NOAA FISHERIES

May 20, 2019

West Coast Region
California Coastal Area Office

Executive Summary

Recent literature documents that juvenile salmonids are mobile within watersheds in order to utilize different habitats, access better water quality, forage, disperse from competitors and predators, and seek refuge from high water velocities during storm events. In many cases, adult and juvenile salmonids face waterfalls of various heights while attempting to migrate upstream. These waterfalls are often caused by human-made structures such as dams or road crossings. While the leaping abilities of adult salmonids have been extensively documented, little information exists on the leaping abilities of juveniles. This gap in our knowledge has resulted in inconsistent state and federal guidelines regarding jump heights at juvenile fish passage facilities in California. Additionally, not understanding the leaping abilities of juvenile salmonids may result in costly over-engineered fish passage facilities, a decrease in the ecological value of habitat, or inadvertent blockage to valuable habitat upstream. To document the leaping abilities of juvenile salmonids, we tested groups of hatchery-reared steelhead (Oncorhynchus mykiss) and coho salmon (Oncorhynchus kisutch) between 40mm and 130mm fork length (FL) in a test flume equipped with a waterfall of different heights at the Warm Springs Fish Hatchery in Geyserville, California. Success over a waterfall was measured by the number of fish upstream of the waterfall at the end of a 24 hour test period. We found that for steelhead at 54F, no fish less than 47mm FL successfully passed a 6 inch waterfall and no fish less than 57mm successfully passed a 12 inch waterfall. We found that passage success for steelhead between 50-100mm FL was approximately 20% better over a 6 inch high waterfall than a 12 inch high waterfall, but that for steelhead > 100mm FL, there was no significant difference in passage success over the two heights. Passage success for these fish averaged over 70%, higher than previously documented. We found that no fish tested were able to successfully leap over an 18 inch waterfall. We found that passage success decreased as water temperature decreased. We found many similar patterns for coho salmon, and we found that success for both species was related to fish length and weight. The results of this study suggest that fish passage facilities with 6 inch jumps likely provide a modest increase in percentage passage of small juveniles compared to 12 inch jumps, but not for fish > 100mm FL. This modest increase in passage of smaller juveniles should be weighed along with other factors when designing a fish passage project, including cost, project footprint, and impacts on habitat. Additional testing is planned on both smaller and larger fish, and at different water temperatures, to further inform design guidelines.

Introduction

Recent literature documents that upstream movement of juvenile salmonids occurs commonly (Adams 2013, Armstrong et al 2013, Kahler et al 2001, Kahler and Quinn 1998). Juveniles may move several miles in order to utilize different habitats, access better water quality, forage, disperse from competitors and predators, and seek refuge from high water velocities during storm events. In many cases, salmonids face waterfalls or other barriers of various heights while attempting to migrate upstream. These barriers are often caused by human-made structures (e.g., dams and road crossings) or effects (e.g., reduced stream flows).

In order to promote utilization of habitat above the barriers, hundreds of fish passage devices have been installed at barrier locations in California alone, and over 3,000 identified barriers remain. In the State of Washington, tens of thousands of culvert barriers remain which may impede fish passage (Pearson et al 2005). The situation is similar throughout the Pacific Northwest, and has relevance nationally and internationally owing to the widespread distribution of rainbow trout, salmon, and the prevalence of barriers to salmonid fish passage. Therefore, designing effective fish passage facilities, based on known juvenile salmon swimming and leaping behavior and abilities, has significant environmental implications for salmonids, as well as significant economic implications regarding the cost of effective fish passage projects.

It has become standard industry practice to design for juvenile upstream passage at fish passage facilities where juveniles are present. However, while the leaping abilities of adult salmonids have been extensively documented (Stuart 1962 in Symons 1978, Powers and Orsborn 1985, Bell 1986, Lauritzen 2000), little information exists on the leaping abilities of juveniles (Pearson et al 2005). Of the information that does exist, passage rates of juveniles over barriers approaching 1.0 foot were very low, and several factors affecting passage success were identified.

