

(Inserted corrected tables 4, 5, 6+7)

IMPRINTING STEELHEAD FOR HOMING

EMIL SLATICK, LYLE G. GILBREATH AND JERREL R. HARMON

National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Northwest and Alaska Fisheries Center, Division of Coastal Zone and Estuarine Studies, Seattle, Washington

Abstract

In 1976 and 1978, experiments were conducted on three stocks of steelhead, *Salmo gairdneri*, to determine if single or sequential controlled stimuli (cues) could be used to imprint steelhead, and perhaps other salmonids, to unique water sources and thus assure homing of fish transported around several hydroelectric dams on the Snake and Columbia Rivers. The steelhead were cued and transported at Dworshak National Fish Hatchery and Tucannon Hatcheries Washington Department of Game (WDG) (Snake River), and at Wells Hatchery (WDG) (mid-Columbia River).

As a single imprint cue, fish were exposed to various mechanical stimuli in combination with a unique water supply prior to transportation. Sequential imprinting involved exposing fish to two or more water sources in a step-by-step process during transportation to establish a signpost system for the route home.

Test-to-control ratios of returning adults indicated high survivals for all test groups (transported) over control groups (nontransported) at our lower Columbia River sampling locations. In all groups except steelhead from Dworshak Hatchery, test fish exhibited a limited or partial homing imprint which enabled these fish to return to the geographic drainage in which the homing sites were located. Preliminary returns from adult steelhead sequentially cued to Dworshak Hatchery indicate the test fish are homing more specifically to the hatchery homing site, 504 miles from the mouth of the Columbia River.

Introduction

The phenomenon of specific homing of Pacific salmon, *Oncorhynchus* spp., and steelhead, *Salmo gairdneri*, to their natal streams has been long known and is one of the most interesting events in the biological world. The specific mechanisms that lead to the homing event, however, remain largely unknown. The literature suggests that homing begins as a learning process early in the fish's life history. This process, referred to as "imprinting," may be defined as a rapid and irreversible learning experience that provides the navigational clues by which salmonid find their way home.

Imprinting may occur throughout the freshwater life; however, Hasler and Wisby (1951) and more recently students of Hasler have postulated that imprinting is most indelible at or near the time of smolt transformation--that time when juveniles begin their seaward migration.

Seaward-bound smolts in the Columbia River system must pass as many as eight major hydroelectric dams while traveling from their natal streams to the ocean. To increase their chance for survival, many of these fish are collected at the uppermost dam, placed in tank trucks or barges, transported around intermediate dams, and released below the lowermost dam in the system. Studies by Ebel et al. (1973), Ebel (1980), and Slatick et al. (1975) have shown that omitting a large portion of the normal migration route by transporting the fish does not diminish the homing ability of these fish--fish that have smolted and migrated several hundred kilometers on their own volition.

A natural extension of the transportation program would be to take the fish directly from the hatcheries, before their initial volitional migration, and transport them directly to the lower river. Partly to answer questions about how this procedure would affect homing, and partly to learn specifically about imprinting, we initiated a homing study involving a number of existing hatchery stocks in the upper Columbia River system. In our studies, we attempted to manipulate the homing process by special handling techniques prior to transporting the fish downriver. The tests were carried out during the time of the fish's normal migration to the ocean.

The primary objectives of the research were to determine: (1) if single or multiple imprints (sequential imprinting) to unique water supplies are necessary to assure homing for various stocks of steelhead; (2) a method to activate the homing imprint; and (3) the relationship between the physiological condition of the fish, e.g., gill $\text{Na}^+\text{-K}^+$ ATPase enzyme activity and various health factors and their ability to imprint. This paper will address the first two objectives.

Methods

Marking and Transport

Juvenile steelhead used in these experiments were selected by the various hatchery managers to represent standard fish produced at their stations. Fish were marked prior to release by adipose fin excision and injection with a magnetic coded wire tag. Fish were also thermal branded so their return as adults could be monitored at key sampling sites on the river without having to sacrifice the fish. Test fish were transported in a truck with a 18,900-liter (5,000-gal) capacity (Smith and Ebel, 1973); a few selected test groups of fish were transported in a barge utilizing a regulated flow-through water system (McCabe et al., 1979).

Imprinting Techniques

A variety of techniques for imprinting the fish were tested; e.g., addition of water from a new source, holding the fish at the new homing site and then releasing them, releasing fish at a new homing site, pumping fish into a new raceway with a different water supply and holding them before release, etc. The application of these techniques is discussed in detail in the following sections.

Evaluation of Returning Adults

The effect of imprinting and transportation on the homing and survival of adult fish was evaluated by comparing returns of transported (test) and nontransported (control) fish to (1) homing sites; (2) other hatcheries; (3) sport, commercial, and Indian fisheries; (4) Bonneville, McNary, and Priest Rapids Dams on the Columbia River; and (5) Little Goose (1977) and Lower Granite (1978 to present) Dams on the Snake River (Fig. 1).

Returns of adults from the 1978 experiments were essentially complete and statistically analyzed. Discrete Multivariate Analysis was used to statistically compare test and control treatments (Bishop et al, 1975). In this procedure the treatments are structured by the G-statistic (Sokal and Rohlf, 1981). Significance was established at $P < 0.05$, $df = 1$.

The extensive sampling program was only possible with the cooperation of the U.S. Fish and Wildlife Service (USFWS), Oregon Department of Fish and Wildlife (ODFW), Washington Departments of Game (WDG) and Fisheries (WDF), and the Idaho Department of Fish and Game (IDFG).

Adult Returns from Imprint Experiments

Tucannon Experiment, 1976

Background

In the spring of 1976, an exploratory homing experiment was initiated using steelhead from the Tucannon Hatchery (WDG) located on the Tucannon River (Fig. 2). The object of the experiment was to determine if smolting steelhead which were denied all natural migration prior to transportation could be imprinted with a homing cue which would allow adult steelhead to return to the Tucannon Hatchery. The imprint method used was the addition of a new water source (spring water) to the regular rearing water (Tucannon River).

Steelhead used in this experiment were reared at the Tucannon Hatchery from eggs obtained from brood stock trapped at Priest Rapids Dam (Chelan Hatchery (WDG) stock) on the mid-Columbia River. The water mix used for the homing imprint during the last 8 days before release consisted of 1/3 spring water and 2/3 river water.

On 19 and 20 May, the juvenile steelhead were hauled by truck in Tucannon River water to Little Goose Dam (on the Snake River) for marking. At Little Goose Dam, the steelhead were unloaded into a raceway containing Snake River water and held for 4 hours before being processed through the marking facility. The fish were marked by excising the adipose fin, branding (RD J), and inserting a coded wire tag (WH-PK-XY-RD). After the fish were marked, they were loaded directly into a fish tanker. The steelhead smolts (17,532) were then transported (in Snake River water) and subsequently released into the Columbia River downstream from Bonneville Dam.

