Section 2

THE EFFECT OF AUTOMATED SUB-SURFACE FEEDERS ON THE BEHAVIOR AND PREDATOR VULNERABILITY OF FALL CHINOOK SALMON

by

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Introduction

Research on feed delivery systems usually focuses on their effects on feeding efficiency, growth, in-culture survival, and in-culture behavior (Alanara 1992, Cho 1992, Tidwell et al. 1991, Tipping et al. 1986). However, with anadromous species like chinook salmon, which often have less than a 2% postrelease survival, it is also crucial to determine how these systems affect their predator vulnerability.

Traditional surface feeding techniques, with pellets broadcast on the surface by hand or moving vehicle, may condition behaviors in salmonids which increase their vulnerability to predators after release. In natural streams, salmonids feed on small insects falling off terrestrial vegetation, emergent insects drifting in the water column, or aquatic insects crawling on the river bottom. More importantly, they maintain an innate wariness of large moving objects at the surface. When a new stimulus, such as the silhouette of a bird, enters their visual field they may respond by (i) orienting to the object and freezing, (ii) rapidly fleeing away from the object, or (iii) seeking cover. The response of hatchery-reared salmonids to large moving objects at the surface delivering food is starkly different. Instead of fleeing, hatchery fish rapidly become conditioned to swim to the surface and fearlessly approach people and vehicles. This conditioned response is displayed even when food is not being delivered. In theory, if this conditioned response were generalized to all moving stimuli at the water surface it would increase the predatory risk from avian predators after release. Similarly, if surface feeding conditions hatchery salmon to be more surface oriented than their naturally-reared counterparts, then it makes them highly vulnerable to avian predators.

Automated subsurface feed delivery systems may be a tool for fish culturists to prevent hatchery-reared salmon becoming conditioned to approach large moving objects at the surface. Such feeders should condition fish to become bottom oriented and maintain their innate wariness of surface objects.

This study compares the depth preference, fright response to models, and predator vulnerability of salmon reared on traditional hand surface feeding and a new automated subsurface feed delivery system. The information is then used to evaluate the automated subsurface feed delivery system for conditioning behaviors to make juveniles less vulnerable to predators after they are released from hatcheries. The results are also used to determine if behaviors conditioned by the traditional hand feeding technique are specific to the object delivering feed, or to any large moving objects at the surface in general.

Methods

The study was conducted with 28,800 swim-up fry of fall chinook salmon (Soos Creek stock) donated by the Soos Creek Hatchery, operated by WDFW. The fish were transported as swim-up fry to the Manchester Research Station in February 1996. They were maintained in two rearing troughs (4-m long) until the experiments commenced. During this pre-experimental period the feed was broadcast on the surface by automated belt feeders.

After two weeks the fish were assigned randomly into six equal lots, numbering 4,800 per lot, and ponded into six raceways (6.4 × 1.5 m, and 0.6-m water depth). The fish in three raceways were fed a standard commercial moist pellet diet through an experimental automated subsurface delivery system. Fish in the other three raceways acted as controls and were fed the same diet broadcast by hand on the surface. Except for the method of feeding, the fish in both treatments received identical husbandry following standard salmon culture protocols.

The automated feed delivery system evaluated in the study was a modification of the system used at the WDFW Bingham Creek Hatchery and described by Maynard et al. (1996). An Allen feeder was fitted into the top of a tapered fiberglass cone supplied with demand feeders (Fig. 1). The cone was supplied with water (40 L/min) pumped in just below the top of the taper. A pipe (2.54-cm diameter) carried water from the bottom of the cone into the raceway. The pipe was branched with fittings to produce four conjoined lines, which ran across the bottom of the raceway. The release of food from the Allen feeder was regulated by an electric timer. When the arms in the Allen feeder were triggered to spin, food dropped into the cone, where it was carried down the piping system and into the raceway by the flowing water. The ends of lines were bent slightly upwards so food would rise to the surface, simulating emergent insect larvae.

In May, the fish in each raceway were systematically sorted and about two-thirds of the fish from each raceway were released. The remaining one-third were anesthetized in tricaine methanesulfonate (MS-222) and tagged photonically for identification. In photonic tagging, a carbon dioxide powered injector is used to produce a high pressure jet that propels microspheres containing fluorescent dyes into the skin. The microsphere tags and injector were supplied by New West Technologies of Santa Rosa, California. Fish reared on the automated underwater feeder were tagged with invisible blue tags and those reared by surface broadcast with invisible red tags. The tagged fish were then returned to their respective raceways and reared as before.

