Monitoring the Three-dimensional Behavior of Acoustically Tagged Salmon Approaching Hydropower Dams in the Pacific Northwest

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Abstract: Acoustic Tags were used to monitor the swimming patterns of downstream migrating salmon (*Oncorhynchus* spp.) smolts approaching various dams in the Columbia River basin in the Pacific Northwest, USA. Tags were implanted into salmon smolts and tracked, in three-dimensions, within the hydrophone array. Many different behaviors were quantified and used to refine fish bypass strategies at hydropower facilities to maximize fish passage efficiency.

Introduction: Over the past 4 years there has been an increase in acoustic tag studies in the Pacific Northwest, USA. While active studies provided valuable information on fish passage (where, when, and how many) they lacked the ability to follow individual fish for long distances in their approach and passage through a hydropower facility. The ability to track individual fish, and thus to assess fine-scale fish behavior, is key in the assessment and improvement of fish passageways.
Methods: Acoustic tags (HTI Model 795 Acoustic Tags) were implanted, either gastrically or surgically, into salmon smolts. Tags were programmed to emit an acoustic pulse, on average, once every second (tag pulse in YELLOW). To detect acoustic signals, passive hydrophones (BLUE) with omni-directional beams were installed at hydropower dams. As few as 6 and as many as 32 hydrophones were used to monitor the transmitted pulse from the tagged fish, based on the size of the coverage area. As fish approached the study area, the transmitted signal from each tag was detected and the arrival time recorded for each hydrophone. The differences in signal arrival times from an individual tag on each hydrophone were used to calculate a three-dimensional position (RED) with resolution of less than 1-meter. Fish were tracked in three-dimensions as they approached and passed into the turbine intakes, spillways, and surface bypass channel entrances at the dams during the 1999, 2000, and 2001 spring and summer outmigrations.
1: **Rock Island Dam (plan view):** Two prominent areas of congregation were observed, one at the face of each powerhouse. The area of congregation at Powerhouse 2 was dominated by high velocity water flow, while the area of congregation at Powerhouse 1 was dominated by a backwater eddy.

2. **Rocky Reach Dam (plan view):** Fish behavior on approach to Rocky Reach Dam was variable. However, there was a tendency for fish to follow sheer zones where there was a sharp change in water velocity.
3. Grand Coulee Dam (plan view): Rainbow trout behavior with respect to a strobe light placed near the dam. Fish were attracted to the strobe beam during the day (displayed on left) and night (not displayed).
4. **Lower Granite Dam (cross-section view):** Migrating coho smolts exhibited two distinct swimming patterns, straight and milling. Milling behavior was observed most often in the top 20 feet of the water column while straight swimming behavior was observed in the middle layer of the water column.
**5: North Fork Dam (3D view):** Spring chinook smolts of both hatchery and wild origin displayed milling behavior in the dam forebay (5 days of residence). Fish congregated at the surface along the face of the dam.
6: **Bonneville Dam (plan view):** Fish approaching the dam did so in the center of the channel, parallel to water flow (BLUE). As they encountered the dam they vectored to the right or left, perpendicular to water flow (GREEN) and also moved back upstream, opposite water flow (YELLOW and MAGENTA).
7: **Cowlitz Falls Dam (plan view)**: Four mixers (black squares) were deployed to generate an artificial water flow in the direction of the dam. With the mixers off fish were distributed randomly throughout the forebay. With mixers on fish were distributed in the mixer plumes.

8: **Mayfield Dam (3D view)**: Two prominent swimming behaviors were observed as fish entered the intake bypass, direct path (A) and milling (B). There was no correlation to swimming behavior based on time of day, time of release, fish size, or residence time in the forebay.
Conclusions: Three dimensional tracks of juvenile salmonids approaching and passing hydropower dams in the Pacific Northwest were collected with the HTI *Model 290 Acoustic Tag Tracking System*. Many different fish behaviors were observed including attraction to strobe lights, fish guidance and orientation along flow, surface milling behavior, direct swimming to bypass, and fish congregation in both high and low flow areas. The fact that juvenile salmonids show different behaviors at different dams suggest that hydropower facilities should “tune” their fish bypass systems, based on behavior observed, to maximize passage efficiency.

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