Stuart (1962, in Symons) concluded that juvenile salmon and brown trout can leap a height of 10 body lengths under optimum conditions, including a plunge pool depth equal to or greater than 1.25 times the fall height. He also observed that most fish leapt from the surface. Symons (1978) found that juveniles of coho (*Oncorhyncus kisutch*) and Atlantic salmon (*Salmo salar*) were capable of leaping falls at least 5 body lengths in height, and that both species leapt the lower (12 cm) falls more readily than the higher falls (27 and 57 cm). He also found that more fish leapt when water temperatures were between 14°C and 17°C than at lower temperatures. Experimental test design included fish between 7.1 and 12.5 cm fork length (FL), a minimum plunge pool depth of 110 cm at maximum fall height (nearly twice the falls height or more), and a test duration of 3-4 days. The proportion of fish that successfully leapt the falls varied between 1 and 6%.

Brandt et al. (2005) found that juvenile brook trout (76 mm total length) were most likely to leap at waterfalls less than 10 cm in height and with plunge pool depths greater than 10 cm.

Pearson et al. (2005) evaluated groups of 100 juvenile coho salmon per trial to determine if they could leap into a culvert test bed set at four different heights (12 cm, 20 cm, 26 cm, 32 cm). 3 hour tests were conducted in full darkness, as previous testing had found that fish were most likely to move upstream during the night. Tests were conducted in relatively cold water conditions (2°C – 6°C). Plunge pool depth was found to influence leaping success. More fish passed a 12 cm jump and entered the test culvert when the plunge pool was 30 cm deep than when it was 42 cm deep. As in Symons (1978), passage rates decreased as jump height increased. Successful passage rates were from 16% to 40% for 12 cm (4.7 in), from 4% to 29% for 20 cm (7.9 in), from 0% to 6% for 26 cm (10 in), and 0% passage for the 32 cm (12.6 in) jump height. Because the fish had to leap up a waterfall, and then swim through a culvert in this experimental design, it is difficult to separate leaping and swimming performance from each other in these results.

These studies included very small numbers of test fish or did not include a test design that isolated leaping height as a test parameter. The resulting gap in our knowledge has resulted in inconsistent state and federal guidelines regarding appropriate design jump heights for juvenile salmonid fish passage facilities. The California Department of Fish and Wildlife's (CDFW) design guideline for the maximum allowable hydraulic drop at culvert outlets is 0.5 feet when juveniles are present (CDFW 2002). However, for culvert retrofits using boulder weirs, the CDFW design guideline for juveniles (and all salmonids) has been increased to 12 inches foot per weir. The National Marine Fisheries Service's (NMFS 2001) design guidelines for the maximum allowable hydraulic drop at culvert outlets is 6 inches when juveniles are present (NMFS 2001 and 2011), and NMFS has generally applied this guideline to boulder weirs as well. The Oregon Department of Fish and Wildlife (ODFW) also has a guideline of 6 inches for maximum jump height (ODFW 2004), but commonly issues waivers for a jump height of 8 inches depending on site conditions.

Design guidelines impact fish passage projects in many ways. While it is commonly assumed that lower jump heights will pass more juveniles, constructing lower jumps requires that more jumps be constructed to gain the same elevation. This may require increasing the overall length of the project, the area disturbed by the project, and the overall project cost. If the overall length of the project is not increased, installing twice as many small jumps will require shorter and shallower plunge pools and shorter riffles. This may change the project habitat from a spawning or holding reach to a fish passage corridor, which may not be desired. Healthy coho salmon populations reside in systems dominated by large wood structures and with deep pools, and Chinook salmon need deep pools and long riffles for spawning habitat. The magnitude of this change may often be large, as passage projects may include up to several dozen 12 inch jumps.

