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

Losses to juvenile and adult Pacific salmon, *Oncorhynchus* spp., and steelhead trout, *Salmo gairdneri*, populations migrating in the Columbia and Snake rivers have increased dramatically in recent years. The principal migratory route over which most salmonids must pass has been artifically altered by construction of a series of dams. The dams, with their associated reservoirs, are a major source of mortality to migrating salmonids. Ebel et al. (1973) summarized the primary causes of mortality which include gas bubble disease, turbines at dams, and predation.

There is evidence that certain stocks of salmonids are in grave danger unless ways are found to increase their populations. For example, 1973 returns of summer-run chinook salmon, *O. tshawytscha*, to the Columbia and Snake rivers reached all-time low proportions.[1] Other wild stocks of steelhead trout and chinook salmon also continue to decline.

The National Marine Fisheries Service conducted transportation experiments at Ice Harbor Dam during 1968-70 to find ways of increasing survival of Snake River salmonids.

In these experiments, juvenile salmon (spring- and summer-run chinook) and steelhead were collected at Ice Harbor Dam and transported to two locations downstream. Evaluation of these tests depended upon adults returning to Ice Harbor Dam and, subsequently, to their native streams. Data on adults returning from releases of juvenile chinook in 1968 and of juvenile steelhead in 1969 were analyzed and reported by Ebel et al. (1973). Analyses of adult returns from releases of juvenile chinook in 1969-70 and of juvenile steelhead in 1970 are covered in this addendum report.

Methods

General Procedures

Migrating juvenile chinook salmon (spring- and summer-run populations) and steelhead trout were collected at Ice Harbor Dam by dipnet from gatewells (Bentley and Raymond 1969) in 1969 and from a bypass collection area (Park and Farr 1972) at Ice Harbor Dam in 1970. Collection from the bypass area differed from dipnetting in that fish were accumulated in a holding area over a 24-h period. After accumulation, the fingerlings were raised by a fish pump about 15 m to an aerated tank truck for hauling to the fish marking facility. In both years populations were mixed and randomized before marking. The adipose fin was excised, a thermal brand (Mighell 1969) placed on the side of the fish, and a magnetic wire tag (Jefferts et al. 1963) injected into the snout of each fish. The control or nontransported group was released about 15 km above Ice Harbor Dam. The transported groups were released 5 km downstream from John Day Dam on the Oregon side of the Columbia River and 1 km downstream from Bonneville Dam on the Washington side of the river (Figure 1). Distinguishing brands and color-coded wire were assigned to each experimental group.

Numbers of juvenile chinook salmon and steelhead trout marked and released at various locations are shown in Table 1. In both 1969 and 1970, collection of juveniles fell below expectations. For example, we were able to mark only 28,956 chinook salmon in 1970. Therefore, numbers of marked returning adults were reduced accordingly.

Evaluation of Returning Adults

The effect of transportation of juveniles on their survival and homing as adult fish was evaluated by comparing recoveries of transported and nontransported adults at various sites in the river system as they returned on their spawning

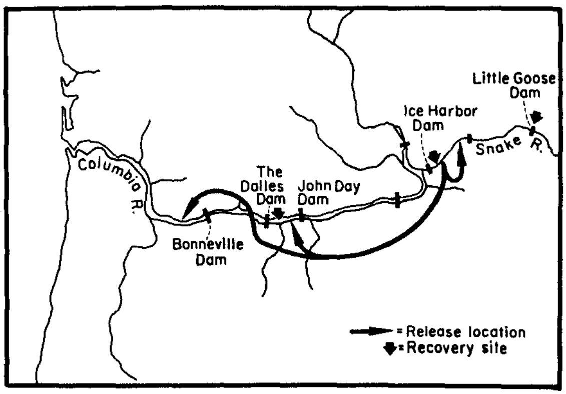

FIGURE 1.–Columbia and Snake rivers, showing release and recovery sites of migrating chinook salmon and steelhead trout.

[1]Annual fish passage report Columbia River projects, 1973. North Pacific Division, U.S. Army Corps of Engineers, P.O. Box 2946, Portland, OR 97208.