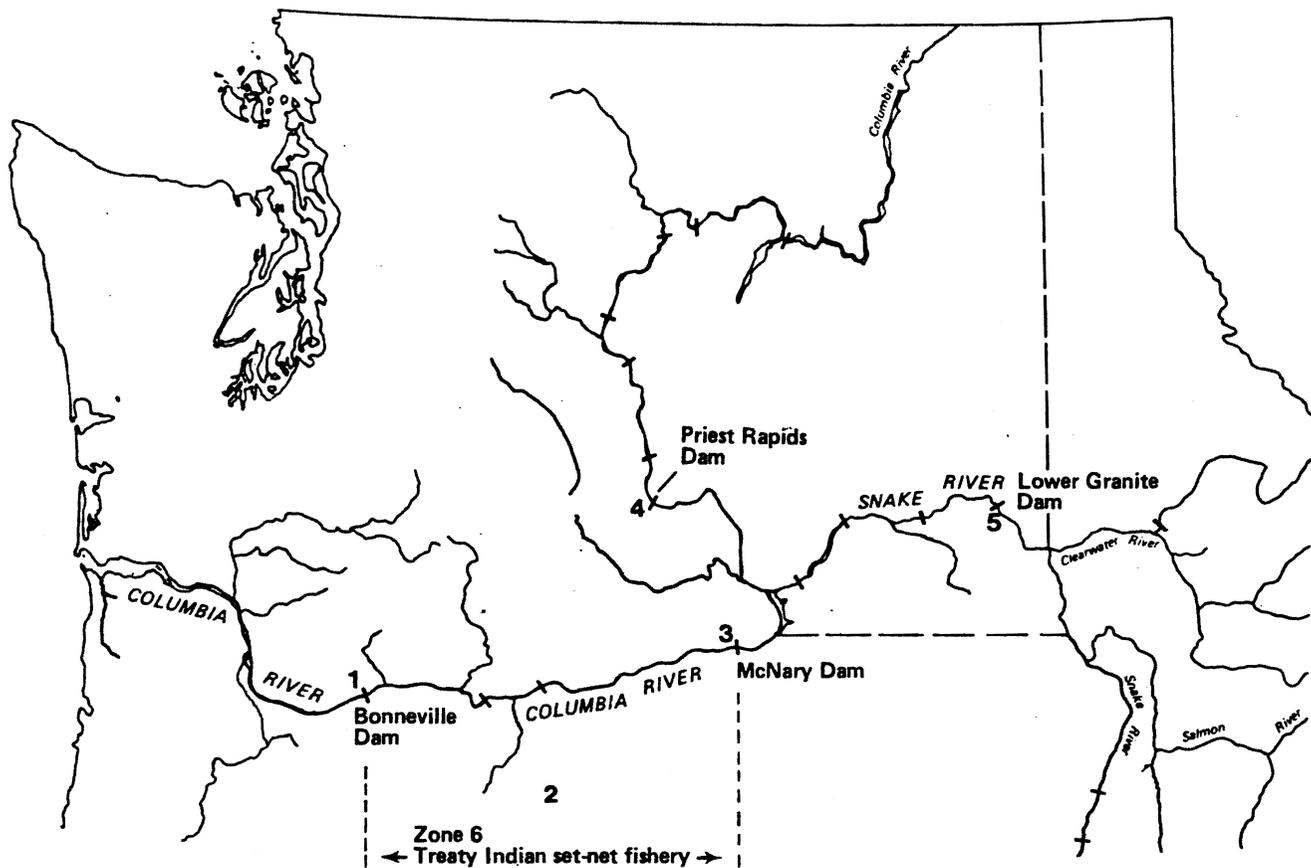


Fig. 1. Map of Columbia River system showing locations of the five major sampling sites-regions in the Columbia River that were used to evaluate return of adult fish.

1976 STEELHEAD HOMING EXPERIMENT, Tucannon River Hatchery

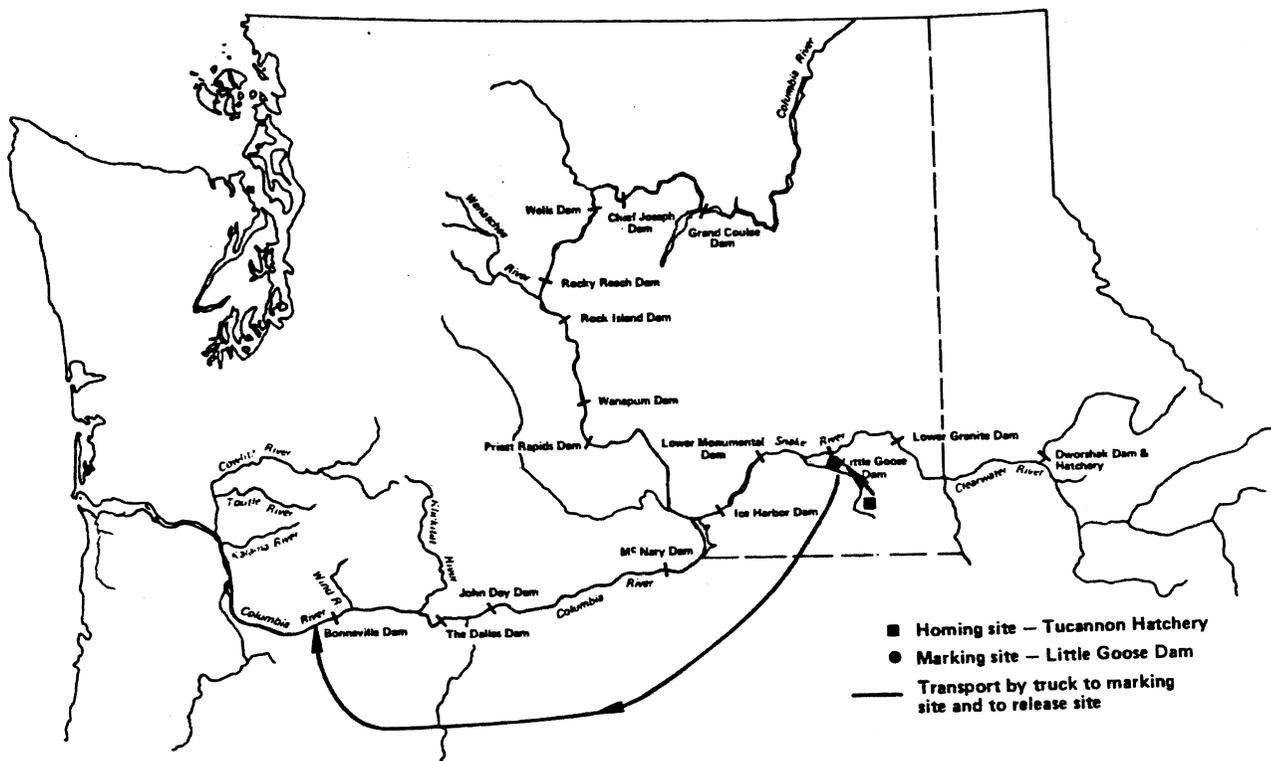


Fig. 2. Study area germane to the 1976 homing experiment with steelhead from the Tucannon Hatchery (WDG).

Results and Discussion

Adult returns (1- and 2-ocean age fish) from the 1976 Tucannon Hatchery releases are completed. A total of 320 adults were recovered at sampling locations on the Columbia and Snake Rivers (Table 1).

Since none of the adult steelhead returned to the Tucannon Hatchery, it is apparent that the method used in 1976 was unsuccessful in inducing steelhead smolts to imprint a homing cue to the hatchery water supply.

However, a total of 279 (1.591%) adult steelhead were recovered in traps at Little Goose and Lower Granite Dams, indicating that a large proportion of smolts received a homing imprint to Snake River water when they were held and marked at Little Goose Dam in 1976. This rate of return is very good for a long-run steelhead stock and compares favorably with a return of 1.547% of the steelhead from the Little Goose Dam general transport release in 1976 (Park, 1980).

These returns provided the first evidence that fish which had been imprinted to a water source, and denied any natural migration by being directly transported from a holding area, will return upriver for long distances (up to 431 miles) to the same water source in substantial numbers as adults.

Although the sampling in the Columbia River was limited, it indicated that this group of adult steelhead contributed up to 97 fish to the Indian gill-net fishery. Based on a rather small sample size, it appears that up to 154 fish strayed up the upper mid-Columbia River above Wells Dam (RM 516).

Well-Winthrop Experiment, 1978

Experimental Design and Background

The object of this experiment was to imprint steelhead from the Wells Hatchery (WDG) with a homing cue to the Winthrop National Fish Hatchery (NFH) (a hatchery other than the hatchery of origin) on the Methow River (Fig. 3) and to determine if a single or sequential homing imprint would cause steelhead to return to the Winthrop NFH site.

The experimental design used five groups of steelhead of approximately 20,000 fish per group. A control group was held 2 days at Winthrop NFH prior to release at the hatchery. The production release was made directly into the Methow River 0.25 mile upstream from the mouth, and three transport groups were held 2 to 8 days 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 then trucked in raceway water and released at Ringold, Washington; 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 to a release site below Bonneville Dam (Table 2). Evaluation was based on comparisons of adult returns for transport releases and the production release with those released as controls at the hatchery.

Results and Discussion

Returns of 1- and 2-ocean age steelhead indicate the methods used in 1978 were unsuccessful in returning the test groups of steelhead to the Winthrop NFH homing site. As 1-ocean age adults, only one fish from each test group returned to the hatchery compared to 18 (0.09%) of the Winthrop NFH control fish (Table 3).