The distribution of the fish in the raceways was evaluated from video observations made during rearing. On an observation day, a high-resolution monochrome video camera was submersed in each raceway and the behavior of the fish videotaped for 50 minutes. The camera faceplate was positioned (about 1.3 m) directly across from the center of a vertical grid (1.37 × 0.55-m deep). The grid was divided into four equal vertical sections and horizontally in the middle to create eight sections in total. Fish were not fed on the days when tapes were made and all six raceways were taped on the same day. The taping was repeated three times at intervals of one week. The tapes were analyzed using video-imaging software and the number of fish in each section was counted. The percentage of fish in each section was then computed and the percentages compared with a two-way ANOVA.

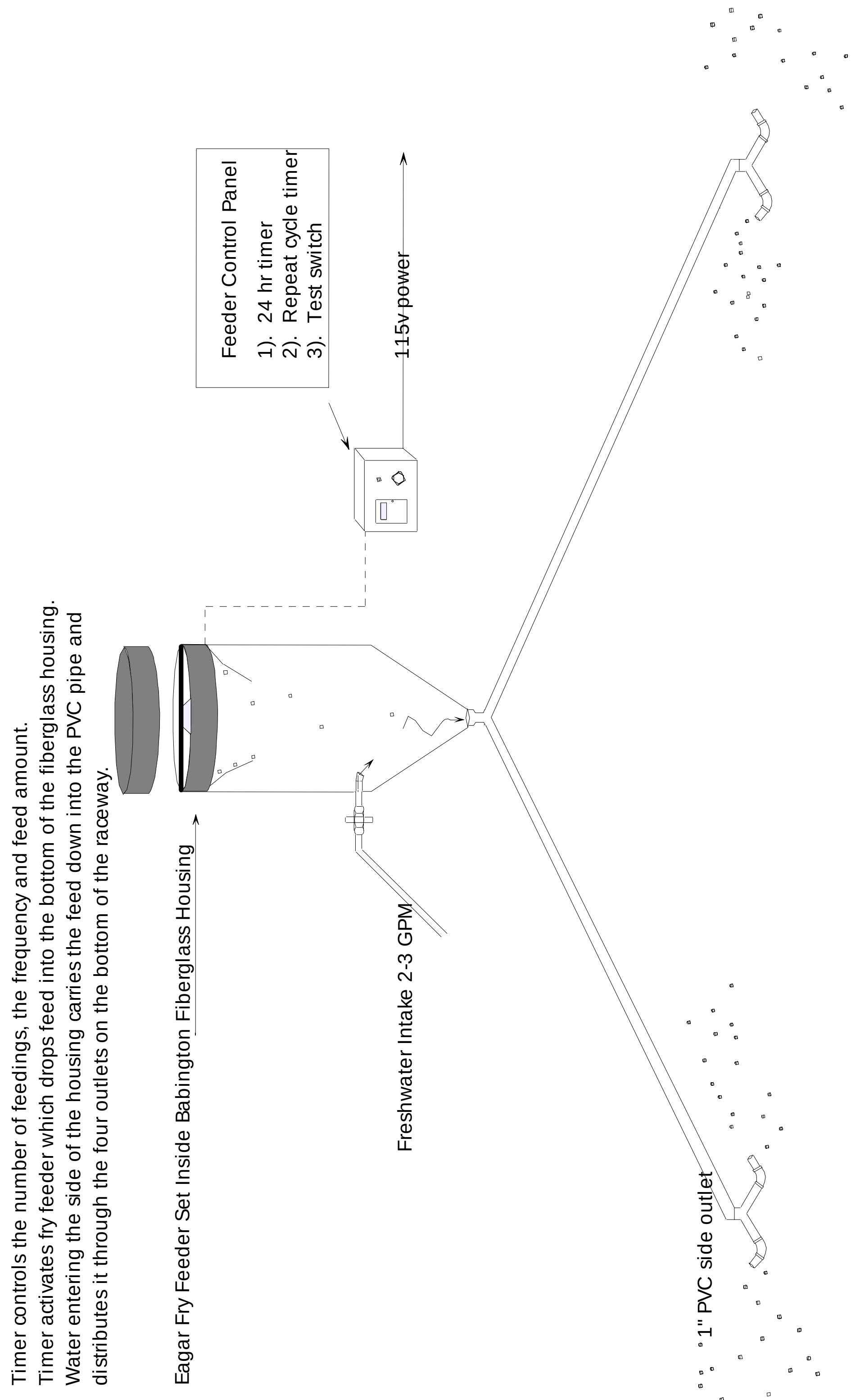

Figure 1. Automated subsurface feed delivery system.

In order to determine if the fish displayed the same depth preference in a new environment as in the tanks, their depth preferences were observed in laboratory aquaria (200-L capacity and 40-cm deep). Both sides and back of each aquarium were covered with gray PVC sheet. Horizontal lines (5.08-cm apart) were drawn across the back sheet to enable the observer to score the depth distribution of the fish. During each test the aquarium was illuminated from above, thus effectively hiding the observer.

A single test would consist of removing fish at random from each treatment, placing one fish in each aquarium, and acclimating them for 44 hours to their new environments. Two fish (one from each treatment) were observed during a trial which lasted 1 hour. The position of the fish in the tank was watched and scored at 10-minute intervals. The score (depth) for the six observations on each fish was averaged and the average depth distribution of fish in the two treatments was compared using a *t*-test. Twenty-one fish from each treatment were observed in the depth distribution tanks.

The predator vulnerability of hand- and automatic-fed fish was compared with bioassays conducted in the predation test arena at Manchester Research Station. The test arena consisted of rectangular tanks (6,000 L, 6.4 × 1.5 × 0.6-m water depth) placed side by side and protected in a fenced area. A chain-link door separated the raceways from the holding area where hooded mergansers were held when not being used in bioassays. The bottom of each tank was lined with pea gravel. Algae were allowed to grow naturally on the sides of the tank and the entire arena was covered with a camouflage net to simulate a more natural environment.