While the agencies that develop design guidelines recognize that the ability of juvenile fish to leap over a barrier depends on many factors (including physical, environmental and hydraulic conditions, and the condition and volition of the fish), they do not have an ample set of basic performance data upon which to base design criteria. We conducted these experiments to add to the body of leaping performance data for juvenile salmonids that can inform the design of successful fish passage structures.

The objective of the first experiment was to measure passage success of age-0 steelhead as a function of size (fork length [FL]) and waterfall height (h_1). The range of jump heights was chosen (from 6 inches to 18 inches) to span and exceed the range of heights currently held as design guidelines by state and federal fisheries agencies in California, Oregon, and Washington. We predicted that there would be a minimum threshold fish length for successful passage at each of the jump heights tested. We predicted that overall passage success would be greater for steelhead than for coho salmon. We predicted that passage success would be greater for both species at a waterfall height of 6 inches than at waterfall heights of 12 or 18 inches. We also predicted that larger fish would be more successful jumpers than smaller fish.

The objective of the second experiment was to measure passage success of age-0 coho salmon in the same test conditions as the first experiment to compare passage performance of the two species.

The objective of the third experiment was to measure passage success of coho salmon at two 6 inch waterfalls in series compared to a single 12 inch waterfall, since two of the smaller waterfalls are required to achieve the vertical gain of one taller waterfall. This test was aimed at evaluating cumulative effects of multiple jumps on passage success. We predicted that more fish would successfully ascend one six inch jump than two six inch jumps in series and that also that more fish would ascend two 6 inch waterfalls in series during the test period than would successfully ascend a single 12 inch waterfall.

The objective of the fourth experiment was to evaluate the effect of water temperature on passage success over the 6 inch and 12 inch jump heights. Swimming performance of salmonids is species and stock specific and is related to water temperature (Lehman et al 2016, Cech et al). If water temperature is too cold, salmonids become less active. If water temperature is too warm, respiration and swimming ability decrease. We predicted that passage performance would decrease at temperatures below 54F. The goal of this experiment was to determine if the results of the first and second experiments could be applied to areas that typically have colder water temperatures when juvenile fish are expected to migrate.

Methods

Experiments were conducted at the U.S. Army Corps of Engineers' (USACE) Warm Springs Fish Hatchery in Geyserville, California. Eyed eggs of steelhead and coho salmon were produced at the hatchery from crosses of adults returning from Dry Creek (tributary to the Russian River) to the hatchery of both wild and hatchery origin. Eyed eggs were kept in upwelling trays at 11.0°C ± 1.0°C until hatched. Sac fry were then transferred to indoor rearing troughs maintained on a natural photoperiod. Swim-up fry were then fed a diet of Bio-Oregon starter and fry feeds until they were large enough for use in our experiment (45 mm FL or larger). Test fish were separated from the hatchery population, used in only one trial, and then returned to the hatchery population so they could not mistakenly be used more than once. The experiments were conducted in a hatchery building with ample diffuse, indirect, natural photoperiod light provided by translucent skylights, windows, and large wall openings. Experiments 1 – 3 were conducted in the spring, summer and fall months between 12 June 2014 and 24 September 2017. Experiment 4 was conducted between 13 November 2018 and 19 January 2018.

Experiment 1- Effects of Waterfall Height and Fish Size on Jumping Success

The experimental system included a fiberglass trough (164 in. long x 32 in. wide x 30 in. deep) supplied with single-pass, aerated (100% O2 saturation) water from nearby Lake Sonoma. To create an experimental waterfall, a 5 inch thick broad-crested weir with a 12 inch wide opening was placed in the middle of the length of the trough. Each of the waterfall heights tested had the same weir configuration. A 5-inch weir thickness was chosen in experiment 1 as a practical representation of the minimum thickness that long-lasting concrete weirs can be formed for fish passage facilities[1]. Water was pumped into the upstream end of the trough, flowed through a head screen to make the flow distribution more uniform, then over the weir and into the plunge pool. It then flowed through a tail screen and down the vertical standpipe. The vertical standpipe controlled plunge pool (jump pool) depth at 12 inches for all three jump heights tested[2]. The flow rate through all tests was 0.185 cfs (83 gpm) and resulted in a depth of 1.75 inches over the lip of the 12 inch wide weir opening. The water temperature remained at 12.7°C ± 0.5°C for the duration of the 21 tests conducted for experiment 1 with a slight diurnal temperature variation (± 0.5°C).