The return rate of these Winthrop NFH fish (0.09%) is in sharp contrast to the return of the Dworshak NFH controls (0.273%) (discussed in the following section). This may be due to the fact that the Winthrop control fish were being introduced to a new water source, whereas the Dworshak control fish were indigenous to the Dworshak NFH water source (North Fork Clearwater River). Although the amount of homing data we presently have is very limited, this type of information may suggest that successful homing to a specific hatchery homing site may be genetically linked (to an unknown degree), and that increased homing returns may be achieved by breeding fish which do return to the hatchery homing site. Data from the Winthrop NFH control group recovered from the sport fishery indicate that even though the returns to the hatchery site were low, these control adults homed very successfully to the Methow River. No adults were recovered outside of their direct migration route up the Columbia River.

Although the results from sampling 1-, 2-, and 3-ocean age adult steelhead at dams indicated the imprint methods used in these experiments were not successful in returning fish to the homing site, they did confirm that a portion of the juveniles in the test groups (transported) implanted a limited (partial) homing cue which enabled them to return as adults to the upper Columbia River. Adults from the transported groups returned up the river as far as McNary Dam (RM 292) at significantly higher rates ($p < 0.05$, $df = 1$) than the control groups. Fish trucked to Ringold NFH returned at a significantly higher rate ($p < 0.05$, $df = 1$) over Priest Rapids Dam (RM 397) than the control fish. By contrast, barged fish to Bonneville returned at a significantly lower ($p < 0.05$, $df = 1$) rate than the control fish over Priest Rapids Dam (Table 4).

Recoveries of tagged fish in the sport fishery provided additional data on the degree of homing of the various test groups to areas above McNary Dam. The major sport fisheries between McNary and Priest Rapids Dams are at Ringold, Washington, and in a stretch of the river 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. 3).

Table 1. Recoveries of adult steelhead from the 1976 Tucannon Homing Experiment. Smolts from the Tucannon Hatchery were marked at Little Goose Dam and transported and released below Bonneville Dam. Recovery period 20 July 1977 to 1 June 1979.

Location	Number juveniles released ^{a/}	No. of adults recaptured			Adult return in % of juveniles released	
		1-ocean age	2-ocean age	Total	Observed ^{b/}	Estimated ^{c/}
<u>Snake River</u>						
Tucannon Hatchery (homing site)	17,532	0	0	0	-	-
Little Goose Dam (marking site)		173	106	279	1.591	2.705
<u>Lower Columbia River</u>						
Commercial fishery		1	0	1	0.006	-
<u>Mid-Columbia River</u>						
Bonneville Dam		-	3	3	0.017	-
Indian fishery		8	16	24	0.137	0.552
<u>Upper Mid-Columbia River</u>						
Wells Dam		5	6	11	0.063	0.878
Other		2	0	2	0.011	-
	Total	189	131	320		

a/ Adjusted for initial tag loss.

b/ Numbers of recaptured steelhead have not been adjusted to include trapping efficiency at the Little Goose facility or for the proportion of the sample from other fisheries.

c/ Based on comparison of known recovery of fish with magnetized wire tags at Lower Granite Dam and the subsequent recovery of these and other marked fish at Dworshak and Pahsimeroi hatcheries upstream from Lower Granite Dam. Returning fish identified at the dam were marked with jaw tags and released to continue their upstream migration. Numbers of these externally-tagged fish arriving at Dworshak and Pahsimeroi hatcheries were compared with the recovery of other wire tagged fish not previously detected and identified at Lower Granite Dam. Estimates for the Indian fishery are based on data from the Oregon Department of Fish and Wildlife. Estimates for Wells Dam are based on data from the Washington Department of Game.

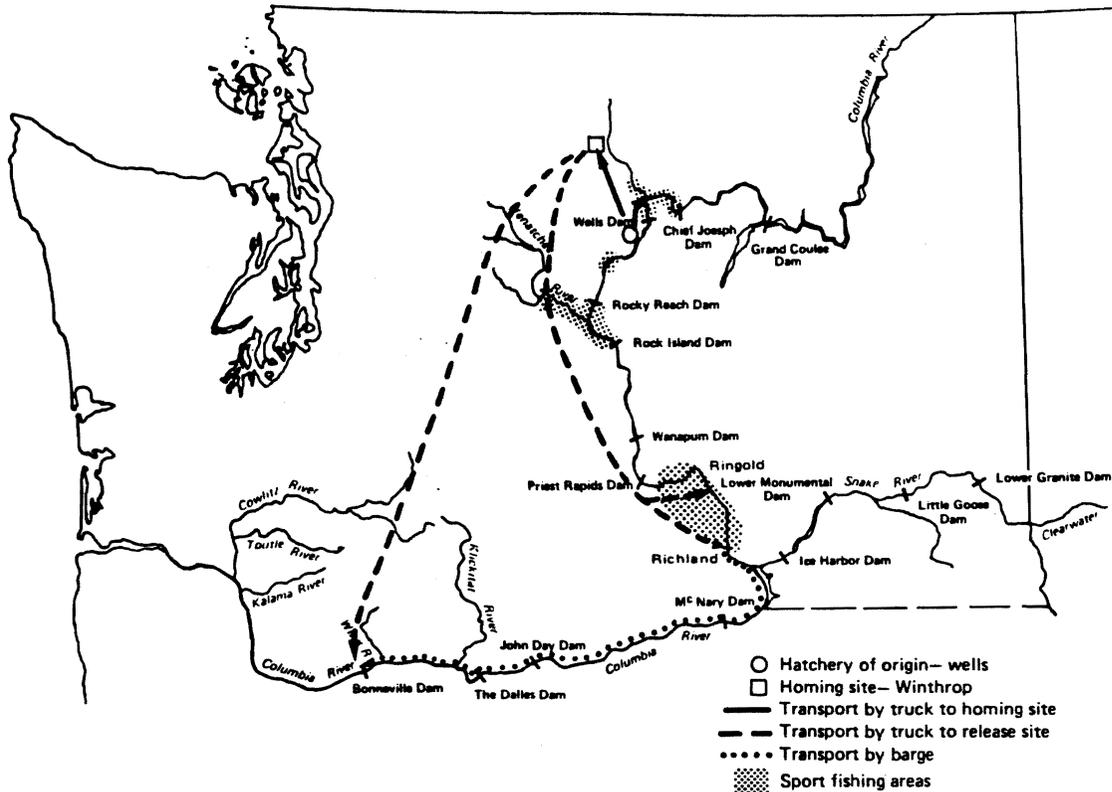


Fig. 3. Study area germane to the 1978 homing experiment with steelhead from Wells-Winthrop hatcheries.

Table 2. Steelhead trout marked in 1978 at Wells Hatchery and imprinted to Winthrop National Fish Hatchery. Test number, mark used, number released, type of imprint, and treatment for various groups are indicated.

Test/control	C.W.T. code	Brand	Number released ^{1/}	Homing imprint	Treatment
Control #1	WH-OR-LG-YW	RA ⌈	19,901	natural migration	Wells Hatchery control-released at production release site in the Methow River 0.25 mile upstream from the mouth.
Control #2	WH-OR-OR-XY	LA)(20,330	natural migration	Winthrop Hatchery control-held 48 h at the hatchery, then released into Methow River at the hatchery site.
Test #1	WH-OR-GN-OR	RA ⌋	19,131	single	Held at least 48 h at Winthrop Hatchery and then trucked in raceway water directly to below Bonneville Dam.
Test #2	WH-OR-YW-LG	RA L	19,979	sequential	Held at least 48 h at Winthrop Hatchery; trucked in raceway water to barge at Richland, WA; and then barged downstream to below Bonneville Dam.
Test #3	WH-OR-OR-RD	RA 7	17,637	sequential	Held at least 48 h at Winthrop Hatchery, trucked in raceway water to Ringold area, and then released into Columbia River to migrate naturally.
		Total	96,978		

^{1/} Adjusted for initial tag loss.

Table 3. Estimated recovery of adult steelhead returning from control and test releases of juveniles from the 1978 Wells-Winthrop hatcheries experiment in eight sampling locations. Recoveries were from June 1979 to March 1981.

