A New Tool to Investigate Fish Movement: JSATS

A new system is being used to determine fish mortality issues related to hydroelectric facilities in the Pacific Northwest. Called the Juvenile Salmon Acoustic Telemetry System (JSATS), this tool allows researchers to better understand fish movement, behavior, and survival around dams and powerhouses.

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Uncertainty regarding the movement, behavior, and survival of juvenile salmon and steelhead as they migrate through large river systems with multiple hydro facilities has driven much of the fisheries research in the northwestern U.S. over the past two decades. Population declines and subsequent listings under the Endangered Species Act (ESA) of several species of Pacific salmon in the Columbia and Snake river basins have increased the need to manage the effects of the hydro system on these anadromous fish populations.[1] Based on information gaps related to juvenile salmonids, regional fisheries managers have a need to estimate behavior, timing, and survival as smolts migrate downstream through the Federal Columbia River Power System (FCRPS).

Recent advancements that resulted in smaller acoustic transmitters have prompted an increase in the use of acoustic telemetry to study juvenile salmonids. Since these advancements, acoustic telemetry has increasingly been used to examine the behavior and survival of yearling and subyearling chinook salmon, sockeye salmon, and steelhead migrating past dams and associated forebays of the Snake and Columbia rivers.[2,3]

Based on the limitations of the technology available in 2001, the Portland District of the U.S. Army Corps of Engineers initiated development of an acoustic telemetry system that would use an active transmitter small enough to be implanted in the majority of the size distribution of juvenile chinook salmon emigrating seaward through the Columbia River estuary. Such a system would enable researchers to address many of the primary management questions related to the effects of the FCRPS on salmonid stocks listed under the ESA. For example, determining the passage route of juvenile fish migrating downstream through the FCRPS is critical to understanding the effects of this hydro system on listed populations.

The resulting juvenile salmon acoustic telemetry system (JSATS) consists of micro-acoustic transmitters, receiving systems, and data processing applications. This article, adapted from an article in the January 2010 issue of *Fisheries*,[4] describes JSATS and presents a sample of data collected using this system. Specifically, data presented includes estimated survival, travel time, route of passage, and three-dimensional (3D) behavior of JSATS-tagged chinook salmon as they migrated through 695 kilometers of the Snake and Columbia rivers, from Lower Granite Dam to the Pacific Ocean (see Figure 1).

Conducting the research

Actively migrating juvenile salmon were collected using juvenile fish bypass systems at Lower Granite Dam on the Snake River. A total of 4,140 captured juvenile salmon were surgically implanted with a TX1411ST passive integrated transponder (PIT) tag manufactured by Destron-Fearing (2 millimeters wide by 12.5 millimeters long) and one JSATS acoustic transmitter manufactured by Advanced Telemetry Systems. Each JSATS tag had a mass of 0.433 grams in air and 0.293 grams in water. The tags were 5.21 millimeters wide, 12 millimeters long, and 3.77 millimeters high (thick). The PIT tag was inserted into the incision, followed by the acoustic transmitter, which was placed with the battery toward the anterior portion of the fish. Both tags were positioned parallel to the long axis of the fish.

Fish were placed in a 120-liter recovery bucket and monitored to ensure that they recovered equilibrium before being transferred to the holding and release tank. Fish were held 12 to 24 hours after surgery before they were released into the tailrace of Lower Granite Dam on ten days from April 24 to May 17, 2008. The released fish had a mean fork length of 133.9 millimeters.

The primary device used to detect JSATS-tagged fish was a Model N201 autonomous

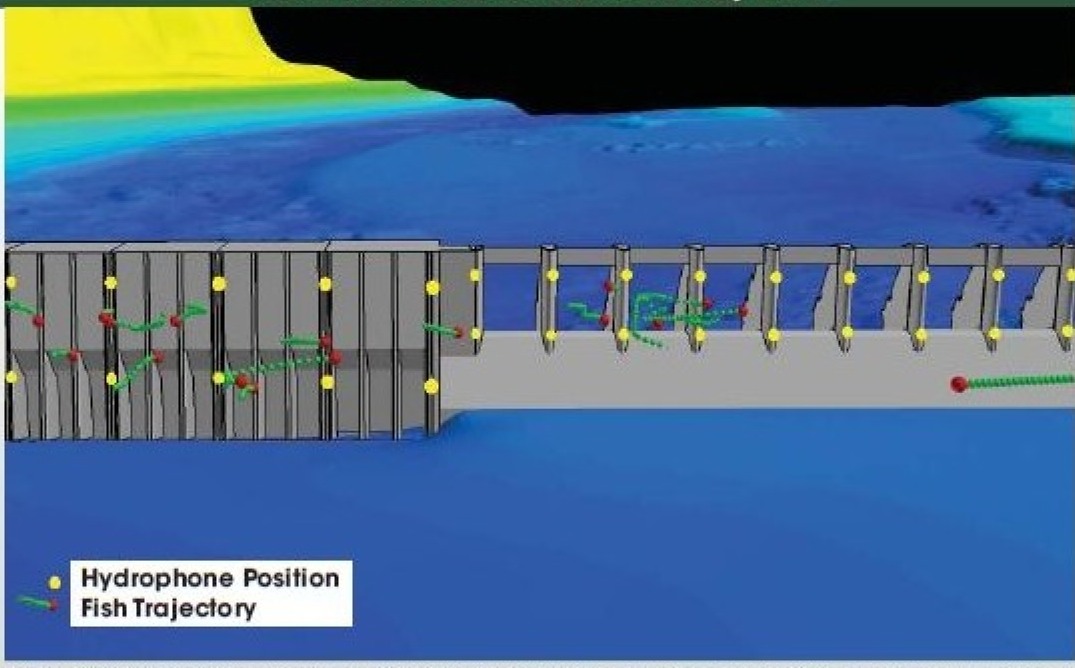
FIGURE 1 Release and Detection Locations

