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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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.

Eggs from pink salmon, *O. gorbuscha,* chum salmon, *O. keta,* sockeye salmon, *O. nerka,* fall chinook salmon, *O. tshawytscha,* coho salmon, *O. kisutch,* and from steelhead trout of Puget Sound stocks were placed in holding aquaria and covered with coarse gravel.

The salmonid fry were subjected to predation tests as soon as the yolk sacs were absorbed. Since the time of emergence from the gravel by the fry of these six species varies, the tests extended from March to June, during which period water temperatures (Table 1) and day lengths differed. The salmon and trout fry were not fed but could be seen mouthing particles entering the holding aquaria. I assume growth of fry negligible and size differences to be fixed by the species and race used. Observations of viability and vigor of fry in the holding aquaria were made before, during, and after testing as a standard of comparison for test fish. Samples of the salmon and trout fry were measured in millimeters from snout to fork of tail (Table 1); their volumes were determined by displacement in a graduated tube. Sculpins were measured in millimeters from snout to end of tail (Table 1).

Twenty sculpins were placed in holding aquaria without food the first day of the experiment. On the second day 10 fry of one species were placed in each stream aquarium and on the third day, 10 sculpins were quietly introduced at the downstream end of each stream aquarium. On the fifth day the fry surviving after 48 h were counted; then both predators and prey were removed. These subjects were not used again. Two to seven replicate tests were made for each species of salmon or trout (Table 1).

Comparative Survival of Salmon and Trout Against Predation

The positions and activities of the salmon, trout, and sculpins in the stream aquaria are first described because these varied between species, affecting predator-prey interrelations. The following sections report on the viability and vigor of fry and on the survival rates of the species of salmon and trout.

The positions and activities of a species of salmon or trout during daylight tests varied. Fish in the stream aquaria maintained positions and apparently fed; chinook and coho salmon displayed intraspecific aggression, indicating accommodation to the enclosure. All species were observed in the deepest areas of the stream aquaria where they distributed themselves vertically 1 cm from the bottom to the water surface. Most of the steelhead trout fry and some pink and chum salmon fry hid under rocks, but this behavior was seldom exhibited by the other salmon species except for short periods when they were frightened.

Torrent sculpin typically spaced themselves through the deeper parts of the stream aquaria. They were distributed through its length with the greatest number at the upstream end. They were inactive and curled around large rocks or partially buried themselves in areas with soft bottoms. The concealment of the sculpins was so complete that I often had to search for as long as 20 min to remove all of them after an experiment.

After the sculpins were placed in the stream aquaria, the salmon and trout fry, on recovering from the disturbance, modified their vertical distribution. Salmon fry reacted to an active sculpin by moving away laterally and upward. In the presence of sculpins all salmon fry increased their distance from the bottom to about 5 cm. Steelhead trout fry, that usually hid under rocks when undisturbed, moved off the bottom and maintained positions near the water surface when sculpins were present. Behavior of the steelhead trout fry was apparently more disturbed by sculpins than was that of the salmon fry.

Sculpins rarely stalked the fry in bright daylight but waited immobile for them to come

TABLE 1.—Survival of salmon and trout fry subjected to predation in 1966 by torrent sculpin, *Cottus rhotheus.*

Species	Date of testing	Water temp[1] (°C)	Test (prey) fish: Number	Test (prey) fish: Length range (mm)	Mean length of predator (mm)	Number of tests	Number of survivors: Total	Number of survivors: Range/test	Percentage survival
Chinook salmon	3-25 to 4-15	6.2	60	38-42	92.0	6	31	1-8	51.7
Chum salmon	5-16 to 5-23	8.7	60	35-38	88.7	6	3	1-2	5.0
Coho salmon	3-25 to 4-15	6.2	70	36-39	91.7	7	53	6-9	75.7
Pink salmon	3- 2 to 3-11	6.2	60	35-37	92.5	6	1	0-1	1.7
Sockeye salmon	4-15 to 4-19	6.1	20	41-43	97.5	2	4	1-3	20.0
Steelhead trout	5- 4 to 5-13	8.9	60	29-31	91.4	6	14	0-7	23.3

[1]Average temperature (°C) at 0800 for 2 days of test.

near. Then they made short, quick lunges at the prey. Little predation occurred during the day and I never observed a sculpin catching a salmon.

Stocks of fry used for testing appeared normal, healthy, and vigorous. A reserve of fry of a species was maintained in holding aquaria during and after testing without mortality—in fact dead or inferior fry were never observed over 2 yr. Pretest salmonids held in stream aquaria often maintained positions in the faster moving water. Individuals that may have been inferior as indicated by use of slow water shallows, by swimming at the downstream end, or by impingement on the outlet screen were never observed.

Results showed variation between rates of predation on a prey species, size of prey species, and on temperature and length of daylight during testing. Predation by torrent sculpin was least on coho and chinook salmon, intermediate on sockeye salmon and steelhead trout, while practically complete on pink and chum salmon (Table 1). Chi-square analysis showed significant differences between all species except for 2 of the 10 combinations tested: sockeye salmon-steelhead trout and pink-chum salmon. The number of survivors per test varied considerably for the chinook salmon and steelhead trout. Steelhead trout were relatively deep bodied but shorter than salmon fry and among the salmon, chum and pink were thin bodied (Table 1 shows lengths; body volume determinations indicated chinook, coho, and sockeye salmon had as much as twice the displacement of the other species). Testing of chum salmon and of steelhead trout was a month or two later in the spring when temperatures were higher (Table 1) and duration of daylight was longer than for other species.