Control or test groups	Number ^{b/} juveniles released (N)	Lower ^{c/} river hatcheries (N)	Indian fishery (N)	Sport fishery ^{a/}				Hatchery ^{d/} broodstock (N)	Winthrop homing site (N)	Total recovery		Test to control ratio
				Lower Columbia River (N)	Ringold area (N)	Entiat & Wenatchee area (N)	Methow area (N)			(N)	(%)	
Winthrop NFH (control)	20,330	0	27	0	0	0	54	7	18	106	0.521	
Lower Methow River Production release site	19,901	2	47	0	17	14	136	18	1	235	1.181	2.27:1
Truck to Bonneville (test)	19,131	2	145	0	158	60	18	14	1	398	2.080	3.99:1
Barge to Bonneville (test)	19,979	1	100	14	94	13	5	3	1	231	1.156	2.22:1
Truck to Ringold (test)	17,637	1	53	14	52	53	41	15	1	230	1.304	2.50:1
TOTAL	96,978	6	372	28	321	140	254	57	22	1200	1.237	

^{a/} From Hisata et al., 1979-80, and Schuck et al., 1980-81.

^{b/} Adjusted for initial tag loss.

^{c/} From Bonneville and Cascade hatcheries (ODFW).

^{d/} From steelhead trapped at Priest Rapids and Wells Dams, for Chelan and Wells hatcheries broodstock.

Table 4. Complete returns to four sampling locations of 1-, 2-, and 3-ocean age steelhead from control and test releases of smolts from the Wells Hatchery which were imprinted to the Winthrop National Fish Hatchery homing site and the Methow River in 1978. Recoveries were from June 1979 to 30 November 1981.

Experiment and sampling location	Homing site	Control or test	Number juveniles released	Number of adults recaptured ^{a/}				Adult return % of juveniles	Test to control ratio
				1-ocean age	2-ocean age	3-ocean age	Total 1, 2, & 3's		
<u>Bonneville Dam</u>									
Winthrop NFH	Winthrop	Control	20,330	4	1	0	5	0.025	
L. Methow River	Methow R.	Test ^{b/}	19,901	8	4	1	13	0.065	2.6:1 NS
Truck to Bonneville	Winthrop	Test	19,131	26	5	5	36	0.188	7.5:1 *
Barge to Bonneville	Winthrop	Test	19,979	14	7	4	25	0.125	5.0:1 *
Truck to Ringold	Winthrop	Test	17,637	23	5	2	30	0.170	6.8:1 *
<u>Indian Fishery</u>									
Winthrop NFH	Winthrop	Control		7	1	0	8	0.039	
L. Methow River	Methow R.	Test ^{b/}		12	2	0	14	0.070	1.8:1 NS
Truck to Bonneville	Winthrop	Test		29	14	2	45	0.235	6.0:1 *
Barge to Bonneville	Winthrop	Test		19	11	1	31	0.155	4.0:1 *
Truck to Ringold	Winthrop	Test		13	3	1	17	0.096	2.5:1 *
<u>McNary Dam</u>									
Winthrop NFH	Winthrop	Control		18	2	0	20	0.098	
L. Methow River	Methow R.	Test ^{b/}		28	6	0	34	0.171	1.7:1 *
Truck to Bonneville	Winthrop	Test		85	4	0	89	0.465	4.7:1 *
Barge to Bonneville	Winthrop	Test		52	5	0	57	0.286	2.9:1 *
Truck to Ringold	Winthrop	Test		62	4	0	66	0.374	3.8:1 *
<u>Priest Rapids Dam</u>									
Winthrop NFH	Winthrop	Control		33	5	0	38	0.187	
L. Methow River	Methow R.	Test ^{b/}		44	11	0	55	0.276	1.5:1 NS
Truck to Bonneville	Winthrop	Test		32	13	0	45	0.235	1.3:1 NS
Barge to Bonneville	Winthrop	Test		14	8	0	22	0.110	0.6:1 *
Truck to Ringold	Winthrop	Test		63	17	0	80	0.454	2.4:1 *
		Total	96,978	586	128	16	730		

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

b/ Washington Department of Game production release site.

NS Nonsignificant.

* $P < 0.05$ $df = 1$: indicates significant difference between the test and control group.

Table 4. Complete returns to four sampling locations of 1-, 2-, and 3-ocean age steelhead from control and test releases of smolts from the Wells Hatchery which were imprinted to the Winthrop National Fish Hatchery homing site and the Methow River in 1978. Recoveries were from June 1979 to 30 November 1981.

Sampling location and experiment	Control or test	Number juveniles released	No. of adults ^{a/} recaptured			Adult ^{d/} return % of juveniles	Test to control ratio
			1-ocean age	2-ocean age	Total 1 & 2's		
<u>Bonneville Dam^{b/}</u>							
Dworshak NFH	Control	30,074	1	13	14	0.047	
Trucked	Test	20,661	1	14	15	0.321	6.82:1 NS
Barged	Test	24,006	1	8	9	0.158	3.86:1 NS
<u>Indian Fishery^{c/}</u>							
Dworshak NFH	Control	100,600 ^{e/}	1	39	40	0.040	
Trucked	Test	20,661	1	44	45	0.218	5.45 **
Barged	Test	24,006	2	51	53	0.221	5.53 **
<u>McNary Dam^{b/}</u>							
Dworshak NFH	Control	30,074	3	18	21	0.070	
Trucked	Test	20,661	0	4	4	0.088	1.26:1 *
Barged	Test	24,006	1	8	9	0.158	2.26:1 *
<u>Lower Granite Dam^{b/}</u>							
Dworshak NFH	Control	30,074	14	170	184	0.612	
Trucked	Test	20,661	2	15	17	0.352	0.58:1 **
Barged	Test	24,006	1	48	49	0.930	1.52:1 **
<u>Clearwater River sport fishery</u>							
Dworshak NFH	Control	100,600	1	75	76	0.076	
Trucked	Test	20,661	0	8	8	0.039	0.51:1 NS
Barged	Test	24,006	0	20	20	0.146	1.92:1 **
<u>Dworshak homing site</u>							
Dworshak NFH	Control	100,600	26	249	275	0.273	
Trucked	Test	20,661	1	53	54	0.261	0.96:1 NS
Barged	Test	24,006	6	101	107	0.446	1.63:1 **
Total branded		74,741	62	938	1000		
Wire-tagged only		70,526					

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

^{b/} Data from branded fish only.

^{c/} Data from coded wire tags only.

^{d/} Adjusted for the difference in detectability between binary and color-coded wire tags as indicated by returns to Dworshak Hatchery.

^{e/} A total of 100,600 were wire tagged for the hatchery control release, of this number 30,074 were branded for inriver adult evaluation.

NS Nonsignificant

* P<0.05, df = 1; indicates significant difference between the test and control group.

** P<0.01, df = 1; indicates significant difference between the test and control group.

Estimated recoveries of 1- and 2-ocean age fish in the sport fishery are summarized in Table 3. These numbers were adjusted for sampling effort (Hisata et al, 1979, 1980; Schuck et al., 1980, 1981). The data obtained generally verified the data obtained from sampling at Priest Rapids Dam: Ringold, Washington, releases had the highest proportion (58% or 94 fish) that homed to areas above Priest Rapids Dam; trucked fish released at Bonneville Dam were next highest at 33% (78 fish); whereas only 14% (18 fish) of the barged fish found their way to areas above Priest Rapids Dam. Of test fish imprinted to areas upstream from Priest Rapids Dam, more than twice as many of the Ringold group, compared to the other two test groups, were able to home to the Methow River as evidenced by the sport catch (41 fish from Ringold, Washington, vs 18 from those trucked to below Bonneville Dam and only five from those barged to below Bonneville Dam).

Impairment of homing was also evident by the numbers of fish straying into the Snake River system where they were monitored at Lower Granite Dam (Snake River Mile 107). Recoveries of marked fish show that some straying occurred from all test groups as well as the Lower Methow River production test group; the only major number of strays (estimate 0.605%) were from the trucked-to-below-Bonneville Dam test group (Table 5).

Differences between treatment groups, with respect to relative survival and homing, are illustrated by the test-to-control ratios at each of the four sampling locations (Fig. 4). Although the test-to-control ratios are not constant, they do indicate up to 7.5 times higher survival for the test groups (transported) than for the control group (nontransported) at the three lower-river sampling locations (Bonneville Dam, Indian fishery, and McNary Dam).

