

Section 9

**INSTREAM POSTRELEASE GROWTH AND SURVIVAL OF CHINOOK SALMON
SMOLTS SUBJECTED TO PREDATOR TRAINING AND
ALTERNATE FEEDING STRATEGIES, 1995**

By

Barry A. Berejikian

Coastal Zone and Estuarine Studies Division
Northwest Fisheries Science Center
National Marine Fisheries Service
National Ocean and Atmospheric Administration
Manchester Marine Experimental Station
P.O. Box 130
Manchester; Washington 98353

,

Contents

	Page
Introduction	,115
Materials and Methods	
Study Site	116
Procedures	116
Results	
Predator Training and Feeding	117
Postrelease survival	117
Changes in Body Size	117
Discussion	124
References	126

.

Introduction

Anadromous salmonids often suffer high mortality **after** being released from hatcheries. Predation can be a major **source** of mortality for juvenile **salmonids** and may be particularly intense on hatchery-reared fish that have incomplete development of antipredator behaviors (Olla and Davis 1989, Berejikian 1995). Naturally occurring fish predators on juvenile salmonids include other salmonids, e.g., Arctic char, *Salvelinus alpinus*; steelhead trout, *Oncorhynchus mykiss*; cutthroat trout, *O. clarki*; and **coho** salmon, *O. kisutch* (Meacham and Clark 1979, Fresh and **Schroder** 1987, Beauchamp 1990, Ruggerone **1992**), as well as non-salmonids, e.g., sculpins, *Cottus* sp.; and squawfish, *Ptychocheilus* sp. (**Ricker** 1941, **Beall** 1972, **Patten** 1975). The rate of predation by piscine **predators** on juvenile **salmonids** is regulated by a host of interacting environmental and biological factors (Ginetz and **Larkin** 1976, Ruggerone and Rogers 1984).

Juvenile **salmonids** have innate antipredator responses that can improve with experience. Predator avoidance ability of juvenile **salmonids** improves after exposure to piscine predators (Ginetz and **Larkin** 1976, **Patten** **1977**), and **learning** in particular may play an important role in predator avoidance ability for chinook salmon (*O. tshawytscha*), **coho** salmon (Thompson 1966, **Olla** and Davis 1989, Healey and Reinhardt 1995) and steelhead trout (Berejikian 1995). Typical hatchery rearing environments possibly obscure the development of anti-predation responses because hatcheries lack sensory stimuli associated with predation (Thompson 1966, **Olla** and Davis 1989). Thus, reduced susceptibility to predators after release may result if juvenile hatchery-reared **salmon** are provided predator stimuli.

There is substantial evidence that fish, including juvenile salmonids, “trade-off” the energetic benefits of foraging with its associated costs, namely, increased vulnerability to predation (Dill and Fraser 1984, Gilliam and Fraser 1987, Magnhagen 1988, Abrahams and Dill 1989). The decisions regarding where, how, and how much to forage are also dependent upon the internal motivational state of the fish. Hungrier **fish** are more willing to accept greater risk to obtain food than satiated, or less hungry fish (Magnhagen 1988). Engaging in risky behaviors such as foraging increases a fish’s vulnerability to predators (**Gilliam** and Fraser 1987) because, like all vertebrates, fish cannot be visually attentive to more than one activity at a time (e.g., foraging and vigilance; Lima and Dill 1990).

Instream postrelease survival of chinook salmon smolts has been estimated to range from a low of 24.6% over a 225 km migratory corridor to 53.3% (2.2 km corridor) in three independent studies (Sections 5 - 7 in this report). Survival differences between experimental treatments in these studies occurred within a week or so after release, suggesting that predation may be the primary source of mortality rather than slower acting factors such as starvation or disease. The present study was designed to test the hypotheses that exposing hatchery-reared fall chinook **salmon** to a piscine predator prior to release will improve their **postrelease** survival and that hungrier fish will suffer greater mortality than less hungry fish due to increased vulnerability to predators.

Materials and Methods

Study Site

This study was conducted at the University of Washington's Big Beef Creek Research Station near **Seabeck**, Washington. The study utilized Big Beef Creek, which enters Hood Canal about 4.5 km north of **Seabeck**. Stream flow during the study period was approximately 0.1 m³/s. The main piscine predators in the stream are cutthroat and steelhead trout (Fresh and **Schroder** 1987). A weir capable of capturing 100% of emigrating smolts exists at the stream's entrance to the estuary.