TABLE 1.–Number of transported and nontransported (control) juvenile chinook salmon and steelhead trout that were marked and released, 1969-70 (figures adjusted for tag loss)[1].

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

[1]Initial tag loss was determined for the control releases by examination of juveniles after recovery at Ice Harbor Dam, 1969-70; tag loss for the test groups were determined by fish held at release sites after transport.

migration. These included returns to the sport, commercial, and Indian fisheries in the Lower Columbia River; to Ice Harbor and Little Goose dams on the Lower Snake River; to Rapid River and Dworshak hatcheries in Idaho; and to the spawning grounds.

Most of the tagged adults were captured at Ice Harbor Dam or Little Goose Dam. At Ice Harbor Dam about 80% of the run of adult fish ascend the south ladder enroute to the spawning grounds. At Little Goose Dam all fish must ascend the single ladder installed there. Adults were recovered at Ice Harbor Dam by a detector-separator device that intercepted tagged salmon and trout (Durkin et al. 1969). At Little Goose Dam, recoveries were made by an improved but similar detector apparatus. A major modification of the system included a Denil-type fishway instead of the pool-and-overfall ladder used at Ice Harbor Dam.[2] Improvements incorporated in the facility at Little Goose Dam increased detection efficiency markedly in 1970.

Results

Returns of Adult Spring and Summer Chinook to Ice Harbor and Little Goose Dams

Numbers of returning adult salmon successfully detected, separated, and identified at the adult separator are listed in Table 2. It should be stressed that the observed return of adults represents only a fraction of the total return of marked fish to Ice Harbor and Little Goose dams. The observed tally is low for the following reasons: 1) approximately 20% of the adult run at Ice Harbor Dam passed up the right bank (north) fishway which did not have a tag detection device; 2) at Little Goose Dam, the barrier gates at the entrance to the automatic separator were open at night (2100-0500) allowing some adults to pass undetected; 3) some tag loss had occurred between tagging and recovery as adults; 4) the tag detection system was less than 100% efficient; 5)

[2]Slatick E. 1974. Laboratory evaluation of a Denil-type steeppass fishway with various entrance and exit conditions for passage of adult salmonids and American shad. Unpubl. manuscr. Natl. Mar. Fish. Serv., NOAA, Pasco, Wash.

TABLE 2.–Percentage of transported and nontransported (control) juvenile chinook salmon (released in 1969 and 1970) that were recaptured as adults at Ice Harbor and Little Goose dams, 1 April through 18 August 1971-73.

Release site and (in parentheses) experimental group of fish	Number of juveniles released[1]	Number recaptured as adults	Percentage return as adults	
			Observed	Estimated[2]
1969:				
Ice Harbor Dam (control)	24,217	47	0.194	0.497
John Day Dam (transported)	14,782	19	0.129	0.356
Bonneville Dam (transported)	13,529	33	0.244	0.581
1970:				
Ice Harbor Dam (control)	8,624	17	0.197	0.323
John Day Dam (transported)	10,159	7	0.069	0.113
Bonneville Dam (transported)	10,173	29	0.286	0.467

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

presumably some adults could have passed upstream through the navigation locks at Ice Harbor and Little Goose dams.

Throughout this section of the report, percentage figures are given which indicate either an increase or decrease in survival of groups of juveniles transported downstream in comparison to control groups not transported but released near the collection point. Some of the increases are statistically significant, some are not; generally those that are significant are indicated. We present the data even though some of it is not statistically significant because it parallels earlier data reported by Ebel et al. (1973).

The combined adult returns—of spring- and summer-run chinook salmon from juveniles transported from Ice Harbor Dam and, subsequently, released at Bonneville Dam—were greater than adult returns from control releases made at Ice Harbor Dam. The combined transportation benefit (Table 2) for spring- and summer-run chinook salmon released in 1969 was 27%; in 1970, 47%.

An analysis of comparative survival to adults for spring- and summer-run chinook salmon by year of transport are presented in Table 3. The transportation benefit indicated for juveniles released in 1969 was 27% for spring-run chinook salmon and 29% for summer-run chinook salmon. Benefits from the 1970 release were 40% for spring-run chinook salmon and 57% for summer-run chinook salmon.