Loss of homing above McNary Dam lowered the test-to-control ratios at Priest Rapids Dam and resulted in fewer transported fish contributing to the sport fishery in the Methow River. However, the limited homing imprints along with higher survival of the transport groups resulted in the transported fish contributing substantially to the Wenatchee and Ringold sport fishery and to the Indian set-net fishery (Table 3). Overall, the total contribution from the test releases to various user groups was 859 fish or over 1.5% of those released. Mainly because of lower survival, the contribution to user groups of control fish was about half that of the transport groups (341 fish or about 0.8%).

Less than half as many Winthrop NFH controls were caught in the sport fishery as those released at the traditional Methow River release site. The difference was probably caused by two factors: the Winthrop NFH release group was exposed to water in the upper Methow River and it is possible that a number of the adults may have migrated to and over-wintered in this upper section of the river, which is above the traditional sport fishing area; the second reason was poorer survival, since adult recoveries of Winthrop NFH releases were lower than recoveries of Methow River releases at each of the sampling sites. Sampling of the 1978 smolt outmigration in 1978 at McNary and John Day Dams showed that the Lower Methow River control group had a three times greater survival than the Winthrop NFH control group at both of these juvenile sampling sites.

The Ringold and Bonneville trucked groups contributed substantially to the Wenatchee and Ringold sport fisheries; whereas, the barged fish contributed mainly to the Ringold fishery. Increased survival of the trucked-to-Bonneville Dam group resulted in these fish contributing over one and one-half times as many adult steelhead to the Ringold sport fishery as those released by the WDG at Ringold (0.826% and 0.514%, respectively, Schuck et al., 1980, 1981). The ability to increase the sport harvest in selected areas by providing a limited homing imprint and enhancing survival by transporting smolts around dams could be a useful tool for future management of these mid-Columbia River stocks.

Dworshak Experiment

Experimental Design and Background

Steelhead reared at Dworshak NFH are indigenous to the North Fork of the Clearwater River and migrate 504 miles before reaching seawater. Previous NMFS studies (Park et al., 1980) showed that steelhead of Dworshak NFH origin that are intercepted at Lower Granite Dam (RM 431) and transported to below Bonneville Dam (RM 145) home successfully to Dworshak NFH. The goal of the 1978 work at Dworshak NFH was to determine if exposure of at least 48 h to home stream water (North Fork of Clearwater River) would assure homing in juvenile steelhead that were denied all natural migration above Bonneville Dam (Fig. 5).

The 1978 test design included a control group released at Dworshak NFH into the North Fork of the Clearwater River and two test groups transported from Dworshak NFH to a release site below Bonneville Dam. Test fish were taken off the normal reconditioned water supply in System #3 by pumping them through an irrigation pipe into raw North Fork Clearwater River water in System #2 raceways, where they were held for 6 days prior to transportation. One test group was moved to Lewiston, Idaho (RM 463) by truck, then barged through the normal migration route. The other test group was moved by truck to the release site below Bonneville Dam (Table 6).

The major portion of the adult returns from 1978 Dworshak NFH releases is complete. The 1980 steelhead run passed our Columbia River sampling stations and began entering Dworshak NFH to spawn in March of 1981. Spawning was completed on the 1980 fish by 12 May 1981. An additional small number of 3-ocean age adults are expected to return with the 1981-1982 run.

Table 5. Adult 1- and 2-ocean age steelhead from the 1978 Wells-Winthrop hatcheries experiment which strayed into the Snake River and were recaptured at Lower Granite Dam (RM107), 1979 to 1981.

Control/ test	Number adults recovered			% of juveniles released	
	1-ocean age	2-ocean age	Total 1 & 2	Observed	Estimated ^{a/}
Winthrop NFH (control)	0	0	0	0.0	0.0
Lower Methow River (control)	1	1	2	0.010	0.029
Truck to Bonneville (test)	60	3	63	0.329	0.605
Barge to Bonneville (test)	3	1	4	0.020	0.046
Truck to Ringold (test)	5	2	7	0.040	0.093

NFH = National Fish Hatchery

^{a/} Park et al., 1981.

Table 5. Adult 1- and 2-ocean age steelhead from the 1978 Wells-Winthrop hatcheries experiment which strayed into the Snake River and were recaptured at Lower Granite Dam (RM107), 1979 to 1981.

Experiment and sampling location	Homing site	Control or test	Number juveniles released	Number of adults recaptured ^{b/}			Total 1, 2, & 3's	Adult ^{a/} return % of juveniles	Test to control ratio
				1-ocean age	2-ocean age	3-ocean age			
<u>Bonneville Dam</u>									
Winthrop NFH	Winthrop	Control	20,330	4	1	0	5	0.025	
L. Methow River	Methow R.	Test ^{b/}	19,901	8	4	1	13	0.065	2.6:1 NS
Truck to Bonneville	Winthrop	Test	19,131	26	5	5	36	0.188	7.5:1 *
Barge to Bonneville	Winthrop	Test	19,979	14	7	4	25	0.125	5.0:1 *
Truck to Ringold	Winthrop	Test	17,637	23	5	2	30	0.170	6.8:1 *
<u>Indian fishery</u>									
Winthrop NFH	Winthrop	Control		7	1	0	8	0.039	
L. Methow River	Methow R.	Test ^{b/}		12	2	0	14	0.070	1.8:1 NS
Truck to Bonneville	Winthrop	Test		29	14	2	45	0.235	6.0:1 *
Barge to Bonneville	Winthrop	Test		19	11	1	31	0.155	4.0:1 *
Truck to Ringold	Winthrop	Test		13	3	1	17	0.096	2.5:1 *
<u>McNary Dam</u>									
Winthrop NFH	Winthrop	Control		18	2	0	20	0.098	
L. Methow River	Methow R.	Test ^{b/}		28	6	0	34	0.171	1.7:1 *
Truck to Bonneville	Winthrop	Test		85	4	0	89	0.465	4.7:1 *
Barge to Bonneville	Winthrop	Test		52	5	0	57	0.286	2.9:1 *
Truck to Ringold	Winthrop	Test		62	4	0	66	0.374	3.8:1 *
<u>Priest Rapids Dam</u>									
Winthrop NFH	Winthrop	Control		33	5	0	38	0.187	
L. Methow River	Methow R.	Test ^{b/}		44	11	0	55	0.276	1.5:1 NS
Truck to Bonneville	Winthrop	Test		32	13	0	45	0.235	1.3:1 NS
Barge to Bonneville	Winthrop	Test		14	8	0	22	0.110	0.6:1 *
Truck to Ringold	Winthrop	Test		63	17	0	80	0.454	2.4:1 *
		Total	96,978	586	128	16	730		

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

^{b/} Washington Department of Farms production release site.

NS Nonsignificant.

* $P < 0.05$ $df + 1$; indicates significant difference between the test and control group.

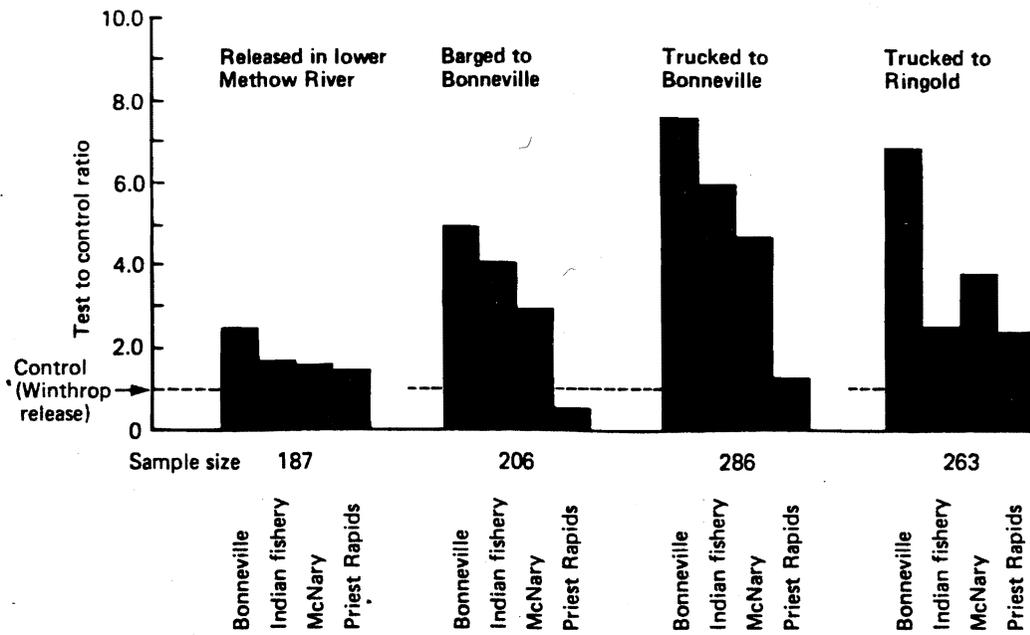


Fig. 4. Test to control ratios for returns to four sampling locations on the Columbia River of combined 1- and 2- ocean age steelhead from control and test releases from the Wells Hatchery which were imprinted to the Winthrop National Fish Hatchery (NFH) homing site on the Methow River in 1978. Recoveries were from June to 30 November 1980. Control fish were released at the Winthrop NFH, 1979. The broken line indicates the level of return for control fish.