A population of fall chinook salmon (originated from the Deschutes River, WA, population) has been perpetuated by spawning adults, then rearing and releasing 3 month-old smolts. The subjects used for this study were progeny of 11 females and at least as many males spawned over **several** weeks in October 1994. Fish were incubated in Heath trays and reared in 7.3-m diameter circular fiberglass tanks in 10°C ± 0.5°C well water. One thousand three hundred fry were removed from the tanks and placed into a single, 1.8-m diameter tank with approximately 30 L/min inflow on 12 April 1994, where they were fed one to four times daily for a total daily ration of 1.5 to 2.8 body weight. All fish were injected with Passive Integrated Transponder (**PIT**) tags on 19 May 1995 and returned to the single rearing vessel.

Procedures

Two hundred fish were removed from the rearing tank at 1400 h on 15 June 1995 (day 1) and 100 fish were placed into each of two 0.75-m tanks receiving a flow of 15 L/min. On days 2 and 3, one tank was fed a ration equal to 2.0% of fish biomass (the "fed" tank) between 0800 and 1000 h and the other tank was not fed ("starved" tank). At 1200 h on day 3, alternate groups of 10 fish from the fed and unfed tanks were anesthetized with MS-222 and the individual PIT codes were recorded along with fish weight (to the nearest 0.1 g) and fork length (to the nearest 0.5 mm) until all 200 fish (100 from each tank) were processed. Within each group of 10 fish, individuals were alternately allocated to one of two identical 2.2-m diameter circular tanks. One tank received two predatory cutthroat trout 2 hours later, and the other tank received no cutthroat. The chinook salmon smolts were left in the "predator" and "control" tanks for 16 hours (1500 h to 0700 h the next day). All fish were then placed in a common 25 L transport tank and transported to a release site located at river kilometer 5.2 (**Rkm**) of Big Beef Creek. Hence, at the time of release, fed fish had been without food for 22 hours and unfed fish had been without food for 72 hours.

The entire process (i.e.; reading tags, feeding, predator exposure, and release) was repeated on 5 consecutive days, such that six releases were made at 0830 h from 17 June to 22 June 1995. The proportion of fish recaptured at the weir were analyzed by a randomized block (without replication) two factor analysis of variance (**ANOVA**) where feeding and predator exposure were the treatment effects and release **day** was the block effect. This analysis assumes no significant block by treatment interactions (Sokal and Rohlf 198 1).

Because fish were individually PIT tagged, we were also able to test for differences in growth and weight loss, changes in condition factors, and travel time to the weir for individual fish. These factors were analyzed by a randomized block **ANOVA** with replication, where release date was the blocking factor. We also recorded the frequency of predatory "bite marks" on chinook salmon smolts recaptured at the weir.

Results

Predator Training and Feeding

Cutthroat placed in the “predator” tanks ate between one and six chinook salmon smolts depending on the release day. Similar numbers of fed and **starved** smolts were eaten during predator training (Table 9-1). The 2 days of feeding prior to release produced fed fish that weighed more ($P = 0.044$) and had a higher mean condition factor ($P = 0.014$) than starved fish at release, but the fed and starved fish recaptured at the weir did not differ in either weight or condition factor ($P > 0.05$ in both cases). Hence, food in the digestive system probably accounted for much of the difference in weight at release.

Postrelease Survival

There was no significant effect of predator training ($P = 0.99$) or feeding regime ($P = 0.68$) on the proportion of chinook salmon smolts recovered at the Big Beef Creek weir (Fig. 9-1). However, the proportion of fish recaptured differed by release day (Chi-square = **20.2, 5 df**, $P < 0.001$). The proportion of fish recaptured decreased on each successive release day and substantial differences in recoveries by release day had occurred by 8 days after release (Fig. 9-2).

The average release weight and length of fish increased from release days 1 through 5 (Fig. 9-3). Within individual release groups, however, neither the release weight nor release length of survivors recovered at the weir differed from the average release lengths and weights of those fish not recovered (two sample t-tests, 1 df, $P > 0.05$ in all cases), indicating no size-selective mortality within a release group.