Combined spring and summer adult returns from the John Day release were 34% less in 1969 and 65% less in 1970 than returns from the controls. Although the lower adult returns from juvenile releases at John Day are unexplained at this time, it is possible that the cumulative stress from collection, handling, and hauling combined with the stress from having to pass two dams (The Dalles Dam and Bonneville Dam) may have been detrimental for fish released at this site.

Returns of Adult Steelhead Trout to Ice Harbor and Little Goose Dams

Table 4 lists the returns of adult steelhead trout (released as juveniles in 1969-70) that were successfully detected, separated, and identified at the automatic separator at Ice Harbor and Little Goose dams. We identified 148 adult steelhead trout from those released in 1969. Of these, 46 were from the control release and 102 from the John Day transport release, which give a transportation benefit of 174%—a significant ($\chi^2 = 34.370$; df = 1) increase.

Adult steelhead trout returns from the 1970 juvenile releases totaled 324 fish. Of these, 71 were from the control release, 75 from the John Day transport release, and 178 from the Bonneville transport release. The transportation benefit from the Bonneville release was 47% ($\chi^2 = 7.315$; df = 1); however, no benefit was derived from transport of juveniles to the John Day release site (adult re-

TABLE 3.—Comparison between transported (released at Bonneville and John Day dams in 1969-70) and nontransported (control) groups of chinook salmon based on numbers of transported and nontransported juvenile fish recaptured as adults at Ice Harbor and Little Goose dams, 1971-73.

Release site (of juveniles) and seasonal race of salmon[1]	No. of salmon recaptured as adults at Ice Harbor and Little Goose dams[2]		Transportation benefit or deficit (−) (Percent)
	Transported	Nontransported	
1969			
Below Bonneville Dam:			
Spring chinook salmon	38	30	27
Summer chinook salmon	22	17	29
Below John Day Dam:			
Spring chinook salmon	23	30	−23
Summer chinook salmon	8	17	−53
1970			
Below Bonneville Dam:			
Spring chinook salmon	14	10	40
Summer chinook salmon	11	7	57
Below John Day Dam:			
Spring chinook salmon	4	10	−60
Summer chinook salmon	2	7	−71

[1]Seasonal races of chinook salmon in the Columbia River system are classified as spring, summer, or fall chinook depending on the time of year that the adults enter the river to spawn.
[2]Numbers recaptured adjusted in relation to numbers released (Table 1).

TABLE 4.—Percentage return and benefit or deficit (-) of transported to nontransported (control) juvenile steelhead trout (released in 1969-70) that were recaptured as adults at Ice Harbor and Little Goose dams, 1970-73.

Release site and (in parentheses) experimental group of fish	Number of juveniles released[1]	Number recaptured as adults				Percentage return as adults		Percentage transported to control benefit or deficit (−)
		One ocean	Two ocean	Three ocean	Total	Observed	Estimated[2]	
1969:								
Ice Harbor Dam (control)	25,313	43	3	0	46	0.182	0.792	—
John Day Dam (transported)	20,430	76	25	1	102	0.499	1.600	174
1970:								
Ice Harbor Dam (control)	18,347	12	58	1	71	0.387	0.729	—
John Day Dam (transported)	20,935	8	66	1	75	0.358	0.610	−7
Bonneville Dam (transported)	31,282	14	162	2	178	0.569	0.924	47

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

turns from this release were 7% less than returns from controls).

Recovery of Marked Chinook Salmon in Commercial and Sport Fisheries

Although only 43 adult chinook salmon (Table 5) were recovered in the commercial and sport fisheries from juvenile releases in 1969, returns indicate a definite benefit from transportation. The benefit of transported fish (John Day-Bonneville releases combined) was 19%.

It was not possible to distinguish between returns of adults to the fishery from juvenile releases at Bonneville and John Day because of the loss of the identifying brands. Brands which would have enabled identification by release site were obliterated by gillnet abrasion. Transported and control groups of juveniles could be distinguished as adults by magnetic tags, but only two codes were used—one for the controls and one for the transported fish (Bonneville and John Day combined). However, if the percentage of adult returns obtained at Ice Harbor and Little Goose dams—where brands of fish returning from releases at Bonneville and John Day were visible—is applied to the total returns of adults as obtained in the commercial fishery, the benefit from transporting juveniles becomes 59% for chinook salmon transported to Bonneville Dam.