In the first series of predation bioassays, 10 fish were selected from each rearing raceway and then transferred to one of the predation bioassay test arenas. Each tank was stocked with a total of 30 fish, with each tank receiving fish from only one rearing treatment. The fish were left in the arena overnight to recover from the effects of handling before mergansers were introduced the next day. After the birds had fished for three hours they were removed from the test arena, the tanks were drained, and the number of fish surviving was counted. This test procedure was repeated 29 times, with treatments alternated between the two tanks. Survival in the two rearing treatments was compared with a *t*-test.

The second series of bioassays was conducted similarly except fish from both rearing treatments were combined in each predation bioassay test arena. When these trials were initiated, fish were only available from two experimental and two control raceways. Five matched-length fish were removed from each raceway and transferred to one of the bioassay tanks. Each bioassay tank was stocked with 10 fish from each rearing treatment. The fish were acclimated overnight to recover from the effects of handling before exposure to the mergansers. The birds fished for only two hours due to the reduced number of fish. At the end of a trial the mergansers were removed from the arena, the water drawn down and the number of survivors from each treatment were identified. The relative survival of fish from the two rearing treatments was again compared with a paired *t*-test.

The response of fish to visual stimuli was observed prior to release. These trials were conducted by an observer located high (2.4 m) above the raceways recording responses to various visual stimuli. A second person moved along the outside of each raceway without being observed, ready to present one of the visual stimuli. The observer then told the carrier which stimulus to raise. The three types used were (i) a full scale model of a great blue heron, (ii) a pointed shovel, and (iii) the person him/herself. The trials were conducted with the stimuli until the response of the fish in all six raceways was recorded for each one. The treatment responses were then statistically compared with a Fisher's exact test.

Results

The behavior of the fish was observed each day from the beginning of the experiment. It was clear from the first day that fish in the two rearing treatments were displaying different responses to the approach of people. Fish in the automatic feeder treatment remained on the bottom and moved away from people approaching the raceway while fish in the hand-fed treatment rose up from the bottom and swam forward when people approached the raceway. This behavioral difference remained throughout the rest of the experiment.