Juvenile salmon for the 2008 study were released at Lower Granite Dam and detected using the juvenile salmon acoustic telemetry system (JSATS) at 16 locations on their way to the Pacific Ocean.

receiver from Sonic Concepts. Each receiver is a positively-buoyant self-contained device that consists of a polyvinyl chloride (PVC) housing with a threaded coupling and O-ring to join the upper and lower portions. The lower housing holds lithium battery packs capable of powering the receiver for 30 days. The upper housing contains an externally mounted hydrophone, water temperature and pressure sensors, and internal analog and digital circuit boards. Data were stored on a 1 GB flash drive. Each receiver was fitted with an external beacon tag that transmitted a unique code every 15 seconds, as well as a polyethylene fin to reduce drag and increase receiver stability under high flow conditions.

During the study, receivers were deployed to position the hydrophone 3 to 4 meters above the river or reservoir bottom in lines that typically ran perpendicular to the shore. A set of receivers across the river in a specific location was referred to as an array. The standard configuration consisted of the receivers affixed by a single attachment point to a short section of rope with three small floats for additional buoyancy, and then to an acoustic release. Receiver and anchor assemblies were deployed by a crew from a 7- to 11-meter-long boat by lowering the assembly to the bottom of the river or reservoir. The acoustic release, which

FIGURE 2 Fish Detection at John Day Dam



Two hydrophones were installed at different elevations (one deep and one shallow) on every pier nose between the turbine units and spillway bays at John Day Dam to monitor the primary routes of passage available to migrating fish and to determine the three-dimensional position of tagged fish.

allowed the receiver to surface when triggered by a signal, was connected to an anchor by another rope that incorporated a bungee section to reduce strain on mooring system components. Receivers were recovered, tested, and redeployed every 28 days to replace batteries and recover data on the flash cards.

To monitor passage behavior and timing of JSATS-tagged fish at John Day Dam on the Columbia River, researchers deployed JSATS receivers across the powerhouse and spillway. Each receiver consisted of four hydrophones connected to a four-channel receiver linked to a high-end desktop computer. Within the computer were two multichannel digital signal processing cards, a global positioning system (GPS) card, and the software necessary to acquire and decode messages from JSATS transmitters.

To monitor the primary routes of passage available to migrating fish and to determine the 3D position of tagged fish, two hydrophones were installed at different elevations (one deep and one shallow) on every pier nose between turbine units and spillway bays, for a total of 21 systems with 84 hydrophones (see Figure 2). Receiver clocks were synchronized to the universal GPS clock, resulting in detection time accuracy on a single system of 250 nanoseconds and across multiple systems of 500 nanoseconds.

Autonomous receivers were deployed in lines at various locations between the Snake River and Pacific Ocean (see Figure 1) to estimate survival of tagged fish. Data processing and filtering was used to produce valid tag detections. This process consists of a set of algorithms that analyzes the characteristics of each transmission, eliminates multi-path signals, and accepts tag codes that are consistent with the transmitter's pulse-rate interval. Tag detections were stored in a database that generated detailed histories for every tagged fish at all detection arrays between the release site and the mouth of the Columbia River. Detection history data were used to estimate survival of fish for successive river reaches. Estimates of survival were based on detection histories using the Cormack-Jolly-Seber (CJS) single-release model.[5,6,7] Survival estimates were calculated using detections of individual fish within the Snake and Columbia rivers on multiple autonomous receiver arrays. Standard errors were calculated with the full CJS model output.

