

**LOW LIGHT AS AN IMPEDIMENT TO
RIVER HERRING MIGRATION**

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EXENDED ABSTRACT ONLY – DO NOT CITE

Introduction

Pipes and box culverts are economical alternatives to bridge construction over small water bodies. In North Carolina, U.S.A., an extensive gill net survey indicated that river herring (*Alosa aestivalis* and *A. pseudoharengus*) no longer occur in streams where bridges have been replaced with pipes or box culverts (Moser and Terra 1999). River herring migration behavior may be affected by such structures because these fishes are anadromous and pass through small streams to reach their traditional spawning grounds. We tested the hypothesis that low lighting inside pipes and culverts is an impediment to river herring migration.

Methods

Field experiments were conducted by artificially shading one side of streams where herring were known to occur. At each of three sites, a 24 X 4 m floating shade was deployed over one half of the stream (oriented along the stream axis). Nylon, 1.2 cm mesh block nets were set along each side and parallel to the shade to prevent fish from moving between treatments after entering the experimental apparatus (Figure 1). Light meters (Onset Hobo) were deployed to record light intensity every 30 min at a depth of 10 cm and were positioned at the edge and

in the middle of the shaded treatment. A 7 cm stretched mesh gill net was set along the upstream edge of the shaded and unshaded treatments (Figure 1). We fished this net within 1 h of dawn and dusk daily throughout the herring migration (April-May). After the first two weeks of sampling, the shade was switched to the other side of the stream. All fish captured were identified, the treatment they had gone through (shaded vs unshaded) was scored, and we recorded whether they were captured on the upstream or downstream side of the net. Binomial tests were used to determine whether fish were captured in the unshaded treatment significantly ($p < 0.05$) more often than in the shaded treatment.

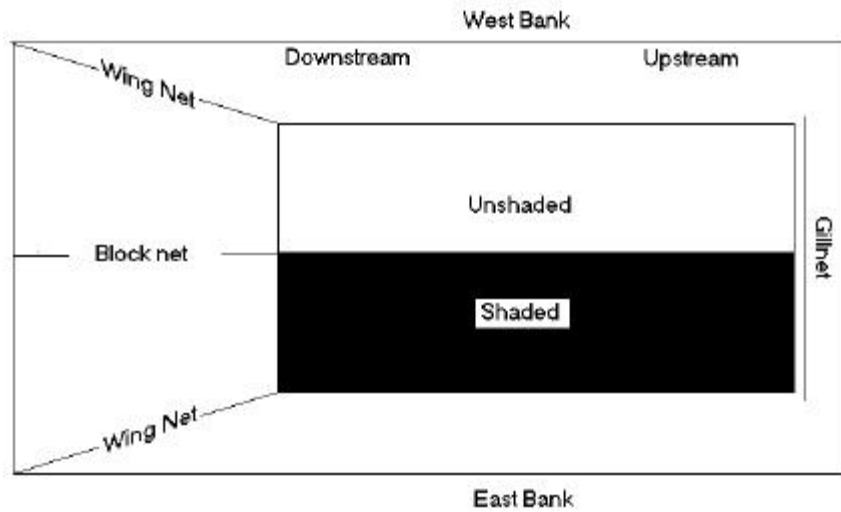


Figure 1. Diagram of the experimental apparatus in a stream.

Results

Continuous light measurements indicated that the artificial shading effectively reduced light levels, and replicated conditions inside culverts and pipes. Maximum recorded light levels at the middle of the shaded treatments were 1.4% (site 1), 0.5% (site 2), and 0.0% (site 3) of light intensity at ambient locations. At sites 2 and 3, herring consistently chose the unshaded treatment, regardless of which side of the stream was shaded (Figure 2). Moreover, they exhibited this behavior during both night and day, and while traveling either

upstream or downstream. At site 1, herring were caught on the darkened side during the day, but this difference was not significant due to low sample sizes.

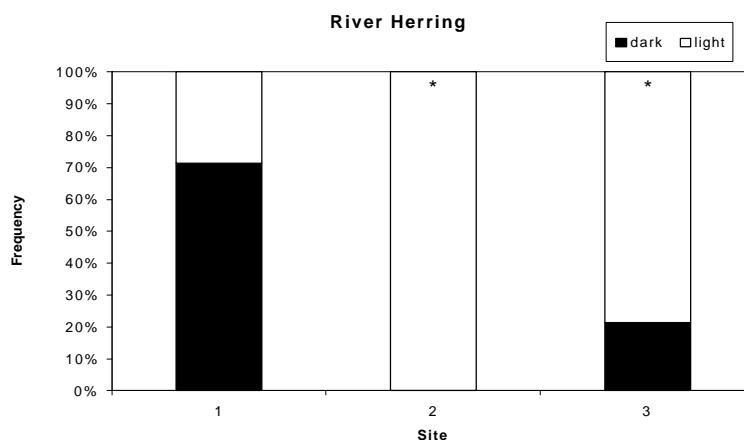


Figure 2. Percent frequency of river herring captured on the shaded (dark bars) and unshaded (light bars) sides of the streams (sites 1, 2 and 3). Significantly higher numbers of herring on the unshaded side are indicated by (*).

Discussion

The number of river herring captured during these experiments was low. Nevertheless, significantly higher numbers of herring passed through unshaded treatments at sites 2 and 3. At these sites available light under the shaded treatments was 0.5% and 0% of ambient, respectively. Fish often require visual cues for orientation and exhibit faster swimming speeds at increased light levels (Pavlov et al. 1972, Katz 1978). Clupeids seem to be particularly sensitive to lighting. Herring (*Clupea harengus*) require light to form schools and are most active during the day (Blaxter and Parrish 1965) and have difficulty avoiding obstacles at night (Blaxter and Batty 1985). Similarly, laboratory observations of alewives indicated that both juveniles and adults are most active during the day (Richkus and Winn 1979). However, our data indicated that very little light is needed for herring to migrate upstream. At site 1, herring passed through light levels that were 1.4% of ambient as frequently as they did through ambient

lighting; and, at all sites, fish migrating at night avoided the shaded treatment as much as daytime migrants.

Acknowledgements

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References

- Blaxter, J.H.S. and B.B. Parrish. 1965. The importance of light in shoaling, avoidance of nets and vertical migration by herring. *J. Cons. perm. int. Explor. Mer.* 30:40-57.
- Blaxter, J.H.S. and R.S. Batty. 1985. Herring behaviour in the dark: responses to stationary and continuously vibrating obstacles. *J. mar. biol. Assoc. U.K.* 65:1031-1049.
- Katz, H.M. 1978. Circadian rhythms in juvenile American shad, *Alosa sapidissima*. *J. Fish Biol.* 12:609-614.
- Moser, M.L. and M.E. Terra. 1999. Low light as an impediment to river herring migration. Final Report to North Carolina Department of Transportation, Raleigh, NC, 112 pp.
- Pavlov, D.S., Y.N. Sbikin, A.Y. Vashinniov and A.D. Mochek. 1972. The effect of light intensity and water temperature on the current velocities critical to fish. *J. Ichthyol.* 12:703-711.
- Richkus, W.A. and H.E. Winn. 1979. Activity cycles of adult and juvenile alewives recorded by two methods. *Trans. Am. Fish. Soc.* 108: 358-365.

**THE EFFECTS OF ACCELERATION AND EXPERIENCE
ON HIGH VELOCITY SWIM PERFORMANCE
IN JUVENILE RAINBOW TROUT**

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Introduction

Swimming performance assessment of fish has focussed mainly on two measures; the maximum achievable or “burst” velocity and the maximum sustainable velocity. The former is usually an invoked startle response and is typically <20 sec in duration, while the latter is the result of a gradual stepwise acceleration to a speed at which the fish fatigues or, specifically, is unable to maintain position in current. The time weighted average of the final two velocities is calculated and referred to as the critical velocity (U_{crit}), which is generally sustainable for at least 200 min (Brett, 1964). These two extremes have been very well characterized (for recent reviews see Hammer, 1995, Domenici and Blake, 1997), yet the intermediate region of swimming performance has received relatively less attention and is arguably where most of the swimming behaviour of stream dwelling fish lies.

Recently, McDonald et al. (1998) developed the fixed velocity sprint test as a tool for assessing intermediate swimming performance in fish. In their study the authors measured the fixed velocity sprint performance of three species of stream dwelling salmonids, and showed that fatigue time scaled with body size ($\text{Length}^4\text{-L}^5$) and was reproducible in repeat trials. Moreover, they showed that when fish were rapidly accelerated to U_{crit} velocities (approx. 6-7 body lengths $\cdot\text{s}^{-1}$ for fish of fingerling size) they would exhaust much more rapidly than if slowly accelerated to the same speed.

Although previous studies have shown that the rate of acceleration affects the outcome of a U_{crit} test (Farlinger and Beamish, 1977), effects of acceleration on sprint performance are not well established. Also not well established is the role of experience in modifying swim performance. In a recent review Davison (1997) concluded that in general, training effects appear modest. However, this may simply be because the training regimes were different from the testing regimes. Therefore, the purpose of this study was to further characterize the effects of acceleration on sprint performance in the rainbow trout and to examine the specific effects of repeated sprint exercise and of other training regimes on sprint performance.

Methods

We used relatively small rainbow trout (1-5 g) of hatchery origin where, because of their age (< 5 months) and the nature of rearing conditions they would have little or no high speed swimming experience. Fish were fed a 4% ration of commercial trout feed, and held in circular 40 L tanks with temperature varying seasonally from 7-18°C. Fish were exercised in groups (typically 10 fish per trial) in an open, recirculating swim flume (102 L volume). Two types of swimming procedures were used in this study: i) a maximum sustainable swimming speed (U_{crit}) test and ii) a sprint test. In both protocols, fish were sequentially removed from the flume as they fatigued, with fatigue time (FT) in minutes used either to calculate U_{crit} , or to provide a measure of performance in the sprint test. The main difference between the U_{crit} and sprint tests is the rate of acceleration to the final velocity ($\sim 7 \text{ BL}\cdot\text{s}^{-1}$), as the fatigue endpoint was identical in both cases.

Results

Effects of acceleration

U_{crit} was $38 \pm 0.8 \text{ cm}\cdot\text{s}^{-1}$ or $6.8 \pm 0.1 \text{ BL}\cdot\text{s}^{-1}$ ($N=20$). In this measurement, acceleration to the final velocity ($41 \pm 0.8 \text{ cm}\cdot\text{s}^{-1}$, i.e. higher than the critical velocity) took $3.3 \pm 0.1 \text{ h}$ from the initial orientation speed of $1 \text{ BL}\cdot\text{s}^{-1}$ and the average duration at the final velocity was $8.9 \pm 1.5 \text{ min}$. In contrast, fish sprinted to $\sim U_{crit}$ velocity over 2 min fatigued in an average time of $3.3 \pm 0.5 \text{ min}$. Lengthening the time for acceleration from 2 to 60 min progressively increased fatigue time, so that a 60 min acceleration period led to a 10 fold increase in FT to an average of $36 \pm 5.0 \text{ min}$.

Effects of training

Sprint training had a number of effects. Firstly, fish oriented to current more rapidly and exhibited a lower incidence of burst and coast swimming during the acceleration period, a swimming behaviour usually noted just prior to fatigue. Secondly, there was an incremental improvement in mean FT over successive daily trials. The amplitude of the increase was as much as 8 fold in as little as 5 days and there was no indication that the performance improvement was reaching a plateau by the end of the training period. However, some fish in each trial failed to show any improvement throughout the training period. Finally, improvements in performance were fairly persistent. When fish were re-tested after 7 days of rest, there was no significant reduction in performance.

Fish that were repeatedly accelerated to sprint velocity, but not fatigued, exhibited a similar magnitude of performance improvement. In contrast, fish manually chased to exhaustion (a more stressful exercise endpoint) or continuously swum at $1 \text{ BL}\cdot\text{s}^{-1}$ (strictly aerobic, low stress exercise) showed no improvement in sprint performance.

Conclusions

Therefore, we conclude that acceleration rate is the most important determinant of sprint endurance in rainbow trout, a finding that suggests that U_{crit} is not a very ecologically relevant measure of swim performance especially in those circumstances where trout are negotiating passage through high velocity

environments. Secondly, we find that experience (i.e. learning and/or training) has a quite profound effect on swimming endurance. This finding is particularly relevant to the comparison of wild to hatchery reared salmonids, as the former is more likely to gain experience of periodic high speed swimming especially if it is a stream resident.

References

- Brett, J.R. 1964. The respiratory metabolism and swimming performance of young sockeye salmon. *J. Fish. Res. Bd. Can.* **21**: 1183-1226.
- Davison, W. 1997. The effects of exercise training on teleost fish: a review of recent literature. *Comp. Biochem. Physiol. A.* **117**: 67-75.
- Domenici, P. and R.W. Blake. 1997. The kinematics and performance of fish fast-start swimming. *J. Exp. Biol.* **200**: 1165-1178.
- Farlinger, S. and F.W.H. Beamish. 1977. Effects of time and velocity increments on the critical swimming speed of largemouth bass (*Micropterus salmoides*). *Trans. Am. Fish. Soc.* **106**: 436-439.
- Hammer, C. 1995. Fatigue and exercise tests with fish. *Comp. Biochem. Physiol. A.* **112**: 1-20.
- McDonald, D.G., C.L. Milligan, W.J. McFarlane, S. Croke, S. Currie, B. Hooke, R.B. Angus, B.L. Tufts and K. Davidson. 1998. Condition and performance of juvenile Atlantic salmon (*Salmo salar*): Effects of rearing practices on hatchery fish and comparison to wild fish. *Can. J. Fish. Aquat. Sci.* **55**: 1208-1219.

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SOCKEYE SALMON AND A WILD ALASKAN WATERFALL:

POSSIBLE LESSONS FOR DAM RETROFITS

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Introduction

Fish ladders have been used for hundreds of years to help migratory fishes move upstream past human-made obstacles such as dams. Even recent designs of these ladders appear to have given little consideration to the behaviors and leaping abilities of the fishes they are supposed to help (Clay, 1995). These inadequate designs seem partly a result of the paucity of information on the behavior and biomechanics of fishes as they leap.

In order to improve fishway design, one must understand fish leaping by studying both the kinematics of the behavior and the hydrological characteristics preferred by the fish. Stuart (1962) briefly described the kinematics of salmonid leaping but few rigorous analyses have ever been published. Stuart (1962) also outlined the physical characteristics of a pool and weir system used by salmonids but no wild waterfalls have been described to our knowledge. We hope to integrate biological considerations with the design and construction of

fish ladders by understanding the preferences, capacities and limitations of wild fishes leaping up natural stream obstacles.

Methods

We analyzed aspects of the biomechanics of leaping in sockeye salmon, *Oncorhynchus nerka*, as they tried to pass the approximately 1 m high waterfall on Brooks River in Katmai National Park, Alaska, USA during their spawning migration (July 11-14, 1999). Digital video recordings were made of leaping salmon from distances of 21-24 m perpendicular to the flow of the stream. The camera was aimed at the base of the waterfall at an angle less than 5° from horizontal. Fish were tracked as they traveled through the air and kinematic parameters of the individual leaps were quantified. Individual fish positions throughout leaps were obtained using Scion Image version 3b. Mathematica version 3.0 software was used to calibrate video frames to real world units and to calculate leaping parameter values (i.e. angles and velocities). Video frames were calibrated using the gravitational constant of 9.8 m/s² and the recorded film speed of 15 f/sec. Leaping parameters were calculated based on ballistic physics (assuming a negligible effect due to air resistance) by applying best fit parabolic functions to the individual leap trajectories. Relative water depths were measured using video of bears wading across the river.

These results are summarized in the context of successful versus unsuccessful leaps and of calculated theoretical parameter values for successful leaps. A successful leap is defined as a leap originating below the waterfall and ending on or above the fall with the fish continuing up the stream (without immediately returning downstream). The theoretical model was constructed using Mathematica version 3.0.

Results

The sockeye salmon we observed had an 11% leaping success rate (29 of 265 recorded leaps). Aerial kinematic parameters were quantified for 47 leaps (22 successful and 25 unsuccessful). These parameters include horizontal velocities, vertical takeoff and landing velocities, resultant takeoff and landing velocities, takeoff and landing angles, and distances between takeoffs and successful landings.

A theoretical model was constructed describing the relationship between the waterfall height and two leap parameters for a successful leap: ¹⁾ distance between takeoff and successful landing and ²⁾ takeoff velocity. This model describes the minimum distance and velocity combinations required for a successful leap.

The salmon almost exclusively leap in a very specific and narrow region of the approximately 30 m wide waterfall. The few fish observed leaping outside of this region were all unsuccessful. The most notable difference between the area of leaping and the rest of the waterfall is the presence of a relatively large plunge pool with a large standing wave or boil at the base of the falls.

Conclusions

The accordance of the kinematic data with the model and the low observed success rate suggest that the proportion of the salmon population arriving at upstream spawning tributaries is low under natural conditions (in the absence of human made obstacles). The restricted region of leaping activity suggests that the fish have very specific hydrological preferences for leaping. These preferences seem to include deep plunge pools that produce a standing wave as suggested by Stuart (1962).

We plan to conduct future studies correlating the hydrology downstream of waterfalls with leaping salmonid kinematics, both underwater and in air. These studies will include a range of plunge pool dimensions and over-spill characteristics that will experimentally investigate the preferences of migrating salmonids at stream obstructions. These results along with the theoretical model describing successful leaps may be used in the development of fish ladders to help maintain a natural passage rate of fishes up streams that contain human made obstacles.

References

- Clay, C. H. 1995. *Design of fishways and other fish facilities*. Lewis Publishers, Boca Raton. P. 248.
- Stuart, T. A. 1962. The leaping behaviour of salmon and trout at falls and obstructions. *Freshwater and Salmon Fisheries Research*. (28): 1-46.

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**ANADROMY IN BROOK TROUT: RELATION TO DIET
PARTITIONING WITH COEXISTING ATLANTIC SALMON**

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Introduction

Many populations of trout have both anadromous (migrant) and non-anadromous (resident) forms in the same river ecosystem (Northcote, 1992). The forms have different life history strategies. Both elements of genetics and environment may govern the partial migration (Jonsson and Jonsson, 1993). In the Sainte-Marguerite River (SMR) ecosystem of Eastern Quebec, Canada, brook trout (*Salvelinus fontinalis*) migrate from those streams where they co-exist with Atlantic salmon (*Salmo salar*) and rarely from that where the trout are the only occupant. Feeding conditions in different streams could be a major environmental determinant of anadromy in trout (Nordeng, 1983). Existence of other competing species, such as the Atlantic salmon, could alter the feeding conditions. We compare here the feeding ecology of trout in two streams of the SMR, Allaire and Epinette, with and without salmon, respectively. Trout outmigrates only from Allaire.

Methods

Fish were caught by electroshocking the chosen stream reaches at 4 hour intervals over 24 h, on three occasions during August-September, 1996. After

anesthetization, length and wet mass of the fish were recorded. Gut contents were collected by pulsed hydraulic gut flushing and frozen until analysis. Contents were identified, enumerated and dried in pre-weighed aluminum pans at 70°C for 72 h to obtain the dry biomass of food taken. Diet similarities between trout and salmon in Allaire and between trout in Allaire and trout in Epinette were calculated using Schoners' Overlap Index (Krebs, 1989). Daily ration of the fish was estimated by Eggers' model (Eggers, 1977; Amundsen et al., 1999). Only fish with fork lengths between 7-14 cm (1+ and 2+ age groups) were selected for this study.



Figure 1. Diet overlap between coexisting trout and salmon in Allaire and between trout in Allaire and trout in Epinette on three sampling occasions in 1996 (I: Aug. 9-12; II: Aug. 28-31; III: Sept. 20-23). Values > 0.6 indicate significant overlap (Krebs, 1989).

Results

The insignificant overlap in diet between salmon and trout in Allaire suggests food partitioning between coexisting salmonids (Figure 1). On all sampling occasion, the diets of trout in the two streams were significantly different (low overlap, Figure 1). The trout in Epinette fed primarily (~70%) on autochthonous aquatic insects (Trichoptera, Ephemeroptera), while the trout in Allaire fed a lot more (up to 80 %) on the allochthonous terrestrial components (adults of Diptera and Hymenoptera) of the stream drift (Table 1). Similar-sized salmon fed predominantly on the aquatic drift (Ephemeroptera). The conditions of the trout for the age groups studied, were comparable in both streams. Assuming a similar gastric evacuation pattern, trout in Epinette fed twice as much as those in Allaire on any sampling occasion (Table 1).

Table 1. Summary of observations in two streams. Values for Condition Factor and Daily Ration (g dry weight of food 100 g⁻¹ wet weight of fish day⁻¹) are averages from all sampling occasions. All other values indicate the range for all occasions pooled.

	Trout in Epinette	Trout in Allaire	Salmon in Allaire
Fish Condition Factor	1.078	1.081	1.157
Daily Ration	1.622	0.709	0.451
Prey Type Taken (%)			
Aquatic	70-76	24-33	80-90
Terrestrial	24-30	67-76	10-20
Major Prey Taxa (%)			
Aquatic			
Ephemeroptera larvae	25-30	8-14	39-60
Trichoptera larvae	27-35	6-15	11-30
Terrestrial			
Diptera adults	2-8	2-23	1-5
Hymenoptera adults	1-4	12-51	0-15

Discussion

In general, the trout in these streams have poor feeding conditions; the total drift densities are very low (~ 4 m⁻³) compared to other salmonid streams (~ 60 m⁻³). This could be further aggravated by the presence of closely related and more

aggressive species such as the salmon. The separation in feeding niches between sympatric and possibly competing trout and salmon in Allaire allows a greater exploitation of resources and their coexistence. However, it appears that a major environmental determinant of partial anadromy of trout seen only in Allaire, could also be related to this food partitioning. The quantitative and qualitative differences in the diet intake of trout in the two streams were not related to the prey availability within the streams.

Feeding on terrestrial invertebrates appears to be less profitable. The allochthonous inputs would depend on the extent of riparian canopy which is very poor along Allaire. Also, our preliminary biochemical analyses indicate a different macromolecular (e.g. fatty acid profile) composition of the terrestrial invertebrates compared to the aquatic ones. The lower intake of food and a more terrestrial invertebrate consumption by trout in Allaire, suggest a different foraging efficiency of the trout in the presence of salmon, when compared to in its absence. This may influence the fitness of the trout in sympatric streams and subsequently may contribute to their partial anadromy.

References

- Amundsen, P.-A., R. Bergersen, H. Huru. and Heggberget, T.G. 1999. Diel feeding rhythms and daily food consumption of juvenile Atlantic salmon in the River Alta, northern Norway. *J. Fish Biol.* 54:58-71
- Eggers, D. M. 1977. Factors in interpreting data obtained by diel sampling of fish stomachs. *Can. J. Fish. Aquat. Sci.* 34:290-294
- Jonsson, B. and N. Jonsson. 1993. Partial migration: niche shift versus sexual maturation in fishes. *Rev. Fish Biol. Fisheries.* 3:348-365
- Krebs, C.J. 1989. *Ecological Methodology*. Harper and Row, New York
- Nordeng, H. 1983. Solution to the "Charr Problem" based on Arctic charr (*Salvelinus alpinus*) in Norway. *Can. J. Fish. Aquat. Sci.* 40:1372-1387
- Northcote, T.G. 1992. Migration and residency in stream salmonids - some ecological considerations and evolutionary consequences. *Nordic J. Freshw. Res.* 67:5-17

**THE POTENTIAL FOR INTRODUCING
ANADROMOUS SOCKEYE SALMON
INTO LAKE TOYA, JAPAN**

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Environmental changes in Lake Toya

Lake Toya, a large, oligotrophic, caldera lake, is located in southwestern Hokkaido, with an elevation of 84 m, a surface area of 70.44 km², a maximum depth of 179 m, and an average depth of 116 m. The lake belongs to the Osaru River system; the only inflow from the river is an artificial water tunnel, which was built in 1939. One outlet is to the river, the Sobetsu Waterfall at a height of 18 m, and the other is the Abuta hydroelectric power station, which sends outflow directly to Funka Bay. A gradual decrease in Lake Toya pH began in 1939 when the inflow of Osaru River water began to contain acid waste from sulfur mining. Lake Toya reached its lowest level, pH 5.0, in 1970. After neutralization began in 1972, the pH rapidly increased and now is about 7.0. The main fishery in the lake is for lacustrine sockeye salmon (*Oncorhynchus nerka*), which were introduced from Lake Akan in 1893. The annual catches of this species fluctuated widely before and after lake acidification and are currently very low, likely because of the over-release of juveniles, which caused a rapid decrease of zooplankton (Fig. 1). There is no direct method for improving lacustrine sockeye salmon resources and we are seeking other alternatives to improve the fishery.

Production of anadromous sockeye salmon from lacustrine form

In Japan, wild anadromous sockeye salmon had not been found since 1900, but lacustrine sockeye salmon are distributed in several lakes. Anadromous sockeye salmon have been produced by artificial releases of smolts derived from

lacustrine form in Lake Shikotsu (Kaeriyama, 1989). Since May of 1995, anadromous sockeye salmon smolts derived from lacustrine sockeye salmon have been released directly into the Osaru River to investigate their homing ability and the possibility for a new fishery resource. In October of 1999, one female and one male maturing sockeye salmon, which had been released as smolts with a fin-clip mark in 1997, were found and captured in the Osaru River. Their body size and GSI (gonad weight x100/body weight) were relatively small, but the number of ovulated eggs was about 4 times greater than lacustrine sockeye salmon. These fish demonstrated their homing ability as well as the likelihood of success in introducing anadromous sockeye salmon into Lake Toya.

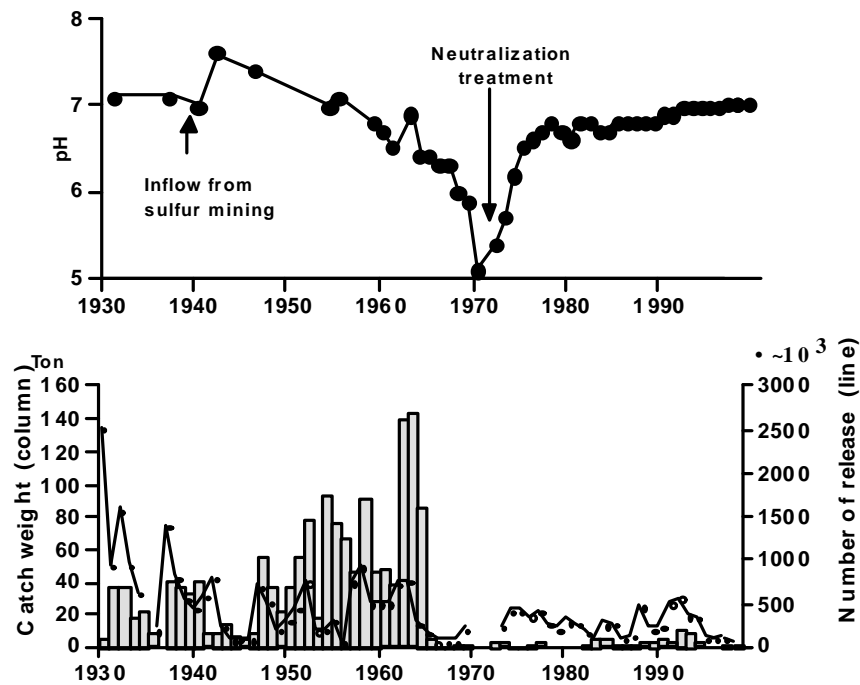


Fig. 1. Changes in pH, catch weight and number of release of lacustrine sockeye salmon in Lake Toya from 1930 to 1999.

The main barrier for down- and up-stream migrations between Lake Toya and the Osaru River is the Sobetsu Waterfall. It is possible to build a fishway specifically designed for anadromous sockeye salmon beside the waterfall, and a model fishway has already been built. The Sobetsu Town residents are expecting to utilize anadromous sockeye salmon for new fisheries resources and the fishway for a new sightseeing spot. We have investigated seawater tolerance related to smoltification of 1⁺ and growth accelerated 0⁺ lacustrine sockeye salmon and demonstrated that both groups have the ability to become smolts in May (Fig. 2), suggesting that smolts can be effectively produced from the stock available. We will also investigate possible influences of this introduction of anadromous sockeye on the ecological environment of Lake Toya.