The proportion of predator-marked smolts (determined by the presence of bite marks) from a given release (all treatments combined) was inversely related to the proportion of smolts recovered at the weir from the same release ($F_{1,4} = 18.8$, $P = 0.012$, Fig. 9-4). This suggests that the number of attacks by piscine predators may have been greater on later release groups, assuming that the capture efficiency (i.e., proportion of successful attacks to total attacks) of the predators did not **decrease** over time (Donnelly and Whoriskey 1993). The ventral orientation of the fine “rake” marks on the smolts appeared to have been caused by the small sharp teeth of a **salmonid** predator. Only one smolt appeared to have been injured by an avian predator.

Changes in Body Size

Fish from later release groups grew (fork length) more than fish from earlier release groups from the time they were released until the time they were captured ($P = 0.034$). There was no difference in mean travel time to the weir by release date ($P = 0.212$), hence fish released on later days grew at a faster rate than did fish released on earlier days.

On average, chinook salmon **smolts** (all release groups combined) lost weight over the first 2 weeks after release. The lowest mean weight at recapture as a proportion of release weight (**recwt/relwt**) occurred 15 days after release. Over the subsequent 3 weeks until the final collection, **recwt/relwt** steadily increased (Fig. 9-5).

Table 9-1. Number of fed **and starved** chinook **salmon** smolts eaten by **cutthroat trout** in the predator training tanks, and the number of smolts (fed and **starved** combined) eaten by the smaller (< 275 mm) and larger (> 275 mm) of the two cutthroat trout, 1994.

Release	Total chinook salmon		<u>Total chinook salmon smolts eaten, by predator size-class</u>					
	<u>smolts eaten</u>		<u>Cutthroat trout < 275 mm</u>			<u>Cutthroat trout > 275 mm</u>		
	Fed	Starved	Length (mm)	Weight (g)	Smolts eaten	Length (mm)	Weight (g)	Smolts eaten
1	1	0	234	117	0	278	208	1
2	3	3	264	145	1	310	218	5
3	3	0	245	118	0	304	260	3
4	1	0	204	79	1	330	310	0
5	0	2	228	108	1	362	367	1
6	1	3	236	107	1	310	218	3
Total	9	8			4			13

