon and steelhead used in our experiments. However, this method was not uniformly successful in returning fish to a homing site.

Differences in homing behavior between steelhead and coho salmon to similar single imprint methods indicated there were some species differences in response to homing cues.

Our data indicated that transported indigenous stock or stocks acclimated to a specific hatchery showed a greater propensity to return to the homing site than non-indigenous stock fish. This behavior suggests that the genotype of the fish has a positive influence on the homing cue induced by the imprint techniques.

The data also indicated that mode of transportation had a significant impact on the success of imprinting fish for return to a specific homing site.

In general, the comparative survival of fish in the test groups was enhanced when they were transported around hydroelectric dams on the Snake and Columbia rivers. In many cases, significantly greater numbers of test than control fish returned to the Columbia River, as indicated by recoveries at Bonneville Dam. For example, despite the fact that homing was impaired on a portion of the transported fish, the return of adult steelhead to the upper river above McNary Dam (RM 292), in most instances, was as great or greater than the return of fish from the control releases.

Even though imprint treatments weren't completely successful in implanting a homing cue to the entire test population of juveniles being transported benefits were possible. The portion of the fish in the test groups that received a poor or impaired homing cue strayed to other areas. Also, the portion of fish that were not ready or able to implant a homing cue at the time they were transported returned as adults to the vicinity of their release site and remained there. Also in many cases, the enhanced survival resulting from transportation still provided as many or more fish back to the homing site or geographic area as returned from the control releases. In general, the net result of the enhanced survival combined with the modification of adult migratory behavior induced by the imprint method used provided greater numbers of fish to the river for sport as well as for native and commercial fisheries while still providing fish for spawning.

We found that both test and control lots of spring chinook salmon had extremely high mortality rates whereas fall chinook salmon subjected to the same handling showed relatively good recovery rates. In the past, Ebel (1973) showed good survival rates for spring chinook salmon that were marked and transported from Ice Harbor Dam. It is apparent that a severe problem existed with spring chinook salmon used in our studies. One possible problem may be bacterial kidney disease (BKD), common in all the spring chinook salmon stocks used. The presence of BKD, when combined with the stress induced by handling and marking, may be the factor that caused the low rates of return.

The effects of imprint strategies on the homing behavior of adult salmonid migrations plus the enhanced survival produced by transportation provide a tool that can be used by fisheries managers to provide more salmon and steelhead to the various user groups. The homing imprint information on various species and stocks can be effectively used to rehabilitate fish populations in the tributary systems of the Columbia River (e.g., the Yakima and Umatilla rivers). Because imprinted fish can be induced to return to different river areas, they can be manipulated to contribute to specific sport or commercial fisheries that are presently underdeveloped with existing hatchery releases.

Our results should be viewed as base line information on the reactions of a given fish stock to the variables within the specific study. Treatments which have been replicated between different years show similar results. Fishery researchers and managers can mix, match, and combine the information on the results and variables from various treatments contained in this report to develop additional imprint techniques to achieve desired results. Imprint strategies will have to be tailored or fine tuned to fit the requirements of the different species and stocks of salmonids to develop the most effective techniques for required management goals.

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INTRODUCTION

Background

The loss of juvenile migrants in the mainstem Columbia and Snake rivers is a significant obstacle to the maximum production of salmon and steelhead trout in the Columbia River Basin. The effects of dams, predation, and pollution all take an enormous toll (Collins 1976). Losses as high as 95% of steelhead and chinook salmon were measured from the Salmon River to The Dalles Dam (Raymond 1979). Losses greater than 50% were measured from the Bonneville pool to the lower estuary for chinook salmon (Ebel 1970). Similar losses were indicated for coho salmon. Obviously, a system that would safely bypass fish around river areas in which these high losses occur would be of immense benefit to the resource.

A system that collects juvenile migrants at up-river dams and transports them around the hazards of many dams and impoundments for release in the lower river is now operational (Matthews et al. 1977). However, an efficient, effective, and far more flexible way to protect the hatchery portion of the downstream migration would be to transport them directly from the hatcheries without releasing them into the hazards of the river system. Unfortunately, previous experiments showed that juvenile fish transported directly from a hatchery did not "home" back to the hatchery as adults (Taft and Shapovalov 1938; Vreeland et al. 1975). Apparently these fish had not received an adequate homing imprint at the time of their release.

The ability to cue fish to a desired homing location (i.e., hatchery of origin or any unique water source) has many applications in the management of salmonids in the Columbia River drainage and other river systems. The ability to cue juvenile salmonids to a homing location in conjunction with transporting them around hazardous areas during their outmigration should substantially increase their survival and subsequent return as adults to hatcheries, streams, and/or harvest areas. Increased returns available to hatcheries could produce an excess of spawning stock required for egg take. This "surplus" could be distributed by the fisheries manager by use of appropriate homing strategies.

The "homing imprint", a rapid and irreversible learning experience that provides the navigational clues by which salmon and steelhead find their way back to their natal area, seems to occur at the time smolts are released into the river system or shortly thereafter (Wagner 1968; Scholz et al. 1975; Cooper et al. 1976). There are several theories on how the homing imprint occurs in fish. It is generally accepted, however, that during the freshwater migration of adult salmonids, odors provide the navigational route to the home-stream. Studies have indicated that olfactory perception in salmonids is very acute--fish are able to detect an odor diluted to as little as one part in $8x10^{10}$ (Alderdice et al. 1954; Idler et al. 1956, 1961; McBride et al. 1962).

Two principal olfactory theories have been proposed. Nordeng (1971, 1977) proposed that the important odors for navigation are population-specific pheromones from juvenile salmon residing in the river. However, Jensen and Duncan (1971) demonstrated that adult coho salmon homed to a spring water source in the Snake River system which did not contain any fish. In returning to the spring water source, these adults would clearly have had to abandon a pheromone scented route in the Columbia River which led back to their hatchery of origin. On the other hand, Hasler and Wisby (1951) proposed that the environmental (organic and inorganic) odors, which are identifiable over the life span of the species, provide the guidance; this view is supported by Brannon (1984).

We believe that environmental odors are specific for various tributaries in the system. This factor, along with unique environmental conditions in stream systems, probably accounts for the genetic diversity of the numerous species and racial stock present. Therefore, we chose the environmental odors concept as most applicable to our experimentation.

Experiments have indicated the possibility of imprinting salmonid smolts in a hatchery without release into a river system (Madison et al. 1973; Cooper et al. 1976; Cooper and Scholz 1976). Previous experiments have suggested that imprinting may be a comparatively rapid phenomenon. In 1971 and 1972, coho and chinook salmon from the Issaquah State Fish Hatchery (SFH) near Seattle, Washington, were exposed for imprinting purposes to water at the National Marine Fisheries Service (NMFS) laboratory in Seattle for periods of time ranging from 4 h to 14 d before release. Adults returned from as little as a 4 h exposure (Groves[1/]). Studies by Ebel et al. (1973), Ebel (1980), and Slatick et al. (1975) have shown that omitting a large portion of a fish's normal migration route via transportation does not diminish the homing ability of fish that have smolted and migrated up to several hundred kilometers on their own volition. It is this area of salmon and steelhead behavior that we examined in detail.

1/ Al Groves, Biologist, Northwest Region, NMFS, 7600 Sand Point Way N.E., Seattle, WA 98115, pers. commun. 1986.

Objectives

The primary objectives of our homing research were as follows:

1. Determine how to imprint a homing cue in hatchery reared salmonids.

2. Provide fishery managers with information to increase the returns of salmon and steelhead to the Columbia River system and to effectively distribute the fish to the various user groups.

STUDY SITES AND FACILITIES

The homing imprint sites and in-river sampling facilities used were spread throughout a major portion of the Columbia River system presently available to anadromous salmonids (Figs. 1 and 2). Selection of the homing imprint sites was based on the following criteria: (1) availability of various stocks of salmon and steelhead at a hatchery which had returning adults for brood stocks, (2) availability of a hatchery with a unique water supply which would permit the introduction of other species of salmonids, and (3) availability of an unmanned site with a unique water supply. All homing sites were located at permanent facilities (hatcheries) except Stavebolt Creek, Oregon, and Pasco, Washington, where special facilities were constructed.

Stavebolt Creek is a tributary to the Lewis and Clark River which drains into Youngs Bay near Astoria, Oregon, (Fig. 1). The imprinting site was a pond supplied soley by water from Stavebolt Creek. Four floating pens 10 x 20 x 6 ft were used to hold the test fish from 4 to 48 h for imprinting. A weir and trap were constructed near the mouth of Stavebolt Creek to intercept returning adults.

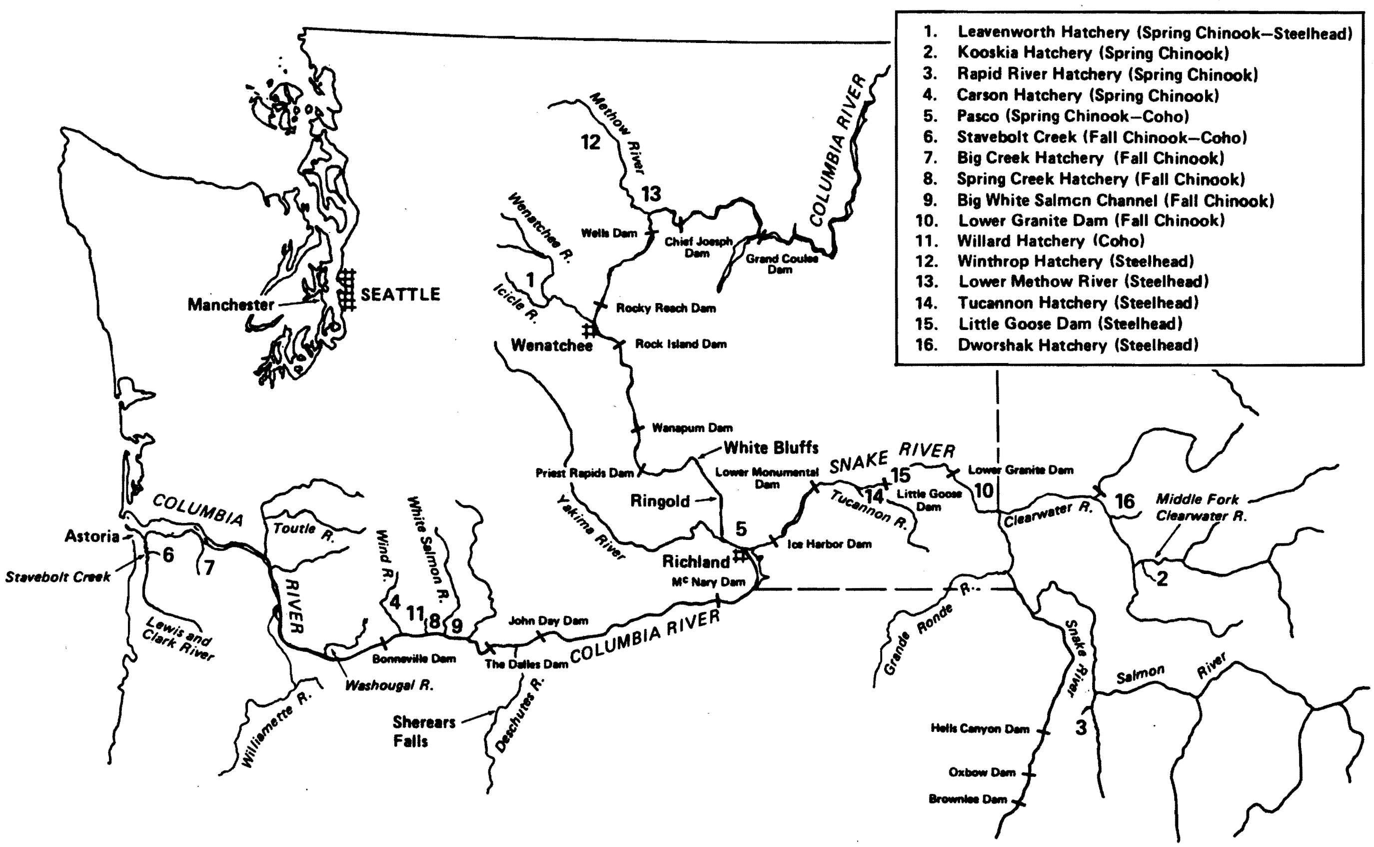

Figure 1.--Area map indicating experimental homing sites, 1978-1980.

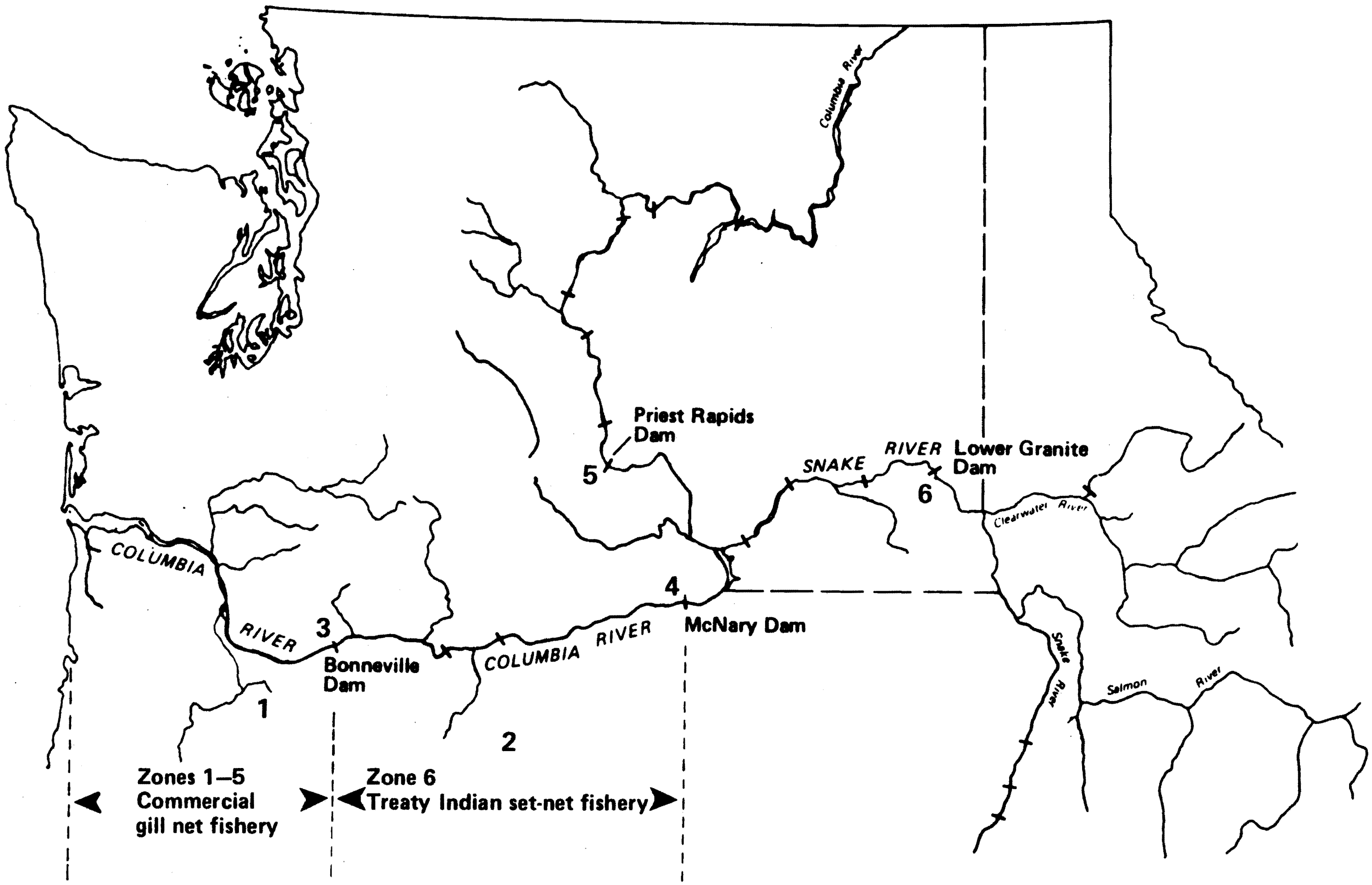

Figure 2.--Map of Columbia River system showing location of six in-river sampling locations.

The Pasco site is located on the first small stream on the east shore of the Columbia River above the confluence of the Snake River. This stream is comprised of ground water which surfaces and is pumped from behind levees at this location. A weir, fish ladder, and three raceways were constructed to imprint juveniles and recover returning adults.

In-river sampling facilities had traps to intercept tagged adults in the fishladders at Bonneville, McNary, and Lower Granite dams without having to sacrifice the fish. The traps consisted of a Denil fishladder leading adults to a tag detection system which shunted tagged fish into a trap (Ebel 1974; Slatick 1975) (Fig. 3).

GENERAL METHODS

Juveniles marked in these experiments were from randomized samples or were selected by the various hatchery managers to represent the standard fish produced at their stations. Fish were marked by adipose fin excision and a magnetic coded wire tag (CWT) (Ebel 1974). Fish (except fall chinook salmon) expected to return as adults to locations above Bonneville Dam were also thermal branded (Mighell 1969; Park and Ebel 1974). Branded adults recovered at in-river traps were identified by brand, jaw tagged to indicate it had been previously identified, and released to continue their upstream migration (Ebel et al. 1973; Gilbreath et al. 1976; Slatick 1976). A tank truck [18,900-liter (5,000-gal) capacity] was used to transport most test fish (Smith and Ebel 1973). A few groups of fish were transported in a barge utilizing a regulated flow-through water system (McCabe et al. 1979).

Random samples of test fish were taken at the various hatcheries and maintained in seawater net-pens at the Manchester Marine Experimental Station, Manchester, Washington. Survival of the sample groups provided a measure of

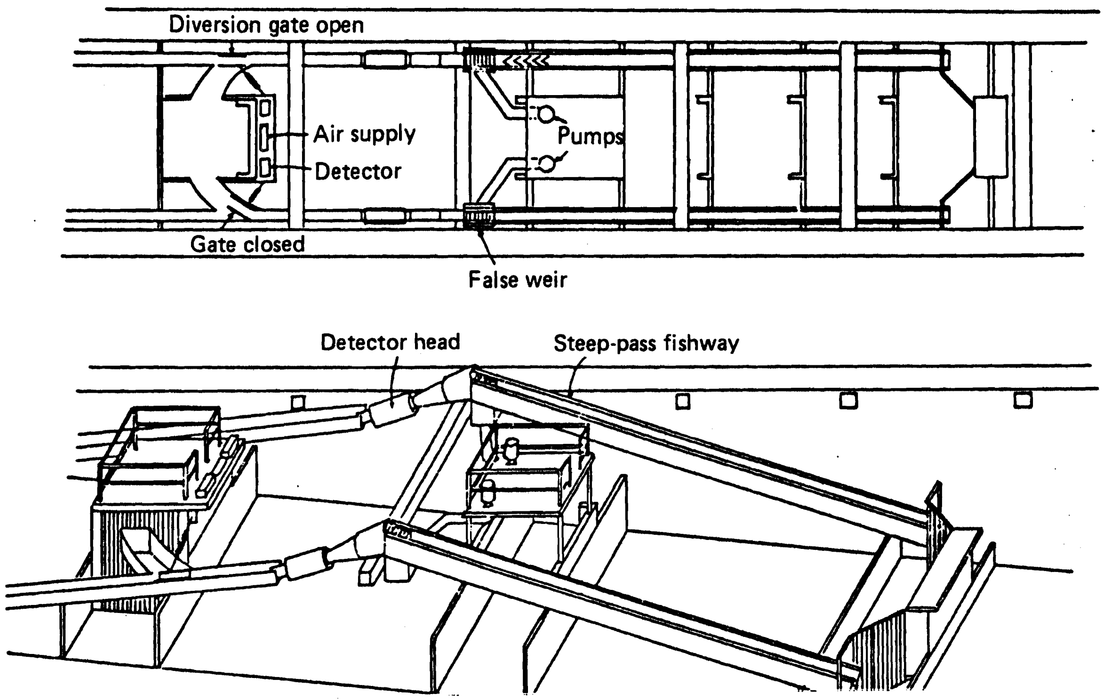

Figure 3.--Plan view and isometric diagrams of wire tag detector and fish separator systems used at Bonneville, McNary, and Lower Granite Dams.

the level of smoltification (physiological readiness to migrate and adapt to seawater). A general health survey of the test fish was provided by additional 60-fish samples taken at the hatcheries and held in fresh water at the Manchester facility. Blood and tissue samples from these fish were tested for various disease organisms (Volume III, Novotny and Zaugg 1979, 1981, 1984).

In the normal release of smolts from a hatchery there is a series of immediate events that may trigger the imprinting of a homing cue. These events occur at a time when there are major changes in the fish's physiology which may make it more sensitive to certain stimuli. The fish are usually released from a crowded hatchery pool into a completely new environment with different physical and chemical water qualitites (e.g., temperature, velocity, turbulence, turbidity, oxygen, odors, etc.); visual phenomena; and spatial relationships. Any one or more of these changes may initiate imprinting.

Since the phenomenon of elevation in gill sodium, potassium stimulated ATPase (Na^+-K^+ ATPase) activity was first reported to be associated with parr-smolt transformation in steelhead (Zaugg and Wagner 1973) and in coho salmon, O. kisutch, (Zaugg and McLain 1970), numerous experiments have been conducted to verify these results and extend observations to other species. As a result, it has been conclusively shown that the rise in gill Na^+-K^+ ATPase activity is one of the many physiological changes which occur at the time of parr-smolt transformation. We utilized gill Na^+-K^+ ATPase activity as a possible biological indicator of the optimum time for imprinting salmonids with homing cue.

Research was designed to delineate the period (imprint "window") when a juvenile was physiologically ready to accept a long-term homing imprint in its "memory" and to determine the stimuli or combination of stimuli (defined as an "event") required to initiate this memory retention (homing imprint).

The techniques used to try and imprint salmon and steelhead are grouped into three major categories: (1) natural migration imprint, (2) single exposure imprint, and (3) sequential exposure imprint.

Natural migration imprinting is cueing fish by allowing them to volitionally travel downstream through the river system on their seaward journey. Because of the locations of the homing sites, two distinct release strategies were employed. In one situation, fish were released directly from their hatchery of origin or the hatchery in which they were reared. In the second situation, when the homing site was not at the hatchery of origin, the fish were either released directly after hauling by truck or held from 4 h to 10 d at the homing site for acclimation and hopefully imprinting.

Single imprinting is cueing fish to a single unique water supply prior to transport and release. Various mechanical stimuli were used in combination with the unique water source to attempt to achieve the single imprint. Most fish subjected to a single imprint were transported by truck and released below Bonneville Dam.

Sequential imprinting is cueing fish to two or more water sources in a step-by-step process to establish a series of signposts for the route "home". This was attempted in two ways. One method was to change the water supply for the fish at the hatchery. The second method was to use a barge with a regulated flow-through water system. Various test lots of fish were then transported by truck, truck and barge, or barge only to a lower river release site.

With variations, these three techniques were used for all species tested: coho salmon, spring and fall chinook salmon, and steelhead. Because of the limited availability of hatchery fish, a number of different racial stocks within the various species were used in the experiments.

The degree of success (ability to home and survival enhancement) for the various treatments of experimental fish is based on the returns of adults previously marked as juveniles with a CWT. Homing is determined by the rate of return of marked adults to the homing sites, and relative survival is measured by the combined total recoveries of CWT at the homing site, from in-river sampling sites, from ocean and river commercial and sport fisheries, and from hatcheries and spawning grounds. Discrete multivariate analysis was used to statistically compare test and control treatments of completed experiments (Bishop et al. 1975). In this procedure, the treatments were structured in contingency tables. The G-statistic was used to test for significance which was established at $P < 0.05$, df = 1 (Sokal and Rohlf 1981).

The study began in 1978, and the juvenile marking phase was completed in 1980. During the 3-year marking phase, over 4 million juvenile salmon and steelhead were marked and released in 23 experiments. The NMFS conducted 19 of the experiments, and the Idaho Cooperative Fishery Research Unit (ICFRU) conducted four under contract to NMFS (Table 1). The 6 years of activities and initial results from the 23 experiments were previously reported by Slatick et al. (1979, 1980, 1981a, 1981b, 1982, 1983, 1984) and in Volume III, Novotny and Zaugg (1979, 1981, 1984). Returns of adult coho salmon, spring and fall chinook salmon, and steelhead are now complete. The final analysis of results are presented by species in this report.

COHO SALMON EXPERIMENTS

Juvenile coho salmon used in all homing experiments were progeny of adults which return to the Little White Salmon River. This stock of coho salmon originated in the Toutle River. Little White Salmon and Willard

Table 1.--Homing imprint experiments 1978-80--species, location, numbers of fish marked and released.

Species and hatchery of origin-homing site	Year fish marked and released 1978 (no.)	1979 (no.)	1980 (no.)	
		Snake River System		
Steelhead				
Dworshak	74,741	-	99,125	
Tucannon	36,686	67,573	-	
Tucannon-L. Goose Dam	-	-	78,091	
Spring chinook salmon				
Kooskia	186,597	-	123,600	
Rapid River	-	-	121,566	
Fall chinook salmon				
Hagerman-Lower Granite Dam	-	-	114,000	
		Columbia River System		
Steelhead				
Chelan-Leavenworth	137,949	137,817	-	
Wells-Winthrop	96,978	62,243	-	
Spring chinook salmon				
Carson-Pasco	-	113,681	-	
Carson	-	159,682	159,327	
Leavenworth	-	-	491,768	
Coho salmon				
Carson-Pasco	102,594	-	-	
Willard-Stavebolt Cr.	414,907	-	-	
Willard	-	-	436,118	
Fall chinook salmon				
White Salmon-Stavebolt Cr.	-	473,027	-	
Big Creek-Stavebolt Creek	-	-	143,805	
Spring Creek	-	-	259,786	
Subtotals by species				Grand Total
Spring chinook salmon	186,597	273,363	896,261	1,356,221
Fall chinook salmon	-	473,027	517,591	990,618
Coho salmon	517,501	-	436,118	953,619
Steelhead	346,354	270,633	188,227	794,213
	1,050,452	1,017,023	2,027,196	4,094,671

National Fish Hatcheries (NFH) are located on the Little White Salmon River, which provides the water supply for both hatcheries. All returning adult coho salmon are collected at the Little White Salmon NFH which is located near the mouth of the river. Juveniles were reared at the Willard NFH, 3.5 miles upstream.