TABLE 5.—Comparison between transported and nontransported groups of chinook salmon based on numbers of transported and nontransported juvenile fish (released in 1969) that were captured as adults by commercial and sport fisheries in the lower Columbia River, February through August 1971 and 1972.

Location of fisheries	No. of salmon recaptured as adults	
	Transported	Nontransported
Upstream from Bonneville Dam (Indian fishery)	8	4
Downstream from Bonneville Dam	17	14
Total	25	18

Adult recoveries in the lower river commercial and sport fisheries from juvenile chinook salmon released in 1970 were insufficient (seven transported and eight control fish) for analysis of transport to control return ratios.

Returns of Adult Chinook Salmon to Spawning Grounds

Spawning ground surveys (Figure 2) and examination of tagged adult chinook salmon at Rapid River Hatchery near Riggins, Idaho, provided further information concerning benefits at their "home" destination from transport of juvenile spring- and summer-run chinook salmon.

In 1971, 12 tagged adult fish (from the 1969 juvenile release) were recovered from the Rapid River Hatchery; an additional 15 were from sport fishermen and spawning ground surveys. Of the total, 15 adults were from the transported groups and 12 from the control group. By adjusting from the ratio of John Day to Bonneville adult returns, we estimated that 12 of the 15 transported fish

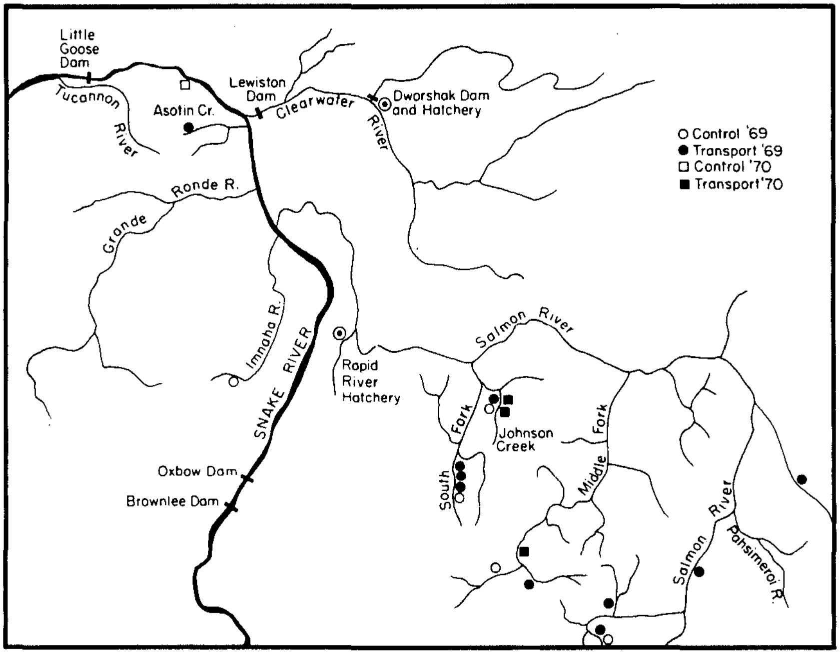

FIGURE 2.–Location of recoveries of tagged adult chinook salmon returning to spawning grounds from 1969-70 experiments.

were from the group released at Bonneville Dam. The transport benefit for the groups of juveniles released at Bonneville becomes 78% when computed on the basis of the number of juveniles released per group.

Too few tagged adult chinook (five Bonneville transports and one control) from the 1970 juvenile releases were collected in 1972 from all sources to make conclusions regarding the effect of transportation.

Discussion

Results from this study, which was a continuation of a study begun by Ebel et al. (1973), corroborated earlier findings, i.e., homing of adults after transportation downstream as juveniles was not seriously affected and survival was increased. Throughout this study, we found no evidence of straying among adults returning from the experimental releases. All comparisons between the adult returns from transported and control groups of juvenile chinook salmon and steelhead trout indicated that survival was definitely increased by transporting juvenile fish to a release site downstream from Bonneville Dam.