Fish growth was monitored from the time they were initially placed in the experiment. When transferred from Soos Creek Hatchery, the fish averaged about 0.45 g and were about 38-mm long. Twenty-six days into the experiment (26 March 1996) fish in the automatic feeder treatment weighed 0.572 g and were 40-mm long, while fish in the hand-fed treatment weighed 0.593 g and were 39-mm long. During this first sampling period no significant differences were observed in fish weight ($P = 0.378$) or length ($P = 0.106$). On 18 April 1996, fish in the automatic feeder treatment averaged 0.679 g in weight and 42 mm in length and those in the hand-fed treatment raceways averaged 0.618 g in weight and 41 mm in length. Although not significantly ($P = 0.074$) different in weight, fish in the hand-fed treatment were significantly ($P = 0.045$) shorter than fish fed by automatic feeders. The overall poor growth of fish in both treatments was due to an infestation of *Costia*, diagnosed on 19 April 1996. The fish were successfully treated with a 1:6,000 formaldehyde bath on 20 April 1996.

A *t*-test indicated in-culture mortality was significantly ($P = 0.005$) higher for fish in the automated than hand-fed treatment (Fig. 2). The mortalities were primarily associated with an epidemic of *Costia*. The number of mortalities dropped sharply after formalin treatment and fish grew well thereafter.

A two-way ANOVA of the in-raceway depth distribution data indicated that, within both treatments, a significantly ($P < 0.001$) greater percentage of the fish were associated with the lower quadrants (Fig. 3). However, between treatments the depth distribution of the fish was nearly identical and not significantly ($P = 0.828$) different. Thus, chinook salmon in both treatments primarily resided in the lower half of the water column when the image of a person was not present within their visual field.

The laboratory observations of chinook salmon also demonstrated their innate benthic orientation, as fish from both treatments remained about 3.5 cm from the bottom. There was again no significant (P = 0.883) difference between the treatments, with fish from both rearing types displaying similar depth distributions in the laboratory test arenas (Fig. 4).

Fish from both treatments were equally vulnerable to merganser predation in both types of bioassays. When the treatments were placed side by side in separate raceways the fish were preyed on in nearly identical percentages, and there was no significant difference (P = 0.722) between treatments (Fig. 5). This was also the case when fish from both treatments were placed in the same raceway (Fig. 6).

The only distinct difference between fish from the two treatments was in their response to visual stimuli at the surface (n = 3). Presented with the model of a great blue heron or a shovel (novel stimuli), fish in both treatments, all six raceways, moved away from the stimulus and oriented themselves to keep it in view (Fig. 7a and b). When presented with the human image at the surface, the hand-fed fish in all three hand-fed raceways swam over to it, as if waiting to be fed, while the fish in all three automatic-fed raceways exhibited a strong fright response (Fig. 7c). Statistical analysis (one-tailed Fisher exact test) indicated the two treatments' fright response to the human image significantly (P = 0.05) differed, while the two treatments' fright response to the model heron and shovel did not significantly (P = 0.50) differ.