Carson NFH - Pasco Homing Site, 1978

Background

This experiment was concerned with imprinting juvenile coho salmon reared at a mid-river hatchery to home as adults to an upriver homing site. Juvenile coho salmon reared at Carson NFH (Little White Salmon brood) were subjected to single, sequential, and natural imprinting at the Pasco homing facility. The objectives of the experiment were to:

1. Determine the relative effectiveness of the three imprinting techniques for returning adults to the Pasco facility.

2. Define the effect of the three imprinting techniques on overall survival.

Experimental Design

Juvenile coho salmon were reared in raceways and pre-marked at Carson NFH. Three groups of fish were imprinted for a minimum of 48 h at the Pasco homing site. The naturally imprinted group (43,961) was released at the homing site. The single imprint group (28,927) was trucked to below Bonneville Dam. The sequentially imprinted group (29,706) was trucked to a barge at Richland, Washington, and barged below Bonneville Dam (see Volume II, Table A1.0 for additional details). Adult returns to the Pasco facility, inriver sampling sites, and the various fisheries were used to evaluate the effectiveness of the three imprinting techniques.

Results and Discussion

A total of 6 jack and 10 adult coho salmon from the naturally imprinted release returned to the Pasco homing site; no fish from the other groups returned to the homing site. Nine coho salmon were recovered at river sampling sites: five from the naturally imprinted group, one each from the barged and the trucked groups at Bonneville Dam, and two from the barged group at McNary Dam. Based on these returns, it is apparent that the coho salmon used in the truck (single imprint) or barge (sequential imprint) experiments did not receive an adequate homing imprint to the Pasco water supply.

A total of 116 tags were recovered from the ocean commercial and sport fishery, and 21 tags were recovered from the Columbia River gillnet fishery, Zones 1-6 (Table 2). Survival of fish from the naturally imprinted group was significantly greater than for fish from the other groups ($P < 0.01$, df = 1). The naturally imprinted group contributed over twice as many fish to the fishery as either of the other groups.

The poor contribution of the single and sequentially imprinted fish to the various fisheries probably resulted from poor survival of the juveniles after their release below Bonneville Dam. Sampling of juveniles in the estuary at Jones Beach (RM 47) also indicated that survival of the naturally imprinted fish was twice that of the single and sequentially imprinted fish (Dawley et al. 1979). Cause of the apparent mortality is unknown; all fish appeared in good condition at time of release. However, a factor which may have influenced the lower survival of the fish released below Bonneville Dam could have been the latent effects of pathogenic infections combined with stress induced by the added crowding, handling, and transport during the experimental releases. A few weeks before the fish were move to Pasco they

Table 2.--A comparison between recoveries of natural, single, and sequentially imprinted groups of adult coho salmon from marked groups of juveniles reared at the Carson Hatchery and imprinted to the Pasco homing site. Recoveries were from September 1978 to February 1980.

Juveniles released			Adult returns										
			Commercial & sport fishery					Adult traps Bonneville & McNary Dams	Stray to hatcheries	Pasco homing site	Total combined return		
			Ocean	River	Combined								
Location	No.	Date	(no.)	(no.)	No.	%	T/C ratio	(no.)	(no.)	no.	No.	%	T/C ratio
Pasco													
natural imprint	43,961	03 May	75	13	88	0.200		5	1	16	110	0.250	
Bonneville													
Single imprint	28,927	01 May	24	5	29	0.100	0.50:1	1	3	0	33	0.114	0.46:1**
Sequential imprint	29,706	04 May	17	3	20	0.067	0.34:1	3	1	0	24	0.081	0.32:1**
Total	102,594		116	21	137			9	5	16	167		

** = Significant difference between single and sequentially imprinted groups and the naturally imprinted group (P < 0.01, df = 1).

experienced an outbreak of coldwater disease and incurred a mortality of 7.8% (Leek[2/]).

Conclusions

1. Natural imprinting was successful in returning adult coho salmon to the Pasco homing site (164 miles upriver from the hatchery of origin).

2. The single and sequential imprint methods were unsuccessful in providing a homing cue in coho salmon which would enable adults to return to the homing site.

3. Survival of fish from the natural imprint group was over twice that of the single and sequential imprint groups.

2/ Steve Leek, Little White Salmon NFH, Cook, Washington 98605, pers. commun. 1979.

Willard NFH - Stavebolt Creek, 1978

Background

This experiment was concerned with imprinting juvenile coho salmon reared at a mid-river site to home as adults to a lower river site. Juveniles reared at Willard NFH were subjected to natural and single imprinting at the Stavebolt Creek homing site (Fig. 1). Success was evaluated by comparing return rates to Stavebolt Creek (tests) with return rates to Willard NFH (controls). The objectives of the experiment were to:

1. Determine the effectiveness of single and natural imprinting of juvenile coho salmon in returning adults to a lower river homing site downstream from their hatchery of origin.

2. Determine the length of time required to imprint a specific homing cue.

3. Define the effect of the level of smoltification on the ability of juvenile coho salmon to accept a specific homing cue.

The Stavebolt Creek homing site, located in northwestern Oregon, was selected for its natural features and made available through the generosity of Mr. Carl Utzinger in allowing us to use the site over the period of our experiments. Stavebolt Creek is a small tributary to the Lewis and Clark River, one of three river systems flowing into Youngs Bay near Astoria, Oregon (Fig. 4). The homing site consisted of: (1) a pond supplied solely by Stavebolt Creek water where fish were held in floating net-pens for imprinting; (2) 600 feet of creek, from the pond to its confluence with the Lewis and Clark River, for natural migration imprinting; and (3) a fish trap near the mouth of the creek for recovering returning adults.

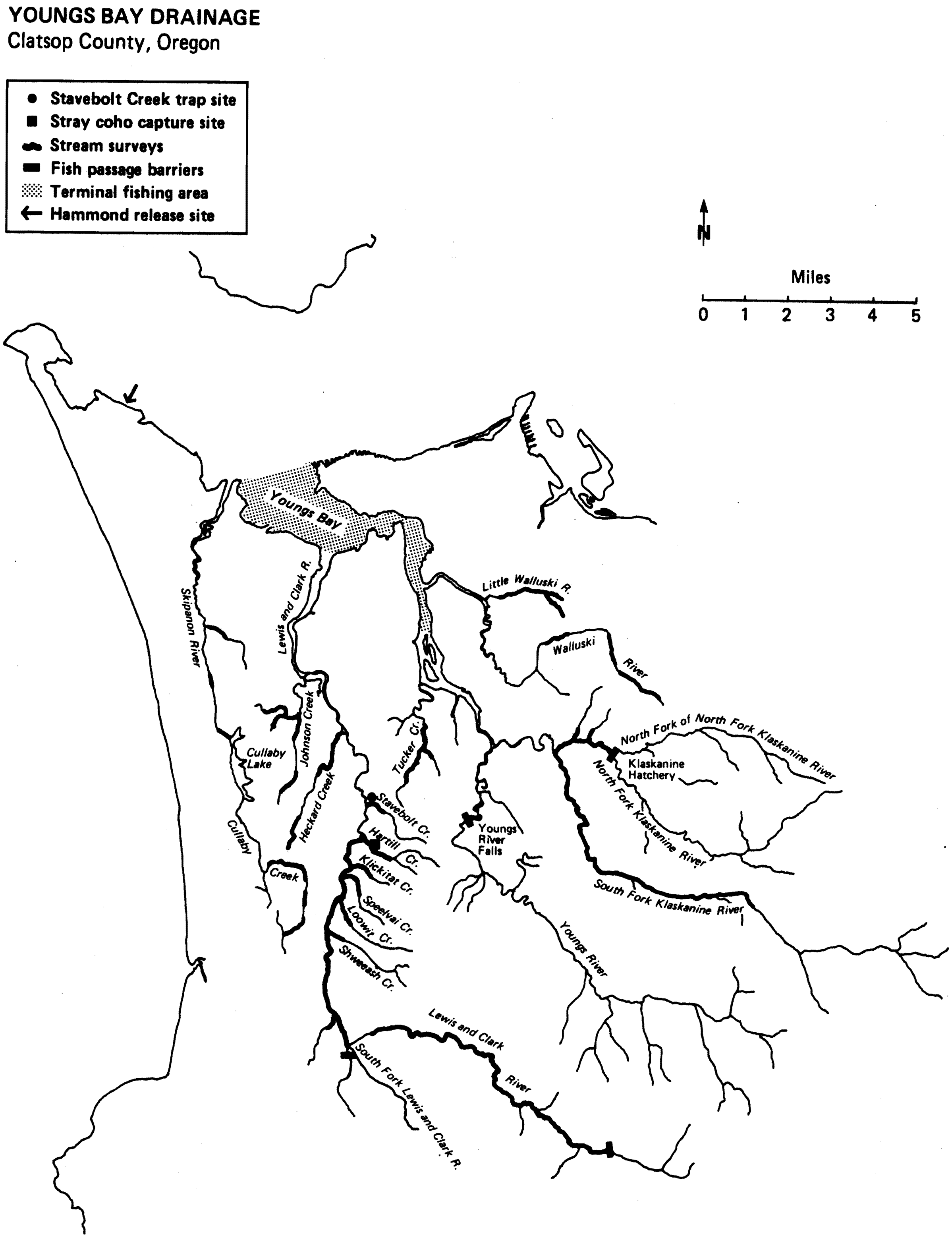

Figure 4.--Location map of release sites and recovery areas pertaining to imprinting coho salmon in the lower Columbia River area.

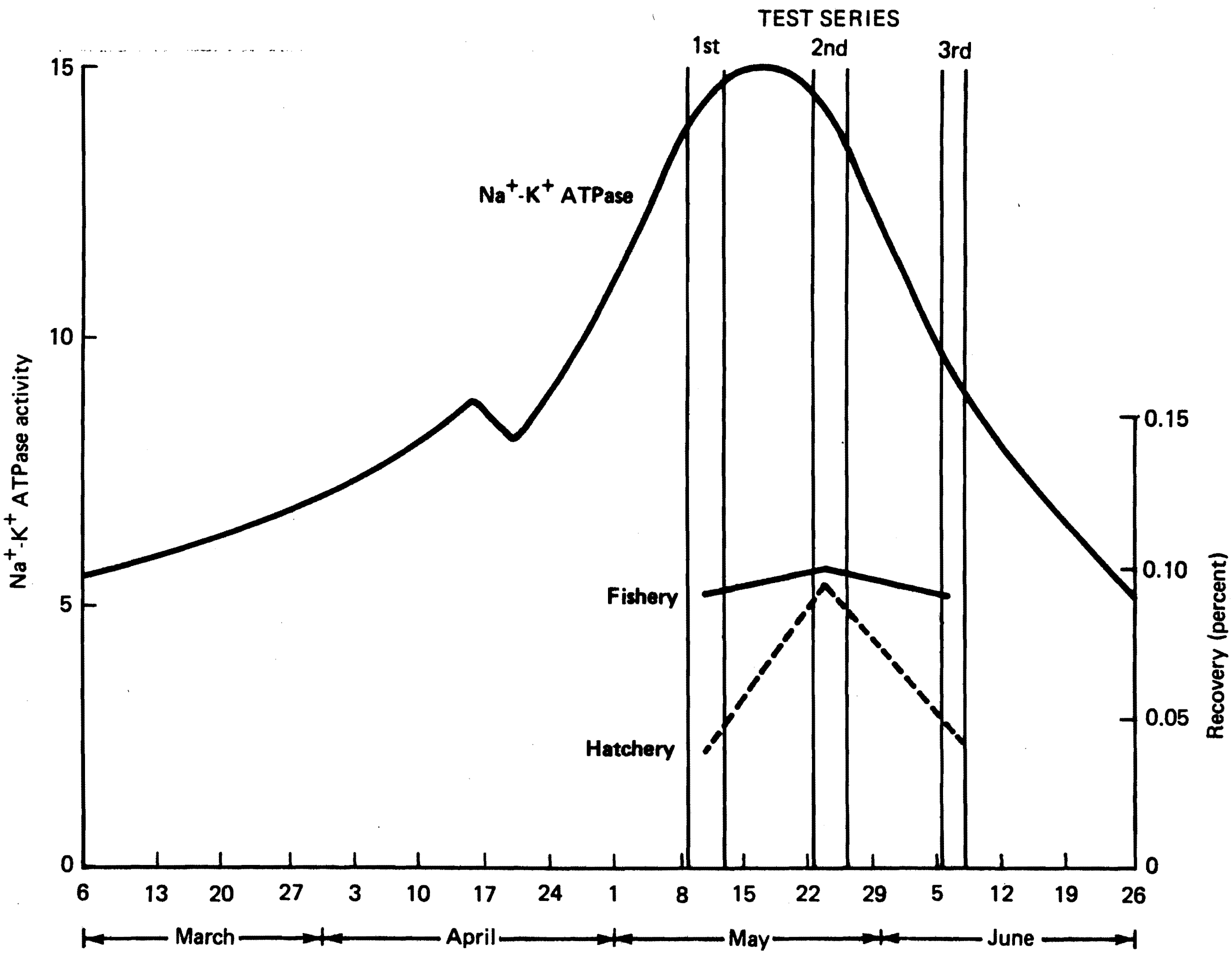

Figure 5.--Na^{+}-K^{+} ATPase activity profile for coho salmon reared at Willard NFH indicating time frame for releasing imprinted fish for 1st, 2nd, and 3rd replicates in 1978. This figure also illustrates the correlation between recoveries of adult coho salmon at the Little White Salmon NFH and in the ocean and Columbia River fisheries in relation to the Na^{+}-K^{+} ATPase activity profile of the juvenile fish released as controls from the Willard NFH. Recoveries are from September 1978 to March 1980.

Since our homing strategy is based on olfactory perception of unique water sources, a desirable feature of the Stavebolt Creek homing site was that the migratory route (north to south) for adults was directly opposite the route from Willard NFH (south to north). This directional difference of the migration route to Stavebolt Creek should not influence returning adults if the homing imprint used by salmon was olfactory perception of a scent route to the homing imprint site. To examine if a single exposure to a unique water source would implant a homing imprint in juvenile coho salmon, the fish were hauled out of the Youngs Bay watershed and released into the Columbia River at Hammond, Oregon (Fig. 5).

Experimental Design

Juvenile coho salmon were reared and pre-marked at the Willard NFH. Na^+-K^+ ATPase enzyme activity was monitored at the hatchery, and experimental and control releases of marked fish were designed to coincide with rising, peak, and falling Na^+-K^+ ATPase enzyme activity (Fig. 5). Each release series consisted of six test groups and one control group of approximately 20,000 fish each. All control groups were released at Willard NFH (natural imprint). During the rising and the beginning of the decline of the Na^+-K^+ ATPase activity, groups of test fish were trucked to Stavebolt Creek (Fig. 4), held in live pens for various periods of time, and released either into Stavebolt Creek directly (natural imprint) or trucked to Hammond, Oregon (RM 8), and released into the Columbia River (single imprint).

During the third release series (falling Na^+-K^+ ATPase activity), the experimental design was aborted due to high water temperatures in the Stavebolt Creek holding pond. An alternate experiment was substituted for the four marked groups remaining at the Willard NFH. The control release was made at Willard NFH as before. The three test groups already at the Stavebolt facility were released into Stavebolt Creek (natural imprint). Two of the three test groups remaining at Willard NFH were placed in tank trucks for 2 h, then returned to the raceway for 4 h; one group was then trucked to below Bonneville Dam and released, and the second group was trucked to Hammond, Oregon, and released (single imprint). The third test group was trucked directly from the hatchery to the release site below Bonneville Dam (no imprint). The objective of this alternative experiment was to determine if a stimulus like simulated trucking could be used to imprint fish transported and released at other sites to home to their hatchery of origin (see Volume II, Table A2.0 for additional details on experimental design).

Results and Discussion

Adult returns from single imprint tests indicate the methods used in 1978 were unsuccessful in returning coho salmon to either the Stavebolt Creek homing site or Willard NFH. Four adults returned to Stavebolt Creek out of 80,000 juveniles imprinted for 24 to 48 h in Stavebolt Creek and then transported and released at Hammond, Oregon. No fish returned from the 4- to 12-h imprint groups. By contrast, 26 fish returned to Willard NFH out of 40,000 juveniles released there as controls (Table 3).

Results from sampling the Columbia River and Youngs Bay fisheries indicated that although the single imprint method used in these experiments was not successful in returning fish to the homing site, it did implant a limited homing cue which caused coho salmon to return to the geographic area adjacent to the homing site, i.e., Youngs Bay (Table 4). This homing cue to Youngs Bay may have been reinforced by the location of the Hammond release site. The flow of the Columbia River would have carried water exiting Youngs Bay along the south shore past the Hammond release site (Fig. 4).

Table 3.—A comparison between control and test groups of adult coho salmon returning to Little White Salmon NFH and Stavebolt Creek homing sites and recovered in the ocean and river fisheries. Recoveries are from September 1978 to December 1979.

Homing imprint	No. of groups	Juveniles released: No.	Location	Date	Adults recovered: Homing sites No.	%	Ocean and river fisheries No.	%	T/C ratio
		Na^+-K^+ ATPase, 1st Release							
Control	1	19,908	Hatchery	09 May	8	0.040	17	0.085	
Single									
4 & 12 h	2	39,364	Hammond	12 & 13 Jun	0	0.000 --	51	0.130	1.53:1 NS
24 & 48 h	2	40,280	Hammond	10 & 11 Jun	3	0.007 *	37	0.092	1.08:1 NS
Natural									
4 & 48 h	2	40,245	Stavebolt	11 & 12 May	15	0.037 NS	54	0.134	1.58:1 NS
		Na^+-K^+ ATPase, 2nd Release							
Control	1	19,943	Hatchery	24 May	18	0.090	20	0.100	
Single									
4 & 12 h	2	39,854	Hammond	24 & 25 May	0	0.000 --	42	0.105	1.05:1 NS
24 & 48 h	2	39,832	Hammond	25 & 26 May	1	0.003 --	44	0.110	1.10:1 NS
Natural									
4 & 48 h	2	41,555	Stavebolt	25 May	15	0.036 *	52	0.125	1.25:1 NS
		Na^+-K^+ ATPase 3rd Release							
Control	1	19,781	Hatchery	08 Jun	9	0.045	16	0.081	
Natural									
5-6 h	2	37,857	Stavebolt	07 Jun	16	0.042 NS	41	0.108	1.33:1 NS
No imprint									
-	1	19,771	Below Bonneville	08 Jun	0	0.000 --	29	0.147	1.81:1 NS
Single									
4 h	1	19,730	Below Bonneville	08 Jun	1	0.005 --	27	0.137	1.69:1 NS
4 h	1	19,622	Hammond	08 Jun	0	0.000 --	19	0.097	1.20:1 NS

* = Significant difference between test and control group ($P < 0.05$, df = 1).
NS = Nonsignificant.
-- = Insufficient recoveries for statistical analysis.

Table 4.--A comparison between control and the groups of coho salmon recovered at Stavebolt Creek, Little White Salmon Hatchery, commercial and sport fisheries, and as strays.

	Adults recovered from group imprinted as indicated						
		Stavebolt Creek		L.W. Salmon Hatchery			
Recovery sites	Control L.W. Salmon[a/]	Natural Imprint (Stavebolt)[b/]	Single Imprint (Hammond)[c/]	Single Imprint (Hammond)[d/]	Single Imprint (B'ville.)[e/]	No Imprint (B'ville.)[f/]	Total[g/]
Homing sites							
Stavebolt Creek	0	46	4	0	0	0	50
L.W. Salmon Hatchery	35	0	0	0	1	0	36
Fisheries							
Youngs Bay	2	15	30	1	0	0	48
Zone 1-2	0	12	12	4	1	1	30
Zone 6	4	0	0	0	1	2	7
Ocean	47	120	132	14	25	26	364
Strays	0	4	5	0	1	2	12
Total	88	197	183	19	29	31	547

a/ 59,632 smolts released.
b/ 119,657 smolts released.
c/ 159,330 smolts released.
d/ 19,622 smolts released.
e/ 19,730 smolts released.
f/ 19,771 smolts released.
g/ 397,742 smolts released.

Adults returning from juveniles released at Stavebolt Creek (natural imprint) showed a positive homing response to Stavebolt Creek. Adults from the 1st and 3rd Na^{+}-K^{+} ATPase release returned to the Stavebolt Creek homing site at about the same rate as controls returned to the hatchery (Table 3).

Straying of adult coho salmon from the Stavebolt Creek (natural imprint) and Hammond (single imprint) releases to other streams in the Youngs Bay system was negligible. One fish was recovered in Hartell Creek, a tributary to the Lewis and Clark River, located 1 mile upstream from the Stavebolt Creek homing site. No marked fish were recovered in the other four stream systems draining into Youngs Bay and containing spawning coho salmon (Fig. 4).

Survival [based on test/control (T/C) ratios] of fish recovered in the ocean and river fisheries that were given a single imprint was slightly better than survival of those released at the hatchery, but the difference in the T/C ratios was not significant (Table 3). There appeared to be little difference between the single and natural imprint methods in relation to relative survival (Table 3), but more fish from the Hammond release were captured in the Youngs Bay fishery (Table 4).

As suggested by Vreeland et al. (1975), one obvious application of using a technique that gives a homing cue is to provide a site specific fishery. As an example, fish surplus to an up-river hatchery's need could be transported to Youngs Bay, given a natural homing imprint, and released. This could provide more adults to the riverine fishery and provide an area where fish could be efficiently harvested without impacting other runs of fish.

An attempt was made to make releases of coho salmon coinciding with rising, high, and declining Na^{+}-K^{+} ATPase enzyme activity to determine its potential as an indicator of the best time period to imprint a homing cue. Data from adult returns of those fish released as controls at the hatchery show that the 2nd release had the best recovery rate both back at the hatchery and in the fishery (Fig. 5). Returns to the hatchery of fish from the 2nd release were statistically significantly better than returns from the 1st and 3rd releases ($P < 0.05$, df = 1). Whether this was a function of time of release (9 May, 24 May, or 8 June) or enzyme activity is not known. The rates of return of test fish to homing sites and in the fishery for all three release periods, however, were about the same, indicating time of release or enzyme activitiy did not have any effect on homing of the various test treatment groups released in 1978 (Table 3).

Based on recoveries from the alternative test during the 3rd release series, releasing coho salmon below Bonneville Dam appeared to increase their contribution to the various fisheries by 69 to 81%, but these fish failed to home back to their hatchery of origin (Table 3). Additional detail on returns from specific releases may be found in Volume II, Tables A2.1 to A2.21.

Conclusions

1. The single imprint method used in 1978 was unsuccessful in enabling adult coho salmon to home back to either Stavebolt Creek or to the Little White Salmon homing sites.

2. Adults which had received a single imprint to Stavebolt Creek (Hammond release) generally homed to Youngs Bay, exhibiting a limited or partial homing response.

3. Coho salmon imprinted and released in Stavebolt Creek (natural imprint) in the 1st and 3rd release series returned to that homing site at about the same rate as control releases back to the hatchery.

4. Survival of both single and natural imprint fish recovered in the ocean and river fisheries was higher but not significantly higher than those released at the hatchery.

5. Imprint techniques used in this experiment can provide fishery managers with a site specific fishery (Youngs Bay) and lower Columbia River while still providing sufficient fish for spawning.

6. Of the three control releases, the 2nd release (near the beginning of the decline of the Na^{+}-K^{+} ATPase curve) had the highest catch rate in the fishery and the highest return rate to the hatchery.

7. No optimum homing imprint period was noted between the three series of test releases of coho salmon which had been imprinted to Stavebolt Creek.

8. Straying of fish from the test groups imprinted to Stavebolt Creek within the Youngs Bay system was negligible.

Willard NFH, 1980

Background

The goal of this experiment was to imprint juvenile coho salmon which were to be transported by truck and barge from their hatchery of origin and released at various locations below Bonneville Dam to return as adults to the Little White Salmon River (hatchery of origin). Juveniles reared at Willard NFH were subjected to single and sequential imprinting methods before being transported. The adult returns from these test groups were compared with adult returns from fish which received a natural migration imprint during their outmigration. The study was designed to determine:

1. Effectiveness of various methods used to activate a homing imprint in coho salmon.

2. Effect of various release locations on the homing ability and relative survival of coho salmon.

3. Effect on relative survival of fish marked in the fall as juveniles vs fish marked as smolting fish in the spring.

Willard NFH is part of the Little White Salmon-Willard Hatchery complex operated by the U.S. Fish and Wildlife Service (USFWS) and located on the Little White Salmon River in southwestern Washington (Fig. 6). Coho salmon released at Willard NFH migrate through 3.5 miles of free-flowing river before entering slack water at Drano Lake. Waters from the Little White Salmon River remain distinct in Drano Lake before merging with the Columbia River at RM 162.0.

A barrier-dam and fish collection facility a few hundred feet above slack water at the Little White Salmon NFH blocks access of returning adults to Willard NFH. All adult coho salmon returning from Willard NFH releases are collected and held for brood stock at Little White Salmon NFH.