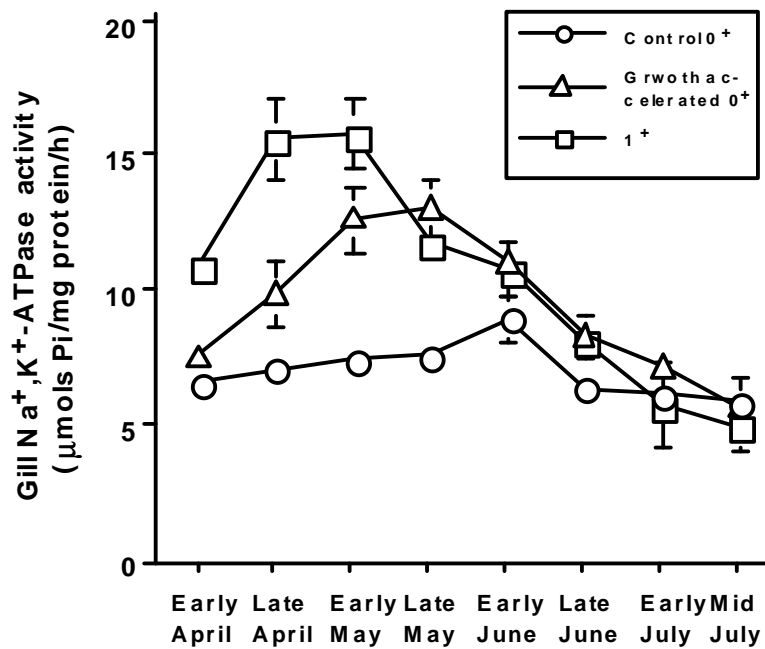


Fig. 2. Changes in gill Na⁺,K⁺-ATPase activity of control 0⁺, growth accelerated 0⁺, and 1⁺ lacustrine sockeye salmon.

References

Ban, M., H. Haruna and H. Ueda. 2000. Seawater tolerance of lacustrine sockeye salmon (*Oncorhynchus nerka*) from Lake Toya.. Bull. Nat. Salmon Resources Cent. 2: 15-20.

Kaeriyama, M. 1989. Aspects of salmon ranching in Japan. Physiol. Ecol. Japan, Spec. 1: 625-638.

**ENERGY RESERVES AND NUTRITIONAL STATUS
OF JUVENILE CHINOOK SALMON
EMIGRATING FROM THE SNAKE RIVER BASIN**

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Salmonid smolts migrating seaward from the Snake River basin in Idaho and Oregon, USA must pass through eight dams and reservoirs on the Snake and Columbia Rivers. The physiological consequences of an extended three- to nine-week migration through the hydropower system—two to six weeks longer than under natural river conditions—are poorly understood. A prolonged migration, in concert with the energy costs associated with dam passage and poor feeding conditions in the reservoirs, could deplete energy reserves needed by smolts for acclimation to the marine environment. This study was undertaken to determine the effects of initial (pre migratory) fish condition, river flow, and distance traveled on the lipid and protein reserves and on the nutritional status of migrating smolts.

Methods

In 1998 and 1999, spring chinook salmon *Oncorhynchus tshawytscha* reared at three hatcheries in the Snake River Basin were sampled prior to release and from bypass systems at selected hydroelectric dams on the Snake and Columbia Rivers. Carcass and gut water, lipid, and ash concentrations and total quantities were determined by standard methods. Body protein quantities were estimated as total dry weight – (lipid weight + ash weight). Plasma triglyceride, cholesterol, and total protein concentrations were determined by autoanalyzer,

as were also plasma activities of the enzymes alanine aminotransferase, aspartate aminotransferase, lactate dehydrogenase, creatine kinase, and alkaline phosphatase. Data were analyzed by analysis of covariance, with fish length as a covariate and with sampling site and hatchery of origin as the independent factors. Only results for 1999 are discussed here, with emphasis on changes occurring after fish entered the hydropower system.

Results

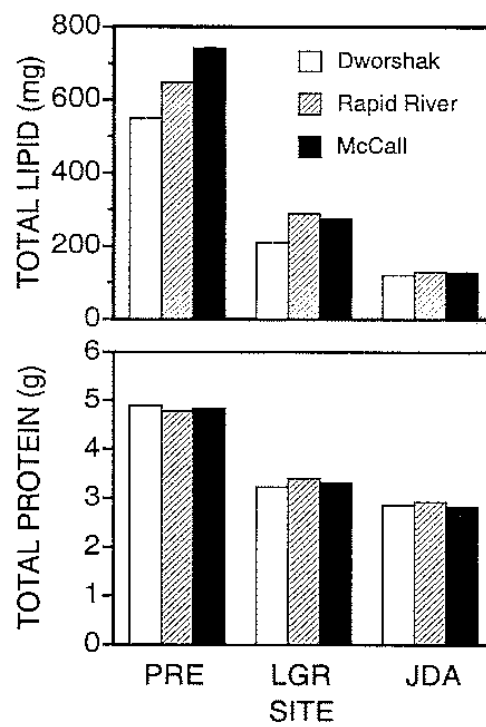


Figure 1. Whole body lipid and protein stores (standardized to fish length of 130 mm) for juvenile chinook salmon sampled prior to release (PRE), and after migrating to Lower Granite Dam (LGR) or John Day Dam (JDA). The fish originated from three Idaho hatcheries (Dworshak, Rapid River, or McCall).

Mean lengths for the three groups of hatchery fish increased slightly (< 3 mm) as the fish migrated from Lower Granite Dam (the first dam encountered on the Snake River) to John Day Dam (the sixth dam, 348 km downstream on the lower Columbia River), but dry weights decreased by 13, 14, and 17% (changes in means for fish from Dworshak, Rapid River, and McCall hatcheries). Lipid reserves declined by 43, 55, and 54% ($P < 0.001$ for site comparison) and protein reserves by 11, 14, and 15% ($P < 0.001$) as the fish migrated between the two dams (Figure 1). Mean lipid concentrations in fish sampled at John Day Dam were 0.74, 0.90, and 0.84% of wet body weight. Declining lipid reserves were accompanied by declining plasma triglyceride, cholesterol, and total protein concentrations ($P < 0.001$ for each). Gluconeogenic enzymes (alanine aminotransferase, aspartate aminotransferase, and lactate dehydrogenase) were significantly elevated relative to prerelease activities in fish sampled at Lower Granite Dam, suggesting an increased rate of conversion of body protein and lipids to glucose, but subsequently declined ($P < 0.01$) in fish arriving at John Day Dam. The activities of enzymes associated with feeding activity (alkaline phosphatase) and with muscle energy metabolism (creatine kinase) also declined significantly as the fish migrated downstream.

Discussion

Juvenile chinook salmon were in negative energy balance throughout the downstream migration. Body lipids were largely depleted in fish arriving at John Day Dam on the lower Columbia River. Total body protein also declined during the migration, a change unlikely to be due only to increased catabolism of energy stores during the parr-smolt transformation. Declining plasma concentrations of triglycerides, cholesterol, and total protein were consistent with food deprivation. Declining activities of alkaline phosphatase, an enzyme which is elevated in actively feeding fish, also indicated low levels of feeding activity. Although plasma activities of gluconeogenic enzymes were elevated in fish entering the hydropower system, activities of these enzymes declined after several additional weeks of migration. These decreased activities, and the concurrent decline in plasma creatine kinase activity, are believed to have been a consequence of increased protein catabolism.

Depletion of lipid reserves and loss of body protein may adversely affect the viability of smolts migrating through the Snake/Columbia River hydropower system. Adverse effects would be most prominent in years of poor feeding conditions in the near-shore marine environment.

**MONITORING THE MIGRATIONS OF WILD SNAKE RIVER
SPRING/SUMMER CHINOOK SALMON SMOLTS
IN THE COLUMBIA RIVER BASIN, USA.**

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Abstract

Before 1989, information on the migrational characteristics of Snake River spring/summer chinook salmon smolts *Oncorhynchus tshawytscha* from individual wild populations was scarce. During summers 1988 through 1998, we PIT tagged wild parr in natal streams. Each subsequent spring and summer, tagged smolts were detected at juvenile bypass systems at dams on the lower Snake and Columbia Rivers. Study goals are to 1) characterize the migration timing of different wild stocks at traps and dams, 2) determine if consistent patterns are apparent, and 3) determine what environmental factors influence migration timing. At Lower Granite Dam, the first dam encountered by migrating smolts, annual migrational timings were consistently protracted and were highly variable among streams and years. By contrast, their hatchery counterparts exhibited compressed and consistent timings over the years. Some timing trends have been observed for a few wild stocks. In addition, for combined wild stocks, we observed 2- to 3-week migrational timing shifts

between relatively warm and cold years. Over all years, peak detections coincided with variable flows before 9 May, but coincided with peak flows from 9 to 31 May. Annually, since 1992, fishery managers have been using this real-time detection information on wild fish stocks to direct daily operations of the hydropower system.

Introduction

In most years from 1966 to the late 1980s, migrations of Snake River yearling chinook salmon *Oncorhynchus tshawytscha* have been monitored by downstream recoveries of freeze-branded fish previously released from upstream hatcheries, river scoop traps, turbine intake gatewells at dams, or dam bypass systems (Bentley and Raymond 1968; Park and Ebel 1974; Raymond 1974, 1979; Ebel 1980). The brands identified groups of fish, but not individuals. The recent development of the passive integrated transponder (PIT) tag (Prentice et al. 1990b), permits identification of individual marked fish. This innovation has allowed the acquisition of more precise information on migrational timing as well as many other important juvenile salmonid behavioral characteristics.

In this paper, we provide summary information on the collection and PIT tagging of wild Snake River spring/summer chinook salmon parr as well as data on the detection and migration timing of the smolts as they migrated through the dams on the Snake and Columbia Rivers each spring and summer from 1989 through 1999. The goals of our study are to characterize migration timing of several individual stocks as well as combined populations of wild spring/summer chinook salmon smolts at traps and dams, determine if timing patterns are consistent, and examine what environmental factors influence or control this behavior.

Methods

From 1988 to 1998, we collected and PIT-tagged wild spring/summer chinook salmon parr from 3 to 17 streams in Idaho and from 2 to 4 streams in Oregon during late summer. Since 1992, Oregon Department of Fish and Wildlife has collected and PIT tagged fish in their streams. During the study's first 3 years, we also PIT tagged from two to four stocks of hatchery spring/summer chinook salmon parr for comparative purposes (Achord et al. 1996).

Wild parr were PIT tagged in spawning and rearing areas that ranged from 172 to 770 river km upstream of Lower Granite Dam, and from 867 to 1,465 river km from the Pacific Ocean. The elevations of most of the natal rearing areas were between 1,524 and 2,134 m in elevation; however, the lowest tagging site was 719 m.

We used primarily two methods to collect wild fish--electrofishing and a seining technique that we developed specifically for this application (Achord et al. 1996). Prentice et al. (1990c) described in detail the components and setup of a typical PIT tagging station. However, for this study, we used portable PIT tagging stations that we designed specifically for use beside streams (Achord et al. 1996). After the fish were tagged, we held them for a minimum of 0.5 hours in live cages in the streams before releasing them as near as possible to the locations from where they were collected. From most streams a subsample of approximately 8-12% were retained for 24 hours in live cages to measure tag loss and delayed mortality.

During the springs and summers from 1989 through 1999, surviving spring/summer chinook salmon smolts PIT tagged the previous summers migrated downstream volitionally through the hydroelectric complex on the Snake and Columbia Rivers. Full PIT-tag monitoring systems were operational within smolt bypass systems at Lower Granite (1986-present), Little Goose (1987-present), and Lower Monumental (1993-present) Dams on the Snake River, and McNary (1986-present), John Day (1998-present), and Bonneville (1997-present) Dams on the Columbia River. Smolts were guided by submersible screens from turbine intakes into the juvenile bypass systems at these dams and subsequently monitored automatically for PIT tags. Prentice et al. (1990a) described in detail the monitoring systems at three of these dams.

Results and Discussion

Fish Collection and Tagging

From 1988 through 1998, we collected a total of 125,766 wild chinook salmon parr in Idaho and Oregon (first 4 years). Annual numbers of wild parr collected ranged from 1,455 in 1996 to 24,874 in 1994. Of those collected, 108,923 were PIT tagged and released. Over these 11 years, overall mortality from collection and tagging averaged 1.4% (annual ranges 0.5 to 2.6%). Overall mortality from

collection over the years averaged 1.1% and overall mortality related to tagging (up to 24-hours) averaged 0.4%. The overall mortality from electrofishing averaged

1.8% and the overall mortality from collection by seining averaged 0.2%. Tag loss was virtually non-existent at 0.02%.

Over the above period, the overall fork length of tagged wild fish averaged 68 mm (annual averages ranged from 63 to 72 mm). The overall average length for wild fish that died after tagging was 64 mm (419 mortalities out of 109,342 tagged). This indicates that smaller fish died at a slightly higher rate than larger fish.

Detections at Dams

During the study period, a total of 13,909 first-time detections of wild smolts were made at dams. From 1993 to 1999, which were years when water was spilled at the dams, the first-time detection numbers were adjusted for spill. The percentage of released fish detected at the dams averaged 12.8% and ranged from 7.6% in 1989 to 32.3% in 1998. We caution against comparing detection rates among the study years because a number of variables differed through time including overall dam operations, the number of dams equipped with PIT-tag monitoring systems, surface bypass collection experiments at Lower Granite Dam in later years, the addition of extended length screens at various dams over various years, and the need to adjust numbers for spill at the dams in some years.

Over the course of the study, the percentages of PIT-tagged released fish from individual wild fish stocks that were detected at dams the following spring varied considerably, ranging from 1.5% to 58.5%. In general, the percentages increased over the years, in part, because of changing conditions at the monitoring dams noted above. However, some stocks consistently exhibited higher detection rates than other stocks. In all years, fish that were smaller at release (55 to 59 mm) were detected at significantly lower rates than fish that were larger at release (65 to 84 mm) ($P < 0.05$). However, the absolute differences in detection rates were not large between the two size groups of fish. For example, while one-third of all fish were 64 mm or smaller at release, they accounted for one-fourth of all detections at dams. Over the 8 to 10 month period between tagging and recovery (including the overwinter period), smaller fish likely had a higher natural mortality rate than larger fish, even in the absence of any handling and tagging. It is noteworthy that the smaller fish

consistently exhibited significantly later timing at the dams ($P < 0.05$). Therefore, we feel it is important to continue tagging small fish (a 55 mm fork-length minimum), to acquire the most accurate and representative migration timing information for these wild stocks.

In 1994, we collected sufficient numbers of fish by both collection methods (electrofishing, seining) in two streams to compare their detections rates at the dams the following year. We found no significant difference in detection rates for fish released the previous year following collection by electrofishing (120/1,661=7.2%) or seining (101/1,460=6.9%) ($P > 0.05$). These data clearly demonstrated that electrofishing had little, if any, delayed effect on these fish compared to fish collected with our relatively benign seining technique which utilized water-to-water transfer techniques.

Migration Timing at Lower Granite Dam

The migration timing of individual wild stocks varied considerably among years and was usually protracted as measured at Lower Granite Dam, the first dam encountered by smolts between their natal rearing areas and the ocean. However, migration timing patterns are emerging for some stocks and groups of stocks, and range from early to late in the migration season. Attempting to relate distance (upstream from Lower Granite Dam) and elevation to the migration timing of wild stocks at the dam has yielded mixed results. In general, stocks from the farthest and highest elevations (from 2,000 to 2,134 m) had the latest timing at the dam. However, at short to intermediate distances from the dam and at elevations from 1,200 to 2,000 m, stock timings varied from early to late in the migration seasons. Most stocks from the lowest elevations (below 1,200 m) displayed the earliest migrational timing. Overall, the stocks displayed high variability in the middle 80% passage dates (10 to 90% passage period) over the years, ranging from 12 to 80 days, during April, May, June, and July.

Normally, large numbers of chinook salmon parr migrate downstream out of the upper tributaries in fall (Edmundson et al. 1968; Bjornn 1971; Raymond 1979). The magnitudes of these migrations differ annually and can result in many fish moving far downstream into larger tributaries, where quality overwintering habitat is more abundant. Factors such as stream discharge, temperature, turbidity, and habitat availability affect the migrations (Bjornn 1971). It is therefore not surprising that migrational timings of the wild stocks at the first dam would be variable and protracted. Raymond (1979) cited water temperature

as one of the most important factors that triggers the downstream movement of hatchery-reared and wild chinook salmon smolts in spring. As water temperatures progressively warm from downstream to upstream in spring, the wild smolt migrations probably begin earlier in the lower elevations than in the higher elevation areas. However, in addition to water temperature, photoperiod plays an important role in smoltification of anadromous salmonids (Saunders and Henderson 1970; Wagner 1974; Ewing et al. 1979; Clarke and Shelbourn 1985; Duston and Saunders 1990; Solbakken et al. 1994).

The annual migrational timing patterns of the combined wild populations was also variable and protracted over the years. The middle 80% passage for these fish averaged 43 days (annual ranges 37 to 55 days), between mid-April and mid-June. By contrast, their hatchery counterparts (combined) exhibited a consistent and compressed migrational timing pattern at the dam. Their middle 80% passage period averaged 26 days between mid-April and mid-May, with little range variation in days. While appearing to exert little influence on the annual migrational patterns of hatchery fish, annual differences in climate (particularly temperature profiles) appear to influence the annual passage distribution shifts for wild fish populations.

Annual variation in climate is emerging as an important factor controlling the overall migrational timing of wild Snake River spring/summer chinook salmon smolts at Lower Granite Dam. In 1990, 1992, 1994, and 1998, we observed relatively warm late-winter and spring conditions and 50% of all wild fish passed this dam from 29 April to 4 May and 90% had passed by the end of May. In the relatively colder (late winter and spring) years of 1989, 1991, and 1993, 50% of all wild fish had not passed the dam until mid-May, and 90% had not passed until mid-June (except in 1993, when unusually high flows moved 90% through the dam by the end of May). During these 7 years, we observed a consistent 2- to 3-week shift in timing of wild fish at the dam between relatively warm and cold years. In 1995, intermediate weather conditions prevailed in late winter and spring (compared to the previous 6 years), and we observed intermediate passage times of 9 May and 5 June, for the 50 and 90% passage dates, respectively. We PIT-tagged wild fish in only three Idaho streams for the 1996 and 1997 smolt migrations. Therefore, we did not compare overall passage timing of wild fish in 1996 and 1997 to other years, since disproportionately high percentages (91 and 73.5%, respectively) of wild fish detections at the dam were from Oregon streams. In all other years 50% or less of wild fish detections were from Oregon streams. In 1999, we experienced different climatic conditions than in all other previous migration years. In late winter, a near-

record snow pack in the Snake River basin resulted in high flows during the early spring period; however, the ensuing flows were moderated by very dry and cold conditions during the remaining spring and early summer period. The fluctuating medium to high flows throughout the spring moved the wild fish through Lower Granite Dam as observed in warmer years, with 50% passing by 3 May and 90% passing by 30 May.

We compared combined detection profiles of wild fish to river flows at Lower Granite Dam. Over all years, peak detections coincided with variable flows before about 9 May; however, between 9 and 31 May, peak detections coincided with peak flows. It appears that water reserved for fish migrations would provide more benefit to wild fish if it is utilized after the first week of May, particularly during years with low stream flows.

Our wild fish study is ongoing. To provide more information on the relationships between parr/smolt movements and environmental conditions, we have established environmental monitoring at five sites in natal rearing areas, four of which are located next to fish traps for juvenile salmonid migrants. Water quality sondes at these sites monitor water temperature, depth (flow), conductivity, dissolved oxygen, pH, and turbidity, continuously on an hourly basis. We have established a database of this environmental data that is available on the Internet at: <http://bemdata.nwfsc.noaa.gov/baseline/intro.html>. As additional environmental monitors and traps are installed in study streams, we can more accurately monitor fry, parr, and smolt movements out of rearing areas and examine the relationships between these movements and environmental parameters within the streams. Mapped over time, this information, along with weather and climate data, will be useful for accurately predicting on an annual basis the migrational characteristics of different wild stocks as they pass downstream through the Snake and Columbia River hydropower system.

Since 1992, fishery managers have been using real-time detection information on wild fish stocks to direct daily operations of the hydropower system, including reserved water releases, and a myriad of dam operations such as spill, bypass operations, power generation loads and schedules, and transportation of smolts. As more information on the migrational behavior of these wild fish stocks become available, decisions can be made to better protect these valuable threatened fish stocks.

More detailed information on this study can be found in our annual reports that are posted on the Internet at:

<http://www.efw.bpa.gov/cgi-bin/FW/publications.cgi>

Click on *Reports*, then *Downstream Migration* and *Water Budget*, then scroll down to project number 9102800.

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References

- Achord, S., G. M. Matthews, O. W. Johnson, and D. M. Marsh. 1996. Use of Passive Integrated Transponder (PIT) tags to monitor migration timing of Snake River chinook salmon smolts. *North American Journal of Fisheries Management* 16:302-313.
- Bentley, W. W., and H. L. Raymond. 1968. Collection of juvenile salmonids from turbine intake gatewells of major dams in the Columbia River system. *Transactions of the American Fisheries Society* 97:124-126.
- Bjornn, T. C. 1971. Trout and salmon movements in two Idaho streams as related to temperature, food, stream flow, cover, and population density. *Transactions of the American Fisheries Society* 100:423-502.
- Clark, W. C., and J. E. Shelbourn. 1985. Growth and development of seawater adaptability by juvenile fall chinook salmon (*Oncorhynchus tshawytscha*) in relation to temperature. *Aquaculture* 45:21-31.

- Duston, J., and R. L. Saunders. 1990. The entrainment role of photoperiod on hypoosmoregulatory and growth related aspects of smolting in Atlantic salmon (*Salmo salar*). *Canadian Journal of Zoology* 68:707-715.
- Ebel, W. J. 1980. Transportation of chinook salmon, *Oncorhynchus tshawytscha*, and steelhead, *Salmo gairdneri*, smolts in the Columbia River and effects on adult returns. *Fishery Bulletin (U.S.)* 78:491-505.
- Edmundson, E., F. E. Everest, and D. W. Chapman. 1968. Permanence of station in juvenile chinook salmon and steelhead trout. *Journal of the Fisheries Research Board of Canada* 25:1453-1464.
- Ewing, R. D., S. L. Johnson, H. J. Pribble, and J. A. Lichatowich. 1979. Temperature and photoperiod effects on gill (Na + K)-ATPase activity in chinook salmon (*Oncorhynchus tshawytscha*). *Journal of Fish Biology* 36:1347-1353.
- Park D. L., and W. J. Ebel. 1974. Marking fishes and invertebrates. II. Brand size and configuration in relation to long term retention on steelhead trout and chinook salmon. *Marine Fisheries Review* 36(7):7-9.
- Prentice, E. F., T. A. Flagg, and C. S. McCutcheon. 1990a. PIT-tag monitoring systems for hydroelectric dams and fish hatcheries. *American Fisheries Society Symposium* 7:323-334.
- Prentice, E. F., T. A. Flagg, C. S. McCutcheon, and D. F. Brastow. 1990b. Feasibility of using implantable passive integrated transponder (PIT) tags in salmonids. *American Fisheries Society Symposium* 7:317-322.
- Prentice, E. F., T. A. Flagg, C. S. McCutcheon, D. F. Brastow, and D. C. Cross. 1990c. Equipment, methods, and an automated data-entry station for PIT tagging. *American Fisheries Society Symposium* 7:335-340.
- Raymond, H. L. 1974. Marking fishes and invertebrates. I. State of the art of fish branding. *Marine Fisheries Review* 36(7):1-6.
- Raymond, H. L. 1979. Effects of dams and impoundments on migrations of juvenile chinook salmon in the Columbia and Snake Rivers, 1966 to 1975. *Transactions of the American Fisheries Society* 108:505-529.

- Saunders, R. L., and E. B. Henderson. 1970. Influence of photoperiod on smolt development and growth of Atlantic salmon (*Salmo salar*). Journal of the Fisheries Research Board of Canada 27:1295-1311.
- Solbakken, V. A., T. Hansen, and S. O. Stefansson. 1994. Effects of photoperiod and temperature on growth and parr-smolt transformation in Atlantic salmon (*Salmo salar* L.) and subsequent performance in seawater. Aquaculture 121:13-27.
- Wagner, H. H. 1974. Photoperiod and temperature regulation of smolting in steelhead trout (*Salmo gairdneri*). Canadian Journal of Zoology 52:219-234.

**USE OF A PIT-TAG 'ELECTRONIC WEIR' TO EXAMINE ATLANTIC
SALMON SMOLT MIGRATION AND WINTER SURVIVAL.**

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EXTENDED ABSTRACT ONLY – DO NOT CITE

There is an increasing need for monitoring movements and migrations of large numbers of fish in rivers and streams. Fish are stocked in many rivers to enhance or restore populations yet we know little about their behavior once they are stocked into tributaries. For instance, Pacific and Atlantic salmon restoration projects stock fry or smolts into tributaries and await their return some years later in order to assess the success of stocking, supplementation, and restoration programs. Successful migration out of tributaries, winter survival in tributaries, and fine-scale movements have rarely been accurately quantified.

Advances in passive integrated transponder (PIT) tag technology, including the low cost of PIT tags, offer the opportunity to locate and individually identify large numbers of fish without disrupting their natural habitat choice, activity, and behaviors. Because PIT tags are passive, remain viable for a number of years, and have a high retention rate when implanted peritoneally, tagged fish can be both recaptured within rearing habitats or detected as they emigrate downstream without trapping or handling the fish. Larger PIT tags (marketed by Texas Instruments) have allowed larger read ranges (1.5 m) and permitted us to construct large antennas that can monitor the width of an entire stream. With these tags and antenna-systems we have developed a method for passively monitoring movements of individuals in their natural environment with only one initial handling. Estimates of detection efficiency using dummy tags and tagged smolts indicate that detection efficiency is > 93%. In the fall of 1998 430

stream-reared parr (9-17 cm; 45% mature parr) from Smith Brook, VT (a tributary of the West River) were PIT tagged and their downstream movement continuously monitored. Thirty fish moved downstream within two months of tagging; 70% of these were mature parr. The following spring 99 fish left during the smolt migration; only fish > 11 cm the previous autumn were detected migrating the following spring. An estimate of smolt recruitment of 25% (99/400) for Smith Brook in 1999 is a combination of size dependent smolt recruitment and winter mortality.

In order to test tag retention and the effect of tagging, 50 fish (9-15 cm) that had been stocked as fry were captured by electrofishing on November 9; thirty-four were PIT-tagged and sixteen were given a combination of colored paint marks in the anal fin to mark individuals fish. The fish were kept in two 1 m diameter tanks with approximately 1 l/min Connecticut River water at ambient temperatures (1-4 °C). The fish were fed brine shrimp and hatchery pellets every other day. There was no tag loss in the thirty-four wild-reared fish maintained in the lab for four months (November 9 to March 7). Growth rate in length (tagged: 0.064 ± 0.011 mm/d; untagged: 0.0495 ± 0.011 mm/d) and weight (tagged: 0.29 ± 0.03 %/d; untagged: 0.17 ± 0.06 %/d) was low in both groups due to the relatively cool ambient temperatures at this time of year, and did not significantly differ ($p > 0.1$, t-test).

It is expected that application of PIT tag technology as a research tool will add significantly to our understanding salmon biology and the effectiveness of salmon restoration efforts. This technique also provides a mechanism for analyzing multiple aspects of behavior in migratory and nonmigratory fishes. Other uses for stream fishes could include examining the effect of stream crossings (e.g., culverts and bridges) on fish habitat use, the effectiveness of barriers (for example electric and sound barriers) on restricting fish movement, microhabitat utilization, and long-term demographic responses to habitat manipulation. This technique can also be applied to many other animal groups to examine habitat utilization, movement, and migratory patterns.

**FRESHWATER TO SALTWATER:
THE ROLE OF CRH IN MIGRATORY BEHAVIOUR
IN JUVENILE SALMONIDS**

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EXTENDED ABSTRACT ONLY – DO NOT CITE

The physiological drivers of migratory behaviour in juvenile salmonids are at present unknown. Evidence suggests that hormones of the thyroid axis are associated with many of the behaviours exhibited by downstream migrants. Recently we have focussed on the behavioural effects of the neurohormone corticotropin releasing hormone (CRH). CRH is produced in response to a stressor and is thought to be the primary activator of the hypothalamic-pituitary-interrenal axis in fish. However, little is known about its role or secretion during times when the animal is not stressed. Amongst vertebrates CRH has activating effects on a number of behaviours commonly associated with the stress response including locomotor activity. CRH also appears to have similar activating effects within the central nervous system of fish. Application of this knowledge has led us to hypothesise that CRH may play a role in initiating the downstream migration of juvenile salmonids but also that migratory movements will be modified following the detection of a stressor. CRH is well situated to co-ordinate both the physiological and behavioural responses observed in smolting salmonids during both the parr-smolt transformation and in the response to a stressor.

