Predator Avoidance Training Can Increase Post-release Survival of Chinook Salmon

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Abstract — Predator avoidance training may be a tool fish culturists can use to increase the post-release survival of hatchery-reared salmonids. Laboratory studies indicate salmonids observing predation on conspecifics have a higher probability of survival in subsequent predation challenges than predator naive fish. In order to test this concept on a hatchery scale, we stocked 16,000 fall chinook salmon (*Oncorhynchus tshawytscha*) swimup fry into each of six 6,000 liter fiberglass raceways equipped with predator tight covers. Fish in three raceways were designated as controls and prior to release were never exposed to predacious birds or fish. Salmon in the other three raceways were exposed to great blue heron (*Ardea herodias*), hooded merganser (*Lophodytes cucullatus*), largemouth bass (*Micropterus salmoides*), and brown catfish (*Ictalurus nebulosus*) predation prior to release. After exposure, tagged fish from each raceway were released into a Puget Sound tributary stream, Curley Creek, to evaluate the effect of training on post-release survival. Significantly ($P < 0.05$) more trained than untrained chinook salmon were recovered at a downstream weir. The 26% higher relative recovery of trained versus untrained fish suggests enhancement and conservation hatcheries can use this approach to increase salmon post-release survival.

Introduction

Fish culturists may be able to use predator avoidance training to improve the post-release survival of hatchery-reared salmonids (Maynard et al. 1995). Laboratory studies indicate salmon rapidly learn to recognize and avoid predators after observing attacks on conspecifics (Patten 1977, Thompson 1966, Olla and Davis 1989). This predator recognition increases an experienced fish's chance of surviving during subsequent predator encounters. Research has also demonstrated that conditioning chinook and chum salmon to avoid electrified models of predacious rainbow trout increases their survival in natural and artificial streams (Thompson 1966, Kanayama 1968). The experiment described in this paper determines if conditioning salmon to avoid live predators also increases post-release survival.

Methods

Ninety-six thousand fall chinook salmon swimup fry donated by the Washington Department of Fish and Wildlife (WDFW) Minter Creek Hatchery were transported to the National Marine Fisheries Service (NMFS) Manchester Marine Experimental Station where they were systematically divided into six equivalent lots. Each lot was then ponded into one of six pilot scale raceways (6.4 m long by 1.5 m wide with a 0.6 m water depth) located at the laboratory's freshwater fish culture facility. The fish in three raceways received experimental predator avoidance training, while fish in the other three raceways served as untrained controls. The control raceways were always covered with bird-tight netting to ensure that unintended predator exposure did not confound the results. Except for predator avoidance training, the fish in both treatments received identical husbandry and were reared following standard salmon culture protocols.

The training process employed a diverse array of predators to ensure the fish were exposed to at least one species they would encounter after release. This also provided us an opportunity to compare each predator species' suitability for conditioning avoidance behavior in hatchery-reared salmon.

In March 1997, training was initiated by uncovering the three predator avoidance conditioning raceways to allow local fish-eating birds access to the fish. Although a young great blue heron (*Ardea herodias*) occasionally fished the raceways, it disappeared within a few weeks and was not observed again. Belted kingfishers (*Ceryle alcyon*) occasionally flew overhead during the study, but were never observed to fish in the raceways. Therefore, we considered this insitu predator exposure at best a limited event.

The primary predator training sessions were conducted by placing predacious birds and fish in cages placed in the raceways. The cages were constructed of a 1.6 m long by 1.1 m wide by 1.1 m tall polyvinyl chloride (PVC) pipe frame that was completely covered with a 3.8 by 3.8 cm mesh net. This size mesh allowed chinook salmon fry to freely swim in and out of the cage, while confining larger predacious birds and fish within the cage. When they were placed in the raceways, the top half of the cages were suspended above the water so that piscivorus birds would not drown. Cages containing no predators were frequently placed in the raceways so that the fish would learn to associate predation events with predators, rather than presence of the cage.

Two phases of cage training were conducted. First, hooded mergansers (*Lophodytes cucullatus*) were placed into these cages for seven 50 minute long training periods in late April 1997. In nearly all training sessions, the mergansers were removed from the raceway before they ceased fishing. This ensured salmon fry experienced nearly continuous negative reinforcement from these predators. The next training experience involved placing two largemouth bass (*Micropterus salmoides*) and one brown catfish (*Lophodytes cucullatus*) in each cage for a week. Prior to being placed in the cage, each fish was tested to ensure it ate chinook salmon fry. Both types of cage training experiences were completed by mid-May 1997.