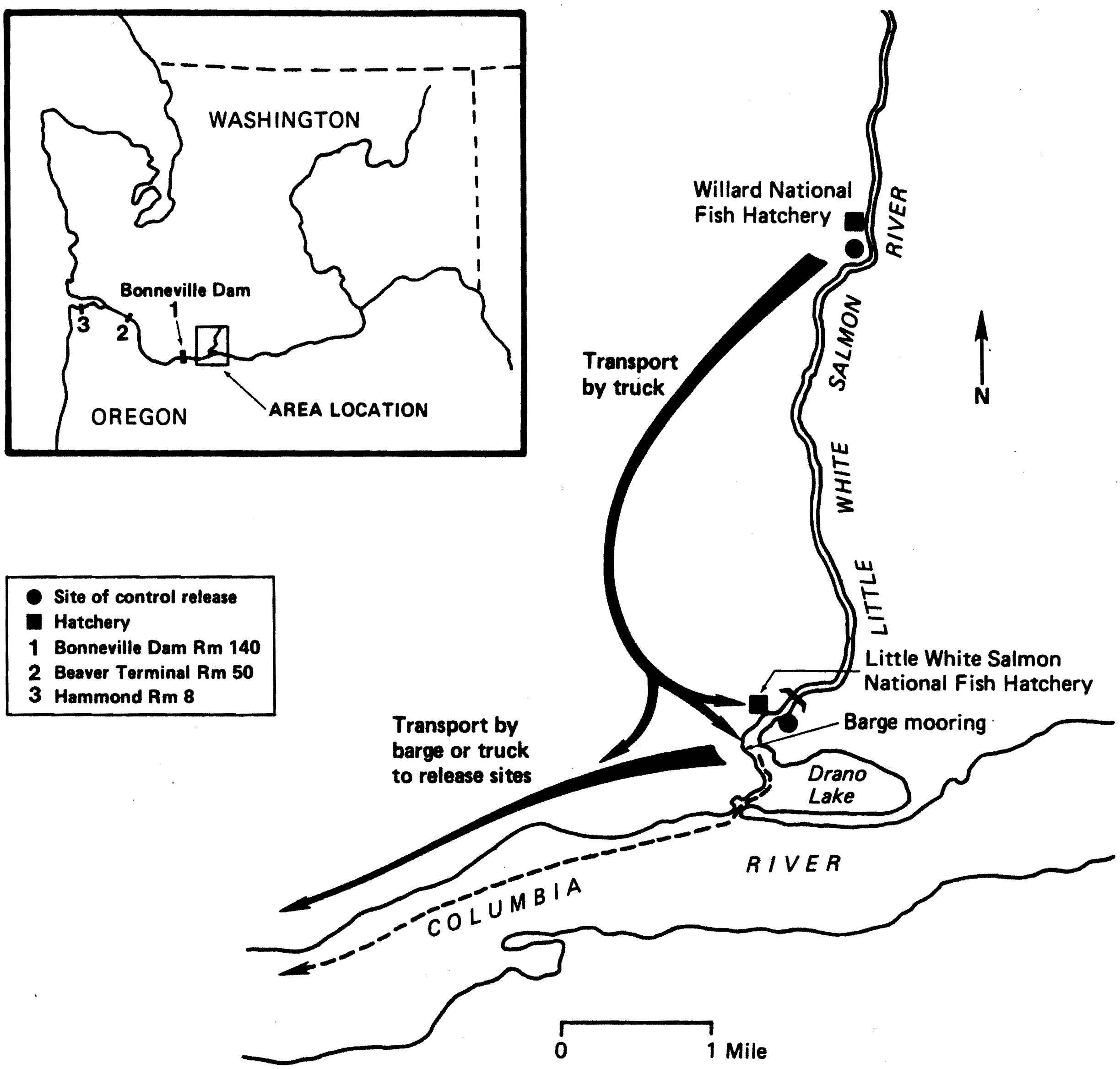

Figure 6.--Little White Salmon - Willard National Fish Hatchery complex and transport routes, 1980.

The site was conducive to technical requirements of the study, particularly the recapture of juvenile migrants. The capability of mooring a fish transport barge in the Little White Salmon River arm of Drano Lake within 200 yards of the Little White Salmon NFH was also an important consideration. A timely evaluation of the study results would be possible, since virtually all rack recoveries of adult coho salmon reared at Willard NFH are completed within approximately 16 months after their release as smolts.

Experimental Design

Experimental groups were provided imprint cues to Little White Salmon River water and then transported by barge or truck to release sites in the Columbia River below Bonneville Dam (RM 140 and 142, respectively), or by truck to Beaver Terminal, Oregon (RM 50), or by truck to Hammond, Oregon (RM 8). The barging portion (sequential imprint) consisted of three test groups that received different treatments in an effort to imprint the smolts to water from the Little White Salmon River. A prior event group (Test Group 1) was passed through 175 feet of pipe into a lower raceway to subject the smolts to an "event" which might possibly trigger their natural homing imprint mechanism. To approximate the natural situation as closely as possible, fish for the limited migration group (Test Group 2) were recaptured at the Little White Salmon NFH following a natural migration of 3.5 miles from Willard NFH. The barged only group (Test Group 3) received no artificial stimulation other than being transported by truck from the raceway they were reared in at Willard NFH to the barge moored in Drano Lake. Three test releases received a single imprint (simulated truck release) and were trucked from the hatchery to three sites below Bonneville Dam (see Volume II, Table A3.0 for additional detail on experimental design).

Recapture of juvenile migrants from the Little White Salmon River was attempted using a self-cleaning scoop trap (Raymond and Collins 1974), but trap efficiency was too low to supply the 50,000-fish goal for Test Group 2 (limited migration). Migrants which entered the water intake to the adult holding ponds at Little White Salmon NFH were captured and used to supplement the trap catch. Only 33,372 juveniles were released--a smaller than desired group.

Handling and especially marking smolted salmonids are generally considered to cause decreased survival. The inclusion of Test Group 2 (recaptured natural migrants) in the study design made it necessary to mark this group during the smolting period. To avoid bias, other groups were also marked in the spring. Concern over the possible adverse effect of spring marking led to the inclusion of Control Group 2 which was marked in November 1979. Their survival was compared with Control Group 3 marked in the spring (both were released in the Little White Salmon River on 23 May).

Results and Discussion

Statistical analysis of hatchery and ocean recoveries determined there was no significant difference ($P < 0.05$, $df = 1$) between Control Group 2 (fall marked) and Control Group 3 (spring marked) recovered in the ocean or at the hatchery (Comparison 1, Table 5). Since there was no significant difference between Control Groups 2 and 3, they were combined to strengthen the statistical analysis.

Homing of the barged groups to the hatchery was quite effective as indicated by only a 0.13 difference between the T/C ratios in the ocean and at the homing site (0.69:1 and 0.56:1, respectively) (Table 6). Most of this 0.13 differential in homing ability was accounted for in increased contribution to the Indian fishery and strays into other hatcheries in the

Table 5.--Statistical treatment of Willard NFH coho salmon homing experiment.

Comparison	Recovery area: Ocean	Recovery area: Hatchery
1. Control 2 vs Control 3	NS	NS
2. Control 1 vs Control 2 & 3	*	*
3. Barge Test 1 vs 2 vs 3	NS	NS
4. Truck Test 5 vs 6	NS	--
5. Pooled barge (Tests 1, 2, 3) vs pooled truck (Tests 5 & 6)	NS	--
6. Pooled truck (Test 5 & 6) vs Truck Test 4	*	--
7. Pooled barge (Tests 1, 2, 3) vs Truck Test 4	*	--
8. Pooled barge (Tests 1, 2, 3) vs pooled control (Groups 2 & 3)	*	*
9. Pooled truck (Tests 5 & 6) vs pooled control (Tests 2 & 3)	*	--
10. Pooled truck (Tests 5 & 6) vs Control 1	*	--
11. Pooled barge (Tests 1, 2, 3) vs Control 1	*	*

* = Significant difference between test and control releases ($P < 0.05$, df = 1).
NS = Nonsignificant.
-- = No test.

Table 6.--Comparison between control and test groups of adult coho salmon recovered at the Little White Salmon NFH and in the ocean fisheries from releases of smolts from the Willard NFH which were imprinted to the Little White Salmon River and released at six different sites in 1980. Recoveries are through 26 February 1982.

Juveniles released					Adult recoveries					
					Hatchery			Ocean		
Treatment		Site	Date	No.[a/]	No.	%	T/C ratio	No.	%	T/C ratio
Control groups (natural imprint)										
Control 1	Fall mark	L.W. Salmon NFH	14 May	43,045	40	0.093		45	0.105	
Control 2	Fall mark	Willard NFH	23 May	42,371	108	0.258		129	0.304	
Control 3	Spring mark	Willard NFH	23 May	51,525	145	0.281		149	0.289	
Control 2 & 3 (pooled)		Willard NFH		93,896	253	0.269		278	0.296	
Barged groups (sequential imprint)										
Test 1	Prior event	Bonneville (RM 140)	25 May	51,417	75	0.146	0.55:1	104	0.202	0.68:1
Test 2	Limited migration	Bonneville (RM 140)	25 May	33,732	47	0.139	0.52:1	64	0.190	0.64:1
Test 3	Barged only	Bonneville (RM 140)	25 May	47,293	79	0.165	0.62:1	103	0.215	0.73:1
Tests 1, 2, & 3 (pooled)		Bonneville (RM 140)	25 May	133,072	201	0.151	0.56:1	271	0.204	0.69:1
Trucked groups (single imprint)										
Test 4	Simulated release[b/]	Dalton Point (RM 142)	21 May	50,786	7	0.014	0.06:1	68	0.134	0.45:1
Test 5	Simulated release	Hammond (RM 8)	23 May	50,619	0	0.000		107	0.211	0.71:1
Test 6	Simulated release	Beaver Terminal (RM 50)1	22 May	51,683	0	0.000		101	0.195	0.66:1
Tests 5 & 6 (pooled)		Estuary areas		102,302	0	0.000		208	0.203	0.69:1

a/ Adjusted for tag loss.

b/ Loaded in truck for 2 h then released into raceway containing L.W. Salmon River water water for 48 h minimum then transported by truck containing L. W. Salmon water.

Bonneville Dam area (Table 7). If the Indian fishery (Zone 6) and stray fish recoveries are added to the numbers of fish which returned to the homing site, the T/C ratio of adults which returned to the Bonneville area from the barged groups was approximately the same as in the ocean (0.68:1 and 0.69:1, respectively). The data further indicated that when imprinting coho salmon smolts to the Little White Salmon River, the direct truck to barging process alone was reasonably effective, and additional stimulation or a short natural migration was not necessary (Comparison 3, Table 5--no significant differences between recoveries of the three barge treatments in either the ocean or back to the hatchery).

The positive homing by the barged groups must be qualified by the following: (1) the return of adult coho salmon to the hatchery from the natural migration (control) releases (Comparison 8, Table 5) was significantly ($P < 0.01$, df = 1) greater than the return of fish from the barged groups and (2) the increased rate of recovery in the Indian fishery and higher straying rate of fish from the barged groups than from the control groups (Table 7) indicate that some barged fish exhibited a homing impairment to the Little White Salmon River. However, the majority of returning adults from both the barged and control groups homed back to the Bonneville area.

By contrast, the single imprint method (direct trucking from the hatchery) used in this experiment did not adequately imprint the juvenile coho salmon to home successfully as adults to the hatchery (homing site). None of the fish trucked to and released at Beaver Terminal and Hammond, Oregon, returned to the hatchery (Table 6). Instead, these fish returned to the release site area as indicated by 56 recoveries in the lower river fishery (Zone 1-5 and Youngs Bay) compared to no recoveries above Bonneville Dam either in the Indian (Zone 6) fishery or the hatcheries (Table 7). Fish

Table 7.--A comparison between recoveries of control and test groups of adult coho salmon from the 1980 Willard NFH experiment in various fisheries and as strays to hatcheries in the Columbia River system.

Site	Pooled controls	Pooled barged	Pooled trucked	Dalton Point trucked
Fisheries				
Zone 1-5	0	1	34	2
Youngs Bay	0	1	22	0
Zone 6	5	17	0	1
Washington terminal[a/]	0	4	0	0
Sport fishery	0	0	0	1
Hatcheries				
Bonneville	1	15	2	6
Cascade	3	11	0	10
Others[b/]	0	0	1	1
Total all areas	9	49	58	21

a/ Skamakawa Creek, Cowlitz River, and Grays River.
b/ Grays River and Washougal SFH.

released at Dalton Point, Oregon, returned as adults to the Bonneville Dam area; however, from this location they strayed into various hatcheries in the area, including the Little White Salmon NFH (Tables 6 and 7).

Relative survival as measured by recovery of adults in ocean fisheries indicates no significant differences between the barged groups, the trucked groups released at Beaver Terminal and Hammond, or these groups combined (Comparisons 3, 4, and 5, Table 5). However, both the barged and lower river truck release groups contributed significantly ($P < 0.05$, df = 1) more fish (51%) to the ocean fisheries than did the Dalton Point truck release group (Table 6). The increased contribution to the ocean fisheries of the barged releases (RM 140) over the Dalton Point shore release (RM 142) in basically the same area suggests that a mid-river release in the main channel may be more productive than the shore release site. However, the eruption of Mount St. Helens could also have been a factor in the lower survival of the Dalton Point release (discussed later). Additional details on recoveries from specific releases may be found in Volume II, Tables A3.1 to A3.9).

Survival of the pooled controls (Groups 2 and 3) was significantly greater than survival of either the barged or trucked test groups (Comparisons 8 and 9, Table 5) ($P < 0.05$, df = 1). The overall rate of return for the pooled controls was 0.3% vs about 0.2% for the transported groups (Table 6). This was unexpected, since the Stavebolt Creek-1978 study (discussed previously) and other studies (Ebel 1970; Slatick et al. 1980; McCabe et al. 1983) demonstrated equal or better survival for fish transported and released below Bonneville Dam compared to fish released at the hatchery. Data on returning adult fish from fall chinook salmon released below Bonneville Dam in 1979 and 1980 (discussed later in this report) also indicate better survival of transported fish.

The return rate for the first control release (0.1%) (Table 6) was significantly lower than either of the other two control groups (Comparison 2, Table 5) or the transported groups (Comparison 10 and 11, Table 5) ($P < 0.05$, df = 1). Possible reasons for the poor returns of the transport groups and the first control group include: (1) stress placed on fish during handling, marking, loading, and transporting; (2) bias from different quality fish between raceways (fish were not randomized prior to marking); and/or (3) the eruption of Mount St. Helens.

With respect to potential stress, there are several factors to consider. Control Group 1 was transported in a 1,500-gallon hatchery truck from Willard NFH and released below Little White Salmon NFH whereas the other two controls (fall vs spring marking comparisons) were released at Willard NFH without added handling or transportation. Two of the barged groups were handled and marked within 5 days of release. The third barge group, as well as the truck releases, were marked approximately 1 month prior to release. It is possible that the added stress of crowding, loading, and transporting shortly after marking could impact survival. Seawater challenge tests for measuring stress indicated that stress levels of handled and marked fish are significantly higher than the stress levels of unmarked fish (Park et al. 1982.).

Differences in rate of return between transported and control fish could have resulted if the quality of fish varied significantly between raceways. The experimental design made it nearly impossible to randomize fish prior to marking. The NMFS did request though, that the fish be comparable in size and weight and be representative of the production release.

Mount St. Helens erupted on 18 May 1980, and the subsequent peak runoff of suspended solids affecting the Columbia River was in evidence by 19 May.

Control Group 1 inadvertently released on 14 May may have been extremely impacted by the relatively warm, turbid flows in the vicinity of the confluence of the Cowlitz River (RM 68). Data from NMFS sampling programs indicate that juveniles from the first control release reached Jones Beach (RM 47) on 19 May, coincident with the peak runoff from the eruption (Dawley et al. 1981). In contrast, the pooled control group (Groups 2 and 3) arrived at Jones Beach around 1 June, after the river conditions had significantly improved.

Mount St. Helens may also have impacted the test groups. The barged fish (Test Groups 1, 2, and 3) were released below Bonneville Dam on 25 May. Test Group 4 (Dalton Point), with the lower survival, was released on 21 May, 4 days earlier. Tests Groups 5 and 6 (Hammond and Beaver Terminal) were trucked downstream and released on 22 and 23 May, respectively, directly into Columbia River water impacted by Mount St. Helens effluent. Timing and location of the release appears critical. The high water temperatures and turbidity from the eruption lasted only a few days. The Beaver Terminal (RM 50) and Hammond (RM 8) releases were on the south shore where the main flow of the Columbia River would have diluted the deleterious effects of the volcanic plume to a degree. However, fish from the Dalton Point (RM 142) release may have been more randomly dispersed across the Columbia River when they came into contact with the more concentrated volcanic plume from the Cowlitz River (RM 68) on the north shore. Therefore, a greater number of fish from this release may have been affected by the volcanic plume. There is evidence from Dawley et al. (1981) that juvenile salmonids migrating through the estuary shortly after the eruption were adversely impacted by the poor environmental conditions encountered. We suspect the eruption of Mount St. Helens may have been the major problem in the reduced survival of the transported fish in this experiment. Similar stresses and non randomizing of fish in raceways have occurred in previous experiments in which transported fish returned at a higher rate than control fish.

Conclusions

1. There was no significant difference in adult survival between paired releases of control groups of juveniles either marked as pre-smolts in the fall or marked during their smolting period in the spring.

2. Barged fish homed successfully to the Little White Salmon NFH. The direct truck to barge process is adequate; no additional stimulation or short natural migration appears necessary.

3. Fish trucked to and released at Beaver Terminal and Hammond, Oregon, were imprinted to home to the lower river; none were recovered at the hatchery.

4. Fish trucked to and released at Dalton Point, Oregon, homed back as adults to the general vicinity of their release site (Bonneville area) and then strayed to various hatcheries in the area.

5. Recoveries of adults from transported fish were significantly less than recoveries of adults from the control releases. We suspect the eruption of Mount St. Helens may have been primarily responsible.

Overview of Imprint Treatments on Coho Salmon

Recoveries of adult coho salmon returning to the Columbia River system indicated that a combination of imprint method, mode of transportation, release site, timing, and physiological condition of the juveniles influenced their future adult migratory behavior.

Natural Migration Imprint

As expected, the majority of the fish demonstrated a positive homing response to their point of release--be it a hatchery or an upper or lower river homing site. The rate of return to Stavebolt Creek was nearly as high as the rate of return of the control releases to the hatchery.

Fish imprinted to areas above McNary Dam contributed more fish to the upper river whereas those released in Youngs Bay contributed substantially more fish to the lower river fishery.

Single Exposure Imprint

The single imprint methods used in these experiments were unsuccessful in returning adult coho salmon to the hatchery or to upper and lower river homing sites. Those trucked from the Pasco homing site and released below Bonneville Dam were generally recovered as adults in the Bonneville area, and those imprinted to Stavebolt Creek and released at Hammond were recovered in the Youngs Bay commercial fishery.

Sequential Exposure Imprint

The sequential imprint method employed with coho salmon in the 1980 Willard NFH experiment provided a positive homing imprint. Test to control ratios of adult coho salmon from all three barged groups that returned to the Little White Salmon River and vicinity were about the same as the T/C ratios measured in the ocean. These returns suggest that the barging process from the Little White Salmon River arm of Drano Lake provided an effective homing cue. Prior stimulation or a short distance (limited) natural migration had no effect on the degree of homing achieved by the barged test groups.

In contrast, the sequential imprint method used in 1978 did not supply the homing cues necessary to return adult coho salmon to the Pasco homing site. The return data did suggest that some fish acquired a homing imprint to the Columbia River above McNary Dam when they were loaded and held in the barge above Richland, Washington.

Application of Findings

1. Juvenile fish surplus to an upriver hatchery's need could be transported to Youngs Bay, given a single exposure imprint, and released. This should provide more adults overall by reducing dam-related mortalities to smolts and providing an area where fish could be efficiently harvested without impacting other runs of fish.

2. A similar fishery and enhanced survival could be realized along with the means of providing sufficient fish for spawning by imprinting fish to Stavebolt Creek (natural migration).

3. Surplus juvenile coho salmon could also be used to enhance the river fisheries above Bonneville Dam. Smolts could be transported to a selected upriver location (such as Richland, Washington), loaded into a barge for imprinting, and barged down river to below Bonneville Dam to reduce dam-related mortalities to smolts thereby enabling greater numbers of adults to be available to the fisheries above Bonneville Dam.

SPRING CHINOOK SALMON EXPERIMENTS

Spring chinook salmon were used in five homing imprint studies by NMFS and two by ICFRU. These chinook salmon represented two principal stocks which had been introduced to various hatcheries in the Columbia River Basin. The majority of fish were of Carson NFH stock. This brood stock was initially introduced to Carson NFH in 1955 and came from the heterogeneous population passing Bonneville Dam enroute to various upriver tributary spawning areas (Wahle and Cheney 1981; Zimmer et al. 1963). The second stock of chinook salmon was from the Rapid River Hatchery in Idaho. This brood stock was introduced to the hatchery in 1964 from the heterogenous population arriving at Hells Canyon Dam on the Snake River (Levendofske[3/]). Details on the treatments for each of the five experiments conducted by NMFS are contained in Volume II, Table B1.0

Kooskia NFH, 1978

Background

This experiment was concerned with imprinting juvenile spring chinook salmon to be transported from an upriver hatchery and released at a downriver site to return as adults to their hatchery of origin. Juveniles reared at Kooskia NFH that were to be transported were subjected to single and sequential imprinting techniques before being released into the Columbia River below Bonneville Dam. Results from the test groups were compared to those of fish released from the hatchery to migrate downstream naturally. The objectives of the experiment were to:

[3/] Tom Levendofske, Idaho Department of Fish and Game, Rapid River Hatchery, Riggins, Idaho, pers. comm. 1986.

1. Determine the effectiveness of single and sequential imprinting techniques in returning adults to the hatchery in comparison to the normal hatchery release method (natural migration imprinting).

2. Determine the effect of the natural, single, and sequential imprinting techniques on overall survival.

Experimental Design

Kooskia NFH water was the imprint media used to implant the primary homing cue in the test fish. During this experiment, the hatchery water supply was obtained from Clear Creek, a tributary of the Middle Fork of the Clearwater River. The experimental design included a control group released with the hatchery production fish into Clear Creek and four test groups that received a single or sequential homing imprint. Juveniles in the single imprint group were trucked in hatchery water to a release site below Bonneville Dam; sequentially imprinted fish were transported by truck or truck and barge to release sites below Bonneville Dam.

Results

Adult recoveries from the experiment were insufficient for analysis. A summary of the adult recoveries by area is presented in Volume II, Tables B1.1 to B1.5.

Carson NFH, 1979 and 1980

Background

This experiment was concerned with imprinting juvenile spring chinook salmon to be transported from a mid-river area hatchery and released at downriver sites to return as adults to their hatchery of origin. Juveniles reared at Carson NFH were subjected to single and sequential imprinting techniques before being transported by truck and released at two sites in the

Columbia River below Bonneville Dam. Results from these test groups were compared to those from fish released from the hatchery into the Wind River to migrate downstream naturally. The study was designed to determine:

1. The effectiveness of single and sequential imprinting techniques used in returning adults to the hatchery in comparison to the normal hatchery release method (natural migration imprinting).

2. The effect of various release locations on the relative overall survival of spring chinook salmon.

Experimental Design

The experimental design consisted of a control group released from Carson NFH and three test groups given a variation of the simulated release imprint techniques. Following a simulated release, test groups were transported by truck and released at Dalton Point (RM 142) or Hammond, Oregon (RM 8). All fish were premarked several months prior to release.

Results

Adult recoveries from the experiments were insufficient for analysis. A summary of adult recoveries by area is presented in Volume II, Tables B2.1 to B2.8.

Carson NFH - Pasco, 1979

Background

This experiment was concerned with imprinting juvenile spring chinook salmon reared at a mid-river area hatchery to home as adults to an upriver homing site. Juveniles reared at Carson NFH were subjected to single, sequential, and natural imprinting techniques at the Pasco homing facility (RM 326) before being released. The objectives of the experiment were to:

1. Determine the relative effectiveness of three imprinting techniques in returning adults to the Pasco facility.

2. Define the effect of three imprinting techniques on overall survival.

Experimental Design

Spring chinook salmon for this experiment were reared in raceways and pre-marked at the Carson NFH located in the Wind River drainage. The eggs for these spring chinook salmon were obtained from adults returning naturally to the Carson NFH.

Our experimental design consisted of a control group released at Pasco and two test groups transported to below Bonneville Dam. The single imprint group was transported by truck, and the sequentially imprinted group was transported by a combination of truck and barge. The fish were released 21-28 April 1979. A similar experiment using coho salmon was conducted in 1978.

Results

Adult recoveries from the experiment were insufficient for analysis. A summary of adult recoveries by area are presented in Volume II, Tables B3.1 to B3.3.

Leavenworth NFH, 1980

Background

This experiment was concerned with imprinting juvenile spring chinook salmon reared at an upper mid-Columbia River hatchery and then transported and released at various downriver sites to return as adults to their hatchery of origin. Juveniles reared at Leavenworth NFH were imprinted to Icicle River water by allowing them to migrate for 1 mile in the Icicle River bypass channel or holding them in a pen before being transported by truck and released into the Columbia River at two downstream sites. The results of these tests were compared with groups of fish released from the hatchery to migrate downstream naturally. This study was designed to determine:

1. Effectiveness of the imprint techniques in returning adults to the hatchery in comparison to the normal hatchery release method (natural migration imprinting).

2. Effect of various release locations on relative overall survival.

3. The effect on relative survival of fish marked in the fall as juveniles vs marking smolting fish in the spring.

Experimental Design

Five marked groups of approximately 100,000 fish per group were used in the study. With the exception of a control group marked in November 1979, experimental handling and marking took place during the spring of 1980 coincident with timing of the natural outmigration--a time we believed the fish were most likely to accept imprinting and exhibit true volitional migration. Handling of most marked groups was extensive. Experimental groups requiring volitional migration were released at the head of the Icicle River bypass channel, recaptured in an inclined screen trap, and then returned to hatchery raceways for marking and subsequent transport.

Groups released at White Bluffs and Dalton Point were transported in 5,000-gallon tank trucks containing hatchery water. Releases were made on 24 and 27 April and 1 May. For groups other than the fall-marked control, fish released on different dates had unique cold brands and wire tag codes. This procedure allowed evaluation of returns in the event of significant mortality in an individual transport load.

Results and Discussion

Statistical analysis of homing objectives was not possible due to low returns for the spring-marked control and truck transport groups. Although returns were low, it is noteworthy that fish transported to White Bluffs (RM 362) returned to Leavenworth NFH about as well as fish from the spring-marked control group (Table 8). There were no returns to the hatchery from fish transported to Dalton Point (RM 142) either from the volitional-migrant or pen-held group, and of the five observed returns, three were indicative of straying (recoveries in the Drano Lake and Sherears Falls sport fisheries and at Klickitat SFH). A summary of adult recoveries by area is presented in Volume II, Tables B4.1 to B4.5.

Homing behavior shown by fish from the White Bluffs release may have resulted from imprinting acquired during migration down the Icicle River bypass channel. Lack of homing for the corresponding Dalton Point releases indicates that regardless of source, the imprint was insufficient to guide the return of fish which had been transported as far downstream as Dalton Point.

Migrating juveniles were sampled at McNary and John Day dams and in the lower Columbia River and at Jones Beach (Dawley et al. 1981; Sims et al. 1981). The data indicated higher in-river juvenile survival for fish transported to White Bluffs and Dalton Point than for control releases from Leavenworth NFH (Table 8). Survival of spring and fall marked control groups was about equal.