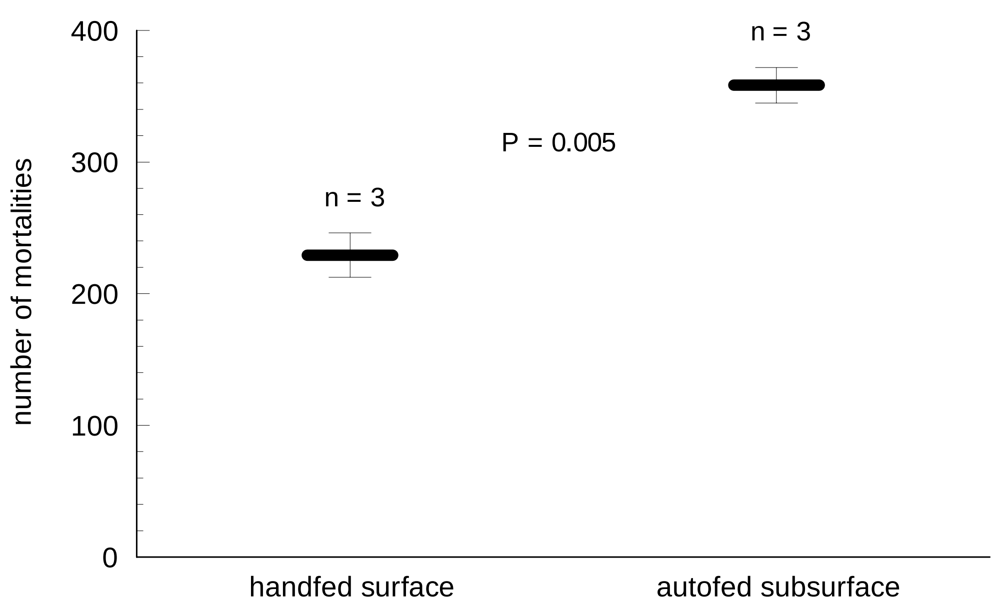

Figure 2. Average in-culture raceway mortality during 1996 underwater feeder study.

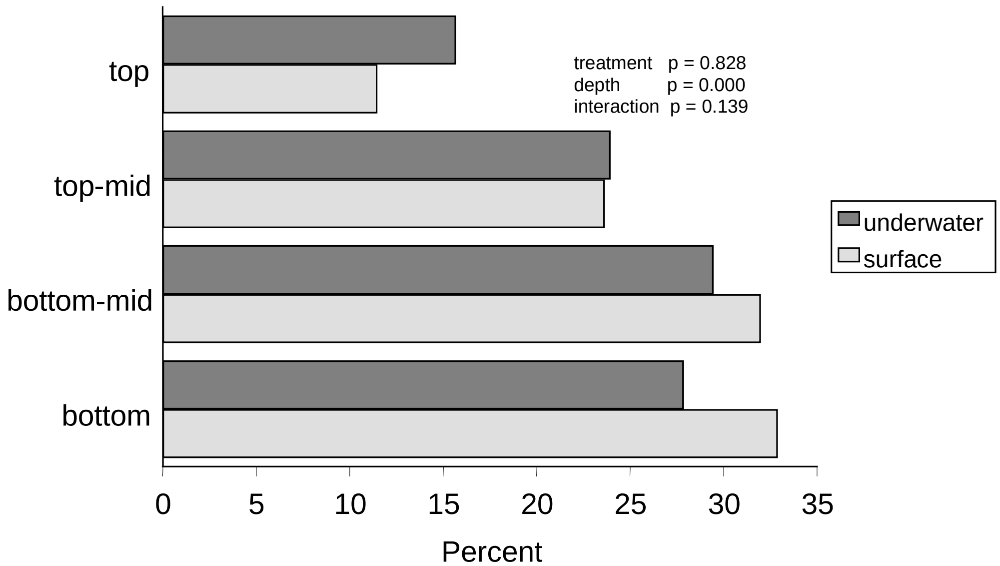

Figure 3. Average depth preference of fish videotaped in raceways.

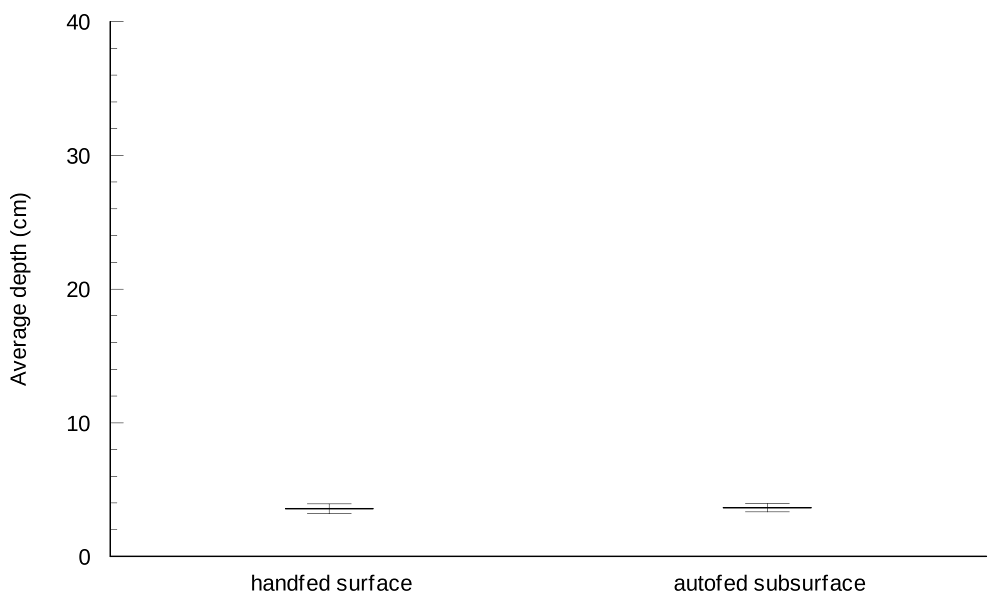

Figure 4. Average depth preference of fish in a laboratory test arena.