We have been particularly concerned with how the percentage return from these experiments might compare with that of unhandled or undisturbed juvenile migrants. Some insight into this matter is shown by a comparison between estimated adult returns from juveniles marked and released as controls and returns of unhandled adult fish to Rapid River Hatchery in Idaho (Table 2); the data indicate that survival of chinook salmon released in our 1968 experiment was greater than that indicated for salmon returning to the Rapid River Hatchery. Adult returns from controls released in 1969 were comparable to hatchery returns, but returns from those released in 1970 were lower than returns to the hatchery.

It is assumed that some stress was placed on juveniles in the collection, handling, marking, and transport processes. These cumulative stresses were not outwardly apparent in the physical condition of the juvenile smolts at the time of handling, but differences in survival of returning adults indicated that condition of the fish at the time of marking must have varied among years.

Our collection methods were changed in 1970 by addition of a fish pump; this added a pumping stress to our fish handling process. Although Park and Farr (1972) indicate no immediate mortality or observed stresses due to pumping from the facility, it is possible there could have been significant delayed effects. The effect of pumping on juvenile chinook salmon and steelhead trout—when added to other cumulative stresses associated with handling in our transport process—is indicated by the lower percentage of adult returns from control releases of juveniles in 1970.

Although smaller numbers of juvenile chinook were released in 1969-70 than in 1968 and a correspondingly small number of adults returned, we believe that the lower percentage of returning adults does indicate that stress factors due to handling were higher in 1970 than in 1969. The addition of two dams—Lower Monumental and Little Goose—placed in operation in 1969 and 1970, upstream from Ice Harbor Dam, must also be considered. Fish had to pass through Lower Monumental Reservoir and Dam in 1969 before being collected at Ice Harbor Dam. In 1970, they had to pass through both reservoirs and dams before being collected. Supersaturation of dissolved nitrogen also became a problem between Little Goose and Ice Harbor dams at this time. Turbines from both Lower Monumental and Little Goose dams were not scheduled for installation until after the spring freshet and as a result large volumes of water had to be passed over the spillways, causing dissolved gas concentrations to be high; a large percentage of the fish arriving at Ice Harbor Dam exhibited obvious signs of gas bubble disease.

If we use the percentage adult returns in relation to juveniles released at the Rapid River Hatchery in Idaho as an indicator of the rate of return of naturally migrating chinook salmon and we compare our percentage return figures, we find our estimate of return of controls was 4.3% in 1968—much higher than the 0.48% adult return recorded for Rapid River Hatchery.[3] The estimated control return of 0.497% for the 1969 outmigration is comparable to the 0.493% return to Rapid River Hatchery, but estimated returns from controls released in 1970 dropped to 0.323% whereas the return to the Rapid River Hatchery was 0.477%. Thus, the stresses placed on juvenile fish prior to collection, in addition to those involved in the handling process, conceivably were instrumental in causing the lower return of adults from the 1969-70 experiments.

When we examine adult returns from juvenile control releases of steelhead trout, we find that the percentage return from control releases of steelhead trout in 1969-70 were much greater than for comparable juvenile releases of chinook salmon. This indicates that the ability of steelhead trout to withstand the cumulative effects of stress is greater than that of chinook salmon.

Using the adult return percentage of steelhead trout to the Dworshak Hatchery from juvenile migrants released at that site in 1970 as a base indicator of the adult return of naturally migrating steelhead trout to Idaho streams, we find that our estimated adult returns from control releases to Ice Harbor and Little Goose dams of 0.792 and 0.729% (in 1969 and 1970, respectively) were somewhat greater than the 0.682%[4] return to Dworshak Hatchery. When our adult control returns are adjusted for the upriver sport catch on steelhead trout, our revised return (0.713% from the juvenile control releases in 1969) was comparable to the 0.682% return to Dworshak Hatchery. The return from the 1970 (control) release of 0.598% was, however, less than the hatchery return of 0.682%.

Based on the foregoing rationale, we believe that our control releases of juvenile chinook salmon and steelhead trout in 1969 returned as adults at rates comparable to those of natural migrating salmonids and that benefits on survival to adults indicated for our transported salmon and steelhead trout represent real increases.