To provide data regarding the effect of transport stress on survival, NMFS personnel met each of the six Dalton Point transport loads, removed samples of approximately 200 fish, and held the samples for observation of

Table 8.--Recoveries of spring chinook salmon marked for the 1980 Leavenworth NFH homing experiment.

	Experimental group and (number released)				
Recovery area	Control 1 marked fall 1979 (98,638)	Control 2 marked spring 1980 (98,789)	Test 1 volitional migr. White Bluffs release (100,105)	Test 2 volitional migr. Dalton Pt. release (98,448)	Test 3 pen held Dalton Pt. release (96,663)
Juvenile recoveries					
McNary Dam[a/]	9,241	11,326	16,289	-	-
John Day Dam[a/]	241	344	876	-	-
Jones Beach[a/]	31	31	85	134	91
Adult recoveries					
Dams					
Bonneville trap	1	2	1	1	0
McNary trap	5	0	0	0	0
Sport fishery					
Drano Lake	0	0	0	1	0
Deschutes River	0	0	0	1	0
Indian ceremonial fishery	0	0	0	1	0
Hatcheries					
Klickitat SFH	0	0	0	0	1
Leavenworth NFH	48[b/]	4	6	0	0
Total	52	6	7	4	1

a/ Recoveries adjusted for sampling effort.

b/ Includes two fish observed previously at the McNary trap.

delayed mortality as described by Park et al. (1981). After 14 days, survival in the samples averaged 94% (range 90-99%) (Newcomb[4/]).

Adult returns from experimental groups were not consistent with the relative outmigrant suvival indicated by juvenile sampling. Equal outmigrant survivals for spring and fall-marked control releases were not reflected in adult returns. Instead, 48 fish from the fall-marked release returned to Leavenworth NFH, but only four fish returned from the spring marked release. Similarly, very low adult returns were observed for the groups transported to White Bluffs and Dalton Point (Table 8).

Drastically reduced survival was common to all groups handled in the spring. Although ultimate survival was affected, it was not due to short-term mortality from stress of handling or transportation as indicated by the high rate of recovery of juveniles at dams and at Jones Beach. Instead, spring handling apparently predisposed these fish to extreme mortality later, perhaps following ocean entry. A causative fact could be related to disease. Results of physiology studies conducted during the spring of 1980 (Volume III, Novotny and Zaugg 1984) confirmed the presence of BKD organisms in 80 and 66% of the spring chinook salmon sampled on 31 March and 28 April, respectively. Studies holding spring chinook salmon in seawater for 3 months lend credence to this hypothesis (Bjornn[5/]). Groups of these fish experienced high losses in seawater due to BKD. Some groups of fish which showed an incidence of BKD as low as 1% (as determined by Indirect Fluorescent Antibody Tests) when

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4/ Dr. Timothy Newcomb, Natl. Mar. Fish. Serv., 2725 Montlake Blvd. E., Seattle, Washington 98112, pers. comm. 1986.

5/ Dr. T. C. Bjornn, Idaho Cooperative Fishery Research Unit, University of Idaho, Moscow, Idaho, pers. comm. 1986.

introduced to seawater, showed an increasing incidence up to 70% and a severe loss when held in seawater.

If we assume from the sampling at Jones Beach that spring chinook salmon juveniles were surviving to the lower Columbia River, then the principal period of high losses occurred from the Columbia River estuary to the time these fish would have grown to a size that could legally be retained in the various ocean fisheries. The poor survival of fish held in the seawater plus the latent mortality from the heavy infestations of BKD strongly indicates that the period of greatest mortality occurred from entry into seawater through the first winter at sea.

Decreased adult returns were also evident for the fall-marked control group, although not to the extent seen for experimental groups handled in the spring. All the 1982 and 1983 returns at Leavenworth NFH were subject to biological sampling according to procedures established by USFWS. Results indicate a return of approximately 2,900 fish (0.203%) from 1,423,000 unmarked spring chinook salmon released in 1980. The percentage return from the fall-marked control (0.050%) was significantly less ($P < 0.01$, df = 1). Handling and marking may have also influenced survival of this group, even though the fish were marked in November and not subjected to further manipulation.

Kooskia NFH, 1980

Background

This experiment (conducted by ICFRU) was concerned with using a relatively short distance migration to imprint juvenile spring chinook salmon to be transported and released at a downstream site to return as adults to their hatchery of origin. Juveniles reared at Kooskia NFH were allowed to migrate 100 m in a flume, collected, transported by truck, and released into the Columbia River below Bonneville Dam. Data from these fish were compared to data from fish released from the hatchery to migrate downstream naturally. The experiment had the following objectives:

1. Determine the effectiveness of the short distance migration imprinting technique in returning adults to the hatchery in comparison to the normal hatchery release method (natural migration imprinting).

2. Determine the effect of the two types of imprinting techniques on overall survival.

Experimental Design

Both the normal-migration and migration-transport groups of spring chinook salmon released from Kooskia NFH in 1980 were tagged (CWT) and fin clipped before any migration was allowed. The normal-migration group was flushed from the raceways and out of the hatchery on 16 April 1980. The migration-transport group was then allowed to migrate voluntarily out of the raceways and across the hatchery in the effluent flume (approximately 100 m) before they were trapped, placed in a truck, and transported to Lower Granite Dam and then to the Lower Columbia River (Bjornn and Ringe 1984). The voluntary migration of the migration-transport group took place over a 12-day period (23 April to 5 May). Fish used in the 1980 releases were yearling smolts that averaged 131 mm total length when released.

Results

Adult recoveries were insufficient for analysis [see Bjornn and Ringe (1984) for summary of adult recoveries].

Rapid River SFH, 1980

Background

This experiment (conducted by ICFRU) also used a short distance migration to imprint juvenile spring chinook salmon to be transported and released at a downstream site to return as adults to their hatchery of origin. Juveniles reared at Rapid River SFH were allowed to migrate 4 km, then collected from Rapid River, transported by truck, and released into the Columbia River below Bonneville Dam. Data from this test were compared to data from fish released from the hatchery to migrate downstream naturally. The experiment had the following objectives:

1. Determine the effectiveness of the short distance migration imprinting technique in returning adults to the hatchery in comparison to the normal hatchery release method (natural migration imprinting).

2. Determine the effect of the two types of imprinting techniques on overall survival.

Experimental Design

A group of fish marked in November 1979 by Idaho Department of Fish and Game (IDFG) personnel for a contribution to fisheries study was used as the normal migration group (control) from Rapid River SFH. Fish were taken from a rearing pond, tagged with a CWT, fin clipped, branded, and then released into the hatchery effluent channel. The channel was not screened so the fish could leave and migrate downstream during the winter or early spring if they chose to do so. Voluntary migration out of the rearing ponds during the fall and winter is normally allowed at Rapid River SFH.

The limited migration group (test) was allowed a migration of 4 km, and then they were collected from Rapid River, marked, and transported by truck in April for release downstream from Bonneville Dam (Bjornn and Ringe 1984).

Results

Adult recoveries from the experiment were insufficient for statistical analysis. A total of 27 marked adults was recovered at the Rapid River SFH--25 from the control releases and 2 from the transported test group [see Bjornn and Ringe (1984), for summary of adult recoveries].

Overview of Imprint Treatments for Spring Chinook Salmon

Research objectives relative to the spring chinook salmon homing experiments were not realized because adult recoveries from all experimental groups were too small to provide a meaningful statistical analysis.

FALL CHINOOK SALMON EXPERIMENTS

Fall chinook salmon were used in four homing experiments (Table 1). These fish represented two discrete genotypes commonly designated "tule" and "upriver bright" chinook salmon. The designation "tule" is applied to fall chinook salmon that are in an advanced state of maturation when they return as adults to the Columbia River. Tule stock chinook salmon used in our mid and lower river experiments were from Spring Creek NFH and Big Creek SFH (ODFW) (Fig. 7). The fish were progeny of naturally returning brood stock adapted to hatchery culture in the mid and lower Columbia River areas.

Upriver bright chinook salmon return to the Columbia River as green fish (not sexually mature), still retaining their silvery ocean coloration. The stock of fish we used migrates over 470 miles to reach their spawning grounds in the Snake River. Our test fish were from brood stock trapped at Ice Harbor Dam on the Snake River and reared at the Hagerman NFH in Idaho.

Spring Creek NFH - White Salmon - Stavebolt Creek, 1979

Background

This experiment was concerned with imprinting fall chinook salmon reared at a mid-river site to home as adults to a lower river homing site. Juveniles from Spring Creek NFH reared for a limited time in the White Salmon River Rearing Channel were subjected to natural migration and single imprinting at the Stavebolt Creek Homing Site. Data from these lower river releases were compared to data from releases of naturally migrating fish from the White Salmon River Rearing Channel. With some modifications, this study is a replicate of the 1978 Willard-Stavebolt Creek experiment with coho salmon. This study was designed to assess:

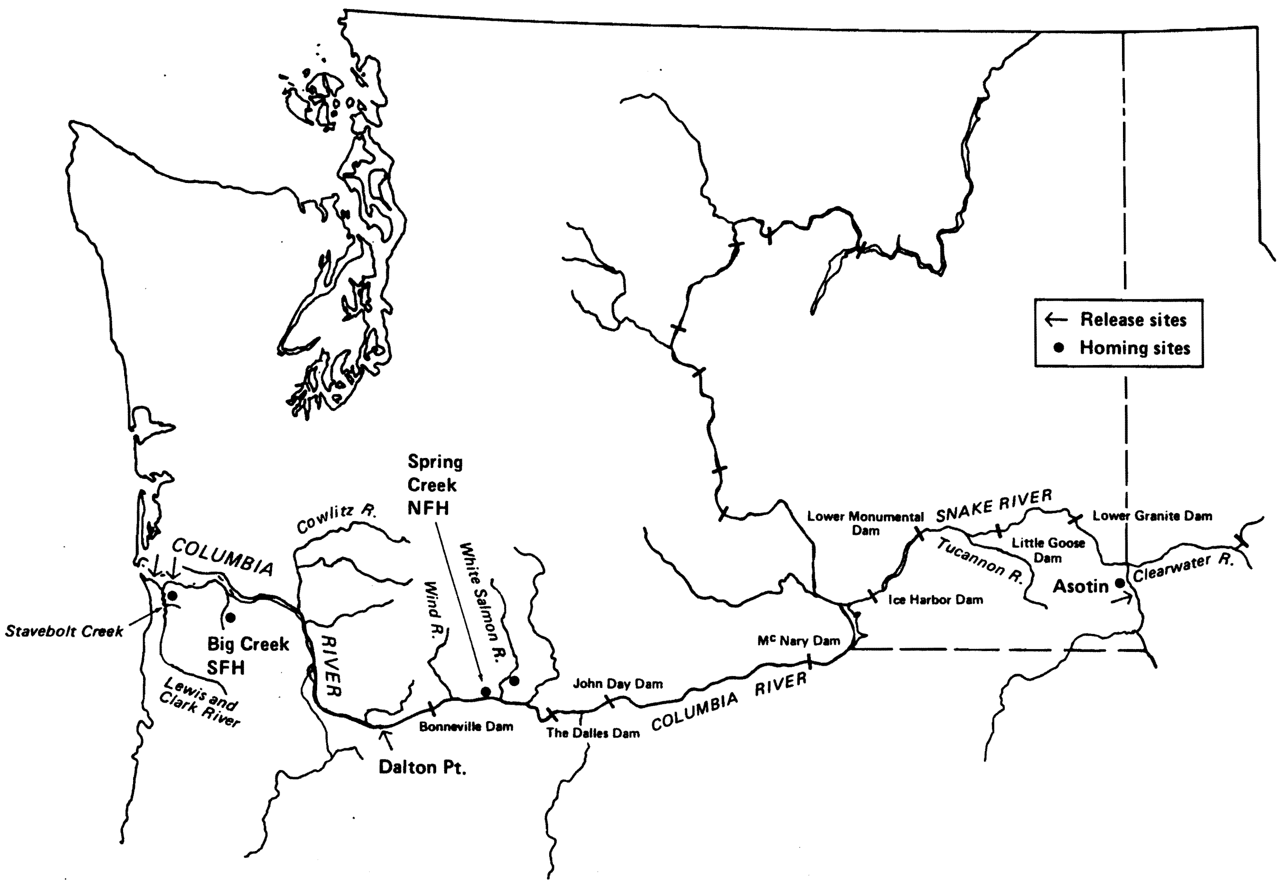

Figure 7.--Study area germane to homing experiments with fall chinook salmon.

1. The level of smoltification at which juvenile fall chinook salmon are most receptive to a homing cue.

2. The time period required to imprint a homing cue.

3. The effectiveness of single and natural migration imprinting in enabling adults to return to a specific homing site below their hatchery of origin.

Experimental Design

Eleven groups totaling 554,586 fish were marked at Spring Creek NFH and moved to the White Salmon River Rearing Channel (a satellite rearing facility) where discrete holding was possible (Fig. 7). Fish were held and reared for 9 to 44 days before release. Test groups were transported by truck to the homing site on Stavebolt Creek. Following holding periods of 4 and 48 h, the fish were released into Stavebolt Creek or into the Columbia River at Hammond, Oregon. Control groups were released into the White Salmon River (additional detail on group treatment may be found in Volume II, Table C1.0)

The first release series was made between 28 and 31 March, the second between 17 and 22 May, and the third on 26 June 1979. Additional details of the experimental design were given in Slatick et al. (1980). Random samples from the study population of fall chinook salmon were sacrificed to determine physiological condition and health. Live samples were transported to Manchester, Washington, and held in the marine net-pens for observation of seawater adaptation. Additional details on methods used to measure fish condition and health are contained in Volume III, Novotny and Zaugg 1981.

Results and Discussion

The three series of test releases were scheduled to coincide with rising, peak, and declining Na^+-K^+ ATPase enzyme levels (Fig. 8). Timing of the releases was based on the 1978 Na^+-K^+ ATPase activity profile for fall chinook salmon at the Spring Creek NFH. The plan to release fish at three clearly different levels of enzyme activity was not executed for three reasons: (1) peak Na^+-K^+ ATPase activity in 1979 was about 10 days earlier than in 1978, (2) fall chinook salmon held at the White Salmon Rearing Channel never reached the expected level of enzyme activity, and (3) the third release series was delayed by an outbreak of Enteric Redmouth Disease.

The disease outbreak reduced the number of fish available for the third release and forced a change in the experimental design. Even though treatment was applied, 32% of the original marked group died. By the time treatment was completed and the disease was controlled, high water temperatures in Stavebolt Creek prevented the planned transfer of test groups; therefore all fish from the third series were released as controls into the White Salmon River.

At the time of release, most of the fish in the third release series were clinically healthy (Volume III, Novotny and Zaugg 1981). However, adult recoveries from these mid-river control releases were extremely low--only four tags (0.004%) were recovered compared to 141 fish from the second release of controls and 207 from the first release (Table 9). The reason for the severe losses in the third control release is unknown; it may have been because of the late June release period, or more likely, it was due to latent effects of the epizootic disease outbreak.

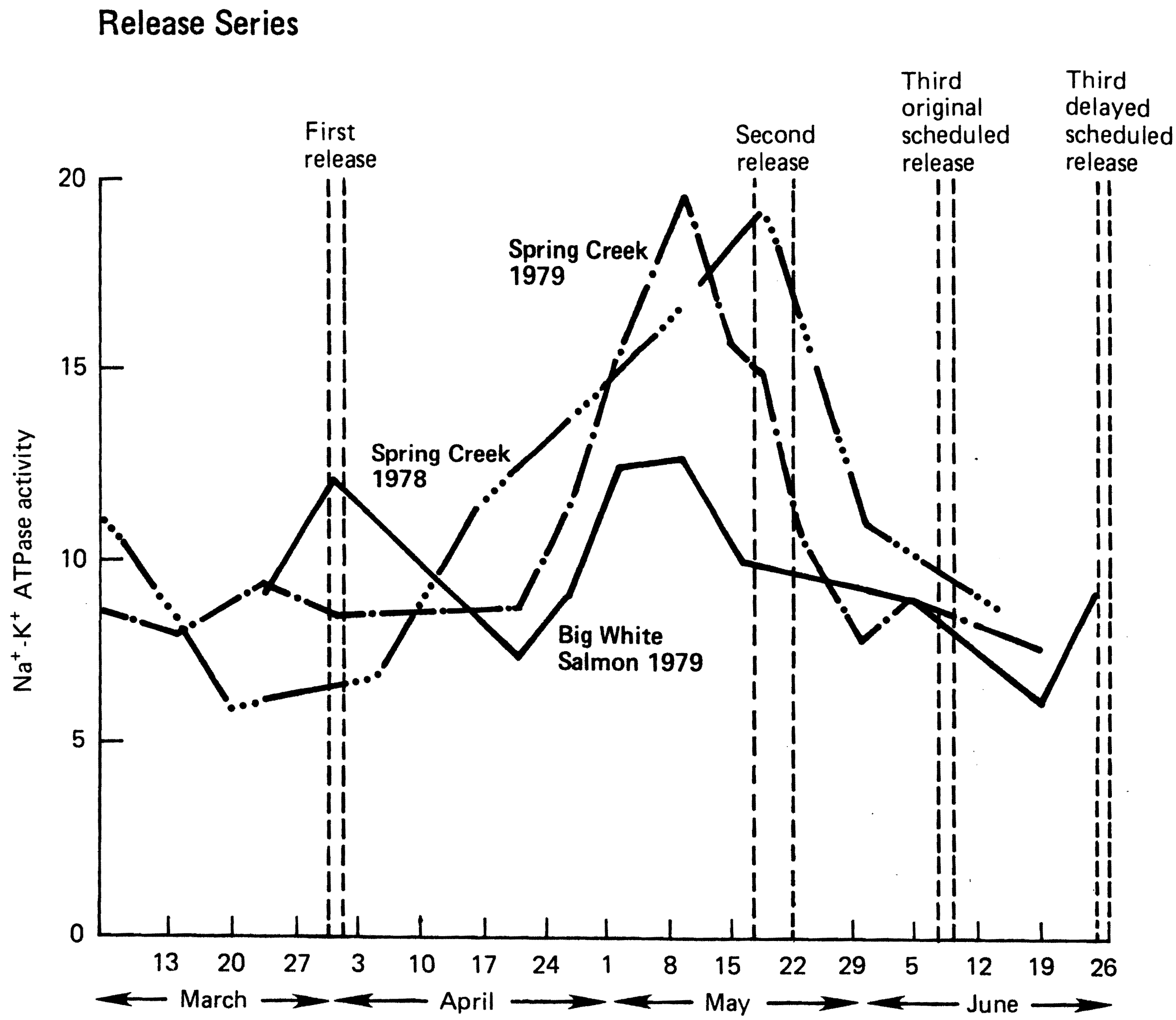

Figure 8.--Gill Na^+-K^+ ATPase activity profiles for fall chinook salmon at Spring Creek NFH 1978 and 1979 and Big White Salmon River Rearing Channel 1979.

Table 9.--Recoveries of tags from control and test groups of fall chinook salmon taken in the ocean and Columbia River fisheries, hatcheries, and on the spawning grounds. As juveniles, these fish were held in the White Salmon River Rearing Channels and then transported and imprinted to Stavebolt Creek for 4- and 48-h periods and released in two locations. Recoveries were from September 1980 to December 1982.

Experimental groups	Juveniles released: No.[a/]	Juveniles released: Date	Adult recoveries: Ocean (no.)	Adult recoveries: Columbia River (no.)	Adult recoveries: Total recovery No.	Adult recoveries: Total recovery %	T/C[b/] ratio
First release series (28 to 31 March 1979)							
Control (White Salmon River release)	42,419	28 Mar	109	98	207	0.488	
Natural imprint (Stavebolt release) 48 h	44,337	30 Mar	205	185	390	0.880	1.80:1**
Single imprint (Hammond release) 48 h	44,401	31 Mar	165	165	330	0.743	1.52:1**
Second release series (17 to 22 May 1979)							
Control (White Salmon River release)	47,788	19 May	77	64	141	0.295	
Natural imprint (Stavebolt release) 4 & 48 h	95,821	17 & 19 May	62	44	106	0.111	0.38:1**
Single imprint (Hammond release) 4 & 48 h	95,592	22 May	13	8	21	0.022	0.07:1**
Third release series (26 June 1979)							
Control (White Salmon River release)	99,669	26 Jun	3	1	4	0.004	
Total	470,027		634	565	1,199		

a/ Adjusted for initial tag loss.
b/ Test/control ratio is based on total recoveries.
** = Significant difference between test and control group ($P < 0.01$, df = 1).

A test of the hypothesis that fall chinook salmon released at different levels of Na^{+}-K^{+} ATPase activity may show different degrees of homing requires significant adult returns to the homing site. Because of the disease problem in the third release and the reduced survival of the second release, the number of adult returns were insufficient to determine the relationship between gill Na^{+}-K^{+} ATPase activity and homing of fall chinook salmon. Data from adults recovered from the first and second releases though, did provide other useful information on homing and survival of various treatment groups.

Recoveries of marked salmon from stream surveys were insufficient to determine differences between 4- and 48-h imprint times but did show the treatment provided a positive homing response to the Stavebolt Creek area. No marked fish were actually recovered in Stavebolt Creek, but 20 marked fish were recovered in the Lewis and Clark River within 4 miles of the creek. No marked fish were recovered in the other three river systems draining into Youngs Bay that contained spawning fall chinook salmon. The lack of spawning in Stavebolt Creek might have been due to rejection of the creek by adults because of extremely low water flows in the creek at the time of spawning.

Data from stream surveys indicated, as they did for coho salmon, that homing of fish released in Stavebolt Creek (natural imprint) was better than for those released at Hammond (single imprint) after being imprinted in Stavebolt Creek. Ten of the fourteen fish recovered from the March release and five of the six fish from the May release were Stavebolt Creek releases (Volume II, Tables C1.1 and C1.11).

Comparisons between recoveries in the various fisheries, hatcheries, and spawning grounds best illustrate the positive homing response of both the

Stavebolt Creek and Hammond releases to Youngs Bay and vicinity (Table 10). Approximately 60% of all test fish recovered from the 1st release series were recovered in Youngs Bay--of the 350 total recoveries from the first series, all but 16 were recovered below the Cowlitz River, and only 4 were recovered above Bonneville Dam. Data from the second release were similar, but totals were much lower.

The influence of the homing imprint on the control and test lots is reflected in the two major areas where the returning adults were recovered. Test fish, which were imprinted to Stavebolt Creek, were recovered principally in the Youngs Bay and lower Columbia River area (97 to 98%) whereas 90 to 94% of the adults from the control release were recovered in the Bonneville area (Table 10).

Survival of fish released in March was almost five times higher than survival of those released in May. A factor which may have influenced the lower survival of fall chinook salmon from the second release series may have been the latent effects of pathogenic infection combined with stress induced by handling and transport during the experimental releases. Organ tissue taken on 19 May from fish held for the second release series indicated exposure to some type of pathogenic infection--probably ERM and/or BKD (Volume III, Novotny and Zaugg 1981). The White Salmon River group (least stressed) produced 2.6 times more adults than those transported and released at Stavebolt Creek (0.295 vs 0.111% return), and those released in Stavebolt Creek produced five times as many adults as those transported to Stavebolt Creek, held, and transported again to Hammond for release. The differences were significant ($P < 0.01$, df = 1). In contrast, transported fish from the

Table 10.--A comparison between recovery percentages of the various treatment groups of adult fall chinook salmon at various locations in the Columbia River. As juveniles, these fish were held in the White Salmon Rearing Channels and then transported and imprinted to Stavebolt Creek for 4- to 48-h periods and released in two locations.

Homing imprint	Release location	No. of adults recovered	Percentages of adults recovered[a/] Youngs Bay	Zone 1-5 fishery	Zone 6 fishery	White Salmon River	Strays	Total Below Bonneville	Total Above Bonneville
1st Release Series									
Natural (Control)	White Salmon R.	98	0	9	23	0	67	10	90
Natural (Test) 48 h	Stavebolt Creek	185	59	29	1	0	11	97	3
Single (Test) 48 h	Hammond	165	59	29	0	0	12	97	3
2nd Release Series									
Natural (Control)	White Salmon R.	64	0	6	39	5	50	6	94
Natural (Test) 4 & 48 h	Stavebolt Creek	44	50	34	0	0	16	98	2
Single (Test) 4 & 48 h	Hammond	8[b/]	75	12	0	0	12	100	0

a/ Numbers rounded off to nearest percent.

b/ Very few fish represented in percentages shown.

March release of apparently healthy fish produced over 1.6 times as many adult fish as the control releases (significant at $P < 0.01$, df = 1). These data suggest a strong correlation between the degree of handling and stress and the latent effects of pathogenic infections on survival of chinook salmon.

The data also suggest that the pathogenic infections encountered in this experiment did not appear to affect the imprinting of these fall chinook salmon. Although, the survival of fish in the second lower river release series was drastically reduced, the riverine migratory behavior of the adults was similar to fish from the first lower river release (Table 10).

These data strongly suggest that if fish are transported to a lower river homing site, contributions to ocean and Lower Columbia River fisheries may be enhanced if the release is made when the juveniles will accept and retain a homing imprint. In contrast to the 1978 coho salmon experiments, fall chinook salmon did not home to the Stavebolt Creek homing site, but some fish did home to the Lewis and Clark River in the vicinity of Stavebolt Creek.

Conclusions

1. Homing of fish released in Stavebolt Creek was better than homing of those released at Hammond after being imprinted in Stavebolt Creek.

2. Test fish generally homed to Youngs Bay and contributed principally to the Zone 1-5 fisheries. Control fish returned to areas above Bonneville Dam and contributed principally to the Zone 6 fishery.

3. Recoveries of fish released in March were six times higher than for those released in May. Survival of those released in June was nil.

4. Transported fish from the March release produced over 1.6 times as many adult fish as the control releases, and there was no significant difference between the rate of return of fish released in Stavebolt Creek and those released in brackish water at Hammond.

5. Data obtained suggest a positive correlation between the degree of handling and stress and the latent effect of pathogenic infections on survival of chinook salmon.

6. The locations of adult riverine recoveries imply that the pathogenic infections encountered did not appear to affect the imprinting of these fall chinook salmon.

Big Creek SFH - Stavebolt Creek, 1980

Background

The goal of this experiment was to imprint juvenile fall chinook salmon from a lower river hatchery to a lower river homing site located in a nearby drainage system. Juveniles from the Big Creek SFH (ODFW) at Knappa, Oregon, were subjected to natural migration and single imprinting in combination with exposure to a limited short distance migration in Stavebolt Creek (Fig. 7). The results of these imprint tests were compared to those for fish which migrated naturally from Big Creek SFH. The objectives of the experiment were to:

1. Determine if the riverine adult migratory behavior of the production release from Big Creek SFH was the same as the subpopulation of fish used in our experiments.