To test these hypotheses we have conducted extensive radiotelemetry work on the Columbia River. Juvenile salmonids (*Oncorhynchus* spp.) were implanted gastrically with radio transmitters and released at several locations above and below the hydroelectric dams. Their migratory behaviour was monitored from the land, air and water. The results of this work suggest that the migratory behaviour of 'stressed' fish is significantly altered compared to 'unstressed' fish. Furthermore the behaviour of stressed fish significantly increased the likelihood of predation.

To investigate whether CRH has an effect on downstream swimming behaviour we conducted studies in the laboratory using artificial streams. The behaviour of both hatchery and wild fish was monitored following intracerebroventricular (ICV) injections of CRH or saline. The results of this study suggest that CRH does indeed have activating effects on downstream movement. However the response to ICV CRH appears to be a bimodal as several fish injected with CRH exhibited holding behaviour that is consistent with observations made on radio tagged fish.

Based on these results we suggest that modifications to the environment by human activities will disrupt normal migratory behaviour by activation of the stress response.

**SWIMMING PERFORMANCE AND MUSCLE FUNCTION RESPOND
TO ELEVATED T₃ HORMONE IN SMOLTING COHO SALMON**

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Introduction

During the parr-smolt transformation, 3,3'-5'-tri-iodo-L-thyronine (T₃) plays a major role in the onset of many physiological, morphological and behavioral smolt-like characteristics. T₃ has been implicated in muscle contractile and molecular modification in many taxa, but T₃-modification of muscle contraction and locomotion in juvenile salmonids has not been addressed. We used isometric and tetanic contractility as measurements of muscle function and critical swimming velocity as a measure of maximum aerobic swimming performance to test the hypothesis that juvenile coho salmon (*Oncorhynchus kisutch*) locomotion is modified by a hyperthyroidal status

Methods

Treatment groups included T₃ pellet-implanted, sham pellet-implanted, or control (no implant) juvenile coho salmon. All fish were anesthetized (MS-222), weighed to the nearest 0.1 g, measured (SL, FL, and TL) to the nearest mm, and held in (outdoor) round holding tanks, incorporating continuous flows of well water and aeration. After the 3-wk treatment period, critical swimming speeds (swimming flume) were determined, blood samples were drawn for

hematocrit measurements, gill tissue was sampled for Na⁺-K⁺ ATPase activity, and muscle bundles were dissected from the hypaxial musculature for *in vitro* twitch and tetany contraction measurements.

Results and Discussion

The surgically implanted (intraperitoneally) T₃ pellets produced some significant changes in the juvenile coho salmon. Critical swimming speeds were significantly decreased in T₃-treated fish, compared with the sham and control fish. In contrast, hematocrit, body weight, body lengths, and gill Na⁺-K⁺ ATPase activity were not different among any of the treatment groups. Tetanic contraction and twitch contraction rates as well as relaxation rates were significantly increased in T₃-treated fish compared with the control and sham fish. T₃ also induced morphological changes such as modified head morphology and increased body silvering, typically associated with the parr-smolt transformation. We conclude that surges in T₃ during the parr stage of the salmonid life cycle, and potentially during the parr-smolt transformation, modify locomotion. T₃-induced modification of muscle contractile kinetics may significantly contribute to decreased maximum aerobic swimming performance.

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**USE OF THE SAN FRANCISCO ESTUARY
BY JUVENILE CHINOOK SALMON**

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EXTENDED ABSTRACT ONLY - DO NOT CITE

Estuaries have been found to serve important nursery and rearing functions for juvenile salmonids emigrating from streams in the Pacific Northwest of North America (Reimers, 1973; Simenstad et al., 1982; Healey, 1991). The San Francisco Estuary, the largest estuary on the West Coast, is a segment in the migration path of juvenile chinook salmon (*Oncorhynchus tshawytscha*) leaving natal streams in the Sacramento - San Joaquin River system of California's Central Valley. All four chinook salmon runs are imperiled: the winter and spring runs are listed under the U.S. Endangered Species Act, and the fall and late-fall runs are candidates for listing. Although dams and water diversions in the Central Valley clearly play significant roles in the stocks' decline, the influence of transiting the highly modified and urbanized San Francisco Estuary is unknown and may contribute to reduced survival. To address this issue, a multiyear study was conducted on the growth and development of juvenile chinook during their emigration through the Estuary, and the influences of environmental factors on their physiological dynamics. Aspects of that investigation are presented here.

Data in this report are from juvenile chinook salmon collected in 1997 during May and June, the period of greatest abundance in the Estuary (Kjelson et al., 1982), at four locations spanning the saline portion of the Estuary (km's 68, 46, 26, and 3 from the Estuary exit) and in the Gulf of the Farallones, the coastal waters seaward of the Estuary exit at the Golden Gate. Juvenile salmon were

collected by trawl and held on ice until returned to the laboratory for analyses. Size, age (otolith increments), stomach contents, and concentrations of lipid classes and total protein were determined. Data were analyzed for variability among locations and capture dates by the general linear model of analysis of variance and by Tukey's studentized range test.

Each sampling location was visited more than once on two successive sweeps of the Estuary, starting at the confluence of the Sacramento and San Joaquin Rivers (km 68) and ending at or near the exit at the Golden Gate (km 3). There were no statistically significant trends in size, age, lipid, and protein variables by sampling date at any location; consequently data for each location from both sweeps were combined for further analysis.

Juvenile chinook were 136 ± 2 d post-hatching when they entered the Estuary (Fig. 1c). Based on the difference between mean otolith increment counts of fish from km 68 and km 3, they spent about 40 d transiting the 65-km span of the Estuary, resulting in a calculated migration rate of 1.6 km/d. Data from coded-wire tagged fish revealed a modal migration rate of 2.6 km/d (n = 17).

While in the Estuary, young chinook salmon grew very little, gaining only 7 mm fork length and 0.9 g weight on average (Fig. 1a & 1b). Once in marine waters of the Gulf of the Farallones, however, growth was rapid. Changes in size within the Estuary were not statistically significant, whereas chinook from coastal waters were longer ($P < 0.0001$) and heavier ($P < 0.001$) than those from the Estuary.

In addition to insignificant growth while in the Estuary, juvenile salmon experienced declining condition (Fig. 2) and no accumulation of lipids or protein. Once in the ocean, however, condition recovered ($P < 0.001$) and triacylglycerols, the primary energy store, were depleted ($P < 0.0005$). Other lipid classes (polar lipids, cholesterol, nonesterified fatty acids, and steryl/wax esters) were unchanged during Estuary transit and ocean residence.

Emigrating salmon appeared to feed more while in the Estuary than prior to entry. More than 80% of individuals in the Estuary contained food in their stomachs whereas 50% had stomach contents when entering the Estuary. There was a progressive change in the importance of prey, from invertebrates to fish larvae, as young chinook migrated from freshwater to the ocean. Feeding was intensified in the ocean: stomach contents were about 0.9% of body weight in ocean fish contrasted with 0.5% in fish from within the Estuary.

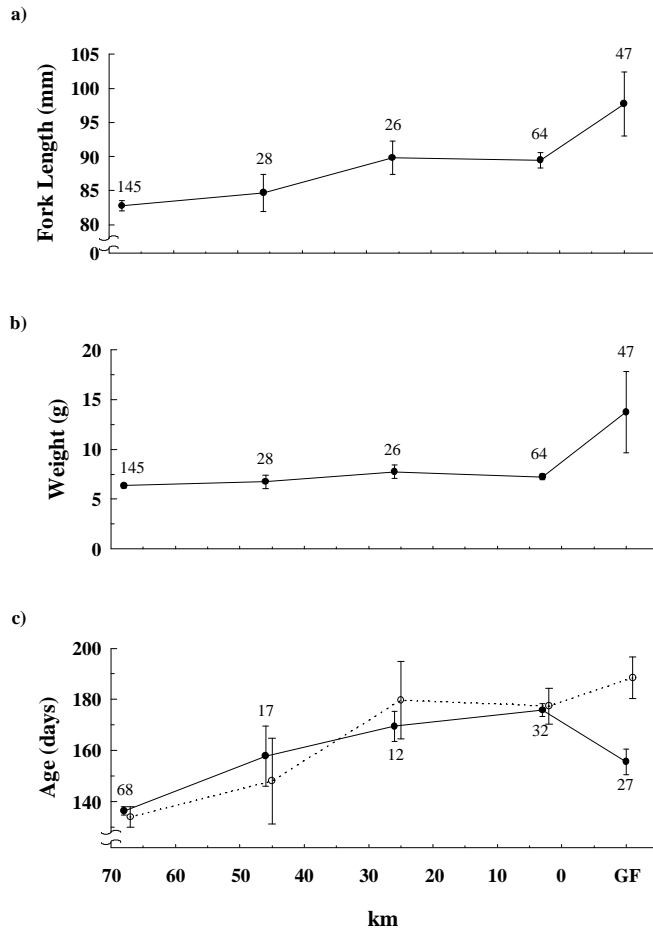


Figure 1. Mean (\pm SE) (a) fork lengths (FL), (b) weights, and (c) ages of juvenile chinook salmon from locations within the San Francisco Estuary (km's 68, 46, 26, 3) and Gulf of the Farallones (GF). Open circles and dashed line in (c) represent calculated ages for all salmon collected at each location from regression:
 $\text{Age} = 26.83 + 1.48 (\text{FL})$. Numbers near means are sample sizes.

**MODELING THE MIGRATORY BEHAVIOR OF JUVENILE SALMON:
WHAT PROCESSES GOVERN DOWNSTREAM MOVEMENT?**

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EXTENDED ABSTRACT ONLY - DO NOT CITE

Introduction

In the Columbia River Basin in the northwestern United States, twelve stocks (4 different species) of anadromous Pacific salmonid have been listed as endangered under the U.S. Endangered Species Act. Recovering stocks will be challenging because each stock behaves uniquely and will respond differently to mitigation actions. Therefore, efforts to restore salmonid populations should include attempts to understand fish behavior, particularly how it varies among stocks or species and throughout life-histories. This talk will present results of modeling of migratory behavior with an emphasis on discerning individual-based behavioral variability and how this behavior evolves through the salmon life-history.

Methods

A model that can describe migrating fish populations is the advection-diffusion equation, which has been applied to a variety of dispersing animal populations (Okubo 1980). The advection term moves fish downstream and the diffusion term spreads the population through time. From this underlying migration equation, one can generate a distribution of travel times through a reach for a group of fish. Fitting this distribution to data requires estimating two parameters: r , downstream migration rate, and σ , rate of population spreading (Figure 1). Zabel and Anderson (1997) applied this equation to spring chinook

salmon migrating through a reservoir in the Snake River, a major tributary of the Columbia River.

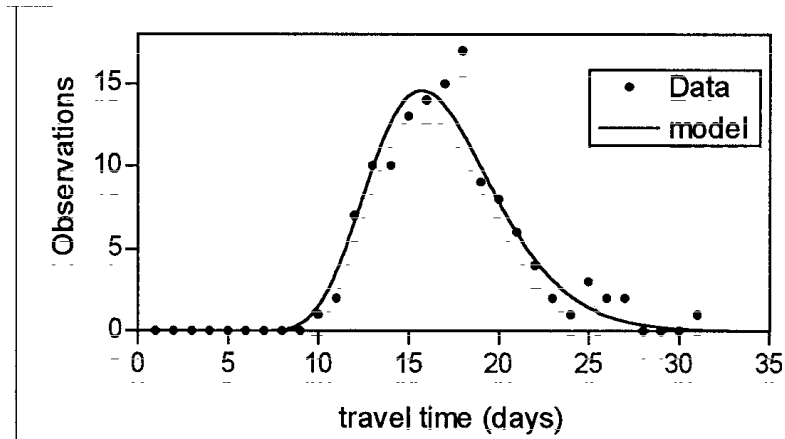


Figure 1. Example of travel time model fit to data. Wild Snake River spring chinook were released at Lower Granite Dam on April 12, 1995 and observed at McNary Dam, 225 km

One of the assumptions of the basic model described above is that all fish within a population follow the same behavioral rules. This may be unrealistic in some cases, but the basic model can serve as a null model to which more complex models can be compared. Here I relaxed this assumption by relating migration rate of individuals to fish length at tagging. In addition, I included covariates flow and release date, which are common to all fish released as a group but vary through a season of releases. This allowed for the effect of individual variability to be compared to variability among release groups. To assess the importance of various factors, I developed a series of equations to model migration rate:

$$\text{Model 0: } r_i = \beta_0 \text{ (null model)}$$

$$\text{Model 1: } r_i = \beta_0 + \beta_1 \cdot \text{length}_i$$

$$\text{Model 2: } r_i = \beta_0 + \beta_1 \cdot \text{length}_i + \beta_2 \cdot \text{flow}_i$$

$$\text{Model 3: } r_i = \beta_0 + \beta_1 \cdot \text{length}_i + \beta_2 \cdot \text{flow}_i + \beta_3 \cdot \text{date}_i$$

where subscript i refers to the i th individual, r_i is migration rate, the β s are coefficients, length_i is the length at tagging (mm), and flow_i is the mean flow (kcfs) during the migratory period, and date_i is the release date (Julian date).

Maximum likelihood was used to fit the β coefficients along with the spread parameter σ . Akaike's Information Criterion (AIC, Akaike 1973) was used to determine which model was most supported by the data. Models 1-3 were compared directly to the null model, and the AIC value provides an indication of the importance of added factors.

The data analyzed were from PIT-tagged (Passive Integrated Transponder) juveniles. PIT tags allow for tracking of individuals as they move downstream and pass detection sites. The general experimental design is to release groups of fish from a single location and tabulate temporal passage distributions at downstream sites.

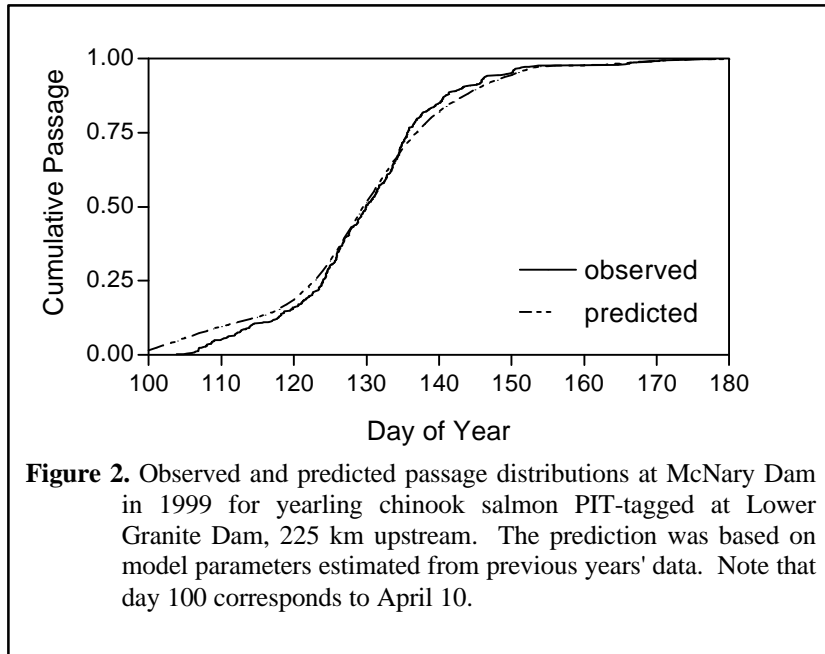
Three stocks of chinook salmon were analyzed. Wild Snake River spring/summer chinook, which migrate as yearlings, were tagged at Lower

Granite Dam (1996, 1998, 1999) on the Snake River and detected at McNary Dam on the Columbia River, 225 km downstream. Run-of-the-river (mixed hatchery and wild) Columbia River fall chinook were tagged at McNary Dam (1999) on the Columbia River and detected 123 km downstream at John Day Dam. Both these stocks were tagged as active migrants. Wild Snake River fall chinook, which migrate as subyearlings, were beach-seined (1995-1999) in their rearing areas in the Snake River as pre-smolts and detected at Lower Granite Dam. Though these fish were tagged at variable locations, their migratory reach was considered to be Lower Granite Reservoir, which is 51 km long. Since these fish were not actively migrating when tagged, their “travel times” were a combination of migration and rearing.

Results and Discussion

For Snake River fall chinook, fish length was the most important factor for determining migration rate. For the Columbia River fall chinook, length was clearly important, but the addition of the flow covariate substantially improved model performance. For the Snake River spring chinook, length was unimportant, while the factor river flow was most important.

As juvenile chinook salmon mature from the rearing stage to a more actively migrating stage, individual variability becomes less important in terms of predicting migration rate, while river velocity becomes more important. This probably reflects that fish must reach a certain developmental threshold (for which fish length is an indicator) before they initiate active downstream migration. As fish more actively migrate, they shift from nearshore rearing habitats to mid-river regions where they are more influenced by river velocity. Understanding the basic biology of endangered populations is crucial for developing recovery plans. While the conceptual model of behavior presented above is not necessarily new, the ability to quantify spatial and temporal patterns in migrating populations is valuable. Figure 2 demonstrates how these results can be used to predict passage distributions at specific points along the migration route, which is useful for determining when to implement management actions aimed at enhancing survival of migrating salmon.



PIT tags are increasingly being used to monitor fish populations world-wide. The modeling approach described here has potential for applications in many river systems where passage timing information is important in decisions on how to manage regulated rivers to improve fish survival.

References

- Akaike, H. 1973. Information theory and an extension of the maximum likelihood principle. Proceedings of the Second International Symposium on Information Theory.
- Okubo, A. 1980. Diffusion and Ecological Problems. Springer-Verlag, New York.
- Zabel, R.W., and J.J. Anderson. 1997. A model of the travel time of migrating

juvenile salmon, with an application to Snake River spring chinook.
North American Journal of Fisheries Management 17:93-100.

**OPTIMAL SWIM SPEEDS AND FORWARD ASSISTS:
ENERGY CONSERVING BEHAVIOURS
OF UP-RIVER MIGRATING ADULT SALMON**

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EXTENDED ABSTRACT ONLY – DO NOT CITE

Introduction

Pacific salmon migrations are energetically expensive and must be completed solely on energy reserves as no feeding takes place enroute. Migrants should be naturally selected to be efficient in their use of energy and attempt to minimize energetic costs of swimming wherever possible. Transport costs could be reduced through several different tactics including swimming in low-speed or reverse-flow current paths, swimming in a burst-then-coast fashion, and/or swimming steadily at hydrodynamic or metabolic optimal speeds (Webb 1995). This last tactic, defined as the cruising speed that minimizes the total energy expended in moving unit mass through unit distance, has received attention theoretically and empirically for fish swimming in still water environments (Brett 1995; Webb 1995 and references within), but has been generally ignored for moving water environments. This study explores the question: do up-river migrating sockeye salmon (*Oncorhynchus nerka*) minimize transport costs by swimming at metabolically optimal speeds, and if so, does this depend on flow conditions?

Methods

We address these questions through the use of bank-side videography and visual observations of individual migrating sockeye salmon at several sites along their migration routes. We used the stereovideographic methods in Boisclair (1992) to estimate ground speeds for individual fish. Swim speeds were estimated from tail beat frequency information (see equations in Hinch and Rand, (1998)). We also determined swim efficiency indices, which provides insights into swimming tactics, for each fish by dividing an individual's ground speed by their swim speed.

We studied three stocks of adult Fraser River sockeye salmon, each of which migrate relatively long distances from the Pacific Ocean. The Early Stuart stock travels upriver 1100 km and gains 700 m elevation; the Chilko stock travels 660 km and gains 1160 m elevation; the Horsefly stock travels 850 km and gains 760 m elevation. These stocks migrate up different Fraser River tributaries enroute to their specific spawning grounds. In August 1997, we made observations on fish in these tributaries. Sockeye travelled in narrow bands, parallel to and near the shore, and were usually highly visible from the banks. The 11 sites we monitored represented a natural range of encountered current speeds. Current speeds were determined by measuring the water speed of each individual's migration path through the observation field using a flow metre. The approximate volume of habitat we monitored at each site was 1-2 m³.

An optimal swim speed model developed by Webb (1995) reported a hyperbolic function that integrates the negative exponential decline of costs from standard metabolism with the positive exponential increase in swim activity metabolism over a range of swim speeds. This function allows for the computation of a swim speed that minimizes cost of transport in still water. We extended this model to moving water environments by including the cost of making forward progress through any encountered current speed by summing swim speed with encountered current speed, thus reflecting fish ground speed. Our optimal migration index was derived by dividing the theoretical minimum energy expenditure (for an individual's encountered water speed) by their observed estimate of energy expenditure (calculated by inputting an individual's observed swim speed and encountered water temperature into a sockeye bioenergetics model from Beauchamp et al. (1989) and solving for a 2500g fish).

Results and Discussion

We found that salmon were highly efficient at migration (i.e. ground speeds equaled or exceeded swim speeds) through reaches with relatively low encountered currents ($< 25 \text{ cm s}^{-1}$) (Figure 1). At some sites with downstream flows, fish received forward assists and moved upstream as though downstream currents did not exist. High swim efficiency indices were associated with low speed or reverse field currents (Figure 1). We speculate that salmon locate and exploit very small reverse flow vortices to achieve this feat.

With encountered currents $< 25 \text{ cm s}^{-1}$, we determined that sockeye salmon migrated according to our optimal swim speed model; that is, migrants minimized transport costs per unit distance traveled (Figure 2). Why optimal swim speeds are employed at low to medium encountered flows and not at high flows may be due to the balancing of energetic costs of migration against the fitness costs of spawning delays. Long distance migrants have limited energy reserves, so when currents are slow, behaviours that minimize energy use per distance traveled are likely adopted. However, at sites with fast currents, the risk of significant delays which could delay and imperil spawning is enhanced, so migrants may exhibit relatively fast swim speeds at those sites in order to minimize travel time per distance traveled.

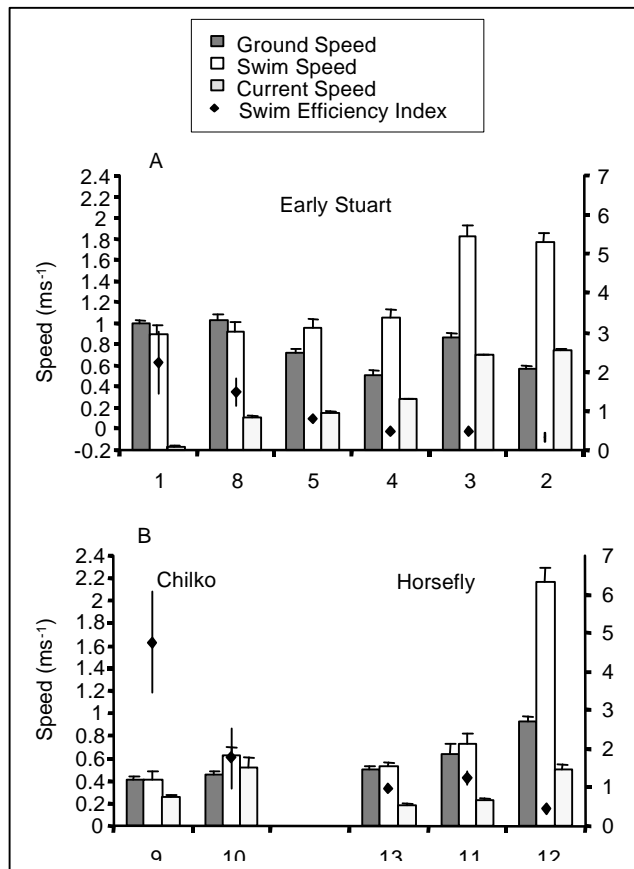


Figure 1. Histograms represent mean (plus 1 SE) ground, swim and encountered current speeds for each study site of Early Stuart (A), and Chilko and Horsefly sockeye stocks (B). Negative currents reflect flows in upstream direction. Diamonds represent mean swim efficiency indices (plus 2 SE). In many instances, SE is very small and is obscured by other symbols. Site numbers reflect sampling order and are listed, within stock, from lowest to highest encountered currents.

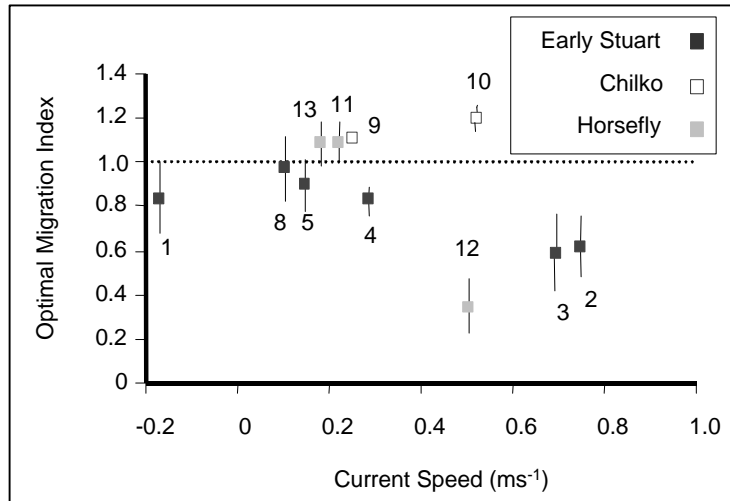


Figure 2. Plot of mean optimal migration indices (plus and minus 1 CI) versus mean encountered current speed. Negative current speeds reflect currents flowing in upstream direction. Numbers reflect study site locations and colours reflect different fish stocks. An index value of one represents an optimal migrator. Values lower than one represent sub-optimal, or inefficient, swim behaviours. Values exceeding one represent super-optimal, or highly efficient, swim behaviours

References

- Beauchamp, D.A., Stewart, D.J. and Thomas, G.L. 1989. Corroboration of a bioenergetics model for sockeye salmon. *Trans. Am. Fish. Soc.* 118:597-607.
- Boisclair, D. 1992. An evaluation of the stereocinematographic method to estimate fish swimming speed. *Can. J. Fish. Aquat. Sci.* 49:523-531.

- Brett, J.R. 1995. Energetics. *In* Physiological ecology of Pacific salmon. *Edited by* C. Groot, L. Margolis and W.C. Clarke, UBC Press, Vancouver, B.C. pp. 3-68.
- Hinch, S.G., and P.S. Rand.1998. Swim speeds and energy use of up-river migrating sockeye salmon: role of local environment and fish characteristics. *Can. J. Fish. Aquat. Sci.* 55:1821-1831.
- Webb, P.W. 1995. Locomotion. *In* Physiological ecology of Pacific salmon. *Edited by* C. Groot, L. Margolis and W.C. Clarke, UBC Press, Vancouver, B.C. pp. 71-99.

**SIMULATING MIGRATION BEHAVIOUR AND
METABOLIC POWER CONSUMPTION
OF UP-RIVER MIGRATING SOCKEYE SALMON
IN THE FRASER RIVER, BC**

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Introduction

Priede (1985) defines two types of selection pressures that are likely to be important in defining an animal's fitness. Type-1 selection is driven by energy conserving behaviours that operate across relatively extended time scales (days to weeks). These behaviours are important as a means to achieve high energy efficiency, thus leading to more energy diverted to metabolic processes that directly influence fitness. Type-2 selection is driven by fine time scale power budgeting (seconds to minutes), where the organism is faced with a defined metabolic scope which serves to limit power consumption at critical points through the organism's life history. Departures from this defined scope in nature result in increased risks of mortality. Adult Pacific salmon from some

stocks presumably are influenced by both types of selection as a result of their costly river migration.

Most efforts at describing adapted behaviours in these fish have involved defining optimal swim speeds that minimize cost of transport (Weihs 1973; Ware 1975). We contend that these examples, along with the examples discussed earlier, are appropriate for investigating type-1 selection, but ignores finer time scale power budgeting implicit in type-2 selection. Swimming bursts measured at the scale of seconds occur routinely in these fish in the field (Hinch and Rand, 1998) and, given that energy costs are a power function of swim speed, these active periods can be inordinately expensive. By coupling the use of electromyogram (EMG) telemetry with simulation modeling, it is possible to generate more accurate measures of energetic costs in situ. In this paper we explore behavioural patterns measured across a broadly defined temporal scale (seconds to weeks) to compare the relative importance of both types of selection operating on energy efficiency during river migration.

We developed a simulation model that accounts for power consumption of upriver migrating sockeye salmon in the Fraser River. Our objective in this modeling study was (1) to test whether averaging over the variability observed in swim speeds introduces a significant bias in predictions of true costs to migrating fish, (2) to describe the fates of stored metabolic energy during the course of the river migration, including an evaluation of the importance of anaerobic costs from burst swimming and defining the full range of power consumed for activity in the field, and (3) to conduct error and risk analyses on the model to rank parameters with respect to their sensitivity, and define risks of increased mortality resulting from energy depletion for the average migrant in any given year based on the natural variability of environmental conditions in the river.