Juvenile steelhead jumping ability was tested at 6 inch, 12 inch, and 18 inch waterfall heights. 6 inch and 12 inch jump heights were chosen as the minimum and maximum rock weir design jump heights in the Pacific Northwest when juveniles are present, and 18 inches was simply the next increment of 6 inches to test. Multiple replicate trials were conducted for each species at 6 inch and 12 inch waterfall heights with approximately 100 randomly selected fish/trial. Only one trial with 262 steelhead was conducted for the 18 inch jump height. Test fish were taken off feed 24 hours preceding a test, then placed in the plunge pool and given 24 hours to ascend the waterfall. No incentive was provided to induce the fish to jump the waterfall. At the end of each trial, fish were removed from above and below the weir, anesthetized with tricaine methanesulfonate (MS-222), weighed (g) and measured (FL, mm), and returned to the hatchery population and not tested again. Success was measured by the number of fish upstream of the waterfall at the end of the 24 hour test period. No barrier was provided to prevent fish from swimming back downstream over the waterfall.

Experiment 2- Jumping Success of Different Species

The experimental conditions were all the same for experiment #2. However, juvenile coho salmon were tested at 6 inch and 12 inch waterfall heights rather than steelhead to compare jumping success between the two species.

Experiment 3- Effect of Multiple Weirs on Jumping Success

The third experiment was conducted under the same conditions as experiments 1 and 2 but with two 6 inch jumps with 5-inch thick weirs in series instead on one. Only coho salmon were used in experiment 2. Three replicate trials were conducted with 100 randomly selected juvenile salmon/trial. Success was measured by the number of fish upstream of both waterfalls at the end of the 24 hour test period. Fish passage success in experiment 3 would be compared to results of experiment 1 for coho salmon and a 12-inch waterfall. Test conditions, including flow rate, water velocity, and depth over the weir were all the same as in experiment 1. The only differences in test condition were that two weirs were installed in series, with a jump pool depth between the two weirs of 6 inches deeper (18 inches total) than the 12 inch pool depth downstream of the first weir.

---

[1] Three trials were also conducted with 12 inch thick weirs to simulate passage conditions over a thick weir crest boulder. Similar results were obtained.

[2] NMFS minimum pool depth criterion for juvenile salmonids is 6 inches and 12 inches for adults.

Experiment 4- Effect of Temperature on Jumping Success

Warm Springs Hatchery juvenile steelhead were again used for experiment 3. However, in order to test the effect of water temperature on passage success, all the test fish were housed in a new, partially recirculating acclimation and holding system constructed for these tests. Test fish were added to the holding system at 54F water temperature, and the water temperature decreased by 2 degree F increments for each test over 4 days until 48F was reached. During the test season, fish were fed the same Oregon Bio Diet at a maintenance feed rate. The holding system included a 5 foot diameter tank supplied with recirculating, ultra-violet irradiated (30,000mws/cm2), chilled freshwater at the same flow rate as the other experiments. The source water was the same as experiments 1 and 2, with 10% make-up water added continually to make up for evaporative loss and to dilute any metabolites. Also, a bead particulate filter and a fluidized, aerated biological filter kept ammonia and nitrate levels to negligible levels. A new fiberglass trough was constructed for test 3 that was supplied with recirculating water chilled to the same temperature as the acclimation and holding system (to within ± 0.5°C). Fish were again taken off feed 24 hours prior to testing, placed in the test trough downstream of the weir and given 24 hours to ascend the jump. Hydraulic conditions (flow rate, depth over weir, weir configuration) were identical to tests 1 and 2.