2. Determine the relative effectiveness of the two imprint techniques in returning adults to the Youngs Bay drainage system and the Stavebolt Creek homing site.

3. Compare overall survival and riverine adult migratory behavior of test fish imprinted to Stavebolt Creek to fish that migrated from the Big Creek SFH.

Experimental Design

The experimental design consisted of a control group and two test groups utilizing juvenile fall chinook salmon from the Big Creek SFH. Groups of 12,000 to 15,000 unmarked juveniles were hauled 30 miles by truck daily from Big Creek SFH to the homing site on Stavebolt Creek over an 8-day period. After a short migration of 600 feet, the fish were recaptured and marked. Fish in Test Group 1 (49,528 fish) received 4 to 6 h of exposure to Stavebolt

Creek water and then were transported to the West Mooring Basin at Astoria, Oregon, and released into the Columbia River immediately above the confluence with Youngs Bay--single imprint. Fish in Test Group 2 (50,414 fish) received 6 to 9 h exposure to Stavebolt Creek water before being released into Stavebolt Creek--natural imprint. The control group of 43,863 fish was marked and released at Big Creek NFH.

A group of 142,400 juveniles was also marked from a random sample of the entire hatchery production as part of the fall chinook salmon hatchery evaluation study. These fish were premarked by Oregon Department of Fish and Wildlife personnel and released 13 May 1980. This marked production release enabled us to compare the behavior of the subpopulation of fish used in our experiment to the behavior of the total salmon population reared and released at the Big Creek SFH (see Volume II, Table C2.0 for additional detail on experimental design).

Results and Discussion

A comparison of adult recoveries from our experimental control release and the hatchery evaluation release showed a close similarity in their migratory behavior. These data are based on a sample of the population which returned to the Columbia River. There were no significant differences between the proportions of these two groups of adults recovered in the Zone 1 gill-net fishery, returning to the Big Creek environs, or straying to other tributary systems in the lower Columbia River (Fig. 9). These data demonstrate that the behavior of fish from the subpopulation used in our experiment was representative of the Big Creek SFH fall chinook salmon population, and that differences in behavior by fish in the test groups would be the result of behavior modification induced by the experimental treatments.

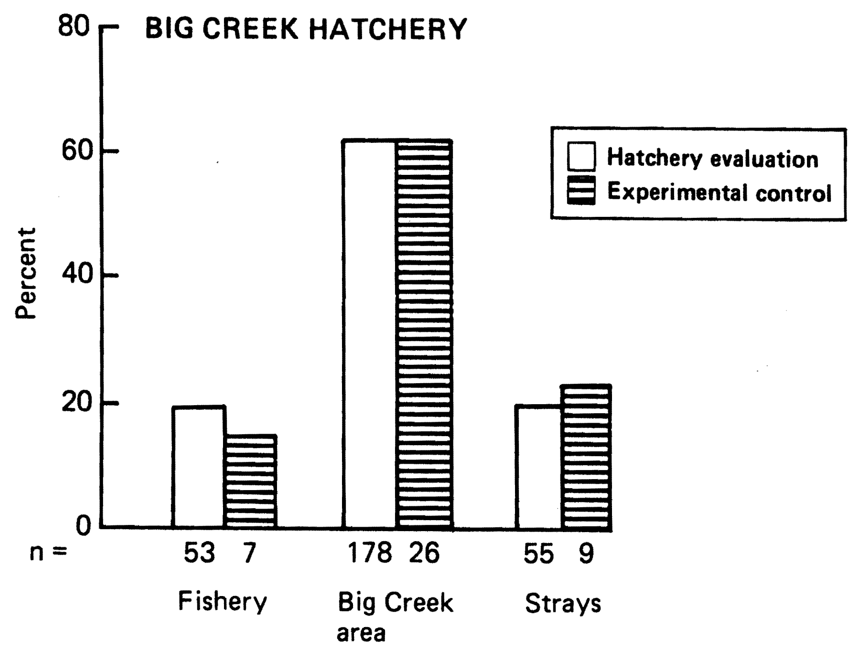

Figure 9.--Comparison of tag recovery locations of adult fall chinook salmon in the Columbia River system from two marked groups of juveniles released at the Big Creek SFH in 1980. Recoveries are through December 1983.

There were significant differences in homing between fish from the control release and the two experimental treatments. There were also significant differences in homing between the two experimental treatments. As expected, the majority of adults from the control release homed to Big Creek. A total of 61% of the recoveries were in the Big Creek homing area; this included the Big Creek terminal fishery, spawning fish in Big Creek, and the Big Creek SFH (Table 11). Twenty-one percent of the fish strayed to other tributaries within a radius of 24 miles, one fish (2%) was recovered from the gill net fishery in Youngs Bay, and six fish (14%) were recovered in the Zone 1 fishery (Table 11, Fig. 10). Additional detail on returns from specific releases are in Volume II, Tables C2.1 to C2.4.

Adults from the Stavebolt Creek release demonstrated a strong positive homing response to Youngs Bay. A total of 29 recoveries (65%) were in the Youngs Bay area and only 1 recovery in the Big Creek area. Of this number, four fish (9%) were recovered in the Lewis and Clark River within 4 miles of the imprint site in Stavebolt Creek (Table 11). No marked fish were recovered in the other two river systems that drain into Youngs Bay and contained spawning fall chinook salmon. The remaining 14 recoveries (31%) were from the Zone 1 fishery adjacent to Youngs Bay. This indicates a positive response for homing to the Stavebolt Creek area (Slatick et al. 1984).

Adults from the Astoria test release did not show as positive a homing response to the Youngs Bay area as fish from the Stavebolt Creek release. Only 36% of the fish released at Astoria homed to Youngs Bay--significantly less than the 65% return from the Stavebolt Creek release ($P < 0.05$, $df = 1$) (Table 11). One fish (2%) was recovered in the Lewis and Clark River and none in the Stavebolt Creek trap. Numbers of recoveries in the Zone 1 fishery were comparable to those from the Stavebolt Creek release.

Table 11.--A comparison between recoveries in various fisheries and spawning escapement locations in the Columbia River of adult fall chinook salmon from the 1980 Big Creek-Stavebolt Creek experiment. Recoveries are through December 1983.

Recovery area	Adults recovered at various locations in Columbia River[a/]					
	Control Big Creek release		Test 1 Astoria release		Test 2 Stavebolt Creek release	
	%	No.	%	No.	%	No.
Commercial fisheries						
Zone 1	14.0	6	26.0	17	31.0	14
Youngs Bay	2.0	1	34.0	22	56.0	25
Big Creek	2.0	1	2.0	1	0.0	0
Subtotal	18.0	8	62.0	40**	87.0	39 **
Spawning escapement						
Lewis and Clark River	0.0	0	2.0	1	9.0	4
Big Creek Hatchery	52.0	22	22.0	14	2.0	1
Big Creek	7.0	3	2.0	1	0.0	0
Other tributaries[b/]	21.0	9	14.0	9	2.0	1
Subtotal	80.0	34	38.0	25**	13.0	6**
Total adults recovered in Columbia River		42		65 NS		45 NS

a/ Numbers rounded off to nearest percent.

b/ Recovery locations include Bear Creek, Gnat Creek, and Plympton Creek in Oregon and Grays River, Skamokawa Creek, Elokoman River, and Abernathy Creek in Washington.

** - Significant difference between test and control releases ($P < 0.01$, df = 1).
NS = Nonsignificant

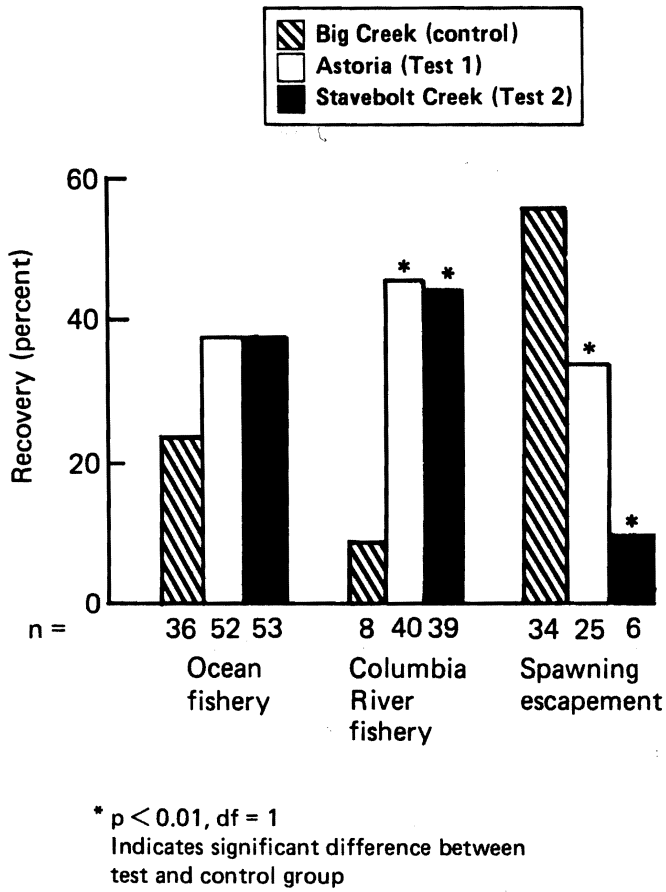

Figure 10.--A comparison of the distribution of adult recoveries from control and test releases of juveniles in the 1980 Big Creek-Stavebolt Creek experiments. Recoveries are through December 1983.

Many of the fish from the Astoria release that did not home to the Youngs Bay area or were not captured in the lower river fisheries continued their migration up the Columbia River to the Big Creek area (hatchery of origin). The percentage return of these fish to the Big Creek SFH was 64% of the returns from the control release.

Total tag recoveries from both the ocean and Columbia River indicate that fish from the Astoria test release had an enhanced relative survival over those released as controls at the hatchery (T/C ratio of 1.33:1). Recoveries from the Stavebolt Creek test release showed a 1.09:1 T/C ratio; however, neither increase was statistically significant (Fig. 10). Although there were no significant overall differences between test and control recoveries back to the Columbia River, there were significant differences between test and control release with respect to contributions to the riverine commercial fisheries and spawning escapement. Both test groups contributed significantly ($P < 0.01$, df = 1) more fish to the fishery whereas significantly ($P < 0.01$, df = 1) more control than test fish were from the spawning escapement recovered in the Big Creek environs and other Columbia River tributaries (Fig. 10).

Adults returning from the Astoria release were harvested at a rate equally as high as the Stavebolt Creek release in all areas (over three times greater than the control release) and returned to the hatchery in numbers equalling 64% of the control release. The rate of return to Big Creek SFH from the 1980 release was 0.1%; a return of 0.067 would be more than sufficient for an egg take.

Conclusions

1. The behavior of fish from the subpopulation used in our experiment was representative of the Big Creek SFH fall chinook salmon population, any

differences in behavior by fish from the test groups were the result of behavior modification induced by the experimental treatments.

2. Adults from the Stavebolt Creek release demonstrated a positive homing response to Youngs Bay.

3. Adults from the Astoria test release did not show as positive a homing response to Youngs Bay as did fish from the Stavebolt Creek release. Most of those that did not home to the bay homed back to Big Creek. Numbers returning to the hatchery were 64% of the return of the control groups.

4. The modified (altered) migratory behavior of adults induced by the experimental treatments affected the numbers of fish entering the spawning escapement or harvested in the river fishery. Test releases contributed significantly more fish to the fisheries whereas control fish contributed significantly more fish to the spawning escapement.

5. Adults returning from the Astoria release had an equally high rate of harvest as the Stavebolt Creek release in the river fishery (over three times greater than the control release) and a return to the hatchery of 64% of the control releases.

6. Imprint and release techniques like those used in the Astoria release could provide significantly more fall chinook salmon to the Columbia River fishery than releasing juveniles directly from the hatchery while providing adequate returns to the hatchery for egg take if the rates of return were similar to those measured for the 1980 releases.

Spring Creek NFH, 1980

Background

This experiment was concerned with imprinting juvenile fall chinook salmon from a mid-river site that were transported and released below

Bonneville Dam to return as adults to their hatchery of origin. Juveniles reared at Spring Creek NFH were subjected to sequential imprint techniques that included being transported by barge before being released into the Columbia River below Bonneville Dam (Fig. 11). The results of these test releases were compared to those of fish released from Spring Creek NFH to migrate downstream naturally. The objectives of the experiment were to:

1. Determine the relative effectiveness of the sequential imprinting techniques in returning adults to the hatchery of origin.

2. Determine the effect of the sequential imprinting techniques on overall survival.

For the evaluation of this experiment, our sampling locations were grouped into two areas: (1) the "Bonneville area," from Tanner Creek upriver to Hood River and (2) the "below-Bonneville area," the Columbia River in Zone 1-5 (Fig. 11).

Experimental Design

The experimental design consisted of a control group and two test groups utilizing 259,786 marked fall chinook salmon from Spring Creek NFH. One experimental group of 99,583 fish was pumped directly from the raceways into a barge; the second group of 99,703 fish was crowded through a 350-ft transport channel before being pumped into the barge. Both groups were given sequential homing cues by being transported to a release site below Bonneville Dam by a barge initially containing Spring Creek water and then Columbia River water. The control group of 60,500 fish was marked by USFWS personnel as part of the fall chinook salmon hatchery evaluation study. Additional details of the experimental design are given in Volume II, Table C3.0.

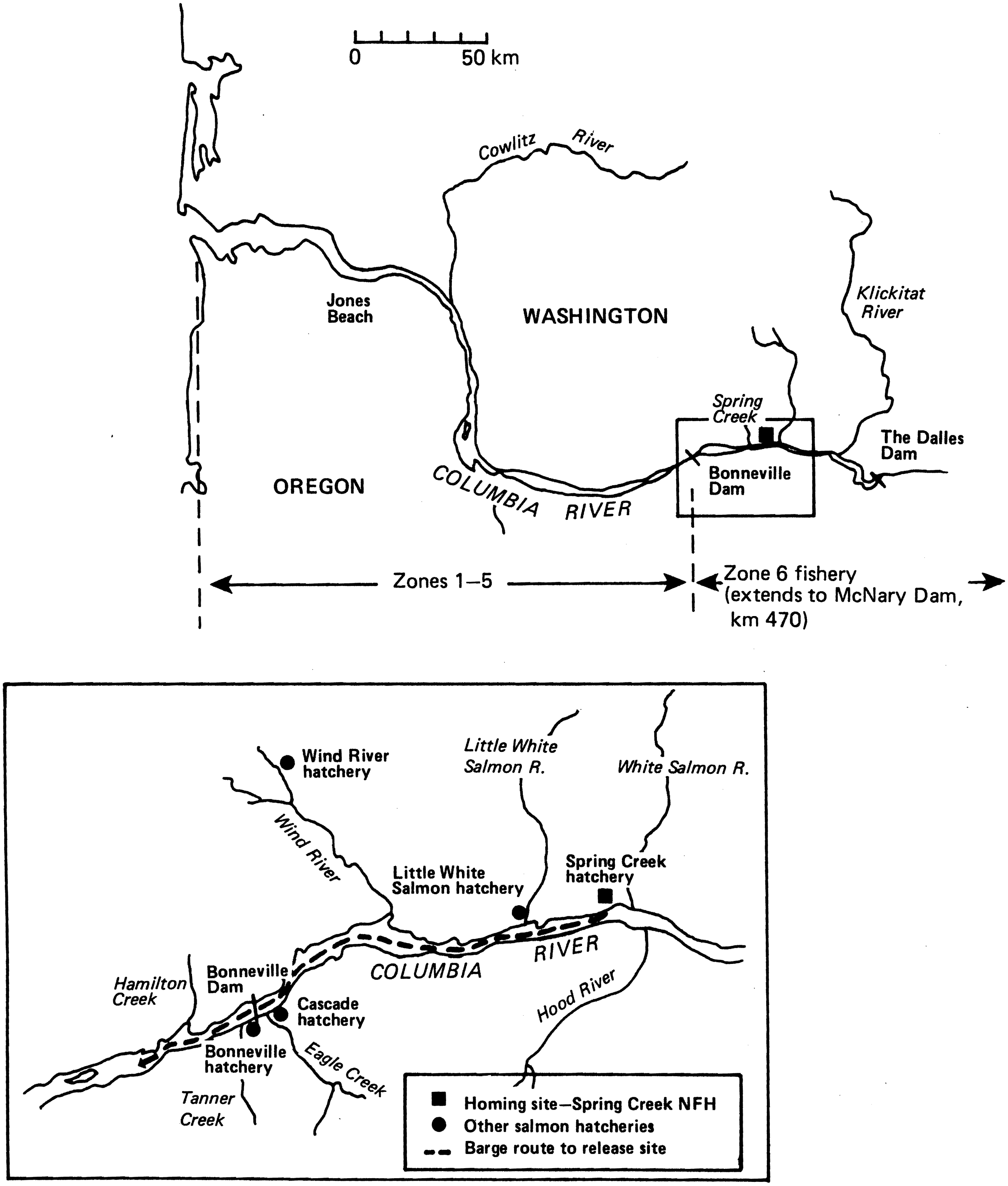

Figure 11.--Location map of release sites and recovery areas for 1980 Spring Creek homing study.

Results and Discussion

This experiment may have been impacted by the eruption of Mount St. Helens on 18 May 1980. Juveniles in the control group were released from Spring Creek NFH on 9 May and migrated seaward under normal river conditions. Median passage of this group at the Jones Beach sampling site was 12-14 May (Dawley et al. 1981). Fish for the two test groups were loaded into the barge and released below Bonneville Dam on 19 May, 1 day after the volcanic eruption. During their seaward migration, the test fish had to contend with the plume of volcanic debris emitting from the Cowlitz River. Median passage of the test fish at Jones Beach was 25 May. There is evidence from Dawley et al. (1981) that survival of subyearling chinook salmon was adversely impacted by the eruption.

Differences in rate of adult recovery of test and control fish in the fishery and back at the Spring Creek NFH homing site indicated that the techniques used to implant a homing imprint in the juvenile fall chinook salmon were not completely successful. Up to two-thirds as many adults from the barged groups returned to Spring Creek NFH as did adults from the control release (Table 12). The lower recovery rates for fish from the test lots were statistically significant from the recovery rates for the control lot at the hatchery ($P < 0.01$, df = 1).

A large number of adults strayed to other hatcheries in the Bonneville area (Volume II, Tables C3.1 to C3.3). Straying was more prevalent for fish from the test groups than from the control group. Of the total hatchery recoveries, about 73% of the test fish and 14% of the control fish were recovered as strays to other hatcheries, primarily the Bonneville Hatchery (Table 13). The straying rate of control fish (14%) indicated that a 100%

Table 12.--Percentage return of fall chinook salmon at hatcheries and in ocean and Columbia River fisheries that were released as control or test groups of smolts following imprinting to the Spring Creek NFH in 1980. Recoveries are through December 1983.

Experimental group	Juveniles released: No.	Juveniles released: Date	Percentage return of fall chinook salmon: Bonneville area: Spring Creek homing site	Bonneville area: Bonneville area hatcheries	Bonneville area: Total hatchery recovery	Bonneville area: Zone 6	Bonneville area: Total	Below Bonneville area: Zone 1-5	Below Bonneville area: Ocean	Below Bonneville area: Total	Total
Control (Spring Creek release)	60,500	09 May	0.200	0.033	0.233	0.200	0.433	0.095	0.388	0.483	0.916
Test 1 (Loaded raceway and barged)	99,583	19 May	0.134**	0.390**	0.524**	0.076**	0.600**	0.101 NS	0.410 NS	0.511 NS	1.111 **
Test 2 (Loaded channel and barged)	99,703	19 May	0.104**	0.267**	0.371**	0.081**	0.452 NS	0.093 NS	0.345 NS	0.438 NS	0.890 NS
Total	259,786										

NS = Nonsignificant difference between test and control groups.
** = Significant difference between test and control groups ($P < 0.001$, df = 1).

Table 13.--A comparison of hatchery recoveries at the homing site and as strays to other hatcheries for fall chinook and coho salmon from the 1980 Spring Creek and Willard NFH homing experiment.

Experimental groups	Adult recoveries at hatcheries			
	Homing site		Other hatcheries	
	%	No.	%	No.
1980 Spring Creek fall chinook salmon				
Control	86.0	121	14.0	20
Barge Test 1	26.0	133	74.0	388
Barge Test 2	28.0	104	72.0	265
1980 Willard Coho Salmon				
Control	98.0	252	2.0	4
Combined barge test	89.0	201	11.0	25

imprinting rate may not be feasible with this stock of fish. The 74 and 72% straying rates infer that a large proportion of the juveniles (from Test Lots 1 and 2, respectively) did not imprint a homing cue when they were loaded into the barge containing Spring Creek NFH water. We believe that the short period these juveniles were in Spring Creek NFH water in the barge (20 min and 1 h 55 min for Test Lots 1 and 2, respectively) was insufficient for the majority of the fish to receive a positive homing imprint.

As previously stated, coho salmon juveniles which had been held in a barge containing Little White Salmon River water for 19 to 21 h exhibited a strong positive homing imprint (see also Slatick et al. 1982). Of the total hatchery recoveries of adult coho salmon, 89% of the fish from the barged test groups and 98% of the fish from the control group returned to the Little White Salmon NFH homing site (Table 13). It is very possible that a longer imprint time (approximately 24 h) in a barge containing Spring Creek NFH water would also give a more positive homing cue to fall chinook salmon smolts to return as adults to the Spring Creek NFH homing site.

The data indicate that even though outmigrants from the barged test lots were released into the Columbia River the day after Mount St. Helens erupted (19 May), their relative survival equalled or surpassed that of the control release that migrated downriver prior to the eruption. Fish from Test Group 1 had a significantly higher overall recovery rate than did fish from the control release (Table 12) ($P < 0.01$, df = 1). Survival of Test Group 2 was much lower and similar to survival of fish from the control release. The stress induced by the extra handling that juveniles received when they were crowded through the transport channel before being pumped into the barge may have contributed to the lower survival rate of the second test group.

There were significant differences in recoveries of fish from the test and control lots by various user groups in the Columbia River system. Up to twice as many barged as control fish were recovered at hatcheries in the Bonneville area. Because of lack of imprinting, significantly more fish from barged groups than from the control group were recovered in hatcheries other than the Spring Creek NFH homing site ($P < 0.01$, df = 1). Conversely, significantly more fish from the control group than from the barged groups were recovered at the Spring Creek NFH and also in the Zone 6 fishery (Table 12) ($P < 0.01$, df = 1). Recoveries in the ocean and Zone 1-5 fishery area showed no significant difference in the numbers of fish taken from either the barged or control lots.

Conclusions

1. Methods used to implant a homing cue in test groups of juvenile fall chinook salmon barged below Bonneville Dam were only partially successful, the barged fish returned up to two-thirds as many adults to Spring Creek NFH as the control release.

2. About 14% of the control lot strayed; therefore, 100% imprinting probably cannot be achieved with this stock at Spring Creek NFH.

3. Barged fish from Test Group 1 produced significantly more adult fish than the control release; the majority of these adults were recovered in the Bonneville area.

Hagerman NFH, 1980

Background

This experiment was concerned with imprinting juvenile fall chinook salmon to be transported and released into the Columbia River below Bonneville Dam to return as adults to the Snake River. Juveniles reared at Hagerman NFH in Idaho were subjected to a natural migration imprint and a single imprint in combination with a limited short distance migration before being transported by truck and released into the Columbia River below Bonneville Dam. The objectives of the experiment were:

1. Determine the relative effectiveness of the two imprinting techniques in returning adults to the Snake River.

2. Define the effect of the two imprinting techniques on overall survival.

Experimental Design

Fish used in this experiment were part of the Snake River fall chinook salmon egg bank program. Adults were collected in September 1979 at Ice Harbor Dam and held at the Tucannon SFH [Washington Department of Game (WDG)]. Eyed eggs were then shipped to Hagerman NFH where the fish were reared until they appeared to be smolts. The fish were tagged (CWT) and had their adipose fin excised in May 1980 and transported from the hatchery in early June.

The normal migration group was transported by truck and released in the Snake River near Asotin, Washington, on 3 June 1980. The migration-transport group (limited migration) was transported by truck to Lower Granite Dam on 5 June 1980 and released into a raceway. The fish then received a limited migration imprint by being allowed to voluntarily move out of a raceway

(Bjornn and Ringe 1984). The fish were then trapped and transported by truck to the lower Columbia River.

Results and Discussion

No fish with CWTs were sacrificed at Lower Granite Dam when the fall chinook salmon were moving downstream in 1980. However, most, if not all, the fish with adipose clips that entered the collection facility during June and early July were probably fall chinook salmon released at Asotin, Washington. NMFS personnel estimated, on the basis of adipose-clipped fish collected during June, that 3,425 of the 60,750 fall chinook salmon released at Asotin were collected at Lower Granite Dam.

Fall chinook salmon that migrated out of the raceway at Lower Granite Dam and then were transported by truck to the lower Columbia River were recaptured in significantly larger numbers in the estuary sampling than those released at Asotin ($P < 0.01$, df = 1). Only 13 of the Asotin-released fish were collected in the estuary samples vs 46 of the migration-transport fish (Table 14).

Adult fall chinook salmon from the group released at Asotin (normal migration) returned to the Snake River at 31 times the rate of adults from the group released in the raceway at Lower Granite Dam and transported to the lower Columbia River (Table 14). Reported recaptures of the normal-migration group through December 1983 were relatively high (0.38% overall) with 57 fish recaptured in ocean fisheries, 5 in Columbia River fisheries, and 170 at Ice Harbor and Lower Granite Dams. In contrast, only 28 (0.05%) of the transport group were recaptured, 20 in the ocean fishery, 3 in the river fishery, and 5 at Snake River dams. Based on ocean recoveries, survival of fish from the

Table 14.--Fall chinook salmon smolts released in the Snake River in 1980 and adults recaptured for the migration-homing study.