Methods

We constructed a simulation model to account for energetic losses resulting from basal and active metabolism during the river spawning migration in Early Stuart sockeye salmon in the Fraser River. The model also accounts for energy flow to maturing gonads. We refined existing bioenergetic models for sockeye salmon to represent the adult migrants in this study. Two different model configurations were developed: 1) a daily time step model that relied on a daily mean swim speed to estimate activity costs, and 2) a finer time scale model (5 s)

that conforms more closely to the sampling rate of the EMG tags used in the field study (Hinch and Rand 1998). We tested the model against energy use data collected through tissue analyses on adults at different points along the migration route during 1956. We summarized the results of this simulation by partitioning the fates of stored energy between basal metabolism, active metabolism and gonad development. We conducted Monte Carlo simulations to determine which parameters were most sensitive in the model. Further, we conducted a risk analysis to help determine the relative mortality risk incurred by adults over the past 44 years given variability in return timing, size at maturity, and variability in river conditions (namely, discharge and water temperature).

Results and Discussion

The most accurate prediction of energy expenditure was obtained by expressing activity as a fine-time scale (5 s) stochastic process. By imposing a daily-time step, predictions of energy use were considerably lower than observed energy use, suggesting the practice of modeling field energetics at a daily-time scale, particularly for relatively active fish, may render dubious results. Daily mean power consumption through the Fraser River Canyon by the average successful migrant was circa 20 W, about four-fold higher than for less constricted reaches. Power consumption predicted at fine-time scales ranged from < 1 W (0.1 body lengths s^{-1}) during periods of reduced activity to 1700 W (8 body lengths s^{-1}) during bursts while navigating through turbulent canyon reaches. Activity dominated the energy budget of these salmon migrants. For our calibration run, 84% of stored energy was consumed by locomotor costs, while less than 20% was consumed by standard metabolism and gonad development. Through Monte Carlo simulations representing environmental variability observed during 1950-94, we determined 8% of the salmon runs during this time resulted in a high risk of exhaustion for the average migrant that could lead to elevated in-river mortality.

Results from our error analyses helped reveal important interactions between behaviour and energetics of sockeye salmon that have relevance to life history and evolutionary strategies for this species. Our results suggest that selective pressures may operate strongly on the behaviours that influence fine time scale power budgeting while enroute to the spawning grounds. This is reflected in the sensitivity of model predictions of energy use to the parameter values that defined the upper limit to the swim speed distribution. These selective

pressures, referred to as type-2 by Priede (1985, see our Introduction), would help define the frequency and magnitude of bursts performed by these salmon as they progress to the spawning grounds. While these bursts appear to be necessary to successfully navigate through some of the more difficult reaches, our results suggest that there must exist strong selective pressures to minimize the frequency and reduce the absolute magnitude of these bursts to avoid risk of energy exhaustion. Fish do appear to restrict these expensive bursts, particularly those that exceed 80% of U_{crit} , to difficult reaches within the Fraser River Canyon and Hell's Gate. If the fish exceed their metabolic scope, periods of stress can ensue that lead to hyperactivity and, ultimately, death (Black 1958; Wood et al. 1983). Hinch and Bratty (2000) have recently shown with EMG telemetry that sockeye that successfully ascended Hell's Gate swam at speeds that approximated their metabolic optima, whereas migrants who attempted to ascend but failed and died all swam at speeds that vastly exceeded optimal speeds. These results suggest that these fish are operating close to a physiological threshold, which may necessitate strong selection that would serve to fine-tune burst swimming behaviour.

Type-1 selection, as defined by Priede (1985, see our Introduction), appears to also play a role in defining energy efficiency of migration in this species. In particular, the mean swim speed defined in the model and the parameters that governed the relationship between mean swim speed and river discharge levels were all important based on the results of our error analysis. This suggests that reducing mean swim speeds in general, or reducing swim speeds under conditions of high river discharge, can be adaptive and result in higher energy efficiency during migration. Over an evolutionary time scale there must be some dynamic equilibrium between expanding field activity scope that allows for marginal increases in power to navigate through difficult reaches (type-2 selection) and more conservative locomotor behaviours that result in longer term savings in energy (type-1 selection).

How can this model be implemented into management? The regulatory body charged with managing these stocks, Fisheries and Oceans Canada (FOC), have adopted a risk-averse strategy for managing B.C. salmon (Blewett et al. 1996). Most of the regulatory effort by FOC is oriented toward managing harvest rates on these stocks as a means to achieve target escapement goals. We feel that it is critical for managers to realize that, while harvest is likely to represent the dominant source of mortality on these stocks in most years, in some years significant "natural" mortality may occur resulting from difficulties encountered during migration. Although we looked at only early Stuart stock in our analysis,

it is reasonable to assume that these risks may also be important for other stocks as well. Although much uncertainty still exists in translating our risk index to an explicit mortality rate, we emphasize that this mortality risk should be included as a factor in pre- and in-season management during years where difficult passage conditions are expected. For example, when model predictions suggest high natural mortality risk for the average migrant in a particular year, harvest could be adjusted to reduce total fishing mortality, thus allowing more fish to successfully reach the spawning grounds.

References

- Black, E.C. 1958. Hyperactivity as a lethal factor in fish. *J. Fish. Res. Board Can.* 15:573-586
- Blewett, E. and 11 co-authors. 1996. Evaluation Study: DFO's Reponse to the Report of the Fraser River Sockeye Public Review Board. EB Experts, Inc., 140 p.
- Hinch, S.G., and J.M. Bratty. 2000. Effects of swim speed and activity pattern on success of adult sockeye salmon migration through an area of difficult passage. *Transactions of the American Fisheries Society.* 129:604-612
- Hinch, S.G., and P.S. Rand. 1998. Swim speeds and energy use of up-river migrating sockeye salmon: role of local environment and fish characteristics. *Can. J. Fish. Aquat. Sci.* 55:1821-1831
- Priede, I.G. 1985. Metabolic scope in fishes, p. 33-64. In P. Tytler and P. Calow [ed.] *Fish energetics: new perspectives.* Croom Helm Ltd., Kent, U.K.
- Ware, D.M. 1975. Growth, metabolism, and optimal swimming speed of a pelagic fish. *J. Fish. Res. Board Can.* 32:33-41
- Weihs, D. 1973. Optimum fish cruising speed. *Nature (London)* 245:48-50
- Wood, C.M., Turner, J.D., and Graham, M.S. 1983. Why do fish die after severe exercise? *J. Fish Biol.* 22:189-201

MIGRATION OF LOWLAND RIVER FISHES

THROUGH FISH PASSES

– THE THREE P’S: PITS, PASSES AND POTAMODROMY

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Background

There is increasing recognition that in lowland rivers many non-salmonid freshwater fish species exhibit potamodromous migratory behaviour (e.g. Lucas & Batley, 1996; Northcote, 1998). European rheophilic cyprinids such as barbel *Barbus barbus* and chub *Leuciscus cephalus* usually move upstream in spring to find appropriate spawning habitat. In winter many fish, including juveniles, move downstream to seek refuge and subsequently move upstream in spring. Increasingly fish passage facilities are being provided for lowland river fishes, but we still have a poor understanding of their migratory behaviour and little information on the efficiency of these fish passes.

Passive integrated transponder (PIT) tags of c. 0.1 g enable attachment to fish of less than 5 g. Each tag contains a microchip but no battery, and is energised by a low frequency magnetic field emitted by the detector, triggering the tag to transmit its unique identity code. The technique, therefore, has great potential for simultaneous study of the behaviour of a wide range of sizes and species of fish that typically occur in lowland rivers. In this study an automated flat-bed passive integrated transponder (PIT) detector array was used to examine the behaviour of fish at a baffled flume pass on the Yorkshire Derwent, North East England.

Methods

The study site was a fish pass at Stamford Bridge weir on the Yorkshire Derwent, NE England (53° 59' N, 0° 55' W). This reach of the river is impounded, with weirs 5 km below and 3 km above Stamford Bridge. The fish community is dominated by riverine cyprinids, including chub and dace, which are lithophilic spawners. These, and other species, aggregate and spawn in the weir pool in spring, but prior to the building of a fish pass in 1996 they could not move further upstream. The pass at Stamford Bridge was built for the Environment Agency in 1996 and is the only route for passage past the weir under all but exceptional flood conditions. The fish pass is of a Denil-type baffled flume design, 10 m long, 0.9 m wide and with a gradient of 1:5.

The PIT detector array followed the principle of Castro-Santos *et al.* (1996), with detectors at the entrance and exit of the pass, and was based upon the flat-bed design of Armstrong *et al.* (1996). The flat-bed design, using a coil embedded in a 2 cm thick plate, is capable of detecting small commercially available low-range PIT tags across the whole width of a typical baffled fish pass and operates at 125 kHz. Tags used were Trovan ID100 (11.7 mm x 1.9 mm, 0.10 g in air). Nominal peak range of detection in water of a typical tag over a single antenna, 0.90 m wide, was 0.18 m, occurring in the midline near each of the ends. In order to improve interrogation of the whole water column, pairs of detectors, vertically spaced by 0.30 m, were used (see Lucas *et al.*, 1999 for further information). Each detector was attached to a power supply and high-sensitivity decoder unit (UKID single point decoder). Records were stored by memory chips and were periodically downloaded onto a portable laptop computer. A coarse screen at the upstream exit prevented large debris entering the pass.

Efficiency of the upstream detectors measured using 20 PIT-tagged brown trout (*Salmo trutta*), observed to swim past the detectors was recorded as 100%. Efficiency of detection measured using PIT tags mounted on poles was in excess of 95% throughout the study. Between 22 May 1998 and 9 April 1999 a total of 401 fish, comprising 11 species with a combined length range of 9-104 cm, were PIT tagged and released downstream of the fish pass. Of these, 241 wild fish were obtained from downstream of the weir, 58 wild fish were displaced from upstream of the weir and 102 were of hatchery origin.

Results

Near-continuous recording between 23 May 1998 and 31 May 1999 demonstrated the effectiveness of the PIT array at this site for recording entry to, and successful exit, of fishes from the pass.

A total of 1271 records from 90 individual fish were recorded at the downstream detectors, and 20 tagged fish were recorded successfully exiting from the top of the pass, giving a pass efficiency of 22.2 %, based on the proportion of different fish which ascended. Fish larger than 20 cm which entered the pass were significantly more successful in ascending it. Overall 22.4 % of tagged fish entered the pass, comprising chub, dace, roach *Rutilus rutilus*, bleak *Alburnus alburnus*, perch *Perca fluviatilis*, pike *Esox lucius* and brown trout, with highest numbers in May and June. There were significant differences in the proportions of different treatment groups of fish entering the pass; the highest value of 43.1% occurred for displaced wild fish and is suggestive of a homing response.

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References

Armstrong, J.D., Braithwaite, V.A. and Rycroft, P. (1996). A flat-bed passive integrated transponder array for monitoring the behaviour of Atlantic salmon parr and other fish. *Journal of Fish Biology*, **48**, 539-541.

- Castro-Santos, T., Haro, A. and Walk, S. (1996). A passive integrated transponder (PIT) tag system for monitoring fishways. *Fisheries Research*, **28**, 253-261.
- Lucas, M.C. and Batley, E. (1996). Seasonal movements and behaviour of adult barbel *Barbus barbus*, a riverine cyprinid fish: implications for river management. *Journal of Applied Ecology*, **33**, 1345-1358.
- Lucas, M.C., Mercer, T., Armstrong, J.D., McGinty, S. and Rycroft, P. (1999). Use of a flat-bed passive integrated transponder antenna array to study the migration and behaviour of lowland river fishes at a fish pass. *Fisheries Research* **44**, 183-191.
- Northcote, T.G. (1998). Migratory behaviour of fish and its significance to movement through riverine fish passage facilities. In *Fish Migration and Fish Bypass Channels* (ed. Jungwirth, M., Schmutz, S. and Weiss, S.), pp. 3-18. Oxford: Fishing News Books, Blackwell Science.

**COMPARATIVE VULNERABILITY OF ENDANGERED FISHES
TO A FISH SCREEN**

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EXTENDED ABSTRACT ONLY - DO NOT CITE

Introduction

In California's Sacramento-San Joaquin estuary, >2000 water diversions extract 4-6 million acre feet of water each year. Some of the larger diversions are equipped with fish screens intended to reduce entrainment losses of resident and migratory fishes. We evaluated the protection offered by a fish screen by comparing the vulnerability of three local endangered fishes, splittail (*Pogonichthys macrolepidotus*), chinook salmon (*Oncorhynchus tshawytscha*), and delta smelt (*Hypomesus transpacificus*), to entrainment, injury, and mortality at a simulated screened water diversion in the Fish Treadmill, a unique annular flume equipped with a fish screen.

Methods

The Fish Treadmill is a large annular flume incorporating a 3-m diameter inner fixed fish screen (vertical wedgewire, 2.3 mm spacing) and a 4.3-m diameter rotatable outer screen to enclose a 0.67-m wide test channel. Fishes were tested for 2 h at 10 combinations of approach (perpendicular flow through the screen, velocity range 0-15 cm/s) and sweeping velocities (parallel flow past the screen, velocity range 0-62 cm/s) at two temperatures (12 and 19°C) during the day

(light conditions) and night (dark conditions). During the exposure, fish performance and behavior, including fish-screen contact events, swimming velocity (through the water), velocity and direction of travel past the screen, and survival, were measured. Short term survival and injuries were assessed 48 h post-exposure.

Results and Discussion

Delta smelt (preliminary data only) were the most sensitive species, suffering significantly greater flow- and screen contact-related mortality rates and, because of strong positive rheotaxis, potential prolonged entrainment near the screen at moderate sweeping flow velocities. Chinook salmon were susceptible to screen contact related non-lethal injuries. Younger parr were more likely to be entrained than older smolts. Splittail were the least vulnerable, insensitive to flow and, apparently, screen contact.

Results of these studies will be applied to develop fish screen flow and adaptive operational criteria that improve protection for these species and others.

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**EXPERIMENTS WITH JUVENILE CHINOOK SALMON
PASSED THROUGH HIGH-VOLUME, FISH-FRIENDLY PUMPS
AT RED BLUFF RESEARCH PUMPING PLANT,
SACRAMENTO RIVER, CALIFORNIA**

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EXTENDED ABSTRACT ONLY – DO NOT CITE

Introduction

Four runs of chinook salmon (*Oncorhynchus tshawytscha* Walbaum) provide the Sacramento River drainage in northern California with the distinction of having adult and juvenile salmon in its water throughout the year (Fisher 1994). Construction of a high dam (184 m) at Shasta, California in 1938-1944 eliminated access to spawning grounds in cold mountain streams at high elevations in the drainage. In 1964, a low-head dam was completed on the Sacramento River downstream of Shasta near Red Bluff, California. The dam at Red Bluff was built, maintained and operated by the U.S. Bureau of Reclamation. Its purpose was to divert water (85 m³/s) to irrigate semi-arid portions of the Central Valley of California.

Fisheries resources in the Sacramento River and its tributaries were affected in a variety of ways when operations at Red Bluff Diversion

Dam began. Impediments for populations of anadromous salmon and steelhead captured the majority of attention. The dam delayed timely passage for adult salmonids on migration runs to upstream spawning grounds. This was due in part to relatively low attraction flows from fish ladders that were put in place when the dam was constructed. Out-migrating juvenile salmonids that were disoriented by turbulence while passing under gates of the dam were fed upon by predators that congregated in the dam's tailwaters. Louvers with bypasses for juveniles were put in place across the channel that carried diverted water and fish into the forebay of the irrigation canal. That system proved unsatisfactory. During 1980-1995, fish ladders at the dam were improved. Modern drum-screens were put in place with bypass conduits that carried diverted fish back to the Sacramento River. In spite of these improvements, salmon runs in the river continued to decline.

As a result of interactions between State and Federal fish regulatory agencies, the gates of Red Bluff Diversion Dam were raised on various experimental schedules during spring and summer of years between 1986 and 1993. In 1993, the National Marine Fisheries Service directed the Bureau of Reclamation to raise gates on the Red Bluff Diversion Dam on September 15 of each year, and to leave them out of the water until the following May 15. This mode of operation allowed for deliveries of water for irrigation during high demand in summer, allowed protected winter-run adult chinook salmon unimpeded passage to upstream spawning grounds, and provided open passage for the majority of winter-run juveniles during their annual out-migration from spawning grounds. The Bureau of Reclamation, as part of its continuing commitment to improve fish-passage at Red Bluff, agreed to construct a Research Pumping Plant at the diversion dam. This pumping plant, in combination with other pumping alternatives available at Red Bluff, would meet water delivery requirements for irrigation during the dam-out period from September to May when demands for irrigation water are relatively low.

Methods

Construction of the Red Bluff Research Pumping Plant was completed in 1995. Two Archimedes lifts (11.58 m long, 3.05 m diameter) and an internal helical pump (0.91 m inlet and outlet) were installed in the plant. Unlike Archimedes lifts that had been successfully employed worldwide in industrial applications

for lifting water and slurries of various solids, the lifts at Red Bluff had revolving barrels, three fixed flights, rotating seals at intakes, fluctuating internal water-surface elevations (about 1 m), and operated at a relatively high rotational speed 26.5 rev/min. The lifts delivered water at 2.4-2.5 m³/s. The internal helical pump installed at Red Bluff was the largest of its kind ever built. During work for this paper the pump was run at 350-375 rev/min and delivered water in the range of 2.3-2.8 m³/s. The predecessor of the internal helical pump at Red Bluff was developed several decades ago to meet the need of the fishmeal industry of Peru for rapid off-loading and delivery of ocean harvest to processing plants (Stahle and Jackson 1982).

The purpose of work for this paper was to compare the two types of pumps in regard to safe passage for juvenile chinook salmon. Juveniles used were hatchery-reared. Two experiments were conducted. Both experiments consisted of repetitious trials in which samples of chinook were passed concurrently through two operating pumps. In one experiment, the Archimedes lifts were compared by passing samples of chinook through each of the two lifts. The two types of pumps in the plant were compared in a second experiment in which one of two Archimedes lifts was selected randomly, and it and the internal helical pump were operated simultaneously during fish-passage trials. *Treatment* samples were released in pump intakes, and *control* samples were released at pump outfalls. Fish from all samples were recovered in holding tanks located on downstream fish-bypass channels. A pump-passage effect (treatment effect) was indicated where the difference between treatment and control samples was statistically significant ($P \neq 0.05$).

Results and Conclusions

In the experiment to compare the Archimedes lifts, no pump-passage effect on mortality was detected for either lift. Mean mortality for all treatment and all control samples used with both lifts was low; 1.2%-1.8%. In the experiment to compare the Archimedes lifts and internal helical pump, no pump-passage effect on mortality was detected for the lifts. A significant pump-passage effect on mortality was detected for the internal helical pump ($P=0.0006$). The estimated pump-passage effect for the helical pump was low (2.6%). Pump-passage effects were not detected in either of the two experiments for %-frequency of surviving fish that were descaled, or for %-fish with other kinds of sub-lethal injuries. The extent of descaling and kinds of other injuries on 99% of surviving fish were not debilitating. We concluded that the Archimedes lifts and internal

helical pump at Red Bluff are indeed "fish-friendly", and can be used successfully for deliveries of irrigation water. This technology is being considered for application at other water diversion sites in California to protect fisheries resources.

References

Fisher, F.W. 1994. Past and present status of Central Valley chinook salmon. *Conservation Biology* 8:870-873.

Stahle, M. and D. Jackson. 1982. The development of a screw centrifugal pump for handling delicate solids. *World Pumps* 185:53-55.

SALMON PARR AS MODELS TO EXPLORE ADULT SALMON

RESPONSE AT FISH PASS

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EXTENDED ABSTRACT ONLY – DO NOT CITE

Introduction

Salmon approaching and moving through passes need to locate and traverse the entrance of each section of the pass. This research focuses on the effectiveness of two different types of fish pass: overflow weir and submerged orifices. An initial approach to the problem has been to use parr as models (Stuart, 1964) to explore the response of salmon to water flows in a scaled-down fish pass. Like anadromous adults, salmon parr move upstream, both spontaneously and following downstream displacement. It has been considered that the behaviour of upstream-migrating parr is similar to that of adults, but clearly extrapolations between the two life stages should be cautious. Two of Stuart's main findings were: 1) salmon parr prefer to jump rather than to swim through orifices, 2) as flow increases through orifices they attract salmon more efficiently but become more difficult to negotiate. These findings have influenced fish pass design, but have not been tested using adult salmon.

Experimental apparatus

The physical model represents a portion of a river downstream of a dam, weir or any other obstruction to fish migration. A removable/vertical board 1,22 m wide with an opening of 0,20 m by 0,10 m divides the flume into two pools.

Three types of openings are tested: the weir, the orifice at the bottom and the orifice at higher elevations: 0.05m or 0.10 m from bottom of the flume. Each may take on two different locations either in the middle or at the side. There are thus six different designs and each has been tested for two different flows: low ($0.012\text{m}^3\text{s}^{-1}$) and high ($0.020\text{m}^3\text{s}^{-1}$) flow.

For each situation, 20 fish were individually tested. Each fish was left in the flume 40 minutes before being removed if it did not go through the passage. The protocol was to assemble the type of pass entrance tested. The fish was then quickly captured and released at the downstream end of the flume. It was then observed continually and records were made of changes in position with time.

Results

Salmon parr readily moved upstream through submerged orifices but were reluctant to jump over weir ($p= 0.00$).

Table 1: Percentage of successful fish for each category

	Weir		Orifice		Orifice at the bottom	
	Side	Middle	0.05 m	0.10 m	Side	Middle
12l/s	0%	0%	65%	25%	70%	95%
20l/s	5%	5%	40%	55%	85%	85%

The time taken by the parr to move through the orifices is influenced by the lateral (side or middle) and vertical (0, 0.05 and 0.10 m from the bottom of the flume) position of the orifice. The most time efficient design is the orifice in the middle.

Salmon parr approaching jets generally followed the sides of the flume and swam into the orifice at an oblique angle thus minimising the period of time in fast water. All those salmon that initially moved directly towards the jets veered away from the fast-flowing water and approached again at an oblique angle.

Detailed measurements of the hydraulics such as velocity and turbulence of the approach area for each design were made. The hydraulic conditions, parr were confronted with, differed greatly depending on whether the water emerged from

a weir or submerged orifice (Fig 1). These differences are correlated to the efficiency of the different designs.

Maximum velocities for the submerged orifices occurred at the vena contracta 0.20m downstream the orifice in the jet centre line. By swimming along the side of the flume, parr avoided high velocities area and stayed in velocities zone, within the range of their cruising or sustained speed (Beach, 1984). To pass a weir, parr leap using the standing wave, generated the by the falling water. If turbulences or aeration phenomenon are too high, the stimulus to jump might be block.

Discussion

The differences between the results of this and Stuart's studies are pronounced. One difference in the experimental designs is that in this study a supply of water from the stock tank was provided, which may have given the requisite cues to release normal homing behaviour. Fish were observed soon after they were released whereas it appears from Stuart's report that his fish were held in the apparatus for many days. The rapid upstream movement we observed is similar to that seen in a field study of brown trout displaced downstream (Armstrong & Herbert, 1999). It is possible that Stuart was observing a response exhibited by fish stranded for long periods in small pools, rather than less inhibited homing behaviour.

References

- Armstrong & Herbert, 1999. Homing movements of displaced stream-dwelling brown trout, *Journal of fish biology*, 50, 445-449
- Beach, M.H. 1984. Fish pass design criteria for the design and approval of fish passes and other structures to facilitate the passage of migratory fish in rivers. *Fisheries Research technical report*, MAFF Dir. Fish. Res., 78,46pp
- Stuart, TA 1962. The Leaping Behaviour of Salmon and Trout at fall and Obstructions. *DAFS Freshwater Fisheries and Salmon Fisheries Research*, 28.

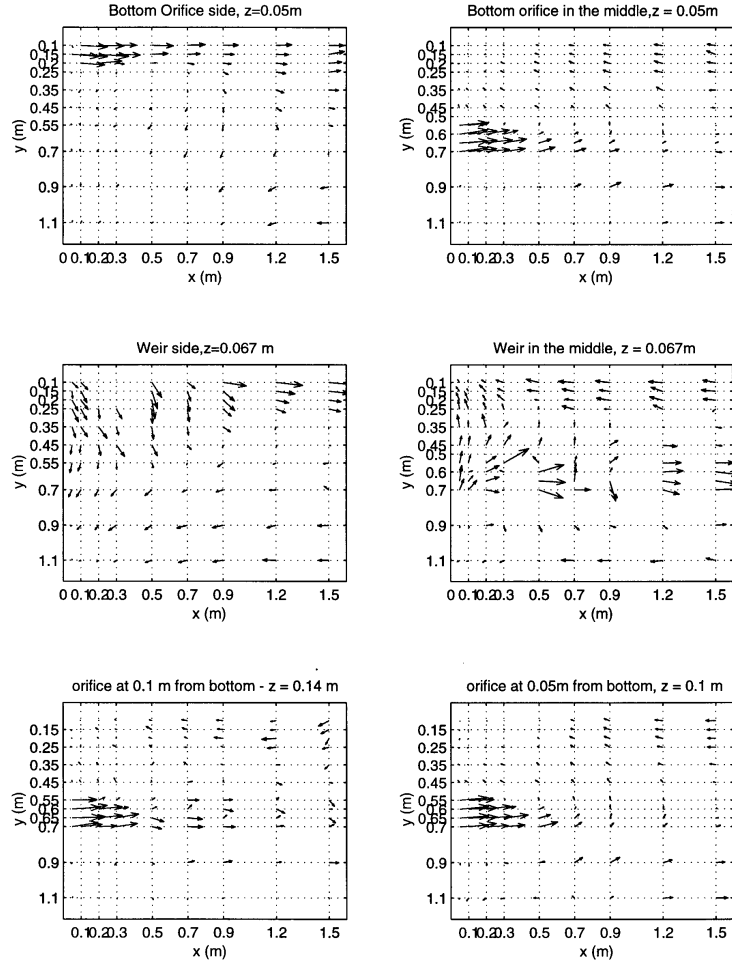


Figure 1: Velocity vectors for the 6 different designs at 12l/s

**DOWNSTREAM PASSAGE AND BEHAVIORAL RESPONSE
OF JUVENILE SALMON AND STEELHEAD
AT HYDROELECTRIC DAMS IN THE COLUMBIA RIVER SYSTEM.**

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Introduction

From 1905 to 1975, an extensive series of hydroelectric dams were constructed on the mainstem Columbia and Snake rivers (Figure 1). These dams converted nearly 1500 km of riverine habitat to a series of reservoirs, created obstacles to upstream passage of adult salmon and steelhead (*Oncorhynchus* spp.), and resulted in high loss rates for juvenile salmonids migrating downstream through turbines. Mitigation of hydro project effects on juvenile salmonids has focused mainly on construction of mechanical bypass systems (in-turbine screens) and increasing the discharge of water over spillways (surface spill). However, not all hydroelectric projects in the Columbia River system currently have bypass screens. Further, application of spill strategies to pass juvenile fish is limited by water quality standards that specify spill levels must not cause lethal gas supersaturation values. Current management agency goals call for 80% fish passage through non-turbine routes. Because these goals are not met at most hydro projects, even those with intake screens in place, some spill is required. These tradeoffs have resulted in focused development and operation of additional mechanical bypass systems. The objective of this paper is to summarize recent research directed at providing a safe route for smolts past hydroelectric projects, including studies related to development of surface collectors and other bypass systems.



Figure 1. Columbia and Snake rivers with hydroelectric projects

Downstream Passage Routes

Juvenile salmon have several passage options when they arrive in the forebay upstream of a hydroelectric project (Figure 2). They can follow the bulk flow through the powerhouse where they may be diverted by intake screens or pass directly through the turbine. They may also pass over the spillway if the hydraulic capacity of the project is exceeded or if any turbine units are shut down. Other routes, including ice and trash sluiceways, are sometimes used to attract and divert fish from the turbine intakes. Surface flow bypass and collection systems are also under development throughout the Columbia River basin.

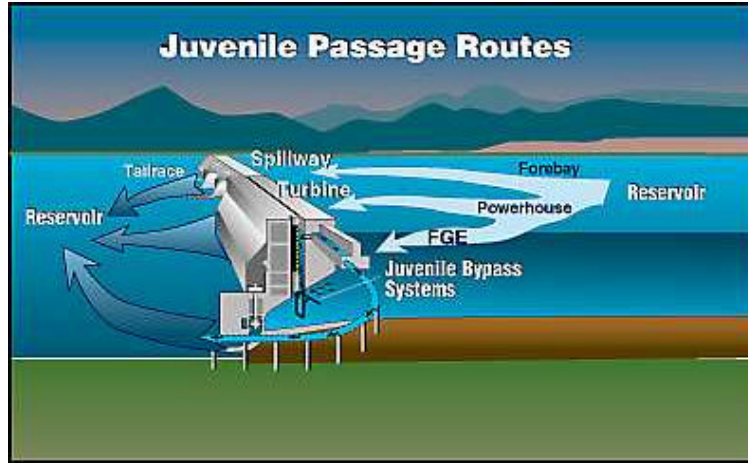


Figure 2: Cross-sectional diagram of juvenile passage routes at a dam

Forebay diversion structures may successfully move fish to a particular passage route. At Lower Granite Dam on the Snake River, a behavioral guidance structure effectively decreased the number of fish entering turbine intakes (Johnson et al 1999). Determining how fish respond to structures is a key unknown for bypass studies. For example, they might respond to structure as a boundary and maintain a certain minimum distance from it, migrate along a particular velocity gradient, or respond to turbulent flow patterns. Knowing this behavior would be helpful in design of both the effective size and placement of fish bypass structures.