The effect of predator avoidance training on post-release survival was evaluated with releases of study fish into the Curley Creek watershed in Kitsap County, WA. These releases were conducted with representative samples of fish from each of the six raceways. These sample fish were removed from the raceways, transferred to six 1.5 m diameter circular tanks, and held from the end of May 1997 until they were released in July 1997. In June 1997, about three weeks before the first release was initiated, the fish were measured to the nearest mm, weighed to the nearest 0.1 g, and tagged with passive integrated transponders (PIT tags). The salmon in the three circulars from the predator avoidance conditioning raceways had their training reinforced by placing one largemouth bass in each tank for the nights of 25 June and 30 June 1997. The unconstrained predators were allowed to prey upon chinook salmon fry in the circular tanks overnight and were removed early the next day.

Releases began three days after the last retraining session, with 51 fish being trucked and released into each of two Curley Creek tributaries on 3 July 1997. The release site on each tributary was 1.3 km upstream of our smolt collection weir on Curley Creek. We were concerned that contagious behavior might confound the results. Contagious behavior is a form of social learning where naive animals mimic the behavior that more experienced members of their group display to predators, food sources, and other new stimuli. We minimized this possibility of contagious behavior confounding the results of the study by releasing fish from only one rearing treatment in each tributary on a given release day. The possibility of fish from the two rearing treatments meeting each other at the release sites was further reduced by allowing at least 48 hours to pass between releases. Tributary effects were controlled by alternating the tributary the fish were released into from one release to the next. A total of 511 control and 510 predator trained fish were released into the Curley Creek watershed during the 10 releases. The difference in recovery between the two treatments was compared with contingency table analysis.

Results

In our study, chinook salmon rapidly learned to avoid mergansers. Prior to the introduction of mergansers to a training cage placed in a raceway, fry readily swam into and out of the cage. However, after three training sessions with mergansers, few fry continued to enter the cage. By the fifth session, almost no chinook salmon entered the cage and nearly all the fish remained at least 15 cm from the cage. Initially, the mergansers averaged more than nine prey per training session. However, this average rapidly declined to less than six prey per training session as fry became conditioned to avoid the birds.

The predator avoidance behavior induced in chinook salmon by largemouth bass and brown catfish differed from that induced by mergansers. When bass and catfish were first introduced, few chinook salmon fry entered the cage. However, chinook salmon began to enter the cage within a day, and after a week's residence with these piscivorus fish there were as many chinook salmon in the cage as outside. This change in prey distribution over time may be related to the difference in merganser and bass hunting tactics. Unlike mergansers, bass and catfish did not continuously pursue prey. Instead, they passed their time either holding in place or slowly cruising around the cage perimeter. Although all fish used in training were proven predators, their appetites were not as great as the mergansers'. For instance, the largemouth bass used in reinforcement training in the circular tanks averaged only five chinook salmon during the 17 hour overnight training period.

Training did not appear to affect fish growth. At tagging, the average fork length (Figure 1) of fish in the trained and control treatments did not significantly ($P = 0.702$) differ. The weight (Figure 2) of fish from both treatments also did not significantly ($P = 0.110$) differ at tagging.

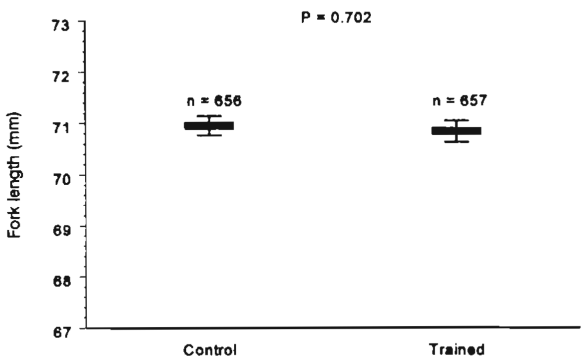

Figure 1. Average fork length of control and predator avoidance trained fall chinook salmon. Horizontal bars are mean values and vertical bars are standard error.

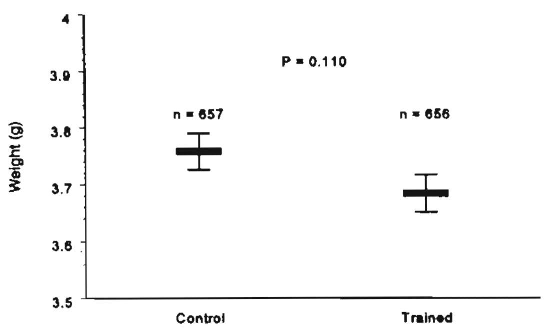

Figure 2. Average weight of control and predator avoidance trained fall chinook salmon. Horizontal bars are mean values and vertical bars are standard error.

Predator avoidance training appears to have increased chinook salmon post-release survival in our study. The post-release recovery of predator conditioned fish was significantly ($P = 0.046$) higher than that of control fish (Figure 3). The relative survival [(% recovery experimental treatment - % recovery control treatment) / (% recovery control treatment)][100%] of predator conditioned fish was 26% higher than that of control fish. Within a week of the last release, the recovery rate of fish from both treatments had drastically dropped. Although the weir was operated into September, only 18.6% of all the fish released were recovered.