Studies to further define stress problems associated with diversion, collection, and handling of naturally migrating juveniles are currently underway. To maximize the effectiveness of a collection and transportation system, stresses from all sources must be minimized.

Conclusion

The homing of adult fish, captured during their seaward migration as juveniles and transported downstream (from Ice Harbor Dam to Bonneville Dam), was not reduced by the transport operation. Although numbers of returning adults were small, comparisons of returns of transported fish versus control fish to Ice Harbor Dam, the spawning grounds, and hatcheries in Idaho indicated that they "homed" satisfactorily. No evidence of straying of transported fish was observed in our surveys.

[3]Pers. commun. Evan Parrish, Hatchery Manager, Rapid River Hatchery, Riggins, Idaho.

[4]Pers. commun. Einer Wold, Hatchery Pathologist, Dworshak Hatchery, Ahsahka, Idaho.

Adult returns indicate a definite benefit is achieved from transporting juvenile chinook salmon and steelhead trout from a collector dam (Ice Harbor) to a release site below Bonneville Dam. Transport benefits were lower than reported from releases made in 1968, but a benefit of 27-47% was still indicated. No steelhead trout were released at Bonneville Dam in 1969, but a 47% benefit was realized from transportation of juveniles to that site in 1970.

Data from returning adults indicate that in general the John Day release site was a poor one. In 1969, however, returns from juvenile steelhead trout releases there were 174% greater than controls. The reduced transport benefit for our John Day release can probably be best explained by the fact that juveniles must still pass over The Dalles and Bonneville dams before entering the ocean. These further stresses probably nullify any initial transport benefit.

The rate of adult return from those juvenile fish transported in 1969 was better than the adult returns from those transported in 1970. Data suggest that stresses to juveniles encountered prior to collection at Ice Harbor and the changed handling procedures in 1970 were a factor.

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EMIL SLATICK
DONN L. PARK
WESLEY J. EBEL

Northwest Fisheries Center
National Marine Fisheries Service, NOAA
2725 Montlake Boulevard East
Seattle, WA 98112

COMPARATIVE VULNERABILITY OF FRY OF PACIFIC SALMON AND STEELHEAD TROUT TO PREDATION BY TORRENT SCULPIN IN STREAM AQUARIA

Predation on fry of salmon and trout by sculpin, *Cottus* spp., is intense in certain situations (Hunter 1959; Sheridan and Meehan 1962; Patten 1962, 1971a, 1972) or of little consequence in others (Ricker 1941; Patten 1971a, 1972). Variation in intensity may be related to such important causes as the environment or to specific differences of the predators or prey.

In this paper I report the comparative ability of steelhead trout, *Salmo gairdneri*, and of five species of Pacific salmon, *Oncorhynchus* spp., to avoid predation by torrent sculpin, *C. rhotheus*, in a fixed environment—stream aquaria. The vulnerability of a species of salmon or steelhead trout, as determined from this study, is related to known information on the duration of residency and behavior of a species in streams. These results help in the assessment of natural causes of mortality that affect the productivity of salmon and steelhead trout. The study was conducted in stream aquaria adjacent to Cedar River near Ravensdale, Wash., in 1966.

Facilities and Procedures

The facilities consisted of two stream aquaria and eight holding aquaria that received water from the Cedar River (more fully described by Patten 1971b). Two stream aquaria used for tests of predation were 2.4 m long and 0.6 m wide and high; water depth ranged from 2 to 18 cm depending on bottom contour. The eight holding aquaria used in the study (to incubate the eggs and maintain the young fish before tests) were 34 cm wide by 41 cm long by 36 cm high; water depth was 18 cm.

Water from the Cedar River was taken at a low dam and supplied by gravity flow to the head box and then to the stream aquaria. Each aquarium had a continuous flow. The water was usually clear, and temperatures recorded at 0800 ranged from 5° to 10°C during the course of the study.

The experimental procedure exposed salmon or trout fry to predation by torrent sculpin under pseudo-natural but controlled conditions. Torrent sculpin were collected by electrofishing in Soos Creek, Wash.; the salmon and steelhead trout fry were reared from eggs to insure that they had no previous experience with predators.