1978 STEELHEAD HOMING EXPERIMENT, Dworshak

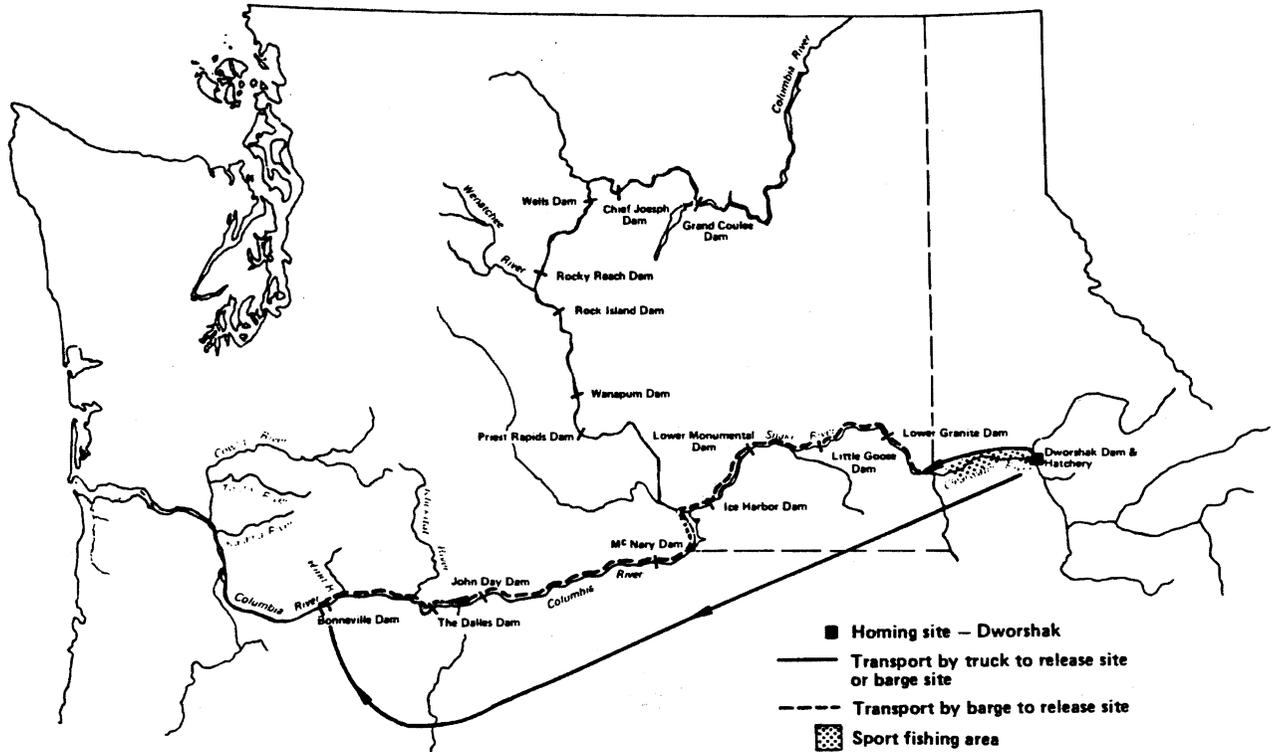


Fig. 5. Study area germane to the 1978 homing experiment with steelhead from Dworshak National Fish Hatchery.

Results and Discussion

Returns of adult steelhead to the Dworshak NFH indicate that the test methods used were successful in varying degrees in returning steelhead to the Dworshak NFH homing site. Test fish that were trucked to Lewiston, Idaho, and then barged showed a significantly greater ($p < 0.01$, $df = 1$) test-to-control benefit ratio of 1.63:1 compared to the test group which was trucked only (0.96:1) or the control group (Table 7). Returns from the barged group provided the first evidence that fish which had been imprinted and transported directly from a hatchery will return as adults in greater numbers than fish which had migrated naturally (control). Returns to the sport fishery above Lower Granite Dam show that the majority of the test and control fish were recovered in the Clearwater River. Test-to-control ratios in this fishery were comparable to ratios back at the hatchery.

Recoveries of returning steelhead from the 1978 outmigration at sampling locations on the Columbia River System indicate differences between treatment groups with respect to relative survival and homing (Fig. 6). Total returns with statistical differences between test and control releases are summarized in Table 7. Major findings were:

1. Adults from the barged group returned at significantly higher rates than the controls except at Bonneville Dam where numbers were insufficient to detect differences.
2. Adults from the trucked group returned at the same rate as barged fish in the Indian fishery, but their return rate was significantly less than barged fish at Lower Granite Dam and at the hatchery.
3. Test-to-control ratios of both barged and trucked fish were considerably higher (over 6:1) in the lower river than at the hatchery (0.96 to 1.63:1).
4. Even though homing of both test groups was impaired, sufficient homing cues were imparted to smolts in the barged release to allow return of a significantly higher ($p < 0.01$, $df = 1$) number of adult fish to the hatchery than were returned from the control group.

Straying of adult steelhead above McNary Dam was minimal, as indicated by recoveries in the sport fisheries and at the hatcheries. Four were recovered in the upper mid-Columbia River--one trucked fish at the mouth of the Methow River and one each control, trucked, and barged fish from the Ringold, Washington, area. Two barged fish were recovered in Idaho: one in the Rapid River Hatchery (IDFG) trap and one at Kooskia NFH. As an item of interest, data from the ocean sampling show that one fish from the barged group was recovered in the net fishery in Puget Sound, Washington.

The majority of Dworshak NFH steelhead return to the Columbia River System as 2-ocean age adults. Effects of transportation and imprinting on the survival and homing of the test groups which were trucked or barged are 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 estimate (minimum) recovery of 2-ocean age adults was 1.389% for the trucked fish, 1.862% for the barged fish, and 0.832% for the control fish (Table 8). These figures reflect the increased survival and subsequent contribution to user groups of the test lots which were transported directly from the Dworshak NFH compared to the higher losses from the control lot (nontransported from Dworshak NFH).

Homing was impaired as indicated by differences between the test-to-control ratios of both test groups (6:1) in the Indian fishery as compared to the test-to-control ratios back at the hatchery 0.96:1 for trucked fish and 1.63:1 for barged fish. Since survival of both groups were comparable (similar test-to-control ratios in the Indian fishery) the differences in the test-to-control ratios back at the hatchery indicates that barged fish (sequential imprint) had a greater ability to home back to the hatchery than the trucked fish (single imprint).

The high overall recovery of test fish in the Indian fishery indicates that a high proportion of the smolts which did not receive a homing imprint to the Dworshak homing site, did return as adults to the vicinity of the Columbia River in which they were released as juveniles. A large number of these nonimprinted fish overwintered in the Bonneville Pool and were available to the gill-net fishery for a longer period of time than fish which were imprinted to the Dworshak homing site (Table 9). Recoveries at Lower Granite Dam indicated that few if any of these fish which winter over in the Bonneville area continued their up-river migration to the Snake River system in the spring.