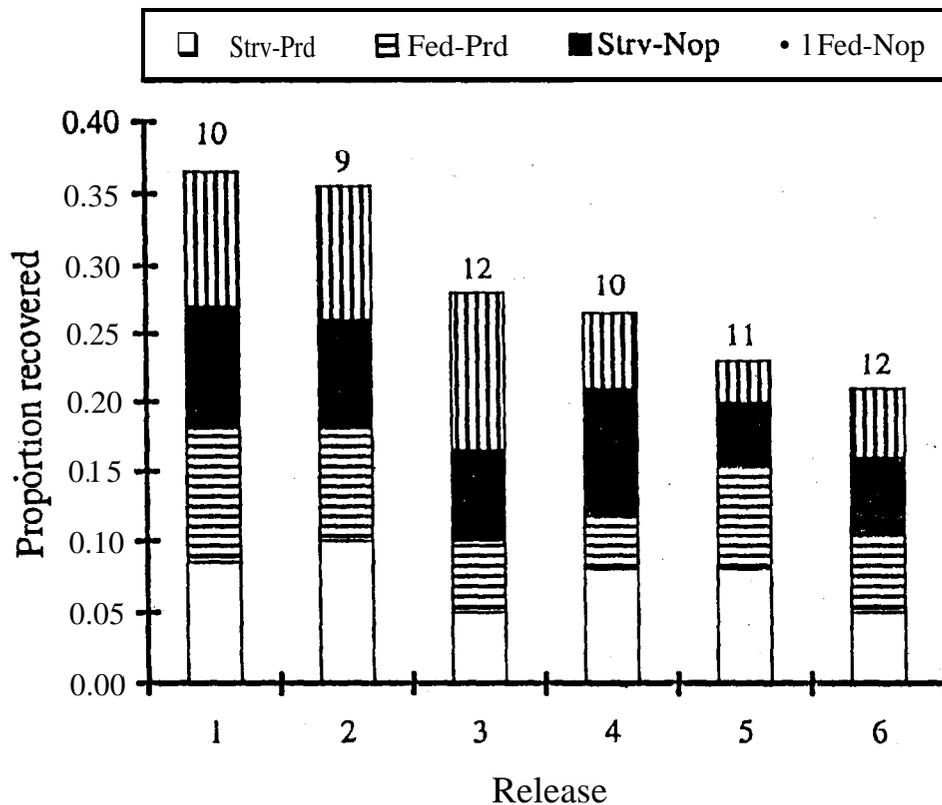


Figure 9-1. The total proportion of chinook salmon molts recovered at the Big Beef Creek weir that were fed and predator trained (Fed-Prd), fed and not trained (Fed-Nop), starved and trained (Strv-Prd), and starved and not trained (Strv-Nop). There was no effect of predator training ($P = 0.99$) or feeding regime ($P = 0.65$) on the proportion of smolts recovered. There was a significant effect of release group on the proportion of fish recovered at the weir ($P = 0.001$). The mean travel times in days to 50% recovery are shown above the bar for each release group.

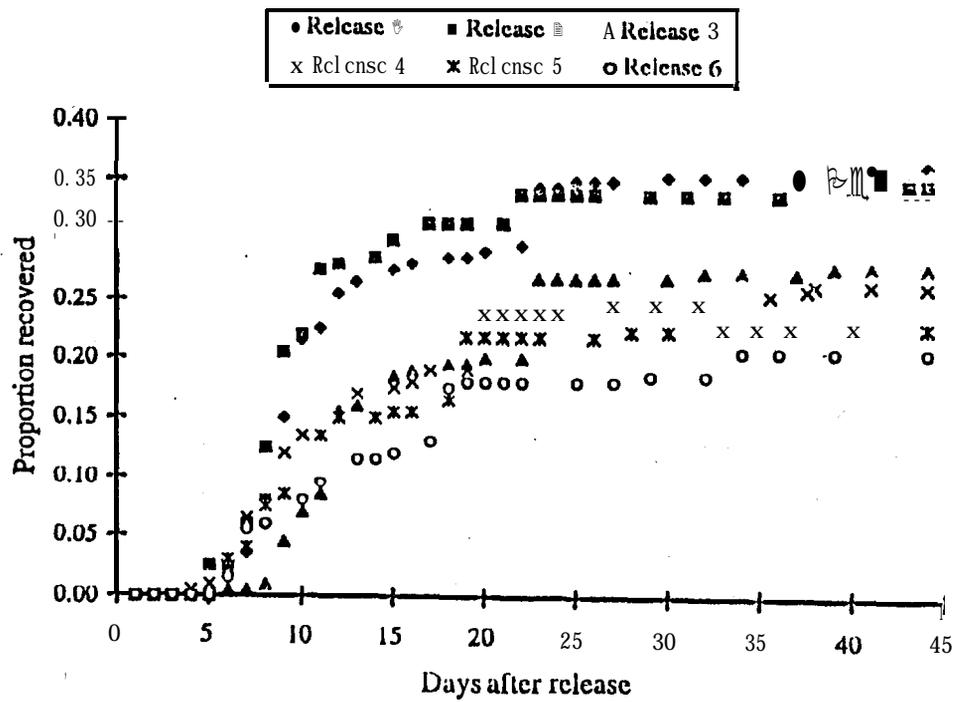


Figure Y-2. Cumulative proportion of chinook salmon smolts recovered from each release (all treatments combined). Note that large differences in recoveries among release groups had occurred by 8 days post release.