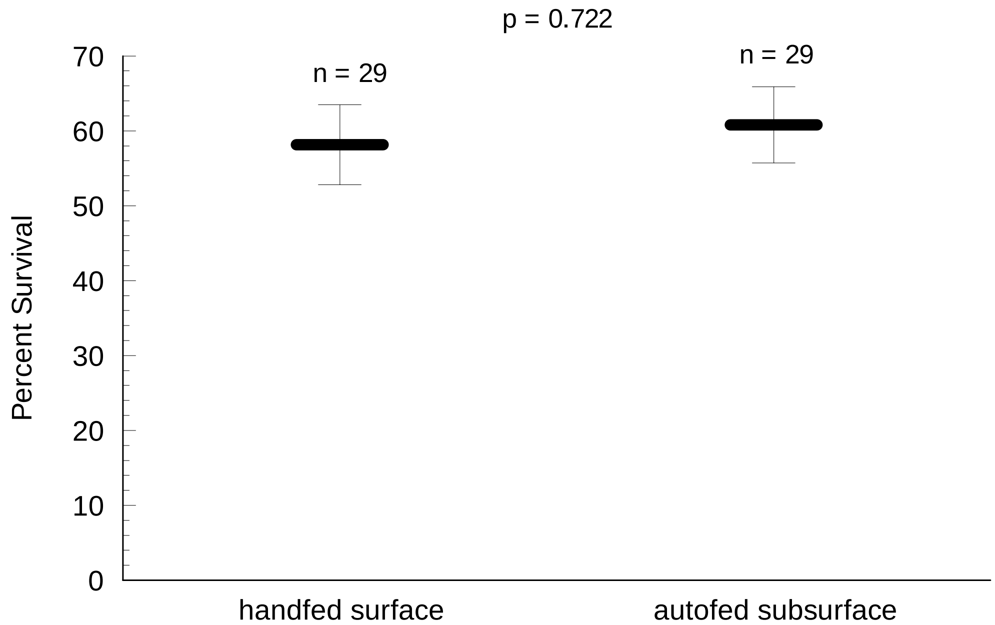

Figure 5. Percent survival after merganser predation with treatments in side by side test arenas.