Under normal conditions steelhead smolts in the Snake River system migrate over an extended period of time (approximately mid-April to mid-June). Within a given population, the proportion of juveniles physiologically able to imprint a homing cue may vary within the migration time period. Therefore, the time period in which juveniles are exposed to an imprint cue before being transported downriver would influence the proportion of juveniles which receive a homing cue that would enable them to return as adults to the homing site.

For example, if we accept the hypothesis that all juveniles in the control release received a homing imprint, that the survival of smolts (in the lower Columbia River below Bonneville Dam and in the ocean) is equal for all juvenile migrants that survived the upper-river outmigration to below Bonneville Dam, and that the rate of survival for all adult steelhead (in the Columbia River system) with homing imprint to the Dworshak NFH is equal, then the difference in the percentage of adult steelhead returning from the control group (based on estimated smolt survival to below Bonneville Dam) compared to the return of the trucked and barged groups will indicate the proportion of juveniles which received a homing imprint.

We estimated that 38,348 smolts from the control group survived to below Bonneville Dam (based on steelhead smolt survival, Sims and Ossiander, 1981). A total of 275 adults (1- and 2-ocean age) returned

Table 6. Steelhead marked in 1978 at Dworshak National Fish Hatchery--test number, mark used, number released, type of imprint, and treatment for various groups are indicated.

Test-control	C.W.T. ^{a/} code	Brand	Number released ^{b/}	Homing imprint	Treatment
Control	10-2-31	LA ☾	30,074 ^{c/}	natural migration	Released with normal hatchery production into North Fork Clearwater River.
Test #1	WH-RD-XY	RA N	20,661	single	Normal production treatment. Held in raw North Fork water at least 48 h and then trucked in North Fork water directly to below Bonneville Dam.
Test #2	WH-RD-YW	RA Z	24,006	sequential	Normal production treatment. Held in raw North Fork water at least 48 h and then trucked in North Fork water to a barge at Lewiston, and then barged down river to below Bonneville Dam.
Total			74,741		

a/ CWT = coded wire tags.

b/ Number released adjusted for initial tag loss.

c/ A total of 100,600 were wire tagged for the hatchery control release, of this number 30,074 were branded for inriver adult evaluation.

Table 7. Returns to five sampling locations and to the Dworshak homing site of steelhead from control and test releases of smolts imprinted to the Dworshak National Fish Hatchery (NFH) in 1978. Recoveries were from September 1979 to 12 May 1981.

Sampling location and experiment	Control or test	Number juveniles released	No. of adults ^{a/} recaptured			Adult ^{d/} return % of juveniles	Test to control ratio
			1-ocean age	2-ocean age	Total 1 & 2's		
<u>Bonneville Dam^{b/}</u>							
Dworshak NFH	Control	30,074	1	13	14	0.047	
Trucked	Test	20,661	1	14	15	0.321	6.82:1 NS
Barged	Test	24,006	1	8	9	0.158	3.36:1 NS
<u>Indian Fishery^{c/}</u>							
Dworshak NFH	Control	100,600 ^{e/}	1	39	40	0.040	
Trucked	Test	20,661	1	44	45	0.218	5.45 **
Barged	Test	24,006	2	51	53	0.221	5.53 **
<u>McNary Dam^{b/}</u>							
Dworshak NFH	Control	30,074	3	18	21	0.070	
Trucked	Test	20,661	0	4	4	0.088	1.26:1 *
Barged	Test	24,006	1	8	9	0.158	2.26:1 *
<u>Lower Granite Dam^{b/}</u>							
Dworshak NFH	Control	30,074	14	170	180	0.612	
Trucked	Test	20,661	2	15	17	0.352	0.58:1 **
Barged	Test	24,006	1	48	49	0.930	1.52:1 **
<u>Clearwater River sport fishery</u>							
Dworshak NFH	Control	100,600	1	75	76	0.076	
Trucked	Test	20,661	0	8	8	0.039	0.51:1 NS
Barged	Test	24,006	0	20	20	0.146	1.92:1 **
<u>Dworshak homing site</u>							
Dworshak NFH	Control	100,600	26	249	275	0.273	
Trucked	Test	20,661	1	53	54	0.261	0.96:1 NS
Barged	Test	24,006	6	101	107	0.446	1.63:1 **
Total branded		74,741	62	938	1000		
Wire-tagged only		70,526					

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

b/ Data from branded fish only.

c/ Data from coded wire tags only.

d/ Adjusted for the difference in detectability between binary and color-coded wire tags as indicated by returns to Dworshak Hatchery.

e/ A total of 100,600 were wire tagged for the hatchery control release, of this number 30,074 were branded for inriver adult evaluation.

NS Non significant

* P<0.05, df = 1; indicates significant difference between the test and control group.

** P<0.01, df = 1; indicates significant difference between the test and control group.

Table 6. Steelhead marked in 1978 at Dworshak National Fish Hatchery--test number, mark used, number released, type of imprint, and treatment for various groups are indicated.

Control/ test	Number adults recovered			% of juveniles released	
	1-ocean age	2-ocean age	Total 1 & 2	Observed	Estimated ^{a/}
Winthrop NFH (control)	0	0	0	0.0	0.0
Lower Methow River (control)	1	1	2	0.010	0.029
Truck to Bonneville (test)	60	3	63	0.329	0.605
Barge to Bonneville (test)	3	1	4	0.020	0.046
Truck to Ringold (test)	5	2	7	0.040	0.093

NFH = National Fish Hatchery

a/ Park et al., 1981.

Table 7. Returns to five sampling locations and to the Dworshak homing site of steelhead from control and test releases of smolts imprinted to the Dworshak National Fish Hatchery (NFH) in 1978. Recoveries were from September 1979 to 12 May 1981.

Test- control	C.W.T. ^{a/} code	Brand	Number released ^{b/}	Homing imprint	Treatment
Control	10-2-31	LA ()	30,074 ^{c/}	natural migration	Released with normal hatchery production into North Fork Clearwater River.
Test #1	WH-RD-XY	RA N	20,661	single	Normal production treatment. Held in raw North Fork water at least 48 h and then trucked in North Fork water directly to below Bonneville Dam.
Test #2	WH-RD-YW	RA Z	24,006	sequential	Normal production treatment. Held in raw North Fork water at least 48 h, trucked in North Fork water to barge at Lewiston and then barged down river to below Bonneville Dam.
Total			74,741		

a/ CWT = coded wire tags.

b/ Number released adjusted for initial tag loss.

c/ A total of 100,600 were wire tagged for the hatchery control release, of this number 30,074 were branded for inriver adult evaluation.

Table 8. 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.

Recovery location	Recovery of 2-ocean age adults ^{a/}					
	Control		Truck		Barge	
	(100,600) ^{b/} N	%	(20,661) ^{b/} N	%	(24,006) ^{b/} N	%
Indian fishery ^{c/} (Zone 6)	117	0.116	134	0.647 *	155	0.645 *
Clearwater River ^{d/} (harvest)	471	0.468	100	0.484 NS	191	0.796 *
Dworshak NFH (homing site)	249	0.248	53	0.257 NS	101	0.421 *
Total	837	0.832	287	1.389 *	447	1.862 *

NFH = National Fish Hatchery

- ^{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 the 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 - personal communication with Steve Pettet IFH.
- NS Nonsignificant
- * $P < 0.05$, $df = 1$; indicates significant difference between the test and control group.