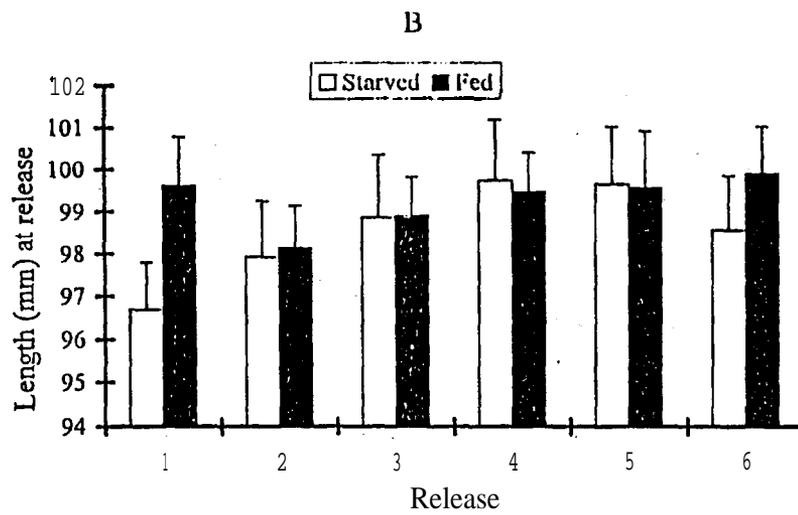
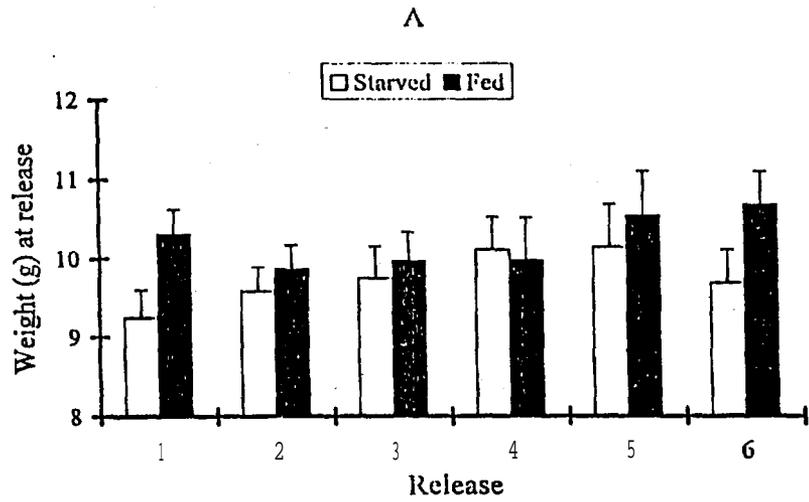


Figure 9-3. Average (A) weights and (B) fork lengths (\pm s.e.) of fed and starved chinook salmon smolts recorded 1 day prior to release.

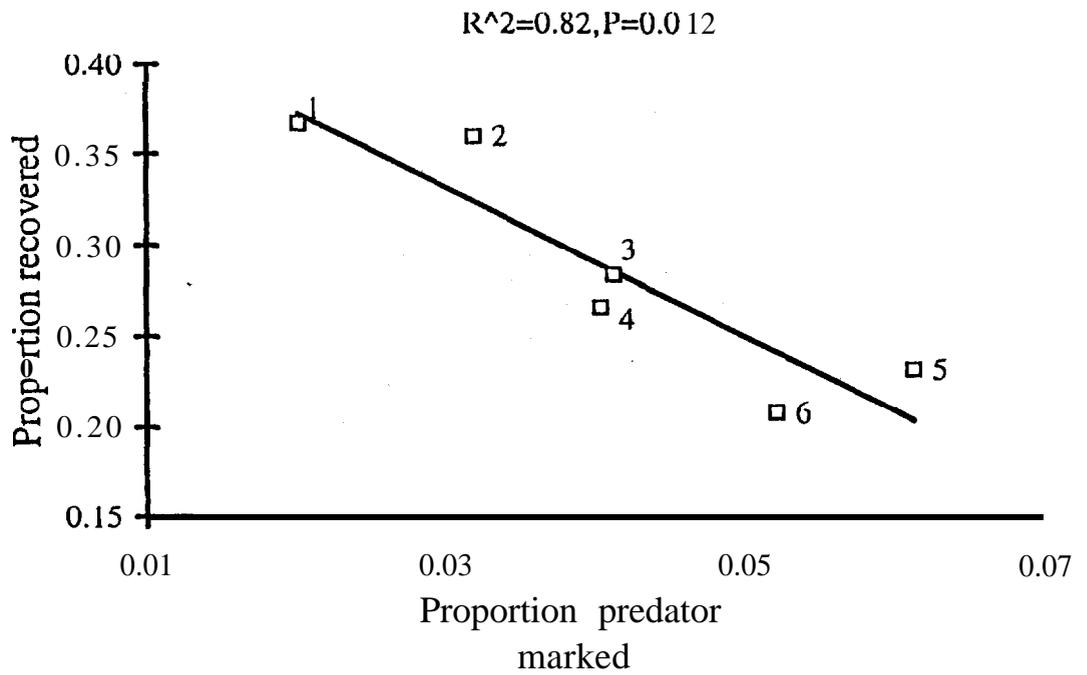


Figure 9-4. The significant linear relationship ($P = 0.012$) between the proportion of chinook salmon molts recovered (both treatments combined) on a given release day and the proportion that were recovered with predator marks. Release days are shown next to individual data points.