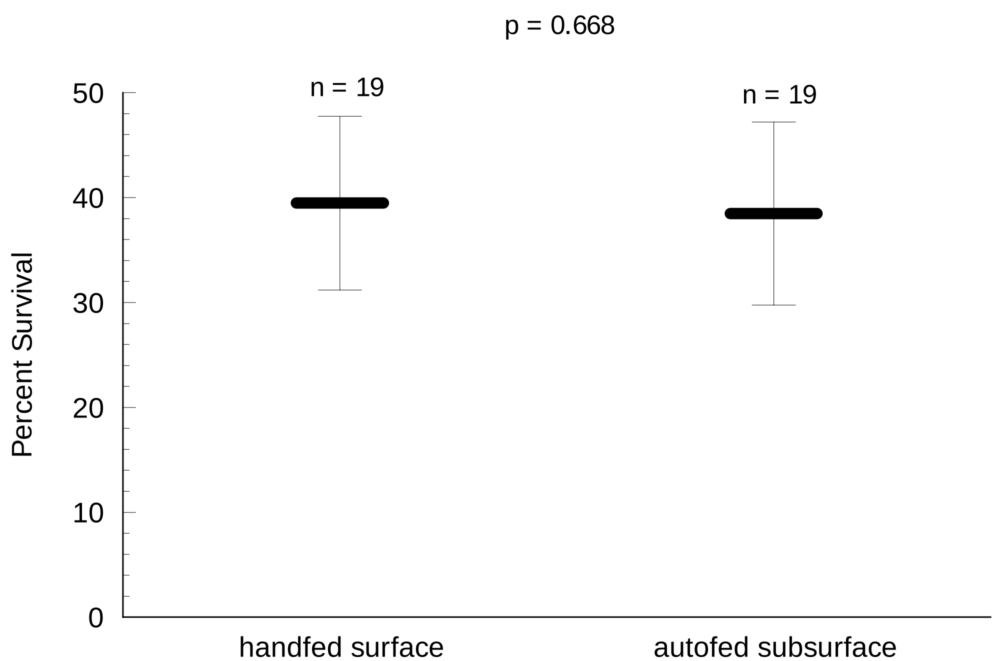

Figure 6. Percent survival after merganser predation in underwater feeder study with both treatments in the same test arena.

Discussion

The automated underwater feed delivery system failed to alter salmon behavior in a manner which might seemingly produce fish less vulnerable to predators. The hand-fed and automatic-fed fish exhibited identical depth preferences, the same response to unfamiliar objects at the surface, and similar vulnerability to predators. The only difference between the two groups was in their response to humans. The positive reward of food had conditioned hand-fed fish to swim towards humans when they were hungry. In contrast, the automatic-fed fish did not associate the human image with any reward. They continued to retain their instinctive response to freeze, remain at a distance, and orient towards any potential threat, whether it was a human being, a model of a heron, or a shovel entering their visual field.

The findings refute the premise that changing feeding methods will alter chinook salmon depth preference. The observations in the raceways and laboratory aquaria demonstrate that chinook salmon tend to reside at similar depths regardless of how they are fed. The aquaria data indicates that chinook salmon tend to remain near the bottom of the water column. These findings support the observations made in other studies (Dauble et al. 1989, Everest and Chapman 1972) that indicate chinook salmon have an innate preference to reside in the lower half of the water column. This does not preclude the fish from temporarily rising to the surface to feed, but they quickly return to deeper water after feeding. As the surface can be a dangerous place for a fish to reside, it is not surprising that hand feeding at the surface does not decondition the inherent tendency of these fish to remain away from it.

This study demonstrates that salmon have the ability to distinguish between specific visual stimuli such as a human image or a model of a heron. Under natural conditions, this specificity should permit fish to adapt gradually to all the neutral and positive visual stimuli they encounter while retaining their innate antipredator response to detect any negative and novel stimuli. This suggests that hand-fed salmon are at no greater risk of being preyed on than machine-fed fish when they are released into the natural environment. The only possible risk to hand-fed salmon would be human activity along the shoreline or in boats attracting fish to the surface where they then become vulnerable to predators. However, it seems unlikely that this conditioned response will generate any meaningful impact on the postrelease survival of hatchery fish.

The 5.2% mortality rate observed in the hand-surface fed treatment fish is similar to the 5.6% six year running average postponding mortality rate experienced by chinook salmon at the WDFW Soos Creek hatchery (Fuss and Ashbrook 1995). The 7.3% in-culture mortality experienced by fish reared on underwater feeders was a 40% increase over these base values. This may have been disease related. During feeding sessions, the underwater feeder may have attracted fish closer to the bottom where they became more vulnerable to parasites and pathogens or poor food hygiene may have contributed to the problem. Hand-fed fish generally received all their food soon after removal from storage, where it was always maintained in well-sealed and dry containers. Although the automatic-fed fish received their food equally promptly, invariably some food hung up in the feed delivery systems and this material became moldy and