Results

<u>Experiment 1: Effects of Waterfall Height and Fish Size on Jumping Success</u>

The top two plots of Figure 1 provide fish length (mm) on the horizontal axis and fish weight (mm) on the vertical axis for 6 inch and 12 inch jump tests for steelhead. The plots include the data for multiple 100-fish tests as indicated. Each red dot represents an individual fish of a certain length and weight that did not ascend the jump. Each black dot represents an individual fish of a certain size and weight that did ascend the jump. These results demonstrate that similar size fish were tested over each weir height, which is important as swimming and jumping ability is positively related to fish length and weight.

The bottom plot of Figure 1 provides fish length (mm) on the horizontal axis and percent of fish in the upper pool on the vertical axis. Percent of fish in the upper pool is the measure of fish passage success we used[3]. The steelhead from the 6 inch jump (N=600) and the 12 inch jump (N=1000) are both included in this plot. Data is provided for the 6 inch jump tests (in blue) and 12 inch jump tests (in red) so passage success over the two jump heights can be compared[4]. As can be seen in Figure 1, no steelhead less than 47mm FL was in the upper pool after 24 hours for the 6 inch jump test, and no steelhead less than 57mm was in the upper pool after 24 hours for the 12 inch jump test. Passage success for steelhead between 50-100mm FL increased with fish length over both jump heights at similar rates, but passage was somewhat better for the 6 inch high waterfall than for the 12 inch high waterfall. However, there was no significant difference in passage success over the two heights for steelhead > 100mm FL. Passage success for

[3] It is possible that fish passed to the upper pool and then returned to the lower pool, one or more times, as no barrier to downstream passage was used.

[4] In order to generate line plots, fish were binned into 5mm size groups, and the % passage success of that group indicated by the position of the line on the vertical axis.

steelhead > 100mm FL over both jump heights averaged over 60%. No steelhead were in the upper pool after 24 hours for the 18 inch jump test.

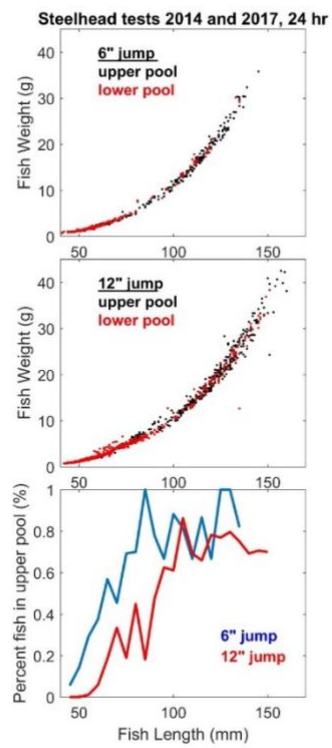

Figure 1-Results of Experiment 1. Effect of jump height on leaping success.

<u>Experiment 2: Effect of Species on Leaping Success</u>

Figure 2 provides results for coho salmon under the same test conditions, with N=300 for the 6 inch jump and N=500 for the 12 inch jump. As with Experiment 1, the top two plots