Innate Predator Avoidance of Species

Differences in rates of predation on the study species are not well explained by observed differences in behavior, size of prey, ambient conditions, or predator related effects but may be due to innate behavior after emergence of fry from the gravel. The only species with greatly divergent behavior in the stream aquaria was the steelhead trout. Remaining near the water surface during day effectively removes them from the influence of sculpin predators; however, they may settle to the substrate at night, a time when sculpins are more effective predators (Patten 1971b).

The larger prey species, those having the longest body lengths and being relatively deep bodied, were not always those with the higher survival. Chinook, coho, and sockeye salmon were the largest. Chinook and coho had the highest survival but the sockeye salmon, the largest prey, had survival similar to the steelhead trout, the smallest prey. Chum and pink salmon were slim and as long as coho and longer than steelhead trout, but their survival was lowest of the species studied. If size of prey or satiation of predators from greater food volumes influenced rates of predation, these factors were apparently less important than other effects on a species level.

Length of day or temperature had no apparent effect on rate of predation. Sculpins are most predaceous on salmon at times of marginal light intensity (Patten 1971b), which might suggest they are more serious predators at times of shorter day lengths. Trends between intensity of sculpin predation on fry and temperatures observed during this and other studies have never been observed.

The data show strong interspecific variations of the study species in vulnerability to predation by the torrent sculpin. I suspect a difference in innate behavior exists; some species are better able to evade predation. Furthermore, the early life history and behavior of the study species may be linked to their predator avoidance abilities. Chum, pink, and sockeye salmon quickly migrate from a stream environment to the sea or a lake where they form schools (Mason 1974, has observed chum salmon forming loose aggregations in estuaries). Schooling may aid these species in avoiding predation (Shelbourn 1966). Chinook and coho salmon and steelhead trout on the average form loose aggregations in streams during a period of growth before migrating to the sea. Forming loose aggregations would increase feeding opportunities in streams. Density of predators may be high in this situation (Patten 1971a) and survival is attained by a well-developed avoidance response for chinook and coho salmon.

Steelhead trout fry had a comparatively high mortality among stream resident species that may have been related in part to their behavior during tests, to their small size or an inferior predator avoidance response. Their survival, at least during the early fry stage, may be increased by unavailability through selection of a protective habitat. Hartman (1965) described the microhabitat of recently emerged steelhead trout and coho salmon in the Chilliwack River, British Columbia, as shallows at stream edges or in close proximity to physical objects. Recently emerged steelhead trout fry, observed adjacent to my study area in the Cedar River in 1965-66, were rarely found along sandy shore areas but were commonly seen among rocks at depths of 1 to 5 cm—when disturbed they hid under the rocks. The use of extreme shallows by steelhead trout fry may in part be an innate response to predators since this type of habitat in streams is relatively barren of other fish.

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HERITABLE RESISTANCE TO GAS BUBBLE DISEASE IN FALL CHINOOK SALMON, *ONCORHYNCHUS TSHAWYTSCHA*[1]

Construction of a series of dams on the Columbia River has resulted in air-supersaturation of the river during spring and early summer. Air-supersaturation is caused by the entrainment of air in water at depths as great as about 15 m in the plunge basins of the spillways below each dam. The level of air-supersaturation varies according to the amount of water-flow over the spillways (Ebel 1969). Supersaturation levels which are known to be fatal to salmonid fishes (Rucker and Hodgeboom 1953; Westgard 1964; Ebel 1969; and Blahm et al. 1975) are often sustained in the Columbia River from April through July, the period when many juvenile salmonids emigrate to the ocean.

Salmonids vary greatly in their tolerance for supersaturation (Ebel 1969). If a portion of this variability is related to additive genetic factors, an increase in the average tolerance of salmon populations to air-supersaturation can be expected as a result of selection. The purpose of this study was to estimate the influence of genetic factors on resistance to gas bubble disease for fall chinook salmon, *Oncorhynchus tshawytscha*. Specifically, the objectives were: 1) To determine the heritability of resistance to death from gas bubble disease for a stock of Columbia River fall chinook salmon, and 2) to determine the inherent level of resistance to gas bubble disease for several fall chinook salmon stocks.

Methods

Estimation of Heritability

Juvenile fall chinook salmon representing 80 families were reared at the Abernathy Salmon Cultural Development Center, near Longview, Wash. The families were produced by mating 20 males to 80 females, 4 females per male, in a nested breeding experiment. One hundred fish from each family were marked by cold-branding (Everest and Edmundson 1967) when they were 4 mo old and their weights averaged 2 g. Each group of 100 fish received a unique mark.

[1]This work was carried out in cooperation with the U.S. Fish and Wildlife Service, Oregon Fish Commission, Oregon Wildlife Commission, and Oregon State University.