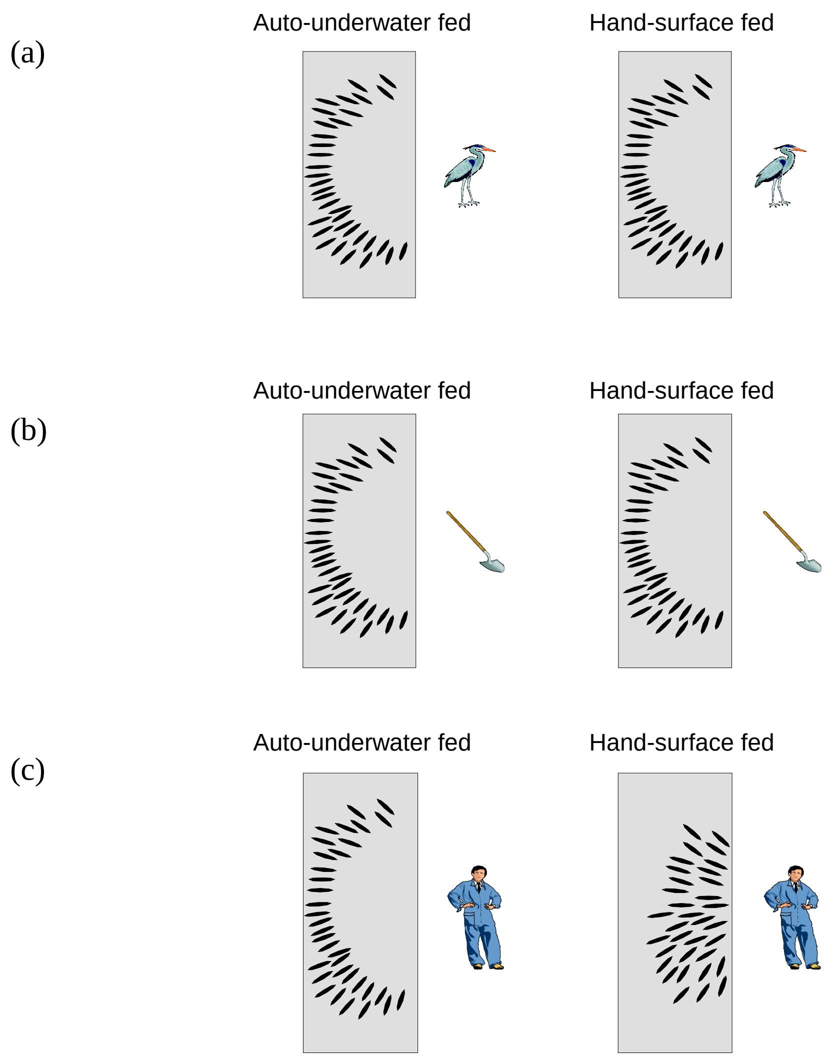

Figure 7. Salmon response to visual image of (a) great blue heron model, (b) shovel, and (c) human image.

decomposed. This material was removed during the weekly feeder cleaning, but may have been dislodged and fed to the fish prior to each cleaning. As research has shown that feeding moldy feeds can cause fish health problems (Ashley 1972, Stickney 1994, Roberts and Shepherd 1997) this aspect of the feed delivery system is probably responsible for producing the increased mortality observed in the automatic subsurface feeder treatment fish. It is recommended that in the future the feed delivery system be cleaned on a daily basis to avoid recurrence of this problem.

One difference the two feeding styles may induce is altered social competition. Scattering food across the surface by hand generally induces frenzied scramble competition in which dominant fish cannot successfully defend their food source (Thorpe et al. 1990, Grant 1993, Ryer and Olla 1996). In contrast, automatic subsurface feeders generate a point-source food supply which can be successfully defended. This scramble competition versus despotic competition was observed in an earlier study with a similar automated underwater feeder (Maynard et al. 1996). With steelhead trout, these point-source feed delivery systems seem to produce fish with increased social dominance (Berejikian et al. 2000). It therefore seems likely that a few fish receiving automated subsurface feed may become despots.

Hand-feeding fish is a traditional approach with several major benefits and no apparent drawbacks, except for being labor intensive (Goddard 1996). When fish are fed by hand their behavior and morphology can be observed, and used to detect the early appearance of disease or environmental problems in the population before they increase mortality. Hand feeding also ensures that feed is delivered fresh. Finally, with hand feeding it is easier to recognize the need to adjust the ration, as fish stop feeding when satiated or continue to search for food if they are still hungry. Observing a satiation response is important, as it not only prevents overfeeding but is also an indication that fish may have been lost due to undetected predation or screen failures.

In conclusion, the subsurface feed delivery system delivered feed well and should require little or no modification. In order to reduce in-culture mortality the entire system should be cleaned each day before the hopper is loaded. However, given the feeding system's inability to change fish depth preference, fish response to novel stimuli, or produce fish less vulnerable to predators there may be no advantage in using an underwater feed delivery system. The only advantage of the subsurface feed delivery system may be when there is a need to produce fish with enhanced social dominance. Therefore, it is recommended that fish continue to be fed by hand because of the benefits associated with observing their feed response.

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