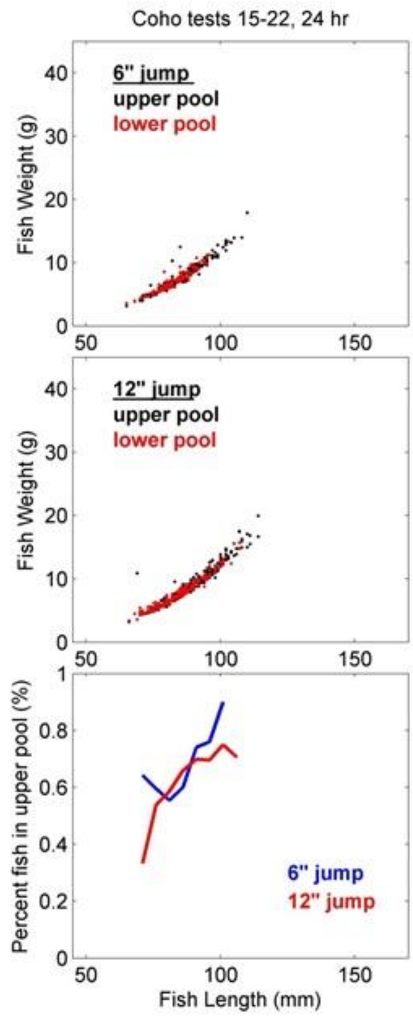

Figure 2-Results of Experiment 2. Effect of species on leaping success.

demonstrate that similar size fish were tested over each weir height, which is important as swimming and jumping ability is positively related to fish length and weight.

Coho salmon were not available over the entire size range of steelhead tested, including coho < 70mm FL or > 105mm FL. However, passage success for coho between 70 and 105mm FL generally increased with length, and there was no significant difference in passage success over the two jump heights for coho in this size range. There was also no significant difference in jumping success between coho and steelhead over the lengths tested. Again, passage success for coho > 100mm FL over both jump heights averaged over 60%.

<u>Experiment 3- Effect of Multiple Weirs on Leaping Success</u>

As with experiments 1 and 2, the top two plots demonstrate that similar size fish were tested over each weir configuration, with N=300 for two 6 inch jumps in series and for one 12 inch jump. In Experiment 3, again only coho salmon between 70mm FL and 105mm FL were available for

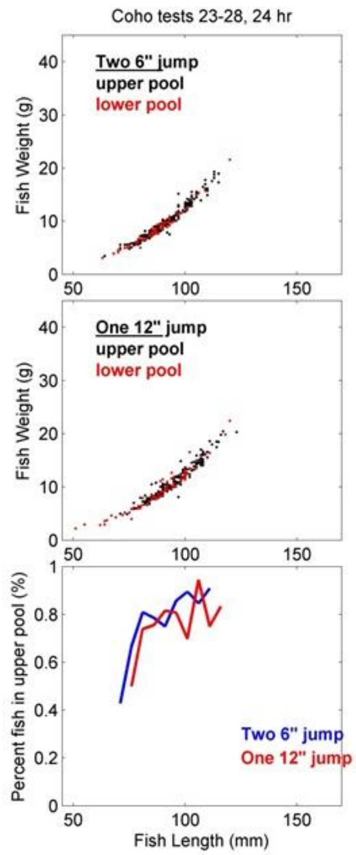

Figure 3- Experiment 3. Effect of multiple weirs on leaping success.

testing. Test fish had to pass both of the 6 inch weirs for passage to be considered successful. Test fish that were between the two weirs at the end of the 24 hour test period (5-7 fish in each of the three tests) were included in the results with the test fish that were not successful at passing the first weir. As seen in Figure 3, passage success for coho between 70 and 105mm FL again generally increased with fish length, and there was no significant difference in passage success between two 6 inch jumps in series and one 12 inch jump for coho in this size range. Passage success for coho > 100mm FL over two 6 inch jumps and one 12 inch jump was 70% or over.

<u>Experiment 4- Effect of Temperature on Leaping Success</u>

The top plot of Figure 4 shows that larger steelhead were included in the tests at colder water temperatures (48F vs 54F). Also, at fish lengths less than approximately 100mm FL, most fish did not pass the jump successfully, and at greater than 100mm, most test fish did pass the jumps successfully.