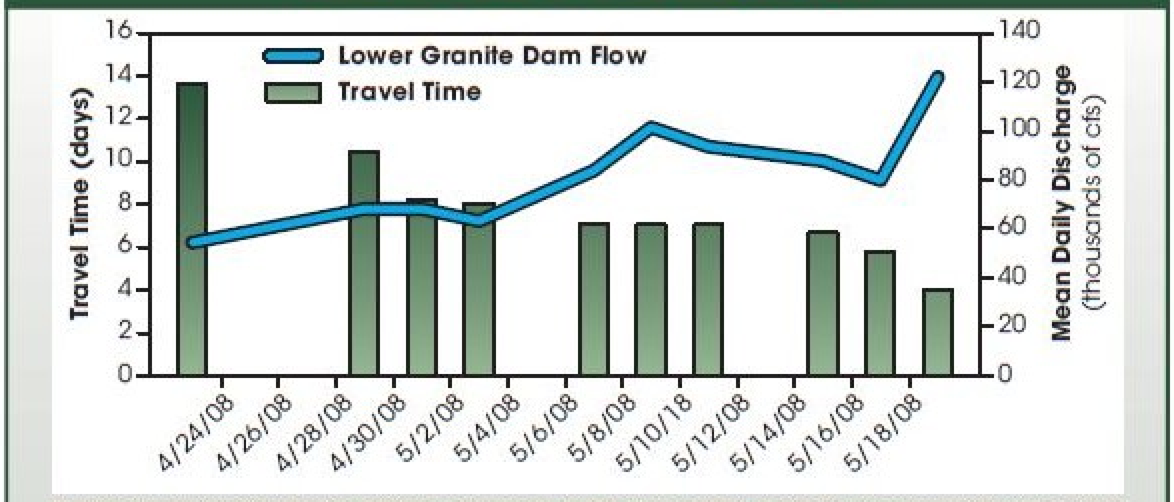
For the system at John Day, time of arrival at each hydrophone was recorded for all detections. Time of arrival detected on four hydrophones was used to solve for the 3D position of fish out to about 100 meters upstream of the dam.[8,9] If more than four hydrophones detected the same signal, the four with the best configuration for 3D tracking were selected.[10,11] The tracks then were used to determine the specific passage route (i.e., spillway bay or turbine unit) for each tagged fish. PIT tag detectionss (in acoustic-tagged fish) were used to determine the percentage of fish that were guided into the juvenile bypass facility.

Results

Acoustic-tagged yearling chinook migrated from Lower Granite Dam to the mouth of the Snake River, a distance of 173 kilometers, in a median travel time of 7.8 days during the spring of 2008 (see Figure 3). Travel time decreased as the season progressed and as river discharge increased. After entering the Columbia River, the fish required another five to six days to move from the mouth of the Snake River to John Day Dam (200 kilometers) and two to three more days to travel over the final stretch of the Columbia River, downstream of Bonneville Dam, to the Pacific Ocean (235 kilometers).

Estimated survival of JSATS-tagged yearling chinook salmon from the Lower Granite tailrace to the mouth of the Snake River ranged from 67 to 89 percent, with an average of 76 percent for fish released between April 24 and May 17, 2008 (see Table 1). Detection probability decreased as river discharge increased but remained high enough to produce precise survival

FIGURE 3 Travel Time versus Release Date



Median travel time for yearling chinook salmon migrating from Lower Granite Dam to the mouth of the Snake River decreased as the season progressed and as river discharge increased. Median travel time for this 173 kilometer distance was 7.8 days in the spring of 2008.

Table 1 — Detection Probability and Estimated Survival

Release Date	Detection Probability	Survival Estimate	Standard Error
April 24, 2008	0.963	0.671	0.024
April 29, 2008	0.976	0.743	0.022
May 1, 2008	0.963	0.772	0.021
May 3, 2008	0.968	0.731	0.022
May 6, 2008	0.956	0.681	0.023
May 8, 2008	0.928	0.717	0.023
May 10, 2008	0.834	0.716	0.023
May 13, 2008	0.497	0.833	0.022
May 15, 2008	0.564	0.820	0.021
May 17, 2008	0.641	0.891	0.018

estimates, with a standard error of about 2 percent throughout the range of conditions between late April and mid-May in the lower Snake River (see Table 1).

Figure 2 shows an example of the "fish tracks" from 3D positions of JSATS acoustic tagged fish at John Day Dam. More than half (58 percent) of the tagged yearling chinook salmon passing John Day Dam in spring 2008 did so through deep spill routes, 16 percent passed over temporary spillway weirs, and 26 percent passed the dam via powerhouse routes. Of this 26 percent passing the powerhouse, about 68 percent were guided by turbine intake screens and passed through the juvenile bypass system while the remaining 32 percent passed through the turbines.