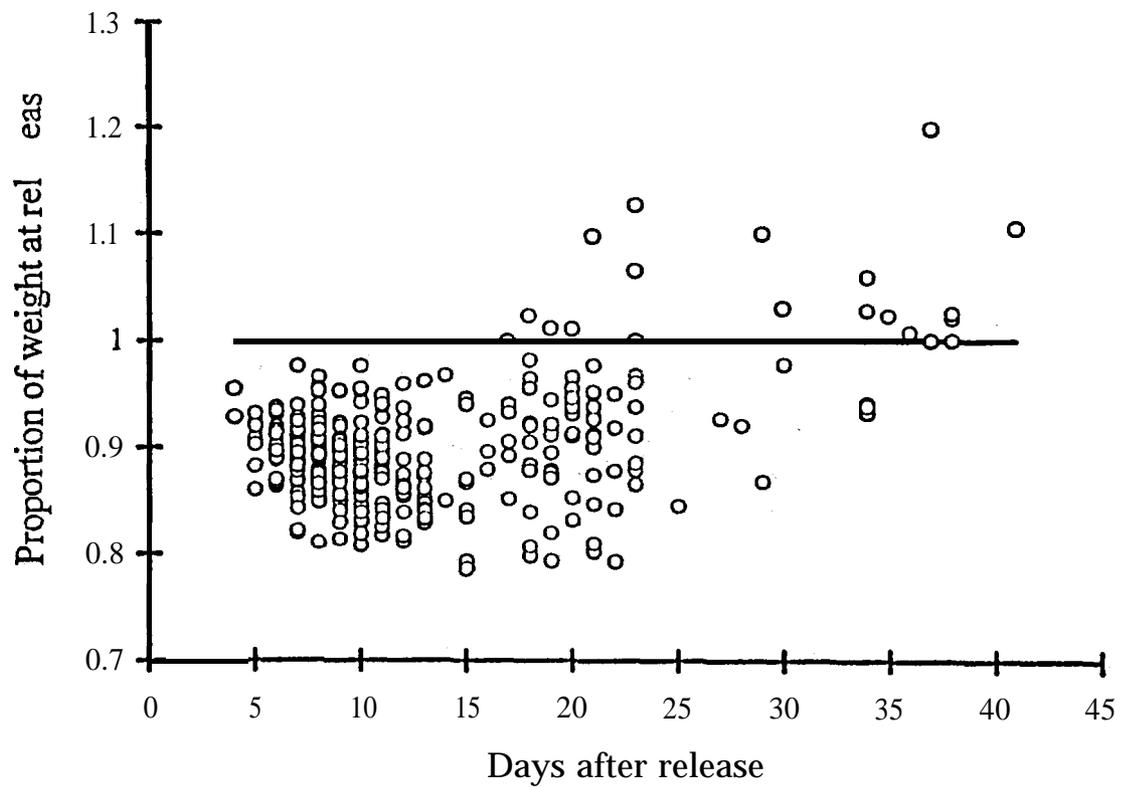


Figure 9-5. The ratio of release weight to recovery weight for 341 chinook salmon molts (both treatments and release groups combined) as a function of travel time to the Big Beef Creek weir. The horizontal line represents a ratio of 1 (i.e., no change in weight).

Discussion

The effect of hunger on predator vulnerability would have been most evident during the first few days after release because after about 2 days, the **amount** of food in the gut (probably the best measure of hunger, Dill 1983) of fed and starved fish would have been about equal. No fish migrated within 2 days, hence the effect of hunger was probably equalized between groups beyond 2 days for the duration of downstream migration, and may have masked any differential survival during the **first 2 days** after release.