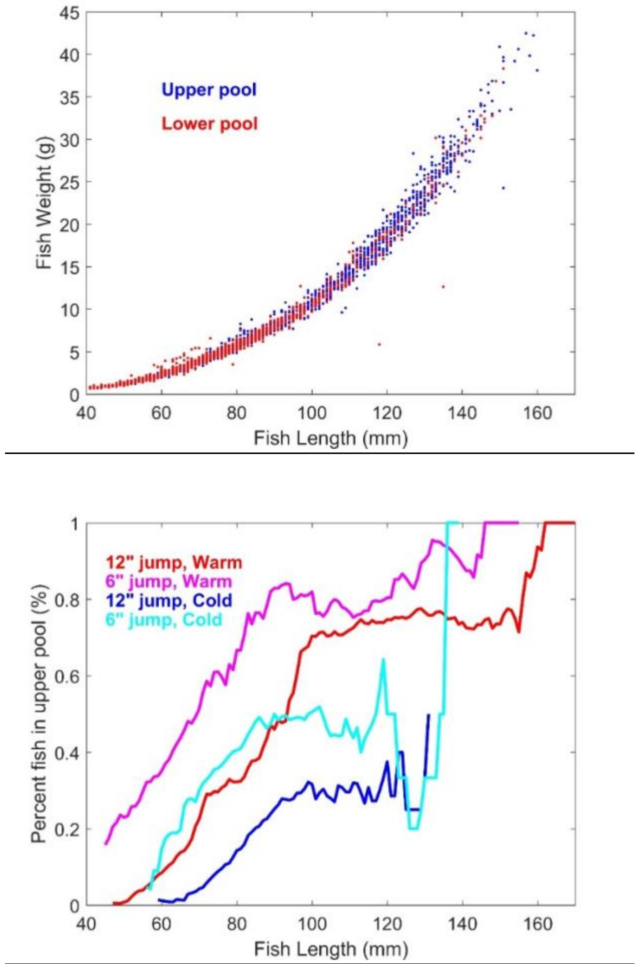

Figure 4-Effect of water temperature on leaping success. "Warm" =54F and "Cold" = 48F.

The bottom plot shows that the percentage of fish in the upper pool decreased in colder water (48F= "cold" and 54F = "warm") for both the 6 inch and 12 inch jumps, and that the minimum length fish passing each jump height increased in colder water (the small end of the size spectrum did not clear the jump at the colder temperature). Again, there appears to be a point around 100mm FL for the 12 inch and 6 inch jumps (warm) where passage success over the two heights converges, and a convergence point at about 120mm FL for the 12 inch and 6 inch jumps (cold). In summary, less fish pass both jump heights in colder water, the minimum length necessary to pass either jump was longer in colder water, and passage performance tends to converge for the 6 inch and 12 inch jumps for both "warm" (54F) and "cold" (48F) conditions.

Discussion

As stated in the Introduction, these experiments were undertaken to provide a larger set of performance data to inform design criteria for juvenile fish passage facilities, in order to find the design jump height for juvenile salmonids that optimizes conditions for juvenile salmonids. We must also consider construction costs and other factors when designing a fish passage facility. NMFS's design guidelines for the maximum allowable hydraulic drop at culvert outlets and boulder weirs is generally 6 inches when juveniles are present. CDFW's design guideline for the maximum allowable hydraulic drop at culvert outlets is 6 inches when juveniles are present, but the design guideline is relaxed to 12 inches per weir for boulder weirs since boulder weirs generally have a great deal of gaps between boulders that can provide various passage opportunities.

In 54F water, for steelhead approaching 100mm FL and larger, there was no discernable difference in fish passage success for 6 inch and 12 inch jumps. For coho, there was no discernable difference in fish passage success for fish approaching 80mm FL and larger. This was also true when comparing two 6 inch jumps to one 12 inch jump. It is possible that this pattern may change with more than two weirs in series. This is an area for future research.

Approximately 20% more steelhead between 50mm and 100mm FL passed the smaller 6 inch jump than the 12 inch jump at 54F and colder water temperatures. It also appears that the minimum length necessary to pass the 12 inch weir tends to be about 10mm longer than necessary to pass the 6 inch weir. Therefore, it is important to establish if it is biologically important to provide the same degree of passage for fish between 50 and 100mm FL, i.e. does the extra 20% in passage performance justify the extra cost of building 6 inch weirs?