Item	Normal-migration group	Migration-transport group
Number of fish marked and released with coded wire tags	60,750	57,713
Wire tag code	5/5/27	5/5/18
Date released	3 June 80	6-23 June 80
Mean total length at release (mm)	93 (n=326)	91 (n=399)
Smolts recaptured in the estuary[a/]	13	46**
Adults recaptured (through July 83)		
Ocean fisheries	57	20**
Columbia River	5	3
Snake River dams	170	5
Adults recaptured (%)		
At Snake River dams	0.280	0.009
Total	0.382	0.049

a/ Fish with coded wire tags.
** = Significant difference between test and control groups ($P<0.01$, df = 1).

migration-transport group was significantly less than fish from the normal migration (control) group ($P < 0.01$, df = 1).

Conclusions

1. The limited migration method used combined with truck transport was unsuccessful in returning adult fall chinook salmon to the Snake River. Except for ocean recoveries, returns were insufficient for analysis.

2. Based on ocean recoveries, survival of fish from the migration transport group was significantly less then for fish from the normal migration group ($P < 0.01$, df = 1).

Overview of Imprint Treatments of Fall Chinook Salmon

Recoveries of adult fall chinook salmon returning to the Columbia River system indicated that the combination of imprint method, mode of transportation, release site, timing, and physiological condition of the juveniles influenced their future adult migratory behavior pattern.

Natural Migration Imprint

The majority of adults from the hatchery of origin releases returned to their respective homing sites at Big Creek and Spring Creek hatcheries or were recovered in nearby gill-net fisheries. Straying by adults occurred from both releases.

Although juvenile salmon released at the lower river site (Stavebolt Creek) were from two different stocks [Big Creek SFH in 1980 and White Salmon River Rearing Channels in 1979 (Spring Creek NFH stock)], the returning adults behaved in a similar manner. The adults demonstrated a positive homing response to the Youngs Bay drainage area.

Adults returning from the mid-river area imprinting site (White Salmon River Rearing Channels) demonstrated a positive response to the Bonneville area. Although these juvenile salmon were held and reared from 9 to 44 days before release, homing of adults back to the White Salmon River was poor. The majority of these fall chinook salmon strayed to hatcheries in the area, with most returning to the Spring Creek NFH--their hatchery of origin.

The straying behavior of adult fall chinook salmon from these lower and mid-river release sites corresponded very closely to conclusions on straying drawn by Lister et al. (1981): (1) the rate of straying increases with decreasing distance between the release and rearing sites, (2) a relatively high proportion of the straying is back to the rearing site, and (3) straying rates tend to decrease with increasing distance between the rearing and downstream release sites.

Single Exposure Imprint

Adults returning from juveniles subjected to the single exposure imprint did not show as positive a homing response as did fish from the natural migration imprint. Fish from the mid-river (Spring Creek stock) which received a single imprint to Stavebolt Creek and were released at Hammond in 1979 showed a significantly ($P < 0.01$, $df = 1$) greater positive homing response to the Youngs Bay area than fish from the lower river area (Big Creek stock) which had been imprinted to Stavebolt Creek and released at Astoria in 1980.

Many of the fish from the Astoria release that did not home to the Youngs Bay area continued their migration up the Columbia River to the Big Creek area (hatchery of origin). In contrast, very few of the fish released at Hammond were recovered in areas other than Youngs Bay.

Sequential Exposure Imprint

Adult recoveries at the Spring Creek NFH homing site indicated that barging to implant a sequential homing imprint in juvenile fall chinook salmon was partly successful. Up to two-thirds as many adults from the test lots as from the control returned to the hatchery. This homing response may be improved by a longer imprint period in the barge. The data indicate that riverine homing behavior by adult fall chinook and coho salmon in the lower Columbia River was similar (homing response to Youngs Bay area) when subjected to the same imprint treatments as juveniles. This suggests that a longer imprint time may improve homing for fall chinook salmon since it was successful with coho salmon.

Application of Findings

1. Fish surplus to an upriver hatchery's need, as with coho salmon, could be transported to Youngs Bay, given a single exposure or natural migration imprint, and released. This should provide more adults by reducing dam-related mortalities to smolts and provide an area (Youngs Bay) where the fish could be harvested without impacting other runs of fish.

2. Fish surplus to a lower river hatchery, such as Big Creek SFH, given a single exposure imprint could provide greater numbers of fish to the riverine fishery and provide sufficient fish for spawning at the hatchery.

3. Direct barging from Spring Creek NFH to below Bonneville Dam with proper sequential exposure imprinting could provide an enhanced fishery and still return sufficient numbers of fish to the hatchery for egg taking.

4. Surplus juvenile fall chinook salmon can also be used to enhance the river fisheries above Bonneville Dam by imprinting them to pre-selected harvest areas and barging the smolts to below Bonneville Dam for release. This would reduce dam-related mortalities to smolts and provide greater adult returns to the harvest areas.

STEELHEAD EXPERIMENTS

Steelhead were used in nine homing experiments (Table 1). These fish included three upriver racial stocks and one lower river stock. The upriver stocks normally travel over 450 miles on their spawning migration whereas the lower river stock normally migrates about 140 miles.

During our studies, steelhead from the Dworshak NFH were the only indigenous stock of fish which were imprinted to their hatchery of origin. These fish were originally from the North Fork of the Clearwater River (Dworshak NFH water supply) and were adapted to hatchery culture. Fish used for the Chelan-Leavenworth and Wells-Winthrop experiments were from brood stock taken from fishways at upper mid-Columbia River (above McNary Dam) dams, and included a combination of both hatchery and wild fish. Brood stock for the Chelan SFH (WDG) experiment were obtained from the fishway at Priest Rapids Dam, and fish for the Wells SFH (WDG) experiment were obtained from the Wells Dam fishway. Steelhead used in the Tucannon SFH studies in 1978 and 1979 (Snake River system) were Skamania stock, a lower river race from the Washougal River, Washington. A map showing the various homing and release sites, sport fishery, and the Zone 6 Indian fishery is contained in Figure 12.

Dworshak NFH, 1978

Background

Juvenile steelhead reared at Dworshak NFH were subjected to single and sequential imprinting with hatchery water prior to being transported and released below Bonneville Dam. Adults from these releases returning to the hatchery were compared to adult returns from naturally imprinted fish released at the hatchery. The objectives of the experienced were to:

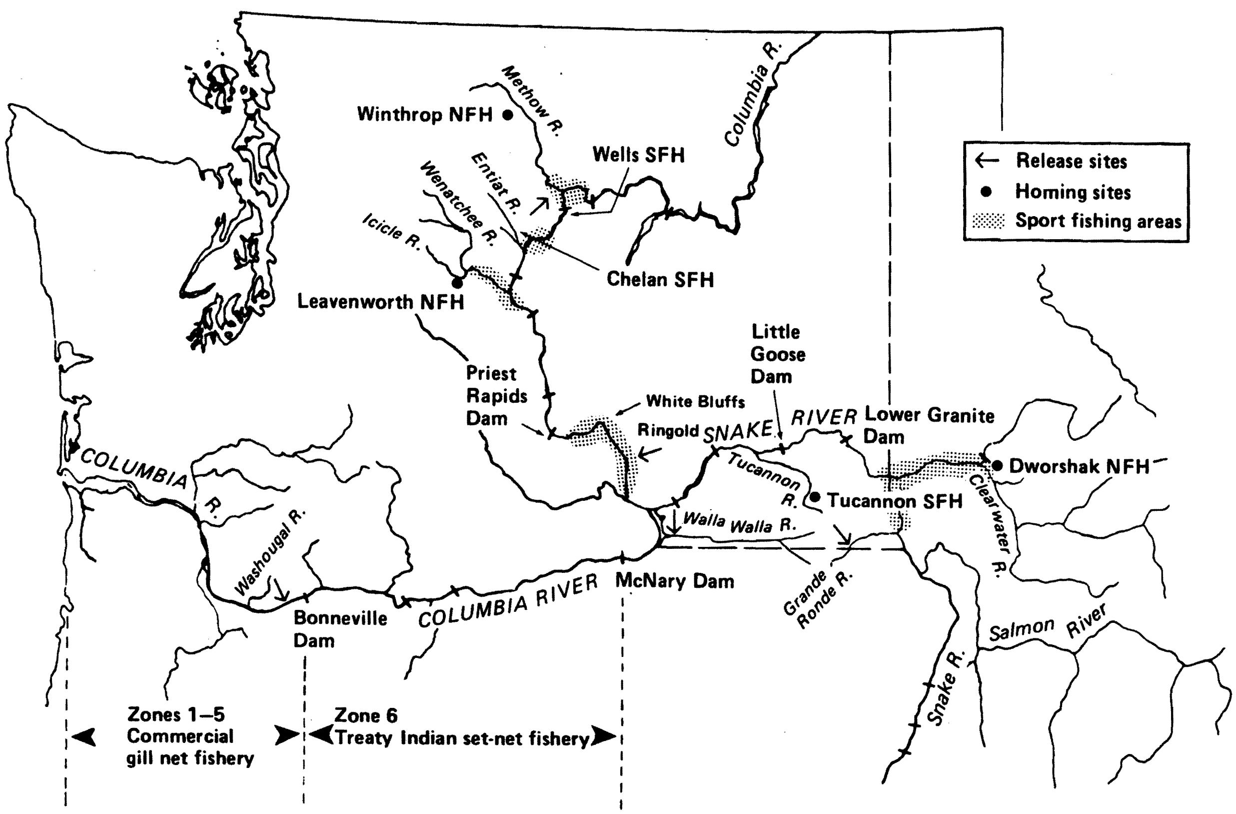

Figure 12.--Study area germane to homing experiments with steelhead.

1. Determine if juvenile steelhead transported and released at downstream sites can be imprinted to return as adults to their hatchery of origin.

2. Define the relative effectiveness of three imprinting techniques.

Experimental Design

A control group of CWT steelhead was released at Dworshak NFH into the North Fork of the Clearwater River (hatchery water supply), and two test groups of CWT steelhead were imprinted with North Fork Clearwater River water, transported, and released below Bonneville Dam. The test groups were taken from the reconditioned hatchery water and held in raw North Fork Clearwater River water for 6 days. One group was trucked to Lewiston, Idaho; held overnight; and barged downstream to the Bonneville Dam release site (sequential imprint). The second test group was trucked directly to Bonneville Dam and released (single imprint). Additional detail on experimental design may be found in Volume II, Table D1.0.

Results and Discussion

Returns of adult steelhead to the Dworshak NFH indicate the test methods used were successful in varying degrees in returning steelhead to the Dworshak NFH homing site. Homing of both barged and trucked transport groups was impaired as indicated by T/C ratios. A T/C ratio of over 3:1 was indicated for transported fish returning to the lower Columbia River compared to 1.54:1 for barged and 1.08:1 for trucked fish back at the hatchery (Table 15). Even though homing of both test groups was impaired, sufficient homing cues were imparted to fish in the barged group to allow a significantly higher return of barged fish than control fish to the hatchery ($P < 0.01$, df=1).

Table 15.--Returns to five sampling locations and to the Dworshak homing site of steelhead from control and test releases of smolts imprinted to the Dworshak NFH in 1978. Recoveries were from September 1979 to 12 May 1981.

Recovery area and experiment[a/]	Juveniles released		Adult returns		
	No.	Date	No.	%[b/]	T/C ratio
<u>Bonneville Dam[c/]</u>					
Dworshak - control	100,600[d/]	21 Apr	13	0.043	-
Trucked to Bonneville	20,661	01 May	16	0.324	7.53:1 NS
Barged to Bonneville	24,006	26 Apr	9	0.157	3.65:1 NS
<u>Indian fishery[e/]</u>					
Dworshak - control			75	0.075	-
Trucked to Bonneville			44	0.213	2.84:1 **
Barged to Bonneville			61	0.254	3.39:1 **
<u>McNary Dam[c/]</u>					
Dworshak - control			21	0.070	-
Trucked to Bonneville			4	0.088	1.26:1 *
Barged to Bonneville			9	0.158	2.26:1 *
<u>Lower Granite Dam[c/]</u>					
Dworshak - control			198	0.658	-
Trucked to Bonneville			19	0.373	0.57:1 **
Barged to Bonneville			50	0.932	1.42:1 **
<u>Clearwater and Snake River sport fishery[e/]</u>					
Dworshak - control			76	0.076	-
Trucked to Bonneville			8	0.039	0.51:1 NS
Barged to Bonneville			22	0.154	2.02:1 **
<u>Dworshak homing site[e/]</u>					
Dworshak - control			280	0.278	-
Trucked to Bonneville			62	0.300	1.08:1 NS
Barged to Bonneville			103	0.429	1.54:1 **

a/ Because of differences in sampling intensity (efficiency) at each trapping site, results are not comparable between sites.
b/ Adjusted for the differences in detectability between binary and color-coded wire tags as indicated by returns to Dworshak hatchery.
c/ Data from branded fish only.
d/ A total of 100,600 were wire tagged for the hatchery control releases. Of this number only 30,074 were branded for inriver adult evaluation.
e/ Data from coded wire tags only.

NS = Nonsignificant
* = Significant difference between the test and control group ($P < 0.05$, df = 1).
** = Significant difference between the test and control group ($P < 0.01$, df = 1).

Effects of transportation on the relative survival and homing of the test groups trucked or barged were demonstrated by recoveries in the two principal fisheries (Zone 6 Indian fishery and Clearwater River harvest) and returns to the Dworshak NFH homing site. The total estimated (minimum) recovery of 2-ocean age adults was 1.44% for the trucked fish and 1.97% for the barged fish; both were significantly higher than the estimated 0.92% recovery for the control fish ($P < 0.05$, df = 1) (Table 16). These figures reflect the increased survival and subsequent contribution to user groups of the test lots transported directly from the Dworshak NFH compared to the higher losses from the control lot (not transported from Dworshak NFH). The difference in rate of return of test and control fish is even more impressive when one considers that approximately 67% of the control fish surviving to Lower Granite Dam were also transported below Bonneville Dam via the regular transportation program, thus providing them greater survival potential (Park et al. 1979). The T/C ratio for returning adults from the 1978 outmigration transported from the collector dams was 3.22:1. This means that approximately three out of four returning adult steelhead from our control release received the benefit of being transported around hydroelectric dams on the Snake and Columbia rivers. It is apparent that without the benefit from transportation, the return of control fish to the hatchery would have been substantially less.

The impaired homing resulted in a large number of the test fish delaying or remaining in the Bonneville Pool as evidenced by the catches in the Indian fishery (Table 16). Nearly 90% of the control fish were taken in the fall fishery during the upstream migration. In contrast, nearly 75% of the test fish taken were those that overwintered in the Bonneville Pool and were caught in the winter gill-net fishery.

Table 16.--Minimum estimated recovery of 2-ocean age steelhead in Indian fishery (Zone 6), Clearwater River harvest, and actual recoveries at Dworshak NFH homing site from control and test releases of smolts imprinted to the Dworshak NFH in 1978.

Location and period of recovery[a]	Control (100,600)[b]		Truck (20,661)[b]		Barge (24,006)[b]	
	No.	%	No.	%	No.	%
Indian fishery[c]						
Fall	190		21		71	
Winter	24		113		113	
Subtotal	214	0.213	134	0.649*	184	0.766*
Clearwater River[d] harvest	467	0.464	107	0.518 NS	188	0.783*
Dworshak NFH (homing site)	249	0.248	57	0.276 NS	100	0.417*
Total	930	0.924	298	1.442*	472	1.966*

a/ Because of differences in recovery (efficiency) at each location, results are not comparable between sites.

b/ Number of juveniles released.

c/ Estimated recoveries based on sampling of Zone 6 Indian fishery.

d/ Estimated recovery of both Indian and sport fisheries based on total estimated Clearwater River harvest by Idaho Fish and Game--(Pettit 1986[e]).

NS = Nonsignificant.

* = Significant differences between the test and control group ($P < 0.05$, df = 1).

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e/ Steve Pettit, Biologist, Idaho Department of Fish and Game, 1540 Warner, Lewiston, ID 83501, pers. commun. 1982.

A key point is that even though homing of the barged group was impaired, there were still enough fish that received a positive homing imprint to provide a significantly greater percentage return of adults to the hatchery and to the Clearwater River sport fishery than did fish released at the hatchery ($P < 0.01$, df=1).

Conclusions

1. Steelhead can be imprinted to return to their hatchery of origin after being transported directly from the hatchery as smolts and released below Bonneville Dam.

2. Steelhead smolts sequentially imprinted by barging returned more than 1.5 times as many adults to the hatchery as smolts that received a single imprint and were trucked directly to below Bonneville Dam, or those released at the hatchery.

3. With the river conditions impacting the outmigration of steelhead in the Columbia River system, returns from the barged group provided the first evidence that fish imprinted and transported directly from a hatchery will return as adults in greater numbers than fish that migrated naturally (controls).

4. Survival of barged and trucked fish was significantly higher than survival of fish released at the hatchery. The difference in rate of return would have been even greater had survival of 67% of the control releases not been enhanced by also being transported around the hydroelectric dams on the Snake and Columbia Rivers.

5. Test fish that did not imprint to their hatchery of origin returned to the area near where they were released as juveniles.

Dworshak NFH, 1980

Background

This experiment was concerned with using a relatively short distance migration to imprint juvenile steelhead to be transported and released at another site to return as adults to their hatchery of origin. Juveniles reared at Dworshak NFH and allowed to volitionally migrate from their rearing area were trapped within the hatchery system, transported, and released into the Columbia River below Bonneville Dam. Adult returns to the hatchery from the test group were compared to adult returns of fish released from the hatchery to migrate naturally. The objectives of the experiment were to:

1. Determine if this imprint technique would return adults back to the hatchery as well or better than the normal hatchery release method (natural migration imprinting).

2. Determine the effect of these two imprinting techniques on overall survival of the test groups.

Experimental Design

Age-1 steelhead produced at Dworshak NFH were used for this experiment. The control group was tagged by IDFG personnel as part of their hatchery contribution studies. On 17 April 1980, 59,125 fish were tagged with CWTs and then released by flushing the holding ponds into the mainstem Clearwater River.

The test group was tagged after the fish voluntarily migrated out of the hatchery ponds down an effluent sluiceway and into a trap. Trapping and marking started on 28 April and finished on 30 April. During the 3 days, 40,010 migrants were trapped and tagged and 8,490 of the tagged fish were also branded (Table 17). Marked fish were hauled to Lower Granite Dam 29 April

Table 17.--Steelhead trout smolts released from Dworshak NFH in 1980 and adults recaptured for the migration-homing study.

Item	Normal-migration group	Migration-transport group
Number of fish marked and released		
Coded wire tags	59,125	40,010
Brands	-	8,490
Wire tag code	5/4/55	10/21/19
Brand used	-	LD 4(4)
Date released	17 April 80	29 April to 2 May 80
Mean total length at release (mm)	185	199
Smolts recaptured in the estuary[a]	106	160**
Adults recaptured		
Ocean fisheries	0	1
Deschutes River	0	4
Columbia River sport & net fisheries	61	224**
Others	6	3
Idaho fishery	37	8**
Dworshak NFH	152	71**
Adults recaptured (%)		
In Idaho	0.320	0.197**
Total	0.433	0.777**

a/ Based on recovery of CWT fish (Bjornn and Ringe, 1984).
** = $P < 0.01$, $DF = 1$; indicates significant difference between test and control groups.

through 2 May and transferred to barges or trucks for transport to the lower Columbia River (Bjornn and Ringe 1984).

Results and Discussion

Timing of the smolt migration through the estuary was spread through 5 weeks (24 April to 2 June) for control fish and 1 week (3 to 9 May) for test fish. At the estuary (Jones Beach), NMFS personnel (Dawley et al. 1981) collected significantly fewer marked steelhead from the control group then from the test group ($P < 0.01$, df = 1) (Table 17). Probably more test fish reached the estuary than control fish because of enhanced survival from transportion. It is also likely that fewer test fish were in a non-smolting condition at the time of release since these fish were all voluntary migrants from the hatchery ponds. The control group included all fish in the ponds and could have included unsmolted fish that did not migrate downriver.

Homing of test fish was impaired as indicated by the significantly greater rate of return from the control group to the Clearwater River ($P < 0.01$, df = 1) (Table 17). In contrast, the overall rate of return of the test group (0.78%) was nearly twice the rate of the control group (0.43%). This difference was also significant ($P < 0.01$, df = 1). Many of the test fish recoveries, though, were from the lower Columbia River fisheries in early spring--an indication they were lost and milling in the Bonneville pool.

Conclusions

1. The limited migration method used was not completely successful in returning adult steelhead to the Dworshak NFH homing site; significantly more fish returned from the control release than from the test release.

2. Significantly greater numbers of adults were recovered in the Columbia River system from the test (transported) releases than from the control (non-transported) releases.

3. Many of the test fish (transported) remained in the vicinity of Bonneville Dam where they were taken in large numbers in the early winter fishery in Zone 6.

Tucannon SFH, 1978

Background

This experiment was concerned with imprinting juvenile steelhead to a unique segment of a hatchery water supply before they were transported and released at a downriver site to enable adults to return to the hatchery homing site. Skamania stock (lower river) steelhead juveniles reared at the Tucannon SFH were subjected to sequential imprinting with hatchery spring water and migration route waters prior to release into the Columbia River below Bonneville Dam. The objectives of the experiment were to:

1. Determine the effectiveness of two sequential imprint techniques in returning adults to the homing site.

2. Determine the effect of sequential imprint techniques on the relative survival of this stock compared to normal hatchery release procedures.

Experimental Design

The spring water portion of the hatchery water supply was used as the initial homing cue. Two groups of fish which had been maintained on 100% Tucannon River water were removed from the hatchery ponds and held 1 h in a tank truck while the composition of the water supply to the ponds was altered. The two groups of test fish were then returned to separate ponds, one of which contained 100% spring water and the other a 20:80% mixture of spring:Tucannon River water. Following a 48-h holding period, the fish were transported by truck around the 34 miles of Tucannon River they would have encountered during a natural outmigration, loaded into a barge moored at Lyons Ferry on the Snake River (near Little Goose Dam), transported to below Bonneville Dam (RM 140), and released on 17 May, providing sequential exposure to the Snake and Columbia river waters along the barge route.

A group of the same stock reared at the Tucannon Hatchery was released into the Grande Ronde River between 30 April and 10 May by the WDG. Relative survival and homing of tests lots were compared with this group. Additional detail on experimental design may be found in Volume II, Table D2.0.

Results and Discussion

Returns of adults indicate that the imprinting techniques used were unsuccessful in returning the test groups of steelhead to the Tucannon Hatchery homing site. No fish were recovered at the hatchery or in our sampling of the Tucannon River. Imprint methods used, however, did implant sufficient homing cues to enable as many of the 100% spring water barge group to return to the Snake River as the Grande Ronde River group (Table 18). In contrast, significantly less 20% spring water fish than either the 100% spring water or Grande Ronde group returned to the Snake River ($P < 0.05$, df = 1). There was no observed straying of test fish to the Columbia River above its confluence with the Snake River. By comparison, five of the fish released in the Grande Ronde River were recovered in the Wenatchee River sport fishery (Volume II, Tables D2.1 to D2.3). This would indicate that straying can be caused by other reasons than transportation and lack of imprinting.

Relative survival of the 100% spring water group (based on overall rate of return) was higher than either the 20% spring water group or the control release (Table 19). Both test groups provided 11 times as many fish to user groups (primarily the Zone 6 Indian Fishery) as the control release.

Besides enhanced survival, the main reason for the higher catch rate of test fish was probably the fact that many of the test fish that had not accepted a homing imprint as juveniles returned and milled in the vicinity of their release site and were more susceptible to the fishery.

Table 18.--Returns to four sampling locations of steelhead from control and test releases of smolts from the Tucannon SFH in 1978. Recoveries were from June 1979 to 30 November 1981.

Sampling location and experiment	No. juveniles released	Adult returns No.[a]	%	T/C ratio
Bonneville Dam				
Grande Ronde R., control	55,557	24	0.043	-
100% spring water, test	18,137	54	0.298	6.93:1 *
20% spring water, test	18,549	28	0.151	3.51:1 *
Indian fishery				
Grande Ronde R., control		8	0.014	-
100% spring water, test		27	0.149	10.64:1 *
20% spring water, test		29	0.156	11.14:1 *
McNary Dam				
Grande Ronde R., control		3	0.005	-
100% spring water, test		3	0.017	3.40:1 NS
20% spring water, test		6	0.032	6.40:1 NS
Lower Granite Dam				
Grande Ronde R., control		110	0.198	-
100% spring water, test		38	0.201	1.02:1 NS
20% spring water, test		11	0.059	0.30:1 *

[a] Because of differences in sampling intensity (efficiency) at each trapping site, results are not comparable between sites.

NS = Nonsignificant

* = Significant difference between the test and control group ($P < 0.05$, df = 1).

Table 19.--Minimum estimated recovery of adult steelhead in the Indian fishery and Lower Granite Dam and actual recoveries in the sport fisheries below Lower Granite Dam from control and test releases of smolts imprinted to the Tucannon SFH in 1978.

Location and period of recovery[a/]	Control (55,557)[b/]		100% spring water barge (18,137)[b/]		20% spring water barge (18,547)[b/]	
	No.	%	No.	%	No.	%
Indian fishery[c/] (Zone 6)						
Fall	5		25		32	
Spring	14		52		45	
Subtotal	19	0.034	77	0.425	77	0.415
Sport fisheries[d/]	8		29		15	
Hatcheries[d/]	0		1		15	
Subtotal	8	0.014	30	0.165	30	0.162
Total	27	0.049	107	0.590[f/]	107	0.577[f/]
Lower Granite Dam[e/]						
Fall	442		152		42	
Spring	1		0		0	
Subtotal	443	0.797	152	0.840	42	0.226
Grand total	470	0.846	259	1.428[f/]	149	0.803[f/]

a/ Because of differences in recovery (efficiency) at each location, results are not comparable between sites.

b/ Number of juveniles released.

c/ Estimated recoveries based on sampling of Zone 6 Indian fishery.

d/ Actual recoveries.

e/ Estimated recoveries are based on recoveries of jaw tagged vs coded wire tagged only adult steelhead at hatcheries upriver from Lower Granite Dam from control and test releases of juveniles from the transportation study in 1978.

f/ Totals for barged fish: $\frac{107 + 107}{18,137 + 18,547} = \frac{214}{36,684} = 0.583\%$, $\frac{259 + 149}{36,684} = 1.112\%$

Conclusions

1. Adults from the test groups failed to return to the Tucannon SFH homing site.

2. During the barging process, a portion of the 100% spring water test group received a homing cue which enabled as many adults to home to the Snake River as adults returning to the Snake River from the control release in the Grande Ronde River.