It is possible that the antipredator training procedure used in this study was not extensive enough to improve antipredator recognition or anti-predation responses for the chinook salmon smolts. However, several studies have noted an increase in predator avoidance ability after only briefly exposing prey to predators. Olla and Davis (1989) trained **coho** salmon to avoid **lingcod** after two, 15 minute exposure periods. Berejikian (1995) found that steelhead fry exposed to visual predation by **sculpin** on other steelhead for 50 minutes had an effect on their subsequent predator avoidance ability. It took only two captures by rainbow trout of chinook salmon and **coho** salmon fry to alter these prey's **antipredator** behavior (Healey and Reinhardt 1995).

Other studies have also shown that prior exposure improves subsequent predator avoidance ability (Ginetz and Larkin 1976, Patten 1977). However, little evidence exists that predator training has improved postrelease survival of salmon smolts into a natural stream. Although Thompson (1966) found higher postrelease survival to a weir for chinook salmon that had been trained with electrified fish models compared with those that had no training, the experimental design precluded a valid statistical evaluation of the experiment. Therefore, although the aforementioned laboratory studies demonstrate the learning ability of juvenile salmon to avoid **predators**, the relevance of these studies to actual increases in postrelease survival has yet to be established.

The **proportion** of fish recovered at the weir declined for each successive release day. Increased piscine predator activity, indicated by the increase in the proportion of fish with bite marks on successive release days, may have been partly responsible. A numerical response (Hunter 1959) of avian predators to the increase in available prey may also have contributed to the poorer survival of later release groups.

Predation by avian predators may have masked any potential differences that may have existed in the ability of trained and untrained fish to recognize and respond to predatory cutthroat trout. In particular, belted kingfishers (*Ceryle alcyon*) were abundant in the study area and were observed feeding on salmonids throughout the 5.2 km stream section. Although the lack of avian predation marks on chinook smolts captured at the weir may indicate that birds were not significant predators, they may simply have had a greater success rate than piscine predators, particularly if the piscine predators were gape-limited and were able to capture chinook salmon smolts but not able to ingest them. On 28 July 1995, we counted (by snorkeling) 31 cutthroat trout with estimated lengths greater than **200** mm in Big Beef Greek from the weir upstream to about Rkm 1. Data from the predator training tanks demonstrates that cutthroat larger than 275 mm captured more smolts than those cutthroat smaller than 275 mm (Table 9-1). Because the majority of cutthroat trout in Big Beef Greek were estimated to be shorter than 275 mm, their capture efficiency on chinook salmon smolts (average fork length = 98 mm) may have been quite low.

Kingfishers are **homeothermic** and therefore have much higher rates of metabolism than salmonids. Hence, they have the metabolic capability of consuming far greater numbers of smolts per predator per unit time. Gastric evacuation rates of salmonids, which limit their rate of food

intake (Ruggerone and Rogers 1984, Ruggerone **1989**), are very slow (e.g., approximately 2 days for *O. mykiss* at **10°C**: Beauchamp 1990) compared to birds, which can process a substantially greater amount of **food per** unit time (cf. Wood 1987). We believe that kingfishers probably consumed far greater numbers of chinook salmon **smolts** than did cutthroat, although we have no data to support this claim. **Future** studies will focus on successfully training salmon **smolts** to avoid the most significant **predator(s)** they are likely to encounter after release, which, depending on the postrelease environment, may include piscine, avian, or even terrestrial predators.