Steelhead — Dworshak Hatchery Experiments — 1978

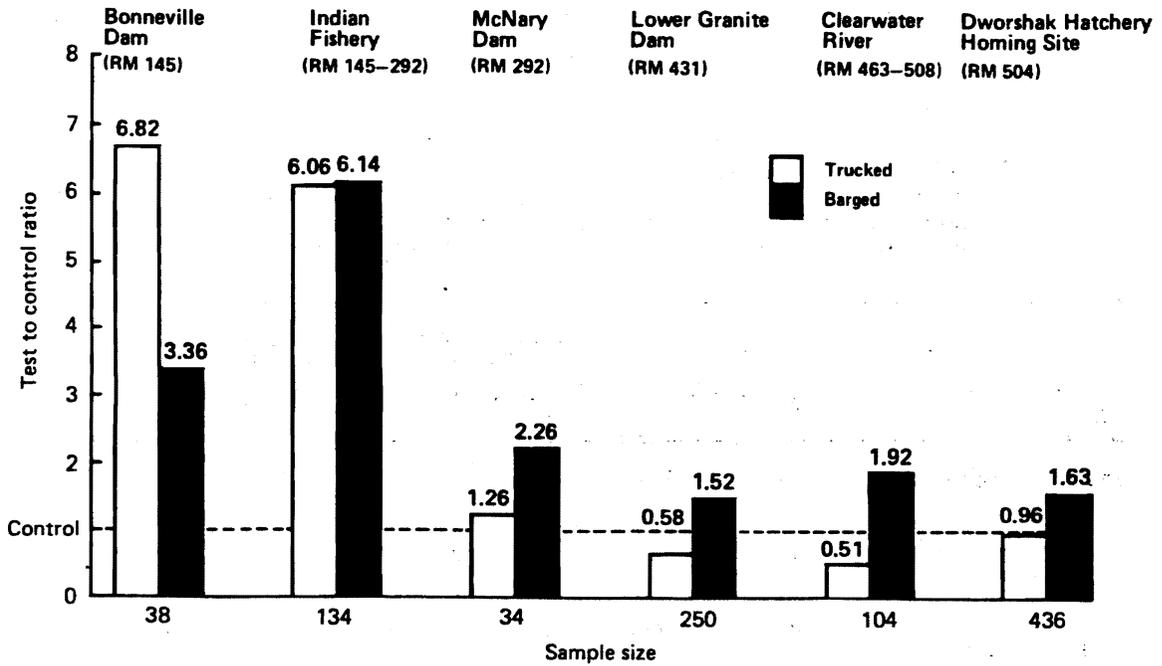


Fig. 6. Preliminary test to control ratios for returns to six sampling locations of combined 1- and 2- ocean age steelhead which were imprinted to the Dworshak National Fish Hatchery homing site on the North Fork of the Clearwater River in 1978. Recoveries were from September 1979 to 12 May 1981.

Table 9. Estimated number and percent recovery of 1- and 2-ocean age steelhead in the Zone 6 Indian fishery from control and test releases of smolts imprinted to the Dworshak NFH in 1978. Recoveries were from September 1979 to 2 April 1981.^{a/}

Test	Juveniles released	Number of adults recaptured						1- & 2-ocean age	
		1-ocean age		2-ocean age			N	Total	Est %
		N	Est %	Fall	Est %	Winter			
Dworshak (Control)	100,600	4	0.003	102	0.101	15	0.015	120	0.119
Trucked (Test)	20,661	3	0.017	27	0.130	107	0.517	137	0.664
Barged (Test)	24,006	6	0.027	50	0.210	105	0.435	161	0.672

NFH = National Fish Hatchery

^{a/} Estimated recoveries based on sampling efficiency of the Zone 6 Indian fishery.

to Dworshak NFH, which would equal a survival rate of 0.717%. Therefore the proportion of the smolts in the truck and barge groups which received a homing imprint would be:

Truck group	0.261% - 0.717 = 36.4% imprinted smolts
Barged group	0.446% - 0.717 = 62.2% imprinted smolts

Based on the above proportions of smolts which received a homing imprint in the truck and barged test groups, and the increased survival due to transportation, it appears that a large number of nonimprinted smolts survived and returned as adults to the area near their release point as juveniles. These adults remained there over the winter and were subjected to the Indian gill-net fishery for a longer duration than fish which had received a homing imprint and continued their upriver migration, as normal, in fall. However, a key point to keep in mind is that, even though homing of the barged group was impaired, there were still enough fish to provide a significantly greater ($p < 0.01$, $df = 1$) percent return to the hatchery homing site and to the Clearwater River fishery in Idaho than did those released at the hatchery.

This is all the more impressive when you consider that an estimated 66.7% of the control fish which survived to Lower Granite Dam were collected and transported to below Bonneville Dam via the regular transportation program. The test-to-control ratio for returning adults from the 1978 outmigration which had been transported from the collector dams was 4.90:1 (Park, 1981). This means that approximately five out of six returning adult steelhead from our release had 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 lower.

In 1982 these positive data led to the development of a more elaborate follow-up study, funded by the Bonneville Power Administration, to try and determine if differences in timing of releases and/or levels of gill Na^+ - K^+ ATPase would result in an increased ability of adult steelhead to home back to the hatchery.

The successful conclusion of this study could lead to a management program which would significantly increase the rate of return of this stock of steelhead and thereby provide an increased benefit to all the user groups who now utilize these fish. If a significant portion of the Dworshak NFH steelhead smolts were transported from the hatchery, it would help reduce the congestion at the collector dams. This would be especially beneficial in aiding the collection and transportation of chinook salmon smolts since the peak of the Dworshak NFH steelhead smolt migration closely coincides with the peak of the chinook salmon outmigration. This could prove to be quite significant in the future as more hatcheries (now under design or construction) start releasing fish and increase the numbers of juvenile salmonids arriving at the collector dams.

Summary and Conclusions

The primary objectives of the research were to determine (1) if single or sequential imprinting to unique water supplies is necessary to assure homing for various stocks of steelhead, (2) a method to activate the homing imprint, and (3) the relationship between the physiological condition of the fish and their ability to imprint.

Tucannon Experiment, 1976

1. The addition of a new water supply (spring water) to smolting fish did not imprint steelhead to the Tucannon Hatchery.
2. Recoveries of large numbers of returning adults in the Snake River indicated that the steelhead smolts imprinted to the Snake River when they were held at Little Goose Dam for marking.

Wells-Winthrop Experiment, 1978

1. The imprinting method of transferring juvenile steelhead from the Wells Hatchery to the Winthrop NFH and holding them for a period of time prior to release was unsuccessful in giving the test fish (transported) a specific homing imprint. The control group (natural migration) did return back as adults to the Winthrop NFH.
2. Steelhead smolts received a limited homing imprint which enabled the test (transported) fish to return 293 miles up the Columbia River without impairment of homing.
3. Although homing was impaired above McNary Dam, test-to-control ratios at Priest Rapids Dam and sport recoveries in the Wenatchee and Methow areas indicated that a portion of the steelhead smolts received a limited imprint which enabled them to return to the geographic area (upper mid-Columbia River) in which the homing site was located.

Dworshak Experiment, 1978

1. Preliminary adult returns show that steelhead can be imprinted to return to their hatchery of origin even though they were transported directly from the hatchery as smolts and released below Bonneville Dam (by-passing the major portion of their natural migration route).
2. Smolts which were sequentially imprinted by barging are returning over one and a half times as many adults to the hatchery than smolts which had received a single imprint and were trucked directly to below Bonneville Dam.
3. Returns from the barged group provided the first evidence that fish which had been imprinted and transported directly from a hatchery will return as adults in greater numbers than fish which had migrated naturally (controls).

Survival and Straying, General

1. Recoveries of adult steelhead at the lower river sampling sites indicate higher survival for test groups (transported) than for control groups (nontransported) returning to the Columbia River.
2. Fish trucked directly to below Bonneville Dam in the Tucannon and Wells-Winthrop Hatchery (nonindigenous stocks) experiments had a substantial amount of straying in the upper river above McNary Dam.
3. Preliminary data indicated negligible straying from the Dworshak (indigenous stocks) trucked group.
4. Barged and control groups showed very little straying above McNary Dam.
5. Test fish which did not imprint for some reason, e.g., they were not physiologically ready or able to imprint a homing cue at the time they were transported, are returning to the area near their point of release as juveniles, as demonstrated by recoveries in the Indian gillnet fishery.
6. Ability of smolts to home successfully to hatchery or homing sites as adults may be genetically related. It appears, however, that a continuous or sequential imprinting scheme as used in the 1978 Dworshak experiment is at least as important as genetic considerations.

Acknowledgments

I wish to thank the U.S. Fish and Wildlife Service and Washington Department of Game for providing the fish and hatcheries and the U.S. Army Corps of Engineers for the use of their barge. I thank the Bonneville Power Administration for providing the funding required to do this research. I also wish to thank all of the personnel of the National Marine Fisheries Service, U.S. Fish and Wildlife Service, Oregon Department of Fish and Wildlife, Washington Departments of Game and Fisheries, and the Idaho Department of Fish and Game for their cooperation in obtaining adult recoveries.

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