3. Those test fish failing to imprint to the Snake River returned as adults to, and remained in, the Columbia River or its tributaries below the confluence of the Snake River.

4. The combination of impaired homing and enhanced survival of transported fish resulted in barged releases providing over 11 times as many fish to the sport and Indian fisheries as did control releases.

Tucannon SFH, 1979

Experimental Design

This experiment was a repeat (with slight modification) of the 1978 Tucannon SFH experiment. The test fish were held in a tanker for 2 h instead of 1 h, and the control fish were released into the Tucannon River instead of the Grande Ronde River. The release into the Tucannon River reduced the distance the natural migration group had to migrate in the Snake River by 107 miles and exposed them to two less hydroelectric dams than were experienced by fish in 1978. However, releasing these fish below the two uppermost dams also deprived them of the benefits of being included in the ongoing fish transportation program. The release into the Tucannon River modified our objectives to:

1. Determine the relative effectiveness of sequential and natural imprinting in returning adult steelhead to the Tucannon SFH homing site.

2. Determine the relative effect of three imprinting techniques on overall survival.

Results and Discussion

The homing behavior of adult steelhead, transported as smolts in 1979, was similar to that seen in the 1978 experiment (Slatick et al. 1982). While no adults from test or control groups returned to the Tucannon Hatchery homing site, a portion of the test fish received a homing cue which enabled some adults to return to the Snake River. Because only one control fish was recovered at Lower Granite Dam, an accurate assessment of homing of test groups could not be made.

Transporting fish from the hatchery to below Bonneville Dam enhanced survival. More than 16 times as many of the 100% spring water test group returned as adults to the Bonneville Dam sampling site as did controls (Table 20). Also, survival of fish from the 100% spring water test group was significantly higher than survival of fish from the 20% spring water test group ($P < 0.01$, $df = 1$). The 16:1 transport benefit was over twice the 6.93:1 benefit for the 100% spring water test group measured in 1978. The increased benefit was more likely due to poorer survival of control releases than to enhanced survival of test fish in 1979. There were only 2 adult recoveries of control releases at Bonneville Dam and 1 at Lower Granite Dam, compared to 24 and 110, respectively in 1978. In addition, those controls that did survive exhibited considerable straying in 1979 (discussed in detail in Steelhead Overview Section).

Table 20.--Complete returns to four sampling locations of steelhead from control and test releases of smolts from the Tucannon SFH 1979. Recoveries from June 1980 to November 1983.

Sampling and experiment	No. juveniles released	Adult return		
		No.[a/]	%[b/]	T/C ratio
<u>Bonneville Dam</u>				
Tucannon, control	24,787	2	0.008	-
100% spring water, test	20,728	27	0.130 **	16.25:1
20% spring water, test	22,058	7	0.031	3.88:1
<u>Indian fishery</u>				
Tucannon, control		0	0.000	-
100% spring water, test		26	0.125	-
20% spring water, test		18	0.081	-
<u>McNary Dam</u>				
Tucannon, control		6	0.024	-
100% spring water, test		0	0.000	
20% spring water, test		2	0.009	0.38:1
<u>Lower Granite Dam</u>				
Tucannon, control		1	0.004	-
100% spring water, test		6	0.028	7.0:1
20% spring water, test		1	0.004	1.0:1

a/ Because of differences in sampling intensity (efficiency) at each trapping site, results are not comparable between sites.

b/ Numbers of controls recovered were too small to test for statistical significance between control and test groups.

** = Significant difference between two test groups ($P < 0.01$, df = 1).

The 0.30% estimated recovery rate of test fish released in 1979 (Table 21) was less that one-third that of the 1.12% estimated recovery of the 1978 release (Table 19), indicating a much lower survival of test fish. This was partly due to lower survival to the river and partly to adverse river conditions impacting survival and/or homing of returning adults in 1981. Adult recoveries in the lower river fisheries indicated that survival of the 1978 release was about 2.5 times higher than the survival of the 1979 release. However, adult recoveries at Lower Granite Dam showed that returns from 1978 test fish releases were more than eight times that of the 1979 release, indicating an additional 70% loss of fish occurred in 1979 between the lower and upper river. We suspect that adverse river conditions were to blame for much of this loss. A majority of adults from this stock of steelhead migrated over Bonneville Dam from June to mid-July 1981, a period of high spill at mainstem dams. During this time, the presence of gas bubble disease in adult steelhead was observed at the Bonneville Dam sampling site (29 June to 6 July 1981). As they migrated upriver, subsequent exposure could have resulted in mortality to some fish.

In addition, adults which were imprinted and continued their migration to the Snake River were confronted with high water temperatures (ranging from 70° to 78°F) from 17 July to 15 September (discussed further in Steelhead Overview Section).

Conclusions

1. Adults from both test and control groups failed to home to the Tucannon SFH homing site.

2. During the barging process, a portion of the test fish received a homing cue which enabled some adults to home to the Snake River.

Table 21.--Minimum estimated recovery of steelhead in Indian Fishery (Zone 6) and Priest Rapids and Lower Granite Dam sampling sites, and actual recoveries in the sport fishery and hatcheries from control and test releases of smolts imprinted to the Tucannon SFH in 1979.

Location and period of recovery[a/]	Control (24,787)[b/]		100% spring water group barge (20,728)[b/]		20% spring water group barge (22,058)[b/]	
	No.	%	No.	%	No.	%
Indian fishery[c/] (Zone 6)						
Fall	0		28		22	
Winter	0		20		7	
Subtotal	0	0.000	48	0.232	29	0.131
Sport fisheries and hatcheries[d/]						
Columbia River system below Snake River	0		11		10	
Columbia River system above Snake River	5		0		1	
Snake River system	0		1		0	
Subtotal	5	0.020	12	0.058	11	0.050
Total	5	0.020	60	0.289[e/]	40	0.181[e/]
Priest Rapids Dam[f/]	8		0		0	
Lower Granite Dam[g/]	3		23		4	
Subtotal	11	0.044	23	0.111	4	0.018
Grand total	16	0.065	83	0.400[e/]	44	0.199[e/]

a/ Because of differences in recovery (efficiency) at each location, results are not comparable between sites.
b/ Number of juveniles released.
c/ Estimated recoveries based on sampling of Zone 6 Indian fishery.
d/ Actual recoveries.

e/ Total for barged fish: $\frac{60 + 40}{20{,}728 + 22{,}058} = \frac{100}{42{,}786} = 0.234\%$, $\frac{83 + 44}{42{,}786} = 0.297\%$

f/ Estimated recoveries based on WDF sampling at Priest Rapids Dam.
g/ Estimated recoveries are based on recoveries of jaw-tagged vs CWT only adult steelhead at hatcheries upriver from Lower Granite Dam from control and test releases of juveniles from the transportation study.

3. Test fish failing to imprint to the Snake River returned as adults to and remained in the Columbia River or its tributaries below the confluence of the Snake River.

4. The combination of impaired homing and enhanced survival of transported fish resulted in barged releases providing approximately 11 times as many fish to the sport and Indian fisheries as control releases.

Tucannon SFH--Little Goose Dam, 1980

Background

This experiment was conducted to assess the influence of the smoltification process (as measured by Na^{+}-K^{+} ATPase enzyme activity) on the ability of juvenile steelhead to accept a homing imprint. Chelan stock steelhead reared at the Tucannon SFH were used in the experiment. The objectives were to:

1. Determine at what phase of the smoltification process juvenile steelhead are most receptive to imprinting a homing cue.

2. Assess the influence of the Na^{+}-K^{+} ATPase level at time of release on the relative survival of Tucannon SFH steelhead.

Experimental Design

Na^{+}-K^{+} ATPase enzyme activity was monitored at the Tucannon Hatchery from 7 March to 12 June 1980. Figure 13 shows the average profile of Na^{+}-K^{+} ATPase activity in relation to dates of release for the three test groups and the WDG release into the Walla Walla River. The test fish were imprinted with Snake River water in a raceway at Little Goose Dam for 8 h then transported by truck and released into the Columbia River below Bonneville Dam. Additional detail on experimental design may be found in Volume II, Table D4.0.

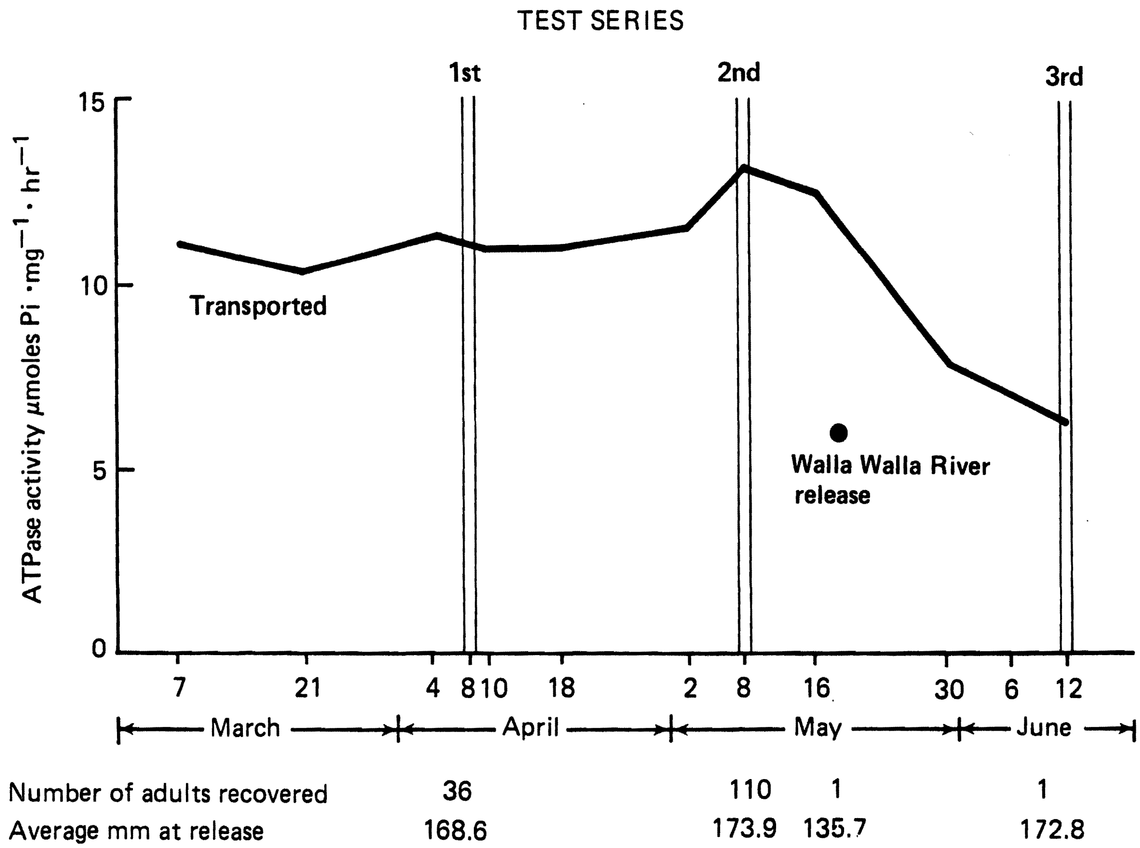

Figure 13.--Composite Na^+-K^+ ATPase profile for steelhead smolts reared at the Tucannon Hatchery, indicating size at release, number of adult recoveries, and time frame for imprinting tests in 1980. Serial releases of marked transported fish were made on 8 April, 8 May, and 12 June 1980.

Results and Discussion

Recoveries of adult steelhead in the Snake River system indicated that juveniles released at or near the peak of the Na^{+}-K^{+} ATPase activity profile (second release) homed back to the Snake River as adults in greater numbers than adults from juveniles released on the rise (first release) or decline (third release) of the profile curve (Table 22). However, the actual return from the 2nd test release was only seven fish (0.035%). This is in contrast to a recovery of 279 fish (1.591%) from a similar experiment in 1976 using the same stock of fish (Slatick et al. 1981b). Obviously, the imprinting technique used in 1980 did not provide the cues needed to return adult fish to the Snake River. Over 80% of the estimated return failed to imprint to the Snake River (57 in Snake River vs 274 overall recovery).

The complete lack of adult recoveries from the third Na^{+}-K^{+} ATPase test group in the fisheries or at the sampling sites in the mid-Columbia and Snake Rivers indicated that these juveniles may had reverted to parr and may have been physiologically unable to imprint a homing cue to the Snake River before they were transported and released below Bonneville Dam. By 12 June, all size groups of fish in the third Na^{+}-K^{+} ATPase release had entered a post-smolt condition (Volume III, Novotny and Zaugg 1984).

Survival of fish from the second Na^{+}-K^{+} ATPase release was significantly greater than from the first release ($P < 0.01$, df = 1). Estimated recoveries indicated that the second release provided 4.1 times more fish to the Indian fishery and 1.75 times more fish to the sport fisheries and hatcheries than the first release (Table 22). Survival of the second release, though, was much less than fish from the 1976 experiment [1.11% vs 4.14% return [(Table 1) (Slatick et al. 1981b)].

Table 22.--Estimated return of adult steelhead in various fisheries and back at the Lower Granite Dam sampling site, from releases of juveniles imprinted to the Walla Walla and Snake Rivers in 1980. Recoveries were from June 1981 to November 1983.

Location and recovery[a]	Walla Walla R. natural migration[b] 17-18 May[c] (17,923)[d] No.	%	1st ATPase release transported[b] 8 April[c] (21,652)[d] No.	%	2nd ATPase release transported[b] 8 May[c] (19,747)[d] No.	%	3rd ATPase release transported[b] 12 June[c] (18,964)[d] No.	%
Indian fishery[e]								
Fall	0		5		25		0	
Winter	0		37		134		0	
Subtotal	0	0.000	42	0.194	159	0.805	0	0.000
Sport fisheries and hatcheries[f]								
Columbia River system below Snake River	0		7		8		0	
Columbia River system above Snake River	0		0		0		1	
Snake River system	0		0		3		0	
Subtotal	0	0.000	7	0.032	11	0.056	1	0.005
Total	0	0.000	49	0.226	170	0.861	1	0.005
Lower Granite Dam[g]	16	0.089	4	0.018	50	0.253	0	0.000
Grand Total	16	0.089	53	0.245	220	1.114	1	0.005

a/ Because of differences in recovery (efficiency) at each location, results are not comparable between sites.
b/ Type of release.
c/ Release date.
d/ Number of juveniles released.
e/ Estimated recoveries based on sampling the Zone 6 fishery.
f/ Actual recoveries.
g/ Estimated recoveries are based on recoveries of jaw-tagged vs coded wire-tagged only adult steelhead at hatcheries upriver from Lower Granite Dam from control and test releases of juveniles from the Transportation Program.

Conclusions

1. Within the Na^{+}-K^{+} ATPase levels tested, it appears that releasing fish near the peak of their Na^{+}-K^{+} ATPase level will promote higher adult returns.

2. Migratory survival of steelhead juveniles that have not smolted or have reverted to parr (as indicated by Na^{+}-K^{+} ATPase enzyme activity) is very poor.

3. Compared to an earlier study in 1976, the optimum release strategy for imprinting a homing cue to the Snake River in juveniles was not achieved in the 1980 experiment.

Wells SFH - Winthrop NFH, 1978-79

Background

This experiment was concerned with imprinting juvenile steelhead reared at an upper mid-Columbia River hatchery to home as adults to a hatchery located further upstream in a tributary river system. Juveniles reared at the Wells Hatchery were subjected to single, sequential, and natural migration imprinting at the Winthrop NFH located on the Methow River. Results from these treatment groups were compared to fish released at the hatchery production release site in the lower Methow River. The objectives of the experiment were to:

1. Determine the relative effectiveness of four imprint techniques in returning adults to the Methow River and the Winthrop NFH homing site.

2. Define the effect of the four imprinting techniques on overall survival.

Experimental Design

In 1978, the experimental design used five groups of steelhead (20,000 fish per group)--a control group held 2 d at Winthrop NFH prior to release at the hatchery, the production release made directly into the Methow River 0.25 mile upstream from the mouth, and three transport groups. Transport groups were held 2 to 8 d at the hatchery in an attempt to imprint them to the hatchery water prior to transporting them downriver by barge or truck. One group was trucked in raceway water to a release site below Bonneville Dam; the second was trucked in raceway water to a barge at Richland, Washington, and barged downstream to below Bonneville Dam; the third group was trucked in raceway water and released at Ringold, Washington.

The test was repeated in 1979, and the experimental design was identical to the 1978 test except there was no Ringold release in 1979 and there were only 10,000 fish in the group trucked to Bonneville Dam. Additional details on experimental design may be found in Volume II, Table D5.0.

Results and Discussion

Recoveries of steelhead indicate that the imprint methods used were unsuccessful in returning the test groups of steelhead to the Winthrop NFH homing site. Only one fish from each test group returned to the hatchery in 1978 and none in 1979. Although imprint methods used in these experiments were not successful in returning fish to the homing site, they did implant a limited homing cue which enabled significantly more fish from all transported groups than fish from control releases from both the 1978 and 1979 releases to home to areas above McNary Dam ($P < 0.01$, df = 1) (Table 23). Homing above this point was more impaired, as indicated by a decline in T/C ratios in both years for the transport groups at Priest Rapids Dam. The difference in T/C

Table 23.--Returns to five sampling locations of adult steelhead from control and test releases of smolts from the Wells Hatchery which were imprinted to the Winthrop NFH homing site and the Methow River in 1978 and 1979. Recoveries were from June 1979 to 30 November 1982.

Sampling location and experiment[a/]	Adult returns from 1978 release			Adult returns from 1979 release		
	No.	%	T/C ratio	No.[b/]	%	T/C ratio
Bonneville Dam						
Winthrop NFH	5	0.025		8	0.044	
L. Methow River	12	0.060	2.4:1 NS	4	0.020	0.45:1
Truck to Bonneville	36	0.188	7.5:1 *	31	0.318	7.23:1 **
Barge to Bonneville	26	0.130	5.2:1 *	35	0.204	4.64:1 **
Truck to Ringold	29	0.164	6.6:1 *	c/		
Indian fishery						
Winthrop NFH	6	0.030		2	0.011	
L. Methow River	14	0.070	2.3:1 NS	1	0.005	0.45:1
Truck to Bonneville	49	0.256	8.5:1 *	44	0.452	41.09:1 **
Barge to Bonneville	31	0.155	5.2:1 *	90	0.525	47.73:1 **
Truck to Ringold	16	0.091	3.0:1 *	c/		
McNary Dam						
Winthrop NFH	21	0.103		5	0.027	
L. Methow River	32	0.161	1.6:1 NS	0	0.000	
Truck to Bonneville	90	0.470	4.6:1 *	9	0.092	3.41:1 *
Barge to Bonneville	57	0.286	2.8:1 *	33	0.192	7.11:1 **
Truck to Ringold	66	0.374	3.6:1 *	c/		
Priest Rapids Dam						
Winthrop NFH	38	0.187		33	0.180	
L. Methow River	55	0.276	1.5:1 NS	11	0.055	0.31:1
Truck to Bonneville	42	0.220	1.2:1 NS	18	0.185	1.03:1 NS
Barge to Bonneville	23	0.115	0.6:1 *	15	0.087	0.48:1 *
Truck to Ringold	81	0.459	2.5:1 *	c/		
Winthrop Homing Site						
Winthrop NFH	19	0.093		4	0.022	
L. Methow River	1	0.005	0.05:1 NS	0	0.000	
Truck to Bonneville	1	0.005	0.05:1 NS	0	0.000	
Barge to Bonneville	1	0.005	0.05:1 NS	0	0.000	
Truck to Ringold	1	0.006	0.06:1 NS	c/		

a/ Because of differences in sampling intensity (efficiency) at each trapping site, results are not comparable between sites.
b/ WDG production release. (Sample sizes were too small for use in the statistical analysis.)
c/ No truck to Ringold in 1979.

NS = Nonsignificant.
* = Significant difference between test and control groups ($P < 0.05$, df = 1).
** = Significant difference between test and control groups ($P < 0.01$, df = 1).

ratios at Priest Rapids Dam reflects the varying degrees of homing cues that resulted from each treatment. For returns from the 1978 release, the test group trucked to Ringold, Washington (2.5:1) was highest, followed by the group trucked to Bonneville Dam (1.2:1), and the group barged from Richland, Washington (0.6:1) (Table 23.). In 1979, there was no Ringold release. The test group trucked to Bonneville Dam was highest (1.03:1) and returned at about the same rate as controls. The group barged from Richland, Washington, was lowest (0.48:1) and as in 1978 returned significantly less fish than the control group ($P < 0.05$, df = 1) (Table 23).

Recoveries of tagged fish in the sport fishery (Tables 24 and 25) and at Lower Granite Dam (Volume II, Tables D5.1 to D5.9) on the Snake River provided additional data on homing of the various test groups to areas above McNary Dam. The intensive sport fish sampling by WDG was terminated prior to the return of 2-ocean age fish from 1979, so for comparative purposes, their estimated contributions to the 1979 sport fisheries contain only 1-ocean age steelhead. Both 1- and 2-ocean age recoveries were obtained from the 1978 release. The major sport fisheries between McNary Dam and Priest Rapids Dam are at Ringold, Washington, and a stretch of several miles immediately below Priest Rapids Dam. The major sport fishing areas above Priest Rapids Dam are in the Wenatchee, Washington, area and at the mouths of the Entiat and Methow rivers (Fig. 12).

Data obtained from the 1978 release in the sport fishery generally verified the data obtained from sampling at Priest Rapids Dam (Table 24). Of the total sport catch above Priest Rapids Dam, 50% (94 fish) were Ringold releases, 41% (78 fish) were trucked fish released at Bonneville Dam, and only 9% (18 fish) were the fish barged from Richland to Bonneville Dam. More than twice as many of the Ringold group, compared to the other two transport

Table 24.--Estimated recovery in the sport and Zone 6 Indian fisheries of adult steelhead returning from control and test releases of juveniles from the 1978 Wells-Winthrop experiment. Recoveries were from 1979 to March 1981.

Control or test groups	Juveniles released: No.[b/]	Juveniles released: Date	Adult recoveries – Sport fishery[a/]: Lower Columbia River (no.)	Ringold area (no.)	Entiat & Wenatchee area (no.)	Methow area (no.)	Total (no.)	Indian[c/] fishery (no.)	Total: No.	Total: %	Total: T/C ratio
Winthrop NFH (control)	20,330	06 May	0	0	0	54	54	20	74	0.364	
Lower Methow River (prod. rel. site)	19,901	27 Apr	0	17	14	136	167	47	214	1.075	2.95:1
Truck to Bonneville (test)	19,131	05 May	0	158	60	18	236	155	391	2.044	5.62:1
Barge to Bonneville (test)	19,979	04 May	14	103	13	5	135	100	235	1.176	3.23:1
Truck to Ringold (test)	17,637	05 May	14	52	53	41	160	53	213	1.208	3.32:1
Total	96,978		28	330	140	254	752	375	1,127	1.162	

a/ From Hisata et al. 1979-1980, and Schuck et al. 1980-1981.

b/ Adjusted for initial tag loss.

c/ Estimated recoveries based on sampling efficiency of the Zone 6 Indian fishery.

groups, were able to home to the Methow River as evidenced by the Methow River sport catch (41 fish from Ringold, Washington, vs 18 from those trucked to Bonneville Dam and only 5 from those barged to Bonneville Dam).

Because of only 1 year of sampling, returns from the 1979 release were far less, but the data obtained were comparable (Table 25). Overall, the data from sampling the sport fishery in both years generally indicated that: (1) barged fish that received an imprint homed to the proximity of the barge loading area rather than to areas upstream from Priest Rapids Dam--much larger catches were observed in the Ringold sport fishery than in the Wenatchee-Entiat sport fishery (Table 24); (2) more trucked than barged fish were imprinted to areas upstream from Priest Rapids Dam, and Bonneville Dam trucked fish provided more fish to the Ringold sport fishery than barged fish in 1978 (Tables 24 and 25); and (3) Bonneville Dam trucked fish were the only group with significant straying into the Snake River (Volume II, Tables D5.1 to D5.9).

A portion of the juveniles in both the trucked and barged groups in 1979 were apparently not ready or able to accept a homing cue at the time they were transported. These adults returned to the area near their point of release near Bonneville Dam and remained there over winter instead of continuing their migration upriver. As a result, they were more vulnerable to the Indian gill net fishery for a longer period of time. This was demonstrated by the recovery from the 1979 release of 100 test fish and no control fish in the winter fishery compared to 34 test and 3 control fish in the fall fishery (Volume II, Tables D5.6 to D5.9).

Transporting fish around dams in 1978 and 1979 significantly enhanced survival, especially the trucked groups ($P < 0.01$, df = 1). Between 7.2 and 7.5 times as many trucked fish and 4.6 to 5.2 times as many barged fish

Table 25.--Estimated recoveries at four sampling locations of 1-ocean age adult steelhead from control and test releases of juveniles from the 1979 Wells-Winthrop experiment. Recoveries were from June 1980 to March 1981.

Control or test groups	Juveniles released[b/]		Adult recoveries: Sport fishery[a/]							
	No.	Date	Ringold area (no.)	Entiat & Wenatchee area (no.)	Methow area (no.)	Total (no.)	Indian[c/] fishery (no.)	Total: No.	Total: %	Total: T/C ratio
Winthrop NFH (control)	18,298	09 May	0	0	34	34	0	34	0.186	
Lower Methow R. (prod. rel. site)	20,052	14 May	0	0	20	20	0	20	0.100	0.54:1
Truck to Bonneville (test)	9,741	05 May	18	10	6	34	43	77	0.790	4.25:1
Barge to Bonneville (test)	17,152	25 Apr	36	19	0	55	154	209	1.219	6.55:1
Total	65,243		54	29	60	143	197	340	0.521	

a/ From Schuck et al. 1980-1981.

b/ Adjusted for initial tag loss.

c/ Estimated recoveries based on sampling efficiency of the Zone 6 Indian fishery.

returned to Bonneville Dam as did fish from control releases (Table 23). The result was a much greater contribution of transported fish to various sport and Indian fisheries. In 1978, the overall rate of return to the user groups was 1.5% for transported fish vs 0.72% for those released in the Methow River (Table 24). In 1979, the return of transported fish was 1.0%, but the return of controls was only 0.14% (Table 25). The lower rate of return for controls probably indicated lower survival of control fish in 1979. The overall decline in numbers recovered from the 1979 release (340 vs 1,127 from the 1978 release) is probably a combination of less sampling in the sport fishery (1-ocean only on 1979 releases) and the lower survival of the control release in 1979.