References

- Abrahams, M. B., and L. M. **Dill**. 1989. A determination of the energetic equivalence of the risk of predation. *Ecology* **10:999-1007**.
- Beauchamp, D. A: 1990. Seasonal and **diel** food habits of rainbow trout stocked as juveniles in Lake Washington. *Trans. Am. Fish. Soc.* **119:475-482**.
- Beall**, E. P. 1972. The use of predator-prey tests to assess the quality of chum salmon (*Oncorhynchus keta*) fry. M.S. Thesis, Univ. Washington 105 p.
- Berejikian, B. A. **1995**. The effects of hatchery and wild ancestry and experience on the relative ability of steelhead trout **fry** (*Oncorhynchus mykiss*) to avoid a benthic predator. *Can. J. Fish. Aquat. Sci.* **52:2076-2082**.
- Dill, L. M. 1983. Adaptive flexibility in the foraging behavior of fishes. *Can. J. Fish. Aquat. Sci.* **40:398-408**.
- Dill, L. M., and A. H. G. Fraser. 1984. Risk of predation and the feeding behavior of juvenile **coho** salmon (*Oncorhynchus kisutch*). *Behav. Ecol. Sociobiol.* **16:65-71**.
- Donnelly, W. A. and F. G. **Whoriskey Jr.** 1993. Transplantation of Atlantic salmon (*Salmo salar*) and crypsis breakdown. In R. J. Gibson and R. E. Cutting (editors), Production of juvenile Atlantic **salmon, Salmo salar**, in natural waters, p. 25-34. *Can. Spec. Publ. Fish. Aquat. Sci.* 118.
- Fresh, **K. L.**, and S. L. **Schroder**. 1987. Influence of the abundance, size, and yolk reserves of juvenile chum salmon (*Oncorhynchus keta*) on predation by freshwater fishes in a small coastal stream. *Can. J. Fish. Aquat. Sci.* **44: 236-243**.
- Gilliam**, J. F., and D. F. Fraser. 1987. Habitat selection under predation hazard: test of a model with foraging minnows. *Ecology* **68:1856-1862**.
- Ginetz, R. M., and P. A. **Larkin**. 1976. Factors affecting rainbow trout (*Salmo gairdneri*) predation on migrant **fry** of sockeye salmon (*Oncorhynchus nerka*). *J. Fish. Res. Board Can.* **33: 19-24**.
- Healey, M. C., and U. Reinhardt. 1995. Predator avoidance in naive and experienced juvenile chinook and **coho** salmon. *Can. J. Fish. Aquat. Sci.* **52:614-622**.
- Hunter, J. G. 1959. Survival and production of pink and chum salmon in a coastal stream. *J. Fish. Res. Board Can.* **16:835-886**.
- Lima, S. L., and L. M. Dill. 1990. Behavioral decisions made under the risk of predation: a review and prospectus. *Can. J. Zool.* **68:619-640**.
- Magnhagen, C. 1988. Predation risk and foraging in juvenile pink (*Oncorhynchus gorbuscha*) and chum salmon (*O. keta*). *Can. J. Fish. Aquat. Sci.* **45: 592-596**.

- Meacham, C. P., and J. M. Clark 1979. Management to increase **anadromous** salmon production. In M.E. **Clepper** (editor), Predator-prey systems in fisheries management, p. 377-386. Sport Fish Institute, Washington D. C.
- Olla**, B. L., and M. W. Davis. 1989. The role of learning and stress in predator avoidance of hatchery-reared **coho salmon** (*Oncorhynchus **kisutch***) juveniles. *Aquaculture*. 76: 209-214.
- Patten**, B. G. 1975. Comparative **vulnerability** of fry of Pacific salmon and steelhead trout to predation by torrent sculpin in stream aquaria. *Fish. Bull.* 73: 931-934.
- Patten**, B. G. 1977. Body size and learned avoidance as factors affecting predation on **coho** salmon **fry** by torrent sculpin (***Cottus rotheus***). *Fish. Bull.* 75: 451-459.
- Ricker**, W. E. 1941. The consumption of young sockeye salmon by **predaceous** fish. *J. Fish. Res. Board Can.* 5:293-313.
- Ruggerone, G. T., and D. E. Rogers. 1984. Arctic char predation on sockeye salmon **smolts** at Little Togiak River, Alaska *Fish. Bull.* 82:401-410.
- Ruggerone, G. T. 1989. Gastric evacuation rates and daily ration of piscivorous **coho** salmon (*Oncorhynchus **kisutch***). *J. Fish Biol.* 34:452-463.
- Ruggerone, G. T. 1992. Threespine stickleback aggregations create a potential predation refuge for sockeye salmon fry. *Can. J. Zool.* 70:1052-1056.
- Sokal**, R. R., and F. J. Rohlf. 1969. *Biometry*. W. H. **Freemant** and Co., San Francisco. 776 p.
- Thompson, R. B. 1966. Effects of predator avoidance conditioning on the postrelease survival rate of artificially propagated salmon. Ph.D. Thesis, Univ. Washington, Seattle, WA. 156 p.
- Wood, C. C. 1987. Predation of juvenile Pacific salmon by the common merganser (***Mergus*** merganser) on eastern Vancouver Island I: Predation during the seaward migration. *Can. J. Fish. Aquat. Sci.* 44:941-949.