Survival of JSATS-tagged yearling chinook between the release point and Bonneville Dam was 49.4 percent, which is consistent with past PIT tag survival estimates from Lower Granite Dam to Bonneville Dam.[12] From Lower Granite to the mouth of the Columbia River, about 39.8 percent of the acoustic-tagged yearling chinook salmon survived. Survival estimates of acoustic-tagged yearling chinook salmon in reaches between Bonneville Dam and the mouth of the Columbia showed that the majority of the loss that occurred below Bonneville Dam happened in the lower 35 kilometers of the Columbia River (see Figure 4), in an area known for high rates of avian predation on juvenile salmonids.[13]

Discussion

JSATS was developed to address critical information gaps related to juvenile salmonid behavior and survival between Bonneville Dam and the Pacific Ocean. Since its inception in 2002, JSATS features have been developed to address factors such as 3D passage behavior and survival at large hydro facilities.

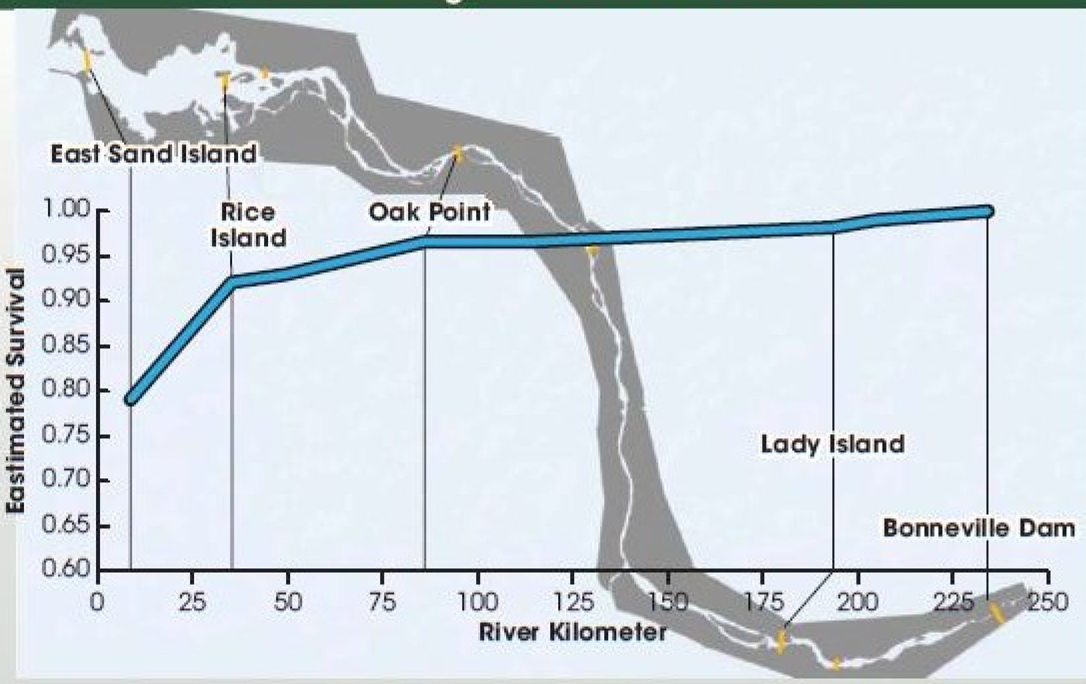
JSATS has been used in many studies to provide information to regional fish managers that can be used to make informed management decisions. For example, in 2010 JSATS was used to evaluate spill patterns at John Day Dam, to estimate dam passage survival of yearling and subyearling chinook salmon and steelhead at The Dalles Dam, to determine the influence of route of passage on survival at Bonneville Dam, and to determine the migratory behavior and survival of juvenile salmonids in the lower 146 miles of the Columbia River and out into the Pacific Ocean.

JSATS differs from most biotelemetry systems in that it has been competitively procured as opposed to being a proprietary system. This procurement has resulted in substantial (>30 percent) reductions in tag cost and size over the past few years. Further refinement and development of JSATS promises to provide detailed fish behavior and survival information — data necessary to inform managers charged with developing strategies to minimize the impacts of the FCRPS on anadromous salmonids. ■

Acknowledgments

Sonic Concepts Inc. provided innovative engineering, prototype development, and production of transmitters and receiving equipment. Advanced Telemetry Systems set a new standard for acoustic tag size and performance. PNNL staff from the ecology and hydrology groups and Marine Sciences and Instrument Development laboratories worked hard to develop and prove this technology. NOAA Fisheries was materially involved in the development and use of JSATS from its inception. The U.S. Army Corps of Engineers, Portland and Walla Walla districts, provided technical direction and funding for the development and use of JSATS.

FIGURE 4 Yearling Chinook Survival Estimates



The majority of the loss of acoustic-tagged yearling salmon downstream from Bonneville Dam occurred in the lower 35 kilometers of the Columbia River. This area is known for high rates of avian predation.

Notes

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For more information on JSATS, see http://jsats/pnl.gov.

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