Although not statistically significant, the recovery of adults from the Winthrop NFH control release in 1978 was consistently lower than the Lower Methow River production release at all four inriver sampling sites (Table 23). The lower survival probably resulted from mortality during the juvenile outmigration in 1978. Sampling of the 1978 smolt outmigration at McNary and John Day Dams in 1978 showed that the lower Methow River production release group had a three times greater recovery than the Winthrop NFH control group at both of these juvenile sampling sites (Sims [6/]).

The reverse occurred in the 1979 release; survival of the lower Methow River production release was less than the survival of the Winthrop NFH control release at the four inriver sampling sites (Table 23). Again, the lower survival probably resulted from mortality during the juvenile outmigration in 1979. Sampling of the 1979 smolt outmigration at Wanapum,

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[6/] Carl Sims, NMFS, NWAFC, 2725 Montlake Blvd. E., Seattle, WA 98112, pers. commun. 1986.

Priest Rapids, McNary, and John Day Dams in 1979 showed that the Winthrop NFH control group had five times greater survival than the lower Methow River production release group based on the average rate of recovery from these four juvenile sampling sites (Raymond and Sims 1980).

Conclusions

1. Imprint methods used in 1978 and 1979 were unsuccessful in returning barged and trucked fish to the homing site but did implant a limited homing cue which enabled many of these fish to return to areas above McNary Dam.

2. Transporting of the test fish around dams by truck or barge significantly enhanced adult survival back to the Columbia River.

3. The limited homing imprint and enhanced survival resulted in greater numbers of transported than control fish being caught by the various user groups.

4. Natural migration imprinting enables this stock of steelhead to return as adults to homing sites (i.e., Methow River and Winthrop NFH) located upstream from their hatchery rearing site.

Chelan SFH - Leavenworth NFH, 1978-79

Background

This experiment was concerned with determining the length of time required to imprint juvenile steelhead reared at an upper mid-Columbia River hatchery to home as adults to a hatchery located on a tributary river downstream from the rearing site. Juveniles reared at the Chelan SFH were subjected to sequential and natural migration imprinting at the Leavenworth NFH. The Leavenworth NFH is located on the Icicle River, a tributary to the Wenatchee River, which flows into the Columbia River 51 miles below the Chelan SFH rearing site. The objectives of the experiment were to:

1. Define the effects of three time periods on imprinting juvenile steelhead.

2. Determine the relative effectiveness of two imprinting techniques in returning adults to the Wenatchee River and the Leavenworth NFH homing site.

3. Define the effect of the two imprinting techniques on overall survival.

Experimental Design

For this experiment, three (test and control) groups were trucked to Leavenworth Hatchery and held in raceways for 10 d, 2 d, or 4 h. The test fish were sequentially imprinted by trucking them in hatchery water (Icicle River) to a barge at Richland, Washington, and then barging them downriver and releasing them in the Columbia River below Bonneville Dam. The control fish were released from the hatchery into the Icicle River (natural migration imprint). The test was repeated in 1979, and the experimental design (by Larry Brown, WDG) was identical to the prior test except the paired 4-h treatment of 1978 was changed to 6 h in 1979. Additional detail on experimental design may be found in Volume II, Table D6.0.

Results and Discussion

The length of time juvenile fish in the control lots were held for imprinting did not make any difference in the rate of return of adults to the hatchery. There was no significant difference between the 4-h, 2-d, and 10-d imprint times in 1978 ($G = 0.74$, $df = 2$, $P = 0.7$) or the 6-h, 2-d, and 10-d imprint times in 1979 ($G = 2.37$, $df = 2$, $P = 0.3$). Similarly, and in most instances, length of imprint time did not appear to affect rate of return of test fish to Bonneville Dam, the Zone 6 Indian fishery, McNary Dam, or Priest Rapids Dam (2 out of 12 samples in 1978 and 1 out of 12 samples in 1979 were significantly different, $P < 0.01$, $df = 2$); therefore, the test groups were combined to illustrate the trends in migratory homing behavior.

The imprint methods used were unsuccessful in returning transported fish to the upper river above Priest Rapids Dam and back to the homing site. The T/C ratios for returning adults to the five sampling locations in 1978 illustrate the increasing loss of homing as these fish moved upstream. The T/C ratio at Bonneville Dam and the Indian fishery was about 3:1. By the time the fish reached McNary Dam, the T/C ratio had dropped to 1.4:1. By the time these adults reached Priest Rapids Dam, the T/C ratio was 0.15:1, indicating nearly complete impairment of homing (Table 26). In 1979, fewer fish were imprinted to areas above McNary Dam as indicated by the lower 1.02:1 T/C ratio at McNary Dam and the higher 12.94:1 T/C ratio in the Indian fishery (non-imprinted fish generally return to the Bonneville area, mill for several months, and are more vulnerable to the Zone 6 fishery).

Table 26.--Returns to five sampling locations of adult steelhead from paired test and control releases of smolts imprinted to Leavenworth NFH homing site for varying lengths of time prior to release in 1978 and 1979. Recoveries were from June 1979 to 30 November 1981.

Experiment and Sampling location[a]	Control or test	1978 No. of juveniles released	1978 No. of adults	1978 % return	1978 Test to control ratio	1979 No. of juveniles released	1979 No. of adults	1979 % return	1979 Test to control ratio
Bonneville Dam,	Control	69,863	31	0.044	2.86:1**	67,317	44	0.065	1.72:1**
	Test	68,086	86	0.126		70,500	79	0.112	
Indian fishery (Zone 6)	Control		47	0.067	3.85:1**		33	0.049	12.94:1**
	Test		176	0.258			447	0.634	
McNary Dam	Control		100	0.143	1.41:1**		54	0.080	1.02:1NS
	Test		137	0.201			58	0.082	
Priest Rapids Dam	Control		166	0.238	0.15:1**		208	0.309	0.06:1**
	Test		24	0.035			12	0.017	
Leavenworth NFH Homing site	Control		64	0.092	0.01:1**		69	0.103	0.01:1**
	Test		1	0.001			1	0.001	

a/ Because of differences in sampling intensity (efficiency) at each trapping site, results are not comparable between sites.

NS = Nonsignificant.

** = Significant difference between the test and control group ($P < 0.01$, df = 1).

The transported fish that received a homing cue that enabled them to migrate upstream as far as McNary Dam, probably received a homing cue to the mid-Columbia River between Richland, Washington, and Priest Rapids Dam when they were loaded and held (approximately 12 to 24 h) in the barge. In both 1978 and 1979: (1) very few adults migrated above Priests Rapids Dam; (2) between 85 and 90% of the test adults recovered in the sport fishery were taken in the Ringold area (free flowing portion of the mid-Columbia River between McNary and Priest Rapids Dams, Table 27); and (3) straying into the Snake River was minimal [recoveries at Lower Granite Dam consisted of only 25 fish from the barged groups and 1 from the control group (Volume II, Tables D6.1 to D6.12)].

A portion of the juveniles in the test groups, especially in 1979, were apparently not ready or able to accept a homing cue at the time they were transported. These adults returned to the area near their point of release near Bonneville Dam and remained there over the winter instead of continuing their migration upriver. This was demonstrated by the recovery of 31 test fish compared to 1 control fish from the 1978 release and 306 test fish compared to 5 control fish from the 1979 release in the winter (February-March) Indian gill-net harvest (Volume II, Tables D6.1 to D6.12). In the combined fall/winter Indian fishery in both years, the recovery of test fish was significantly greater than control fish ($P < 0.01$, df = 1) (Table 27).

Transporting the fish around dams significantly enhanced survival of adults returning to the Lower Columbia River as indicated by the 2.86:1 T/C ratio at Bonneville Dam in 1978 and 1.72:1 ratio in 1979 ($P < 0.01$, df = 1). Overall recovery of steelhead to the various user groups was 1.35% in 1978 and 1.65% in 1979. Rate of return of test fish was higher than control fish in

Table 27.--Estimated recovery of adult steelhead from the 1978-1979 Chelan-Leavenworth experiment in sport and Indian fisheries. Recoveries were from June 1979 to March 1982.

Control or test groups	Sport fishery[a/] Lower[b/] Columbia River (no.)	Ringold area (no.)	Entiat & Wenatchee area (no.)	Methow area (no.)	Total	Indian[c/] fishery (no.)	Total recovery No.	Total recovery %	Test to control ratio
1978									
Control	2	34	622	29	687	157	844	1.208	
Test	7	325	48	5	385	580	965	1.417	1.08:1
Total	9	359	670	34	1,072	737	1,809	1.311	
1979									
Control	0	0	960	14	974	63	1,037	1.540	
Test	0	306	19	0	325	933	1,258	1.784	1.16:1
Total	0	306	979	14	1,303	996	2,295	1.665	

a/ From Hista et al. 1979-1980, and Schuck et al. 1980-1981.

b/ From observed recoveries--no estimates available.

c/ Estimated recoveries based upon sample efficiency of the Zone 6 Indian fishery.

both years, but the difference was not significant. Control releases contributed greater numbers of fish to the sport fishery above Priest Rapids Dam, but test releases contributed greater numbers of fish to the Indian fishery and the Ringold area sport fishery (Table 27).

Conclusions

1. There was no significant difference between the rate of adult returns to the homing site in relation to the length of time (4-6 h, 2 d, and 10 d) the juveniles were held for imprinting.

2. Imprint methods used in 1978-79 in conjunction with truck to barge transportion of juvenile steelhead were unsuccessful in returning adults to the homing site.

3. A portion of the fish in the transported treatment groups imprinted to the mid-Columbia River when they were loaded on to the barge as juveniles.

4. Transporting the juvenile steelhead around dams significantly enhanced the survival of adults returning to the lower Columbia River.

Overview of Imprint Treatments of Steelhead

Recoveries of adult steelhead returning to the Columbia River system indicated that the combination of imprint method, mode of transportation, release site, timing, and physiological condition of the juveniles influenced their future adult migratory behavior pattern. The results also suggest that the genotype of the fish can influence the rate of return of transported fish to a homing site.

The effects of imprint strategies used in our studies to modify adult migratory behavior are compared by adjusting the data to illustrate comparable numbers of adult steelhead recovered from the various sampling locations (Tables 28, 29, 30). A common release of 100,000 fish per test condition was used to reflect the numbers of adults which would be recovered.

Natural Migration Imprint

The natural migration imprint technique was not uniformly successful in returning adult steelhead to a hatchery homing site. Indigenous Dworshak stocks returned the greatest number of adults back to the hatchery homing site (257 to 278 fish). Non-indigenous upriver stocks also returned to their hatchery homing sites but at a significantly lower rate ($P < 0.01$, df = 1)--60 fish at Winthrop NFH and 85 to 117 fish per group (average 97 fish) at Leavenworth NFH (Table 28). None of the lower river stocks imprinted to the Tucannon SFH returned back to the hatchery homing site as adults.

Migratory behavior of adult returns in the Columbia River system was quite uniform. Most of the fish were observed in the upper river areas (above McNary Dam, RM 292) on a direct migration route to their homing sites. Very few fish strayed to other systems leading away from their migration route. Adults returning from the 1979 Tucannon SFH release were an exception to this general migratory pattern. The majority of these fish observed above McNary

Table 28.--Adult recoveries of steelhead trout which as juveniles migrated naturally from seven release locations, (adjusted for a release of 100,000 fish per test).

	Release locations and year of experiment							
	Indigenous		Nonindigenous					
	upper river stock[a]		Lower river stock[b]		Upper river stock			
Recovery locations	Dworshak Hatchery 1978	Dworshak Hatchery 1980	Grande Ronde R. 1978	Tucannon Hatchery 1979	Walla Walla R.[c] 1980	Lower Methow R.[d] 1978-1979	Winthrop Hatchery[d] 1978-1979	Leavenworth Hatchery[c] 1978-1979
Columbia River to McNary Dam								
Bonneville Dam	43	-	45	8	0	40	34	55
Zone 6 fishery	75	103	18	0	0	38	21	58
Sport fishery	9	0	7	0	0	3	0	4
Sub-total	127	103	70	8	0	81	55	117
Upper Mid-Columbia and Snake Rivers								
McNary Dam	70	-	5	24	0	80	67	112
Lower Granite Dam	658	-	198	4	6	0	0	1
Priest Rapids Dam	0	-	0	4	0	165	184	273
Sport fishery areas								
Snake and Clearwater	81	64	4	0	0	0	0	1
Ringold	0	0	0	0	0	10	5	5
Entiat and Wenatchee	0	0	2	20	0	5	3	370
Methow	0	0	0	0	0	268	142	20
Homing sites	278	257	e/	0	0	f/	60	97
Other hatcheries[g]	0	0	0	0	0	53	52	23
Subtotal	1,087	321	209	52	6	581	513	902
Unknown	1	0	2	0	0	0	0	1
Total	1,215	424	281	60	6	662	568	1,020

a/ Dworshak stock.
b/ Skamania stock.
c/ Chelan stock.
d/ Wells stock.
e/ Homing site evaluation is Snake River data above--Lower Granite Dam (198) and Snake and Clearwater (4).
f/ Homing site evaluation is Methow River sport fishery data above (268).
g/ Fish in upper mid-Columbia River are collected for brood stock at Priest Rapids and Wells Dams.

Table 29.--Adult recoveries of steelhead trout which as juveniles received a single exposure to a unique water source before being transported by truck to two release locations on the Columbia River. (adjusted for a release of 100,000 fish per test).

	Homing sites, year of experiment, and release locations			
	Indigenous Upper river stock[a/]	Non-indigenous Upper river stock		
	Dworshak Hatchery	Tucannon Hatchery Snake River[b/]	Winthrop Hatchery[c/]	
	1978	1980	1978	1978-1979
Recovery locations	Bonneville	Bonneville	Ringold	Bonneville
Columbia River to McNary Dams				
Bonneville Dam	356	16	164	232
Zone 6 fishery	213	186	102	332
Sport fishery	5	21	6	24
Other	0	3	6	10
Subtotal	574	226	278	598
Upper Mid-Columbia and Snake Rivers				
McNary Dam	88	0	374	343
Lower Granite Dam	425	8	40	298
Priest Rapids Dam	23	2	459	208
Sport fishery areas				
Snake and Clearwater	39	3	11	0
Ringold	5	0	136	90
Entiat and Wenatchee	0	0	102	59
Methow	5	0	164	52
Homing sites	300	d/	6	3
Other hatcheries	0	2	79	69
Subtotal	885	15	1,371	1,122
Unknown	5	0	0	0
Total	1,464	241	1,649	1,720

a/ Dworshak stock.

b/ Chelan stock.

c/ Wells stock.

d/ Homing site evaluation is from Snake River data above--Lower Granite Dam (8) and Snake and Clearwater (3).

Table 30.--Adult recoveries of steelhead trout which as juveniles received a sequential imprint by being transported by truck and barge to a release site below Bonenville Dam (adjusted for a release of 100,000 fish per test).

	Homing sites, and year of experiment				
	Indigenous		Non-indigenous		
	Upper river stock[a/]		Lower river stock	Upper river stock	
Recovery locations	Dworshak Hatchery 1978	Dworshak Hatchery 1980	Tucannon Hatchery[b/] 1978-1979	Winthrop Hatchery[c/] 1978-1979	Leavenworth[d/] 1978-1979
Columbia River to McNary Dam					
Bonneville Dam	171	0	147	164	119
Zone 6 fishery	254	560	140	334	458
Sport fishery	8	10	75	24	35
Other	8	0	25	13	5
Subtotal	441	570	387	535	617
Upper Mid-Columbia and Snake Rivers					
McNary Dam	171	0	14	245	141
Lower Granite Dam	961	47	72	16	18
Priest Rapids Dam	0	0	0	102	26
Sport fishery areas					
Snake and Clearwater	104	22	5	0	0
Ringold	4	0	3	81	90
Entiat and Wenatchee	0	0		8	11
Methow	0	0		8	4
Homing sites	429	177		3	1
Other hatcheries	8	5	1	13	4
Subtotal	1,677	251	95	476	295
Unknown	0	0	0	5	3
Total	2,118	821	482	1,016	915

a/ Dworshak stock.
b/ Skamania stock.
c/ Wells stock.
d/ Chelan stock.

Dam did not return to the Snake River system but were recovered as strays in the upper mid-Columbia River (Table 28).

A possible explanation for the anomaly in behavior of the 1979 Tucannon SFH release may be high water temperatures. A majority of adults from this lower river stock of steelhead migrated over Bonneville Dam from June to mid-July 1981. Adults which were imprinted and continued their migration to the Snake River were confronted with high water temperatures (ranging from 70° to 78°F) from 17 July to 15 September. Historically, such temperatures result in a thermal block to migrating steelhead. In most years, such temperatures occur for a 2- to 3-week period in late August and early September. Fish generally hold in the cooler Columbia River below the mouth of the Snake River until water temperatures in the Snake River begin to drop. For late migrating fish, a short delay is not a problem. However, a delay of over 2 months as occurred in 1981 may have been sufficient to induce some of these fish to continue up the cooler upper mid-Columbia River.

In the Wells-Winthrop experiment a stock of non-indigenous steelhead was transported from the Wells SFH (WDG) (in Wells SFH water) to a production release site in the lower Methow River and also to the Winthrop NFH (50 miles further upstream) where the juveniles were held 2 to 4 d for imprinting before being released. There was no significant difference in the overall recovery of fish from these two groups (662 and 568, respectively) when the data from 1978 and 1979 are pooled (Table 28). Also, there was no significant difference in the numbers of adults which migrated over Priest Rapids Dam from these two release groups, however, signficantly greater numbers of fish from the lower Methow River release than from the Winthrop River release were taken in the targeted sport fishery in the Methow River area ($P < 0.01$, df = 1) (268 and 142 fish, respectively). This difference may have been due to the fact that the Winthrop River release group was exposed to water in the upper Methow River, and it is possible that a number of adults may have migrated rapidly upstream and over-wintered above the traditional sport fishery area at the mouth of the river.

In the Snake River system, adult recoveries from the 1978 release of indigenous upriver steelhead at Dworshak NFH were significantly greater than recoveries from releases of lower river stock fish in the Grande Ronde River in 1978 ($P < 0.01$, $df = 1$). Juveniles from both of these release groups had about an equal distance to travel and were exposed to the same hazards inherent in an outmigration down the Snake River, but over three times as many adults returned to Lower Granite Dam on the Snake River from the Dworshak NFH release than from the Grande Ronde River release (Table 28). This information suggests that even though this lower river stock of steelhead will return upriver to at least as far as Lower Granite Dam on the Snake River, better returns of adults to upper river areas would be achieved by using indigenous upriver stocks of steelhead.

Single Exposure Imprint

The single imprint method of trucking steelhead directly from Dworshak Hatchery for release below Bonneville Dam was partly successful on this indigenous upriver stock in that it returned about the same number of adults to the Dworshak NFH homing site as the natural migration release (300 and 278 fish, respectively, Tables 29 and 28). However, homing was impaired on a portion of these test smolts as indicated by the significantly greater number of adults (2.8:1) taken in the Zone 6 Indian fishery compared to the number of adults taken from the natural migration release ($P < 0.01$, $df = 1$). There was some straying of adults above McNary Dam as indicated by the recoveries of 33 stray fish in the upper mid-Columbia River compared to no straying from the natural imprint group.

The single imprint method used with non-indigenous upriver stock was unsuccessful in returning adults to the Winthrop NFH homing site, but did implant a limited homing cue in a portion of these fish, which in combination with higher survival enabled significantly greater numbers of them to return as adults to the upper Columbia River than fish from the natural migration ($P < 0.01$, df = 1). Between 343 and 374 fish from the single imprint groups were observed up the river as far as McNary Dam in comparison to only 67 to 80 fish from the natural migration groups (Tables 29 and 28). Fish trucked to Ringold returned at a significantly ($P < 0.01$, df = 1) higher rate over Priest Rapids Dam than fish from the natural migration groups and also contributed more fish to the Methow River sport fishery than the Winthrop NFH natural migration group. However, fish which were trucked to Bonneville Dam returned over Priest Rapids Dam at a rate comparable to fish from the natural migration groups and contributed far fewer fish to the Methow River sport fishery--indicating homing was considerably less than the Ringold release.

Many of the juveniles trucked below Bonneville Dam were apparently not ready or able to accept a homing cue at the time they were transported. These fish returned as adults to the area near their point of release near Bonneville Dam and remained there over winter instead of continuing their migration upriver. As a result, they were vulnerable to both the fall and winter Indian gill net fishery. In contrast, most of the control releases were imprinted, migrating rapidly upstream and were much less vulnerable to the Zone 6 fishery. This was demonstrated by the recovery of 213 transported fish vs 75 natural migration fish from the 1978 Dworshak experiment and 332 trucked vs 59 natural migration fish from the 1978-79 Wells-Winthrop experiment. Recoveries at Lower Granite and McNary Dams indicated that few if any of the indigenous and non-indigenous upriver stock steelhead which over wintered in the Bonneville Dam area continued their upriver migration to the Snake or upper mid-Columbia Rivers in the spring.

Sequential Exposure Imprint

Two sequential type imprint methods were used with indigenous upriver stock (Dworshak) steelhead. In 1978, Dworshak NFH stock steelhead were transported by truck to a barge on the Clearwater River in Lewiston, Idaho; held overnight; and then barged through the normal migration route to below Bonneville Dam. This method was successful in that it returned significantly more adults to the Dworshak NFH homing site than returned from the natural migration release (429 and 278 fish, respectively, Tables 28 and 30) ($P < 0.01$, df = 1). Even so, homing was impaired for a portion of these barged fish as evidenced by a T/C ratio of 3.5:1 in the lower river compared to 1.54:1 for fish returning to the Dworshak NFH homing site. The higher survival of transported fish as evidenced by 3.5 times as many fish returning to the lower river as control releases is even more impressive when one considers that approximately 67% of the control fish surviving to Lower Granite Dam were provided additional survival enhancement by being transported around hydroelectric dams on the Snake and Columbia Rivers.

Another sequential imprint strategy used with Dworshak stock utilized marked fish that had voluntarily migrated out of ponds, were hauled by truck to Lower Granite Dam on the Snake River, and then were transferred to barges or trucks for transport to the lower Columbia River (Bjornn and Ringe 1984) (see Dworshak NFH, 1980 in this report). This method was not as successful in returning adults to the Dworshak NFH homing site. Significantly more fish from the naturally migrating group than from the sequentially imprinted group returned to the Dworshak NFH homing site ($P < 0.01$, df = 1). Impaired homing on a large portion of these transported fish was evidenced by adult recovery ratios of over 5:1 in the lower river compared to 0.69:1 at the homing site (Tables 28 and 30).

Our sequential imprint techniques were unsuccessful in returning non-indigenous stock adults to specific upriver homing sites. However, they did implant a limited homing cue in a portion of these fish which, in combination with higher survival, enabled as many or greater numbers of them to return as adults to areas above McNary Dam as those from the natural migration groups. Upriver stock adults from the Chelan-Leavenworth tests returned over McNary Dam (RM 292) at a rate similar to fish from the natural migration groups (control) whereas fish from the Wells-Winthrop tests returned at a significantly greater rate ($P < 0.05$, df = 1). As previously discussed, the most apparent loss of homing for these sequentially imprinted (barged) fish occurred in the 104-mile section of river between McNary and Priest Rapids Dams. This was verified by the low T/C ratios at Priest Rapids Dam, the low number of test fish recovered in the sport fishery above the dam, and the large number of test fish taken in the sport fishery between Ringold and Priest Rapids Dam. These data suggest that a portion of the fish in these test lots imprinted to this section of the Columbia River when they were loaded and held in the barge as juveniles.

Straying of adults above McNary Dam to rivers outside the drainage area of the homing site was minimal. This was indicated by an average of only 4 fish from the Dworshak and Tucannon lots recovered in the upper mid-Columbia River area and an average of 17 fish from the Winthrop and Leavenworth lots recovered in the Snake River area.

Homing was impaired on portions of the various test groups barged to below Bonneville Dam. Their behavior was similar to the single imprint trucked groups. These adults also returned to the area near their point of release near Bonneville Dam and remained there over the winter where many were captured in the Zone 6 fishery. Few, if any, of these fish resumed their migration to the upper river areas.

Application of Findings

1. Indigenous upriver stocks of fish will provide a higher rate of return than non-indigenous stocks back to upriver hatcheries.

2. Non-indigenous steelhead given a single exposure imprint and trucked from the Methow River to below Priest Rapids Dam for release at Ringold (with enhanced survival and partial homing) should return significantly more steelhead above Priest Rapids Dam than fish released directly into the Methow River. The net result is a greater contribution of those fish to a sport fishery all the way from Ringold to the Methow River.

3. Non-indigenous groups of steelhead given either a single (trucked directly from the hatchery to below Bonneville Dam) or sequential (trucked to Richland, Washington, then barged to below Bonneville Dam) exposure imprint (with enhanced survival and limited homing) will provide significantly more fish to the sport fishery between Ringold and Priest Rapids Dam than those released directly into the Methow River. In addition, because of the impaired

homing, use of this technique will provide a significant contribution to the Zone 6 fishery.

4. Sequential exposure imprint techniques used to barge indigenous stocks of steelhead from Dworshak Hatchery can return over 1.5 times as many fish back to the hatchery and over twice as many fish to the fisheries as those released directly from the hatchery.

CONCLUSIONS AND RECOMMENDATIONS

1. Homing cues can be implanted in juvenile salmonids.

2. Imprinting will range from very successful to partial or limited to unsuccessful.

3. Sequential imprinting using truck and/or barge transportation will likely be more effective than the single imprint method.

4. There are species differences in responding to homing cues.

5. Indigenous stocks are more likely to return to a homing site than are non-indigenous stocks.

6. Mode of transportation can impact the degree of success for imprinting fish to return to a specific homing site.

7. Because imprinted fish can be induced to return to different areas, the fish can be manipulated to contribute to specific fisheries that are presently underdeveloped with existing hatchery releases.

8. Even when homing is impaired, strategies can be developed that will increase net benefits to the fisheries as a whole.

9. Selective imprint strategies plus enhanced survival due to transportation around high risk areas can provide a tool that Columbia River fisheries managers can use to provide more salmon and steelhead to various user groups.

10. The research reported here should be used as a baseline for further research to fine tune the requirements for imprinting specific species and stocks of salmonids to develop the most effective techniques for reaching desired mangement goals.

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