We believe that smolts respond to environmental stimuli over a range of measurement scales that collectively influence the passage route a smolt takes past a dam. Collecting data across the full range of response and measurement scales, and integrating this information within experimental protocols, would provide a greater understanding of the biological basis for smolt passage at hydroelectric facilities. (Table 1)

Recent hydroacoustic and radio telemetry studies have shown that smolt distributions immediately upstream of hydroelectric projects are affected across both channel ($10^2 - 10^4$ m) and local (10^1 to 10^2 m) measurement scales (reviewed in Dauble et al. 1999). For example, smolts appear to follow the bulk flow in the thalweg. Site-specific differences in forebay bathymetry influence bulk flow and affect smolts distribution, i.e., both depth and channel dimensions

may allow smolts to disperse vertically and horizontally. The amount of river flow and turbine operations also influence fish approach patterns and affect the relative numbers of smolts available for each passage route (Johnson et al. 1999). Projects that are not aligned perpendicular to the flow typically have more complex forebay hydraulics and more variable fish distributions.

Table 1. Spatial hierarchy describing conceptual measurement scales for comparing smolt response to its environment (modified from Dauble et al. 1999)

Measurement Scale	Quantitative Dimension	Forebay Zone	Principal Features
Channel	$10^2 - 10^4$ m	Approach	Approach, channel depth and shape, discharge, shoreline features, current pattern
Local	$10^1 - 10^2$ m	Discovery	Forebay bathymetry, structures, velocity, gradients, sound, light
Site	$10^0 - 10^1$ m	Decision	Velocity gradients, Turbulence, other fish, structures, sound, light

Fish Response to Flow

Various studies support the prevailing hypothesis that downstream migrant smolts can detect water velocity and acceleration fields at dams. How fish use this information is a key feature of surface bypass development, yet is largely unknown. Most surface bypass structures have been designed to create flow fields at fine scale ($10^0 - 10^1$ m) dimensions. Flownets may have a threshold size, below which smolt passage is reduced (Haro et al 1998). Other studies indicated that smolts detect and respond to near field flow characteristics associated with different bypass screen designs (Nessler and Davidson 1995). Potential differences between flow field signals produced from ambient (e.g., from turbine operations) versus those produced from bypass structure flow fields i.e., “the signal-to-noise ratio,” are likely to influence smolt behavior and passage. Ambient light also affects the vertical distribution of juvenile salmonids. Smolt response to turbulence, flownets, sound, and light would be expected to occur at scales $<10^1$ m.

Summary

Several factors influence the downstream passage success of juvenile salmonids at hydroelectric dams in the mainstem Columbia and Snake rivers. The primary physical factors present in the forebay upstream of the dams include river discharge, channel morphology, and hydraulics resulting from project operations. To date, cause-and-effect analysis relative to performance of smolt bypass systems has focused almost entirely on local hydraulics. Other environmental variables, such as sound and light, should also be measured and factored into smolt behavioral response. Future efforts should focus on increasing the opportunity of discovery for downstream passage routes. To do this, additional research is needed to evaluate what conditions, and at what measurement scale, smolts actually respond to.

References

- Dauble, D.D., S.M. Anglea, and G.E. Johnson. 1999. Surface flow bypass development in the Columbia and Snake rivers and implication for Lower Granite Dam. Prepared for the U.S. Army Corps of Engineers, Walla Walla District, Walla Walla, Washington.
- Haro, A., M. Odeh, J. Norecha, and T. Castro-Santos. 1998. Effect of water acceleration on downstream migratory behavior and passage of Atlantic salmon smolts and juvenile American shad at surface bypasses. *Transactions of the American Fisheries Society*. 127:118-127.
- Johnson, R.L. and 8 coauthors. 1999. Hydroacoustic evaluation of fish passage and behavior at Lower Granite Dam in spring 1998. Prepared for the U.S. Army Corps of Engineers, Walla Walla District, Walla Walla, Washington.
- Nessler, R. and R. Davison. 1995. Imaging smolt behavior on an extended length submerged bar screen and an extended-length submerged traveling screen at the Dalles Dam in 1993. Technical Report EL-95-13. U.S. Army Corps of Engineers, Waterways Experiment Station, Vicksburg, Mississippi.

**OSMOREGULATORY RESPONSES IN STRIPED BASS *MORONE*
SAXATILIS LARVAE: SURVIVAL, GROWTH, YOLK ABSORPTION,
AND DEVELOPMENT OF CHLORIDE CELLS IN BODY SKIN.**

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Abstract

Survival, growth, and number of chloride cells were measured during and after exposure to a range of osmotic conditions in anadromous Striped bass *Morone saxatilis* larvae (ages: 9-41 days post hatch). Larvae were held at 0.7ppt prior to salinity challenge tests at 0, 0.1, 0.7, 5, 11, and 33ppt. Higher survival rates were recorded at 11 and 5ppt, while unexpectedly low survival was observed at 0.7ppt. Late yolk-sac larvae showed particularly low survival at 0.7ppt. During this stage, few chloride cells were observed on the integument; these chloride cells increased gradually as larvae developed. Higher yolk absorption rates and lower growth in postflexion larvae occurred at 0.7ppt than at 5 or 11ppt. These results suggest that 5-11ppt result in minimal osmoregulatory expenditures. However, wild larvae mainly distribute in estuarine tidal freshwater habitats (< 2ppt) above the salt front. The salt front and associated maximum turbidity zone concentrate the zooplankton prey of larval striped bass. Therefore, we examined salinity tolerance in both starved and fed larvae. At 0.7ppt fed larvae exhibited higher survival than the starved larvae. No significant differences occurred between fed and starved larvae at higher salinities. We speculate that increased energetic costs due to osmoregulation in freshwater may be offset by higher zooplankton prey availability in these habitats.

Introduction

Striped bass *Morone saxatilis* is an anadromous teleost occurring on the eastern coast of North America, which spawns in tidal freshwater habitats in spring and invades salt water during the early juvenile stage. During juvenile and adult periods, striped bass occur across the broad range of freshwater, estuarine, and marine salinity (Setzler-Hamilton et al. 1981). The early development of euryhaline osmoregulation is poorly known for striped bass, but salinity is known to influence larval and young-of-the-year survival and growth rate (Lal et al. 1977; Otwell and Merriner 1977; Secor et al. 2000). Further the ontogeny of osmoregulation may provide insight to the evolution of this taxa. Waldman (1986) has proposed that anadromy in Moronidae, which may be derived from an ancestral marine form despite the general proposal by Gross (1987) is derived exclusively from freshwater ancestors.

During the larval period, striped bass in the Chesapeake Bay distributes in 0-2ppt, which is the area of salt front between FW and brackish water overlapping broadly with the maximum turbidity zone (Secor and Houde 1995; Secor et al. 1995), but in rearing experiments, 3-12ppt is believed to be optimal for their survival and growth (Lal et al. 1977). In teleosts occurring in freshwater, branchial chloride cells play a chief role in ion uptake (Flik et al. 1996). Because larvae have undifferentiated gills, chloride cells in body skin are believed to be important in ionoregulation (Hiroi et al. 1998). This study examines the osmotic response of fed and starved striped bass larvae to a range of estuarine salinity (0.7-11ppt), by observing differences in survival, growth, yolk absorption, and number of chloride cells.

Materials and Methods

Striped bass larvae (9 days post hatch) originating from Patuxent River broodstock (Chesapeake Bay, Maryland) were obtained from a Maryland Department of Natural Resources hatchery on April 26th, 1999. Larvae were transported to Chesapeake Biological Laboratory (CBL) at 19°C and 0.7ppt salinity, and were subsequently held under these same conditions in 100-liter tanks. Water temperature in the stock tanks increased gradually to simulate natural conditions in the Patuxent River so that at experiments' end (41 days post hatch), temperature reached to 25°C. Twenty percent of the water in the stock tanks was changed daily. Finfold larvae (9-19 days post hatch) were fed *Artemia* spp. nauplii cultured at 5ppt and enriched by DHA (Docosahexaenoic

acid). From 20 days post hatch, larvae were fed an artificial diet (0.4mm Kyowa ©). Subsamples of 30 larvae were drawn from the stock tank on the first day of salinity challenge trials. They were fixed by 4% normal formalin in phosphate buffer (pH 7.1) or Bouin solution for 24 hours and preserved in 70% ethanol at 4°C for later immunocytochemical analysis.

Salinity challenge trials were initiated 13, 18, 23, 30, 37 days post hatch. Six salinity levels (0, 0.1, 0.7, 5, 11, and 33ppt), each replicated thrice were established using 1-liter beakers. Thirty larvae were transferred from the stock tank (0.7ppt) to each beaker, and they were observed at 0, 1, 3, 6, 12, 24, 48, and 72 hours after transfer. Dead larvae were removed by pipette. After the test, surviving larvae were fixed and preserved as described above. Larvae were not fed in this set of salinity challenge trials.

The effect of feeding on osmotic responses was examined for the second series of trials. Larvae (18, 23, 30, 37 days post hatch) were introduced to 3 salinity levels (0.7, 5, 11ppt) and two feeding levels (unfed and fed *Artemia* spp. nauplii with 500 individuals l⁻¹), each replicated thrice in 1-l beakers. Larvae in fed treatments were fed at 1 and 24 hours after transfer. Temperatures were maintained between 18-22°C and did not differ among treatment levels. Dead larvae were recorded during the trials and all larvae at trials end were fixed and preserved as described above.

A third set of short-term 4-days growth trials were conducted for post-flexion larvae (30 days post hatch) supplied with artificial diet and reared at 0.7, 5, 11ppt in 30 liter tanks. Each of three replicates was supplied with 300 larvae and samples (n=30) were fixed in formalin 0, 2 and 4 days. Temperature ranged 20-22°C and larvae were fed artificial diet (600mg day⁻¹) in each treatment.

From preserved material in the first set of trials (0.7, 5, and 11ppt), yolk absorption during the period of 13 days post hatch was estimated by measuring the largest lateral areas of yolk. The yolk areas were traced on paper using a light microscope with a camera lucida. Images were digitized with a flat bed scanner (Canon, Japan) and were measured using public domain U.S. National Institute of Health image analysis software. A mean diameter was calculated for yolk areas. Yolk was assumed to be spherical ($4/3\pi r^3$), and its volume was calculated by the mean diameter.

To detect chloride cells in the yolk-sac membrane and body skin, antiserum specific for Na⁺, K⁺-ATPase α -subunit was used as a specific probe (Ura et al.

1996). Chloride cells were stained by whole mount immunocytochemistry based on the avidin-biotin-peroxidase complex (ABC) method (Hsu et al. 1981) using commercial reagents (DAKO sABC kit, Glostrup, Denmark). The method of staining followed the method of Hiroi et al. (1998). For the quantitative analysis, three sites each 1 mm² were selected randomly in the larva's body, and densities and sectional areas of chloride cells were estimated. These measurements were performed by the same method described above for estimation of yolk volume.

All data are expressed by means and standard errors. For the comparison of salinity tolerance between experimental salinity, survival rates of unfed larvae at 72 hours were analyzed in each phase. Also, comparison of salinity tolerance between fed and unfed fish was analyzed with the survival at 48 hours. Significant differences in all data were conducted by Turkey-Kraimer test for multiple comparison after one way analysis of variance.

Results

Striped bass larvae under unfed conditions showed the highest survival at 5 or 11ppt throughout the early ontogeny, despite acclimation to 0.7ppt in the stock tank (Table 1). Late yolk-sac larvae exhibited particularly low survival at 0.7ppt compared to other stages. In addition, the density of chloride cells in body skin was lower during this stage. Although the sectional area of chloride cells did not change through development (Figure 1), the density of chloride cells tended to increase throughout the ontogeny.

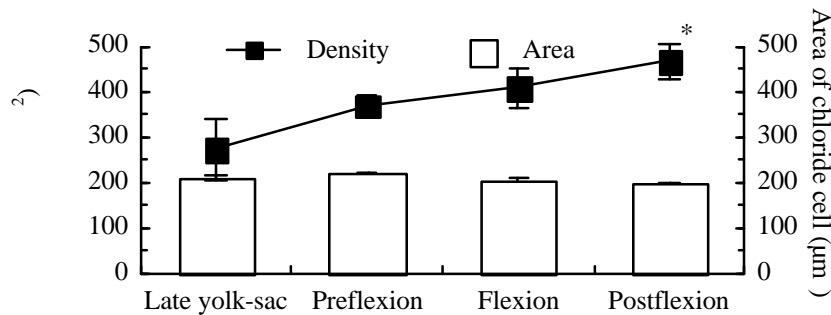


Figure 1. Development of skin chloride cells in density and sectional areas. Data are means±S.E.M. An asterisk in density indicates significant differences ($p>0.05$).

No larvae survived at both 0ppt and 33ppt, and survival was very low at 0.1ppt. A significant ontogenetic effect on salinity tolerance occurred for 0.7ppt: survival at this level was higher for post-flexion larvae and juveniles than for early stage larvae. Further in development, juveniles exhibited some tolerance to 33ppt level (11% survival) but not at 0ppt (Table 1).

Estimated yolk volumes of late yolk-sac larva (13 days post hatch) in 0.7ppt was significantly smaller after 72 hours transfer than those of larvae in 5 or 11ppt, indicating a higher yolk utilization rate (Figure 2). Growth increments of post-flexion larvae indicated significant differences at 4 days after transfer; growth increments were highest, intermediate, and lowest at 11ppt, 5ppt, and 0.7ppt, respectively (ANOVA: $p < 0.05$) (Figure 3).

At 0.7ppt salinity level, fed larvae at pre-flexion and flexion phases showed substantially higher survival (92%, 94%, respectively) than unfed larvae (30%, 37%, respectively). During these phases, in contrast to unfed larvae that showed lower survival at 0.7ppt than at higher salinities, fed larvae showed no significant differences in survival among salinities. Regardless of feeding level, post-flexion larvae and juveniles did not exhibit similar survival responses across salinity levels (Table 1, Table 2).

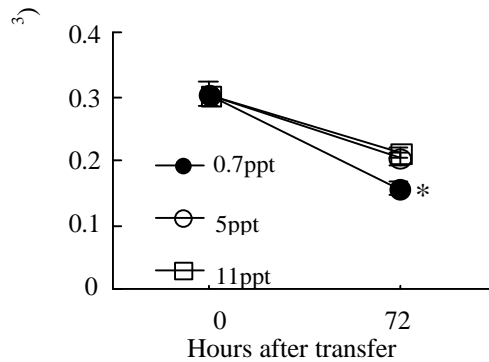


Figure 2. Estimated yolk volume in late yolk-sac larvae (13DPH) after exposed each salinity. Data are means \pm S.E.M and an asterisk indicates significant differences between salinities.

Discussion

Survival rate of larvae transferred to 0.7ppt increased in later stages of development, but no larvae could survive at 0ppt and 33ppt until transformation

to juvenile. On the other hand, in young juveniles, moderate survival was observed even exposed to SW (33ppt) (Table 1.), suggesting the lack of full-

Table 1. Survival rate of striped bass at 72 hours exposed to test salinities during early life history. Data are means±S.E.Ms based on three replicates. Within a column, means with the same letter are not significant differences (P>0.05).

Salinity	Late yolk-sac	Preflexion	Flexion	Postflexion	Juvenile
0ppt	0.00±0.00 a	0.00±0.00 a	0.00±0.00 a	0.00±0.00 a	0.00±0.00a
	0.00±0.00 a	1.59±1.59 a	1.96±1.96 a	5.45±4.04 a	14.48±12.80
5ppt	3.23±3.23 a	29.91±29.91 ab	36.70±18.89 ab	35.73±15.59 ab	50.00±14.70 b
	67.90±7.66 b	46.44±11.56 ab	82.05±7.78 b	59.23±10.42 b	55.46±8.48 b
11ppt	80.30±10.74 b	77.52±5.47 b	67.18±17.73 b	41.44±11.46 ab	56.76±12.96 b
	0.00±0.00 a	0.00±0.00 a	0.00±0.00 a	0.00±0.00 a	11.02±6.56 ab

Salinity	Feeding	Preflexion	Flexion	Postflexion	Juvenile
0.7ppt	Unfed	29.91±29.91 a	36.70±18.89 a	35.73±15.59 a	50.00±14.70 a
	Fed	91.70±3.40 ab	93.95±0.49 b	64.27±8.90 a	69.91±18.29 a
5ppt	Unfed	46.44±11.56 ab	79.16±4.49 ab	59.23±10.42 a	55.46±8.48 a
	Fed	97.04±1.81 b	93.76±3.83 b	78.60±5.39 a	53.55±16.06 a
11ppt	Unfed	77.52±5.47 ab	67.18±17.73 ab	41.44±11.46 a	56.76±8.48 a
	Fed	98.53±0.75 b	96.13±2.37 b	78.40±5.52 a	100.00±0.00 a

Comparison with survival at 48 hours after exposure between fed and unfed larvae.

are not significant differences (p>0.05).

euhalinity prior to the completion of larva to juvenile transformation. Although the larvae used for experiments were reared at 0.7ppt, higher survival was recorded at 5 and 11ppt than those at 0.7ppt. Similar to our results, Lal et al. (1977) reported 3-12ppt as the optimal salinity for larval survival of striped bass. Morgan II et al. (1981) found that salinity tolerance of newly hatched larvae varied with temperature, and that the highest survival at optimal temperature conditions (ca. 18°C) was obtained at 10ppt. Other studies also provide evidence that the optimal salinity of striped bass larvae is in the range of 5-11ppt as observed in this study (Minton and Harrell 1990; Winger and Lasier 1994). Body fluid of teleosts is osmotically equivalent to one third SW (11ppt) (Evans, 1984), therefore the fish reared at 11ppt is expected to consume minimal energy for osmoregulation. Maybe this is the most probable explanation for higher survival rate found at 5 or 11ppt.

Density of chloride cells in body skin in striped bass larvae at 0.7ppt increased gradually as development proceeded (Figure 1), in parallel to the increase of survival rate at 0.7ppt. Although not statistically significant ($p=0.1326$), late yolk-sac larvae (13 d post hatch) had less chloride cells than pre-flexion larvae and flexion larvae. Chloride cells in body skin is suggested to serve a role for SW adaptation during larval stages of teleosts (Shiraishi et al. 1997; Hiroi et al. 1998; Katoh et al. 2000). Moreover, yolk-sac larvae reared in FW also have chloride cells on their yolk-sac membrane, with size changing in response to environmental salinity (Kaneko et al. 1995; Shiraishi et al. 1997). Taken together with our result, chloride cells in larval striped bass possibly support hyperosmoregulation in low salinity areas of nursery habitats. Distribution of branchial chloride cells in chum salmon fry in FW (Uchida et al. 1996) and FW acclimated Japanese sea bass (Hirai et al. 1999), are different from those of SW adapted fish. Chloride cells of FW fish also increase their density when transferred to soft water or experimentally prepared low calcium water (Perry and Wood 1985, McCormick et al. 1992, Greco et al. 1996), suggesting a role of gill chloride cells play a role to ion uptake in freshwater. Therefore, it is expected that chloride cells in body skin of striped bass larvae is similarly involved in ion uptake in hypo-osmotic environments.

Experimental results indicate that larvae encountering hypo-osmotic conditions might expend greater amounts of energy on basal metabolism. Yolk absorption of the late yolk-sac larvae at 0.7ppt was significantly higher than at 5 or 11ppt and growth at post-flexion larvae at 0.7ppt was significantly slower than at 5 or 11ppt. Finally, for low salinity treatment survival was substantially enhanced by feeding larvae (Table 2). Eggs and larvae of teleosts generally regulate their

internal osmolarity at a level near those of the body fluids of adults (Alderdice, 1988). To maintain this level, Na^+ , K^+ -ATPase within chloride cells is well known to regulate ionic balance (Karnerky et al. 1976). Low osmotic stress and

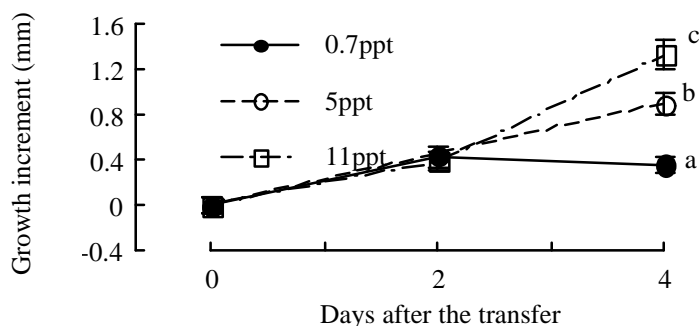


Figure 3. Growth increments to salinity in larval striped bass (30 days post hatch; post-flexion period). Growth increments are calculated as follow : Growth increment (mm) = SL (mm) at each days - Mean SL (mm) at Day 0. The letters on right shoulder of mean at Day 4 indicate significant differences ($p>0.05$).

rate of yolk utilization was reported for catadromous *Chanos chanos* larvae at 15ppt, perhaps due to iso-osmotic conditions (Swanson, 1996). Under osmotic stress, larvae may consume their yolk to produce this enzyme and ATP, and the consumption might make higher mortality of unfed striped bass larvae at 0.7ppt. However, for a Canadian population of striped bass, Peterson et al. (1996) observed yolk utilization in larvae originating from a Canadian population, and found higher yolk utilization in larvae at 10ppt than those at 1 or 5ppt. Although the difference between fish in our study and Canadian population might be caused by populational differences, our study suggests that iso-osmotic condition (11ppt) is an optimal salinity of survival and growth of striped bass larvae in Chesapeake Bay.

In the field, striped bass eggs and larvae distribute in 0-2ppt (Setzler-Hamilton et al. 1981, Uphoff 1989, Secor et al. 1995, Robichaud-LeBlanc et al. 1996, Rutherford et al. 1997), which is a substantially lower salinity than the optimum indicated by our laboratory experiments. Our feeding experiment, however, demonstrated that survival of fed larvae in expected natural nursery conditions (0.7 ppt) was nearly two-fold higher than survival of unfed larvae (Table 2). We believe that food provided an important subsidy of internal stores of energy and

ions and needed to maintain osmolarity at iso-osmotic salinity. To determine specifically the role of diet on osmoregulation will require more detailed analysis.

Our result suggests that increased osmotic costs associated with hypo-osmotic nursery conditions could be offset by increased foraging opportunities in these environments. Indeed, tidal salt front regions (0-2ppt) characterized by local peaks in zooplankton are also commonly observed (Beaven and Mihursky 1980, Setler-Hamilton et al. 1981, Tsai et al. 1991, Secor et al. 1995, McGovern et al. 1996). Also, the ichthyoplankton surveys in the upper Chesapeake Bay indicate that the salt front and associated maximum turbidity zone contain high abundance of both striped bass and white perch *Morone americana* larvae distribute in that zone (North and Houde, Chesapeake Biological Laboratory, personal communication,) and in the Patuxent and Potomac sub-estuaries, peak density of Moronidae larvae occur where conductivity is $< 800 \mu\text{mhos}/\text{cm}^2$, near or upriver from the maximum turbidity zone (Secor and Houde 1995, Rutherford et al. 1997). In a larval tagging study by fluorescent marker, Secor et al. (1995) released striped bass larvae above and below the salt front and observed complete mortality of those released below the salt front. They suggested that the salt front is an important retention feature curtailing down-stream dispersal by early stage larvae. Dovel (1981) in his critical zone hypothesis proposed that benefits attributed to this oligohaline nursery zone included both increased prey availability due to a hydraulic retention front, and lower pre-dation due to high turbidity (Dovel 1981, Secor et al. 1998). Thus, although oligohaline nurseries may impose energetic costs due to osmoregulation, these costs may be offset by ecological attributes of the nursery zone.

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References

- Alderdice, D.F. 1988 Osmotic and ionic regulation in teleost eggs and larvae. In 'Fish Physiology Vol. XIA' Ed by W.S. Hoar, and D.J. Randall, Academic Press, New York, pp 163-252.
- Beaven, M. and J.A. Mihursky 1980 Food and feeding habits of larval striped bass: an analysis of larval striped bass stomachs from the 1976 Potomac Estuary collection. Final report to Maryland Power Plant Siting Program. University of Maryland, Chesapeake Biological Laboratory UMCEES 79-45-CBL, Solomons, Maryland, USA.
- Dovel W.L. 1981 Ichthyoplankton of the lower Hudson estuary, New York, USA. New York Fish and Game Journal 28: 21-39.
- Evans, D.H. 1984 The role of gill permeability and transport mechanisms in euryhalinity. In 'Fish Physiology Vol. XB' Ed by W.S. Hoar, and D.J. Randall, Academic Press, New York, pp 239-283.
- Greco, A.M., J.C. Fenwick, and S.F. Perry 1996 The effects of soft-water acclimation on gill structure in the rainbow trout *Oncorhynchus mykiss*. Cell Tissue Res. 285: 75-82.
- Gross, M.R. 1987 Evolution of diadromy in fishes. In 'Common strategies of anadromous and catadromous fishes. 'Ed by M.J. Dadswell, R.J. Klauda, C.M. Moffitt, R.L. Saundars, R.A. Rulifson, and J.E. Cooper. American Fisheries Society Symposium 1:14-25. American Fisheries Society, Bethesda, Maryland.
- Hirai, N., M. Tagawa, T. Kaneko, T. Seikai, and M. Tanaka 1999 Distributional changes in branchial chloride cells during freshwater adaptation in Japanese Sea Bass *Lateolabrax japonicus*. Zool. Sci. 16: 43-49.
- Hiroi, J., T. Kaneko, T. Seikai, and M. Tanaka 1998 Developmental sequence of chloride cells in the body skin and gills of Japanese flounder (*Paralichthys olivaceus*) larvae. Zool. Sci. 15: 455-460.

- Hsu, S.M., L. Raine, H. Franger 1981 Use of avidin-biotin-peroxidase complex (ABC) in immunoperoxidase techniques: A comparison between ABC and unlabeled antibody (PAP) procedures. *J. Histochem. Cytochem.* 9: 77-580.
- Kaneko, T., S. Hasegawa, Y. Takagi, M. Tagawa, and T. Hirano 1995 Hypo-osmoregulatory ability of eyed-stage embryos of chum salmon. *Mar. Biol.* 122: 165-170.
- Karnerky Jr. K.J., K.B. Kinter, W.B. Kinter, and C.E. Stirling 1976 Teleost chloride cell II. Autoradiographic localization of gill Na⁺, K⁺-ATPase in killifish *Fundulus heteroclitus* adapted to low and high environments. *J. Cell Biol.* 70: 157-177.
- Katoh, F., A. Shimizu, K. Uchida, and T. Kaneko 2000 Shift of chloride cell distribution during early life stages in seawater-adapted Killifish, *Fundulus heteroclitus*. *Zool. Sci.* 17: 11-18.
- Lal, K., R. Lasker, and A. Kujis 1977 Acclimation and rearing of striped bass larvae in sea water. *Calif. Fish and Game* 63: 210-218.
- McCormick, S.D., S. Hasegawa, and T. Hirano 1992 Calcium uptake in the skin of a freshwater teleost. *Proc. Natl. Acad. Sci. USA* 89:3635-3638.
- McGovern, J.C. and J.E. Olney 1996 Factors affecting survival of early life stages and subsequent recruitment of striped bass on the Pamunkey River, Virginia. *Can. J. Fish. Aquat. Sci.* 53: 1713-1726.
- Minton, R.V. and R.M. Harrell 1990 The culture of striped bass and hybrids in brackish water. In 'Culture and propagation of striped bass and its hybrids.' Ed by R.M. Harrell, J.H. Kerby, and R.V. Minton, Striped bass committee, Southern division, American fisheries Society, Bethesda, Maryland, pp243-251.
- Morgan II, R.P., V.J. Rasin Jr., and R.L. Copp 1981 Temperature and salinity effects on development striped bass eggs and larvae. *Trans. Am. Fish. Soc.* 110: 95-99.