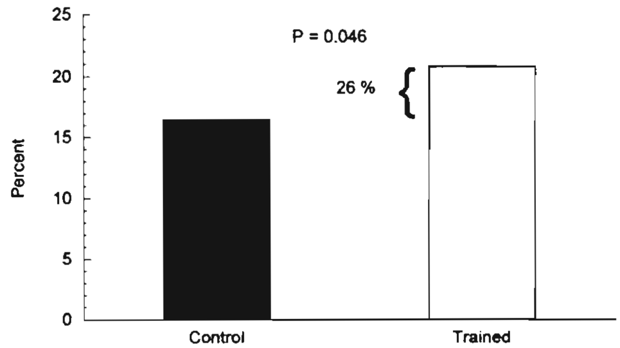

Figure 3. Percent post-release recovery of control and predator avoidance trained fall chinook salmon recaptured at the Curley Creek weir.

Discussion

This study confirms that predator avoidance training with live predators can increase the post-release survival of hatchery-reared salmonids. The benefits of this training can be considerable with the post-release survival of predator trained fish being 26% higher than untrained fish. The predator avoidance training protocol used in this study required only a slight increase in operational costs. During predator avoidance training, less than two hours of personnel time are expended per day in handling mergansers. The birds rapidly learned to enter the training cage, the cage was easily transported to and from the raceways, and once the cage was placed in the raceway it did not appear to interfere with routine fish culture operations. A pair of hooded mergansers can be purchased for about $125, and it takes less than 10 minutes a day to maintain them in captivity. The bass and catfish have similarly low acquisition, handling, and maintenance costs. The increased survival benefits of predator avoidance training thus far outweighed the slight increase in operational costs in our experiment.

Predator avoidance training has a very favorable cost:benefit ratio. This ratio is based on the number of fish sacrificed in training that would have successfully migrated downstream compared to the increase in number of successful downstream migrants due to training. The prerelease exposure of chinook salmon to limited (0.6% mortality) hooded merganser and largemouth bass predation increased post-release survival by 26%. This required that approximately 100 fish be sacrificed to train the remaining 15,900 fish to avoid predators after release. With the 20-50% instream survival rates experienced by control fish in past studies (Maynard et al. 1995), this predator training produces an additional 775-1937 fish surviving migration through the stream corridor. This yields a very favorable 1:40 cost:benefit ratio.

Although predator avoidance training is a useful tool for increasing post-release survival, it only needs to be implemented at those facilities that produce predator naive fish. Hatcheries allowing predators to enter their ponds due to a lack of bird netting and electric fences are probably already providing uncontrolled predator avoidance training.

Programs using hatcheries to produce fish to enhance the fishery or mitigate for habitat loss can potentially derive several benefits from adopting predator avoidance training protocols. The most obvious benefit would be to simply use the increased post-release survival generated by predator avoidance training to boost the number of fish available for harvest. The increased post-release survival generated by predator avoidance training might also be used to reduce the number of fish that must be reared and released to produce an equivalent number of fish for harvest or to meet mitigation goals. The increased survival generated by predator avoidance training could be used to lower operational costs with fewer fish needing to be fed, marked, etc. to produce an equivalent number of recruits to the fishery. Increased post-release survival would permit facilities to meet their enhancement and mitigation goals, while removing fewer wild fish for broodstock and releasing fewer smolts to negatively interact with wild fish in the migratory corridor. Both these factors are important considerations in permitting enhancement operations to continue in areas where they may impact endangered and threatened stocks.

The development of predator training protocols is in its infancy. Research should be conducted to determine if live predators or electrified models (such as those used by Thompson 1966 and Kanayama 1968) provide the best conditioning stimulus. Work should also be carried out to determine if visual, acoustic, chemical, or a combination of cues provides the information necessary for effective predator avoidance training. This research will not only refine techniques, but will provide nonlethal training protocols that can be used in the reintroduction of endangered and threatened stocks of salmon.

Predator avoidance training offers conservation programs an urgently needed opportunity to increase the survival of captive reared animals that are being reintroduced to the wild. In supplementation programs, where a small number of fish may be sacrificed in training, live predators can be used to condition fish to avoid predators they will encounter after release. However, at facilities rearing protected fish that cannot be sacrificed during training, nonlethal approaches to predator avoidance training probably should be used. Nonlethal training may potentially be accomplished by conditioning fish with electrified predator models. Alternatively, if visual cues are all that is needed to condition fish to avoid predators, nonlethal training may be achieved by simply having captive-reared fish visually witness (live or videotaped) predation events on conspecifics from nonlisted stocks. In general, predator avoidance training is a valuable technique that both fishery enhancement and conservation hatcheries can use to increase the post-release survival of their fish.

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