Conclusions

Salmonid populations in the Pacific Northwest need access to a greater portion of their historical habitat, more geographic diversity, and better quality habitat for recovery. The common thinking in the fish passage community has been that most juvenile salmonids would not successfully pass a 12 inch weir. These data showed that a 6 inch jump height provided about 20% better passage efficiency than a 12 inch jump height for juveniles less than 100mm, but that passage efficiencies were about the same for fish longer than 100mm FL. In water temperatures that are colder, and where it is important that the highest percentage of small fish are able to successfully navigate a fish passage structure, a stronger justification for including 6 inch jumps in a fish passage facility remains.

References

Adams, C.C. 2013. Survival and Movement of Juvenile Coho Salmon (Onchorhynchus kisutch) in the Shasta River, California. Master's Thesis. Humboldt State University, Arcata, California.

Armstrong, J. B. et al. Diel horizontal migration in streams: Juvenile fish exploit spatial heterogeneity in thermal and trophic resources. Ecology, 94(9), 2066-2075.

Bell, M. C. 1991. Fisheries Handbook of Engineering Requirements and Biological Criteria. U.S. Army Corps of Engineers, North Pacific Division, Fish Passage Development of Evaluation Program.

Brandt, M. M. *et al*. 2005. Effects of Waterfall Dimensions and Light Intensity on Age-0 Brook Trout Jumping Performance. Transactions of the American Fisheries Society 134: 496-502.

California Department of Fish and Wildlife. 2002. Culvert Criteria for Fish Passage.

Kahler, T. H., P. Roni, and T. P. Quinn. 2001. Summer movement and growth of juvenile anadromous salmonids in small western Washington streams. Canadian Journal of Fisheries and Aquatic Sciences 58:1947–1956.

Kahler, T. H., and T. P. Quinn. 1998. Juvenile and resident salmonid movement and passage through culverts. Washington State Transportation Center, Research Report WA-RD 457.1, University of Washington, Seattle.

Lauritzen, D. V., F. Hertel, and M. S. Gordon. 2000. A Kinematic Examination of Wild Sockeye Salmon Jumping Up Natural Waterfalls. Journal of Fish Biology 67:1010-1020.

Lehman B. *et al*. 2016. Relationships between Chinook Salmon Swimming Performance and Water Quality in the San Joaquin River. Transactions of the American Fisheries Society 146:349–358.

National Marine Fisheries Service. 2001. Guidelines for Salmonid Passage at Stream Crossings. National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Southwest Region.

National Marine Fisheries Service. 2011. Anadromous salmonid passage facility design. National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Northwest Region, Seattle.

Pearson, W. H., M. C. Richmond, G. E. Johnson, S. L. Sargeant, R. P. Mueller, V. I. Cullinan, Z. Deng, B. Dibrani, G. R. Guensch, C. W. May, L. K. O'Rourke, K. L. Sobocinski, and H. M. Tritico. 2005. Protocols for evaluation of upstream passage of juvenile salmonids in an experimental culvert test bed. Battelle Memorial Institute, Research Report WA-RD 614.1, Richland, Washington.

Powers, P. D. and J. F. Orsborn. 1985. Analysis of Barriers to Upstream Migration. Submitted to Bonneville Power Administration, Part of a BPA Fisheries Project on the Development of New Concepts in Fish Ladder Design.

Stuart, T. A. 1962. The Leaping Behavior of Salmon and Trout at Falls and Obstructions. Freshwater Salmon Fish. Res.28: 46 p.

Symons, P. E. K. 1978. Leaping Behavior of Juvenile Coho (*Oncorhynchus kisutch*) and Atlantic Salmon (*Salmo salar*). J. Fish. Bd. Can.: 907-909.