- Otwell, W.S. and J.V. Merriner 1975 Survival and growth of juvenile Striped bass, *Morone saxatilis*, in a factorial experiment with temperature, salinity and age. Trans. Am. Fish. Soc. 104: 560-566.
- Perry, S.F. and C.M. Wood 1985 Kinetics of branchial calcium uptake in the rainbow trout: Effects of acclimation to various external calcium levels. J. Exp. Biol. 116: 411-433.
- Peterson, R.H., D.J. Martin-Robichaud, and Å. Berge 1996 Influence of temperature and salinity on length and yolk utilization of striped bass larvae. Aqua. Int. 4: 89-103.
- Robichaud-LeBlanc, K.A., S.C. Courtenay, and A. Locke 1996 Spawning and early life history of a northern population of striped bass (*Morone saxatilis*) in the Miramichi River estuary, Gulf of St. Lawrence. Can. J. Zool. 74: 1645-1655.
- Rutherford, E.S., E.D. Houde, and R.M. Nyman 1997 Relationship of larval-stage growth and mortality to recruitment of striped bass, *Morone saxatilis*, in Chesapeake Bay. Estuaries 20: 174-198.
- Secor, D. H. and E. D. Houde 1995 Temperature effects on the timing of striped bass egg production, larval viability, and recruitment potential in the Patuxent River (Chesapeake Bay). Estuaries 18: 527-533.
- Secor, D.H., E.D. Houde, and D.M. Monteleone 1995 A mark-release experiment on larval striped bass *Morone saxatilis* in a Chesapeake Bay tributary. ICES J. mar. Sci. 52: 87-101.
- Secor, D. H., T. Gunderson and K. Karlson 2000 Effect of salinity and temperature on growth performance in anadromous (Chesapeake Bay) and nonanadromous (Santee-Cooper) strains of striped bass *Morone saxatilis*. Copeia 2000: 291-296.
- Setzler-Hamilton, E.M., W.R. Boynton, J.A. Mihursky, T.T. Polgar, and K.V. Wood 1981 Spatial and temporal distribution of striped bass eggs, larvae, and juveniles in the Potomac Estuary. Trans. Am. Fish. Soc. 110: 121-136.

- Shiraishi, K., T. Kaneko, S. Hasegawa, and T. Hirano 1997 Development of multicellular complexes of chloride cells in the yolk-sac membrane of tilapia (*Oreochromis mossambicus*) embryos and larvae in seawater. *Cell Tissue Res.* 288: 583-590.
- Swanson, C. 1996 Early development of milkfish: effects of salinity on embryonic and larval metabolism, yolk absorption and growth. *J. Fish Biol.* 48: 405-421.
- Tsai, C., M. Wiley, and A. Chai 1991 Rise and fall of the Potomac River striped bass stock: A hypothesis of the role of Sewage. *Trans. Am. Fish. Soc.* 120:1-22.
- Uchida, K., T. Kanako, K. Yamauchi, and T. Hirano 1996 Morphometrical analysis of chloride cell activity in the gill filaments and lamellae and changes in Na^+ , K^+ -ATPase activity during seawater adaptation in chum salmon fry. *J. Exp. Zool.* 276: 193-200.
- Uphoff Jr., J.H. 1989 Environmental effects on survival of eggs, larvae, and juveniles of striped bass in the Choptank River, Maryland. *Trans. Am. Fish. Soc.* 118: 251-263.
- Ura, K., K. Soyano, N. Omoto, S. Adachi, and K. Yamauchi 1996 Localization of Na^+ , K^+ -ATPase in tissues of rabbit and teleosts using anti-serum directed against a partial sequence of the α -subunit. *Zool. Sci.* 13: 219-227.
- Waldman, J.R. 1986 Diagnostic value of Morone dentition. *Trans. Am. Fish. Soc.* 115: 900-907.
- Winger, P.V. and P.J. Lasier 1994 Effects of salinity on striped bass eggs and larvae from the Savannah River, Georgia. *Trans. Am. Fish. Soc.* 123:904-912.

**USING HABITAT SELECTION THEORY TO PREDICT THE
MIGRATORY BEHAVIOUR OF STREAM FISH**

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EXTENDED ABSTRACT ONLY – DO NOT CITE

Introduction

In this extended abstract I will explain how the logic of a habitat selection model for drift-feeding stream salmonids (Hughes, 1998; 2000) can be used to predict how the probability of long-distance inter-annual movement will change as body size increases. The model predicts that movement probability will decrease as fish get bigger and that the largest fish in the population will not move at all. I also test these two predictions using data on the movement of Arctic grayling (*Thymallus arcticus*) in the lower 160~km of a 240~km long sub-arctic river in Interior Alaska.

Model Background and Development

The model described by Hughes (1998; 2000) represents the stream habitat as a series of feeding positions that can be ranked in order of profitability (potential growth rate). All sizes of fish under consideration are assumed to rank these positions in the same order, and competition for profitable positions is assumed to sort fish so that the rank-size of each fish matches the rank desirability of its position. This means that the largest fish in the population will occupy the most profitable position, the second largest fish the second most profitable position, and so on. The result is a stable distribution in which each fish occupies the most profitable position that it is large enough to defend.

Under these assumptions the only reason a fish should move is to occupy a more profitable position, the only way these become available is when larger fish die. This means that the opportunity a fish has to obtain a better position by moving will be proportional to the number of larger fish multiplied by the annual mortality rate. It follows that the smallest fish in the population will be the most likely to change feeding positions from one summer to the next, that the probability of movement will decrease with fish size, and that the largest fish in the population will have a movement probability of zero.

Testing Predictions

I tested the model's predictions using data on long distance inter-annual movements of Arctic grayling in the lower 140 km of the 260 km long Chena River, Yukon River drainage, Alaska. These data were collected by the Alaska Department of Fish and Game between 1991 and 1995 during their annual abundance assessments using an electrofishing boat (pulsed direct current). In all years both banks of the entire 140~km section were fished twice each summer during July and August and in most year fish were marked with individually numbered tags. All fish sampled were assigned a capture location with a precision of 5 km or better.

I analyzed data on fish that were captured in two consecutive years. The sample size for this analysis was 974 fish. I divided this sample into five length groups 150-199 mm, 200-249 mm, 250-299 mm, 300-349 mm, and >349mm and then calculated the proportion of fish in each group making inter-annual movements of at least 10~km. The number of fish in each of the length groups was 67, 393, 342, 143, and 29 fish respectively. I used linear regression to test the hypothesis that the probability of long-distance movement declined with fish size, and the hypothesis that the movement probability of the largest fish in the population was zero.

Results and Discussion

The model's predictions were well supported. The slope of a simple linear regression of the probability of fish movement on fish length was negative and crossed the x-axis at a length close to that of the largest fish in the population. The regression equation was: $p\text{-move} = 0.277 - 0.00075 \text{ fish length}$ ($p < 0.001$; $R^2 = 0.99$). The largest fish captured between 1991 and 1995 was

410~mm, and this point on the x-axis lies above the upper 95% confidence band of the movement vs. body-size regression. The regression line itself crosses the x-axis at 370mm, only 0.5% of the fish sampled between 1991 and 1995 were larger than this. These results suggest that, at least for Arctic grayling, habitat selection theory can be developed to make useful predictions about migratory behavior.

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References

- Hughes, N. F. 1998. A model of habitat selection by drift-feeding stream salmonids at different scales. *Ecology* 79: 281-294.
- Hughes, N. F. 2000. Testing the ability of habitat selection theory to predict interannual movement patterns of a drift-feeding salmonid. *Ecology of Freshwater Fish* 2000: 9: 4-8.

**PERFORMANCE OF FISH LIFT RECENTLY BUILT AT THE
TOUVEDO DAM ON THE LIMA RIVER, PORTUGAL**

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EXTENDED ABSTRACT ONLY – DO NOT CITE

Introduction and main goals

From March 1998 to February 1999, upstream fish passage was continuously monitored by video tape analysis at the Touvedo Dam on the Lima River in northern Portugal. The fish lift was monitored with an automatic video recording system to test its efficiency, to acquire data on migratory patterns of the different species, as well as to validate some design criteria of such a fish facility. While being lifted, fish passage was recorded on videotape for later detailed analysis.

Site description

The fish lift is provided with three entrances, located in the tailrace area of the powerhouse (Figure 1). The attraction towards the entrances is achieved by discharging a flow of maximum 4,5 m³/s, which is equally distributed between the entrances. Approximately 1/3 of this flow is gravity water from the above

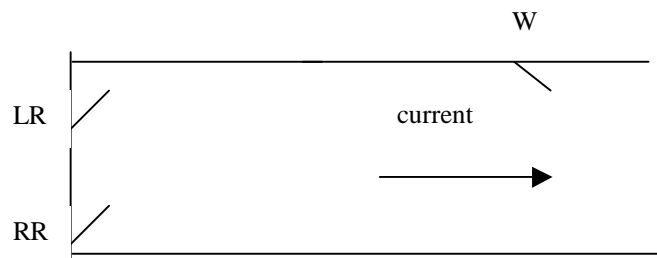
reservoir, and the remaining 2/3 is pumped from the tailrace area by means of two submerged pumps. The current creates a flow in the attraction circuit (channel), against which the migrating fish swim. Once in the circuit, the fish swim towards and eventually into the lift cage. After being lifted, the cage puts the fish into the upper channel where, swimming against the current that circulates there, they reach the reservoir and are able to continue their migration further upstream.

Materials and methods

Two video cameras and an automatic video recorder system were installed in an observatory room established near the transfer canal leading to the reservoir.

Analysis of the number of individuals and the percentage abundance was undertaken for each fish species that used the fish lift. One-way analysis of variance (ANOVA) was used to test for significant differences on a catch-per-unit-effort, CPUE (ind day⁻¹) basis for each fish species, between all months. Mann-Whitney Rank Sum Test (Zar, 1996) was used to detect significant differences between diurnal and nocturnal number of individuals per cycle.

The effect of water temperature, head- and tailwater level, air temperature, precipitation and river discharge at the dam on fish numbers in the fish lift, was tested by a forward stepwise multiple regression procedure (Zar, 1996).



-Location of the entrances in the tailrace area. LR- left rear entrance, RR- right rear entrance, W- wing entrance.

Results

A total of 1206 individuals of 7 species were transferred by the fish lift. Cyprinids were the dominant group captured, in which nase *Chondrostoma polylepis* (31,8%) was the most abundant specie, followed by barbel *Barbus bocagei* (21,1%), dace *Leuciscus carolitertii* (19,2%) and roach *Rutilus arcasi* (7,1%). Brown trout *Salmo trutta* and European eel *Anguilla anguilla* accounted for around 10%, whereas Atlantic salmon *Salmo salar* was very rarely captured.

Most seasonal movements of cyprinid fishes were observed in spring and were reproductive migrations. The timing of the run varies and its commencement appears to be mainly dependent on water temperature (Table 1). Similar results were also reported by other authors (Rodriguez-Ruiz & Granado-Lorencio, 1992) in other Iberian river.

Roach, dace and nase began migration in mid-April till the end of summer. Movements of barbel began in mid-May due to the later warming of the water. Salmonids migrated in June-July and autumn. Significant differences were not found at all in species hourly activity, except for nase and barbel, in June and July, respectively.

Water velocities in the three entrances were generally within the range of critical swimming speeds for fish, although 2,4 m/s, the upper limit of the range for best water velocities at the fishway entrances (Larinier, 1992) achieved when the station was running on, is more suitable for trout than for cyprinids.

Velocities within the attraction circuit were according to the minimum range of critical speeds (0,3-0,6 m/s) that leads to the appearance of fish orientation against the current (Travade *et al.*, 1992). Although in sections 2 and 3, water velocities seemed to be more suitable for fish orientation towards the lift cage, they didn't reach 1,0 m/s, which is considered to be the optimum value to avoid disturbance on fish behaviour (Clay, 1995).

Table 1. - Variables entered in the model of the forward stepwise regression analysis explaining species frequencies in the fish lift. Six different factors were analysed, but only those with significant values ($p < 0,05$) are included in the table.

Variable	F	r ²
Nase		
Water temperature	12,5**	0,18
Precipitation	9,15*	0,07
Both		0,25
Barbel		
Water temperature	7,24**	0,14
Dace		
River flow	11,5**	0,20
Trout		
Air temperature	6,31*	0,10
European eel		
Water temperature	11,51***	0,20
Air temperature	8,8**	0,08
Headwater level	9,4**	0,11
All three factors		0,40

* $p < 0,05$, ** $p < 0,01$, *** $p < 0,001$

Conclusions

The relative efficiency of the fishlift permitted cyprinids, salmonids and eels, a species with lesser swimming abilities, to pass upstream. All of them were found to occur downstream Touvedo dam in similar proportions, whereas diadromous species were not found either these areas or in the fishlift. Water velocities in the entrances appeared to encourage fish to enter in the attraction circuit, although for cyprinids and eels, they were somewhat high, occurring at the same time as the station was running on.

However, the lower-velocity in the attraction circuit may not be sufficient for producing the best orientation towards the cage and therefore causing the return of fish to the river.

References

- Clay, C.H. 1995. Design of fishways and other fish facilities, 2nd edition. Lewis publishers, Boca Ration, Florida. 248p.
- Larinier, M. 1992. Implantation des passes à poissons. Bull. Fr. Pêche Piscic. 326-327: 30-44.
- Rodriguez-Ruiz, A. and Granado-Lorencio, C. 1992. Spawning period and migration of three species of cyprinids in a stream with Mediterranean regimen (SW Spain). J. Fish Biol. 41: 545-556
- Travade, F., Larinier, M., Trivellato, D. & Dartiguelongue, J. 1992. Conception d'un ascenseur à poissons adapté à l'alose (*Alosa alosa*) sur un grand cours d'eau: l'ascenseur de Golfech sur la Garonne. Hydroécol. Appl. Tome 4, 1.: 91-119.
- Zar, J.H. 1996. *Biostatistical Analysis*. Prentice-Hall International, Inc., New Jersey. 662p.

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**SPRINTING PERFORMANCE
OF UPSTREAM MIGRATORY FISHES**

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Abstract

Migratory fishes are often confronted with zones of high velocity flow that must be traversed in order to reach spawning habitat. These challenges can be exacerbated by dams and other anthropogenic obstacles with profound implications for spawning success. The extent to which a given velocity challenge will impede migration is difficult to predict, however, because existing data on swimming performance (largely derived from respirometry studies) fail to quantify maximum anaerobic locomotor capacity of free-swimming species. We addressed this issue using a 23-m long open-channel flume that fish enter volitionally and swim against controlled water velocities of 1.5- 4.5 m*s⁻¹. Performance indicators included distance and duration of ascent and maximum swimming speed. Distance of ascent and duration of time spent in the flume varied among species, being determined largely by water velocity and body length. We observed maximum volitional swimming speeds of 10-22 lengths s⁻¹, well in excess of maxima predicted in the literature, and found evidence that sprinting behavior may reflect a tradeoff between speed and distance of ascent.

Introduction

The speed at which fish swim fundamentally affects their ecology and life history. This is particularly true of migratory species, where fish need to cross

long distances and, in the case of many anadromous species, zones of high velocity in order to complete their life cycle. The limits to performance are intrinsically interesting, providing biologists with insights on the constraints on evolution imposed by the environment, and providing engineers with boundaries for hydraulic criteria used in the design of fish passage structures.

Much of fish locomotion research has focused on the energetics of swimming, and on the relationship between swim speed and endurance. Respirometers, based on a prototype developed by Brett (1964), have been used to determine metabolic costs of swimming up to maximum sustainable speeds (U_{crit}). Various studies have shown that morphology affects swimming efficiency and that U_{crit}

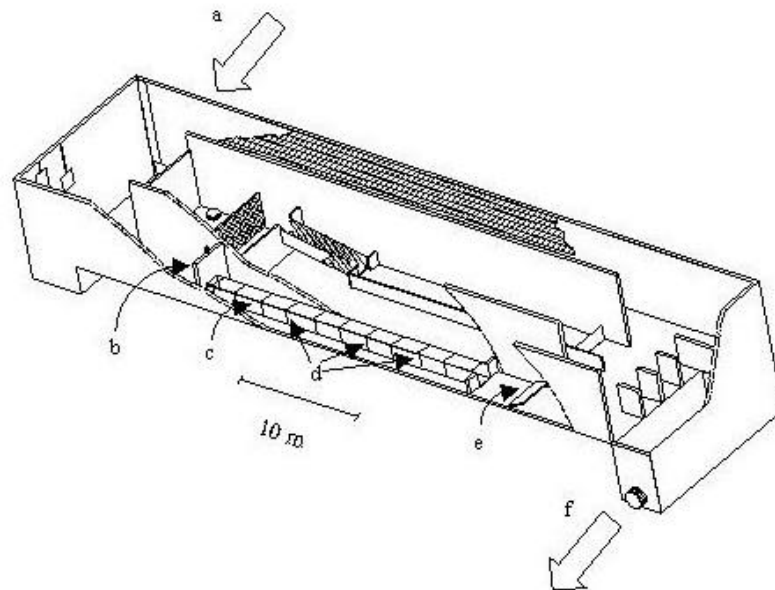


Figure 1. Flume facility at the Conte Anadromous Fish Research Center. Water enters the structure from a power canal (a), and is routed to the near flume, where a headpond is retained by a bulkhead with submerged slide gate (b). Water flows through the gate and into the burst-swimming flume (c), where progress of fish against the velocity challenge is monitored by an array of PIT tag antennas (d). Water depth is controlled by a tailwater gate (e), over which it flows before returning to the river through an outfall pipe (f).

increases with body length (e.g. Brett 1965a; Graham et al. 1994). The relationship between size, shape, and swimming ability remains elusive, however, in part due to limited availability of data over a range of these values.

Effectively missing from the fish swimming literature are studies quantifying maximum through-water swimming speed (U_{max}) of free-swimming fish, and quantitative assessments of their ability to overcome velocity obstacles. Herein we present results describing sprinting performance of a suite of six migratory species, in terms of both speed attained and distance covered.

Methods

The S.O. Conte Anadromous Fish Research Center (USGS-BRD) houses a large flume facility designed for research and development of new fish passage structures (*i.e.* fish ladders, etc.; Haro et al. 1998; Haro et al. 1999; Figure 1). This facility is situated next to a hydroelectric power canal at Connecticut River km 197, near the Massachusetts-Vermont border (USA). Water is supplied to structures within the flumes through a 1.2-m diameter pipe coming from the power canal (Figure 1a), and outflow is routed to the bypassed reach of the river through a 2-m diameter pipe (Figure 1f). Flow of up to $10 \text{ m}^3 \text{ s}^{-1}$ can be controlled to within $\pm .05 \text{ m}^3 \text{ s}^{-1}$ by gate valves.

An experimental apparatus was constructed at the Conte lab that enabled us to examine and describe burst-swimming performance of a variety of migratory fish species in a controlled laboratory setting (Figure 1). The design consisted of a flume, 1 m^2 in cross section and 23 m long. Water was supplied from a headpond and slide gate designed to allow control of water velocities entering the flume. Depth was controlled by a combination of headpond/gate settings and a tailwater gate. All velocities, depths, etc. were monitored by computer and controlled by the investigators. Downstream of the flume was the tailwater or staging area, a low velocity zone from which fish volitionally entered the flume and attempted to swim against the flow.

Fish were captured at least one day before testing, measured and sexed (where possible). A small (3.8 mm diameter x 32.5 mm long), uniquely encoded transponding telemetry (PIT) tag attached to a fishhook was then attached to the fish through the cartilage at the base of the dorsal fin. Fish were held overnight in flow-through holding ponds connected to the flume building by a system of canals. This arrangement allowed fish to be seined into the test area

immediately before beginning each trial without being handled, an important feature because any handling is likely to affect performance.

Fish were presented with velocity challenges of 1.5, 2.5, 3.5, or 4.5 m s⁻¹. The smaller species (alewife and blueback herring) were not subject to the highest velocity because they were effectively constrained by 3.5 m s⁻¹.

Ascent of fish up the flume was monitored using an array of PIT tag antennas (Castro-Santos et al. 1996), along with standard and high-speed video. Standard

Table 1. Numbers of fish ascending the burst-swimming flume by species and velocity

Species	Fork Length (mm)			N
	Min	Max	Mean	
American shad (<i>Alosa sapidissima</i>)	325	520	417	642
Alewife (<i>A. pseudoharengus</i>)	215	265	239	177
Blueback herring (<i>A. aestivalis</i>)	200	245	220	78
Striped bass (<i>Morone saxatilis</i>)	235	970	486	103
Walleye (<i>Stizostedion vitreum</i>)	225	445	320	94
White sucker (<i>Catostomus comersoni</i>)	285	505	392	177

video was also used to determine the position of fish in three dimensions. One wall of the flume was made of clear acrylic, and an array of mirrors along the length of the flume set at 45° to this wall allowed a single camera to monitor both horizontal and vertical position. Due to the length of the flume, however, four cameras were required to assure complete coverage with a minimum of distortion.

This experimental setup provided a unique opportunity to study volitional burst-

swimming behavior. Because these fish have an innate motivation to move upstream, the jet of water issuing from the flume serves as the only cue necessary to motivate fish to enter and swim against the velocity provided. Thus, this structure simultaneously provides motivation and an enclosed arena, allowing precise measurement of behaviors and kinematics associated with burst-swimming.

Results

We collected sprinting performance data from 1253 fish of six species between 1997 and 1999 (Table 1). Figure 2 shows maximum distance of ascent achieved by each species against velocity challenges of 1.5 – 4.5 m s⁻¹. Although some species were able to ascend the entire length of the flume at low velocities, none was able to progress beyond 10 m against velocities of 4.5 m s⁻¹.

Another measure of performance is maximum attained speed (U_{max}). Figure 3 shows preliminary U_{max} data for all six species. Maximum speed varied between species and increased with water velocity. The highest average speeds ranged from 10 L s⁻¹ (striped bass) to 23 L s⁻¹ (blueback herring).

Maximum speed also varied within species. For example, male American shad had higher U_{max} values than females, an effect that is even more pronounced when adjusted for body size (Figure 4).

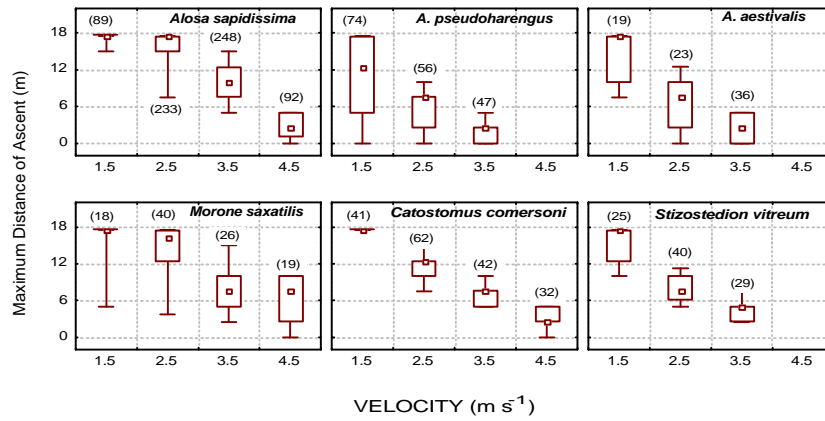


Figure 2. Maximum distance of ascent against controlled velocity by species. Data are median, quartiles, and upper and lower 10th percentiles, with sample sizes in parentheses.

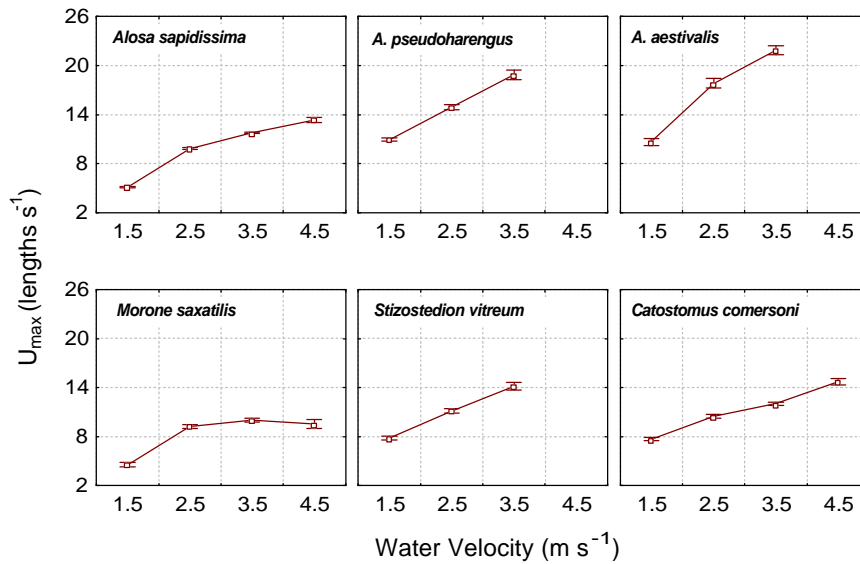


Figure 3. Maximum swim speed (U_{max}) by species and velocity. Data are mean \pm 2 SE.

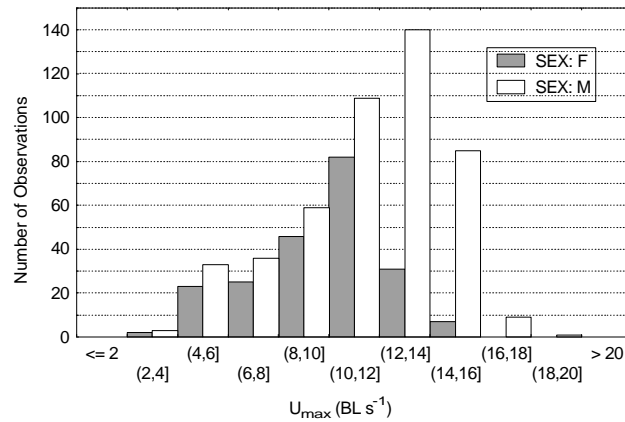


Figure 4. Maximum observed swim speed (U_{max} , in body lengths per second (BL s⁻¹)) of American shad by sex.

Discussion

Meaningful estimates of swimming performance have been difficult to obtain, and our results demonstrate the dramatic effect experimental apparatus and design can have. Previous work (Brett 1965b; Wardle 1975; Webb 1975; Videler and Wardle 1991; Videler 1993) has consistently predicted lower maximum sprint speeds from those we observed. For example, Wardle (1975) predicted maximum sprint speeds of about 10 L s⁻¹ for subcarangiform swimmers the size of American shad, walleye, and white suckers, and of about 15 L s⁻¹ for alewife and blueback herring. By contrast, we observed fish outperforming these values by 50%, and the fact that maximum speed increased linearly with water velocity suggests that even greater speeds are possible. The only species that did not show this trend of increased speed at higher water velocities was the striped bass. This may reflect the large size range in this species relative to the others. Smaller bass tended not to enter the flume at higher velocities, and thus our data may reflect velocity based size selection, rather than actual decreased performance at higher velocities.

These discrepancies in maximum speed estimates are probably due to the limitations of the techniques used by previous researchers. Because of the scale

of our apparatus, we were able to observe volitional sprinting behavior, without resorting to the coercive techniques typical of other experiments (*e.g.*, electric shock, closed respirometers). It is reasonable to assume that such coercion can induce stress, thereby limiting performance.

Previous work has also failed to predict intraspecific differences in performance such as those we observed between male and female American shad. The greater U_{max} values attained by males may be due in part to their smaller size ($\bar{x} = 40.0$ cm) relative to females ($\bar{x} = 45.1$ cm). However, although Wardle (1975) predicts greater values for smaller fish, the observed differences in U_{max} are far greater than predicted. This suggests underlying differences between sexes in either ability or motivation to perform; the former could result from greater investment in gonads characteristic of the females of this species, the latter could reflect some as-yet undescribed life-history characteristic.

The observed differences in performance of similarly sized but morphologically distinct species (*i.e.* American shad, walleye, white sucker) suggests that interspecific differences in morphology or behavior could influence performance. Little information is available describing differences in performance among subcarangiform swimmers, and further investigation is needed to describe the relationship between morphology and kinematics of this mode of swimming.

Acknowledgments

This work would not have been possible without the support of the Engineering section of the Conte Anadromous Fish Research Center. Specifically, the flume structure was designed and modeled by Mufeed Odeh and John Noreika, Phil Rocasah directed its construction, and Steve Walk oversaw the hydraulic instrumentation. Phil Herzig (U.S. Fish and Wildlife Service) was instrumental in the collection of striped bass, and Ken Sprankle (New Hampshire Fish and Game) provided walleye and white suckers.

References

- Brett, J.R. 1964. The respiratory metabolism and swimming performance of young sockeye salmon. *J. Fish. Res. Bd. Canada* 21:1183-1226.
- Brett, J.R. 1965a. The relations of size to the rate of oxygen consumption and sustained swimming speeds of sockeye salmon (*Oncorhynchus nerka*). *J. Fish. Res. Bd. Canada* 22:1491-1501.
- Brett, J.R. 1965b. The swimming energetics of salmon. *Sci. Am.* 213:80-85.
- Castro-Santos, T., Haro, A., and Walk, S. 1996. A passive integrated transponder (PIT) tagging system for monitoring fishways. *Fisheries Research* 28:253-261.
- Graham, J.B., Dewar, H., Lai, N.C., Korsemeier, K.E., Fields, P.A., Knower, T., Shadwick, R.E., Shabetai, R., and Brill, R.W. 1994. Swimming physiology of pelagic fishes. *In* *Mechanics and Physiology of Animal Swimming*. Edited by L. Maddock, Q. Bone, and J.M.V. Rayner. Cambridge University Press, Cambridge.
- Haro, A., Odeh, M., Castro-Santos, T., and Noreika, J. 1999. Effect of slope and headpond on passage of American shad and blueback herring through simple Denil and deepened Alaska steep pass fishways. *N. Am. J. Fish. Mgt.* 19:51-58.
- Haro, A., Odeh, M., Noreika, J., and Castro-Santos, T. 1998. Effect of water acceleration on downstream migratory behavior and passage of Atlantic

salmon smolts and juvenile American shad at surface bypasses. *Trans. Am. Fish. Soc.* 127:118-127.

Videler, J.J. 1993. *Fish Swimming*. Chapman & Hall, London.

Videler, J.J. and Wardle, C.S. 1991. Fish swimming stride by stride: speed limits and endurance. *Rev. Fish Biol. Fisheries* 1:23-40.

Wardle, C.S. 1975. Limit of fish swimming speed. *Nature* 255:725-727.

Webb, P.W. 1975. Hydrodynamics and energetics of fish propulsion. *Bull. Fish. Res. Bd. Canada* 190:1-158.

**PERFORMANCE AND BEHAVIOR OF CHINOOK SALMON
NEAR A FISH SCREEN**

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EXTENDED ABSTRACT ONLY - DO NOT CITE

Introduction

In the Sacramento-San Joaquin watershed (California), chinook salmon (*Oncorhynchus tshawytscha*) parr and smolts are exposed to many small (e.g., 50 ft³/s) and large (e.g., > 5000 ft³/s) water diversions along their migratory path. Loss of these young fish at diversions, by entrainment and/or fish screen-related injuries and mortality, is thought to have contributed to the species' population decline. While some of these diversions are equipped with fish screens intended to protect fishes by excluding them from exported water, our understanding of optimal fish screen design and operational criteria is limited for this endangered species. As part of a large research program to improve fish screen criteria, we examined performance and behavior of fall-run chinook salmon parr and smolts in complex flow regimes similar to those near screened water diversions in a large annular flume equipped with a fish screen (the "Fish Treadmill").

Methods

Fish were tested for 2 h in ten flow regimes derived from combinations of an approach flow (through the screen, velocity range 0-15 cm/s) and a sweeping

flow (past the screen, velocity range 0-62 cm/s), two seasonal temperatures (12 and 19 C, winter/spring and summer/fall, respectively), and during the day (light conditions) and night (dark conditions). We measured screen contact rates, swimming velocity (through the water), rheotaxis, velocity past the screen, and post-experiment survival and injury.

Results and Discussion

Both parr and smolts experienced frequent flow-dependent temporary screen contacts (especially at night) but few fish became impinged on the screen. Survival was uniformly high but, for parr, injury rates were directly related to screen contact rates. Parr exhibited greater positive rheotaxis than smolts at intermediate flows, slowing downstream screen passage. For this species, optimal fish screen design would probably minimize screen contact and promote downstream passage.

Acknowledgments

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**THE EFFECTS OF A BARRAGE ON THE MIGRATION
OF ATLANTIC SALMON SMOLTS AND ADULTS**

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EXTENDED ABSTRACT ONLY - DO NOT CITE

Introduction

In recent years there has been increasing interest in the UK in the construction of estuarine barrages for urban regeneration, hydroelectric power generation and flood defence purposes. However, there has been wide concern that these constructions may have a significant impact on the estuarine environment and the species that inhabit these ecosystems. Of particular concern are the possible effects an estuarine barrage may have on diadromous fish species, which move between fresh and salt water environments. The construction of a tidal barrage across the lower sections of an estuary may affect the behaviour of migratory species, such as Atlantic salmon and sea trout, in a number of ways. Firstly, by modifying the tidal regime within the estuary it may significantly reduce the ebb and flood tidal cues which are used by salmonids to orientate (Moore *et al.*, 1995). Secondly, by reducing saline intrusion and “flushing” during the ebb tide cycle, both the aquatic environment and water quality will be modified. Thirdly, the barrage may form a physical barrier to the passage of both juvenile and adult salmonids.

Between 1993 and 1995 an acoustic telemetry study of the migratory behaviour of both juvenile and adult salmonids (Atlantic salmon, *Salmo salar* and sea trout, *Salmo trutta*) was carried out in the vicinity of a barrage on the River Tawe in South Wales (Russell *et al.*, 1998). The barrage consists of a primary and secondary weir, a navigation lock, and a 'pool and traverse' fish pass. The Tawe estuary experiences a large tidal range and approximately 71 % of tides overtop the barrage and allow the influx of salt water into the impoundment for about 16 % of the total time. During overtopping there is limited mixing of fresh water and salt water in the impoundment, and some saline stratification may extend up to 5 km upstream of the barrage. The surface area of water within the impoundment is about 22 ha.

The localised upstream movements of 76 kHz acoustically tagged returning adult salmonids (n = 28) were investigated in the immediate vicinity of the barrage and associated fish pass using a High Resolution (HiRes) tracking system (Russell *et al.*, 1998). The behaviour of salmonid smolts (n = 52), tagged with 300 kHz miniature acoustic transmitters, was also monitored during their spring seaward emigration within the impounded estuary using an array of 300kHz acoustic sonar buoys (Moore *et al.*, 1996).

Movements of adult salmonids

The majority of adult salmonids (73 %) which approached the barrage were found to hold station for relatively long periods of time, often fairly close (<10 m) to the barrage structure. Many of these fish holding station (~50 %) were clearly attracted by the plume of water discharging from the fish pass and spent continuous periods of sometimes some hours within a radius of a few metres adjacent to or in the plume. Other fish adopted a rotational pattern of movement or moved along the length of the barrage, occasionally holding station in shallower water at the margins of the estuary. Many of the fish recorded approaching the barrage (68 %) were not subsequently recorded within the impoundment, immediately upstream of the barrage, within the period of acoustic life of the tag.

Passage over the barrage itself commonly occurred around high water on overtopping tides, with fish mostly migrating over the primary or secondary weirs (78 % of those recorded passing the barrage). Fish appeared to either hold station below the weirs before moving upstream when conditions were suitable or approached and crossed the barrage more rapidly on a flooding tide.

However, two fish were also recorded moving through the fish pass when the barrage was not over-topped by the tide. Two of the fish which were recorded crossing the secondary weir briefly dropped below the barrage before immediately re-entering the impoundment, again over the secondary weir. The movement of fish over the barrage was significantly unimodal with respect to the tidal cycle (Rayleigh Test $r = 0.64$, $p < 0.05$, $n = 9$), with a mean passage time of 4 minutes after high water.

On crossing the barrage into the impoundment, the movements of most fish appeared to become fairly random with quite long periods (an hour or two to several days) of residency relatively close to the barrage (<100 m). Three fish (43 % of those tracked into the impoundment) subsequently dropped back over the barrage for varying periods, some momentarily, others for periods of a few hours to a few days, before either moving out to sea (1 fish) or re-entering the impoundment (2 fish). One fish traversed the barrage three times in this way before moving further up the impoundment.

The movements of salmonid smolts

The movement of salmonid smolts through the impounded estuary and into the lower estuary, downstream of the barrage, was not continuous. On reaching the barrage the fish ceased their downstream emigration. The mean residence time of fish immediately above the barrage was 54.76 ± 23.1 hours (mean \pm S.E.M.). The time spent by individual smolts in the vicinity of the barrage ranged from 0.2 to 389.53 hours. This represented between 0.28 and 99.0% of the total time spent by the smolts within the tidal and impounded sections of the estuary. The movement of smolts upstream of the barrage was predominantly random and there was no consistent pattern of movement of smolts during the period that they were in the vicinity of the Tawe Barrage. A number of smolts demonstrated exploratory movements within the study area. Individuals were monitored moving back and forth along the length of the barrage, and in a circular pattern within the impoundment. It was also observed that in a number of instances smolts within the study area moved in the direction of the navigation lock during its filling. This suggests that the localised increase in flow within the impoundment as a result of filling the lock basin acted as a stimulus for the smolts to continue downstream emigration. Fish that successfully negotiated the barrage did so by migrating through the ship lock or over the weir during an over-topping flood tide.

The construction of the barrage, which resulted in the formation of a largely freshwater lake, the length of the original estuary, modified the tidal cycle and removed the strong ebb tide currents that the smolts used to emigrate rapidly seawards. The significant reduction in the tidal cycle also resulted in poor water quality above the barrage and the concentration of contaminants within the impoundment. The exposure of salmon smolts to sub-lethal levels of pesticides, and oestrogenic compounds (Madsen *et al.*, 1996) have been shown to significantly effect the hypo-osmoregulatory capabilities of the fish and result in high mortality once the fish migrate into the marine environment. In addition to the delay to migration caused by estuarine barrages, toxic mechanisms that interfere with smoltification and the adaptation of the smolts to the marine environment may also be a factor in the decline of some salmon stocks.

References

- Madsen, S.S., Mathiesen, A.B. & Korsgaard, B. 1997. Effects of 17 β -estradiol and 4-nonylphenol on smoltification and vitellogenesis in Atlantic salmon (*Salmo salar* L). *Fish Physiology and Biochemistry* 17: 303-312
- Moore, A., Potter, E.C.E., Milner, N.J. & Bamber, S. 1995. The migratory behaviour of wild Atlantic salmon (*Salmo salar* L) smolts in the estuary of the River Conwy, North Wales. *Canadian Journal of Fisheries and Aquatic Sciences* 52(9): 1923-1935
- Moore, A., Stonehewer, R.O., Kell, L.T., Challiss, M.J., Ives, M. J., Russell, I.C., Riley, W.D. & Mee, D.M. 1996. The movements of emigrating salmonid smolts in relation to the Tawe barrage, Swansea. In: *Barrages: Engineering Design & Environmental Impacts*. Edited by N. Burt & J. Watts. HR Wallingford Ltd. John Wiley & Sons Ltd. 409-417
- Russell, I.C., Moore, A., Ives, S., Kell, L.T., Ives, M.J. & Stonehewer, R.O. 1998. The migratory behaviour of juvenile and adult salmonids in relation to an estuarine barrage. *Hydrobiologia*. 371-372(1-3): 321-333

**THE INFLUENCE OF ROCK RAMP FISHWAYS
ON THE HYDRAULIC CHARACTERISTICS OF WEIRS**

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Abstract

A physical model of a weir and rock ramp fishway installation on the Thomson River, Victoria, was constructed to evaluate the effect of rock ramp fishway design on the rating curve of the weir. Two different designs with 1:20 slopes, one constructed with a pool between the weir and fishway crests and the other constructed fully up to the weir crest were evaluated. The pool-type and full length rock ramp fishways affected the weir rating curve by 50% and 20%, respectively. Removal of large resting rocks from the fishway surface was found to decrease the effect of the fishway on the weir rating curve by approximately 5%. The presence of a rock ramp fishway downstream of the weir crest elevated the upstream water level for a given discharge.

Introduction

Weirs are regulatory structures commonly used for flow measurement and water level control in streams. However, these structures also present a barrier to fish passage and threaten the existence of many migratory species (O'Brien 1996, Bell 1986).

Considerable research, particularly in North America (Katopodis 1981, Bell 1986) has resulted in the design of structures that allow successful passage of

salmonid species for upstream migration and spawning. Australian fish are considerably different in character to salmon, tending to swim at lesser velocities and not to jump (Mallen-Cooper 1996). Consequently, modified fishway designs have been developed for Australian streams. One such design is the rock ramp fishway, which is considered to be the most viable option for weirs with a low head drop (O'Brien 1999). Rock ramp fishways are suitable for weir heights up to about 2m. They tend to be impractical for higher weirs because of the volume and length of fishway required to reduce the water gradient sufficiently to enable fish passage.

A disadvantage of the construction of rock ramp fishways at gauging weirs is the potential of the fishway to elevate the downstream water level such that the weir crest becomes drowned. This, in turn, affects the rating curve of the weir. This issue is of major practical importance because the construction of a fishway at a small flow measurement weir will require resource-intensive, manual re-rating of the weir. This must be done over several years to obtain the rating curve for a complete range of flows.

This paper presents the results of an experimental study of the effect of several rock ramp fishway designs on the rating curve of a small gauging weir. Included in this study were such issues as rock ramp slope and the influence of resting rocks. The weir and fishway installation at Cowwarr Weir, West Gippsland, was selected as the prototype due to the presence of a standard gauging weir with a rock ramp fishway downstream.

Design and construction aspects of the model are discussed first. The results are then presented and discussed and potential for further work in this field is explained.

Experimental methodology

The gauging weir itself is compound in nature and consists of a 10 m wide central sharp-crested section inset 0.30 m below flanking "broad-crested" concrete sills.

Unlike the recommended Victorian rock ramp fishway design (O'Brien 1998), the fishway at Cowwarr does not ascend up to the weir crest but terminates at a similar height to the sharp-crest approximately 3 m downstream of the weir, thereby creating a large pool immediately downstream of the weir. Larger rocks

protrude from the surface of the fishway to produce resting areas for the ascending fish. A recessed gutter has been provided in the centre of the fishway to allow passage at low flows. Figure 1 shows a photograph of the prototype fishway installation.



Figure 1: Prototype Fishway Installation.

A fixed-bed scale model of the Cowwarr Weir fishway was constructed in the Monash University Civil Engineering Hydraulics Laboratory to a scale of 1:9. Figure 2 shows a photograph of the constructed model.

The central weir section consisted of a central knife-edge constructed from a brass plate flanked by broad crest sections constructed from marine ply.

The flow was monitored using two electromagnetic flowmeters of size 150 and 300 mm installed in parallel branches of the supply. In this way, the full range of tested flows were measured to an accuracy of $\pm 0.5\%$. Water surface elevations were monitored using pitot-static tubes connected to stilling wells. The accuracy of water level measurement was ± 0.1 mm.

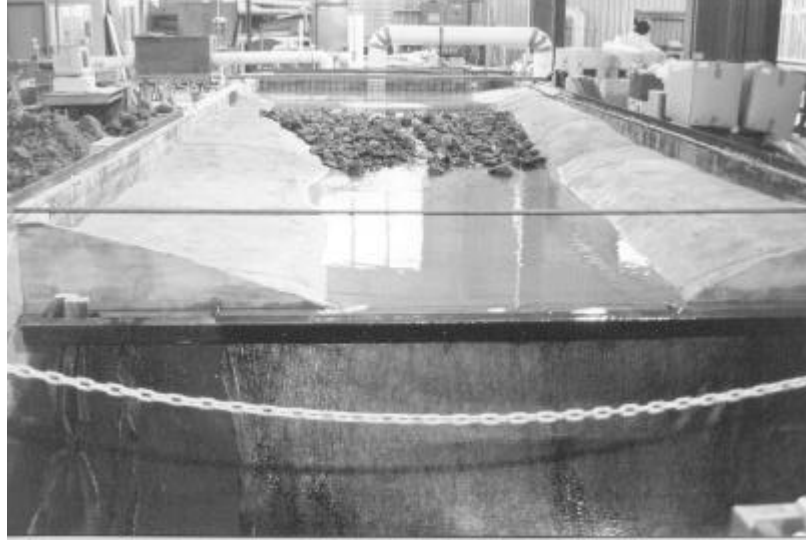


Figure 2: Model Weir and Fishway Installation.

For each test, the upstream water level was measured for a number of increasing pre-selected flow rates. Longitudinal flow profiles, both with and without the fishway in place, were measured across the weir crest to examine the effect of the fishway on the nappe and the corresponding effect on the rating curve.

Results and Discussion

Cowwarr Weir Pool Type Rock Ramp Fishway

The water surface level in the upstream weir pool relative to the knife edge was recorded for each of the test flow rates with the Cowwarr model fishway in place. These results were plotted, as shown in Figure 3, as a height-discharge relationship and compared to the theoretically derived relationship for the weir alone.

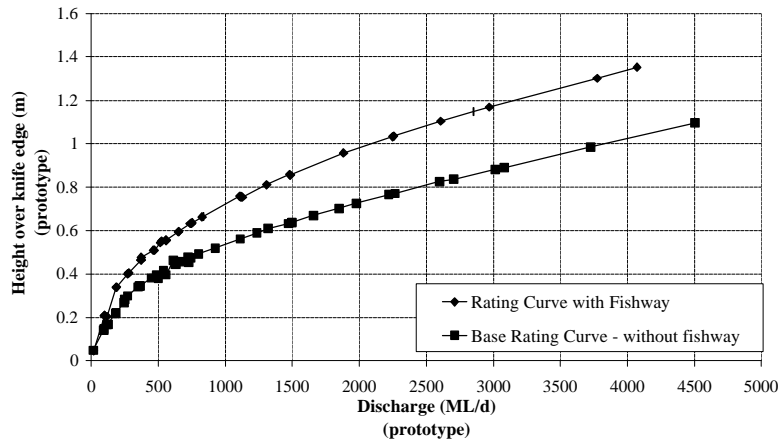


Figure 3: Rating Curve for Cowwarr Weir Fishway

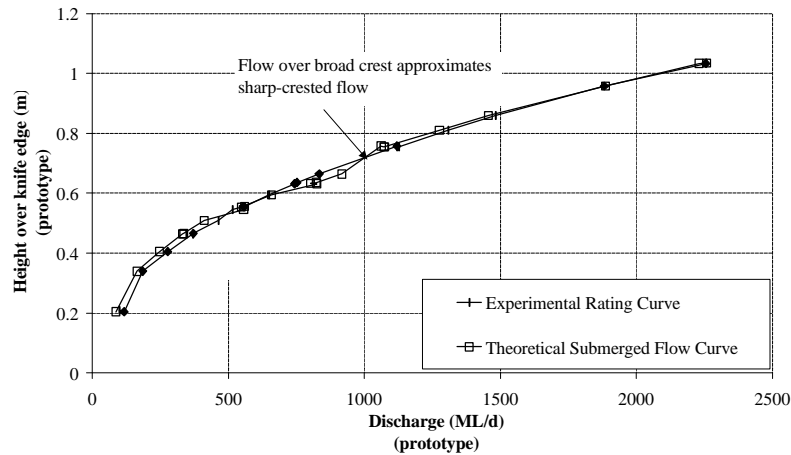
It is evident that the presence of the fishway downstream of the weir crest increases the water surface elevation for a given discharge by between 25 and 30 %. This increase was due to the presence of submerged flow over the weir crest. As the fishway did not extend back to the weir crest, a pool equal in height to the fishway crest formed between the weir and fishway crests, thereby submerging the weir crest.

The experimental rating curve with the weir in place was then plotted against a theoretically determined submerged rating curve. The result, plotted in Figure 4, shows excellent agreement.

Effect of Resting Rock Location

Initially, larger resting rocks were placed along a central S-shaped low flow gutter from the weir crest to the downstream end of the fishway, as shown in Figure 2. The longitudinal spacing between the rocks was approximately 0.30 m. Subsequent trials with the 1:20 and 1:10 sloped fishways investigated the effect of the removal and relocation of the resting rocks on the rating curve of the weir.

Figure 4: Experimental and Theoretical Submerged Flow Curves for Cowarr



Model Fishway

It was observed that the removal of the larger protruding resting rocks from the fishway surface had a small but significant effect on the weir/fishway rating curve, as shown in Figure 5 for the 1:20 sloped full length rock ramp fishway. Similar discrepancies between the fishway and base rating curves were observed for the 1:10 sloped fishway. In both cases an increase in discharge of approximately 4% for a given water surface elevation relative to the weir crest was observed following removal of the resting rocks. It is possible that removal of the resting rocks from the fishway may have increased the nappe pressure, thereby increasing the discharge for a given height.

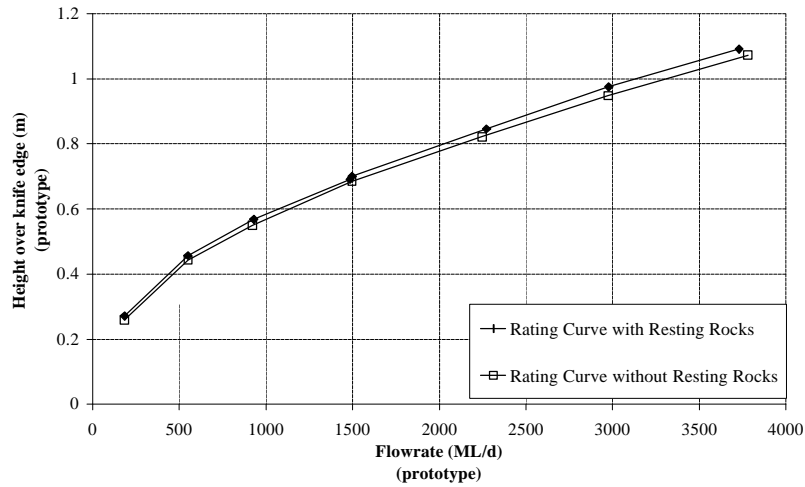


Figure 5: Effect of Resting Rocks in 1:20 sloped fishway on Cowwarr Weir Rating Curve

Comparison Between Full Length and Pool-Type Fishways

Both of the fishways investigated (pool-type fishway and full-length fishway) were shown to have a significant effect on the rating curve of the weir. A comparison of the effect of the two 1:20 sloped fishway designs is shown in Figure 6. The mechanism affecting flow over the weir crest is different for both fishway types, resulting in the observed differences in their effect on the weir rating curve.

The full length fishway affected the weir rating curve through interference with the nappe. The pool-type fishway, on the other hand, affected the weir rating curve through the creation of submerged flow over the weir crest.

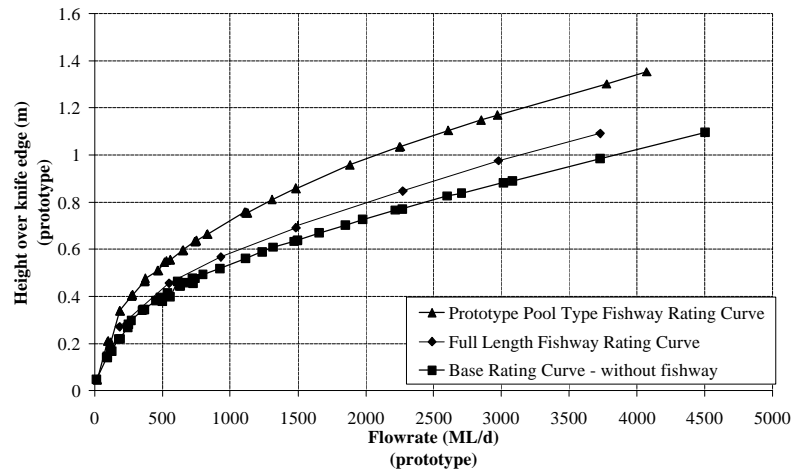


Figure 6: Effect of Two Fishway Designs on Weir Rating Curve

Conclusions and Recommendations

On the basis of this study, the following conclusions are drawn:

1. Construction of a rock ramp fishway downstream of a sharp-crested weir has a significant effect on the rating curve of the weir. It is therefore vital that this effect be considered, by physical model or other means, if a rock ramp fishway is to be constructed at an existing discharge measurement weir. Further investigations are necessary to determine the effect on the rating curves of other types of weir.
2. The pool-type fishway and full-length fishway affected the rating curve of the weir differently. A decrease of 50% in the discharge for a given water surface elevation was observed for the pool-type fishway compared to a decrease of only 20% for the full-length fishway. The full length fishway design is therefore recommended for construction at existing weir sites, especially if flooding is a concern.
3. The presence of resting rocks on the surface of the fishway reduces the discharge for a given water surface elevation. It is therefore recommended that the number of large surface rocks, especially near the weir crest, be

restricted to the minimum necessary to allow passage of all target fish species. Further work is required to identify the migratory preferences of Australian fish.

References

- Bell, M. C. 1986. Fisheries Handbook of Engineering Requirements and Biological Criteria. US Army Corps of Engineers.
- Katopodis, C. 1981. Considerations in the Design of Fishways for Freshwater Species. 5th Canadian Hydrotechnical Conference. Fredricton: N.B.
- Mallen-Cooper, M. 1996. Fishways and Freshwater Fish Migration in South-Eastern Australia. Sydney: University of Technology.
- O'Brien, T. (1996). Design Considerations for Coastal Waterways, Report on Rock Fishways. Melbourne: Marine and Freshwater Resources Institute.
- O'Brien, T. 1998. Fish Passage on Small Instream Structures. Melbourne: Marine and Freshwater Resources Institute.
- O'Brien, T. et al. 1999. Providing Fish Passage at Small Instream Structures. Water 99 Joint Congress, Brisbane: Institution of Engineers Australia.

Acknowledgements

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**DEVELOPMENT OF A TAGGING PROTOCOL
FOR OUTMIGRANT**

JUVENILE LAMPREY, *LAMPETRA TRIDENTATA*

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EXTENDED ABSTRACT ONLY- DO NOT CITE

Introduction

Pacific lamprey populations are experiencing a precipitous decline in abundance throughout the Pacific Northwest of the U.S.A. While the decline of lamprey is widespread, it is of great concern in the Columbia River system (Close *et al.*, 1995).

Recovery is dependent on identification of sources of mortality. While very little is known about their migratory biology, successful outmigration relies on safe passage through dams. Therefore, paramount to recovery is developing a way of monitoring fish during migration; hence the need for an appropriate tagging and detection system.

We have been exploring the use of radio telemetry and PIT tags to monitor juvenile lamprey outmigration. Development of an effective tagging system is

dependent on obtaining a tag of appropriate physical characteristics that has the necessary transmitting and/or sensing parameters, allows for normal behavior, and provides an adequate “recapture” system.

Methods/Results

Radio- tags

Due to the small size of juvenile lamprey and restrictions in available tag size, radio-tags (12.5 mm X 5 mm X 2.5 mm, 0.43 g.) were mounted externally, approximately mid body, and laterally on the fish. The tag is attached with suture (Ethicon 5.0 non-absorbable), at two anchor points, from the attachment loop at the battery end of the tag in addition to a suture loop around the base of the tag where the antenna exits the transmitter. Forty-five animals were tagged in this manner, in which approximately 25% of the tags were removed (by the lamprey) by the third day post-tagging. All of the tags were detached by day 15 (Fig. 1).

PIT tags are small enough for internal implantation (8 mm X 2 mm X 2 mm) in juvenile lamprey. In an initial experiment, 45 juvenile lamprey (each group) were either implanted with PIT tags using a single scalpel-incision, given an incision only (sham) or left intact (control). Approximately 25% of both the PIT-tagged and sham animals died by day 6 post-tagging; there was no mortality over this period in the control group (Fig. 2).

In a second experiment, 36 animals (each group) were either PIT-tagged using the single incision method described above, but with the use of a dissecting microscope to avoid damaging the digestive tract and given oxygen-enriched recovery, or left intact. The results of this experiment reduced mortality by 10% over the same period (Fig. 2).

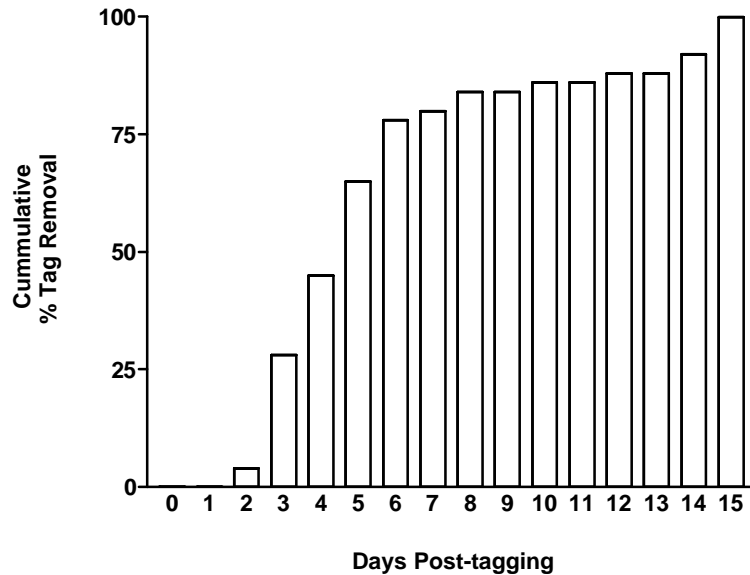


Figure 1. Cumulative percentage of radio-tags removed by juvenile lamprey. Lamprey were externally tagged with radio-tag dummies that were the same weight, shape and density as real tags. Tags were attached by suture mid-body and lateral on the fish. All of the tags were removed by day 15 post-tagging.

PIT-tags

Regression analysis of the length and weight data from the previous two experiments indicates that 99% of the mortality in both trials was those animals smaller than 150 mm in length. In a third experiment, 35 animals (each group) were selected for relatively large size (150 mm total length) and either PIT-tagged by the method in the second experiment or left intact. Results suggest that nearly 100% survival can be obtained by PIT-tagging animals with total lengths greater than 150 mm. (Fig 2).

Swimming Behavior

In separate experiments, radio-tagged and PIT-tagged juvenile lamprey were

subjected to flows similar to what they may encounter in and around Columbia River hydroelectric projects. For the radio-tag experiment 6 animals were tagged as described previously and along with 6 untagged, fish were placed into one of three chambers (2 tagged and 2 control fish per chamber) of a swim tube. Animals were allowed to attach or “hold fast” to the side of the tube, at which time, flows were gradually (within 1 minute) increased to 2.5 ft./sec. Animals were then monitored by video for a twenty-four hour period and time of detachment from the tube was recorded. By 12 hours, 100% of the radio-tagged animals were detached. Untagged fish remained attached by 24 hours post-treatment. Eight PIT-tagged and eight untagged fish were subjected to the same conditions as described above. By 24 hours post-treatment, all animals (tagged and untagged) remained attached to the swim tube.

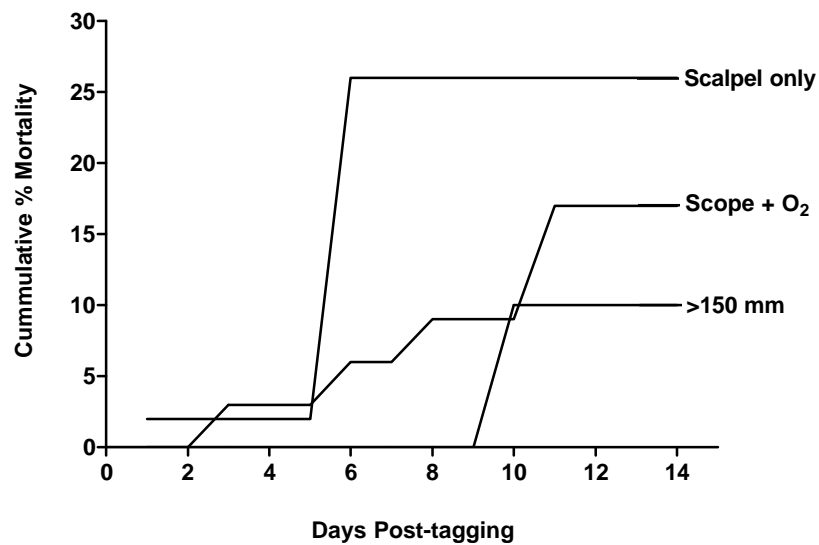


Figure 2. Cumulative percent mortality for three PIT tagging procedures. Animals were PIT-tagged using a scalpel incision only, using a scalpel incision under a dissecting microscope and provided and oxygen enriched recovery, or selected for size greater than 150 mm and tagged

using the scope + O₂ method. Fourteen days post-tagging, the size biased group had fewer mortalities.

Discussion

We have determined that the maximal size for an implantable telemetry tag for juvenile pacific lamprey is the size of a miniature PIT tag. Mortality associated with implantation can be significantly reduced by improved surgical techniques and the use of animals greater than 150 mm in total length. External application of the smallest radio-tag currently available may be able to provide some information about migratory behavior through hydroelectric projects on the Columbia River, however, results from these experiments clearly showed that the external attachment of these radio-tags alters behavior as compared to PIT-tagged or untagged fish. Reductions in the size of radio-tags would be of great benefit.

Acknowledgements

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References

Close, D.A., M. Fitzpatrick, H. Li, B. Parker, D. Hatch, and G. James. 1995. Status report of the Pacific lamprey (*Lampetra tridentata*) in the Columbia River basin. Report for the U.S. Dept. Energy, Bonneville Power Admin. Contract No. 95BI-39067: 34pp.

PACIFIC LAMPREY MIGRATION BEHAVIOR

IN A COMPLEX ENVIRONMENT:

OBSTACLES TO PASSAGE

AT COLUMBIA RIVER DAMS

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EXTENDED ABSTRACT ONLY – DO NOT CITE

Introduction

Pacific lamprey, *Lampetra tridentata*, are parasitic, anadromous petromyzontiforms endemic to the Columbia River drainage in the northwestern United States. After entering freshwater, the adults cease parasitic behavior and move upstream via free-swimming anguilliform locomotion to reach spawning habitats. Recent counts of adult Pacific lamprey passing hydroelectric dams on the Columbia River indicate a decline in lamprey abundance (Starke and Dalen 1995). This may be attributed to obstruction of adult lamprey migration by the dams and subsequent reductions in recruitment. We used radio tracking to assess passage efficiency and migration behavior of Pacific lamprey at Bonneville Dam, the hydroelectric dam located furthest downstream in this drainage.

Methods

We captured adult lamprey at night in a trap located in the Bonneville Dam fish ladder during their upstream migration in May - September of 1998 and 1999. Each fish was measured and a small radio transmitter (< 2% of lamprey body

weight) was surgically implanted in the body cavity. All fish were released 3 km downstream from the dam. They were relocated via both mobile surveys with a portable receiver, and an array of 32 fixed site receivers that logged the time and date of individual fish passage at key positions in and around the fish ladders at Bonneville Dam (Figure 1). Passage efficiency was defined as the number of lamprey that successfully negotiated an area of interest divided by the number that entered that area.

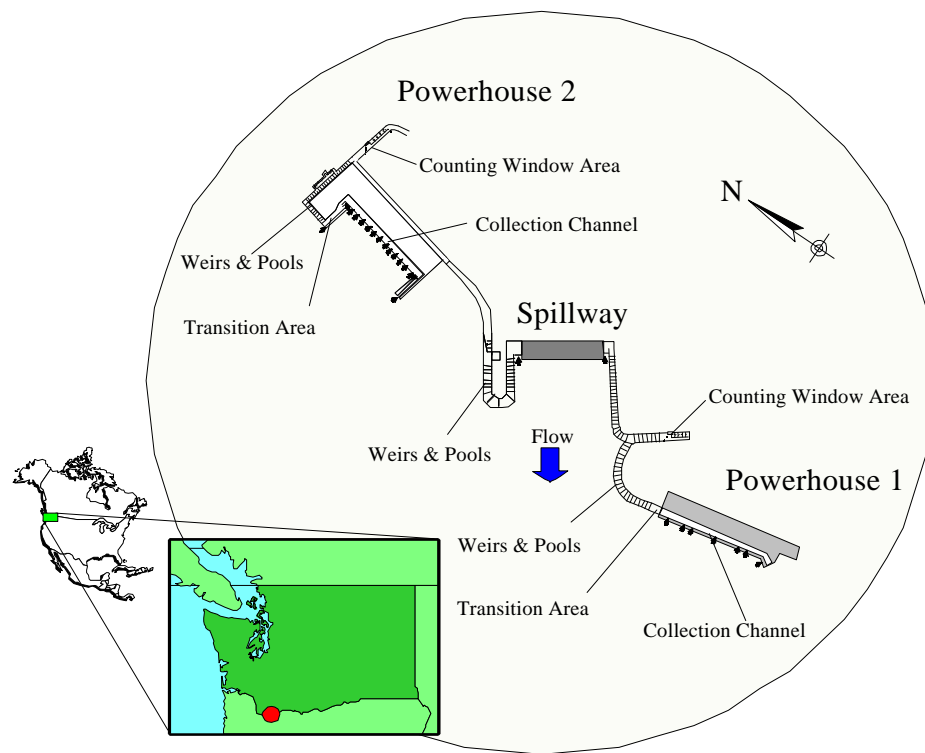


Figure 1. Study area at Bonneville Dam in the Columbia River drainage. Small black arrows represent fish ladder entrances along the base of the dam.

Results

We tagged 205 lamprey in 1998, and 199 lamprey in 1999. In both years, approximately 90% of the fish migrated upstream after surgical implantation of radio transmitters, indicating that tag effects were low. Less than half of the lamprey that approached Bonneville Dam successfully negotiated the fish ladders: 39% in 1998 and 45% in 1999. In both years, passage efficiency was lowest through collection channels, transition areas, and past counting windows (Table 1).

Table 1. The number of lamprey that negotiated an area of interest divided by the number that entered that area (passage efficiency) in 1998 and 1999 at the Bonneville Dam fish ladder system.

Area of Interest	Passage Efficiency	
	1998	1999
Fish ladder entrances	154÷182 (85%)	161÷183 (88%)
Collection channels and transition areas	105÷154 (68%)	103÷161 (64%)
Weirs and pools	99÷ 105 (94%)	102÷103 (99%)
Counting window area	71÷ 99 (72%)	81÷102 (80%)

Discussion

The fish ladders at hydropower dams on the Columbia River were constructed to facilitate salmonid passage, but were not designed to pass lamprey. Contrary to expectation, lamprey successfully negotiated high current velocity areas at the fish ladder entrances and in the weir and pool sections of the fishway. This, in spite of the relatively low burst speed and reduced swimming performance of lamprey relative to other fishes (Beamish 1974, Mesa et al. 1999). However, collection channels, transition areas, and the counting windows represented obstacles to upstream movement of Pacific lamprey. We hypothesize that the lack of attachment sites and turbulent currents in the collection channels and transition areas deterred or delayed lamprey. Unlike salmonids, lamprey moved through the fishways primarily at night. Our results suggest that intense lighting at the counting stations, particularly during the night, can also repulse lamprey. Other lamprey species exhibit negative phototaxis and dark-adapted lamprey

may be particularly sensitive to light (Protosav 1968, Ullen 1996). Future studies will investigate both the spectral sensitivity and phototactic responses of migrating Pacific lamprey in an effort to ameliorate their passage at counting stations.

Acknowledgements

John Vella, Northwest Fisheries Science Center (NWFSC), and members of the Idaho Cooperative Fish and Wildlife Research Unit (ICFWRU) contributed to the field tracking effort. Ben Sandford (NWFSC) assisted with statistical analysis and Ken Tolotti (ICFWRU) provided receiver maintenance and transferred data collected at fixed sites. Ted Bjornn (ICFWRU) contributed to proposal development, administration and oversight of the fixed site array. This work was funded by the U.S. Army Corps of Engineers.

References

- Beamish, F.W. H. 1974. Swimming performance of adult sea lamprey, *Petromyzon marinus*, in relation to weight and temperature. Trans. Am. Fish. Soc. 103:355-358.
- Mesa, M.G., J.M. Bayer, J.G. Seelye and L.K. Weiland. 1999. Draft Annual Report to U.S. Army Corps of Engineers, Portland District, Portland OR, 24 pp.
- Protosav, V.R. 1968. Vision and near orientation of fish. Israel Program for Scientific Translations, Ltd, Jerusalem, 175pp.
- Starke, G.M. and J.T. Dalen. 1995. Pacific lamprey (*Lampetra tridentata*) passage patterns past Bonneville Dam and incidental observations of lamprey at the Portland District Columbia River dams in 1993. U.S. Army Corps of Engineers, CENPP-OP-PF, Cascade Locks, OR 138 pp.
- Ullen, F. 1996. Neural mechanisms for the visual control of spatial orientation and locomotion: electrophysiological and behavioral studies of the supraspinal control of posture and steering in the lamprey central nervous system, with special reference to visuo-motor mechanisms. Thesis, Nobel Institute for Neurophysiology, Stockholm.

**HYDRAULIC APPARATUS
FOR FISH PASSAGE EXPERIMENTATION**

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EXTENDED ABSTRACT ONLY – DO NOT CITE

Introduction

Hydraulic engineers and biologists have worked on different aspects of the same fish passage and bioengineering projects for years. Projects include fish migration and passage, river restoration, and hydropower development, among others. Successful solution of such problems requires understanding and appreciation of fish biology by engineers and of hydrodynamics by biologists. This is essential to having a successful working relationship and as a result successful bioengineering systems.

A fish passage structure is a complicated hydraulic system that presents migratory fish with many challenges, which they face less frequently in their natural habitat. These include high flow velocities, large-scale turbulence and shear stress, high concentrations of bubbles, and various structural components. An engineer can design better systems given basic biological information such as fish swimming abilities, fish energetics, and flow velocity requirements. Recently, “fish friendly” designs that incorporate biological criteria have been

on the rise. However, these biological criteria are scarce, and sometimes nonexistent.

Field studies result in valuable understanding of migratory fish behaviors on a large scale. The studies include many variables that, when combined, affect the measured behaviors of the test fish. It is desirable to measure fish behavior response to individual hydraulic phenomena and to determine design criteria for systems that minimize damage to fish. Therefore, laboratory setups are needed to simulate field hydraulics to facilitate the study of the effects these conditions may have on the behavior and physiology of fish. A variety of fish species, sizes, gender and life stages should be tested.

Swimming Abilities of Fish

Swimming speeds and traveled distances of migratory fishes are essential to designing fish passage structures. Available data are limited and sometimes unreliable. We designed a swim speed flume to determine volitional fish swimming abilities and corresponding distances traveled under given/controlled hydraulic conditions (e.g. varying flow velocity, water depth, and turbulence intensities). The open channel hydraulic system is capable of replicating severe hydraulic conditions similar to those existing at fish passage structures.

The swim speed flume consists of a headpond with a slide gate, a 24-m long straight channel (1x1 m cross-section), and a plunge pool with an adjustable tailgate. The flume provides velocities of 0 to 4.5 m/s at water depths ranging from 0.1 to 1 m. Several antennae (to detect Passive Integrated Transponder, or PIT, tags) are mounted along the length of the flume for close monitoring of tagged test fish released to volitionally swim upstream at a controlled velocity and water depth conditions. Video cameras are used to monitor fish behavior within different velocity zones across the flume and collect other data such as fish tail beat frequencies.

Fish Energetics

Knowledge of migratory anadromous and riverine fish energetics (e.g. metabolic rates) is essential to understanding the cost of locomotion in these fishes during their migratory journey. Water flows inside fish passage structures may have velocities and turbulence intensities that exceed migratory fish's energetic abilities, or compromise their long term ability to survive and successfully

reproduce. Therefore, information regarding energetic costs of swimming can greatly assist engineers in designing effective passage structures. Swimming respirometers have been used to do just that for decades.

A swimming respirometer is a closed conduit hydraulic system used to determine a fish's ability to swim and evaluate their oxygen consumption and energy use at given water velocities. Our 30.5 cm diameter 1.2 m long clear acrylic respirometer has a constant water volume and provides flow velocities of up to 3 m/s; adequate for testing anadromous fish as large as adult American shad *Alosa sapadissima* (total length 35-60 cm). The test chamber is surrounded by steel reducing elbows (30.5 cm to 20.3 cm inside diameter) that have flow straightening vanes. The varying velocities are achieved by a variable frequency driven 60 HP pump, which provides accurately repeatable hydraulic conditions. A Chiller/Heater unit is used to maintain constant water temperature during testing. Oxygen is also regulated.

Effects of Hydraulic Phenomena on Migratory Fish

Flow through hydraulic systems experience numerous geometric, kinematic, and dynamic changes. These result from changes in dimensions, velocities, changing energy forms, and forces acting on the fluid. These changes create hydraulic phenomena (e.g. turbulence, shear stress, and cavitation) that are believed to be damaging to fish at high levels. Fish are also likely to be damaged due to strike and grinding near structures (e.g. turbines) in the flow.

Fish experience a combination of hydraulic phenomena simultaneously and repeatedly in a hydraulic system. However, several researchers have attempted to isolate each phenomenon and study its effects without great success. Identifying the effects of a single phenomenon requires an experimental apparatus that amplifies it and insures that other phenomena do not affect the test fish greatly. This helps in establishing biological and engineering design criteria that can be used in designing fish friendly hydraulic systems.

The Bio-Hydraulic Turbine Test Stand apparatus (BiHTTS) is made of an upstream reservoir or pump to provide varying hydraulic heads, a closed conduit simulating a penstock to a turbine, a test module containing simulated turbine system components (e.g. turning vane, wicket gate, etc.), and a downstream collection chamber. BiHTTS simulates field flow conditions near hydropower turbine system components. The test module is large enough to accommodate

downstream migrating juvenile anadromous fish such as Atlantic salmon (*Salmo salar*) smolts and juvenile American shad (*Alosa sapidissima*).

The effects of various hydraulic phenomena (e.g. shear stress and turbulence) on fish passing close to the simulated turbine system components can be studied. Also, probabilities of damage to fish due to strike and abrasion can be determined. The Test Module can accommodate a single turbine component or a combination of components. The size of passage zones around test components is large enough to accommodate test fish and also simulate realistic flow conditions.

Summary

The description of experimental apparatus is intended to give the reader an idea about the challenges facing engineers and biologists in the area of fish passage technology development and fish friendly engineering design. Design criteria that minimize damage to fish are essential to developing systems that work. It is also recommended that instrumentation and study protocols be developed to conduct experiments and evaluations of systems in the field under natural conditions.

**TEMPERATURE EFFECTS ON THE STRESS RESPONSES AND
RECOVERY OF YOUNG SPLITTAIL EXPOSED TO A FISH SCREEN**

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EXTENDED ABSTRACT ONLY - DO NOT CITE

Introduction

The splittail, *Pogonichthys macrolepidotus*, is a threatened native species of the Sacramento-San Joaquin Delta system of northern California. Juveniles of this species may be vulnerable to >2,000 water diversions located throughout the Delta system. Because small young-of-the-year splittail are present in the Delta during spring and summer, we investigated the effects of two temperatures on their physiological stress responses and recovery when exposed to a simulated fish screen in an annular swimming apparatus.

Methods

Groups of 20 fish (standard length: 6-8 cm) per experiment were exposed to a circular 3-m diameter wedge-wire fish screen with 2.3 mm vertical bar spacing in a 0.67-m wide test channel for 2 hr during the day under ten different combinations of approach flow (through the screen, range 0-15 cm/s) and sweeping flow (pass the screen, range 0-62 cm/s) at two temperatures (12 and 19 C) with three replicates per treatment. We measured plasma cortisol, lactate, and glucose concentrations and blood hematocrit before the start of the experiment (resting sample), at the end of the experiment, and at 0.5, 2, 24, and

48 h post-experiment with two fish per sampling time. We also measured screen contact rates, swimming velocities, injuries, and 48-hr survival. Data were analyzed using ANOVA models.

Results and Discussion

Generally, plasma cortisol, lactate and glucose levels of splittail at both temperatures increased above resting levels immediately after exposure to the fish screen at all flow combinations. This increase was followed by a greater increase at 0.5 h post-experiment, and a further increase (glucose at 19 C) or a decrease (for all above parameters at 12 C, and cortisol and lactate at 19 C) at 2 h post-experiment, and returned to resting levels at 24 and 48 h post-experiment. Blood hematocrit levels at both temperatures generally showed a slightly increasing trend above resting levels immediately after the experiment followed by a gradual decline during the 48 h post-experiment. None of the physiological responses immediately after the experiment correlated with screen contact rates, swimming velocity, or injuries. However, splittail had significantly higher cortisol, glucose, and hematocrit levels at 19 C than at 12 C showing greater physiological stress responses associated with the higher temperature.

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**DEVELOPING SPAWNING AND INCUBATION CHANNELS
FOR RIVER RUN MIGRATORY MAHSEERS IN NEPAL**

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Abstract

Number of river run migratory Deep-bodied mahseer *Tor tor* is declining due to over-fishing, environmental pollution and habitat modification due to dams. For conservation and management of this endangered game fish require special incubation techniques. Technique has been developed for spawning and rearing in natural and artificial substrata and introduction hatchery bred fries into depleted natural population. Fertilized eggs of mahseer up to fry stage has been studied in intergravel water. The field and laboratory results show that there is possibility of augmenting the mahseer population of the migratory mahseer by artificial breeding, releasing and replenishing the depleted stock. The paper also highlights need of developing novel type spawning channel or incubation and incubating facilities for increasing mahseer fry resources for faster propagation.

Introduction

The Deep-bodied mahseer (*Tor tor*) is popularly known as Himalayan Salmon and is an endangered cyprinid occurring in the snowfed running waters of Nepal, Shrestha (1990). The scientific literature of consists only a few fairly rudimentary remarks on natural and artificial breeding and incubation of mahseer eggs. A preliminary study on migration and spawning was furnished by Shrestha (1994). The literature on spawning and incubation of Salmonid eggs is voluminous (Baily and Taylor, 1974 and Bam and Simpson, 1976). But the published information on concerning spawning and incubation of mahseer eggs is scanty because mahseer is

vary difficult to breed in captivity and yet no reliable incubation techniques have been developed for faster propagation of this species. In the present paper an attempt is made study incubation success of the mahseer eggs by using different incubating devices in the mountain stream environment of Nepal.

Methodology

In the past three years, I have tried to locate natural spawning ground of Deep-bodied mahseer around feeder streams of Trisuli (feeder stream creeks such as Tadi, Sindurae, Khahare etc.). However, I found only one spawning site near Gadkhar fish farm at Chokedovan which was found to be utilized for spawning year after year. Field observation was carried out from 1995 - 1999 at this site and period and duration of spawning, size and number of individuals in each spawner group were recorded. The water quality and hydro-biological parameters of the study area were noted. The migrants were also captured to determine their physical conditions and to study spawning behavior in captivity. The propagation of the mahseer is detailed in my previous studies (Shrestha 1990, 1992).

River run adult mahseers were also trapped from the creeks at night by means of gill nets. They were put in a large cloth tank or happa (size 4X3X2m) for acclimatization. The happas were suspended in the flowing creek water. Inside happa male and female fishes were put in a ratio 3:1 and were administered with carp pituitary extract injection (0.4gm/body weight of fish). Fishes were fed twice daily with rice bran, oil cake etc. Stripped eggs from breeders were fertilized with wet and dry methods and reared in a series of incubators by putting them safely in semi-natural incubating channel.

Table 1: Water quality of Mahseer spawning incubation channel at Gadkhar creek

Factors	Values
Temperature	30 °C
Color	Brown
Visibility (m)	0.38
Compensation depth	0.89
pH	7.5
Oxygen	11
Dissolved solids	159
Hardness	46
Specific conductance	280
Chloride	19
Sulphate	15
Calcium	23
Magnesium	2.6
Iron	0.10

Observation

A series of incubation channels were fed by creek water and constructed in a creek nearby the Gadkhar fish hatchery where fertilized fish eggs are artificially buried rather allowing the fish to deposit eggs naturally. In the incubation channels fish eggs can be stocked in higher densities. Densities (2000 eyed eggs/ft²) of surface area yield high survival in fry stage. A variety of incubators both wooden or plastic incubators of different sizes were also used to incubate mahseer eggs in the incubation channel. Dead eggs were removed or siphoned. The advanced fish fry after hatching drops from the egg incubator and work their way into gravel substrate. Preferred flow mahseer eggs are considered to be 1.0-1.5 cfs. The riverside incubation channel is effective for golden mahseer eggs.

The experimental incubation channels do need sophisticated hatchery operation, simple facilities available near water mill (Ghatta) was used to build incubation facilities 1) Requires less space 2) increases survival of eyed egg and fry over natural production because of controlled flow and clear water from spawning creek 3) less capital cost. Transfer of Salmonid incubation technology developed in USA

found to be useful on mahseer living in ecological condition of mountain rivers of Nepal.

Use of Artificial Incubators for Incubation

A typical incubation channel constructed in Gadkhar at embankment of creek (Khahare Khola) is of 6 ft wide, 50 ft long and 12 inches deep. Fertilized eggs were placed in turf or plastic incubators with small orifice at top for allowing rapid dispersion of swim up fries. The fries development in the gravel substrate and their emergence time was recorded (Table 2 and 3).

Table 2: Gravel Incubators Mahseer Eggs Subjected to Incubation at Different Temperature and Velocity

Field Sites	Upper reaches or mouth of creek	Middle reaches of creek	Confluence site of creek and stream
No. of Gravel Incubators	5	5	5
Incubating Temp. °C	30	28	22
No. of eggs Incubated	21500	21500	21500
Gravel size (mm) (mean)	50	28	12
Average current vel. m/sec	1.2	0.8	0.5
Dissolved O ₂ (ppm)	9	7	10
Time taken for hatching	48	60	72
Time taken for emergence as fry (hrs)	240	232	215
No. of eggs hatched (Mean)	21428	21395	21223

Table 3: Comparative Table Showing Incubation Success in Different Incubators

Type of Incubators	Wooden Incubator	Plastic Incubator	Turf Incubator
Gravel Size in Inch	0.5 to 2	0.5 to 2	0.5 to 2
No. of Egg Incubated	2000	2000	2000
No. of Egg Hatched as Sacfry	1898	1848	1945
Hatching Time (hrs.)	72	70	72
Hatching Temperature (°C)	25	28	30
Time taken for emergence as fry (hrs)	216	210	192
Dissolved Oxygen (ppm)	10	10	10
Current velocity m/sec	0.5	0.5	0.5

The water was supplied to the channel from Gadkhar creek. The silt free spring water was also tried and had been very much successful and insured higher survival than natural water of the river. For incubation, besides plastic incubators and metal or wooden turf incubators having 4 X 4 X 4 ft were used.

An experimental natural spawning channel at the confluence of Tadi river and Khahare Khola (creek) was selected due to optimum gravel bed and water flow condition for spawning and incubation. The gravel size in the creek was 0.5 to 0.6 inches. The gradient of creek was 0.2 to 0.5 percent which promoted good interchange between surface and intergravel water. During the peak spawning season (September) water depth as 1.5 feet was present. To study natural incubation under natural condition freshly fertilized eggs were put into freshly prepared gravel beds with controlled flows of water or regulated flow condition was allowed to run naturally over the spawning assembly of the gravel beds or fertilized egg produced by stripping male and female mahseer is manually buried in an incubation channel. The hatching development and remission of the fry took 240 hrs.

Conclusion

On the basis of my field observations in the incubation channel at Gadkhar creek, it was noted that the incubation of mahseer eggs in the creek was always associated with low water level, monsoon rain. Sinha, Jhingran and Ganapati (1974) indicated that no single factor could yet be recognized as the most important for spawning and early development major carp such as mahseer. The present study also suggests many factors as noted to be responsible for the successful spawning, development and incubation are (i) clean and continuous water flow and steady water level, (ii) increasing current velocity. High turbidity (low transparency), (iii) optimum water surface temperature (28 to 30 °C), (iv) high level of dissolved oxygen and conductivity (8 to 12 ppm), (v) slight acidic nature of water, (vi) presence of fine gravel with intergravel flow, oxygen retaining red and particles rich in ferromagnetic or volcanic ashes protect embryo from infection of parasites. The interaction of all these factors provides unique hydrological conditions at the semi-natural incubation ground which might provide rheotactic effects for effective incubation.

Due to remoteness and inaccessibility hatchery system in Nepal is in developing stage. In fish hatchery of Nepal, mahseer sac fry is prone to infection of molds *Saprolegnia* because sac fry undergo long periods of latency extending from 48 to 92 hrs. In future more effective incubation system suited in the ecological condition of mountain stream to be developed.

Mean incubation periods of fry in the Gadkhar hatchery were estimated at 6 to 8 days. But incubation periods in creek were estimated at 8 to 12 days depending on the temperature of creek water. In creek developmental rate is slower than in hatchery due to lower temperature and intergravel flow.

References

- Bailey, J.E. and S.G. Taylor. 1974. Salmon fry production in a gravel incubator hatchery. Auk Creek, Alaska, 1971-1972. NOAA. Tech. Memo. NMFS, ABFL. 3. 13 p.
- Bams, R.A. and K.S. Simpson. 1976. Substrate incubator workshop. Report on current state of Art Fisheries and Marine Service. Environment Canada.
- Shrestha, T.K. 1990. Rare Fishes of Himalayan Waters of Nepal. J. of Fish Biology 37 (Supplement A) Academic Press, London. 213-219 p.
- Shrestha, T.K. 1992. Propagation of Mahseer in the Himalayan Waters of Nepal. In: National Research Council. 1992. Aquaculture and Schistosomiasis: Proceedings of a network meeting held in Manila, Philippines, August 6-10, 1991. National Academy Press. Washington, D.C. 61-78 p.
- Shrestha, T.K. 1994. Migration and Spawning of Golden Mahseer in Himalayan Waters of Nepal. J. Freshwater Biol, India. 6(1): 71-77.
- Sinha, V.R.P., V.G. Jhingran and S.V. Ganapati. 1974. A review on spawning of the Indian major carps. Arch. Hydrobiol. 73: 518-536.

